A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped Storage Hydropower

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HydroWIRES Initiative

The electricity system in the United States is changing rapidly with the large-scale addition of variable renewables. The flexible capabilities of hydropower, including pumped storage hydropower (PSH), make it well-positioned to aid in integrating these variable resources while supporting grid reliability and resilience. Recognizing these challenges and opportunities, WPTO has launched a new initiative known as HydroWIRES: Water Innovation for a Resilient Electricity System.[1] HydroWIRES is focused on understanding and supporting the changing role of hydropower in the evolving electricity system in the United States. Through the HydroWIRES initiative, WPTO seeks to understand and drive utilization of the full potential of hydropower resources to help reduce system-wide costs and contribute to electricity system reliability and resilience, now and into the future.

HydroWIRES is distinguished in its close engagement with the DOE National Laboratories. Five National Laboratories—Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, and PNNL—work as a team to provide strategic insight and develop connections across the DOE portfolio that add significant value to the HydroWIRES initiative. HydroWIRES operates in conjunction with the DOE Grid Modernization Initiative,[2] which focuses on the development of new architectural concepts, tools, and technologies that measure, analyze, predict, protect, and control the grid of the future, and on enabling the institutional conditions that allow for quicker development and widespread adoption of these tools and technologies. HydroWIRES also operates in conjunction with the DOE Energy Storage Grand Challenge,[3] the vision of which is to create and sustain global leadership in energy storage utilization and exports, with a secure domestic manufacturing supply chain that does not depend on foreign sources of critical materials.

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[1] https://www.energy.gov/eere/water/hydrowires-initiative
[2] https://www.energy.gov/grid-modernization-initiative
[3] https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge
[4] https://hydrosource.ornl.gov/

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Results in Brief

- Pumped storage hydropower (PSH) is characterized as either open-loop (continuously connected to a naturally flowing water feature) or closed-loop (not continuously connected to a naturally flowing water feature). All of the 43 PSH projects operating in the United States are open-loop, so the environmental effects of closed-loop are not well-documented.

- This report: (1) compares the potential environmental effects of constructing and operating open-loop and closed-loop PSH projects; (2) describes how effects are avoided, minimized, or mitigated at existing and proposed projects in the United States and other countries; and (3) discusses the relative significance of the environmental issues.

- The report concludes that the environmental effects of closed-loop projects are generally lower (i.e., more localized and of shorter duration) than those of open-loop projects because they: (1) are located "off-stream," potentially minimizing aquatic and terrestrial impacts, and; (2) often have greater siting flexibility than open-loop projects.

- In particular, the impacts to aquatic resources are typically lower for closed-loop projects than for open-loop, as closed-loop projects are not continuously connected to any naturally-flowing body of water. This avoids the movement of water between reservoir and free-flowing water that drives many impacts of open-loop projects. For closed-loop projects, the impacts on aquatic resources are primarily related to the initial withdrawal of surface water for reservoir fill, which could reduce the availability of surface water for other uses.

- However, for both above-ground and underground closed-loop projects using groundwater, impacts to geology and soils and groundwater could generally be higher than those of open-loop. Closed-loop projects using groundwater as the source for initial filling of their reservoirs and replacing evaporative and seepage losses may impact groundwater quality due to the effects on groundwater circulation patterns and chemistry. Impacts to groundwater quantity resulting from the large quantities of water necessary for reservoir fill and refill could reduce the availability of groundwater for other uses.

- There is one specific circumstance in which the impacts of constructing the new upper reservoir and power generation facilities could be lower than those of constructing a new closed-loop project: open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir is added later for PSH operations (i.e., an "add-on" project). However, the impacts of project operations would still likely be higher than for closed-loop because the add-on project's lower reservoir is still continuously connected to and affects a naturally flowing water feature.

Executive Summary

Background

Pumped storage hydropower (PSH) is a type of energy storage that uses the pumping and release of water between two reservoirs at different elevations to store water and generate electricity (Figure ES-1). When demand for electricity is low, a PSH project can use low cost energy to pump water from the lower reservoir to the upper reservoir for storage. When demand for electricity is high, a PSH project can release water from the upper reservoir through a powerhouse to generate electricity. Traditionally, this meant that PSH plants generated power during the day and pumped at night, with modest diurnal or seasonal variation.

Today, PSH pumping operations are changing to facilitate the integration of the tremendous growth of variable renewable energy (VRE) generating resources, especially wind and solar, on the U.S. grid. PSH facilities are often a least cost option for high capacity (both energy and power), long-duration storage, and can provide the flexibility and fast response that a high-VRE-penetration grid requires. PSH faces its own set of challenges in construction and operation, however, including high initial capital costs, long construction timeframes, uncertainty in revenue streams (similar to all storage), and potential environmental impacts. The U.S. Department of Energy's (DOE) HydroWIRES initiative includes research to address each of these challenges. This report focuses on potential environmental impacts: specifically, the degree to which impacts can be reduced by using closed-loop pumped storage systems as opposed to the traditionally more common open loop systems.

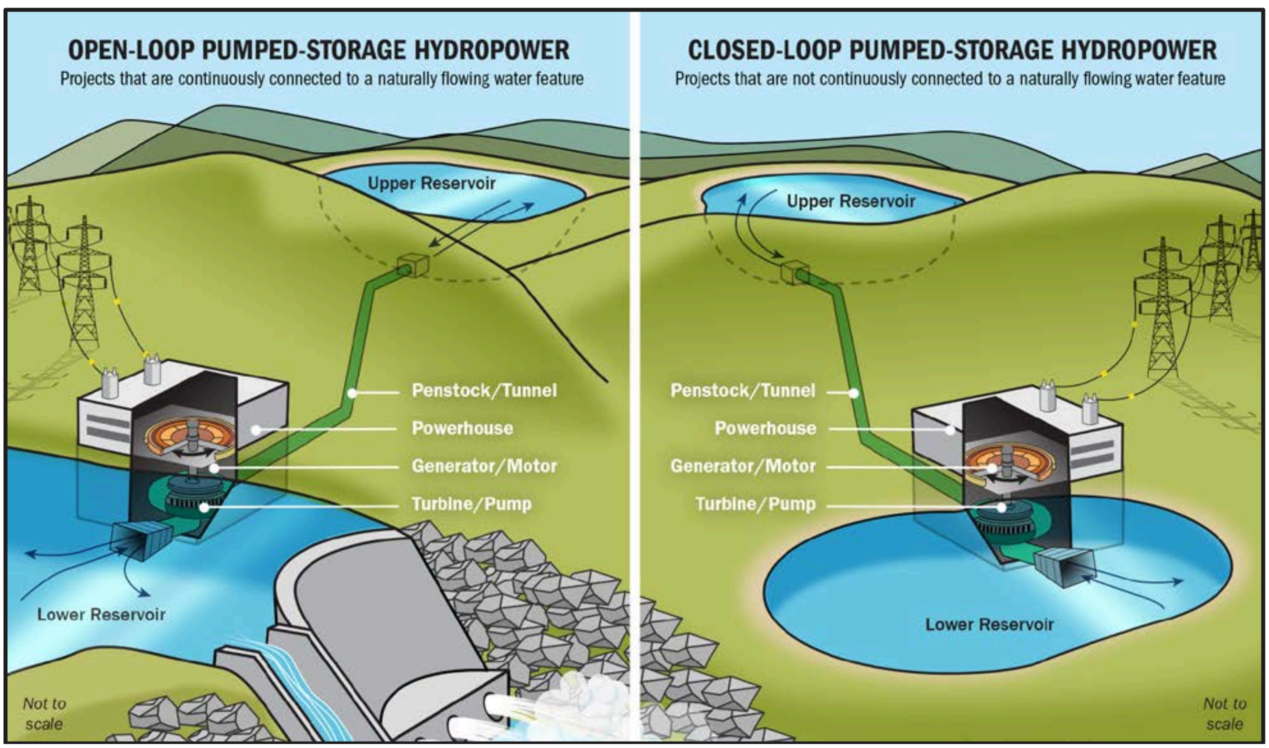

Figure ES-1. Generic comparison of open-loop and closed-loop PSH projects. (S*ource*: DOE 2019)

Closed-loop vs. Open-loop PSH

PSH facilities can be characterized as either open-loop or closed-loop (Figure ES-1), with respect to their connectivity to other water bodies. DOE defines open-loop PSH as “continuously connected to a naturally flowing water feature,” and closed-loop PSH as “not continuously connected to a naturally flowing water feature” (DOE 2016; 2019). The term *continuously* is key in these definitions because some PSH projects are considered closed-loop even though they could withdraw water from naturally flowing surface water features initially to fill their reservoirs and periodically to replace evaporative and seepage losses. In contrast, open-loop PSH projects typically involve damming a naturally flowing water feature to create the lower reservoir.

In its 2019 rulemaking on an expedited licensing review process for closed-loop PSH projects, the Federal Energy Regulatory Commission (FERC) defines certain qualifying criteria for closed-loop projects. Two of the criteria state that a project “utilize only reservoirs situated at locations other than natural waterways, lakes, wetlands, and other natural surface water features;” and “rely only on temporary withdrawals from surface waters or groundwater for the sole purposes of initial fill and periodic recharge needed for project operation” (FERC 2019a).

The FERC criteria do not change the basic definition of closed-loop PSH; rather, they simply define those closed-loop projects that are eligible for expedited licensing review. We discuss FERC’s 2019 rulemaking in Section 2.0 of this report.

PSH in the United States

There are 43 PSH projects operating in the United States, with a total capacity of 21.6 gigawatts (GW) (DOE 2018). All of these existing projects are open-loop systems, and most were authorized and constructed more than 30 years ago. In recent years, however, FERC has seen an increase in the number of preliminary permit and license applications filed for closed-loop PSH projects (FERC 2018). In fact, since the beginning of 2014, FERC has issued only four original licenses for new PSH projects: one open-loop system (the Iowa Hill Project in California) and three closed-loop systems (the Eagle Mountain Project in California, the Gordon Butte Project in Montana, and the Swan Lake North Project in Oregon).

The modeled growth scenarios presented in DOE’s 2016 *Hydropower Vision* report suggest that the United States hydropower industry’s combined generating and storage capacity could grow from 101 GW to nearly 150 GW by 2050, with as much as 36 GW of this new capacity coming from PSH. The report states that innovative technology and system design concepts, including closed-loop PSH systems, will be essential to achieve this growth (DOE 2016).

Need for the Report

With the potential for growth in closed-loop PSH capacity, project developers, regulators, resource agencies, and other stakeholders should understand the environmental effects of these projects when compared to open-loop PSH systems, as well as measures to avoid, minimize, and mitigate those effects (when we refer to “effects” or “impacts” we are referring to adverse effects or impacts unless noted otherwise). Importantly, because all the PSH projects constructed in the United States to date are open-loop, the potential environmental effects of closed-loop systems are not as well-documented as the effects of open-loop systems.

To address this knowledge gap, the DOE Water Power Technologies Office, under its HydroWIRES Initiative, has prepared this report to (1) compare the potential environmental effects of open-loop PSH projects with those of closed-loop PSH projects; (2) describe how these effects are being avoided, minimized, or mitigated at existing projects in other countries and proposed projects in the United States; and (3) discuss the relative significance of the environmental issues.

Approach

Methodology

The comparison of the environmental effects of open-loop and closed-loop PSH in this report is based on two reviews:

1. A literature review of journal articles, technical reports, and presentations on the environmental effects of PSH (Appendix B). This review includes literature from the United States as well as from countries where PSH projects have been constructed.
2. A review of the FERC licensing record (e.g., National Environmental Policy Act documents and hydropower license orders) to identify the environmental effects anticipated and mitigation measures proposed for six of the closed-loop PSH projects currently licensed or permitted in the United States (Appendix C). For comparison, this review also discusses the environmental effects and mitigation measures for four open-loop PSH projects proposed or currently operating in the United States.

Scope – Project Types

The comparison with open-loop PSH systems focuses on the three closed-loop PSH project types most commonly proposed for development in the United States:

- above-ground closed-loop projects using surface water (typically involves the construction of two above-ground reservoirs that are filled and replenished using a surface water source);
- above-ground closed-loop projects using groundwater (typically involves the construction of two above-ground reservoirs that are filled and replenished using a groundwater source); and
- underground closed-loop projects using groundwater (can involve the construction of one above-ground reservoir and one underground reservoir, or two underground reservoirs, that are filled and replenished using a groundwater source).

The comparison of effects between open-loop and closed-loop projects is <u>relative</u>; that is, it characterizes the impacts of each project type as generally lower than, similar to, or higher than another project type. The comparison reflects general trends among project types because there are sometimes exceptions to the examples cited. The comparison is based on both spatial (location) and temporal (duration) factors and reflects both the severity and likelihood of effects.

Scope – Potential Impacts

For each project type, the report focuses on the impacts of both project construction and operations on the potentially affected environmental resources most often discussed in the literature and FERC documents reviewed. The assessment considers both aquatic resources and terrestrial resources.

<u>Aquatic Resources</u>:

- **Surface water quality and quantity.** The impacts of PSH construction and operations are primarily related to 1) the initial withdrawal of surface water for reservoir fill and 2) the movement of water between and within the project water bodies, whether they be naturally occurring lakes, rivers, or constructed reservoirs.

- **Groundwater quality and quantity.** For PSH projects that use groundwater as the source for filling their reservoir initially and for replacing evaporative and seepage losses (typically closed-loop), there is the potential for impacts to both groundwater quality and quantity.
- **Aquatic ecology**. The impacts of PSH construction and operations on fish and other aquatic ecology are primarily related to the instream construction of dams (for open-loop projects), the initial withdrawal of surface water for reservoir fill, and the movement of water between and within the project water bodies, especially naturally flowing lakes or rivers. Potentially affected terrestrial resources include:

<u>Terrestrial Resources</u>

- **Geology and soils**. As with any large infrastructure project, PSH construction has impacts on geology and soils as project reservoirs and related facilities require large-scale excavation and tunneling. Project operations may also affect geology and soils due to reservoir shoreline erosion.
- **Terrestrial ecology.** Construction may have impacts on terrestrial ecology as project reservoirs and related facilities require clearing and/or inundating large land areas that provide wildlife habitat.
- **Land use, recreation, visual resources, and cultural resources**. Construction requires the clearing and/or inundation of large land areas, especially for the project reservoirs. Committing large land areas to PSH development can have impacts on existing and planned land uses, recreation, visual resources, or cultural resources at the project site and in the vicinity.

The report does not compare open-loop and closed-loop PSH projects in terms of potential greenhouse gas (GHG) emissions or emissions reductions, as these topics were not addressed in any of the literature or FERC records reviewed. DOE outlines this issue for conventional hydropower in its 2016 *Hydropower Vision* report (DOE 2016), but not specifically for PSH projects. DOE plans to conduct additional research on the topic of GHG emissions from reservoirs in general (i.e., not just PSH reservoirs or conventional hydropower reservoirs, but all reservoirs).

For the environmental resource areas examined, the following sub-sections provide a relative comparison of the environmental effects of open-loop and closed-loop PSH based on the literature review and the FERC records review. Section 3.0 of this report provides a more detailed discussion of these potential environmental effects. The comparison often focuses on impacts to aquatic resources (surface water, groundwater, and aquatic ecology) because those are typically the resource areas for which the differences between open-loop and closed-loop PSH systems are most apparent.

Summary of Findings

The environmental effects of closed-loop PSH projects are generally lower – both more localized and of shorter duration – than those of open-loop PSH projects. This is because closed-loop PSH projects: (1) are located “off-stream,” potentially minimizing aquatic and terrestrial impacts, and; (2) often have greater siting flexibility than open-loop PSH projects. However, as discussed below, certain specific impacts of closed-loop systems can be higher than those of open-loop systems, particularly for geology and soils and groundwater. This can be due to, for example, the need to construct two above-ground reservoirs rather than one or the impact of groundwater withdrawal or circulation.

There is one type of open-loop project where impacts may be as low, if not lower, than closed-loop PSH: open-loop projects where the lower reservoir was already constructed for other purposes[1] and an upper reservoir was added for PSH operations at a later date. Such “add-on” PSH projects comprise 12 of the 43

[1] E.g., flood control, conventional hydropower, irrigation

existing PSH projects in the United States. With this type of add-on open-loop project, it is likely that initial construction impacts be lower than those of constructing a closed-loop project, as only one new reservoir needs to be built. On the other hand, operational impacts are still likely to be higher than for a closed-loop project because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

Finally, we note that although this report discusses the environmental effects of both open-loop PSH and closed-loop PSH projects, it does not imply that PSH projects have environmental effects that cannot be mitigated. In addition, many PSH projects under development have their own unique characteristics, such as being built in a pre-existing mine or quarry, or otherwise taking advantage of existing infrastructure. In all cases, the impacts of any specific facility need to be considered on their own merit.

With increased interest in closed-loop PSH development, project developers, regulators, resource agencies, and other stakeholders should understand the environmental effects of closed-loop systems (as well as measures to avoid, minimize, and mitigate effects) and include them in the environmental review of any proposed project.

Impacts of Construction

Surface Water Quality and Quantity

As summarized in Table ES-1, impacts to surface water quality during construction are typically relatively higher for open-loop projects than for closed-loop projects using surface water because open-loop project construction and initial reservoir fill commonly requires damming a naturally flowing water feature to create the lower reservoir (rather than constructing an artificial lower reservoir as with closed-loop). Such damming may inundate a large land area and have adverse effects on water quality in the naturally flowing water feature. One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date as a separate action. With this type of add-on open-loop project, the surface water quality impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a new closed-loop project.

The surface water quantity impacts of construction could be similar for either open-loop or closed-loop projects, resulting in a consumptive water use that could reduce the supply for other uses such as irrigation, recreation, industrial, and municipal. This impact could be exacerbated by evaporative and seepage losses of surface water from above-ground reservoirs. Consumptive use impacts might be higher in closed-loop projects because they could hold the surface water in a closed system (as opposed to an open system that is continuously connected to a naturally flowing water body), but the water could be returned to the original source (minus evaporative and seepage losses) if needed.

The surface water impacts of constructing closed-loop projects using groundwater could be relatively lower, except in cases where reservoir seepage affects groundwater, or the transfer of groundwater contaminants affects reservoir surface water quality during initial fill.

Groundwater Quality and Quantity

For open-loop PSH projects and closed-loop PSH projects that are not connected to groundwater, potential impacts to groundwater during construction are generally limited to the effects of underground construction or tunneling or reservoir seepage on groundwater quality or flow (Table ES-1). Conversely, closed-loop PSH projects using groundwater for their initial reservoir fill during construction have the potential for relatively higher impacts to both groundwater quality and quantity.

Aquatic Ecology

During construction, open-loop projects have relatively higher impacts on fish and other aquatic ecology than closed-loop projects because of their initial effects on the naturally flowing water bodies that are dammed and inundated for their lower reservoirs (Table ES-1). One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date. With this type of add-on open-loop project, the aquatic ecology impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a closed-loop project.

Closed-loop projects using surface water for their initial reservoir fill during construction may have similar impingement and entrainment impacts during the initial withdrawal period, but these impacts are of shorter duration than at open-loop projects. The impacts to aquatic ecology of constructing closed-loop projects using groundwater could be the smallest of all project types.

Table ES-1. Summary of relative comparison: Construction impacts on aquatic resources open-loop PSH vs. closed-loop PSH.

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fill)	Surface Water (Construction and Initial Fill)
Surface Water Quality	H Higher	L Lower	L Lower
Surface Water Quantity	S Similar	L Lower	S Similar
Groundwater Quality	L Lower	H Higher	L Lower
Groundwater Quantity	L Lower	H Higher	L Lower
Aquatic Ecology	H Higher	L Lower	L Lower

Geology and Soils

Construction of both open-loop and closed-loop PSH projects affects geology and soils primarily due to large-scale excavation for above-ground reservoirs and project facilities and excavation/ tunneling for underground project facilities and pipelines (Table ES-2). Because above-ground and underground closed-loop projects typically involve excavating two artificial reservoirs (upper and lower), their initial impacts to geology and soils may be relatively higher than those of open-loop projects, which typically involve excavating only one artificial reservoir (upper). Also, the impacts of constructing a new upper reservoir at an open-loop project where the lower reservoir was already constructed for other purposes could be similar to or lower than those of constructing a closed-loop project.

Terrestrial Ecology, Land Use, Recreation, Visual Resources, and Cultural Resources

During project construction, open-loop projects generally have higher impacts than closed-loop projects on terrestrial ecology, land use, recreation, visual resources, and cultural resources because they typically have less flexibility in facility siting (Table ES-2). That is, open-loop projects are typically sited on a naturally flowing water feature, which serves as the project's lower reservoir. Thus, it is often difficult to avoid disturbing the sensitive terrestrial ecology, land uses, recreation, visual resources, and cultural resources around these naturally flowing water features. One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date. With this type of add-on open-loop project, the impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a closed-loop project.

Conversely, above-ground closed-loop projects can be sited further from their water source, and water is typically delivered to the project reservoirs by pipeline. Given this siting flexibility, above-ground closed-loop projects can also be sited closer to residential, commercial, and industrial energy consumers, thereby shortening transmission line corridors and reducing related impacts to terrestrial resources. Underground closed-loop projects typically have the smallest impacts on these resources of all the PSH project types because they disturb smaller land surface areas.

Table ES-2. Summary of relative comparison: Construction impacts on terrestrial resources open-loop PSH vs. closed-loop PSH.

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fil)	Surface Water (Construction and Initial Fill)
Geology and Soils	**Lower**	**Higher**	**Higher**
Terrestrial Ecology	**Higher**	**Lower**	**Lower**
Land Use	**Higher**	**Lower**	**Lower**
Recreation	**Higher**	**Lower**	**Lower**
Visual Resources	**Higher**	**Lower**	**Lower**
Cultural Resources	**Higher**	**Lower**	**Lower**

Impacts of Operation

Surface Water Quality and Quantity

In Table ES-3, open-loop projects typically have more widespread and longer-lasting impacts on surface water quality during operations due to their regular (typically daily) pattern of water withdrawal from and discharge to the naturally flowing water bodies to which they are connected. The surface water quality impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction. Closed-loop projects with above-ground reservoirs typically have lower impacts on surface water quality than open-loop projects because they do not have regular (only initial and periodic) withdrawals from naturally flowing water bodies and have no discharges to those water bodies.

Table ES-3. Summary of relative comparison: Operations impacts on aquatic resources open-loop PSH vs. closed-loop PSH.

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal/Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Surface Water Quality	H **Higher**	L **Lower**	L **Lower**
Surface Water Quantity	S **Similar**	L **Lower**	S **Similar**
Groundwater Quality	L **Lower**	H **Higher**	L **Lower**
Groundwater Quantity	L **Lower**	H **Higher**	L **Lower**
Aquatic Ecology	H **Higher**	L **Lower**	L **Lower**

For surface water quantity, both open-loop and closed-loop projects (whether connected to surface water or groundwater) with above-ground reservoirs are similar in that they experience evaporation and seepage from their reservoirs during operations, the rates of which depend on local atmospheric and geologic conditions, the use of reservoir liners, and other factors. The issue of consumptive use impacts might be higher in closed-loop projects because they could hold the surface water in a closed system (as opposed to an open system that is continuously connected to a naturally flowing water body), but the water could be returned to the original source (minus evaporative and seepage losses) if needed.

Closed-loop projects with underground reservoirs (which use groundwater) have the lowest surface water quality and quantity impacts of all the PSH project types.

Groundwater Quality and Quantity

For open-loop PSH projects and closed-loop PSH projects that are not connected to groundwater, potential impacts to groundwater during operations are generally limited to the effects of reservoir seepage on groundwater flow and quality (Table ES-3). Conversely, closed-loop PSH projects using groundwater for periodic replenishment of evaporative and seepage losses during operations have the potential for relatively higher impacts to both groundwater quality and quantity.

Aquatic Ecology

Open-loop projects have more widespread and longer-lasting impacts on fish and other aquatic ecology than closed-loop projects during pumping and generation operations because they have ongoing (rather than initial and periodic) effects on the naturally flowing water feature to which they are connected (Table ES-3). The aquatic ecology impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

Similar types of impacts could occur at closed-loop projects using surface water, but they could be less widespread and of shorter duration because closed-loop projects are not continuously withdrawing from and discharging to their surface water source. Also, the artificial reservoirs constructed for closed-loop projects support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems. However, the ecological impacts of closed-loop projects withdrawing large quantities of water from surface water bodies, even if it is not done continuously, should be considered in any environmental assessment.

Geology and Soils

Both open-loop and closed-loop PSH pumping and generating operations may affect geology and soils primarily due to large and frequent reservoir water-level fluctuations and resulting shoreline erosion (Table ES-4). These impacts may be relatively higher at open-loop projects, including add-on projects where the lower reservoir was already constructed for other purposes, because of the potential effects of their shoreline erosion and resulting sedimentation on the naturally flowing water bodies to which they are connected.

Table ES-4. Summary of relative comparison: Operations impacts on terrestrial resources open-loop PSH vs. closed-loop PSH.

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal and Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Geology and Soils	**Higher**	**Lower**	**Lower**
Terrestrial Ecology	**Higher**	**Lower**	**Lower**
Land Use	**Higher**	**Lower**	**Lower**
Recreation	**Higher**	**Lower**	**Lower**
Visual Resources	**Higher**	**Lower**	**Lower**
Cultural Resources	**Higher**	**Lower**	**Lower**

Terrestrial Ecology, Land Use, Recreation, Visual Resources, and Cultural Resources

Open-loop projects tend to have more widespread and longer-lasting impacts on terrestrial ecology, land use, recreation, visual resources, and cultural resources during generating and pumping operations because of their lack of siting flexibility and their ongoing impacts on the water quality and quantity and aquatic ecology of their naturally flowing water source (Table ES-4). The impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

One possible exception is due to one of the operational benefits of closed-loop projects: essentially an unlimited ramping rate for pumping or generating because of no fish impingement concerns. However, while this unlimited ramping could not affect fish in a closed-loop system, there is the potential avian or terrestrial species impacts due to rapid reservoir fluctuations that might not occur with an open-loop system.

Not surprisingly, closed-loop projects with underground reservoirs (especially those located in former underground mining pits) typically have the smallest operational impacts on these terrestrial resources of all PSH project types.

Recommendations

The DOE Water Power Technologies Office, under its HydroWIRES Initiative, has prepared this report to address the knowledge gap about the potential environmental effects of closed-loop PSH, but additional research is needed to better characterize and assess those environmental effects for all potentially affected resources.

Because geology and soils and groundwater are the environmental resources for which closed-loop PSH is likely to have relatively higher impacts than open-loop PSH, the recommendations for additional research discussed in Section 4.0 focus on characterizing and assessing potential effects on geology and soils and groundwater quality and quantity. This is especially important for those above-ground and underground closed-loop projects that propose to use groundwater combined with either surface or underground mine pits for their reservoirs.

In addition to the geology and soils and groundwater research discussed in Section 4.0, we recommend conducting in-depth interviews with PSH developers (including some who have developed closed-loop PSH projects in other countries), resource agency staff, staff from non-governmental organizations, and other stakeholders to solicit their input to better characterize the potential environmental effects of closed-loop PSH projects.

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Acronyms and Abbreviations

ALP	Alternative Licensing Process
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CAES	compressed air energy storage
CDFW	California Department of Fish and Wildlife
CEQA	California Environmental Quality Act
cfs	cubic feet per second
DO	dissolved oxygen
DOE	U.S. Department of Energy
EA	environmental assessment
EIS	environmental impact statement
EPA	Environmental Protection Agency
FEIS	final environmental impact statement
FERC	Federal Energy Regulatory Commission
FPA	Federal Power Act
FPC	Federal Power Commission
GHG	greenhouse gas(es)
gpm	gallons per minute
GW	gigawatts
ILP	Integrated Licensing Process
LCA	life-cycle analysis
LWD	large woody debris
mg/L	milligrams/liter
MIF	minimum instream flows
msl	mean sea level
MW	megawatt
NGVD	National Geodetic Vertical Datum
NHA	National Hydropower Association
PAD	pre-application document
PHES	pumped hydro energy storage
pO_2	oxygen partial pressure
PSH	pumped storage hydropower
SCE	Southern California Edison
SMUD	Sacramento Municipal Utility District
TDS	total dissolved solids
TLP	Traditional Licensing Process
UPSH	underground pumped storage hydropower
USFS	United States Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VEPCO	Virginia Electric and Power Company
VRE	variable renewable energy
WPTO	Water Power Technologies Office
WWTP	wastewater treatment plant

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1.0 Introduction

1.1 Background

Pumped storage hydropower (PSH) is a type of energy storage that uses the pumping and release of water between two reservoirs at different elevations to store water and then generate electricity (Figure 1). For example, when demand for electricity is low, a PSH project can use low cost energy to pump water from the lower reservoir to the upper reservoir for storage. When demand for electricity is higher, a PSH project can release water from the upper reservoir through a powerhouse to generate electricity (FERC 2018). With the tremendous growth of variable renewable generating resources (especially wind and solar) on the U.S. grid, PSH pumping operations have in some cases shifted to daytime hours to store excess generation.

PSH currently accounts for about 95 percent of all utility-scale energy storage in the United States (DOE 2019). It is expected that this storage capacity will be critical for the continued growth and integration of renewable energy sources and for providing a range of ancillary services to support the reliable and efficient functioning of the electric grid (DOE 2019; FERC 2018).

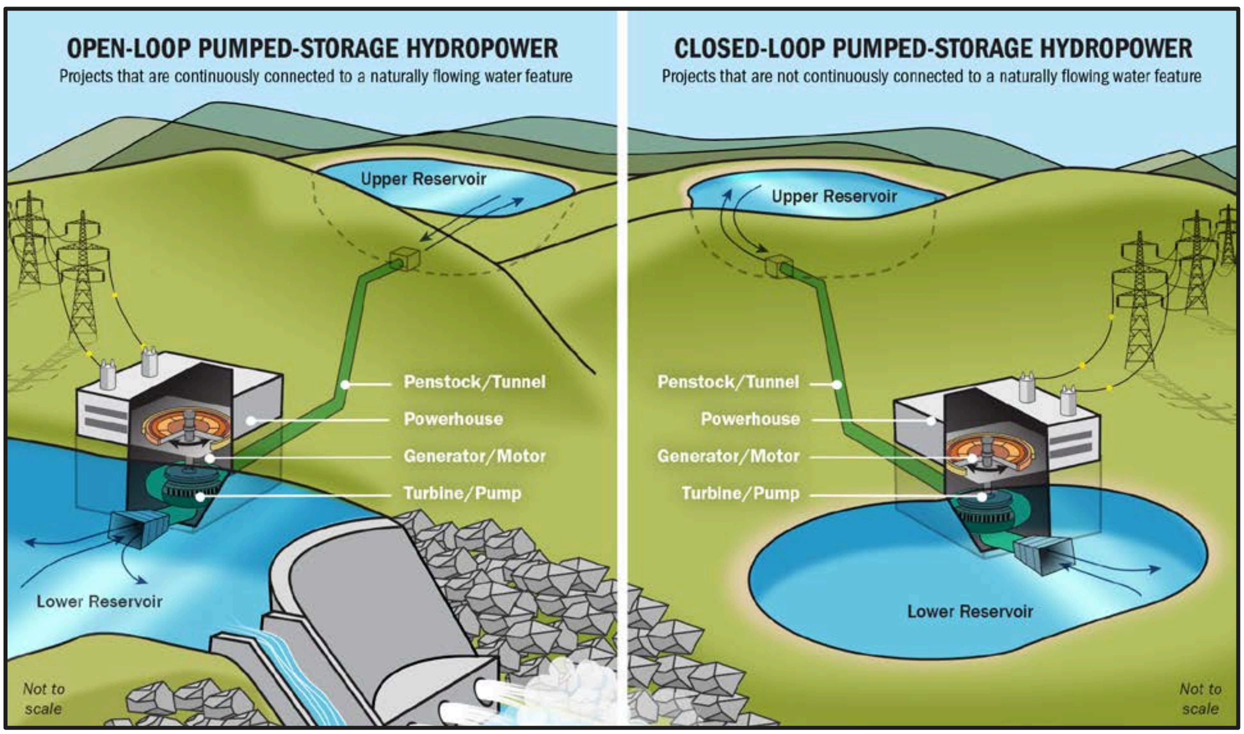

Figure 1. Generic comparison of open-loop and closed-loop PSH projects. (S*ource*: DOE 2019)

PSH facilities can be characterized as either open-loop or closed-loop, with respect to their connectivity to other water bodies (Figure 1). The U.S. Department of Energy (DOE) defines open-loop PSH as "continuously connected to a naturally flowing water feature," and closed-loop PSH as "not continuously connected to a naturally flowing water feature" (DOE 2016; 2019). The term *continuously* is key in these definitions, because some PSH projects are considered closed-loop even though they would withdraw water from naturally flowing surface water features initially to fill their reservoirs and periodically to make up evaporative and seepage losses. In contrast, open-loop PSH projects typically involve damming a naturally flowing water feature to create the lower reservoir.

In its 2019 rulemaking on an expedited licensing review process for closed-loop PSH projects, the Federal Energy Regulatory Commission (FERC) defines certain qualifying criteria for closed-loop projects. Two of the criteria state that a project: “utilize only reservoirs situated at locations other than natural waterways, lakes, wetlands, and other natural surface water features;” and “rely only on temporary withdrawals from surface waters or groundwater for the sole purposes of initial fill and periodic recharge needed for project operation” (FERC 2019a).

The FERC criteria do not change the basic definition of closed-loop PSH; rather, they simply define those closed-loop projects that are eligible for expedited licensing review. For example, a PSH project could still be considered closed-loop, but not be eligible for expedited review by FERC because its water pipeline or transmission lines could adversely affect threatened or endangered species. We discuss FERC’s 2019 rulemaking further in Section 2.0 of this report.

There are 43 PSH projects operating in the United States, with a total capacity of 21.6 gigawatts (GW) (DOE 2018). Figure 2 shows the locations of these existing PSH projects, and Appendix A provides information about each project. All of these existing projects are open-loop systems, and most were authorized and constructed more than 30 years ago. In recent years, however, FERC has seen an increase in the number of preliminary permit and license applications filed for closed-loop PSH projects (FERC 2018).

The modeled growth scenarios presented in DOE’s 2016 *Hydropower Vision* report suggest that the United States hydropower industry’s combined generating and storage capacity could grow from 101 GW to nearly 150 GW by 2050, with as much as 36 GW of this new capacity coming from PSH. The report states that innovative technology and system design concepts, including “alternative closed-loop PSH systems,” will be essential to achieve this growth (DOE 2016).

1.2 Need for the Report

With the potential for growth in closed-loop PSH capacity, project developers, regulators, resource agencies, and other stakeholders should understand the environmental effects of these projects when compared to open-loop PSH systems, as well as measures to avoid, minimize, and mitigate those effects (when we refer to “effects” or “impacts” we are referring to adverse effects or impacts unless noted otherwise). Importantly, because all the PSH projects constructed to date in the United States are open-loop, the potential environmental effects of closed-loop systems are not well documented compared to the effects of open-loop systems.

To address this knowledge gap, the DOE Water Power Technologies Office (WPTO), under its HydroWIRES Initiative, has prepared this report to:

- compare the potential environmental effects of closed-loop PSH projects with those of open-loop PSH projects;
- describe how these effects are being avoided, minimized, or mitigated at existing projects in other countries and proposed projects in the United States; and
- discuss the relative significance of the environmental issues.

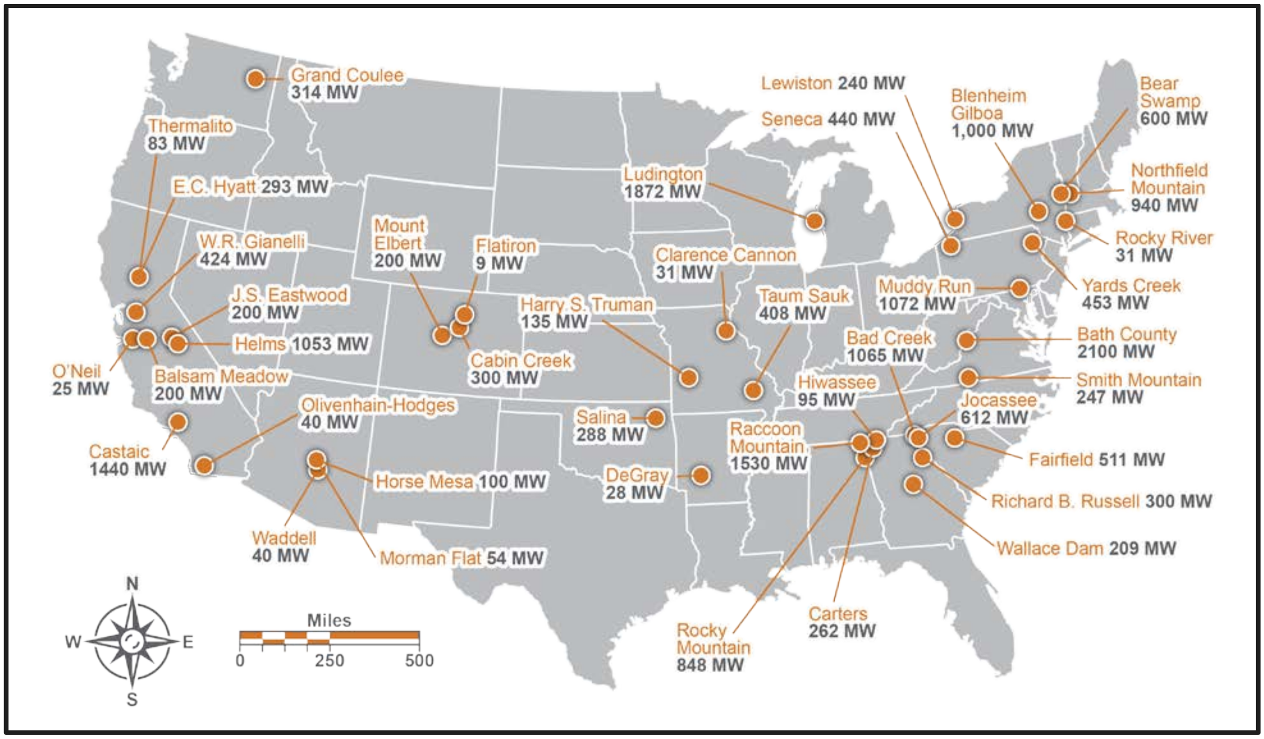

Figure 2. Existing PSH projects in the United States (all open-loop systems). (S*ource*: Modified from MWH 2009)

1.3 Organization of the Report

Section 2.0 of this report describes the current FERC hydropower licensing process, emphasizing some recent regulatory changes that affect closed-loop PSH development. Section 3.0 then provides a summary comparison of the environmental effects of closed-loop and open-loop PSH systems and discusses the relative significance of those issues. The comparison and discussion are based on the results of a literature review (Appendix B) and a FERC records review (Appendix C).

The literature review includes journal articles, technical reports, and presentations on the environmental effects of PSH systems. It includes literature from the United States as well as countries where closed-loop PSH projects have been constructed.

The FERC records review examines the FERC licensing record (e.g., National Environmental Policy Act documents and license orders) to identify the environmental effects anticipated and mitigation measures proposed for six of the closed-loop PSH projects currently licensed or permitted in the United States. For comparison, the FERC records review also discusses the environmental effects and mitigation measures for four open-loop PSH projects proposed or currently operating in the United States.

Section 4.0 of this report discusses our conclusions and identifies some topics for additional research to help fill remaining knowledge gaps related to the environmental effects of closed-loop PSH development. Finally, Section 5.0 provides citations for the documents referenced in sections 1.0 through 4.0, while the appendices include their own sub-sections on references and bibliography.

2.0 Regulatory Status of Closed-Loop Pumped Storage Hydropower in the United States

2.1 The FERC Hydropower Licensing Process

Under the Federal Power Act (FPA), FERC issues three basic types of authorization for hydropower projects in the United States: licenses, including both original licenses and new licenses (relicenses); preliminary permits; and exemptions.

Licenses. FPA Section 23(b) mandates FERC licensing for any hydropower project that:

1. is located on a navigable waterway;
2. occupies federal public land or a federal reservation;
3. uses surplus water or water power from a government dam; or
4. is located on a non-navigable Commerce Clause stream, affects the interests of interstate or foreign commerce, and has undergone construction or modification since August 26, 1935.

Original licenses are currently restricted to newly constructed projects or existing projects that come under FERC's jurisdiction, and are issued for a 30- to 50-year period. FERC's current regulations provide three alternatives for hydropower developers to use in preparing license applications: the integrated licensing process (ILP); the traditional licensing process (TLP); and the alternative licensing process (ALP). The ILP is the default licensing process; license applicants must request and receive approval from FERC to use the TLP or ALP. The ILP provides tight structure and timelines in the pre-filing period. Goals of the ILP are to involve FERC licensing staff at the onset of the process to address study requests, record disputes, and bring timeline rigor. The TLP offers applicants the most control over "pre-filing" activities before a license application is filed with FERC. This was the only licensing process until a large class of hydropower projects sought license renewal in the early 1990s under the Electricity Consumers Protection Act of 1986, which set new balances between public and private uses of waterways for hydropower. At that time, FERC created the ALP, which provides broad structure over pre-filing activities and fosters flexible timelines, stakeholder collaboration, applicant-prepared environmental assessments (EA), and settlements. Detailed information about each process, including flow charts, is available at FERC's "Licensing" webpage (FERC 2019b).

FERC has the authority to issue new licenses (relicenses) for existing projects at which the original FERC license has expired. At least two years before the original license expires, the licensee must file an application for new license using either the ILP, TLP, or ALP. Currently, projects undergoing relicensing make up most of the proposals being evaluated by FERC hydropower licensing staff (FERC 2019b).

As part of the licensing process, FERC assesses the potential environmental impacts of constructing and operating a proposed project (original license) or continuing operation of an existing project (new license). This assessment is completed as either an EA or an environmental impact statement (EIS) under the National Environmental Policy Act and may incorporate comments and recommended (and in some cases mandatory) terms and conditions from a variety of stakeholders including other federal agencies, state and local agencies, tribes, non-governmental organizations, and the public.

The final step in the FERC licensing process is the determination of whether to issue the project's original or new license order, which stipulates the conditions under which the project may be constructed and operated over the 30- or 50-year license term. In addition to measures proposed by the applicant, the license order includes environmental protection, mitigation, and enhancement measures recommended by

FERC staff and recommended or mandated by other federal, state, and local agencies and tribes. Projects with an "active" FERC license have been issued a FERC license order. Projects "pending" FERC licensing are those for which FERC has accepted and is reviewing the license application but has not issued a license order.

Preliminary Permits. A FERC preliminary permit, issued for up to four years, does not authorize project construction, but maintains "priority of application for license" (i.e., guaranteed first-to-file status) while the permittee studies the site and prepares to apply for an original license. In practice, this means another applicant cannot file an application for the same site during the term. The permittee must submit periodic reports to FERC on the status of its studies. It is not necessary to obtain a preliminary permit to apply for or receive a FERC license (FERC 2019b). Projects with an "active" FERC preliminary permit have been issued a permit. Projects "pending" FERC permitting are those for which FERC has accepted and is reviewing the preliminary permit application but has not issued a permit.

Exemptions. FERC issues two types of exemptions from the licensing requirements of FPA Part I:

1. Small hydropower exemptions for projects that are 10 megawatts (MW) or less and will be built at an existing dam, or projects that utilize a natural water feature for head or an existing project that has a capacity of 10 MW or less and proposes to increase capacity.
2. Conduit exemptions for constructing a hydropower project on an existing conduit (e.g., an irrigation canal). Conduit exemptions are authorized for generating capacities 40 MW or less. The conduit has to have been constructed primarily for purposes other than power production (FERC 2019b).

2.2 Recent Changes to the FERC Hydropower Licensing Process

In recent years, FERC has seen an increase in the number of preliminary permit and original license applications filed for closed-loop PSH projects (Table 1). In fact, since the beginning of 2014, FERC has issued only four original licenses for new PSH projects: one open-loop system (the Iowa Hill Project in California) and three closed-loop systems (the Eagle Mountain Project in California, the Gordon Butte Project in Montana, and the Swan Lake North Project in Oregon). Figure 3 indicates the location of the proposed PSH projects (both open- and closed-loop) in the United States with active ("issued authorization") and pending ("pending application") FERC licenses or active ("issued") and pending FERC preliminary permits.

The increased interest in PSH among project developers, regulators, resource agencies, and other stakeholders has led to increased regulatory activity to facilitate, and in some cases promote, new closed-loop PSH development. In response, FERC has reevaluated its hydropower licensing review process for qualifying closed-loop PSH projects, and even its hydropower licensing jurisdiction for certain types of closed-loop PSH projects.

In October 2018, Congress passed the *America's Water Infrastructure Act of 2018* (Public Law No. 115-270) requiring FERC to establish "an expedited process for issuing and amending licenses for closed-loop pumped storage projects." The Act requires FERC to convene:

> "an interagency task force, with appropriate federal and state agencies and Indian tribes represented, to coordinate the regulatory processes associated with the authorizations required to construct and operate closed-loop pumped storage projects." The expedited process stipulated in the Act would result in a final decision on a license application "by not later than 2 years after receipt of a completed application for such license" (United States Congress 2018).

Table 1. Proposed closed-loop PSH projects in the United States with an active or pending FERC license or preliminary permit (as of December 2019). (*Source:* FERC 2019b)

Project Name	FERC No.	State	Issue Date (or Date Filed)	Expire Date	Authorized or Proposed Capacity (MW)	Current Application Type
Active FERC Licenses						
Eagle Mountain	13123	CA	06/19/14	05/31/64	1,300.0	NA
Gordon Butte	13642	MT	12/14/16	11/30/66	400.0	NA
Swan Lake North	13318	OR	04/30/19	04/29/69	393.3	NA
Pending FERC Licenses						
Mineville	12635	NY	02/13/15		240.0	Original License
Hydro Battery Pearl Hill	14795	WA	10/25/16		5.0	Original License
Active FERC Preliminary Permits						
New Summit	14612	OH	10/16/14	09/30/19	1,500.0	NA
Blue Diamond	14804	NV	06/22/17	05/31/20	450.0	NA
Shenandoah	14805	PA	05/01/17	04/30/20	405.0	NA
Allegheny	14820	PA	06/13/17	05/31/20	123.00	NA
Bacon Ridge	14823	PA	06/15/17	05/21/20	116.0	NA
Mooresville Energy	14830	NY	12/08/17	11/30/20	49.0	NA
Bison Creek	14850	CA	03/12/18	02/28/21	480.0	NA
White Pine	14851	NV	10/25/17	09/30/20	500.0	NA
Big Chino Valley	14859	AZ	12/28/17	11/30/20	2,000.0	NA
Two Dot Butte	14860	MT	01/19/18	12/31/20	280.0	NA
Banner Mountain	14863	WY	05/08/18	04/30/21	400.0	NA
Sacaton	14869	AZ	07/19/18	06/30/21	150.0	NA
Badger Mountain	14892	WA	10/02/18	03/31/23	300.0	NA
Eastern Industries	14961	PA	09/05/19	08/31/23	884.3	NA
Wrightstown	14963	PA	01/10/19	04/30/23	20.0	NA
Pending FERC Preliminary Permits						
Packer-Banks	14966	PA	02/25/19		400.0	Preliminary Permit
Gila River Indian Community	14989	AZ	04/30/19		2100.0	Preliminary Permit
Salt River Indian Springs	14990	AZ	05/03/19		1500.0	Preliminary Permit
Haiwee	14991	CA	05/03/19		800.0	Preliminary Permit
Sweetwater	15008	NM	09/23/19		600.00	Preliminary Permit
JD Sky	15009	AZ	10/02/19		311.00	Preliminary Permit
Casa Grande	15010	AZ	10/11/19		864.00	Preliminary Permit
Delaney	15011	AZ	10/11/19		864.00	Preliminary Permit
Ulysses	15012	WV	10/16/19		180.00	Preliminary Permit

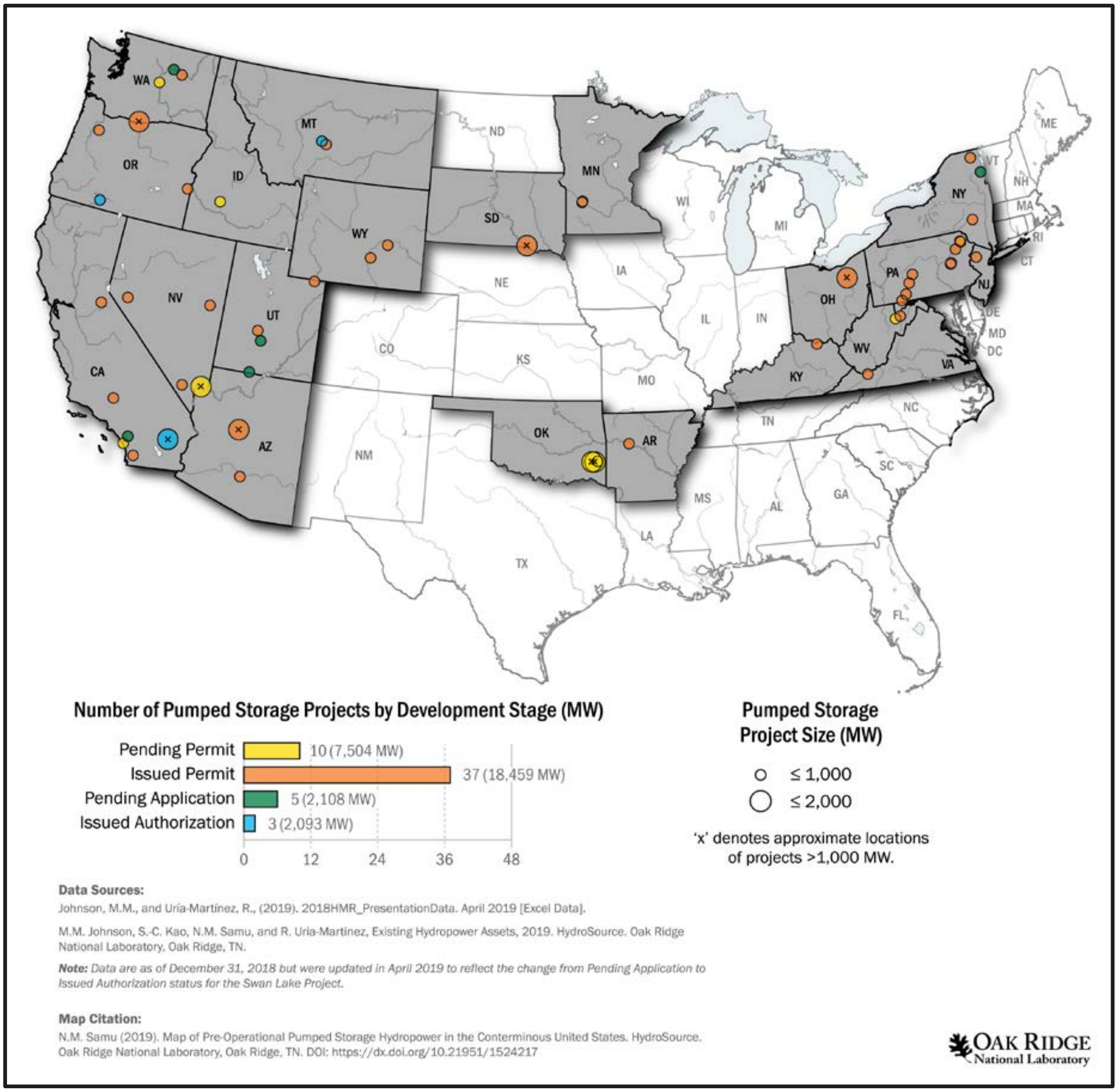

Figure 3. Proposed open-loop and closed-loop PSH projects in the United States. (*Source*: Samu 2019)

In January 2019, FERC issued a Notice of Proposed Rulemaking for the expedited process (FERC 2019c). FERC issued the final rule in April 2019 (FERC 2019a), establishing the criteria for expedited license processing. The criteria require that the PSH project:

1. cause little to no change to existing surface and groundwater flows and uses;
2. is unlikely to adversely affect species listed as a threatened species or endangered species, or designated critical habitat of such species, under the Endangered Species Act of 1973;
3. utilize only reservoirs situated at locations other than natural waterways, lakes, wetlands, and other natural surface water features; and
4. rely only on temporary withdrawals from surface waters or groundwater for the sole purposes of initial fill and periodic recharge needed for project operation.

The final rule does not create a new licensing process or alter any of FERC's three existing licensing processes (ILP, TLP, or ALP); rather, it establishes procedures for FERC to determine, on a case-by-case basis, whether original license applications for closed-loop PSH projects qualify for expedited processing. For qualifying projects using either the ILP, TLP, or ALP, expedited processing means that FERC will issue a final license decision "no later than two years after the Commission receives a completed license application" (FERC 2019a). However, the level of environmental review required under the expedited process remains the same as that required under the existing ILP, TLP, and ALP.

In addition to expedited licensing review, three recent FERC staff decisions regarding closed-loop PSH projects "confirm that, for purposes of establishing the mandatory licensing requirements under the FPA, groundwater is not a non-navigable Commerce Clause stream" (Gerard and Hites 2018). This means that a project "that uses only groundwater as its water source will not require FERC licensing if the project does not trigger other jurisdictional tests" under FPA Section 23(b) (Gerard and Hites 2018). The three proposed projects involved in the decisions would be closed-loop PSH systems using groundwater and reclaimed surface mine pits on private land in Pennsylvania:

- Pennsylvania Pumped Storage Project (FERC Order 161 FERC ¶ 62,215 issued December 19, 2017);
- Old Forge Bore Hole Reclamation Pumped Storage Project (FERC Order 163 FERC ¶ 62,067 issued May 1, 2018);
- Vandling Drift Reclamation Pumped Storage Project (FERC Order 163 FERC ¶ 62,192 issued June 19, 2018).

These three projects did not meet any of the FPA Section 23(b) jurisdictional requirements. These recent decisions reverse previous FERC assertions of jurisdiction over groundwater under FPA Section 4(e) (Swiger et al. 2017) and could allow some closed-loop PSH projects to avoid the FERC licensing process altogether. However, the projects would still be subject to environmental review and permitting approval by other federal, state, and local resource agencies.

With this expedited FERC license review process for qualifying closed-loop PSH projects, and no FERC licensing requirements for some closed-loop PSH projects using groundwater, project developers, regulators, resource agencies, and other stakeholders should understand the environmental effects of these projects when compared to open-loop PSH systems, as well as measures to avoid, minimize, and mitigate those effects. This will be especially true for those closed-loop PSH projects that FERC deems to be outside its regulatory jurisdiction. This report is intended to provide information to promote that understanding.

3.0 A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped Storage Hydropower

3.1 Methodology

This section compares the potential environmental effects of open-loop and closed-loop PSH and discusses the relative significance of those effects. The comparison is based on two reviews:

1. A literature review of journal articles, technical reports, and presentations on the environmental effects of PSH (Appendix B). This review includes literature from the United States as well as from countries where closed-loop PSH projects have been constructed. Appendix B describes the methodology for conducting the literature review.
2. A review of the FERC licensing record (e.g., National Environmental Policy Act documents and license orders) to identify the environmental effects anticipated and mitigation measures proposed for six of the closed-loop PSH projects currently licensed or permitted in the United States (Appendix C). For comparison, this review also discusses the environmental effects and mitigation measures for four open-loop PSH projects proposed or currently operating in the United States. Appendix C describes the methodology for conducting the FERC records review.

There are numerous design alternatives for closed-loop PSH systems; DOE's 2016 *Hydropower Vision* report (DOE 2016) and *2017 Hydropower Market Report* (DOE 2018) provide good overviews of some alternatives. However, this report focuses on the three closed-loop PSH project types most commonly proposed for development in the United States:

- above-ground closed-loop projects using surface water (typically involves the construction of two above-ground reservoirs that are filled and replenished using a surface water source) (Figure 1);
- above-ground closed-loop projects using groundwater (typically involves the construction of two above-ground reservoirs that are filled and replenished using a groundwater source) (Figure 1); and
- underground closed-loop projects using groundwater (can involve the construction of one above-ground reservoir and one underground reservoir, or two underground reservoirs, that are filled and replenished using a groundwater source) (Figure 4).

This report focuses on the potentially affected environmental resources most often discussed in the literature and FERC documents reviewed, dividing them into aquatic resources and terrestrial resources:

Potentially affected aquatic resources include:

- Surface water quality and quantity. The impacts of PSH construction and operations are primarily related to the initial withdrawal of surface water for reservoir fill and the movement of water between and within the project water bodies, whether they be naturally occurring lakes, rivers, or constructed reservoirs. This withdrawal and movement can affect surface water quality parameters such as temperature and dissolved oxygen and can affect the availability of surface water for other uses (i.e., it can be a consumptive use of surface water).

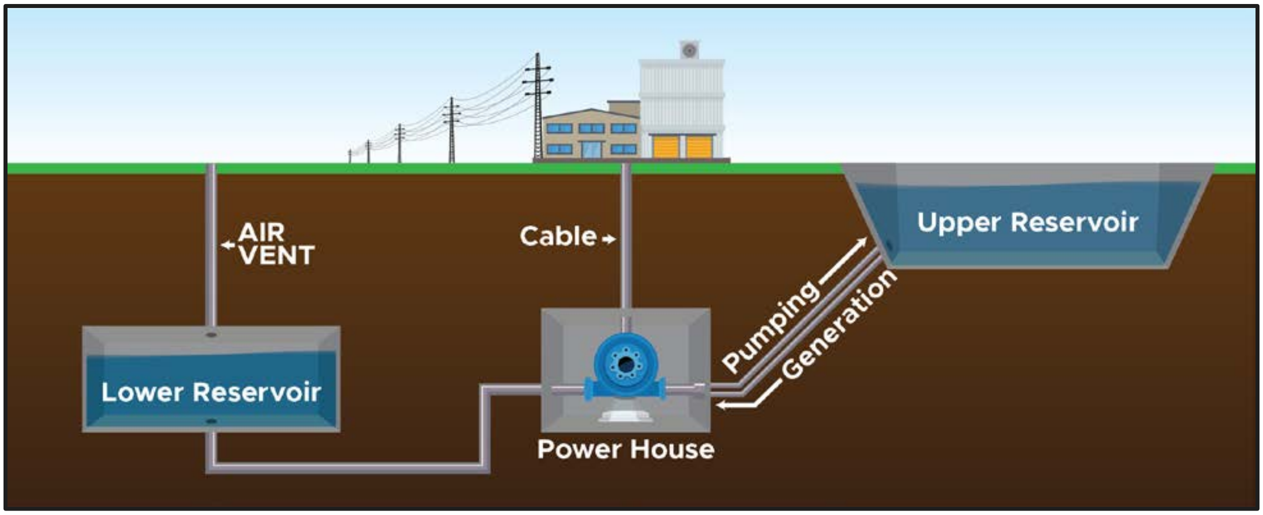

Figure 4. Conceptual diagram of an underground pumped storage hydropower project. (Source: Based on ESA 2019)

- Groundwater quality and quantity. For closed-loop PSH projects that would use groundwater as the source for filling their reservoir initially and for replacing evaporative and seepage losses, there is the potential for impacts to both groundwater quality and quantity. Impacts to groundwater quality could come from the project's effects on groundwater circulation patterns and chemistry as it pumps groundwater to fill and refill the reservoirs. Impacts to groundwater quantity could come from the large quantities of groundwater that the project would pump to fill and refill the reservoirs, which could affect the availability of groundwater for other uses (i.e., it can be a consumptive use of groundwater).
- Aquatic ecology. The impacts of PSH construction and operations on fish and other aquatic ecology are primarily related to the initial withdrawal of surface water for reservoir fill and the movement of water between and within the project water bodies, especially naturally flowing lakes or rivers. This withdrawal and movement of water can affect fish and other aquatic species directly through habitat loss and impingement and entrainment or indirectly through changes to water quality and temperature. Because closed-loop PSH projects are located "off-stream" (i.e., not continuously connected to any naturally flowing water feature), they typically can avoid some of the impacts of open-loop projects on aquatic ecology.

Potentially affected terrestrial resources include:

- Geology and soils. For both open-loop and closed-loop PSH projects, construction has impacts on geology and soils as project reservoirs and related facilities require large-scale excavation and tunneling. Project operations can also affect geology and soils due to reservoir shoreline erosion.
- Terrestrial ecology. For both open-loop and closed-loop PSH projects, construction has impacts on terrestrial ecology as project reservoirs and related facilities require clearing and/or inundating large land areas that provide wildlife habitat. Some of these impacts can be reduced by constructing project reservoirs and other facilities underground, but the impacts of constructing above-ground open-loop and closed-loop systems are similar. The primary difference is that closed-loop projects typically have greater siting flexibility than open-loop projects and can be sited to avoid impacts to terrestrial ecology.
- Land use, recreation, visual resources, and cultural resources. For both open-loop and closed-loop PSH projects, construction requires the clearing and/or inundation of large land areas,

especially for the project reservoirs. Committing large land areas to PSH development can have impacts on existing and planned land uses, recreation, visual resources, or cultural resources at the project site and in the vicinity. Some of these impacts can be reduced by constructing project reservoirs and other facilities underground, but the impacts of constructing above-ground open-loop and closed-loop systems are similar. The primary difference is that closed-loop projects typically have greater siting flexibility than open-loop projects and can be sited to avoid impacts.

The report does not compare open-loop and closed-loop PSH projects in terms of potential greenhouse gas (GHG) emissions or emissions reductions because these topics were not addressed in any of the literature or FERC records reviewed. DOE outlines this issue for conventional hydropower in its 2016 *Hydropower Vision* report (DOE 2016), but not specifically for PSH projects. DOE plans to conduct additional research on the topic of GHG emissions from reservoirs in general (i.e., not just PSH reservoirs or conventional hydropower reservoirs, but all reservoirs).

The comparison of effects between open-loop and closed-loop projects is relative; that is, it characterizes the impacts of each project type as generally lower than, similar to, or higher than another project type. The comparison reflects general trends among project types because there are sometimes exceptions to the examples cited. The comparison is based on both spatial (location) and temporal (duration) factors and reflects both the severity and likelihood of effects.

For the environmental resource areas examined, Table 2 and Table 3 (aquatic resources) and Table 7 and Table 8 (terrestrial resources) and the following sub-sections provide a relative comparison of the environmental effects of open-loop and closed-loop PSH based on the literature review and the FERC records review. For example, open-loop projects typically have relatively higher impacts on surface water and aquatic ecology than closed-loop projects. Likewise, closed-loop projects using groundwater typically have higher impacts on groundwater than closed-loop projects using surface water or open-loop projects. The comparison focuses on impacts to aquatic resources (surface water, groundwater, and aquatic ecology) because those are typically the resource areas for which the differences between open-loop and closed-loop PSH systems are most apparent.

Overall, the environmental effects of closed-loop PSH projects are generally lower (i.e., more localized and of shorter duration) than those of open-loop PSH projects because they: (1) are located “off-stream,” potentially minimizing aquatic and terrestrial impacts, and; (2) often have greater siting flexibility than open-loop PSH projects. However, as discussed in the following sub-sections, for some resources the impacts of closed-loop systems are generally higher than those of open-loop systems, particularly for geology and soils (e.g., impacts of constructing two above-ground reservoirs rather than one) and groundwater (e.g., impacts of initial groundwater withdrawal for above-ground projects *or* daily groundwater circulation for underground projects on aquifers used for irrigation, municipal water supply, and private wells).

One possible project-specific exception to these general conclusions is for open-loop projects where the lower reservoir was already constructed for other purposes (e.g., flood control, conventional hydropower, irrigation) and an upper reservoir was added for PSH operations at a later date as a separate action (i.e., an “add-on” open-loop PSH project). Of the 43 existing PSH projects in the United States, 12 are add-on projects. With this type of add-on open-loop project, many of the impacts of constructing the new upper reservoir and power generation facilities could be lower than those of constructing a new closed-loop project. However, the impacts of operations could still be generally higher than for a closed-loop project because the add-on project’s lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

3.2 Aquatic Resources

3.2.1 Surface Water Quality and Quantity

The impacts of PSH construction and operations on surface water quality and quantity are primarily related to the initial withdrawal of surface water for reservoir fill and the movement of water between and within the project water bodies, whether they be naturally occurring lakes, rivers, or constructed reservoirs. During pumping operations, surface water is withdrawn from the lower reservoir and pumped to the upper reservoir. During power generation, the flow of surface water is reversed from upper to lower reservoir.

Construction. As indicated in Table 2, impacts to surface water quality during construction are typically relatively higher for open-loop projects than for closed-loop projects using surface water because open-loop project construction and initial reservoir fill commonly requires damming a naturally flowing water feature to create the lower reservoir (rather than constructing an artificial lower reservoir as with closed-loop). Such damming may inundate a large land area and have adverse effects on water quality in the naturally flowing water feature, including but not limited to:

- changes in surface water temperature;
- reduced dissolved oxygen content in surface water; and
- alterations in sediment transport processes and connectivity.

One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date as a separate action. With this type of add-on open-loop project, the surface water quality impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a new closed-loop project.

The surface water quality impacts of constructing closed-loop projects using groundwater would be relatively lower, except in cases where underground reservoir seepage or the transfer of groundwater contaminants affects reservoir surface water quality during initial fill. Also, pumping groundwater from an aquifer may increase recharge to, or decrease discharge from, connected surface water bodies such as streams, lakes, and wetlands. Any of these effects may damage the affected surface water bodies, their associated ecosystems, or other water users such as irrigation and drinking water wells, especially if there are connections to the ocean or a gradient of salinity and specialized ecosystems.

The surface water quantity impacts of construction could be similar for either open-loop or closed-loop projects, resulting in a consumptive water use that could reduce the supply for other uses such as irrigation, recreation, industrial, and municipal water supply. This impact would be exacerbated by evaporative and seepage losses of surface water from above-ground reservoirs. Consumptive use impacts might be higher in closed-loop projects because they would hold the surface water in a closed system (as opposed to an open system that is continuously connected to a naturally flowing water body), but the water could be returned to the original source (minus evaporative and seepage losses) if needed.

Operations. In Table 3, open-loop projects typically have more widespread and longer-lasting impacts on surface water quality during operations due to their regular (typically daily) pattern of water withdrawal from and discharge to the naturally flowing water bodies to which they are connected.

Table 2. Relative comparison: Construction impacts on aquatic resources open-loop PSH vs. closed-loop PSH.

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fill)	Surface Water (Construction and Initial Fill)
Surface Water Quality			
Surface water temperature	H Higher	L Lower	L Lower
Reduced dissolved oxygen in surface water	H Higher	L Lower	L Lower
Alterations in sediment transport processes and connectivity	H Higher	NA	L Lower
Transfer of underground leachate contaminants to surface water	L Lower	H Higher	L Lower
Surface Water Quantity			
Surface water supply for other uses (e.g., irrigation, recreation, municipal)	S Similar	L Lower	S Similar
Groundwater Quality			
Groundwater temperature and chemistry (e.g., water/ore-body interactions)	L Lower	H Higher	L Lower
Groundwater circulation and flow patterns	L Lower	H Higher	L Lower

Table 2. Relative comparison: Construction impacts on aquatic resources open-loop PSH vs. closed-loop PSH. (continued)

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fill)	Surface Water (Construction and Initial Fill)
Groundwater Quantity			
Groundwater supply for other uses (e.g., irrigation, recreation, municipal)	Lower	Higher	Lower
Groundwater recharge of surface waters	Lower	Higher	Lower
Aquatic Ecology			
Loss of riverine habitat	Higher	NA	Lower
Loss of littoral habitat	Higher	NA	Lower
Impingement and entrainment of fish and other aquatic species	Similar	NA	Similar
Migration delays or losses in sediment transport or river connectivity due to hydraulic changes	Higher	NA	Lower

Table 3. Relative comparison: Operations impacts on aquatic resources open-loop PSH vs. closed-loop PSH.

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal/Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Surface Water Quality			
Sedimentation due to reservoir shoreline erosion	Higher	Lower	Lower
Changes in sediment transport	Higher	Lower	Lower
Surface water temperature	Higher	Lower	Lower
Reservoir water circulation patterns	Higher	Lower	Lower
Concentration of dissolved solids, nutrients, and heavy metals in surface water due to evaporation	Higher	Lower	Lower
Decreased reservoir light penetration	Higher	Lower	Lower
Surface Water Quantity			
Reservoir evaporative losses	Similar	Similar	Similar
Groundwater Quality			
Groundwater temperature and chemistry (e.g., water/ore-body interactions)	Lower	Higher	Lower
Groundwater circulation and flow patterns	Lower	Higher	Lower

Table 3. Relative comparison: <u>Operations</u> impacts on aquatic resources open-loop PSH vs. closed-loop PSH. (continued)

Aquatic Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal/Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Groundwater Quantity			
Groundwater supply for other uses (e.g., irrigation, recreation, municipal)	**Lower**	**Higher**	**Lower**
Groundwater recharge of surface waters	**Lower**	**Higher**	**Lower**
Aquatic Ecology			
Impingement and entrainment of fish and other aquatic species	**Higher**	**NA**	**Lower**
Migration delays or losses in river connectivity due to hydraulic changes	**Higher**	**NA**	**Lower**

Potential surface water quality impacts of operations include, but are not limited to:

- increased sedimentation due to reservoir shoreline erosion resulting from rapid reservoir fluctuations;
- changes in sediment transport and deposition due to rapid reservoir fluctuations;
- changes in surface water temperature due to pumping and generating operations;
- changes in reservoir water circulation patterns due to pumping and generating operations;
- increased concentrations of dissolved solids, nutrients, and heavy metals in above-ground reservoir surface water due to evaporation; and
- decreased light penetration in above-ground reservoirs (which can affect aquatic plant and animal species) due to increased sedimentation from shoreline erosion.

The surface water quality impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

Closed-loop projects with above-ground reservoirs typically have lower impacts on surface water quality than open-loop projects because they do not have regular (only initial and periodic) withdrawals from naturally flowing water bodies and have no discharges to those water bodies. Closed-loop projects with underground reservoirs (which use groundwater) have the lowest surface water quality impacts of all the PSH project types, except in cases where underground reservoir seepage or the transfer of groundwater contaminants during pumping and generating operations affects surface water quality.

For surface water quantity, both open-loop projects and closed-loop projects (whether connected to surface water or groundwater) with above-ground reservoirs are similar in that they experience evaporation and seepage from their reservoirs during operations, the rates of which depend on local atmospheric and geologic conditions, the use of reservoir liners, and other factors. The issue of consumptive use impacts might be higher in closed-loop projects because they would hold the surface water in a closed system (as opposed to an open system that is continuously connected to a naturally flowing water body), but the water could be returned to the original source (minus evaporative and seepage losses) if needed. Closed-loop projects with underground reservoirs use groundwater and are not affected by evaporation, and thus typically have lower impacts on surface water quantity (primarily due to reservoir seepage) during operations.

Table 4 provides more detail about potential PSH impacts to surface water quality and quantity by citing some of the project examples discussed in Appendix C.

3.2.2 Groundwater Quality and Quantity

Closed-loop PSH projects that would use groundwater as the source for filling their reservoir initially and for replacing evaporative and seepage losses can adversely affect both groundwater quality and quantity. Impacts to groundwater quality could come from the project's effects on groundwater circulation patterns and chemistry as it pumps groundwater to fill and refill the reservoirs. Impacts to groundwater quantity could come from the large quantities of groundwater that the project would pump to fill and refill the reservoirs, resulting in a consumptive use that could reduce the supply for other uses. Open-loop projects and closed-loop projects using surface water can also affect groundwater, but the impacts are typically relatively lower than for closed-loop projects using groundwater.

<u>Construction</u>. For open-loop PSH projects and closed-loop PSH projects that are not connected to groundwater, potential impacts to groundwater during construction are generally limited to the effects of underground construction or tunneling or reservoir seepage on groundwater quality or flow (Table 2). Conversely, closed-loop PSH projects using groundwater for their initial reservoir fill during construction have the potential for relatively higher impacts to both groundwater quality and quantity.

Potential impacts to groundwater quality could occur due to pumping groundwater into the closed-loop reservoirs (whether above-ground or underground) and resulting impacts including but not limited to:

- changes in groundwater temperature, hydrochemical processes, chemical concentrations, and mixing due to water/ore body interactions, and;
- changes in groundwater circulation and flow patterns due to pumping.

The groundwater quantity impacts of constructing closed-loop projects that use groundwater for initial reservoir fill could include:

- increases in the consumptive use of groundwater, reducing the supply for other uses such as irrigation, recreation, industrial, and municipal;
- changes to groundwater aquifer recharge and connectivity and groundwater excursions due to pumping for initial reservoir fill, and;

- reservoir seepage may raise surrounding groundwater levels, potentially affecting nearby structures or facilities.

Impacts to groundwater quantity are more likely for closed-loop projects with above-ground reservoirs than for closed-loop projects with underground reservoirs due to the need to replace evaporative losses.

Table 4. Project examples of potential PSH impacts to surface water quality and quantity.

Closed-Loop PSH
Project examples (see Appendix C): Mineville: Pumping groundwater to surface for dewatering underground upper reservoir (during construction) and removing excess groundwater from natural recharge (during operations) could affect surface water quality and aquatic terrestrial resources in Mill Brook tributary stream. Gordon Butte: Surface water withdrawals could reduce streamflow in Cottonwood Creek, which could affect irrigation supply. Also, it could affect aquatic and riparian ecological resources. Eagle Mountain: Evaporative losses from surface reservoirs could increase concentrations of dissolved solids, nutrients, and heavy metals in reservoir water, which require water treatment. Project would include a water treatment system to protect water quality—a reverse osmosis system with associated pipelines and desalination ponds. Eagle Mountain: Filling open pit iron ore mine reservoirs could reduce surface water quality due to water/ore-body interactions and seepage. Swan Lake North: Exchanging water between two project reservoirs could reduce surface water quality by concentrating dissolved solids, nutrients, and heavy metals. Big Chino Valley: Groundwater withdrawals could reduce baseflow into upper Verde River; could affect water supply for irrigation, livestock grazing, and domestic and municipal water supplies. Also, reduced flows in Verde River could affect fish, other aquatic resources, cultural resources, and existing wild and scenic river designations.
Open-Loop PSH
Project examples (see Appendix C): Iowa Hill: Project operations could affect water quality and temperature in Slab Creek Reservoir. Agencies recommended measures to minimize or prevent sediment mobilization and/or increased turbidity in Slab Creek Reservoir and the South Fork American River downstream of the reservoir. Bath County: License required pre-construction water quality studies at selected locations on Back Creek and Little Back Creek. Monthly testing of DO, temperature, pH, conductivity, total alkalinity, turbidity, suspended solids, ortho- and total phosphorus, inorganic and fecal coliforms, biochemical oxygen demand, flow, and any other significant parameter. Bath County: License required post-operational water quality monitoring program sampling for first five years including the same parameters measured during pre-construction monitoring program. Big Creek Nos. 2A, 8, and Eastwood: Under Settlement Agreement, Southern California Edison (SCE) to implement increased minimum instream flows (MIF) in bypassed reaches downstream of project diversion dams. Big Creek Nos. 2A, 8, and Eastwood: SCE to implement a Temperature Monitoring and Management Plan to document the effects of proposed modified instream flows on water temperatures and allow for adaptive management where needed. Big Creek Nos. 2A, 8, and Eastwood: SCE to implement sediment management measures to pass accumulated sediment through project facilities (followed by flushing flows to redistribute passed sediments), remove accumulated sediment from behind dams, if needed, and monitor turbidity and pool filling.

Open-Loop PSH
Big Creek Nos. 2A, 8, and Eastwood: SCE to decommission and remove four smaller, secondary diversions/reservoirs to enhance water temperature by restoring the affected stream reaches to essentially natural flow conditions.
Smith Mountain: When Smith Mountain Lake is stratified (late spring to early fall) and releases colder, less-oxygenated water, it can result in DO levels below Virginia's standard of 4.0 milligrams/liter (mg/L) in Leesville Lake. FERC license order requires Appalachian Power to implement a *Water Quality Monitoring Plan* that includes: (a) modifying operations at Smith Mountain from July through September to bring units on- and off-line in a manner that prioritizes withdrawing water from higher in the lake's water column; (b) monitoring DO and water temperature in both project lakes for the first five years of the new license (with continuous monitoring during the first two years); and (c) establishing a Water Quality Technical Review Committee to review the monitoring results.
Smith Mountain: Water management at the project affects water uses within the project lakes and downstream, especially during low-flow conditions. Maintaining sufficient flow for aquatic resources and recreational uses downstream can lead to a drawdown of Smith Mountain Lake; conversely, ensuring that lake levels are adequate for recreation can require a reduction in flows from Leesville that could harm downstream resources. FERC license order requires Appalachian Power to use an Operations Model to forecast future Smith Mountain Lake levels and adjust downstream flow releases based on the probability of Smith Mountain Lake elevations reaching certain levels in the future. The license order also requires Appalachian Power to modify its auto-cycling operation at the Leesville development from 18 minutes every twohours to nine minutes every hour. This operations protocol is included in the project's *Water Management Plan*, which also includes: (a) monthly minimum flows for aquatic organisms, habitat, and recreation in the Roanoke River downstream from Leesville; (b) operational restrictions during droughts, including absolute minimum flows; (c) a variance process for the operational provisions; (d) flood control operations; (e) a monitoring and reporting component to ensure that the project is operated in accordance with the license; and (f) an adaptive management component with a 5-year review and update cycle.

Operations. For both open-loop PSH projects and closed-loop PSH projects that are not connected to groundwater, potential impacts to groundwater during operations are generally limited to the effects of reservoir seepage on groundwater flow and quality (Table 3). Closed-loop PSH projects using groundwater for periodic replenishment of evaporative and seepage losses during operations have the potential for more widespread and longer-lasting impacts to both groundwater quality and quantity, such as those described above for construction. Impacts to groundwater quantity are more likely for closed-loop projects with above-ground reservoirs than for closed-loop projects with underground reservoirs due to the need to replace evaporative losses.

Potential impacts to groundwater quality during operations could occur due to the movement of groundwater into and between the reservoirs and resulting impacts including but not limited to:

- changes in groundwater temperature, hydrochemical processes, chemical concentrations and mixing due to water/ore body interactions, and;
- changes in groundwater circulation and flow patterns due to pumping and generating operations.

The groundwater quantity impacts of operating closed-loop projects that use groundwater for replenishing evaporative and seepage losses could include:

- increases in the consumptive use of groundwater, reducing the supply for other uses such as irrigation, recreation, industrial, and municipal, and;
- changes to groundwater aquifer recharge and connectivity and groundwater excursions due to pumping and generating operations.

As during construction, impacts to groundwater quantity during operations are more likely for closed-loop projects with above-ground reservoirs than for closed-loop projects with underground reservoirs due to the need to replace evaporative losses.

Table 5 provides more detail about potential impacts to groundwater quality and quantity by citing some of the project examples discussed in Appendix C.

Table 5. Project examples of potential PSH impacts to groundwater quality and quantity.

Closed-Loop PSH
Project examples (see Appendix C):
Eagle Mountain: Filling open pit iron ore mine reservoirs could reduce groundwater quality due to water/ore-body interactions and seepage. Project would include water treatment system to protect groundwater quality—a reverse osmosis system with associated pipelines and desalination ponds.
Eagle Mountain: Groundwater overdraft in Chuckwalla Basin—connected to Colorado River—could reduce water supply to private wells and reduce Chuckwalla aquifer storativity.
Mineville: Underground pumping could reduce water quality in private wells. Water/ore-body interactions between underground iron ore mine pit reservoirs could reduce groundwater quality.
Swan Lake North: Groundwater withdrawals could affect water supply for irrigation.
Big Chino Valley: Groundwater withdrawals could reduce baseflow into upper Verde River; could affect water supply for irrigation, livestock grazing, and domestic and municipal water supplies. Also, reduced flows in Verde River could affect fish, other aquatic resources, cultural resources, and existing wild and scenic river designations.
Gordon Butte: Dewatering excavated areas during construction could affect groundwater used for municipal water supply.
Open-Loop PSH
Project example (see Appendix C):
Iowa Hill: Agencies recommended that prior to construction of an underground tunnel between reservoirs the licensee prepare a plan for managing groundwater inflows and/or discharge during construction and for groundwater monitoring and management once construction is completed. The agencies recommended monitoring potentially affected springs and creeks for five years after the tunneling operation is completed.

3.2.3 Aquatic Ecology

The impacts of PSH construction and operations on fish and other aquatic ecology are primarily related to the instream construction of dams (for open-loop projects), the initial withdrawal of surface water for reservoir fill, and the movement of water between and within the project water bodies, especially naturally flowing lakes or rivers. This dam construction and withdrawal and movement of water can affect aquatic species directly through habitat loss and impingement and entrainment or indirectly through changes to water quality and temperature. Because closed-loop PSH projects are located "off-stream" (i.e., not continuously connected to any naturally flowing water feature), they typically can avoid some of the impacts of open-loop projects on aquatic ecology.

Construction. During construction, open-loop projects typically have relatively higher impacts on fish and other aquatic ecology than closed-loop projects because of their initial impacts on the naturally flowing water bodies that are dammed and inundated for their lower reservoirs (Table 2). One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date. With this type of add-on open-loop project, the aquatic ecology impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a new closed-loop project.

The potential impacts of constructing both open-loop and closed-loop projects that would use surface water for their initial reservoir fill include but are not limited to:

- loss of riverine and littoral habitat in naturally flowing water bodies;
- losses of fish and other aquatic species from naturally flowing water bodies due to impingement and entrainment in project facilities during surface water withdrawal for initial reservoir fill, and;
- migration delays of fish and other species or losses in habitat connectivity due to hydraulic changes in naturally flowing water bodies.

Open-loop and closed-loop projects using surface water for their initial reservoir fill during construction may have similar impingement and entrainment impacts during the initial reservoir fill period, but closed-loop projects typically would not involve dam construction in a naturally flowing water body and subsequent effects on habitat and connectivity. The impacts to aquatic ecology of constructing closed-loop projects using groundwater would be the smallest of all project types.

Operations. Open-loop projects have more widespread and longer-lasting impacts on aquatic ecology than closed-loop projects during pumping and generation operations because they have ongoing (rather than initial and periodic) effects on the naturally flowing water feature to which they are connected (Table 3). The aquatic ecology impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

The potential impacts of both project types include, but are not limited to:

- effects on surface water quality and quantity (Section 3.2.1) that can have subsequent effects on aquatic species;
- rapid reservoir water-level fluctuations that can affect aquatic habitat and species;
- impingement and entrainment of fish and other aquatic species in project facilities during pumping and generating cycles; and
- migration delays of fish or other species or losses in habitat connectivity due to hydraulic changes in naturally flowing water bodies.

Open-loop and closed-loop projects using surface water to replace evaporative and seepage losses could have similar types of impacts during operations, but closed-loop project impacts could be less widespread and of shorter duration because they are not continuously withdrawing from and discharging to their surface water source. Also, the artificial reservoirs constructed for closed-loop projects support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems. However, the aquatic ecology impacts of closed-loop projects withdrawing large quantities of water from surface water bodies can have adverse effects, even if it is not done continuously.

Table 6 provides more detail about potential PSH impacts to aquatic ecology by citing some of the project examples discussed in Appendix C.

Table 6. Project examples of potential PSH impacts to aquatic ecology.

Closed-Loop PSH
Project examples (see Appendix C):
Gordon Butte: Surface water withdrawals could reduce streamflow in Cottonwood Creek, which could affect aquatic and riparian ecological resources.
Mineville: Pumping groundwater to surface for dewatering underground upper reservoir (during construction) and removing excess groundwater from natural recharge (during operations) could affect surface water quality and aquatic terrestrial resources in Mill Brook tributary stream.
Open-Loop PSH
Project examples (see Appendix C):
Iowa Hill: Project operations could affect water quality and temperature in Slab Creek Reservoir, with resulting impacts on hardhead (a native fish species) in the reservoir. Agencies recommended measures to prevent the current populations of hardhead and other fish present in Slab Creek Reservoir from falling below self-sustaining levels due to Iowa Hill operations.
Iowa Hill: Project operations could result in entrainment of hardhead and other fish into the intake/outlet structure in Slab Creek Reservoir. Agencies recommended measures to minimize or prevent fish entrainment into the intake/outlet structure.
Iowa Hill: Project operations could affect water temperature in Slab Creek Reservoir and water temperature and flows downstream in the South Fork American River, with resulting impacts on existing foothills yellow-tailed frog populations. The foothills yellow-tailed frog is a federal Species of Concern and California Species of Special Concern.
Bath County: Project construction eliminated about 3.3 miles of stream habitat for trout on Back Creek. License required licensee to improve the existing warm water fishery for approximately 1.0 mile downstream of the lower reservoir dam to this impact. Mitigation included constructing two recreation ponds for fishing, planting cover along the bank of the stream, and improving the stream bed to establish an optimum ratio of riffles to pools.
Big Creek Nos. 2A, 8, and Eastwood: Project operations affect aquatic habitats and sediment transport in bypassed stream reaches. Settlement Agreement and FERC Final Environmental Impact Statement (FEIS) include measures focused on improving the ecological health and suitability of reaches downstream of project dams.
Big Creek Nos. 2A, 8, and Eastwood: SCE to implement increased MIF in bypassed reaches downstream of project diversion dams.
Big Creek Nos. 2A, 8, and Eastwood: SCE to implement channel and riparian maintenance flows in the South Fork San Joaquin River and six of its tributaries.
Big Creek Nos. 2A, 8, and Eastwood: SCE to implement sediment management measures to pass accumulated sediment through project facilities (followed by flushing flows to redistribute passed sediments), remove accumulated sediment from behind dams, if needed, and monitor turbidity and pool filling.
Big Creek Nos. 2A, 8, and Eastwood: SCE to decommission and remove four smaller, secondary diversions/reservoirs to enhance fish habitat by restoring the affected stream reaches to essentially natural flow conditions.
Smith Mountain: Primary impacts of continued project operations on aquatic ecology are those to fish in the project reservoirs and downstream due to changes in water quality (reduced temperature and DO) and water quantity (reduced instream flows). Operational parameters required in the *Water Management Plan* provide higher annual lake levels in Smith Mountain Lake, particularly during low-inflow conditions, which benefiting aquatic habitat in the lake, the lake's fish populations, and recreational use. Required changes to operational protocol prioritizes withdrawing water from higher in the water column, thereby reducing the amount of low DO water passing through the development and enhancing DO levels in the Smith Mountain discharge, benefiting aquatic species in Leesville Lake. Required changes to downstream flows below Leesville Dan provide "nearly optimal" habitat for the fish species of concern in the Roanoke River.

3.3 Terrestrial Resources

Our impact comparison focuses on aquatic resources (surface water, groundwater, and aquatic ecology) because those are typically the resource areas for which the differences between open-loop and closed-loop PSH systems are most apparent. However, as discussed in the following sub-sections, there are also differences between open-loop and closed-loop project impacts on terrestrial resources (geology and soils, terrestrial ecology, land use, recreation, visual resources and cultural resources).

3.3.1 Geology and Soils

Construction. Construction of both open-loop and closed-loop PSH projects affects geology and soils primarily due to large-scale excavation for above-ground reservoirs and project facilities and excavation/ tunneling for underground reservoirs, project facilities, and pipelines (Table 7). Because above-ground closed-loop projects typically involve excavating two artificial reservoirs (upper and lower), their initial impacts to geology and soils may be relatively higher than those of open-loop projects, which typically involve excavating only one artificial reservoir (upper). Also, the impacts of constructing a new upper reservoir at an open-loop project where the lower reservoir was already constructed for other purposes could be similar to or lower than those of constructing a closed-loop project.

The impacts of construction for both project types can include, but are not limited to:

- large-scale surface excavation that can result in increased erosion and the need for spoils disposal;
- large-scale underground excavation and tunneling and the need for spoils disposal;
- surface land subsidence (the gradual caving in or sinking of an area of land) due to underground excavation and tunneling;
- surface land subsidence due to pumping groundwater from an aquifer for initial reservoir fill;
- increase seismicity due to underground excavation and tunneling; and
- increased seismicity due to pumping groundwater from an aquifer for initial reservoir fill;

Operations. Both open-loop and closed-loop PSH pumping and generating operations may affect geology and soils primarily due to large and frequent reservoir water-level fluctuations and resulting shoreline erosion (Table 8). These impacts may be relatively higher at open-loop projects, including add-on projects where the lower reservoir was already constructed for other purposes, because of the potential effects of their shoreline erosion and resulting sedimentation on the naturally flowing water bodies to which they are connected.

For closed-loop projects using groundwater, operations may cause surface land subsidence and/or induced seismicity due to pumping and circulating groundwater from and through an underground aquifer. Table 7 provides more detail about potential PSH impacts to geology and soils by citing some of the project examples discussed in Appendix C.

Table 7. Relative comparison: Construction impacts on terrestrial resources open-loop PSH vs. closed-loop PSH.

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fill)	Surface Water (Construction and Initial Fill)
Geology and Soils			
Surface excavation and increased erosion and spoils	Lower	Higher	Higher
Tunneling and increased spoils	Similar	Similar	Similar
Surface land subsidence	Lower	Higher	Lower
Induced seismicity	Lower	Higher	Lower
Terrestrial Ecology			
Vegetative clearing	Higher	Lower	Lower
Wildlife habitat disturbance	Higher	Lower	Lower
Land Use			
Existing and planned uses, especially in sensitive areas	Higher	Lower	Lower
Recreation			
Recreational fisheries and boating	Higher	NA	Lower
Recreational access	Higher	Lower	Lower

Table 7. Relative comparison: Construction impacts on terrestrial resources open-loop PSH vs. closed-loop PSH. (continued)

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Construction and Initial Fill)	Groundwater (Construction and Initial Fill)	Surface Water (Construction and Initial Fill)
Visual Resources			
Construction activities viewed from sensitive areas	**Higher**	**Lower**	**Lower**
Cultural Resources			
Surface excavation and underground tunneling	**Higher**	**Lower**	**Lower**
Access to cultural sites and practices	**Higher**	**Lower**	**Lower**

Table 8. Relative comparison: Operations impacts on terrestrial resources open-loop PSH vs. closed-loop PSH.

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal and Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Geology and Soils			
Reservoir shoreline erosion	Higher	Lower	Lower
Surface Land Subsidence	Lower	Higher	Lower
Induced seismicity	Lower	Higher	Lower
Terrestrial Ecology			
Water quality impacts on wildlife	Higher	Lower	Lower
Land Use			
Existing and planned uses, especially in sensitive areas	Higher	Lower	Lower
Recreation			
Recreational fisheries	Higher	Lower	Lower
Recreational access	Higher	Lower	Lower
Visual Resources			
Project facilities viewed from sensitive areas	Higher	Lower	Lower
Views of reservoir shoreline erosion	Higher	Lower	Lower

Table 8. Relative comparison: Operations impacts on terrestrial resources open-loop PSH vs. closed-loop PSH. (continued)

Terrestrial Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts	
	Surface Water (Operation; Daily Withdrawal and Discharge)	Groundwater (Operation; Periodic Withdrawal from Source)	Surface Water (Operation; Periodic Withdrawal from Source)
Cultural Resources			
Shoreline erosion exposing resources	H **Higher**	L **Lower**	L **Lower**
Access to cultural sites and practices	H **Higher**	L **Lower**	L **Lower**

Table 9. Project examples of potential PSH impacts to geology and soils.

Closed-Loop PSH
Project examples (see Appendix C): Swan Lake North, Big Chino Valley, Gordon Butte, and Parker Knoll[1] each plan to excavate two new above-ground reservoirs, increasing surface excavation and the need for spoils disposal. Eagle Mountain: Land subsidence caused by groundwater overdraft or seepage could affect the underground Colorado River Aqueduct. Eagle Mountain, Parker Knoll, and Big Chino Valley each plan to excavate an underground pipeline to access groundwater wells or a surface water body, increasing underground excavation and the need for spoils disposal. Mineville: FERC DEIS raises concerns about increased surface land subsidence and induced seismicity in the project area due to project construction (underground tunneling and excavation and mine dewatering) and operations (movement of groundwater in mine shafts).
Open-Loop PSH
Project examples (see Appendix C): Iowa Hill[2] (Upper America River Project): planned to construct one new above-ground reservoir and excavate for underground project facilities. Bath County: construction included underground excavation for two 1,300-foot-long, 18-foot diameter penstocks. Smith Mountain: reservoir shoreline erosion continues, with wind-driven waves and boat wakes being the two main causes of erosion. Water-level fluctuations associated with pumping operations are not a significant source of erosion, but they increase the shoreline’s susceptibility to erosion caused by waves and boat wakes. FERC license order requires Appalachian Power to implement an *Erosion Monitoring Plan* to monitor and stabilize as needed

[1] FERC dismissed the Parker Knoll Project license application on October 4, 2018, because the applicant failed to provide either (1) a copy of the water quality certification for the project, (2) a copy of the certification request, including proof of the date on which the certifying agency received the request, or (3) evidence of waiver of certification (see Appendix C).

[2] In 2016, the Sacramento Municipal Utility District board of directors canceled plans to construct the Iowa Hill Project due to cost and financial risks (see Appendix C).

Open-Loop PSH
shoreline areas with scarp heights of less than 5 feet (scarp is defined as a relatively continuous cliff or steep slope produced by erosion between two relatively level surfaces). Smith Mountain: by 2009, sediment accumulated in Smith Mountain Lake and Leesville Lake had decreased the lakes' storage volumes by about 6 percent and 11 percent, respectively. Sedimentation continues, primarily due to land use practices outside the project boundary. Project operations affect reservoir water levels and circulation patterns and may redistribute sediment in the lakes, although it is concentrated in inlets and coves where tributary rivers and streams enter the lakes. FERC license requires Appalachian Power to implement a *Sedimentation Monitoring Plan* to monitor areas of concern and provide dredging as needed at public boat ramps.

3.3.2 Terrestrial Ecology, Land Use, Recreation, Visual Resources, and Cultural Resources

Construction. During project construction, open-loop projects generally have relatively higher impacts than closed-loop projects on terrestrial ecology, land use, recreation, visual resources, and cultural resources because they typically have less flexibility in facility siting (Table 7). That is, open-loop projects are typically sited on a naturally flowing water feature, which serves as the project's lower reservoir. Thus, it is often difficult to avoid disturbing the sensitive terrestrial resources around these naturally flowing water features. One exception could be for open-loop projects where the lower reservoir was already constructed for other purposes and an upper reservoir was added for PSH operations at a later date. With this type of add-on open-loop project, the impacts of constructing the new upper reservoir could be similar to or lower than those of constructing a new closed-loop project.

Conversely, above-ground closed-loop projects can be sited further from their water source, and water is typically delivered to the lower reservoir by pipeline. Given this siting flexibility, above-ground closed-loop projects can also be sited closer to residential, commercial, and industrial energy consumers, thereby shortening transmission line corridors and reducing related impacts to terrestrial resources. Underground closed-loop projects typically have the smallest impacts on these resources of all the PSH project types because they disturb smaller land surface areas

For both open-loop and closed-loop PSH projects (less so for underground projects), construction requires vast land areas, especially for the project reservoirs. Committing large land areas to PSH development may have adverse impacts on terrestrial ecology, land use, recreation, visual resources, and cultural resources, especially if there are sensitive ecological, recreational, visual, or cultural resources nearby. These impacts can be reduced by constructing project reservoirs and other facilities underground, but the general types of impacts of constructing above-ground open-loop and closed-loop systems are similar and include, but are not limited to:

- large-scale vegetative clearing, surface excavation, and underground tunneling and excavation could temporarily disturb terrestrial wildlife and permanently disturb or eliminate their habitat;
- altering existing and planned land uses, especially in sensitive ecological, recreational, visual, and cultural areas;
- the impacts of construction on surface water quality and quantity (Section 3.2.1) and aquatic ecology (Section 3.2.3) in naturally flowing water features could adversely affect terrestrial wildlife and recreational fisheries and boating;
- the short-term presence of construction equipment and materials could temporarily disturb terrestrial wildlife, restrict or eliminate access to recreational areas and cultural sites and practices, and create visual impacts when viewed from sensitive areas;

- large-scale vegetative clearing, surface excavation, and underground tunneling and excavation could destroy cultural resources; and
- large-scale inundation of land areas associated with above-ground reservoir construction could restrict or eliminate access to cultural sites and practices and destroy cultural resources.

Although most of these impacts are adverse, some can be beneficial. For example, damming naturally flowing water features to create reservoirs at some open-loop PSH projects (such as Smith Mountain in Virginia) can create recreational opportunities. However, some PSH reservoirs (especially at closed-loop projects and the upper reservoir at open-loop projects) are closed to recreation due to safety concerns.

Operations. Open-loop projects also tend to have more widespread and longer-lasting impacts on terrestrial ecology, land use, recreation, visual resources, and cultural resources during generating and pumping operations because of their lack of siting flexibility and their ongoing impacts on the water quality and quantity and aquatic ecology of their naturally flowing water source (Table 8). The impacts of operations at add-on open-loop projects could still be generally higher than for closed-loop projects because the add-on project's lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

One possible exception is due to one of the operational benefits of closed-loop projects: essentially an unlimited ramping rate for pumping or generating because of no fish impingement concerns. However, while this unlimited ramping would not affect fish in a closed-loop system, there is the potential avian or terrestrial species impacts due to rapid reservoir fluctuations that might not occur with an open-loop system.

Not surprisingly, closed-loop projects with underground reservoirs (especially those located in former underground mining pits) have the smallest operational impacts on these terrestrial resources of all PSH project types.

The general types of impacts of operating above-ground open-loop and closed-loop systems are similar and include, but are not limited to:

- reservoir shoreline erosion (especially on naturally flowing water features) due to large and frequent reservoir water-level fluctuations (Section 3.3.1) could adversely affect terrestrial species and habitat, alter existing and planned land uses, create visual impacts when viewed from sensitive areas, and expose and/or destroy cultural resources;
- the impacts of operations on surface water quality and quantity (Section 3.2.1) and aquatic ecology (Section 3.2.3) in naturally flowing water features could adversely affect terrestrial wildlife and recreational fisheries and boating, and;
- the long-term presence of above-ground project facilities could disturb terrestrial wildlife, restrict or eliminate access to recreational areas and cultural sites or practices, and create visual impacts when viewed from sensitive areas.

Table 10 provides more detail about potential PSH impacts to terrestrial ecology, land use, recreation, visual resources, and cultural resources, by citing some of the project examples discussed in Appendix C.

Table 10. Project examples of potential PSH impacts to terrestrial ecology, land use, recreation, visual resources, and cultural resources.

Closed-Loop PSH
Project examples (see Appendix C):
Mineville: FERC DEIS recommends measures to protect the federally listed endangered Indiana bat and threatened northern long-eared bat, a New York State species of special concern (eastern small-footed bat), and other hibernating bat species (tri-colored bat, little brown bat, and big brown bat).
Eagle Mountain: Constructing new 15.5-mile underground water delivery pipeline could affect terrestrial species and habitat, including Couch's spadefoot toad (Bureau of Land Management [BLM] Sensitive Species and California Species of Special Concern), a sub-population of desert bighorn sheep (BLM sensitive species), and the federally-listed desert tortoise.
Eagle Mountain: Project construction and lighting could adversely affect views from the Joshua Tree National Park, located about 1.5 miles from the project.
Swan Lake North: FERC FEIS concludes that project construction would have "significant unavoidable adverse effects on the Swan Lake Rim Traditional Cultural Property."
Big Chino Valley: Reduced flows in Verde River due to groundwater withdrawal could affect visual resources, cultural resources, and the river's designation as a wild and scenic river.
Gordon Butte: Gordon Butte is a prominent landform about 1,025 feet above the Musselshell River valley. Project construction and lighting could adversely affect views of Gordon Butte.
Gordon Butte: Constructing two new project reservoirs and associated facilities could adversely affect six known cultural resource sites.
Open-Loop PSH
Project examples (see Appendix C):
Iowa Hill: Project construction and operation could remove wildlife habitat in the Eldorado National Forest and surrounding areas. To mitigate for loss of wildlife habitat, agencies recommended that licensee purchase lands with an equivalent habitat value (or a conservation easement for an equivalent habitat value) to be managed as wildlife habitat over the term of the license.
Iowa Hill: Project construction and operations could affect recreational access to Slab Creek and other areas in the Eldorado National Forest. Agencies recommended that prior to construction the licensee develop a Recreation Access Plan to address recreation access to the Slab Creek Reservoir during project construction and operations.
Iowa Hill: Agencies recommended measures to prevent the creation of dangerous hydraulic conditions within Slab Creek Reservoir that could affect recreational activity.
Iowa Hill: Project construction and operation could affect viewsheds in the Eldorado National Forest and surrounding areas. Forest Service recommended that the licensee develop a design for the project that "meets the visual quality standards of the Eldorado National Forest Land and Resource Management Plan to ensure adequate protection during utilization of the Forest."
Iowa Hill: Project construction could affect cultural resources in the Eldorado National Forest and surrounding areas. Forest Service recommended that the licensee develop a Cultural Resources Management Plan to protect resources.
Bath County: Project construction eliminated about 3.3 miles of stream habitat for trout on Back Creek. License required licensee to improve the existing warm water fishery for approximately 1.0 mile downstream of the lower reservoir dam to this impact. Mitigation included constructing two recreation ponds for fishing, planting cover along the bank of the stream, and improving the stream bed to establish an optimum ratio of riffles to pools.

Open-Loop PSH
Big Creek Nos. 2A, 8, and Eastwood: to mitigate project impacts and enhance aquatic-based recreation, under the Settlement Agreement SCE would develop an accessible fishing platform on the South Fork San Joaquin River and an accessible boat loading facility on Florence Lake. Big Creek Nos. 2A, 8, and Eastwood: to mitigate project impacts and enhance aquatic-based recreation, SCE would pay for California Department of Fish and Wildlife fish stocking in Big Creek Project reservoirs and stream reaches. Big Creek Nos. 2A, 8, and Eastwood: to enhance aquatic-based recreation, SCE would provide channel and riparian maintenance flows from Florence Lake during wet and above average water years so that the descending portion of the flow release is timed to facilitate whitewater boating opportunities. Also, SCE would provide higher water levels in Florence Lake during July and August to enhance flatwater boating opportunities. Smith Mountain: FERC license order requires Appalachian Power to implement a *Sedimentation Monitoring Plan* that includes monitoring areas of concern every five years and periodic reporting. Also, Appalachian Power is required to dredge an area in Smith Mountain Lake where sediment impedes access at the Hardy Ford Public Boat Launch and to remove, as necessary, sediment that affects the use of other public boat ramps. Smith Mountain: Operational parameters required in the *Water Management Plan* would provide higher annual lake levels in Smith Mountain Lake, particularly during low-inflow conditions, to address impacts to aquatic habitat, fish populations, and recreational use. Downstream flows below Leesville Dan required in the *Water Management Plan* would address impacts to habitat for recreational fish species in the Roanoke River, mainly black bass and striped bass.

4.0 Conclusions and Recommendations

Based on the discussion in Section 3.0, the literature review in Appendix B, and the review of FERC licensing and permitting records in Appendix C, this section discusses our conclusions and some recommendations for additional research to help fill remaining knowledge gaps related to the environmental effects of closed-loop PSH.

4.1 Conclusions

In our literature and FERC records reviews, we focused on the closed-loop PSH project types most commonly proposed for development in the United States—above-ground projects using either surface water or groundwater to fill and maintain reservoirs—but we also discuss underground projects using groundwater.

Similarly, we focused on the potentially affected environmental resources most often discussed in the literature and FERC documents reviewed, dividing them into aquatic resources (surface water and groundwater quality and quantity and aquatic ecology) and terrestrial resources (geology and soils, terrestrial ecology, land use, recreation, and visual and cultural resources).

Based on our review, we conclude that the environmental effects of closed-loop PSH projects are generally lower (i.e., more localized and of shorter duration) than those of open-loop PSH projects because they: (1) are located “off-stream,” potentially minimizing aquatic and terrestrial impacts, and; (2) often have greater siting flexibility than open-loop PSH projects. However, for some resources the impacts of closed-loop systems are generally higher than those of open-loop systems, particularly for geology and soils (e.g., impacts of constructing two above-ground reservoirs rather than one) and groundwater (e.g., impacts of initial groundwater withdrawal for above-ground projects *or* daily groundwater circulation for underground projects on aquifers used for irrigation, municipal water supply, and private wells).

One possible project-specific exception to these general conclusions is for open-loop projects where the lower reservoir was already constructed for other purposes (e.g., flood control, conventional hydropower, irrigation) and an upper reservoir was added for PSH operations at a later date as a separate action (i.e., an “add-on” open-loop PSH project). With this type of add-on open-loop project, many of the impacts of constructing the new upper reservoir and power generation facilities could be lower than those of constructing a new closed-loop project. However, the impacts of operations could still be generally higher than for a closed-loop project because the add-on project’s lower reservoir is still continuously connected to, and may affect, the naturally flowing water feature that was dammed for its original construction.

Finally, we note that although this report discusses the environmental effects of both open-loop PSH and closed-loop PSH projects, it does not imply that PSH projects have environmental effects that cannot be mitigated.

Because the type and significance of environmental impacts depends on project location, size, configuration, and operation, impacts must be assessed on a case-by-case basis for both closed-loop and open-loop projects. With increased interest in closed-loop PSH development, project developers, regulators, resource agencies, and other stakeholders should understand the environmental effects of closed-loop systems (as well as measures to avoid, minimize, and mitigate effects) and include them in the environmental analysis of any proposed project.

4.2 Recommendations

All the PSH projects constructed in the United States to date are open-loop, so the potential environmental effects of closed-loop systems are not well documented compared to the effects of open-loop systems. The DOE WPTO, through its HydroWIRES initiative, has prepared this report to help address knowledge gaps based on existing literature and FERC records, but additional research is needed to better characterize and assess the environmental effects of closed-loop PSH.

Because geology and soils and groundwater are the environmental resources for which closed-loop PSH is likely to have relatively higher impacts than open-loop PSH, recommendations for additional research typically focus on the potential effects of closed-loop projects on geology and soils and groundwater quality and quantity. This is especially important for those closed-loop projects that would use groundwater combined with either surface or underground mine pits for their reservoirs.

In Section B.5 of our literature review (Appendix B), we discuss several journal articles that describe the results of efforts to model the impacts of underground closed-loop PSH project operations on groundwater flow and chemistry. The articles stress the need for additional groundwater modeling, but conclude that:

> "the hydrochemical changes induced by real underground PSH projects could be different from those discussed in the article and will vary for each specific site because they depend on the chemical composition of the medium surrounding the underground reservoir" (Pujades 2018).

The articles stress that changes to groundwater flow and chemistry could have significant impacts on the environment and even on PSH project efficiency, such that "if they are not properly considered, they could put at risk the whole feasibility of future underground PSH plants" (Pujades 2018).

Because these potential impacts to groundwater flow and chemistry are so important, the articles recommend that any preliminary studies for selecting abandoned mine sites as potential underground reservoirs for PSH include:

> "… a detailed hydraulic and hydrochemical characterization of the geological medium by means of field tests (pumping and tracer tests), mineralogical analyzes and laboratory tests. In addition, the main characteristics of the plant (volume of the underground reservoir, flowrates, pumping/discharging frequencies, etc.) must be considered and the aeration process in the surface reservoir must be investigated to precisely quantify the gas exchanges. All this information should be integrated into reactive transport models for predicting the consequences of reactive transport processes induced by underground PSH. Monitoring will be also needed during the operational phase of underground PSH plants to verify that hydrochemistry evolves as expected" (Pujades 2018).

To address these and other related topics, in April 2019 FERC conducted a public workshop on "Closed-Loop Pumped Storage Projects at Abandoned Mine Sites" as part of its rulemaking to establish an expedited license review process for closed-loop PSH projects under the *America's Water Infrastructure Act of 2018* (Public Law No. 115-270) (see Section 2.0). The purpose of the workshop was "to explore potential opportunities for development of closed-loop pumped storage projects at abandoned mine sites," and it addressed both above ground and underground sites (FERC 2019d).

During the workshop, FERC staff asked a panel of experts a series of pre-published questions about various topics related to PSH development at abandoned mine sites. FERC used the panelists' responses to the questions, as well as to some questions posed by audience members, in developing its October 2019 *Guidance for Applicants Seeking Licenses or Preliminary Permits for Closed-Loop Pumped Storage Projects at Abandoned Mine Sites (Docket No. AD19-8-000)* (FERC 2019e).

FERC staff's list of questions included some topics where additional research is needed to characterize and assess the environmental impacts of closed-loop PSH using abandoned mines, including:

- How many abandoned mine sites are there in the United States?
- What are the types of sites and in which states or regions are they typically located?
- How does a developer identify abandoned mines that could be used for PSH?
- Are there tools available to identify potential closed-loop PSH project sites at abandoned mines?
- What types of abandoned mines are most conducive for closed-loop PSH development? What are those characteristics?
- Are there advantages of abandoned mine sites compared to other more conventional PSH sites?
- What are the challenges of siting closed-loop PSH projects at abandoned mine sites?
- Are there specific challenges depending on the type of abandoned mines, for example, coal mine versus hard rock mine?
- What are the likely environmental issues a developer could expect at abandoned mine sites? (FERC 2019d).

Although these questions and the FERC guidance issued in October 2019 focus on abandoned mine sites, research should be conducted to answer similar questions for closed-loop PSH projects at other types of sites.

Another recommendation for additional research is to conduct in-depth interviews with PSH developers (including some who have developed closed-loop PSH projects in other countries), resource agency staff, staff from non-governmental organizations, and other stakeholders to solicit their input to better characterize the potential environmental effects of all types of closed-loop PSH projects (not just those at abandoned mine sites). Such interviews could focus on environmental issues that require additional research, as well as technical and regulatory measures that have been proposed or implemented to avoid, minimize, and mitigate environmental impacts. In particular, the interviews could provide valuable information about the effectiveness of measures that have been implemented in other countries.

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Appendix A

Operating Pumped Storage Hydropower Projects in the United States

Appendix A
Operating Pumped Storage Hydropower Projects in the United States

Table A.1. Operating pumped storage hydropower projects in the United States. (all open-loop systems)

Project Name	FERC No.	State	License Issue Date	License Expire Date	Authorized Capacity (MW)	Licensee/ Operator	Waterway	Current Application Type
Bad Creek	2740	SC	08/01/77	07/31/27	1,400.0	Duke Energy Carolinas, LLC	Whitewater River	NA
Bath County	2716	VA	01/10/77	12/31/26	3,003.0	Allegheny Generating Company	Little Back Creek	NA
Bear Swamp	2669	MA	04/28/70	03/31/20	676.0	Bear Swamp Power Company, LLC	Deerfield River	NA
Big Creek Nos. 2A, 8, and Eastwood	67	CA	08/09/78	02/28/09	373.3	Southern California Edison Company	South Fork San Juaquin River	Pending Relicense
Blenheim-Gilboa	2685	NY	06/06/69	04/30/19	1,160.0	New York Power Authority	Schoharie Creek	Pending Relicense
Cabin Creek	2351	CO	05/27/14	04/30/54	336.0	Public Service Company of Colorado	South Clear Creek	NA
Carters Dam	NA	GA	NA	NA	250.0	U.S. Army Corps of Engineers (USACE)	Coosawattee River	NA
Castaic (South State Water Project Hydropower)	2426	CA	03/22/78	01/31/22	1,775.1	California Department of Water Resources (CDWR)/Los Angeles Department of Water & Power	California Aqueduct	NA
Clarence Cannon Dam	NA	MO	NA	NA	58.0	USACE	Mark Twain Lake	NA
DeGray Lake	NA	AR	NA	NA	28.0	USACE	Caddo River	NA
Edward Hyatt (Oroville)	2100	CA	02/11/57	01/31/07	819.0	CDWR	Feather River	Pending Relicense
Fairfield	1894	SC	08/28/74	06/30/20	511.2	South Carolina Electric & Gas	Broad	Pending Relicense
Flatiron	NA	CO	NA	NA	94.5	Bureau of Reclamation (BOR)	Colorado River	NA

TableA.1. Operating pumped storage hydropower projects in the United States. (all open-loop systems). (continued)

Project Name	FERC No.	State	License Issue Date	License Expire Date	Authorized Capacity (MW)	Licensee/ Operator	Waterway	Current Application Type
Harry S. Truman	NA	MO	NA	NA	161.4	USACE	Osage River	NA
Helms	2735	CA	05/18/76	04/30/26	1,053.0	Pacific Gas & Electric Company	North Fork Kings Creek	NA
Hiwassee Dam	NA	NC	NA	NA	185.0	Tennessee Valley Authority (TVA)	Hiwassee River	NA
Horse Mesa	NA	AZ	NA	NA	97.0	BOR	Salt River	NA
Jocassee	2503	SC	08/16/16	08/31/46	867.6	Duke Energy Carolinas, LLC	Little River	NA
John W. Keys III	NA	WA	NA	NA	314.0	BOR	Columbia River	NA
Lewiston	2216	NY	03/15/07	08/31/57	2,755.5	New York Power Authority	Niagara River	NA
Ludington	2680	MI	07/01/19	06/30/69	1,742.5	Consumers Energy Company	Lake Michigan	NA
Mormon Flat	NA	AZ	NA	NA	50.0	BOR	Salt River	NA
Mount Elbert	NA	CO	NA	NA	200.0	BOR	Trans-Mountain Diversion	NA
Muddy Run	2355	PA	12/22/15	11/30/55	1,072.0	Exelon Generating Company, LLC	Muddy Run	NA
New Waddell Dam	NA	AZ	NA	NA	45.0	BOR	Agua Fria River	NA
Northfield Mountain	2485	MA	05/14/68	04/30/18	1,166.8	FirstLight Hydro Generating Company	Connecticut River	Pending Relicense
Olivenhain-Hodges	12473[1]	CA	12/31/03	NA	40.0	San Diego County Water Authority	Lake Hodges/San Dieguito River	NA
O'Neil	NA	CA	NA	NA	25.2	BOR/CDWR	San Luis Creek	NA
Raccoon Mountain	NA	TN	NA	NA	1,652	TVA	Tennessee River	NA
Richard B. Russell	NA	SC/ GA	NA	NA	600.0	USACE	Savannah River	NA
Rocky Mountain	2725	GA	01/21/77	12/31/26	904.0	Georgia Power Company	Oostanaula	NA

[1] FERC conduit exemption. Considered an open-loop project because its lower reservoir (Lakes Hodges) was created by damming the San Dieguito River. Lake Hodges inflows and outflows are from and to the San Dieguito River.

TableA.1. Operating pumped storage hydropower projects in the United States. (all open-loop systems). (continued)

Project Name	FERC No.	State	License Issue Date	License Expire Date	Authorized Capacity (MW)	Licensee/ Operator	Waterway	Current Application Type
Rocky River	2576	CT	06/23/04	05/31/44	114.9	FirstLight Hydro Generating Company	Housatonic River	NA
Salina	2524	OK	10/16/15	11/30/45	259.8	Grand River Dam Authority	Neosho River	NA
San Luis (William R. Gianelli)	NA	CA	NA	NA	424.0	BOR/CDWR	San Luis Creek	NA
Seneca	2280	PA	07/22/15	11/30/65	452.4	Seneca Generation, LLC	Allegheny River	NA
Smith Mountain	2210	VA	12/15/09	03/31/39	636.0	Appalachian Power Company	Roanoke (Staunton) River	NA
Taum Sauk	2277	MO	07/17/14	06/30/44	442.5	Ameren Missouri	East Fork Black River	NA
Thermalito	2100	CA	02/11/57	01/31/07	120	CDWR	Feather River	Pending Relicense
Wallace Dam	2413	GA	08/06/69	05/31/20	324.0	Georgia Power Company	Oconee River	Pending Relicense
Yards Creek	2309	NJ	05/09/13	04/30/53	364.5	Jersey Central Power & Light	Yards Creek	NA

(*Sources:* FERC 2019b. *Licenses.* https://www.ferc.gov/industries/hydropower/gen-info/licensing.asp?csrt=18145540375265195679; DOE 2016. *Hydropower Vision: A New Chapter for America's First Renewable Electricity Source*. https://www.energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-10262016_0.pdf; Dames and Moore 1981. *An Assessment of Hydroelectric Pumped Storage*. In *National Hydroelectric Power Resources Study*. https://www.iwr.usace.army.mil/portals/70/docs/iwrreports/iwr019-000001-000517.pdf.

Appendix B

Literature Review

Appendix B
Literature Review

B.1 Introduction

This appendix describes the results of a literature review conducted to identify and compare the environmental effects of open-loop and closed-loop pumped storage hydropower (PSH). Because no closed-loop PSH projects have been developed in the United States and only a few have been developed in other countries, the environmental effects of closed-loop systems are not well documented compared to those of open-loop systems.

B.2 Methodology

We began the search for documents to include in the literature review by reviewing the reference lists of existing reports with which we were familiar, including:

- *Pumped Storage and Potential Hydropower from Conduits: Report to Congress*, February 2015 (DOE 2015);
- *Hydropower Vision: A New Chapter for America's First Renewable Electricity Source* (DOE 2016);
- *2017 Hydropower Market Report* (DOE 2018);
- *Challenges and Opportunities for New Pumped Storage Development: A White Paper Developed by NHA's Pumped Storage Development Council* (NHA 2017); and
- *2018 Pumped Storage Report* (NHA 2018).

Next, we conducted an internet search using basic phrases such as "pumped storage hydro," "closed-loop pumped storage hydro," "environmental effects of pumped storage hydro," "environmental impacts of pumped storage hydro," and many other variations of these and similar phrases. Once we found a potential source in the reports listed above or through the internet search, we reviewed its reference list to find additional sources. We repeated this process until we began to see the same sources repeatedly.

We found numerous sources on PSH in general (see Section B.10 "References and Bibliography" at the end of this appendix) but found only the following sources on "environmental effects" associated with PSH (or related topics) for use in the literature review: 13 journal articles, five technical reports, and five presentations (this excludes the Federal Energy Regulatory Commission (FERC) documents and other project-related documents discussed in Appendix C).

We discuss our review of these "environmental" sources in the sub-sections below on surface water quality and quantity, groundwater quality and quantity, aquatic and terrestrial ecology, geology and soils, land use, and visual and aesthetic resources. There is, of course, much overlap among impacts to the various resource areas, as discussed in the sub-sections.

B.3 Summary of the Literature Review

Table B.1 presents a general summary of the potential impacts of closed-loop PSH versus open-loop PSH from the literature review. Overall, the literature suggests that closed-loop and open-loop projects would have similar impacts during construction, with some differences as discussed below. However, the literature suggests that during project operations, closed-loop systems would have impacts that are less widespread and of shorter duration than open-loop systems for almost every environmental resource. The primary exception could be for impacts to groundwater for those closed-loop projects using groundwater for their initial reservoir fill and to replace evaporative and seepage losses.

B.4 Overall Impacts of Existing PSH

We found only one source that directly compares the environmental impacts of an existing closed-loop PSH project with those of an existing open-loop PSH project and other energy-storage technologies: the stoRE Project's 2013 presentation "What are the Environmental Effects of Pumped Hydro Energy Storage (PHES) and How Can Future Development Proceed?" (stoRE 2013). The stoRE Project is sponsored by the European Union's Intelligent Energy for Europe Program, with the goal of facilitating "the realization of the ambitious objectives for renewable energy by unlocking the potential for energy storage infrastructure" (stoRE 2018). The stoRE 2013 presentation compares the impacts of four existing European energy-storage projects:

1. closed-loop PSH project (Turlough Hill in Ireland);
2. "semi-open-loop" PSH project, which is defined as having "one artificial reservoir and one reservoir part of river system" (Goldisthal in Germany);
3. open-loop PSH project (Thissavros in Greece); and
4. compressed air energy storage (CAES) project (Huntdorf in Germany).

Figure B.1 presents a graphic summary of the stoRE 2013 comparison, with impact levels categorized as Low ("L"), Medium ("M"), or High ("H"). The presentation focuses on three broad impact areas, with "potential issues" in each area:

1. Human Interaction (Population, Transport, Cultural Heritage, and Material Assets);
2. Ecology and Natural Systems (Biodiversity, Fisheries, Landscape & Visuals, Air and Climate, Water Resources and Quality); and
3. Physical Environment (Noise & Vibration, Soils & Geology, Hydrology & Hydrogeology).

As indicated in Figure B.1, the 2013 stoRE presentation concludes that the CAES project (Huntdorf) has the least environmental impact of the four projects, with the possible exception of impacts to "Air and Climate." The closed-loop PSH project (Turlough Hill) and the semi-open-loop PSH project (Goldisthal) have more significant impacts than the CAES project. However, the semi-open-loop project has greater impacts on "Soils & Geology" than the closed-loop project. The presentation concludes that the open-loop PSH project (Thissavros) has the most significant environmental impacts of the four projects (stoRE 2013).

Table B.1. Summary of impacts of closed-loop PSH versus open-loop PSH from literature review.

Environmental Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts
Surface Water	Open-loop project operations may increase shoreline erosion and sedimentation with adverse effects on reservoir water quality. Evaporative losses from reservoirs may increase concentrations of dissolved solids, nutrients, and heavy metals in reservoir water, which may be transferred to connected surface water bodies. Pumping and generating operations affect water temperature and dissolved oxygen concentrations by mixing water from the two reservoirs. Pumping and generating operations increase the intensity and change the pattern of water circulation in the two reservoirs. Reservoir level fluctuations caused by pumping and generating weaken the ice cover around the edges of reservoirs. Light penetration in reservoirs decreases during project operations due to erosion from wave action and fluctuating water levels and resuspension of fine bottom sediments.	For closed-loop projects with above-ground reservoirs, impacts to surface water quality and quantity would be relatively lower than the impacts discussed in this table for open-loop projects. Most impacts to aquatic ecology could be avoided because there is no continuous connection to a naturally flowing water body. Using surface water for initial reservoir fill and to replace water losses from evaporation and seepage may reduce water supply for irrigation, recreation, municipal water supply, and other uses. For projects with underground reservoirs, impacts to surface water quality and quantity generally would be smaller than for open-loop. One exception: impacts of water/ore-body chemical interaction in mine pit reservoirs. Also, underground reservoirs would have much less evaporation than above ground. Pumping groundwater from underground mines to the surface for dewatering during construction or to dispose of natural groundwater recharge during operations may affect water quality in surface waters.
Groundwater	Open-loop projects are connected to surface water bodies, so potential impacts to groundwater are generally limited to the effects of construction and reservoir seepage on groundwater quality. Seepage from reservoirs may cause the movement of reservoir water into the surrounding groundwater and possibly nearby surface water bodies. Seepage from reservoirs may raise the surrounding groundwater levels, potentially affecting nearby structures or facilities.	For closed-loop projects that would use surface water for initial reservoir fill and to replace water losses from evaporation and seepage, potential groundwater quality impacts are similar to those discussed in this table for open-loop projects. For closed-loop projects that would use groundwater as the source for filling the reservoir initially and for replacing evaporative and seepage losses, there is the potential for impacts to both groundwater quality and quantity. Impacts to groundwater quality would result from the project's effects on groundwater circulation rates, patterns, and chemistry as it pumps groundwater to fill and refill the reservoirs.

Table B.1. Summary of impacts of closed-loop PSH versus open-loop PSH from literature review. (continued)

<table>
<tr><th>Environmental Resource</th><th>Open-Loop PSH Impacts</th><th>Closed-Loop PSH Impacts</th></tr>
<tr><td>Groundwater (continued)</td><td></td><td>Impacts to groundwater quantity would result from the large quantities of groundwater that the project would pump to fill and refill the reservoirs.

Using groundwater reduces the amount of water stored in the aquifer and may change groundwater levels near the pumped wells (with or without surface reservoirs), which may affect other users of the same groundwater resource.

Pumping groundwater from an aquifer may increase recharge to, or decrease discharge from, connected streams, lakes, and wetlands. Any of these effects may damage the affected surface water bodies, their associated ecosystems, or other water users such as irrigation and drinking water wells.

Pumping groundwater from an aquifer and reducing its storage may result in land subsidence (the gradual caving in or sinking of an area of land).

Using groundwater may alter water chemistry by exposing water to different environments (e.g., between underground and surface reservoirs or between different geologic formations).

For underground projects, pumping may cause mineralization of water and transfer of lower rock body heat to the upper reservoir.</td></tr>
<tr><td>Aquatic Ecology</td><td>Open-loop projects are continuously connected to a naturally flowing water feature, so they typically would have more widespread and longer-lasting impacts on aquatic ecological resources than closed-loop projects.

Impacts of reservoir fluctuations due to open-loop project operations may include:
• altered biological production due to short-term reductions in the wetted littoral zone during power generation and short-term expansions of the wetted littoral zone during pumping;
• effects on reservoir temperature stratification;</td><td>Closed-loop projects are located “off-stream” (i.e., not continuously connected to a naturally flowing water feature), so they can avoid many of the impacts of open-loop projects on aquatic ecological resources.

Using surface water for initial reservoir fill and to replace water losses from evaporation and seepage may reduce water supply and quality and affect aquatic ecological resources.

Pumping groundwater from underground mines to the surface for dewatering during construction or to dispose of natural groundwater recharge during operations may affect water quality and aquatic ecological resources in surface waters.</td></tr>
</table>

Table B.1. Summary of impacts of closed-loop PSH versus open-loop PSH from literature review. (continued)

Environmental Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts
Aquatic Ecology	• entrainment of fish and other organisms in the intake and turbine facilities; • impingement of fish and other organisms on trash racks; • the transfer of fish and other organisms (including exotic species) from one project reservoir to the other; and migration delays or losses in river connectivity due to changes in hydraulic conditions and entrainment.	
Geology and Soils	Excavation for above-ground reservoirs and other project facilities may create runoff, erosion, and spoil material. Excavation for underground project facilities (e.g., tunnels, powerhouses) may create additional runoff, erosion, and spoil material. Project operations increase reservoir water-level fluctuations and cause increased reservoir shoreline erosion and sedimentation.	For closed-loop projects with above-ground reservoirs, impacts would be similar to those discussed in this table for open-loop projects. For projects with underground reservoirs, excavation may create additional spoil material and increase the potential for land subsidence (the gradual caving in or sinking of an area of land). Using groundwater for initial reservoir fill and to replace water losses from evaporation and seepage may cause land subsidence due to groundwater withdrawals. Excavation for underground pipelines to access groundwater wells may create additional runoff, erosion, and spoil material. The literature identifies additional "geological, hydrological, geochemical, geothermal, and geotechnical" challenges for underground projects.
Terrestrial Ecology	Constructing and operating project reservoirs and other facilities clears vast areas of terrestrial habitat and may affect sensitive animal and plant species. Impacts to terrestrial ecology often cannot be avoided due to siting constraints (i.e., limited by topographical conditions and proximity to water source).	For closed-loop projects with above-ground reservoirs, impacts to terrestrial ecology would be relatively lower than those of open-loop projects because closed-loop projects have fewer siting constraints (i.e., not as limited by topographical conditions and proximity to water source), so sensitive habitats and species may be avoided. For projects with underground reservoirs, impacts to terrestrial ecology would be much smaller than for open-loop or for closed-loop with above-ground reservoirs. For projects using groundwater, constructing an underground pipeline to access groundwater wells may clear additional habitat and affect sensitive animal and plant species.

Table B.1. Summary of impacts of closed-loop PSH versus open-loop PSH from literature review. (continued)

Environmental Resource	Open-Loop PSH Impacts	Closed-Loop PSH Impacts
Land Use	Constructing project reservoirs and other facilities clears vast areas of land, affecting existing and planned land uses. Impacts to important land uses often cannot be avoided due to siting constraints (i.e., limited by topographical conditions and proximity to water source).	For closed-loop projects with above-ground reservoirs, land use impacts would be relatively lower than those of open-loop projects because closed-loop projects have fewer siting constraints (i.e., not as limited by topographical conditions and proximity to water source), so important land uses can be avoided. Because closed-loop projects have fewer siting constraints, they may be located closer to generating resources and/or load demand centers. For projects with underground reservoirs, impacts to land use would be much smaller than for open-loop or for closed-loop with above-ground reservoirs. For projects using groundwater, constructing an underground pipeline to access groundwater wells may affect additional land uses.
Visual Resources	The initial construction and continued presence of above-ground project reservoirs and other facilities (including lengthy transmission lines) may affect viewsheds from sensitive areas such as parks, recreation areas, wilderness areas, etc. Impacts to sensitive viewsheds often cannot be avoided due to siting constraints (i.e., limited by topographical conditions and proximity to water source).	For closed-loop projects with above-ground reservoirs, visual impacts would be relatively lower than those of open-loop projects because closed-loop projects have fewer siting constraints (i.e., not as limited by topographical conditions and proximity to water source), so sensitive viewsheds from parks, recreation areas, wilderness, etc., can be avoided. For projects with underground reservoirs, visual impacts would be much smaller than for open-loop or for closed-loop with above-ground reservoirs.
Cultural Resources	Constructing and operating project reservoirs and other facilities clears vast areas of land and may affect known and undiscovered cultural resources. Impacts to cultural resources often cannot be avoided due to siting constraints (i.e., limited by topographical conditions and proximity to water source).	For closed-loop projects with above-ground reservoirs, impacts to cultural resources would relatively lower than those of open-loop projects because closed-loop projects have fewer siting constraints (i.e., not as limited by topographical conditions and proximity to water source), so known cultural resources can be avoided. For projects using groundwater, constructing an underground pipeline to access groundwater wells may clear additional land areas and affect cultural resources.

Environmental Impact

	Potential Issues/EIA Terms of Reference	Huntdorf (CAES)	Turlough Hill (closed-loop)	Goldisthal (semi-open-loop)	Thissavros (open-loop)
Human Interaction	Population	L	L	L	L
	Transport	L	L	L	L
	Cultural Heritage	L	L	L	L
	Material Assets	L	L	L	L
Ecology & Natural Systems	Biodiversity	L	H	H	H
	Fisheries	L	M	M	H
	Landscape & Visuals	L	M	M	M
	Air & Climate	L-H	L-H	L-H	L-H
	Water Resources & Quality	L	M	M	H
Physical Environment	Noise & Vibration	L	L	L	L
	Soils & Geology	L	L	M	H
	Hydrology & Hydrogeology	L	H	H	H

Figure B.1. Comparison of the environmental impacts of four European energy-storage projects. (*Source*: stoRE 2013)

Regarding the closed-loop PSH project (Turlough Hill), the 2013 stoRE presentation concludes that the project has High impacts on "Biodiversity" and "Hydrology & Hydrogeology" (and perhaps "Air & Climate"), and Medium impacts on "Fisheries," "Landscape & Visuals," and "Water Resources & Quality" (stoRE 2013). Unfortunately, the presentation does not specify what the impacts are nor what measures have (or have not) been implemented to avoid or mitigate the impacts. It does, however, support the conclusion that the impacts of closed-loop systems are generally smaller than those of open-loop systems.

A more recent journal article from Germany, "Life-cycle Impacts of Pumped Hydropower Storage and Battery Storage" (Immendoerfer 2017), describes the results of a "simplified" life-cycle analysis (LCA) comparison of the environmental impacts of two energy storage options: open-loop PSH and utility-scale lithium-ion batteries. The article deliberately focuses on the question "Which storage technology performs better environmentally if a range of global environmental impacts are considered over the entire life-cycle?" The article defines the functional unit for comparing the two technologies in the base case as "the provision of 9.6 GWh stored energy over a time span of 80 years" (Immendoerfer 2017).

The article compares the impacts of open-loop PSH with those of utility-scale lithium-ion batteries for seven resource categories:

1. "Global Warming Potential;"
2. "Cumulative Energy Demand (Fossil);"
3. "Cumulative Exergy Demand—Minerals ("exergy" is a measure of the energy that is available to be used in a system);"
4. "Cumulative Exergy Demand—Metals;"
5. "Natural Land Transformation;"
6. "Eutrophication (excessive richness of nutrients in a water body);" and
7. "Human Health (carcinogenic)."

The only resource category in which the impacts of open-loop PSH exceed those of the utility-scale battery is in natural land transformation. The article states that this difference results from the "land qualities" assumed:

> "The pumped hydropower store would be sited on virgin natural land of high ecological quality. For the utility-scale battery, the category "unspecified land" was chosen, which is made up from 40% greenfield and 60% brownfield land. This is deemed appropriate, as utility-scale batteries are more likely to be sited on brownfield sites, such as industrial areas and wastelands. In addition, the feasibility of smaller hydropower stores, e.g., on landfills is being currently analyzed which would also change the land quality being changed and thus the results for the indicator natural land transformation" (Immendoerfer 2017).

Although the 2017 Immendoerfer article does not state it explicitly, it can be assumed that the "land qualities" argument would favor closed-loop PSH systems over open-loop PSH systems because the former has fewer locational constraints than the latter, and thus could be sited on land of lower "quality" (e.g., abandoned mines, quarries, etc.) and have reduced environmental impacts.

In its conclusions, the 2017 Immendoerfer article ponders whether PSH and batteries are comparable as energy-storage technologies over long time spans (over 80 years) given that PSH is designed to serve long-term storage requirements while batteries are better suited to fulfill short-term requirements. While acknowledging that the two technologies are not "unconditionally comparable," the article argues on behalf of the global, life-cycle environmental benefits of PSH for Germany:

> "Ultimately, part of the motivation for this piece of work was the opposition towards new pumped hydropower storage plants encountered whenever new installations are being planned. Given the clearly lower overall impacts for pumped hydropower storage, it appears advisable that these results and others like these are being fed into the public debate. Nevertheless, it has to be also recognized that the somewhat abstract nature of the numerical results for LCA indicators will have to compete against the concern for visible, tangible, and

> well-loved local flora, fauna, and landscapes. The challenge, therefore, is to present LCA results in a way which shows that impacts elsewhere in the world or in the future are just as important and as painfully felt as those in the present time and place" (Immendoerfer 2017).

Given the "clearly lower overall impacts" of open-loop PSH compared to batteries as described in this article, the potential for even lower overall impacts with closed-loop PSH could make it an even more attractive option for energy storage. But closed-loop PSH systems can have environmental impacts that should be considered, too, as discussed in the following resource-specific sub-sections.

B.5 Water Quality and Quantity

Because most of the environmental impacts of PSH project operations are related to the movement of water between and within the project water bodies during pumping and power generation, we begin the discussion of resource-specific impacts with those to water quality and quantity. We discuss impacts to surface water quality and quantity in Section B.5.1 and impacts to groundwater quality and quantity in Section B.5.2. The impacts discussed in the following sub-sections are summarized in Table B.1.

B.5.1 Surface Water Quality and Quantity

For surface water quality and quantity, the impacts of PSH construction and operations are primarily related to the initial withdrawal of surface water for reservoir fill and the movement of water between and within the project water bodies, whether they be naturally occurring lakes, rivers, or constructed reservoirs. During pumping operations, water is pumped from the lower water body to the upper water body. During power generation, the flow of water is reversed from upper to lower. The impacts discussed below are summarized in Table B.1.

One early assessment of the environmental effects of open-loop PSH projects in the United States is the 1981 report *An Assessment of Hydroelectric Pumped Storage* (Dames and Moore 1981), prepared for the U.S. Army Engineer Institute for Water Resources. This report describes the results of an examination of the "technical, environmental, and economic characteristics" of five existing and one proposed open-loop PSH projects selected as case study sites: (1) the Taum Sauk Project in Missouri; (2) the Northfield Mountain Project in Connecticut; (3) the Ludington Project in Michigan; (4) the Helms Project in California (under construction in 1981); (5) the Blenheim-Gilboa Project in New York; and (6) the Breakabeen/Prattsville Project (a project proposed in 1981 that was canceled in 1987). The report does not specifically address closed-loop PSH.

Regarding water quantity, the 1981 Dames and Moore report states that although PSH projects consume relatively little water (i.e., only relatively minor losses due to seepage and evaporation), they do require (and reuse, rather than consume) large quantities of water during operation, especially when compared to other energy-storage alternatives. The report's conclusion regarding large quantities of water being reused for operations is true for both open-loop and closed-loop PSH systems. The difference is that open-loop systems are *continuously* connected to a naturally flowing water feature during operations, while closed-loop systems are not (although they might draw water from a naturally flowing feature to fill the system initially and replace evaporative losses). For water quantity, this distinction is most important when the closed-loop system uses groundwater (rather than surface water) to fill the system initially and replace losses, as discussed in Section B.5.2.

For water quality, the 1981 Dames and Moore report describes the adverse effects of reservoir water-level fluctuations during open-loop PSH operations, which result in increased bank erosion and the subsequent impacts of increased sedimentation on reservoir water quality. To the extent that above-ground reservoirs are constructed for closed-loop projects, these same water quality impacts are likely. However, they would likely result in fewer impacts to aquatic ecology than for open-loop projects that are continuously connected to a natural water body.

Although the 1981 Dames and Moore report does not address closed-loop PSH systems, it does conclude that underground PSH projects have significantly fewer environmental impacts than conventional PSH projects because water use is characteristically less and, consequently, the magnitude of water quality change is proportionately reduced. The report outlines some major environmental impacts of underground PSH, including mineralization of water, transfer of lower rock body heat to the upper reservoir during pumping, and potential eutrophication in reservoirs (Dames and Moore 1981).

Another early assessment of the environmental effects of open-loop PSH projects in the United States is the 1993 report Aquatic Ecology Studies of Twin Lakes, Colorado 1971-86: Effects of a Pumped Storage Hydroelectric Project on a Pair of Montane Lakes (DOI 1993) prepared by the Bureau of Reclamation (BOR) and the Colorado Cooperative Fishery Research Unit at Colorado State University. The report describes the results of some pre- and post-construction limnology and fishery studies conducted to determine and quantify the effects on aquatic ecology of constructing and operating the BOR's Mt. Elbert PSH project.

The 1993 DOI report identifies a number of water quality impacts related to open-loop PSH development and operations:

- Raised lake levels exposed previously unflooded soils to erosion by wave action and water surface fluctuations, which contributed to a decline in water clarity in the lakes.
- Inundating new terrain resulted in an increase in internal nutrient loading and total phosphorus and nitrate concentrations increased significantly in both lakes.
- Pumping and generating operations affected water temperature by mixing water from the two lakes.
- Pumping and generating operations increased the intensity of water circulation and changed the pattern of water circulation in the two lakes.
- Lake level fluctuations caused by pumping and generating weakened the ice cover around the edges of the lakes.
- Light penetration in both lakes decreased significantly during project operations due to erosion from wave action and fluctuating water levels, resuspension of fine bottom sediments, and increased chlorophyll-a concentrations in the lower lake (DOI 1993).

Although these water quality impacts were identified for an open-loop PSH project, similar impacts are likely for closed-loop projects where above-ground reservoirs are constructed. They would likely result in fewer impacts to aquatic ecology, however, than open-loop projects that are continuously connected to a natural water body.

Another valuable assessment of the environmental effects of PSH projects, including closed-loop systems, is the 2009 *Technical Analysis of Pumped Storage and Integration with Wind Power in the Pacific Northwest* (MWH 2009), prepared for the U.S. Army Corps of Engineers, Northwest Division, Hydroelectric Design Center. The 2009 MWH report notes that one water quantity issue for both open-loop and closed-loop PSH projects is evaporative losses from the reservoirs. If evaporative losses are significant, supplemental water supply would be required to refill the reservoir volume. The report states that "at least one developer has in the past proposed reservoirs with floating covers to limit evaporation and the need to furnish makeup water," but cites two technical problems with this solution. First, the water surface level of a PSH reservoir may fluctuate over a wide range and providing a guarantee for the performance of a floating cover would be difficult (MHW 2009). Second, "solar radiation, in conjunction with the restricted evaporation and its associated cooling effects, would cause the temperature of the stored water to reach high levels." In one MWH study, it was estimated that reservoir water temperatures could reach nearly 65.6°C (150°F) without supplemental cooling (MWH 2009).

Another water quantity issue for both open-loop and closed-loop PSH projects is reservoir leakage. The 2009 MHW report states that a liner may be required in one or both reservoirs. Seepage through the liner could still occur, but lining systems can include a leak detection and seepage collection system designed to capture seepage, and the effluent from such a system can be pumped back to the reservoir to avoid water losses (MWH 2009).

The 2009 MWH report states that developing a PSH project requires analysis and modeling of the expected water quality changes. In an open-loop system, there could be "temperature increases to waters of the lower reservoir by cycling the water through the upper reservoir system if exposed to solar radiation and ambient temperatures and wind." In a closed-loop system, effects to a river or lake "would be limited to nonexistent, but the water used in the closed system could have its own water quality problems over time as temperature increases and evaporation concentrates pollutants." For closed-loop PSH projects, the report concludes that:

> "… a water treatment system and program would likely be needed to address water quality considerations of both the initial fill waters, the periodic make up water, and water used in daily operations along with any periodic discharges from the project reservoirs. Groundwater could also be affected, both positively and/or possibly adversely; however, the lining of reservoirs could reduce leakage and mitigate adverse effects" (MWH 2009).

Overall, the 2009 MWH report concludes that:

> "… it is probably more expensive to develop a closed-loop system than a conventional river basin lower reservoir. However, the overall cost of reservoir storage is often a rather small percentage of the total pumped storage hydro cost. If choosing a closed-loop system reduces permitting time by improving public acceptance or reducing the impact on existing fisheries, then the added costs may be justified" (MWH 2009).

The 2011 journal article "Opportunities and barriers to pumped-hydro energy storage in the United States" (Yang and Jackson 2011) focuses on new approaches to PSH development, including "off-stream systems, and those using underground reservoirs, groundwater system and abandoned quarries and mines."

The 2011 Yang and Jackson article notes that closed-loop systems (which it refers to as "off-stream" systems), especially those using groundwater, reduce or eliminate impacts to aquatic ecosystems. The article states that using abandoned quarries, mines, and underground caverns can avoid some impacts to existing water bodies, but that "the hydrological and environmental interactions still need considerable evaluation for each project" (Yang and Jackson 2011).

The article cites one proposed PSH project in California, the 280-MW Mulqueeney Ranch Project (FERC No. 12807), as "particularly interesting" in its proposed use of innovative approaches (the Mulqueeney Ranch Project application is no longer active, and FERC denied the project applicant's request for a second preliminary permit extension in 2014). The applicant proposed to use recycled wastewater as the water resource for its closed-loop PSH system. The article cites many advantages to that project design:

> "Not only would the use of wastewater alleviate concerns for fish populations, but the pumped hydropower energy-storage operation may actually improve the quality of the water it uses to operate. The pumping operation can be designed to aerate the water, and storage could become an extended aerobic biological treatment. In addition, wastewater treatment plants are typically located near major population centers, which are demand centers for electricity. Storing electricity nearby would reduce the need for transmission upgrades" (Yang and Jackson 2011).

The article notes that the Mulqueeney Ranch Project proposal called for diverting 500 acre-feet of recycled wastewater per year from a nearby wastewater treatment plant (WWTP), equivalent to 0.446 million gallons per day. Citing U.S. Environmental Protection Agency (EPA) *Clean Watershed Survey 2004* data, the article states that there are 6,135 WWTPs in the United States with output flows of more than 0.45 million gallons per day and concludes that it is likely that some of these WWTPs may find suitable PSH opportunities nearby (Yang and Jackson 2011).

The 2012 article "The History, Present State, and Future Prospects of Underground Pumped Hydro for Massive Energy Storage" (Pickard 2012) argues that PSH development is "seriously limited by a shortage of suitable reservoir sites" and that:

> "The obvious solution is to excavate an underground reservoir many hundreds of meters below surface level and to exchange water between it and a surface reservoir created immediately above it and diked using spoil from the excavation" (Pickard 2012).

The 2012 Pickard article states that for underground PSH, one water quality issue is "the gradual increase in the temperature of cycled water due to absorbing the turnaround losses of the energy storage and retrieval processes." The article suggests that this impact would not be significant for underground PSH, however, "because gradual temperature increase of the pumped water is not a serious problem for conventional pumped hydro." The article concludes that the project designer "need only make the surface area of the upper reservoir large enough for evaporative cooling to limit the rise: if the designer is aware of the problem, it should be possible to circumvent this heating if an adequate supply of water is available to maintain the upper reservoir at the desired capacity" (Pickard 2012).

A 2012 presentation, "Environmental Impacts of Pumped Storage Hydropower Plants: Norwegian Perspectives" (Bakken 2012), describes the research conducted by Norway's Center for Environmental Design of Renewable Energy regarding the biological impacts of open-loop PSH project operations. The presentation identifies several "physical impacts" on reservoirs, including:

- More rapid and frequent water level changes (short-term);
- Changes in reservoir filling over the year;
- Reduction in permanent wetted littoral zone (short-term);
- Changes in circulation patterns (water velocity and directions); and
- Changes in water temperature and ice formation.

A second 2012 presentation from Norway, "Impacts of Pumped Storage Hydropower on the Ecosystem of Reservoirs" (Sundt-Hansen and Palm Helland 2012), describes similar physical impacts of PSH operations on reservoirs, including:

- Increased frequency of draining and filling of reservoir;
- Less predictable water level;

- Changed circulation pattern, may affect thermal stratification; and
- Changes in water temperature and ice formation.

A more recent Norwegian report, *Environmental Impacts of Pumped Storage Hydro Power Plants* (Patocka 2014), builds on the 2012 Bakken and Sundt-Hansen presentations to provide a more detailed discussion of the impacts of PSH operations compared with those of conventional hydropower. The report focuses on two broad categories of impacts that result from fluctuating reservoir levels: physical impacts and biological impacts. Within each of these two categories, the report discusses specific impacts, as described below. Unfortunately, the report makes no distinction between open-loop and closed-loop PSH systems.

The primary driver of physical impacts associated with PSH operations is rapid and frequent water level changes in project reservoirs, which causes:

- Short-term reduction in the reservoir's wetted littoral zone when the water level is dropping. Reservoirs with very steep banks have smaller reductions of the wetted littoral zone; reservoir banks with gentle slopes will be affected over a much larger area.
- Changes in reservoir water circulation patterns, which depend on the temperature of the water, the distribution of water temperature over reservoir depth, and the flow conditions (speed and volume) at the reservoir inlet.
- Changes in reservoir water temperature and ice formation due to a higher number of dynamic outflows and inflows (Patocka 2014).

Although the water quality impacts described in Bakken 2012, Sundt-Hansen and Palm Helland 2012, and Patocka 2014 are for open-loop PSH projects, similar impacts are likely for closed-loop projects with above-ground reservoirs. However, they would likely result in fewer impacts to aquatic ecology than for open-loop projects that are continuously connected to a natural water body.

The 2018 article from Switzerland "Effects of Lake–Reservoir Pumped Storage Operations on Temperature and Water Quality" (Kobler et al. 2018) assesses the water quality impacts of open-loop PSH operations in terms of (1) the exchange of water between two connected water bodies and (2) deep-water withdrawal from the upper water body. The article reports on simulations of different operating scenarios conducted using the numerical hydrodynamic and water quality model CE-QUAL-W2 (Kobler et al. 2018).

For extended PSH operations, the article describes significant impacts due to the water exchange between the two reservoirs on the seasonal dynamics of temperatures, stratification, nutrients, and ice cover, especially in the smaller upper reservoir. Deep-water withdrawal strongly decreases the strength of summer stratification in the upper reservoir, shortening its duration by approximately 1.5 months, consequently improving oxygen availability and reducing the accumulation of nutrients in the hypolimnion. The article states that these findings "highlight the importance of assessing the effects of different options for water withdrawal depths in the design of PS hydropower plants" (Kobler et al. 2018).

The 2018 Kobler article also states that PSH operations modify physical and geochemical (abiotic) as well as ecological (biotic) properties of the connected water bodies. Abiotic effects include changes of water temperature, stratification, water-level fluctuations, sediment resuspension, oxygen and nutrient cycling in the water column as well as modifications of inorganic suspended sediment, which accordingly alter light penetration. Additionally, lake-internal circulation patterns as well as ice cover may be affected (Kobler et al. 2018).

Overall, the 2018 Kobler article concludes that the effects of the water exchange due to PSH operations are small compared to the effects of deep-water withdrawal. This conclusion highlights the importance of withdrawal depth as a crucial parameter in the design of PSH plants for reducing ecological impacts (Kobler et al. 2018).

The water quality impacts described in Kobler et al. (2018) are for open-loop PSH projects, but similar impacts are likely for closed-loop projects with above-ground reservoirs. Again, however, they would likely result in fewer impacts to aquatic ecology than for open-loop projects that are continuously connected to a natural water body.

B.5.2 Groundwater Quality and Quantity

For open-loop PSH projects, which are connected to surface water bodies, potential impacts to groundwater are generally limited to the effects of reservoir seepage on groundwater quality. For closed-loop PSH projects that are not connected to groundwater, the potential for groundwater quality impacts is similar to that for open-loop systems. However, for those closed-loop projects that would use groundwater as the source for filling their reservoir initially and for replacing evaporative and seepage losses, there is the potential for impacts to both groundwater quality and quantity. As discussed below, impacts to groundwater quality would come from the project's effects on groundwater circulation patterns and chemistry as it pumps groundwater to fill and refill the reservoirs. Impacts to groundwater quantity would come from the large quantities of groundwater that the project would pump to fill and refill the reservoirs. The impacts discussed below are summarized in Table B.1.

The 1981 Dames and Moore report does not discuss closed-loop PSH systems, but it does conclude that underground PSH projects have significantly fewer environmental impacts than conventional PSH projects because water use is characteristically less and, consequently, the magnitude of water quality change is proportionately reduced. Although the report states that groundwater and geologic conditions are major siting factors in underground PSH development, it concludes that no significant groundwater impacts are likely (Dames and Moore 1981). This, of course, does not include the potential impacts of closed-loop PSH projects that would use groundwater.

The 2009 MWH report specifically addresses the use of groundwater by closed-loop PSH projects to fill the reservoir initially. The report cautions that when considering the use of groundwater:

> "a pumping test to determine the sustainable yield would be required . . . This can be quite costly and time consuming. One program reviewed by MWH (but never implemented) would have required a test of about six months in duration and a cost of about $500,000" (MWH 2009).

The report also notes that pumping groundwater to balance water losses from evaporation and leakages "would require energy and therefore reduce the overall cycle efficiency of the PSH project" (MWH 2009).

The 2009 MWH report states that another possibility for filling closed-loop PSH systems is to use treated wastewater. The report concludes that "case-by-case study would be required to examine particular water quality considerations, but wastewater treated and used for such purposes as lawn and ornamental irrigation or for dust control could probably be used as the supply for a pumped storage project" (MWH 2009).

The 2010 presentation "Pumped Hydro Energy Storage (PHES) Using Abandoned Mine Pits on the Mesabi Iron Range of Minnesota" (Fosnacht 2010) discusses the potential for developing closed-loop PSH projects using open iron ore pit mines as reservoirs. In terms of "surface and groundwater exchange," the presentation identifies four key questions to focus resource impact assessments:

1. Within what area surrounding the pit will groundwater flow (direction and magnitude) be changed?
2. How might these changes affect the oxidation/reduction of iron and sulfur within the affected area and, therefore, the water quality in pit lakes?
3. How might PSH development affect ongoing and future mine land reclamation efforts?
4. What is the potential for PSH to exacerbate existing water resource issues in the region? (e.g., sulfate, fish-mercury, heavy metals, sedimentation, etc.) (Fosnacht 2010).

The 2011 Yang and Jackson article focuses on new approaches to PSH development, including "off-stream systems, and those using underground reservoirs, groundwater system and abandoned quarries and mines." The article notes that closed-loop systems (which it refers to as "off-stream" systems), especially those using groundwater, reduce or eliminate impacts to aquatic ecosystems. The article states that using abandoned quarries, mines, and underground caverns can avoid some impacts to existing water bodies, but that "the hydrological and environmental interactions still need considerable evaluation for each project" (Yang and Jackson 2011).

As indicated in Figure B.1, the 2013 stoRE presentation concludes that the Turlough Hill closed-loop PSH project in Ireland has "High" impacts on "Hydrology & Hydrogeology" (stoRE 2013). Unfortunately, the presentation does not specify what the impacts are nor what measures have (or have not) been implemented to avoid or mitigate the impacts.

Much of the research conducted to predict the impacts of closed-loop PSH on groundwater has focused on underground PSH projects. The 2016 article "Underground Pumped Storage Hydroelectricity Using Abandoned Works (Deep Mines or Open Pits) and the Impact on Groundwater Flow" (Pujades et al. 2016a) examines the interaction between underground PSH plants and the surrounding geological media, with an emphasis on impacts to groundwater flow. The article describes a numerical modeling effort to characterize the impacts on groundwater flow (Pujades et al. 2016a).

Pujades et al. (2016a) states that two impacts are expected from the interaction between underground PSH projects and groundwater: 1) alteration of the piezometric head distribution in the surrounding aquifer and 2) modification of the chemical composition of the groundwater.

The article states that modifications to the piezometric head (the water pressure within an aquifer) may have negative consequences. For example, lowering of heads can cause the drying of wells and springs, death of phreatophytes (plants that depend on groundwater for their water supply), seawater intrusion in coastal aquifers, and ground subsidence. Alternatively, rising water levels can cause soil salinization, flooding of building basements, water logging, mobilization of contaminants contained in the unsaturated zone, and numerous geotechnical problems such as a reduction of the bearing capacity of shallow foundations, the expansion of heavily compacted fills under foundation structures or the settlement of poorly compacted fills upon wetting (Pujades et al. 2016a).

Pujades et al. (2016a) concludes that the main impact of underground PSH operations on groundwater "consists of oscillation of the piezometric head," the magnitude of which "depends on the characteristics of the aquifer/geological medium, the mine and the pumping and injection intervals." If an average piezometric head is considered, it drops at early times after the start of project operations and then recovers progressively. The impact magnitude is lower in geological media with low hydraulic diffusivity; however, the parameter that plays the most important role is the volume of water stored in the mine. Its variation modifies considerably the groundwater flow impacts (Pujades et al. 2016a).

A second 2016 article, “Underground Pumped Storage Hydropower Plants Using Open Pit Mines: How Do Groundwater Exchanges Influence the Efficiency?” (Pujades et al. 2016b) takes a different approach by examining the effects of groundwater exchanges on underground PSH project efficiency. Specifically, groundwater exchanges can influence the efficiency of the pumps and turbines by affecting the head difference between the reservoirs. The article describes a numerical modeling effort to characterize these effects (Pujades et al. 2016b).

Pujades et al. (2016b) states that project efficiency improves when groundwater exchanges increase. Thus, the highest efficiencies are reached when (1) the underground reservoir is located in a transmissive porous medium and (2) the walls of the open pit mine do not constrain the groundwater exchanges (i.e., they are not waterproofed). However, the article concludes that developers must reach a compromise, because the characteristics that increase project efficiency also increase the likelihood of environmental impacts, as described in Pujades 2016a (Pujades 2016b).

In the 2017 article “Water Chemical Evolution in Underground Pumped Storage Hydropower Plants and Induced Consequences” (Pujades et al. 2017), the authors examine the second of two types of impacts from the interaction between underground PSH plants and groundwater (as identified in Pujades et al. 2016a): modification of the chemical composition of the groundwater. The article describes a numerical reactive transport modeling effort to characterize potential impacts on groundwater quality (Pujades et al. 2017).

Pujades et al. (2017) states that underground PSH activities may induce hydrochemical variations, such as an increase in oxygen partial pressure (pO_2), which may cause negative environmental consequences, especially in coal-mined areas where the presence of sulfide minerals is common. In a hypothetical underground PSH project using an abandoned mine, water pumped to the surface for the upper reservoir is aerated and its initial chemical composition evolves to be in equilibrium with the atmosphere, leading to an increase of pO_2 and associated chemical reactions (Pujades et al. 2017).

When this water is released into the underground reservoir, it may react with the surrounding porous and fractured medium and with the water occupying the reservoir. This could cause the precipitation or dissolution of minerals and associated impacts (e.g., reduction or increase of the pH). In the specific case of abandoned coal mines, where sulfides are frequently present, the increase of pO_2 in the upper reservoir may induce sulfide oxidation when the water is released in the underground reservoir. This would lead to very low pH values (i.e., acidification), and could then affect the surrounding groundwater quality through the seepage exchange fluxes between the underground reservoir and the surrounding geological layers. In addition, pH of water pumped and stored in the upper reservoir would also decrease with time. Thus, the water quality of surface water streams may be affected if some overflow water stored in the upper reservoir is released. This possibility exists given the progressive filling of the underground reservoir by groundwater seepage inflows (Pujades et al. 2017).

Pujades et al. (2017) also states that pyrite mineral dissolution in the vicinity of the underground reservoir could slightly increase the hydraulic conductivity and effective drainage porosity (the storage coefficient) of the surrounding porous medium. Consequently, groundwater exchanges between the underground reservoir and the surrounding porous medium could also be increased, resulting in potential impacts on groundwater (Pujades et al. 2017).

Pujades et al. (2017) concludes that for the design of future underground PSH projects, it will be essential to estimate hydrochemistry related issues, especially in coal-mined contexts where the presence of sulfides is common. Predictions using reactive transport modeling are useful to estimate the groundwater quality evolution in and around underground PSH systems. However, a detailed case-specific geological and hydrogeological characterization will be needed in real cases to obtain reliable predictions (Pujades et al. 2017).

The 2017 article "Interactions Between Groundwater and the Cavity of an Old Slate Mine Used as Lower Reservoir of an UPSH (Underground Pumped Storage Hydroelectricity): A Modelling Approach" (Bodeux et al. 2017), examines the hydrogeological consequences of continuous pumping and injection associated with PSH operations. The modeling involved two pumping/injection scenarios, a reference slate rock case and a sensitivity analysis of variations of aquifer hydraulic conductivity values (Bodeux et al. 2017).

Bodeux et al. (2017) assesses groundwater impacts in terms of oscillations of piezometric heads and mean drawdown around the mine cavity. Such groundwater oscillations and drawdown around the cavity could interfere with other human activities, such as pumping wells, or cause geomechanical instabilities in the surrounding rock environment. The article concludes that the value of hydraulic conductivity clearly influences the magnitude of the aquifer response, and that seepage into the cavity may occur over time. The volume of seeped water varies depending on the hydraulic conductivity and could become significant in underground PSH operations (Bodeux et al. 2017).

In the 2018 article "Hydrochemical Changes Induced by Underground Pumped Storage Hydropower and Their Associated Impacts" (Pujades et al. 2018a), the authors conduct a similar examination of chemical changes to water due to underground PSH operations. Like Pujades et al. (2017), the article describes a numerical reactive transport modeling effort to characterize potential impacts on water quality (Pujades 2018a).

Pujades et al. (2018a) states that during underground PSH operations, water hydrochemistry continuously changes, varying to reach chemical equilibrium with the atmosphere in the surface reservoir and with the surrounding porous medium and groundwater in the underground reservoir. Such hydrochemical variations may lead to reactions in the reservoirs and in the surrounding porous medium, causing potentially negative environmental consequences, especially when pyrite is present in the surrounding porous medium. In this case, pyrite oxidation leads to a decrease in pH and the precipitation of goethite or schwertmannite in the surface reservoir. The decrease in pH is mitigated when calcite is present in the porous medium. However, other concerns may arise, such as slight increases in pH, the precipitation of ferrihydrite and calcite in the surface reservoir, and the oxidation of pyrite and dissolution of calcite in the surrounding porous medium (Pujades et al. 2018a).

Pujades et al. (2018a) states that the main concern regarding the use of abandoned mines is that mine walls are generally not waterproofed. Thus, underground PSH plants interact with the surrounding porous medium exchanging water. Under natural conditions, water in the underground reservoir and groundwater in the surrounding porous medium are in chemical equilibrium with the porous materials. However, once the activity of the underground PSH plant starts, water from the underground reservoir is pumped, discharged and stored in the surface reservoir. During this operation, water is aerated, and therefore, its chemical composition changes towards equilibrium with the atmosphere. This equilibrium is directly related to a variation in the dissolved O_2 and CO_2 concentrations. When this water is subsequently discharged from the surface to the underground reservoir, it changes again towards another chemical equilibrium with the surrounding porous medium (Pujades et al. 2018a).

This continuous change in the water chemistry may lead to the precipitation and dissolution of minerals and their associated impacts such as variations in pH (Pujades et al. 2018a). For example, the oxidation of sulfides, which are common in coal-mined environments, would result in groundwater with a very low pH. As a result, the underground PSH activity would possibly affect the surrounding groundwater quality. If part of the pumped water must be discharged in surface water bodies because groundwater inflows fill the underground cavity, the quality of these surface water bodies could also be affected (Pujades et al. 2018a).

Pujades et al. (2018a) reports that the hydrochemical changes induced by underground PSH and their associated consequences decrease 1) when water is stored in the surface reservoir over a shorter period and 2) when aeration, which occurs when pumped water is discharged and stored into the surface reservoir, is lower. Thus, the pumping/discharging frequency and the method to discharge and to store the pumped water in the surface reservoir determine the reactions and their associated impacts (Pujades et al. 2018a).

Pujades et al. (2018a) concludes that the hydrochemical changes induced by real underground PSH projects could be different from those discussed in the article and will vary for each specific site because they depend on the chemical composition of the medium surrounding the underground reservoir. However, the article stresses that hydrochemical changes could seriously impact the environment (and project efficiency); in fact, "if they are not properly considered, they could put at risk the whole feasibility of future UPSH plants" (Pujades et al. 2018a).

Because these hydrochemical impacts are so important, Pujades et al. (2018a) argues that "preliminary studies focused on determining the hydrochemical changes and their consequences should be mandatory." These preliminary studies, which should be considered for the selection of potential abandoned mines to be used as underground reservoirs, must consist of:

> "… a detailed hydraulic and hydrochemical characterization of the geological medium by means of field tests (pumping and tracer tests), mineralogical analyzes and laboratory tests. In addition, the main characteristics of the plant (volume of the underground reservoir, flowrates, pumping/discharging frequencies, etc.) must be considered and the aeration process in the surface reservoir must be investigated to precisely quantify the gas exchanges. All this information should be integrated into reactive transport models for predicting the consequences of reactive transport processes induced by UPSH. Monitoring will be also needed during the operational phase of UPSH plants to verify that hydrochemistry evolves as expected" (Pujades et al. 2018a).

In the 2018 article "Hydrochemical Changes Induced by Underground Pumped Storage Hydropower: Influence of Aquifer Parameters in Coal Mine Environments" (Pujades et al. 2018b), the authors examine similar topics as in Pujades et al. (2017) and Pujades et al. (2018a), but with an emphasis on the effects of chemical changes in groundwater in a coal mine environment. In particular, the article examines the influence of aquifer hydraulic parameters, and associated pH variations (with the presence of pyrite), on underground PSH systems (Pujades et al. 2018b).

The 2018 article "Pump Hydro Energy Storage Systems (PHES) in Groundwater Flooded Quarries" (Poulain et al. 2018) describes numerical modeling efforts to investigate the interactions between generic flooded open pit quarries and adjacent unconfined aquifers during various PSH cyclic stresses. The article states that because flooded quarries are generally connected to unconfined aquifers, pumping or injecting large volumes of water within short-time intervals may have an impact on the adjacent aquifers. Conversely, water exchanges between the quarry and the aquifer may also influence the water-level fluctuations in the lower reservoir (Poulain et al. 2018).

Poulain et al. (2018) concludes that for rock media characterized by high hydraulic conductivity and porosity values, water volume exchanges during PSH cycles may significantly affect the amplitude of water-level fluctuations in the quarry (lower reservoir), and as a consequence, the project's efficiency in producing power. Regarding the impact of PSH cyclic stresses on the surrounding environment, the article concludes that the distance of influence is potentially high under specific conditions, and is enhanced with the occurrence of rock heterogeneities, such as fractures. The impact around a quarry used as a lower reservoir thus appears as an important constraining factor regarding the feasibility of PSH systems, to be assessed carefully if groundwater-level fluctuations around the quarry are expected to have adverse effects (Poulain et al. 2018).

B.6 Aquatic and Terrestrial Ecology

Because closed-loop PSH projects are located "off-stream" (i.e., not continuously connected to any naturally flowing water feature), they can avoid many of the impacts of open-loop projects on aquatic and terrestrial ecological resources. However, closed-loop projects that use water from naturally flowing surface water features can have ecological impacts by withdrawing large quantities of water from their sources, even if it is not done continuously. The impacts discussed below are summarized in Table B.1.

The 1981 Dames and Moore report summarizes the ecological impacts of open-loop PSH reservoir operations as reduction of benthic organisms, effects on temperature stratification, and impacts on fish habitats. The report states that additional impacts on aquatic and terrestrial species may result from spoil disposal from underground excavations, cutting of access roads, and dam construction. Although the report does not address closed-loop PSH systems, it does conclude that underground PSH projects have significantly fewer environmental impacts than conventional PSH projects because land and water use is characteristically less and, consequently, the magnitude of ecological impacts is proportionately reduced. The report also concludes that because underground PSH projects are not dependent upon topographic conditions to provide an adequate potential head, "they may be located closer to the load demand center, reducing the need for transmission systems and their resultant environmental impacts" (Dames and Moore 1981).

Most of the ecological impacts discussed in Dames and Moore 1981 for constructing and operating open-loop projects could also occur at closed-loop projects. However, they might be somewhat reduced because the artificial reservoirs at closed-loop projects likely would support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems.

The 1993 DOI report states that changes in biota in the project lakes due to increased inflow during PSH operations, or to the raising of the lakes, were not as clearly identified as changes in either physical or chemical parameters due to PSH operations. This is because "biological responses to changing environmental conditions tend to be integrative when the change is not immediately lethal and the length of time for response to chronic change is dependent on the life cycles of the organisms." . . . However, certain changes in primary production (i.e., chlorophyll-a concentration, carbon fixation rate, and phytoplankton populations), and secondary production (i.e., zooplankton, benthic organisms, mysid shrimp, and fish populations), were documented during PSH project operations (DOI 1993).

In addition to impacting the forage base, PSH operations also resulted in direct entrainment of fish. Entrainment probability is a function of several factors, including:

- seasonal and daily movement rates,
- time of pumping,
- seasonal movements into the tailrace area,
- home range locations and size,

- extent of excursions out of the home range,
- timing of shoreward movements,
- water temperature preferences,
- attraction to currents, and
- feeding activities (DOI 1993).

However, DOI (1993) reports that the most detrimental impact to the Twin Lakes fishery occurs during pump-back cycles. Before the Mt. Elbert PSH project was constructed, at least 40 percent of lake trout home ranges in Lower Twin Lakes included an area close to the power plant location. This area experienced changes with project operations, making the area more attractive to lake trout and increasing the likelihood of entrainment (DOI 1993). Again, the impacts discussed in DOI (1993) could occur at closed-loop projects, but they might be somewhat reduced because the artificial reservoirs likely would support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems.

The 2009 MWH report states that effects on fishery resources are highly dependent on the location and interconnectedness of the PSH project, and that developing a closed-loop system "would greatly reduce the chance of riverine fisheries being adversely affected." For an open-loop system, the report cites potential fisheries impacts as the effect of reservoir fluctuations on fisheries and fish entrainment in the intake facilities and turbine (MWH 2009). Similarly, Yang and Jackson (2011) notes that closed-loop systems, especially those using groundwater, reduce or eliminate impacts to aquatic ecosystems.

In 2013, staff from Alden, HDR, and the Louis Berger Group, Inc., presented an online seminar titled "Pumped Storage Project Considerations." One part of the seminar is a presentation on the environmental impacts of open-loop PSH, focusing on "Fish Protection Considerations" (Amaral 2013). The presentation discusses potential impacts to fish, as well as possible mitigation measures, based on studies conducted at four existing PSH projects: Northfield Mountain in Massachusetts, Ludington in Michigan, Richard B. Russell in South Carolina/Georgia, and Muddy Run in Pennsylvania.

The 2013 Amaral presentation highlights the primary effects of open-loop PSH reservoir operations on fish as impacts due to entrainment through turbines and/or impingement on trash racks. Those impacts could include the transfer of fish from one reservoir to another, the loss of fish due to turbine/pump mortality, mortality from impingement on bar racks, and migration delays in rivers due to changes in hydraulic conditions and entrainment. The presentation states that the risk of entrainment and impingement depends on project design and operation, environmental and hydraulic conditions, and biological factors (species, size, movement patterns), and that the severity of impacts depends on the magnitude of losses or other effects (e.g., migration delays), existing population levels (i.e., depressed or healthy), and life history strategy and biology of species of interest (i.e., resident species vs. diadromous) (Amaral 2013). Again, the impacts discussed in Amaral 2013 could occur at closed-loop projects, but they might be somewhat reduced because the artificial reservoirs likely would support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems.

The Amaral 2013 presentation concludes with a discussion of potential mitigation alternatives, including some that have been used at the four-case study PSH projects. One alternative is to use fish protection systems designed to reduce entrainment and impingement, including narrow-spaced bar racks, screening systems, barrier nets, and behavioral deterrents (sound, strobe lights, air bubble curtains). A second alternative is to modify project operations, including reduced pumping at night and reduced generation during day (Amaral 2013).

As indicated in Figure B.1, the 2013 stoRE presentation concludes that the Turlough Hill closed-loop PSH project in Ireland has High impacts on Biodiversity and Medium impacts on Fisheries. Unfortunately, the presentation does not specify what the impacts are nor what measures have (or have not) been implemented to avoid or mitigate the impacts.

The report *Life Cycle Assessment of a Pumped Storage Power Plant* (Torres 2011), published in Norway, focuses on the potential greenhouse gas emissions of the various generation technologies for which PSH provides energy storage (rather than the impacts of the PSH itself). However, the report does mention some "specific alterations on the natural environment in relation to hydraulic conditions" created by PSH reservoir operations in Norway:

> "… the alterations can be drastic due to the geographical location, because of ice formation, temperature changes, substrates alteration and erosion. In addition, the possibility of abrupt changes on the downstream flow due to operational reasons, can strongly affect the organisms because of alterations in their habitat. Factors as ramping rates, cover, substrates, season and light conditions can affect fish behavior" (Torres 2011).

Bakken (2012), Patocka (2014), and Kobler et al. (2018) each describe a number of potential biological impacts resulting from open-loop PSH operations, including the following from Patocka (2014):

- A higher risk of spreading species, including exotic species, compared to conventional hydropower operations. Aquatic species that are small enough to pass through turbines during pumping can be transferred from the lower reservoir to the upper one. This could introduce them to a new ecosystem, which they would not have been able to reach without pumping operations. If conditions are favorable, these species can develop and reproduce in and around the upper reservoir, leading to a significant reduction or even extinction of the existing flora or fauna in the ecosystem in and around the upper reservoir.
- Impacts on biological production in the littoral zone due to short-term reductions in the wetted littoral zone during power generation. Similarly, pumping can lead to short-term expansions of the wetted littoral zone.
- Decreased visibility in the reservoir water due to frequent stirring and moving of sediment from the reservoir bed, and also from the inflow of sediment from the natural water way through pumping.
- Changes in ice cover dynamics in the reservoirs, including delays in ice cover formation, a thinner ice layer during winter, and earlier ice thawing in spring. In terms of biological impacts, thinner ice allows more light to enter the lower water layers of the reservoir, resulting in better conditions for photosynthesis. As the ice cover thaws earlier in spring, the reservoir warms and the active season for organisms starts earlier and lasts longer, resulting in the stimulation of primary production.
- Increased mortality for higher and larger species due to turbine passage during both pumping and power generation (Patocka 2014).

These impacts could occur at closed-loop projects, but they might be somewhat reduced because the artificial reservoirs likely would support fewer ecological resources (at least initially) than the naturally flowing water bodies affected by open-loop systems.

B.7 Geology and Soils

For both open-loop and closed-loop PSH projects, construction would have impacts on geology and soils as project reservoirs and related facilities require large-scale excavation and tunneling. The impacts discussed below are summarized in Figure B.1.

The 1981 Dames and Moore report lists one major environmental impact of constructing underground PSH projects as the disposal of large quantities of spoil material excavated for the lower reservoir. Pickard (2012) also raises this issue but suggests that impacts can be mitigated by using the spoil material in constructing the upper reservoir.

Similarly, operations at both open-loop and closed-loop PSH projects have adverse impacts on geology and soils due to fluctuating reservoir water levels and increased shoreline erosion. The 1993 DOI report states that raised lake levels at existing lakes can expose previously unflooded soils to erosion by wave action and water surface fluctuations. Bakken 2012, Sundt-Hansen and Palm Helland 2012, and Patocka 2014 all describe increased erosion due to PSH operations:

> ". . . rapid and frequent reservoir water level fluctuations at PSH projects cause reduced stability of reservoir banks due to water pressure variations and erosion due to wave exposure. Because water level variations are more rapid and frequent with PSH operations, water pressure variations are also much faster and larger, leading to instability of the reservoir banks" (Patocka 2014).

The 2012 article "Geotechnical Issues in the Creation of Underground Reservoirs for Massive Energy Storage" (Uddin 2012) discusses geotechnical challenges for the design and stability of massive energy-storage caverns constructed in hard rock formations, including those for underground PSH. The article states that, in general, the challenges are a combination of the geological, hydrological, geochemical, geothermal, and geotechnical.

With regard to environmental conditions, Uddin 2012 states that underground PSH projects are:

> "virtually free of topographic restrictions, for example, the required upper reservoir does not require any essential relationship to the surrounding topographic conditions. Moreover, the utilization of extremely high head, which is readily applicable to the UPH concept, reduces the size of the reservoir in comparison with a conventional plant of similar operating characteristics. Therefore, a large range of alternatives is available for the selection of an upper reservoir site, ranging from the use of abandoned quarry sites, through the development of an artificial reservoir built upon derelict land (e.g., strip-mined areas), to the use of existing reservoirs such as lakes, the ocean, etc. Thus, from the point of view of the major surface work, the upper reservoir, there exists a considerable freedom in the choice of location. One major importance of this degree of freedom lies in its potential for selecting a location at which the subsurface condition approaches the ideal for housing the lower reservoir excavation" (Uddin 2012).

Uddin 2012 reports that much of the technical and economic feasibility of an underground PSH project hinges on excavating the required reservoir volume with a minimum of cost due to remedial measures (supporting, grouting, etc.) or schedule delays in areas of difficult rock conditions. The primary constraint imposed by the concept is the adequate performance of the host rock during construction. The long-term operational performance "generally is of lesser importance in terms of raveling of rock from the reservoir tunnels, permeability of the rock mass (within reasonable limits), and even collapse of individual tunnel sections" (Uddin 2012).

The 2018 article "Reflection Phenomena in Underground Pumped Storage Reservoirs" (Pummer and Schüttrumpf 2018) states that because reservoirs for underground PSH projects differ in design from typical reservoirs for stability and space reasons, their hydraulic design is essential to ensure satisfactory hydraulic performance. The article discusses a hybrid modeling study, using a combination of physical and numerical modeling to analyze waves in ventilated underground reservoir systems with a great length to height ratio (to account for the operational requirements of energy supply systems with a high percentage of renewable sources). The multifaceted and narrow design of the reservoirs leads to complex free surface flows. The results show excessive wave heights through wave reflections, caused by the impermeable reservoir boundaries. The article concludes that knowledge of these excessive wave heights is essential for the successful design, construction, and operation of underground PSH projects (Pummer and Schüttrumpf 2018).

B.8 Land Use and Recreation

For both open-loop and closed-loop PSH projects (except for underground projects), construction requires vast land areas, especially for the project reservoirs. Committing large land areas to PSH development can have impacts on existing and planned land uses near the site, especially if there are sensitive ecological, visual, recreational, or cultural resources nearby. Land use impacts can be reduced by constructing project reservoirs and other facilities underground, but the land use impacts of constructing above-ground open-loop and closed-loop systems are similar. The primary difference is that closed-loop projects have greater siting flexibility than open-loop projects and can be sited to avoid land use impacts. The impacts discussed below are summarized in Table B.1.

The 1981 Dames and Moore report identifies some land use impacts from conventional PSH development and operations, including flooding agricultural land, reducing forest productivity, and both positive and negative effects on recreation. The report states that because PSH uses relatively large land areas compared to other energy-storage alternatives, its potential effects on land use, terrestrial ecology, and aesthetics are significant, but that "the use of existing reservoirs or lakes as part of the pumped storage system is likely to lessen these effects to some degree" (Dames and Moore 1981).

The Dames and Moore report cites an estimate that a conventional PSH project with two reservoirs, head varying between 300 and 1,000 feet, and a 1,000 megawatt-hour capacity may require a total land area of between 500 and 10,000 acres. For an underground PSH project, however, the surface area needed for reservoirs may be only half the surface area required for a conventional PSH project with the same head and capacity. The other energy-storage alternatives examined in the report—utility thermal storage, compressed air, and advanced batteries—generally need less than two percent of the land area required for a conventional PSH project of equal capacity, and less than ten percent of the land area required for an underground PSH project of equal capacity (Dames and Moore 1981).

Dames and Moore (1981) also concludes that because underground PSH projects are not dependent upon topographic conditions to provide an adequate potential head, they may be located closer to the load demand center, reducing the need for transmission systems and their resultant environmental impacts. Similarly, Pickard (2012) states that conventional PSH projects are frequently "fought to a standstill by environmentally concerned groups, often because of the prime landscape they affected," but that underground PSH would normally be built near load centers but on land of lesser value (Pickard 2012).

Immendoerfer et al. (2017) states that the only category in which the impacts of PSH exceed those of utility-scale lithium-ion batteries is in "natural land transformation" because of the "land qualities" assumed. Although the article does not state it explicitly, it can be assumed that the "land qualities" argument would favor closed-loop PSH systems over open-loop PSH systems because the former has fewer locational constraints than the latter, and thus could be sited on land of lower "quality" (e.g., abandoned mines, quarries, etc.) and have less significant environmental impacts.

Regarding impacts to recreational land uses, the 2009 MWH report states that due to the extent and frequency of cycling of waters in a PSH system, one or both reservoirs experience large fluctuations in water levels which can make them unsuitable for recreation. In an open system where the lower reservoir is a larger reservoir, the effect can be minimal because the amount of water cycled through the system is small compared to the size of the reservoir. Some PSH projects can offer "non-water-based recreation opportunities that can be provided by designing the project around community needs," but most closed-loop project sites "are generally not in locations of high recreation uses, although aesthetic considerations will arise in the planning that can also be mitigated through proper design considerations" (MWH 2009).

B.9 Visual Resources

As discussed in Section B.8, construction of either open-loop or closed-loop PSH projects require disturbing large land areas, especially for the project reservoirs. Such large-scale disturbance can have impacts on the visual landscape, especially if there are sensitive recreational or cultural resources nearby. Also, PSH operations can have aesthetic impacts caused by fluctuating reservoir water levels and subsequent shoreline erosion, as well as by the lights and noise generated by project facilities. Aesthetic impacts can be reduced by constructing and operating project reservoirs and other facilities underground, but the aesthetic impacts of above-ground open-loop and closed-loop systems are similar. The primary difference is that closed-loop projects have greater siting flexibility than open-loop projects and can be sited to avoid impacts on visual resources. The impacts discussed below are summarized in Table B.1.

The 1981 Dames and Moore report describes the adverse effects of reservoir water-level fluctuations during PSH operations in terms of increased bank erosion and subsequent impacts to aesthetic resources. Although the report does not address closed-loop PSH systems, it does conclude that underground PSH projects have significantly fewer environmental impacts than conventional PSH projects because land use is characteristically less and, consequently, the magnitude of aesthetic alteration is proportionately reduced (Dames and Moore 1981).

As indicated in Figure B.1, the 2013 stoRE presentation concludes that the Turlough Hill closed-loop PSH project in Ireland has Medium impact on Landscape and Visuals (stoRE 2013). Bakken (2012) and Patocka (2014) describe how rapid and frequent reservoir water-level fluctuations at open-loop PSH projects cause:

> "… changes in the landscape due to shoreline erosion or the accumulation of floating material caused by water level changes. Short-term exposure of the littoral zone due to water level drawdowns can also create aesthetic impacts" (Patocka 2014).

Although these aesthetic impacts could occur at closed-loop projects, they might be somewhat reduced because closed-loop projects have fewer locational constraints than open-loop projects and thus can be sited on land of lower "quality" (e.g., abandoned mines, quarries, etc.) and have less significant aesthetic impacts (Immendoerfer et al. 2017).

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Appendix C

FERC Records Review

Appendix C
FERC Records Review

C.1 Introduction

This appendix describes the results of a review of the Federal Energy Regulatory Commission (FERC) licensing record (e.g., National Environmental Policy Act documents, license orders) to identify the environmental effects anticipated and the mitigation measures proposed for six closed-loop pumped storage hydropower (PSH) projects licensed and permitted in the United States. The review includes two types of closed-loop PSH projects: (1) those that would use groundwater for their initial reservoir fill and to replace evaporative and seepage losses; and (2) those that would use surface water for their initial reservoir fill and to replace evaporative and seepage losses. For comparison, the FERC records review also discusses the environmental effects anticipated and the mitigation measures included for four open-loop PSH projects proposed or currently operating in the United States.

C.2 Methodology

We began the FERC records review by identifying a sample of ten PSH projects (six closed-loop and four open-loop) for which FERC licensing documents are readily available. We selected more closed-loop projects than open-loop projects for the FERC records review because the literature reviewed (Appendix B) focused primarily on open-loop systems. For the closed-loop PSH sample, we selected six proposed projects that: (1) have had recent FERC permitting or licensing activity; (2) represent both groundwater and surface water project types; and (3) represent a geographic distribution across the United States.

As indicated in Table C.1, the FERC records review begins with four proposed closed-loop PSH projects that would use groundwater: (1) Eagle Mountain in California (Section C.4.1); (2) Mineville in New York (Section C.4.2); (3) Swan Lake North in Oregon (Section C.4.3); and (4) Big Chino Valley in Arizona (Section C.4.4). The review continues with two proposed closed-loop PSH projects that would use surface water: (1) Gordon Butte in Montana (Section C.5.1) and (2) Parker Knoll in Utah[1] (Section C.5.2).

For the open-loop PSH sample, we selected four proposed or existing projects that: (1) have had recent FERC permitting or licensing activity; and (2) represent different types and ages of projects in different parts of the United States. As indicated in Table C.1, the records review concludes with the following open-loop PSH projects: (1) Iowa Hill in California[2] (Section C.6.1); (2) Bath County in Virginia (Section C.6.2); (3) Big Creek (Nos. 2A, 8, and Eastwood) in California (Section C.6.3); and (4) Smith Mountain in Virginia (Section C.6.4).

[1] FERC dismissed the Parker Knoll Project license application on October 4, 2018, because the applicant failed to provide either (1) a copy of the water quality certification for the project, (2) a copy of the certification request, including proof of the date on which the certifying agency received the request, or (3) evidence of waiver of certification (FERC 2018c).

[2] In 2016, the Sacramento Municipal Utility District board of directors canceled plans to construct the Iowa Hill Project due to cost and financial risks (Ingram 2016).

Table C.1. Proposed and existing PSH projects included in the FERC records review.

Project Name State Capacity FERC No.	Project Type	Current Status	Primary Data Sources
Eagle Mountain California 1,300 MW No. 13123	Closed-Loop (groundwater)	Proposed; Licensed	FERC Final Environmental Impact Statement (FEIS) (2012); FERC License Order (2014)
Mineville New York 240 MW No. 12635	Closed-Loop (groundwater)	Proposed; License Pending	MHC license application (2015); FERC Draft Environmental Impact Statement (DEIS) (2019)
Swan Lake North Oregon 393 MW No. 13318	Closed-Loop (groundwater)	Proposed; Licensed	FERC FEIS (2019); FERC License Order (2019)
Big Chino Valley Arizona 2,000 MW No. 14859	Closed-Loop (groundwater)	Proposed; Preliminary Permit	ITC - Big Chino Valley Pumped Storage pre-application document (2018); FERC letter approving use of traditional licensing process (2018)
Gordon Butte Montana 400 MW No. 13642	Closed-Loop (surface water)	Proposed; Licensed	FERC Environmental Assessment (2016); FERC License Order (2016)
Parker Knoll Utah 1,000 MW No. 13239	Closed-Loop (surface water)	Proposed; Preliminary Permit; Canceled	Parker Knoll Hydro license application (Symbiotics, LLC 2011)
Iowa Hill California 400 MW No. 2101	Open-Loop	Proposed; Licensed; Canceled	FERC FEIS (2008); FERC License Order (2014)
Bath County Virginia 3,003 MW No. 2716	Open-Loop	Existing	FPC License Order (1977)
Big Creek 2A, 8, and Eastwood California 373 MW No. 67	Open-Loop	Existing	FERC FEIS (2009)
Smith Mountain Virginia 636 MW No. 2210	Open-Loop	Existing	FERC License Order (2009)

Once we identified these ten projects, we accessed documents from their FERC licensing record using the online FERC eLibrary (https://www.ferc.gov/docs-filing/elibrary.asp) and through internet searches. Table C.1 lists the primary documents we used as sources for each project, and Section C.7 contains the complete list of references and bibliography for this appendix.

C.3 Summary of the FERC Records Review

Overall, the FERC records review suggests that closed-loop and open-loop projects would have similar impacts during construction, with some differences as discussed in the following sub-sections. However, the review suggests that during project operations, closed-loop systems would have impacts that are less widespread and of shorter duration for almost every environmental resource. The primary exception is groundwater for those closed-loop projects using groundwater for their initial reservoir fill and to replace evaporative and seepage losses.

Because the impact of both closed-loop and open-loop PSH systems on surface water and groundwater are so important to any broader environmental assessment, Table C.2 provides additional information about the specific project examples discussed in Appendix C. Also, the FERC records review provided more information than the literature review (Appendix B) about potential impacts to many of the terrestrial resource areas (especially land use, recreation, visual resources, and cultural resources), and that information is discussed in the following sub-sections.

C.4 Proposed Closed-Loop PSH Projects Using Groundwater

C.4.1 Eagle Mountain

The Eagle Mountain Project (FERC No. 13123) is a proposed 1,300-MW closed-loop project that would be located in two largely inactive iron ore mining pits at the Eagle Mountain mine in Riverside County, California, near the town of Desert Center. As discussed below, the project would use water pumped from three new groundwater wells for the initial reservoir fill and to replace evaporative and seepage losses. The project would occupy 2,527 acres of land, of which 699 acres is federal land managed by the Bureau of Land Management (BLM) and the remaining 1,828 acres is privately owned (FERC 2014a).

FERC issued Eagle Crest Energy Company an original license for the Eagle Mountain Project in 2014. In 2017, the U.S. Fish and Wildlife Service (USFWS) issued a revised Biological Opinion analyzing the effects of the project on the desert tortoise and including recommendations and terms and conditions to reduce impacts to desert tortoise during project construction and operations. In August 2018, BLM approved the right-of-way for the project's transmission line and water supply pipeline on BLM-managed lands near Desert Center. In October 2018, the *America's Water Infrastructure Act of 2018* (Public Law No. 115-270) became law (United States Congress 2018) and allows FERC to extend the construction start deadline for the Eagle Mountain Project by as much as eight years (Roth 2018).

Project Facilities. The Eagle Mountain Project's primary features would include an upper reservoir, an upper water conveyance system, a powerhouse with generating/pumping facilities, a lower water conveyance system, a lower reservoir, water supply and treatment facilities, and a transmission system. The upper reservoir would be constructed in an existing mine pit; two roller-compacted concrete dams, each a little over 1,000 feet long, would be added at low points along the pit's rim to provide a reservoir surface area of 191 acres and an active storage capacity of 17,700 acre-feet at an elevation of 2,485 feet above mean sea level (msl) (FERC 2014a).

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed.

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Proposed Closed-Loop Projects Using Groundwater for Initial Fill and Refill				
Eagle Mountain California 1,300 MW No. 13123	Three new groundwater wells located offsite; water delivered via new 15.5-mile underground pipeline.	2 reservoirs above ground using existing open iron ore mine pits. Upper reservoir: 191 ac; active storage 17,700 ac-ft. Lower reservoir: 163 ac; active storage 17,700 ac-ft. Total project size: 2,527 ac.	Initial fill: 17,700 Annual refill: 2,507	*Surface Water Quantity:* Groundwater overdraft in Chuckwalla Basin—connected to Colorado River—could consume Colorado River water. *Groundwater Quantity:* Groundwater withdrawal could reduce water supply to private wells. *Groundwater Quantity:* Groundwater withdrawal could reduce Chuckwalla aquifer storativity. *Surface Water and Groundwater Quality:* Filling open pit iron ore mine reservoirs could reduce surface water and groundwater quality due to water/ore-body interactions and seepage. *Groundwater Quantity:* Subsidence caused by groundwater overdraft or seepage could affect underground Colorado River Aqueduct.
Mineville New York 240 MW No. 12635	Existing groundwater contained in flooded, abandoned iron ore mine complex.	2 reservoirs below ground using existing enclosed iron ore mine pits. Upper reservoir: 4.0 ac; active storage 2,448 ac-ft. Lower reservoir: 5.1 ac; active storage 2,448 ac-ft.	NA	*Surface Water Quality:* Pumping groundwater to surface for dewatering underground upper reservoir (during construction) and removing excess groundwater from natural recharge (during operations) could reduce surface water quality in Mill Brook tributary stream. *Groundwater Quality:* Underground pumping could reduce water quality in private wells. *Groundwater Quality:* Water/ore-body interactions between underground iron ore mine pit reservoirs could reduce groundwater quality.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Swan Lake North Oregon 393 MW No. 1331	Groundwater from existing agricultural pumping system; water delivered via existing underground irrigation network.	2 new reservoirs constructed above ground. Upper reservoir: 64.21 ac; active storage 2,568 ac-ft. Lower reservoir: 60.14 ac; active storage 2,581 ac-ft. Total project size: 2,040 ac.	Initial fill: 2,581 Annual refill: 357	*Groundwater Quantity:* Groundwater withdrawals could affect water supply for irrigation. *Surface Water Quality:* Exchanging water between two project reservoirs could reduce surface water quality by concentrating dissolved solids, nutrients, and heavy metals.
Big Chino Valley Arizona 2,000 MW No. 14859	Applicant has not decided whether to use existing or new groundwater wells; water delivered via new underground pipeline (length and route depends on existing vs. new wells).	2 new reservoirs constructed above ground. Upper reservoir: 119 ac; active storage 19,800 ac-ft. Lower reservoir: 301 ac; active storage 19,800 ac-ft. Total project size: 23,633 ac.	Initial fill: 22,500 -24,300 Annual refill: 925	*Groundwater and Surface Water Quantity:* Groundwater withdrawals could reduce baseflow into upper Verde River; could affect water supply for irrigation, livestock grazing, and domestic and municipal water supplies. *Surface Water Quality and Quantity:* Fish, other aquatic resources, cultural resources, and existing wild and scenic river designation could be affected if groundwater withdrawals adversely affect flow in upper Verde River.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Proposed Closed-Loop Projects Using Surface Water for Initial Fill and Refill				
Gordon Butte Montana 400 MW No. 13642	Cottonwood Creek (tributary to South Fork Musselshell River); water delivered via existing irrigation system.	2 new reservoirs constructed above ground. Upper reservoir: 63 ac; active storage 4,070 ac-ft. Lower reservoir: 88 ac; active storage 4,070 ac-ft. Total project size: 442 ac.	Initial fill: 4,685 Annual refill: 500	*Surface Water Quantity:* Withdrawals could reduce streamflow in Cottonwood Creek, could affect irrigation supply. *Streamflows:* Withdrawals could reduce streamflow in Cottonwood Creek, could affect aquatic and riparian ecological resources. *Groundwater Quality:* Dewatering excavated areas during construction could affect groundwater used for municipal water supply.
Parker Knoll Utah 1,000 MW No. 13239	Otter Creek Reservoir; water delivered via new 13-mile underground pipeline.	2 new reservoirs constructed above ground. Upper reservoir: 110 ac; active storage 6,780 ac-ft. Lower reservoir: 130 ac; active storage 6,760 ac-ft. Total project size: 857.2 ac.	Initial fill: 7,900 Annual refill: 800	*Surface Water Quantity:* Withdrawals could reduce water supply in Otter Creek Reservoir, could affect irrigation supply. *Streamflows:* Withdrawals could reduce streamflow below Otter Creek Reservoir, could affect aquatic and riparian ecological resources. *Surface Water Quality:* Exchanging water between two project reservoirs could reduce surface water quality by concentrating dissolved solids and nutrients. *Groundwater Quality:* Excavation during construction could affect groundwater by creating seepage paths that could adversely affect water quality and aquatic and terrestrial ecological resources by altering the water table and surrounding soil.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Proposed Open-Loop Project Continuously Connected to <u>Surface Water</u> for Operations				
Iowa Hill (Upper American River Project) California 400 MW No. 2101	Existing Slab Creek Reservoir	2 above-ground reservoirs; one existing (Slab Creek) and one new construction (Iowa Hill). Upper Reservoir (Iowa Hill): 100 ac.; active storage 6,400-ac-ft. Lower Reservoir (Slab Creek): 280 ac; active storage 16,600 ac-ft.	NA	*Surface Water Quality:* Project operations could affect water quality and temperature in Slab Creek Reservoir. Agencies recommended measures to minimize or prevent sediment mobilization and/or increased turbidity in Slab Creek Reservoir and the South Fork American River downstream of the reservoir. *Surface Water Quality:* California State Water Board reserved the authority to require the licensee to develop a mercury management plan if future research and/or water quality and metals bioaccumulation monitoring indicate that project reservoir operations increase the mobilization or methylation of mercury. *Groundwater Quality*: Agencies recommended that prior to construction of an underground tunnel between reservoirs the licensee prepare a plan for managing groundwater inflows and/or discharge during construction and for groundwater monitoring and management once construction is completed. The agencies recommended monitoring potentially affected springs and creeks for five years after the tunneling operation is completed.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Existing Open-Loop Projects Continuously Connected to Surface Water for Operations				
Bath County Virginia 3,003 MW No. 2716	Back Creek and Little Back Creek	2 reservoirs above ground. Upper reservoir: 265 ac on Little Back Creek; active storage 22,500 ac-ft. Lower reservoir: 555 ac. on Back Creek; active storage 22,500 ac-ft.	NA	*Surface Water Quality*: License required pre-construction water quality studies at selected locations on Back Creek and Little Back Creek. Monthly testing of dissolved oxygen, temperature, pH, conductivity, total alkalinity, turbidity, suspended solids, ortho- and total phosphorus, inorganic and fecal coliforms, biochemical oxygen demand, flow, and any other significant parameter. *Surface Water Quality*: License required post-operational water quality monitoring program sampling for first 5 years including the same parameters measured during pre-construction monitoring program.
Big Creek 2A, 8, and Eastwood California 373 MW No. 67	South Fork San Joaquin River, Big Creek, and Stevenson Creek	4 primary reservoirs (and 11 smaller, secondary reservoirs) above ground. Florence Lake: 962 ac; active storage 64,406 ac-ft. Shaver Lake: 2,184 ac; active storage 135,568 ac-ft. Big Creek Dam 5 Reservoir: 3.3 ac; active storage 47 ac-ft. Balsam Meadows Lake: 60 ac; active storage 1,570 ac-ft.	NA	*Surface Water Quality and Quantity*: Current project operations affect aquatic habitats and sediment transport in bypassed stream reaches. Settlement Agreement and FERC FEIS include measures focused on improving the ecological health and suitability of reaches downstream of project dams. *Surface Water Quality and Quantity*: Southern California Edison (SCE) to implement increased minimum instream flows (MIF) in bypassed reaches downstream of project diversion dams. *Surface Water Quality and Quantity*: SCE to implement channel and riparian maintenance flows in the South Fork San Joaquin River and six of its tributaries. *Surface Water Quality and Quantity:* SCE to implement a Temperature Monitoring and Management Plan to document the effects of proposed modified instream flows on water temperatures and allow for adaptive management where needed.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Big Creek 2A, 8, and Eastwood California 373 MW No. 67 (continued)				*Surface Water Quality and Quantity*: SCE to implement sediment management measures to pass accumulated sediment through project facilities (followed by flushing flows to redistribute passed sediments), remove accumulated sediment from behind dams, if needed, and monitor turbidity and pool filling. *Surface Water Quality and Quantity:* SCE to decommission and remove four smaller, secondary diversions/reservoirs to enhance fish habitat and water temperature by restoring the affected stream reaches to essentially natural flow conditions.
Smith Mountain Virginia 636 MW No. 2210	Roanoke River	2 reservoirs above ground. Upper reservoir (Smith Mountain Lake): 20,260 ac. Lower reservoir (Leesville Lake): 3,269 ac. Total project size: 25,600 ac.	NA	*Surface Water Quality*: water discharged from Smith Mountain Dam can have low temperatures and low dissolved oxygen (DO) concentrations under certain generation conditions. When Smith Mountain Lake is stratified (late spring to early fall), releasing colder, less-oxygenated water, it can result in DO levels below Virginia's standard of 4.0 milligrams/liter (mg/L) in Leesville Lake. FERC license order requires Appalachian Power to implement a *Water Quality Monitoring Plan* that includes: (a) modifying operations at Smith Mountain from July through September to bring units on- and off-line in a manner that prioritizes withdrawing water from higher in the lake's water column; (b) monitoring DO and water temperature in both project lakes for the first five years of the new license (with continuous monitoring during the first two years); and (c) establishing a Water Quality Technical Review Committee to review the monitoring results.

Table C.2. Summary of potential water quality and quantity impacts for the proposed and existing PSH projects reviewed. (continued)

Project Name State Capacity FERC No.	Water Source	Reservoirs	Withdrawal (acre-feet)	Potential Impacts Identified in Preliminary Permit and License Applications, FERC NEPA Documents, and FERC License Orders (see Section C.4)
Smith Mountain Virginia 636 MW No. 2210 (continued)				*Surface Water Quantity*: water management at the Smith Mountain Project affects water uses within the project reservoirs and downstream, especially during low-flow conditions. Maintaining sufficient flow for aquatic resources and recreational uses downstream can lead to a drawdown of Smith Mountain Lake; conversely, ensuring that lake levels are adequate for recreation can require a reduction in flows from Leesville that could harm downstream resources. The FERC license order requires Appalachian Power to use an Operations Model to forecast future Smith Mountain Lake levels and adjust downstream flow releases based on the probability of Smith Mountain Lake elevations reaching certain levels in the future. The license order also requires Appalachian Power to modify its auto-cycling operation at the Leesville development from 18 minutes every 2 hours to 9 minutes every hour. This operations protocol is included in the project's *Water Management Plan*, which also includes: (a) monthly minimum flows for aquatic organisms, habitat, and recreation in the Roanoke River downstream from Leesville; (b) operational restrictions during droughts, including absolute minimum flows; (c) a variance process for the operational provisions; (d) flood control operations; (e) a monitoring and reporting component to ensure that the project is operated in accordance with the license; and (f) an adaptive management component with a 5-year review and update cycle.

A second existing mine pit would serve as the project's lower reservoir. The 163-acre lower reservoir would have a total storage capacity of 21,900 acre-feet and a usable storage of 17,700 acre-feet at a normal maximum water surface elevation of 1,092 feet msl. The entire storage capacity of the lower reservoir can be contained within the existing pit; therefore, no dams are necessary to form the lower reservoir (FERC 2014a).

The project would include a water supply system to convey water from three new groundwater wells for the initial reservoir fill and future replenishment. The water supply system would include the three new wells, with pumps located about 13.0 miles southeast of the project, and a 15.5-mile-long underground water supply pipeline (co-located with the project's transmission lines) extending from the wells to the lower reservoir. The water treatment system would be used to maintain reservoir water quality and would include a reverse osmosis system and associated pipelines and desalination ponds (FERC 2014a).

The project's energy-storage volume would permit it to generate at full capacity for up to 10 hours each weekday, with up to 14 hours of pumping each weekday night and additional pumping during the weekend to fully refill the upper reservoir. The daily water-level fluctuation would be about 100 feet in the upper reservoir and 150 feet in the lower reservoir (FERC 2014a).

Environmental Impacts and Mitigation. FERC issued the *Final Environmental Impact Statement for the Proposed Eagle Mountain Pumped Storage Hydroelectric Project (P-13123-002)* in 2012 (FERC 2012), and the *Order Issuing Original License: Eagle Mountain Pumped Storage Hydroelectric Project (P-13123-002)* in 2014 (FERC 2014a). In 2015, FERC upheld its 2014 license order by issuing the *Order Denying Rehearing and Denying Stay: Eagle Mountain Pumped Storage Hydroelectric Project (P-13123-003)* (FERC 2015).

The FEIS identifies a number of potential environmental impacts and the license order includes protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's construction and operation as a closed-loop system, primarily impacts to groundwater and surface water quality and quantity. These impacts would include those from constructing and operating the three new wells and the 15.5-mile-long underground water supply pipeline, both of which are necessary for the project to use groundwater.

C.4.1.1 Groundwater

BLM expressed concern about the Eagle Mountain Project's effects on the Chuckwalla Valley Groundwater Basin, which is connected to the Colorado River through the Palo Verde Mesa Groundwater Basin and the Palo Verde Valley Groundwater Basin. BLM estimated groundwater outflow from the Chuckwalla Basin into the Palo Verde Mesa Basin to be between about 400 and 1,200 acre-feet per year. Using the U.S. Geological Survey's (USGS) Accounting Surface Method, BLM estimated that the accounting surface within the Chuckwalla Valley is between 238 feet and 240 feet above msl, and that water pumped from this level is groundwater that would be replaced by Colorado River water (FERC 2014a).

FERC concluded that BLM had misapplied the Accounting Surface Method to the project. Under the method, the accounting surface is defined as the elevation of the static water table that would exist in the portion of the river aquifer located outside of the river floodplain if the river aquifer consisted entirely of river water. If a well has a static water-level elevation above the accounting surface, it is presumed that water drawn from the well is replaced by precipitation and tributary accretion and not by the lower

Colorado River. If a well has a static water-level elevation below the accounting surface, it is presumed that water drawn from the well is replaced by the Colorado River and thus consumes Colorado River water (FERC 2014a).

The USGS's Colorado River Accounting Surface estimates that the accounting surface is between 238 and 240 feet above msl in the Chuckwalla Valley Groundwater Basin. FERC states that the actual groundwater level in the basin near the project's proposed water supply wells is about 450 feet above msl, or about 210 feet above the accounting surface. The maximum projected drawdown at the project's wells is 50 feet, leaving the water table at its lowest point still 160 feet above the accounting surface. FERC concluded that "because the project's water supply wells would retain the groundwater water level at its lowest point, 160 feet above the accounting surface, the project would not consume lower Colorado River water" (FERC 2014a).

BLM predicted that the Eagle Mountain Project, when combined with the nearby Desert Harvest (Solar) Project and other water users in the valley, would cause overdraft conditions in the Chuckwalla Valley Groundwater Basin during each year between 2014 and 2025. BLM predicted a total water use for the project of 4,456 acre-feet per year for initial filling of the system and 2,050 acre-feet per year for normal operations, to compensate for losses due to evaporation and leakage (FERC 2014a). However, the FERC FEIS estimates the project's water use substantially higher, at 17,700 acre-feet per year for initial fill and 2,507 acre-feet per year for normal operations. The FEIS found that recharge in the Chuckwalla Valley Groundwater Basin is about 12,700 acre-feet per year, which exceeds project withdrawals in all years with the exception of the initial fill period. The FEIS estimates that cumulative groundwater withdrawals in the Chuckwalla Groundwater basin would be between 14,667 and 18,381 acre-feet per year during the period of normal operations, which means there would be a slight overdraft of the aquifer compared to its annual recharge. However, the total amount of water available in storage in the aquifer is estimated to be 10 million acre-feet, so the total groundwater withdrawal from the project over a 50-year license term would be less than one percent of the volume of available groundwater stored in the aquifer (FERC 2014a).

To address concerns over groundwater impacts, the California State Water Resources Control Board (State Water Board) recommended:

1. monitoring groundwater levels to confirm that project pumping rates do not exceed historic (1965-1986) pumping rates;
2. limiting the amount, the project may drawdown the groundwater table (maximum allowable change); and
3. monitoring aquifer drawdown at ten monitoring wells (FERC 2014a).

The State Water Board also recommended that the amount the project may draw down the groundwater table (maximum allowable change) at well MW-111 in the Palen Valley near the Colorado River Aqueduct be determined post-licensing and in consultation with the State Water Board. Article 403 of the FERC license requires the licensee to develop a plan, in consultation with the State Water Board, to establish a network of water-level monitoring wells and sets the maximum allowable change for each well. The FERC license specifies that if the project's water withdrawals cause the water level to decline by more than the maximum allowable change, the licensee must reduce pumping. The license also requires the licensee to establish the maximum allowable change to the groundwater table at well MW-111, or an appropriate alternative at a nearby site (FERC 2014a).

The State Water Board recommended that prior to project construction, the licensee study project effects on the reduction in the Chuckwalla aquifer storage capacity that could occur if the Chuckwalla aquifer is confined and the cone of depression caused by the project's groundwater pumping lowers the groundwater surface to a point below the top of the aquifer. License Article 401 requires the licensee to investigate both aquifer confinement and project effects on storage capacity. Depending on the results of this investigation, the final design of the long-term groundwater monitoring network and the maximum allowable drawdown in the monitoring wells (required by Article 403) may be modified to ensure that the project does not lower the groundwater surface to an elevation below the top of a confined aquifer (FERC 2014a).

The State Water Board also recommended that, if the monitoring results indicate project operations have adversely affected water levels of existing nearby privately-owned wells (by increasing the pumping depth by more than 5 feet, as compared to the pre-project baseline condition), the licensee should develop a plan to mitigate the impacts to the neighboring wells. The State Water Board identified five potential mitigation measures: (1) reduce or cease project pumping, (2) replace pumps or modify pumping systems on affected wells (3) deepen affected well(s), (4) replace affected well(s) with a new well(s), and (5) compensate well owners for increased pumping costs associated with lower water levels (FERC 2014a). However, FERC did not include these conditions in the license because:

> "The Commission does not have the authority to adjudicate claims for, or to require, payment of damages. Well owners who believe that their wells are adversely affected by the project and its drafting of the aquifer must seek redress in the appropriate court. Moreover, Section 10(c) of the FPA makes clear that a licensee of a hydropower project 'shall be liable for all damages occasioned to the property of others by the construction, maintenance, or operation of the project works…'." (FERC 2014a).

The Environmental Protection Agency (EPA) expressed concern about the project's effects on groundwater quality and the unknown extent of acid rock drainage from filling the two reservoirs. The FERC license requires the licensee to collect field samples and conduct analyses to determine the site-specific acid production potential and neutralizing capacity. Although the project's reverse osmosis system to maintain water quality in the reservoir would not be designed to treat pH, if the required water quality monitoring shows a drop in pH, the system could be retrofitted to treat the water. License Article 401 requires the licensee to conduct site investigations to determine potential water quality impacts to the reservoirs and groundwater associated with ore-body contact. Article 402 requires the licensee to test excavated material for acid-producing potential and, if necessary, dispose of it outside the reservoir. Article 406 requires the licensee to operate the reverse osmosis desalination facility to maintain the reservoir at the same water quality as the source groundwater. FERC concluded that the testing and disposal requirements combined with the treatment system, and the seepage recovery system discussed below, would protect water quality both in the reservoir and in the groundwater (FERC 2014a).

The Metropolitan Water District expressed concern that the groundwater level and quality monitoring would not extend past the initial four years of monitoring and suggested a long-term monitoring schedule. FERC stated that in the first four years of project operation, the water table would drop significantly because of the large amount of pumping required for the initial reservoir fill. However, in the long term, the effect of the groundwater withdrawal by the project would not cause the aquifer to approach depletion nor cause the groundwater table to decline below maximum historical drawdown levels. License Article 403 requires the licensee to develop a groundwater monitoring plan, with monthly monitoring during the first four years of pumping (i.e., the initial fill period), quarterly monitoring for the next seven years (to capture the maximum water table decline), and semi-annual monitoring thereafter, for the term of the license when changes to groundwater levels are expected to be small. Article 404 requires groundwater quality monitoring in the vicinity of the project's reservoirs, desalination ponds, seepage recovery wells, and water supply wells over the term of the license (FERC 2014a).

To minimize seepage from the project reservoirs, the State Water Board recommended that the reservoirs be partially or fully lined, and that vertical seepage interceptor wells be installed to recover seepage from the reservoirs. The State Water Board also recommended groundwater quality monitoring with the installation of horizontal monitoring wells underneath brine ponds to (1) quantify seepage, (2) monitor groundwater quality, and (3) allow for early detection of groundwater degradation. The State Water Board also recommended that the licensee develop a seepage management plan to identify zones of anticipated seepage, establish criteria for evaluating seepage management strategies, provide corrective actions to address a potential reservoir liner failure, finalize seepage abatement measures to minimize seepage from the reservoirs, and develop final seepage recovery well designs to maintain groundwater levels (FERC 2014a).

Because seepage from the reservoirs has the potential to raise local groundwater levels and adversely affect a proposed landfill in the vicinity, the FEIS recommended various measures to control seepage and manage groundwater levels consistent with the State Water Board's recommendations. License Article 405 requires the licensee to use reservoir liners to control seepage and to conduct aquifer testing to confirm that aquifer characteristics such as seepage are as expected. Article 405 also requires licensee to develop a seepage management and monitoring plan detailing the location and pumping capacity of the seepage recovery wells and the final design of the reservoir liner. The article also requires the installation of observation wells to monitor the groundwater levels below the Colorado River Aqueduct and the proposed landfill, and a seepage management plan to regulate the rise in groundwater levels below the aqueduct and maintain groundwater levels at least five feet below the bottom of landfill liners. In addition, consistent with the State Water Board's recommendations, the license requires development of a groundwater quality monitoring plan (Article 404) and the protection of groundwater at the desalination ponds (Article 406) (FERC 2014a).

The Metropolitan Water District expressed concern that the Eagle Mountain Project could threaten the integrity of the underground Colorado River Aqueduct, which passes just over 1.0 mile east of the lower reservoir. The Water District stated that ground subsidence caused by seepage from the reservoirs or by over-drafting of the aquifer during project operations could affect the stability of the buried aqueduct. To prevent soil subsidence caused by excessive drawdown of the water table, Article 403 requires the licensee to establish a network of groundwater monitoring wells with maximum allowable change thresholds, with an adaptive management component requiring the reduction of water withdrawals should drawdown exceed the allowable thresholds. To prevent subsidence caused by liquefaction, Article 405 requires the installation of seepage recovery wells between the reservoir and the aqueduct and a seepage control design that would limit the rate of seepage from the reservoirs. Article 403 also requires monitoring of the groundwater levels below the aqueduct (FERC 2014a).

C.4.1.2 Surface Water

The State Water Board recommended that reservoir water quality be maintained at a level equivalent to, or better than, baseline water quality values, and that seepage from the reservoirs not cause groundwater to exhibit a pH of less than 6.5 or greater than 8.5 or acquire taste, odor, toxicity or color that creates a nuisance or impairs beneficial use. The State Water Board recommended a surface water monitoring plan to ensure that reservoir water quality is maintained. The State Water Board also recommended that the licensee develop and implement a water treatment, waste management, and disposal plan to maintain the reservoirs' water quality (FERC 2014a).

The FEIS concluded that the licensee could maintain water quality through the operation of its proposed reverse osmosis desalination facility. The system would take untreated water from the upper reservoir and return clean water to the lower reservoir. The filtrate water, which would be high in salts, would be discharged to desalination ponds where evaporation would change the filtrate into solids to be disposed of. License Article 406 requires reservoir and reverse osmosis facility monitoring to ensure that water quality is maintained in a manner consistent with that recommended by the State Water Board. Consistent with the State Water Board's recommendation for a water treatment, waste management, and disposal plan, Article 408 requires the licensee to implement a salt management storage and disposal plan (FERC 2014a).

The State Water Board recommends that, prior to project construction, the licensee evaluate the potential effects on reservoir and groundwater quality that may result from water contact with any remaining mine ore bodies at the Eagle Mountain mine. Because the creation of a pumped storage reservoir in a former open pit iron mine has the potential to acidify water in the reservoir, License Article 402 requires an evaluation and testing of the acid-producing potential of remnant ore bodies (FERC 2014a).

C.4.2 Mineville

The Mineville Project (FERC No. 12635) is a proposed 240-MW closed-loop project that would be located in an abandoned underground iron ore mine complex in the town of Moriah, in Essex County, New York. As discussed below, the project would use the groundwater that has flooded the closed mine complex to fill its two underground reservoirs. Land rights for the project would be leased from the town of Moriah, which owns the surface access structure land parcel (MHC 2015).

In February 2015, Moriah Hydro Corporation filed with FERC an application for an original license for the Mineville Project. On June 18, 2019, FERC issued the *Draft Environmental Impact Statement for Hydropower License: Mineville Energy Storage Project (P-12635-002), New York* (FERC 2019f).

Project Facilities. The Mineville Project's primary features are described below:

- An upper reservoir located within the upper portion of the Harmony Mine between elevations 495 and 1,095 feet above msl, with a surface area of 4.0 acres and a storage capacity of 2,448 acre-feet (in the DEIS, FERC staff independently calculated the storage capacity of the upper reservoir as 1,114 acre-feet);
- A lower reservoir in the lower portion of the Old Bed mine between elevations −1,075 and −1,555 feet msl, with a surface area of 5.1 acres and a storage capacity of 2,448 acre-feet (in the DEIS, FERC staff independently calculated the storage capacity of the lower reservoir as 463 acre-feet);
- A 14-foot-diameter, 2,955-foot-long upper reservoir shaft connecting the upper reservoir to the high-pressure penstock located below the powerhouse chamber floor;
- A 14-foot-diameter, 2,955-foot-long lower reservoir shaft connecting the lower reservoir and the lower reservoir ventilation tunnel;
- A 25-foot-diameter main shaft extending from the surface down to the powerhouse chamber;
- 15-foot-diameter high- and low-pressure steel penstocks embedded beneath the powerhouse chamber floor;
- A 320-foot-long, 80-foot-wide powerhouse chamber;
- A 274-foot-long, 36-foot-wide underground electrical equipment chamber adjacent to the powerhouse chamber;
- A 3,600-foot-long, 10-foot-high, and 15-foot-wide underground electrical tunnel containing 34.5-kilovolt transmission lines, connecting the underground electrical equipment chamber to a new 15-foot by 15-foot aboveground concrete electrical vault adjacent to an existing transmission line located about 1.0 horizontal mile from the underground powerhouse chamber; and

- Appurtenant facilities (MHC 2015; FERC 2019f).

The project would be constructed in a decommissioned underground iron ore mine that has not operated since the early 1970s and is currently sealed and flooded. Both the upper and lower reservoirs would be contained within the existing underground mine with minimal surface features (none of which would be water elements) (MHC 2015).

The existing mine complex includes the interconnected Old Bed, Bonanza Open Pit, and Harmony Mines. According to the license application, these mines are not shafts that lead downward to large caverns or cavities. The iron ore excavation process followed thin veins of ore downward from the surface, much like the veins in a leaf. Only 0.03 percent of the total volume of rock represented by the extent of the mines was removed, so 99.97 percent of the mined zone remains as original solid rock (MHC 2015). All the voids are now completely filled with groundwater, which has, over time, reached the surface level of the overburden layer. Hence, groundwater seeps and exits to the surface above the top of the solid rock through the porous overburden layer. From that point, the water finds its way to a small stream that bisects the surface area above the mines (MHC 2015).

Environmental Impacts and Mitigation. The license application and the FERC DEIS identify a number of potential environmental impacts and protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's construction and operation as an underground closed-loop system, primarily impacts to geology and soils, groundwater, and surface water and quality and quantity.

C.4.2.1 Geology and Soils

The DEIS identifies induced seismicity and subsidence as the most important issues related to geology and soils at the Mineville Project. FERC staff state that risks to the project from naturally occurring earthquakes could include structural effects on the existing project mines and the proposed underground facilities. To address this issue, FERC staff recommend the applicant develop a geotechnical investigation plan that includes the applicant's proposed geotechnical investigations along with additional investigations of the mined-out spaces of each reservoir following dewatering. FERC staff state that the plan and additional studies would provide "a more comprehensive evaluation of the quality of the rock mass, strength, and the safety margin for earthquake loading and help inform the project's final design" (FERC 2019f).

The DEIS states that project construction could affect stress conditions due to excavation for shafts and power facilities as well as by the dewatering of the project mines. During project operations, the daily movement of water between the two reservoirs could affect stress conditions. Induced earthquakes could result from subsurface stress changes during power facility construction, dewatering, and project operation, as well as localized pillar and roof collapses that could develop during project operation. To address these issues, FERC staff recommend the applicant develop and implement a seismic monitoring plan, to include a seismic monitoring network around the project area. Staff also recommend extending the applicant's post-construction seismic monitoring to 10 years to provide an understanding of the effect of project operation on rock mass instabilities such as collapses or rockbursts (FERC 2019f).

The applicant reports that land within and surrounding the project boundary has experienced subsidence and cave-ins as result of settling and degradation of materials used for filling and sealing the mine access shafts and pits. The DEIS states that during project construction, dewatering of the project mines would result in a loss of groundwater from the pore spaces of the fill of the access shafts, which could increase the effective stress in the fill, resulting in further compaction and increased risk of subsidence and cave-ins. During project operation, the constant wetting and drying from water moving between the project reservoirs would mobilize particles in the fill within the three shafts connected to the Harmony Mine if the bedrock/overburden interface were not tightly sealed with a concrete cap. Mobilized sediment would then be transported down into the upper reservoir, and the fill in the shaft would settle further. To address these potential effects, FERC staff recommends modifying the applicant's mine shaft and pit resealing plan to include routine inspections and maintenance to ensure the effectiveness of the reconstructed seals and to help prevent residual settling or further subsidence and cave-ins during project operation (FERC 2019f).

C.4.2.2 Groundwater

The Mineville Project would use a decommissioned underground mine complex that has been completely flooded by natural groundwater seepage up to the level of the rock and overburden interface. The flooding rate has been documented at approximately 320 gallons per minute (gpm) (0.71 cfs [cubic feet per second]). The mine flooding occurred between 1979 and 2003 (MHC 2015).

The Mill Brook surface tributary stream, unnamed but identified as C-86-5, traverses the above-ground portion of the project site. The stream has a groundwater contact point due to overflow seepage from the mines (MHC 2015).

To develop the upper reservoir, MHC anticipates partial dewatering of the upper portion of the mine with a controlled short-term increase in groundwater discharge to the C-86-5 tributary. Partial dewatering would include removing approximately 120,000,000 cubic feet of water, a discharge estimated to be 4.85 cfs for a period of 12 months into the C-86-5 tributary. This would represent a 5.6 percent increase in the one-year reoccurrence flow (MHC 2015).

After construction, the groundwater used in the pumped storage generation process would be reused and cycled between the upper and lower reservoirs. As an underground, closed-loop system that is not open to the atmosphere, there would be no evaporative losses during operations and thus no need for external makeup water. However, normal, natural recharge of the groundwater volumes from surface infiltration via the overburden would continue. Left unchecked, this infiltration would gradually refill the entire mine as it did from 1979 to 2003. To prevent that gradual refill, an estimated 328 gpm (0.73 cfs) of water would need to be pumped from the upper reservoir and discharged to the C-86-5 tributary. This long-term continuous discharge would represent 0.84 percent of the one-year reoccurrence flow (MHC 2015).

The DEIS states that the project mines are thought to be hydraulically connected to adjacent mines, and that dewatering the project mines and project operation would likely affect groundwater elevation in all mines. To address this issue, FERC staff recommends the applicant develop a project mine sealing plan to include its proposal to grout leaking seals of major water-bearing seams and discontinuities and seal all incidental inter-mine connections. However, FERC staff also recommends intermittent inspections and maintenance to ensure isolation of the project mines from groundwater intrusion (FERC 2019f).

FERC staff also recommends the applicant modify its proposed groundwater monitoring to include development of a formal groundwater monitoring plan and increase the number of monitoring stations. The resulting data would "provide a better understanding of groundwater hydrology in the project area and confirm hydraulic isolation of the project mines following implementation of measures in staff's recommended project mine sealing plan (e.g., grouting major water-bearing seams and incidental inter-mine connections)" (FERC 2091f).

The groundwater that would be used for the project is not currently used for domestic water supply. The water supply for the town of Moriah currently comes from Bartlett Pond, a surface water body that is not connected to the project mine and is fed from North Pond in the Town of Westport. However, to ensure complete protection of individual residential water supplies for those homes currently serviced by individual wells, the applicant would pay to extend the municipal water system along Witherbee Road, Chipmunk Street, and Lower Silver Hill Road within the project boundary using ductile iron water mains flow (MHC 2015).

Concern has been raised that during project dewatering and operations, water in the lower reservoir that is pumped into the upper reservoir could have been exposed to a different mineral assemblage in the lower reservoir and could have different quality from water in the upper reservoir. The applicant states that agencies have requested a groundwater quality study as part of the project review. The mines are fully flooded at present, and their shafts and entry points have been sealed with over 100 feet of rock fill and concrete. Thus, the applicant states that the water in the mine is inaccessible and will remain that way until project construction commences. The applicant has committed, however, to assess the water quality within the mines through laboratory testing prior to the dewatering phase of construction. A portion of the groundwater accumulated in the mines would be pumped out and monitored for water quality. If iron or manganese levels are found to exceed New York Department of Environmental Conservation limits and water quality standards, then water would be treated and remediated before it is discharged into the C-86-5 tributary. That process would be accomplished via simple aeration methods followed by a sufficient detention period to allow oxidization of iron and manganese, and ultimately their removal through settling. Monitoring of water quality and volume would be performed during construction and then continuously throughout the life of the project (MHC 2015; FERC 201f).

The applicant states that concern has been raised that the project could require authorization from the EPA under the Underground Injection Control Program. The applicant reviewed the EPA documents *Technical Program Overview: Underground Injection Control Regulations* and *Statement of Basis and Purpose: Underground Injection Control Regulations*, as well as Underground Injection Control information available on the EPA website. The information states that the Underground Injection Control Program is responsible for regulating the construction, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal. For the Mineville Project, no foreign materials would be injected below the surface, and there would be no construction or operation of injection wells that place fluids underground. No water, sand, or chemicals would be pumped into the ground to break apart rock, as is done for hydraulic fracturing of gas wells. The construction and operation of the project would bear no resemblance to hydraulic fracturing, injection-based mining, or geotechnical extraction operations, so the applicant believes that the project is not subject to EPA authorization under the Underground Injection Control Program (MHC 2015).

C.4.2.3 Surface Water

As discussed under the Groundwater section, to develop the upper reservoir the applicant anticipates partial dewatering of the existing mine. Dewatering would involve a controlled short-term (12-month) increase in groundwater discharge to the C-86-5 tributary. The dewatering rate would be approximately 4.85 cfs or 2,177 gpm. Upon completion of project construction, it is anticipated that normal (historic) groundwater seepage from the surface and overburden would be pumped to the C-86-5 tributary. The overflow rate would equal the normal groundwater infiltration seepage rate (approximately 320 gpm or 0.71 cfs) (MHC 2015).

Impacts are not considered likely because the natural yearly flow fluctuation in the C-86-5 tributary varies between 1 and 87 cfs (in a one-year recurrence interval). The proposed maximum pump rate would be less than five percent of the average annual high flow value. The flow would be less than four percent of the two-year high flow, and two percent of the ten-year high flow. The morphology of the C-86-5 tributary from the mine outlet to its confluence with Mill Brook has more than adequate capacity to accommodate this proposed minimal flow augmentation (MHC 2015).

Prior to the dewatering phase of project construction, water quality within the mine would be verified using historical records and sampling and laboratory testing. Because this overflow water currently discharges from the mine at the overburden contact, it is not expected that the dewatering discharge water quality would be any different. If iron or manganese are found to exceed New York Department of Environmental Conservation limits and water quality standards, then water would be treated and remediated as discussed above for groundwater (MHC 2015).

Although construction and operation of the project are not expected to have any adverse impacts on the tributary's water quality, the applicant proposes to install real-time monitoring at the overburden contact on tributary C-86-5, with regular posting of water quality parameters available to the public on a related website, for the life of the project. Parameters to be monitored would include flow, temperature, pH, conductivity, turbidity, dissolved oxygen, total organic carbon, iron, and manganese. Again, if iron or manganese are found to exceed New York Department of Environmental Conservation limits and water quality standards, then water would be treated and remediated as discussed above for groundwater (MHC 2015). FERC staff recommends that the applicant's water quality monitoring and treatment plan include provisions for polychlorinated biphenyl PCB monitoring and defining water quality conditions under which treatment or a temporary stoppage or termination of dewatering would occur (FERC 2019f).

C.4.3 Swan Lake North

The Swan Lake North Project (FERC No. 13318) is a proposed 393-MW closed-loop project that would be located about 11.0 miles northeast of the city of Klamath Falls, in Klamath County, Oregon. As discussed below, water to initially fill the project reservoirs and replace water lost to evaporation and seepage would come from groundwater supplied by the local groundwater agricultural pumping system and delivered to the lower reservoir via an existing underground irrigation network. The project would occupy 730 acres of federal land administered by BLM and BOR, and 1,310 acres of state, county, and private lands (FERC 2019g).

In October 2015, Swan Lake North Hydro, LLC, filed an application for a FERC license to construct and operate the Swan Lake North Project. In January 2019, FERC issued the *Final Environmental Impact Statement for the Swan Lake North Pumped Storage Project (P-13318-003), Oregon* (FERC 2019g). FERC issued an original license for the Swan Lake North Project in April 2019 (FERC 2019h). FERC's environmental review process for the project was likely expedited by the fact that it is designated as a "FAST 41 Project" under Title 41 of the *Fixing America's Surface Transportation Act of 2015*.[1]

Project Facilities. The Swan Lake North Project's primary features would include a new upper and lower reservoir, a high-pressure steel penstock between the upper reservoir and the powerhouse, a powerhouse with generating/pumping facilities, three low-pressure steel penstocks from the powerhouse to the lower reservoir, a transmission line and substation, access roads to the lower and upper reservoirs, and accompanying facilities. The asphalt, concrete, and geomembrane-lined upper reservoir would be created by a 7,972-foot-long, 58-foot-high earthen embankment, and would have a surface area of 64.21 acres and a storage capacity of 2,568 acre-feet at a maximum surface elevation of 6,128 feet above msl (FERC 2019g).

[1] https://www.permits.performance.gov/projects/swan-lake-north-pumped-storage-n

The asphalt, concrete, and geomembrane-lined lower reservoir would be created by an 8,003-foot-long, 65-foot-high earthen embankment, and would have a surface area of 60.14 acres and a storage capacity of 2,581 acre-feet at a maximum surface elevation of 4,457 feet msl. Each reservoir would be fitted with a drainage system designed to detect, collect, and monitor water leakage from the reservoirs (FERC 2019g).

The 2,581 acre-feet of groundwater needed to initially fill the reservoirs and the 357-acre-feet needed annually to make up for evaporative and seepage losses would be supplied by the local groundwater agricultural pumping system and delivered to the lower reservoir via an existing agricultural irrigation network (FERC 2019g).

The project is designed to pump approximately 2,110 acre-feet of water from the lower reservoir to the upper reservoir in approximately 11.5 hours; it would provide a maximum of 9.5 hours of generation per day at maximum generating output. Likely operations would consist of a pumping/generation cycle frequency of 0.8 time per day, on average, with a maximum cycle frequency of 1.2 times per day. The maximum water-level fluctuations would be 44 feet in the upper reservoir and 50 feet in the lower reservoir (FERC 2019g).

Environmental Impacts and Mitigation. The FEIS identifies a number of potential environmental impacts and recommends protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's operation as a closed-loop system, primarily impacts to groundwater and surface water and quality and quantity.

C.4.3.1 Groundwater

Existing agricultural wells and water rights would be used to obtain water to initially fill the project reservoirs and periodically make up for evaporative losses. To initially fill the reservoirs, the project would withdraw 3,001 acre-feet of groundwater from three existing, permitted groundwater wells. The 3,001 acre-feet would consist of 2,581 acre-feet that would be used as the operating volume of the reservoir and extra 420 acre-feet to account for evaporation and leakage over the first year. Thereafter, the applicant estimates it would need 420 acre-feet annually to make up for evaporation (357 acre-feet) and leakage (63 acre-feet). The initial fill of the reservoirs would be completed within four months to a year. The water would be delivered to the lower reservoir via an existing underground agricultural irrigation network connecting the existing pumping wells (FERC 2019g).

Water deliveries would be constrained by the conditions of the existing groundwater well network and established, permitted pumping rates and volumes. The proposed reservoirs would be lined to prevent or minimize seepage of project water into groundwater. Based on the groundwater interference pumping tests conducted by the applicant, Oregon Water Resources Department determined that project-related water withdrawals would not interfere with existing water rights or adversely affect existing groundwater and surface water conditions in the project area. Oregon Water Resources Department based its conclusion on the conditions that the proposed project would:

- use existing, permitted groundwater only (i.e., no new groundwater use);
- use existing, permitted pumping rates;
- use existing, permitted annual extraction volumes; and
- forego use of groundwater wells for irrigation purposes during initial filling of reservoirs (FERC 2019g).

Rather than providing licensing recommendations, Oregon Water Resources Department has indicated that it would likely place the following conditions on the project's water right:

- Requirements for recording and reporting monthly water use for the initial fill and maintenance filling of the reservoirs;
- Requirements for measuring and monitoring static water levels in March of each year to evaluate potential long-term declines in the water level;
- Establishment of an observation well at a location designated by Oregon Water Resources Department staff to determine the magnitude and timing of groundwater-level response during the initial fill of the reservoirs and to monitor potential impacts on neighboring wells and water right holders; and
- Adjustments to the rate and timing of the initial fill if data from the observation well indicate the initial fill is having a negative effect on existing neighboring wells within the project area.

In the FEIS, FERC staff concluded that the actual drawdowns caused by the proposed reservoir filling would be minimal based on the results of the applicant's single and multiple-well tests, particularly for wells located south of the apparent flow boundary between the North Swan Lake and Central Swan Lake to Poe Valley subareas. Further, staff concluded that the estimated pumping rates for the project would extend the pumping period from four months to a year (rather than to the typical irrigation season) and that this distribution of pumping would reduce the potential for interferences with other irrigation wells during peak demand periods (FERC 2019g).

FERC staff concluded that because water deliveries to the project would be constrained by the conditions of the existing groundwater well network and established permitted pumping rates and volumes, there would be no change from existing conditions and thus the project would not create additional or excessive stress on groundwater resources. Groundwater conditions in the project area are not expected to change because the proposed groundwater wells have been operated at their permitted rates and volumes during the recent historical period (FERC 2019g).

C.4.3.2 Surface Water

With regard to surface water quality, as water is exchanged between the project reservoirs during operations, dissolved solids, nutrients, and heavy metals could become concentrated. The applicant proposes to develop an adaptive water quality monitoring and management plan to monitor any changes in reservoir concentrations of dissolved solids, nutrients, and heavy metals over time. Implementing this plan would ensure that any deterioration in water quality would be detected and steps taken to protect operations and wildlife that may incidentally come in contact with project waters. The applicant's proposal to seal the reservoirs with an impervious geomembrane and lining them with concrete would prevent seepage into the groundwater that may adversely affect groundwater quality (FERC 2019g).

FERC staff acknowledges that total dissolved solids (TDS) concentrations in the project reservoirs would increase steadily over the lifetime of the project but concludes that they would not rise to a level that would negatively impact wildlife because concentrations are estimated to remain below the 1,000 mg/L threshold used by the USGS to classify fresh water. Although similar information on nutrient, heavy metals, and other water quality constituent concentrations in the groundwater is not available, FERC staff expect similar trends if they are present in the groundwater used by the project (FERC 2019g).

Surface water runoff is an important source of water for Swan Lake and neighboring wetlands. During scoping, some commenters expressed concerns with how the project might affect instream flow into Swan

Lake and the resources that depend on the lake (e.g., waterfowl). To minimize effects on the hydrology of Swan Lake, the applicant proposes to construct berms around the project reservoirs to route runoff from precipitation around the reservoir, thus only capturing the precipitation that falls on the reservoirs. FERC staff concurs with this proposal (FERC 2019g).

C.4.4 Big Chino Valley

The Big Chino Valley Project (FERC No. 14859) is a proposed 2,000-MW closed-loop project that would be located 37 miles northwest of Chino Valley in Yavapai, Coconino, and Mohave Counties, Arizona. As discussed below, water to initially fill the project reservoirs and replace water lost to evaporation and seepage would come from groundwater supplied by the Big Chino aquifer and delivered via a new underground pipeline. The project, including transmission lines, would occupy a total of over 23,633 acres of land, of which 16,285 acres would be private lands (mostly ranch lands), 7,257 acres would be state lands, and 91 acres would be federal lands within the Prescott National Forest (ITC 2018b).

In December 2017, FERC issued Big Chino Valley Pumped Storage, LLC (Big Chino), a preliminary permit for the project. On March 30, 2018, Big Chino filed with FERC the *Pre-Application Document: Big Chino Valley Pumped Storage Project, FERC Project No. 14859, Yavapai, Coconino, and Mohave Counties, Arizona* (ITC 2018b) and a request to use the traditional licensing process (TLP). FERC approved use of the TLP in May 2018, and Big Chino plans to submit a license application for the project in early 2020 (ITC 2018a).

Project Facilities. The Big Chino Valley Project's primary features would include a new upper dam and reservoir, a new lower dam and reservoir, inlet-outlet structures, an underground powerhouse, water conveyance between reservoirs, transmission lines, and an access road (ITC 2018b).

The 3,600-foot-long rockfill dam for the upper reservoir would be approximately 380 feet high with a crest elevation of 6,561 feet. The upper reservoir would have a surface area of approximately 119 acres at normal maximum operating pool, with usable storage capacity of 19,800 acre-feet. The permittee expects to provide seepage and infiltration control with an impermeable reservoir liner. A dam drainage system would be provided under the upstream face, and it would be connected to a seepage collection and monitoring system along the downstream dam toe (ITC 2018b).

The 2,200-foot-long rockfill dam for the lower reservoir would be approximately 250 feet high with a crest elevation of 5,300 feet. The lower reservoir would have a surface area of approximately 301 acres at normal maximum operating pool, with usable storage capacity of 19,800 acre-feet. The permittee expects to provide seepage and infiltration control with an impermeable reservoir liner (ITC 2018b).

The project may require new groundwater wells. Big Chino is performing hydro-geophysical work to determine the optimal location of withdrawal wells. There are three existing wells located on the property about 8.0 miles southeast of the lower reservoir. If these three wells are determined to be the best location, then new wells would not have to be drilled. If a location closer to the reservoir would work, then Big Chino would drill those wells. Connection from the wells to the lower reservoir would be by a new underground pipeline. The length and location of that pipeline would depend on where the optimal well location is determined to be (ITC 2018c).

Environmental Impacts and Mitigation. The pre-application document (PAD) and FERC's approval letter identify a number of potential environmental impacts, and the PAD proposes some protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project.

Therefore, this discussion focuses on those potential impacts that would result from the project's construction and operation as a closed-loop system, primarily impacts to groundwater and surface water and quality and quantity.

C.4.4.1 Groundwater and Surface Water

The project would be located in the Big Chino sub-basin of the Verde River watershed and would use groundwater from the Big Chino sub-basin to provide the initial fill of the project's lower reservoir and to replace water lost annually to evaporation. The Big Chino sub-basin supplies the headwaters of the Verde River, a perennial watercourse with unique natural habitat features and important cultural and religious values that supports multiple protected species. Additionally, the Big Chino sub-basin groundwater is used for local agriculture, grazing, domestic, and municipal water supplies (ITC 2018b).

With regard to groundwater quantity, Big Chino states:

- Studies conducted during the licensing process would assess the potential effects of groundwater withdrawal and inform the development of any mitigation measures that may be required.
- Big Chino is conducting feasibility-level engineering studies that include refinements to initial fill requirements. These initial studies currently project an initial fill volume of approximately 22,500 acre-feet (Year 1) up to a total of 24,300 acre-feet (by Year 4), depending on the length of time required to fill.
- The most recent calculations of expected annual average precipitation (475 acre-feet) and evaporation (1,400 acre-feet) over the project reservoir surface areas indicate that following the initial fill, approximately 925 acre-feet of water, on average, would need to be replaced annually. Existing water rights on lands used for the project total approximately 2,000 acre-feet annually. Consequently, there would be an average annual benefit to the Big Chino aquifer of approximately 1,075 acre-feet, or 35,000 acre-feet of groundwater over the course of an anticipated 50-year license (ITC 2018b).

The PAD identifies the following potential impacts to groundwater and surface water:

- In requesting use of the TLP by FERC, Big Chino stated that because there is a large amount of existing, relevant, and reasonably available information on groundwater within the Big Chino aquifer, it does not believe that the issue is complex or controversial, and that it would be able to resolve these issues collaboratively and proactively with full consultation with stakeholders (FERC 2018a). In response to this assertion:

– The Hopi Tribe stated that the groundwater impacts would be challenging to resolve.

– The United States Forest Service (USFS) noted that the degree of uncertainty surrounding the project's potential impacts to groundwater supplies associated with the Big Chino aquifer and related surface water flows to the Verde River would likely generate controversy as the development of the license application progresses.

– The Apache Nation commented that the project is extremely complex and controversial with direct, indirect, and cumulative impacts on the Big Chino sub-basin and the Verde River. The Apache Nation also commented that issues on water rights, culture resources studies, and wild and scenic river designation would need to be discussed and resolved.

– The Salt River Valley Water Users' Association and Salt River Project Agricultural Improvement and Power District identified controversial issues as water rights, the need for specific authorization from Arizona State Legislature for electric generation, and groundwater flow modeling (FERC 2018a).

In its reply to these comments, Big Chino states that the study and mitigation of groundwater-related impacts, while critical, is not controversial. Big Chino states that it intends to minimize controversy and adversarial conflict by addressing this issue proactively. As an example, Big Chino notes that it invited stakeholders to participate in modeling analyzes by providing technical input and additional hydrologic data which can aid in model calibration (FERC 2018a).

FERC concluded that:

> "although Big Chino may have underestimated the level of anticipated controversy associated with the project, particularly those associated with groundwater withdrawals from the Big Chino aquifer, this resource issue is not so complex that it cannot be addressed through a well implemented TLP. Big Chino has compiled substantial information on the environmental resources in the project area, including the Big Chino aquifer, and has proposed to develop studies collaboratively to address the groundwater issues" (FERC 2018a).

C.5 Proposed Closed-Loop PSH Projects Using Surface Water

C.5.1 Gordon Butte

The Gordon Butte Project (FERC No. 13642) is a proposed 400-MW closed-loop project that would be located on private land in Meagher County, Montana, approximately 3.0 miles west of the town of Martinsdale. As discussed below, the project would use surface water from Cottonwood Creek (a tributary to the South Fork of the Musselshell River) for the initial reservoir fill and to replace evaporative and seepage losses. The project would occupy 442 acres of private land owned by 71 Ranch LP (FERC 2016b).

FERC issued GB Energy Park, LLC, an original license for the Gordon Butte Project in 2016, only 15 months after it submitted its license application. The developer cites not being located on federal land and not having critical habitat or endangered species as among the factors that resulted in the relatively rapid licensing process (Borquist et al. 2017; DOE 2018). FERC's environmental review process for the Gordon Butte Project was likely expedited by the fact that it is designated as a "FAST 41 Project" under Title 41 of the *Fixing America's Surface Transportation Act of 2015*[1].

Project Facilities. The Gordon Butte Project's primary features would include an upper and lower reservoir, three dams, an underground vertical shaft tunnel and penstock tunnel to convey water between the upper and lower reservoir, a powerhouse with generating/pumping facilities, a transmission line, two substations, and an access road to the lower reservoir (FERC 2016b).

The 3,000-foot-long by 1,000-foot-wide upper reservoir would be impounded by a 90-foot-high, 7,500-foot-long concrete faced rockfill dam constructed on Gordon Butte, a prominent landform that rises about 1,025 feet above the Musselshell River valley. The upper reservoir would have a normal maximum pool elevation of 6,027 feet msl, an active storage capacity of 4,070 acre-feet, and a surface area of approximately 63 acres (FERC 2016b).

The 2,300-foot-long by 1,900-foot-wide lower reservoir would be created by a combination of excavation and two 60-foot-high, 500- and 750-foot-long concrete faced rockfill dams. The lower reservoir would have a normal maximum pool elevation of 5,057 feet msl, an active storage capacity of 4,070 acre-feet, and a surface area of approximately 88 acres (FERC 2016b).

[1] https://www.permits.performance.gov/projects/gordon-butte-pumped-storage-n

Water to initially fill the reservoirs (4,685 acre-feet) and to replace evaporative and seepage losses (approximately 500 acre-feet per year) would be supplied from Cottonwood Creek via 71 Ranch's existing irrigation system. That system includes an existing diversion structure on Cottonwood Creek and an existing 5.5-mile-long, 4-foot-wide, 4-foot-deep earthen irrigation canal connected to the diversion structure. The licensee would install a trash rack and flow control slide gate at the terminus of the irrigation canal. The gate would connect to a 150-foot-long, 4-foot-diameter pipe that would discharge flows to the lower reservoir (FERC 2016b).

The 4,000 acre-feet of water to be cycled back and forth between the project reservoirs would allow for an estimated 8.5 hours of energy generation at continuous maximum discharge. During normal operation, the lower reservoir would maintain a minimum pool volume of 442 acre-feet during pumping, while the upper reservoir would maintain a minimum pool volume of 243 acre-feet during generation. Therefore, at least 4,685 acre-feet of water would be needed to generate at maximum capacity under normal operation (FERC 2016b).

Environmental Impacts and Mitigation. FERC issued both the *Environmental Assessment for Hydropower License: Gordon Butte Pumped Storage Project, FERC Project No. 13642-003, Montana* (FERC 2016a) and the *Order Issuing Original License: Gordon Butte Pumped Storage Project, FERC Project No. 13642-003, Montana* (FERC 2016b) in 2016.

The EA identifies a number of potential environmental impacts, and the license order includes protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's operation as a closed-loop system, primarily impacts to surface water and groundwater quality and quantity.

C.5.1.1 Surface Water

To identify changes in reservoir water quality over the license term, the licensee proposed to monitor water quality in Cottonwood Creek prior to construction to establish baseline conditions, and in the project reservoirs twice per year during project operation. In the EA, however, FERC staff determined there would be minimal project-related benefits from monitoring water quality prior to construction because sufficient information already exists from previous studies that characterize baseline water quality conditions in Cottonwood Creek. FERC staff also determined there would be minimal benefits from long-term water quality monitoring of the project reservoirs because the reservoirs would be sealed off from the surrounding rock and would operate as a self-contained closed-loop system, thus preventing any contact with surrounding water sources and groundwater. Accordingly, the FERC license does not require the licensee's proposed water quality monitoring measures (FERC 2016b).

With regard to water quantity, stream flows in Cottonwood Creek typically increase with mountain snowmelt and spring rains in May and June. On average, the available flow in Cottonwood Creek immediately above the project diversion increases from about 70 cfs in April to 300-325 cfs in May and June, before decreasing again in July and August. Under existing conditions, Cottonwood Creek is heavily diverted for agricultural purposes from mid-May through September and there are times when creek flows are insufficient to meet existing demands and the creek is dewatered, particularly downstream of the proposed project diversion during the late summer and early fall months. In September 2014, for example, the licensee measured flow in Cottonwood Creek just below the diversion, and recorded a flow of 3 cfs in September, which contrasts with flows of 50 cfs recorded in April and 55 cfs recorded in July (FERC 2016b).

In the EA, FERC staff estimated that the project would require 4,685 acre-feet of water from Cottonwood Creek to fill the reservoir initially and about 500 acre-feet each year to make up for evaporative and seepage losses. Project diversions for initial fill and annual makeup water would result in an additional consumptive use of Cottonwood Creek streamflow, which could adversely affect downstream water users and aquatic resources in Cottonwood Creek depending on the timing and rate of withdrawal (FERC 2016b).

To protect aquatic and riparian habitat in Cottonwood Creek and maintain existing surface water uses downstream of the diversion, the licensee proposed to restrict its flow diversions from Cottonwood Creek to 50 cfs or less (equivalent to 71 Ranch's irrigation diversion under existing conditions), only withdraw water for initial fill and evaporation refills between April 15 and June 30 when flows are naturally high, and maintain a minimum flow of 16 cfs at the existing stream staff gage in Cottonwood Creek when filling the reservoirs. Relative to existing conditions, the net result of filling the reservoir under these restrictions would be no more than 10 cfs of additional consumptive use, which FERC staff concluded would have negligible effects on other surface water uses. Therefore, Article 404 of the FERC license requires the licensee's proposed restrictions on diversion flows for reservoir filling. License Article 405 requires the licensee to maintain a minimum flow of 16 cfs in Cottonwood Creek when diverting flow for the initial and periodic refilling of the reservoir (FERC 2016b).

To make sure that flow diversions for reservoir filling do not adversely affect existing surface water uses in the South Fork and main stem Musselshell River below Cottonwood Creek, the licensee proposed to (1) coordinate with the District Court Musselshell River Distribution Project, Upper Musselshell Water User Association, and Deadman's Basin Water User Association whenever the project is diverting water from Cottonwood Creek for reservoir filling; (2) only divert water for reservoir filling when downstream water rights are satisfied as determined by the District Court Musselshell River Distribution Project; and 3) adjust or cease its diversions from Cottonwood Creek for reservoir filling to maintain minimum flows in the South Fork or main stem Musselshell River (FERC 2016b).

The proposed minimum flows during reservoir filling would range between 194 and 664 cfs in the South Fork, depending on the date and whether Martinsdale Reservoir (located about 5 miles east of the proposed project) was being filled, and 80 cfs in the main stem Musselshell River. The licensee would monitor compliance with the minimum flows using an existing USGS gage located on the South Fork and three existing USGS gages on the main stem Musselshell River from Martinsdale downstream to Shawmut, Montana. The licensee would only divert water for reservoir filling when sufficient flow is available to meet other, non-hydroelectric project water demand and minimum flow requirements (FERC 2016b).

Because the project flow diversion would be relatively small and natural flows in Cottonwood Creek on average exceed the requirements to meet existing uses downstream during the months that the licensee proposes to fill the reservoirs, the FERC license does not require the licensee to coordinate project water withdrawals with the District Court Musselshell River Distribution Project, the Upper Musselshell Water User Association, or the Deadman's Basin Water User Association or to monitor minimum flows in the South Fork or main stem of the Musselshell River (FERC 2016b).

To monitor compliance with the reservoir filling restrictions and instream flow requirements of the license, the licensee is required to develop an operation compliance monitoring plan that includes (1) a description of all gages or recording devices that would be used to monitor compliance with the operational requirements of the license, (2) the method of calibration for each gage and/or recording device (3) the frequency of recording for each gage and/or recording device, (4) a provision to maintain a log of diversions for reservoir filling, (5) procedures for recording, maintaining, and reporting the monitoring data to FERC, and (6) a schedule for reporting deviations from the operational requirements of the license to FERC (FERC 2016b).

C.5.1.2 Groundwater

The FERC EA states that Gordon Butte receives more precipitation than the surrounding lower elevation plains, resulting in recharge to groundwater beneath the butte. A portion of this recharge eventually supplies the groundwater that emerges at springs that are utilized as public water supply sources for the town of Martinsdale. The closest of the three springs serving the town is Box Car Spring, which is located at least 1.0 mile to the northeast of the proposed powerhouse and tunnel sites. To protect the town of Martinsdale's water supply during and after construction, the licensee proposes to implement its Box Car Spring Monitoring Program Plan, which includes monitoring flow rate, pressure, and water quality from Box Car Spring and consulting with the Meagher County Commission to identify appropriate mitigation measures, if warranted (FERC 2016b).

Construction of the power tunnel and powerhouse would require dewatering of excavated areas which could disrupt groundwater flowing to water supply springs located near construction areas. Potential temporary mitigation measures include the licensee providing water trucks for residents to use for non-potable water needs and distributing potable bottled water to residents to use for drinking and cooking needs until the problem is corrected. Potential long-term mitigation measures include expanding the current water storage system, drilling a replacement well to replace flow provided by Box Car Spring, developing a new spring source, or constructing a new water treatment facility to treat surface water from a nearby water source (e.g., Musselshell River or Martinsdale Reservoir) (FERC 2016b).

In the EA, FERC staff determined that excavation and groundwater dewatering during construction are unlikely to affect the flow or water quality of Box Car Spring. Furthermore, any impacts on the water supply would be limited and temporary because the upper reservoir would only affect a small percentage of the total recharge basin and once construction is complete, the powerhouse and power tunnel would be sealed off from the surrounding rock, thus allowing groundwater to flow unabated around these facilities. For these reasons, staff did not recommend, and this license does not require that the licensee implement its proposed Box Car Spring Monitoring Plan (FERC 2016b).

C.5.2 Parker Knoll

The Parker Knoll Project (FERC No. 13239) is a proposed 1,000-MW closed-loop project that would be located at Parker Mountain near the town of Richfield in Piute County, Utah. As discussed below, the project would use surface water from the existing Otter Creek Reservoir for the initial reservoir fill and to replace evaporative and seepage losses. The project would occupy a total of 857.2 acres of land, of which 398.5 acres is private and state-owned land and 458.7 acres is federal land administered by BLM (Symbiotics 2011).

In November 2011, Parker Knoll Hydro, LLC, filed with FERC an application for an original license for the Parker Knoll Project (Symbiotics 2011). On March 7, 2018, FERC accepted the license application for review. However, FERC dismissed the license application on October 4, 2018, because the applicant failed to provide either (1) a copy of the water quality certification for the project; (2) a copy of the certification request, including proof of the date on which the certifying agency received the request; or (3) evidence of waiver of certification (FERC 2018c). Regardless, we include the Parker Knoll Project in this report because it is a good example of a closed-loop project that would use surface water rather than groundwater.

Project Facilities. The Parker Knoll Project's primary features would include: (1) an approximately 175-foot-high upper main dam with a crest length of approximately 1,650 feet and one saddle dam; (2) an upper reservoir with a storage capacity of approximately 6,780 acre-feet and a surface area of approximately 110 acres; (3) an approximately 100-foot-high lower dam with a crest length of approximately 1,750 feet and two saddle dams; (4) a lower reservoir with storage capacity of approximately 6,760 acre-feet and a surface area of approximately 130 acres; (5) a headrace tunnel; (6) a vertical shaft; (7) a steel-lined penstock tunnel; (8) a tailrace tunnel; (9) a powerhouse; (10) a substation; (11) a 68,000-foot-long fill pipeline and system; (12) approximately one mile of transmission line; and (13) appurtenant facilities (Symbiotics 2011).

The fill pipeline would be used to supply water for the initial fill of the lower reservoir and to periodically provide water to replace seepage and evaporation losses. The pipeline would include an intake structure at Otter Creek Reservoir, four lift stations, and other ancillary facilities. The pipeline would convey water approximately 13 miles from Otter Creek Reservoir to the proposed lower reservoir. The pipeline alignment is generally parallel to the existing transmission line that runs along the east side of Otter Creek (Symbiotics 2011).

The project is designed for a daily generation period of up to 10 hours, and a pumping period of about 14 hours to return the water to the upper reservoir (Symbiotics 2011).

Environmental Impacts and Mitigation. The license application identifies a number of potential environmental impacts and proposes protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to a closed-loop project and would also occur with the construction and operation of an open-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's construction and operation as a closed-loop system, primarily impacts to surface water and groundwater quantity and quality.

C.5.2.1 Surface Water

The Parker Knoll Project would be located within both the Sevier River and Colorado River basins. Water would be pumped from Otter Creek Reservoir to fill the lower reservoir initially and to replace water losses due to evaporation and seepage. Otter Creek Reservoir is located approximately 12 miles south of the project within the Sevier River Basin (Symbiotics 2011).

At the proposed maximum normal pool elevation of 9,600 feet msl, the upper reservoir would have a storage capacity of approximately 6,780 acre-feet and a surface area of approximately 110 acres. With a maximum normal pool elevation at 7,650 feet msl, the lower reservoir would have a storage capacity of approximately 6,760 acre-feet and a surface area of approximately 130 acres. During project operations, approximately 5,900 to 6,100 acre-feet of water would be exchanged between the two reservoirs. Daily water-level fluctuation in the upper reservoir would be approximately 110 feet, and approximately 6 feet in the lower reservoir. Estimated annual evaporative losses from the lower reservoir would be larger than those from the upper reservoir because the upper reservoir would receive more than double the precipitation. Total seepage amounts are unknown at this time, but the upper reservoir would be unlined and would have higher seepage rates than the lower reservoir. Annual evaporative and seepage losses from the combined reservoir system are estimated to be approximately 800 acre-feet (Symbiotics 2011).

The license application states that due to the sheer size of the project, the initial estimated fill of 7,900 acre-feet of water from Otter Creek Reservoir could impact the Sevier Basin's hydrology. Timing and duration of the filling period would ultimately determine the nature of this impact. Due to the sizing of the pipeline and pumps, it would take at least two years to fill the lower project reservoir. The maximum rate of pumping would be 4,380 acre-feet for the first year, and the remaining water would be pumped during the second year. In addition, water would be required annually to offset losses due to evaporation and seepage (Symbiotics 2011).

Otter Creek Reservoir has a capacity of 52,660 acre-feet at full pool, with a surface area of 2,440 acres. Otter Creek Reservoir has annual evaporation of approximately 4,470 acre-feet. The surface area of the proposed lower reservoir would be approximately six percent that of Otter Creek (Symbiotics 2011).

The rate of withdrawal from Otter Creek Reservoir would be up to 12 acre-feet per day for the initial fill and would be based on water availability from irrigation companies during the year. In terms of the effect of this maximum daily withdrawal as a percent of the average available storage, the largest impact is associated with the lowest reservoir volumes in late September, but withdrawal is only 0.11 percent of the daily reservoir capacity. During full reservoir in May, the withdrawal is 0.03 percent of the daily reservoir capacity. The proposed initial fill pumping rate of 12 acre-feet per day represents 0.03 percent to 0.11 percent of the reservoir daily volume, or cumulatively, 0.14 percent of the average instantaneous full capacity. During the non-irrigation season, the reservoir would not fill as quickly; during the irrigation season, less water would be released (Symbiotics 2011).

The applicant assumes that during periods of unusually low water levels in Otter Creek Reservoir, water would not be withdrawn for the project. It is estimated that pumping during the initial fill would occur approximately 85 percent of the total time to account for non-pumping time required for maintenance, power outages, limits on available water, etc. For supplemental filling, it is assumed that pumping would occur during a three-month period for 90 percent of the total time to allow for potential downtime (Symbiotics 2011).

Pumping water from Otter Creek Reservoir to the lower reservoir would require a static vertical lift of about 1,300 feet over a horizontal length of about 68,000 feet. Preliminary lift station locations have been evaluated based on flow rate, pipe size, and pressure, but the final number and capacity of the lift stations depends on pipe diameter, material, wall thickness, and surge protection equipment (Symbiotics 2011).

The license application states that removing water from Otter Creek Reservoir would impact the amount of water released downstream from the reservoir because this water is currently released for an irrigation diversion downstream of Piute Reservoir. The impact would occur only during the irrigation season. During non-irrigation months, no water (except leakage) leaves the dam. To evaluate this impact, the applicant analyzed average daily and monthly hydrologic data from the USGS and Sevier Water Users Association from 2006 to 2011. During the irrigation season of April through September, the use of stored water to fill the proposed reservoirs would result in a range of reduced flows downstream of the project until the point at which the water would otherwise have been diverted for irrigation. The withdrawal rate necessary to fill the project reservoirs would result in reduced flows below Otter Creek Reservoir in the East Fork of the Sevier River ranging from 5.7 to 17.8 cfs. On average, this reduction in flow reflects a maximum of 14 percent of the flows in April and a minimum of eight percent of the flows in July from the reservoir outlet. As water is added through tributary inflow downstream, the percentage of reduced flow would lessen, but the total cfs removed for the project would remain the same. This impact is transitory and would last only during the initial fill of the reservoirs (Symbiotics 2011).

Water withdrawn from Otter Creek Reservoir to offset the project's losses to evaporation and seepage would also reduce downstream flows during the irrigation season. Annually, flows would be reduced from April to September, ranging from 1 cfs in April to 3.2 cfs in July (Symbiotics 2011).

Impacts would also include a loss of stream wetted area for approximately 60 miles downstream of Otter Creek Reservoir during the two-year fill period. To assess these potential impacts, the applicant compared the diverted amounts of water to the historical average flows and gage heights. This analysis shows that the maximum percentage of water reduced in the river occurs in the Otter Creek outflow during May, with a 14.1 percent reduction. The least effect was below Piute Reservoir in April (1.9 percent reduction in flow). The remaining months vary between these extremes. No impact is expected during the non-irrigation season of October to March (Symbiotics 2011).

During project operations, the loss of stream wetted area below Otter Creek Reservoir due to withdrawals to replace project water would be less significant. The applicant's analysis shows that the maximum percentage of water reduced in the river would occur in the Otter Creek outflow during May, with a 2.6 percent reduction. The least effect was below Piute Reservoir in April, which had a 0.3 percent reduction in flow. The remaining months vary between these extremes. No impact is expected during the non-irrigation season (Symbiotics 2011).

Water in the Sevier River Basin is fully allocated, primarily for agricultural irrigation, and no additional water rights are available from the State of Utah. However, the applicant intends to purchase a lease from various water right holders for the initial fill and water required to offset annual losses due to seepage and evaporation. Negotiations with water right holders in the basin have been ongoing over the past two years; a memorandum of understanding has been developed to acquire the necessary water for the project from Otter Creek Reservoir (Symbiotics 2011).

Regarding water quality, as water is exchanged between the two project reservoirs, the potential exists to concentrate various water constituents, including TDS and nutrients. During the study period, the applicant used the water budget for the project to estimate the accretion of constituents in the project's reservoirs over time. Inputs to the proposed reservoirs included water transferred from Otter Creek Reservoir, rainfall into the reservoirs, and their very small drainage basins (328 and 257 acres). Outflow included evaporation and seepage into the upper unlined reservoir substrate. Using measurements of conductivity and TDS in Otter Creek Reservoir, modeling predicts an increase in TDS over time, but the reservoir water never exceeds the 1,000 mg/L threshold used by the USGS to classify fresh water. The trajectory for phosphorus is less straightforward to predict, as it would likely depend on the biotic community that develops in the reservoirs. In order to address this uncertainty, the applicant proposes to develop an adaptive water quality monitoring program for the proposed reservoirs.

C.5.2.2 Groundwater

The license application states that excavation during project construction could affect groundwater by creating seepage paths that could adversely affect natural resources by altering the water table and surrounding soil. Faults often act as groundwater barriers with very different conditions from one side of the fault to another. Crossing the fault with the proposed tunnel could create a preferential path for water to move from one side of the fault more easily to the other (Symbiotics 2011).

The applicant proposes to develop and implement a plan for managing the flow of groundwater during construction. During construction, the applicant would document all groundwater encountered and propose corrective measures if the levels encountered are different than expected. The approved plan would also include mitigative measures in the case of any adverse effects to ensure that the proposed development would not create any significant impact (Symbiotics 2011).

C.6 Proposed and Existing Open-Loop PSH Projects

C.6.1 Iowa Hill

In 2005, the Sacramento Municipal Utility District (SMUD) filed with FERC an application for a new license to continue operation and maintenance of its existing 637.3-MW Upper American River Hydroelectric Project (No. 2101), and to construct, as a part of the project, the proposed 400-MW Iowa Hill PSH Development (Iowa Hill Project). The Iowa Hill Project would be located in El Dorado County, California, and would occupy 185 acres of federal land within the Eldorado National Forest. As discussed below, the Iowa Hill Project would use surface water from the existing Slab Creek Reservoir for the initial reservoir fill and ongoing operations (FERC 2014b).

FERC issued SMUD a new license for the Upper American Project, including the Iowa Hill Project, in 2014 (FERC 2014b). In 2016, SMUD canceled plans to construct the Iowa Hill Project due to cost and financial risks (Ingram 2016). Regardless, we include the Iowa Hill Project in this report because it is the latest open-loop PSH project licensed by FERC and a good example of current environmental issues and mitigation strategies.

Project Facilities. The Iowa Hill Project's primary features would include: (1) a new 100-acre Iowa Hill upper reservoir with a storage capacity of 6,400-acre-feet, created by an off-stream, rock-filled earthen dike of varying height (maximum height 280 feet) and 5,900 feet in circumference with a geotextile liner on the reservoir floor and the inside surface of the dike; (2) a new Iowa Hill tunnel, an underground water conduit extending from Iowa Hill Reservoir to the existing Slab Creek Reservoir; (3) a new underground Iowa Hill powerhouse on the Iowa Hill tunnel; (4) a new Iowa Hill switchyard; and (5) a new 230-kV transmission line connecting the Iowa Hill switchyard to the existing Camino-White Rock transmission line (FERC 2014b).

Environmental Impacts and Mitigation. FERC issued the *Final Environmental Impact Statement for Hydropower License: Upper American River Hydroelectric Project (FERC Project No. 2101-084), California, and Chili Bar Hydroelectric Project (FERC Project No. 2155-024), California* (FERC 2008) (including the Iowa Hill Project) in 2008. The FEIS analyzes the potential impacts of the project and the environmental measures proposed in a Settlement Agreement among stakeholders and additional measures recommended by FERC and USFS staff.

The FEIS identifies a number of potential environmental impacts, and the license order includes protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to an open-loop project and would also occur with the construction and operation of a closed-loop project. Therefore, this discussion focuses on those potential impacts that would result from the project's operation as an open-loop system, including impacts to surface water and groundwater quality but primarily impacts to aquatic ecological resources.

C.6.1.1 Surface Water and Groundwater

Due to concerns over the project's potential impacts on surface water quality in the existing Slab Creek Reservoir, the water quality certification issued by the California State Water Resources Control Board and the FERC license order require the licensee to consult with the State Water Board, USFWS, and California Department of Fish and Wildlife (CDFW) during project design to ensure that the project's design, construction, and operation complies with water quality standards. The water quality certification requires that the project design, construction, and operation:

- comply water quality standards;
- minimize or prevent sediment mobilization and/or increased turbidity in Slab Creek Reservoir and the South Fork American River downstream of the reservoir;
- minimize or prevent fish entrainment into the intake/outlet structure;
- prevent the creation of dangerous hydraulic conditions within Slab Creek Reservoir that may affect recreational activity; and
- prevent the current populations of fish present in Slab Creek Reservoir from falling below self-sustaining levels due to project operations (FERC 2014b).

Also, the State Water Board reserved the authority to require the licensee to develop a mercury management plan if future research and/or water quality and metals bioaccumulation monitoring indicate that Iowa Hill Project operations increase the mobilization or methylation of mercury. Such a plan should include a review of potential measures to reduce the amount of methyl mercury or rate of mercury methylation in the watershed (such as changes to power operations, reservoir management, sediment dredging, and/or sediment capping) and an examination of the feasibility of implementing those measures. The plan should also describe any necessary measures to protect human health from exposure through fish consumption (such as posting health warnings at reservoirs, operating recreational fishing as catch and release only, or ceasing to stock reservoirs). If, based on the information contained in the plan or other information, the State Water Board determines there are appropriate and feasible measures the licensee could implement to reduce the amount of methyl mercury, reduce the mobilization or methylation of mercury and/or protect human health, the licensee would be required to develop an implementation plan and submit it to the State Water Board for approval (FERC 2014b).

Parties to the Iowa Hill Settlement Agreement also raised concerns about potential impacts to groundwater quality. However, unlike groundwater quality and quantity issues related to closed-loop projects that would use groundwater for reservoir fill and replenishment, the groundwater concerns at Iowa Hill were about the impacts of constructing the project's underground tunnel. So, the Settlement Agreement and the FERC license order require that prior to construction, the licensee must consult with the USFS and the Central Valley Water Board to prepare a plan for managing groundwater inflows and/or discharge during construction and for groundwater monitoring and management once construction is completed. The plan must include the following:

a. A completed survey that encompasses the portion of the Iowa Hill area that would be potentially affected by the proposed tunnel;

b. Monitoring of the springs and creeks for five years after the tunneling operation is completed with monitoring data submitted monthly and written monitoring reports submitted to the State Water Board, Central Valley Water Board, and USFS biannually by June 1 and December 1 of each year, or as specified in individual or general permits administered by the Central Valley Water Board;

c. A method for accurate quantification of groundwater encountered during tunnel boring operations;

d. A method for verifying that groundwater seepage is controlled after tunnel construction;

e. Identification of corrective measures that would be taken if the tunnel boring operation encounters more groundwater than originally predicted in the EA for Iowa Hill or the completed tunnel seeps; and

f. Potential mitigation measures for all identifiable impacts (FERC 2014b).

C.6.1.2 Aquatic Ecological Resources

As discussed in Section C.6.1.1, the water quality certification issued by the California State Water Resources Control Board and the FERC license order require that the Iowa Hill Project design, construction, and operation:

- minimize or prevent fish entrainment into the intake/outlet structure; and
- prevent the current populations of fish present in Slab Creek Reservoir from falling below self-sustaining levels due to project operations (FERC 2014b).

Due to specific concerns over the project's potential impacts on hardhead in the existing Slab Creek Reservoir, prior to construction the licensee must consult with the USFS, CDFW, USFWS, and State Water Board to develop a Slab Creek Reservoir Hardhead Monitoring Plan (Hardhead Plan). The Hardhead Plan must:

- Provide for hardhead monitoring during all four seasons of the year to establish the locations of all life stages (including edgewater locations) within Slab Creek Reservoir and in the water fluctuation zone upstream on the South Fork American River above and below the Iowa Hill intake/outlet structure.
- Include monitoring for the location of hardhead life stages during, at least, the two years immediately prior to and two years immediately after Iowa Hill operations begin.
- Describe a method to monitor hardhead in Slab Creek Reservoir to determine whether entrainment is occurring due to the operation of Iowa Hill. Monitoring for entrainment must be implemented during the first two years after Iowa Hill begins to operate and may be extended if needed (FERC 2014b).

The licensee must also submit an annual report to the USFS, CDFW, USFWS, and the State Water Board describing the results of the Slab Creek Reservoir hardhead monitoring activities for the prior calendar year's monitoring by May 1 of each subsequent year. If monitoring indicates that entrainment is occurring, the State Water Board would consult with CDFW and the licensee, and if appropriate, require the licensee to develop appropriate mitigation measures.

To further protect aquatic ecological resources in the existing Slab Creek Reservoir, the Settlement Agreement, and the FERC license order requires the licensee to develop a plan to monitor edgewater temperatures between May and September in the reservoir during, at least, the two years immediately prior to and two years immediately after Iowa Hill operations begin. The monitoring must document how temperatures in shallow water areas are affected by Iowa Hill operations, and the monitoring locations must be selected in consultation with the USFS, CDFW, USFWS, and State Water Board. The licensee must submit to those agencies an annual report that describes the results of the edgewater temperature monitoring activities for the prior calendar year's monitoring (FERC 2014b).

To support existing populations of the foothills yellow-tailed frog in the South Fork American River downstream of Slab Creek Reservoir, the Settlement Agreement and the FERC license order stipulate that Iowa Hill Project operations not reduce water temperature below 12°C (53.6°F) during the months of June (after the descending limb of the hydrograph), July, and August in the South Fork American River below Slab Creek Reservoir Dam downstream of Mosquito Bridge. Also, the licensee must ensure that flow fluctuations in the South Fork American River below Slab Creek Reservoir Dam do not occur as a result of Iowa Hill Project operations, with the exception of flow fluctuations that result from specific requirements of the license, such as recreation streamflows (FERC 2014b).

C.6.2 Bath County

The Bath County Project (FERC No. 2716) is an existing 3,003-MW open-loop project located near the town of Mountain Grove in Bath County, Virginia. In terms of generating capacity, Bath County is the largest PSH project in the world. As discussed below, the project uses surface water from Back Creek and Little Back Creek for reservoir fill and operations. The project's hydroelectric facilities and related buildings (excluding transmission line corridors) occupy about 2,375 acres within the George Washington National Forest (FPC 1977).

Virginia Electric and Power Company (VEPCO) filed with the Federal Power Commission (FPC) (the predecessor of FERC) an application for an original license for the Bath County Project in July 1973. FPC issued the original project license in January 1977, and that license expires in 2026 (FERC 2018b). Project construction began in 1977 with an original capacity of 2,100 MW and was completed in 1985. The project's six turbines were upgraded between 2004 and 2009, increasing total generating capacity to 3,003 MW. The project is now owned jointly by Dominion Energy (60 percent), Bath County Energy, LLC (24 percent), and Allegheny Power System (16 percent) (Dominion Energy 2019).

Project Facilities. The Bath County Project's primary hydropower features include: (1) a 135-foot-high, 2,400-foot-long lower reservoir dam across Back Creek; (2) a lower reservoir with a surface area of 555 acres that extends 3.3 miles upstream from the Back Creek dam and impounds 28,000 acre-feet of water (22,500 acre-feet of usable storage); (3) a 460-foot-high, 2,200-foot-long upper reservoir dam across Little Back Creek; (4) an upper reservoir with a surface area of 265 acres that extends 2.0 miles upstream from the Little Back Creek dam and impounds 35,500 acre-feet of water; (5) an above-ground powerhouse; and (6) appurtenant facilities (FPC 1977; Dominion Energy 2019).

Because water levels in both project reservoirs fluctuate widely during project operations (up to 60 feet in the lower reservoir, and up to 105 feet in the upper reservoir), they were deemed unsuitable for recreational use (FPC 1977). To address project impacts to fishing in Back Creek (discussed below) and recreational needs in the project area, VEPCO constructed a recreational complex on a 410-acre tract along Back Creek downstream of the lower reservoir dam. Facilities include campgrounds, picnic areas, a comfort station (and sewage treatment plant), hiking trails, and two ponds, constructed out of land used for borrow pits during construction of the project. One pond covers about 27 acres and includes a swimming area with a beach and bath house, and the second pond covers about 45 acres and includes a boat launching ramp. Fishing is encouraged at both ponds (FPC 1977; Dominion Energy 2019).

Environmental Impacts and Mitigation. The FPC issued its FEIS for the Bath County Project in September 1975. Based on the FEIS, the 1977 FPC license order identified a number of potential environmental impacts, as well as protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to an open-loop project and would also occur with the construction and operation of a closed-loop project. Therefore, this discussion focuses on those potential impacts that have resulted from the Bath County Project's construction and operation as an open-loop system, primarily impacts to surface water quality and aquatic ecological resources.

C.6.2.1 Surface Water

The FEIS and FPC license order conclude that constructing and operating the Bath County Project could have adverse impacts on surface water quality in Back Creek and Little Back Creek. To address this potential impact, the license order requires VEPCO to cooperate with the Virginia State Water Control Board and the Virginia Commission of Game and Inland Fisheries to:

1. Continue, until the project becomes operational, pre-construction water quality studies at selected locations on Back Creek (above and below the site of the lower reservoir and below the mouth of Little Back Creek), and on Little Back Creek below the site of the upper reservoir. Water samples shall be taken on a monthly basis and shall include measurement of dissolved oxygen, temperature, pH, conductivity, total alkalinity, turbidity, suspended solids, ortho- and total phosphorus, inorganic and fecal coliforms, biochemical oxygen demand, flow, and any other significant parameter;
2. Conduct, for a period of five years from the date the project becomes operational, a post-operation water quality monitoring program at the stations used in the pre-construction monitoring program, plus additional stations in the recreational ponds, in the lower reservoir, and on Back Creek downstream of the outflow from the recreational ponds. Samples shall be taken at least monthly and shall include measurements of the parameters measured during the pre-construction monitoring program, temperature and dissolved oxygen profiles, and over depth measurements of other significant parameters of water in the lower reservoir; and
3. File with the FPC annual progress reports during the course of the studies and, within one year after the monitoring program ends, file a final report which includes the findings of the program and recommendations for any needed further sampling or for proposed changes in the operation of the project or the installation of additional facilities to protect the aquatic environment as are shown to be desirable by the studies (FPC 1977).

The license order also reserves the FPC's right, after notice and the opportunity for hearing, to require additional studies and to require such reasonable changes in the project and its operation as may be found necessary or appropriate to maintain or improve the aquatic environment.

C.6.2.2 Aquatic Ecological Resources

The FEIS and FPC license order conclude that constructing and operating the Bath County Project would have adverse impacts on fish and fishing in Back Creek, and that those impacts would warrant mitigation. Construction of the project eliminated about 2.0 miles of stream habitat on Little Back Creek and about 3.3 miles of stream habitat on Back Creek. However, the FEIS and license order conclude that impacts to Little Back Creek would not require mitigation because it is "too small a stream to support a significant number of fish and other valuable aquatic organisms" (FPC 1977). For Back Creek, VEPCO proposed to improve the existing warm water fishery for approximately 1.0 miles downstream of the lower reservoir dam to mitigate for eliminating fishing potential in the 3.3 miles of Back Creek inundated above the dam. The proposal included constructing the two recreation ponds for fishing, planting of cover along the bank of the stream, and improving the stream bed to establish an optimum ratio of riffles to pools (FPC 1977).

The FPC license order specifies that VEPCO consult with USFWS, USFS, and the Virginia Commission of Game and Inland Fisheries to develop a plan to avoid or mitigate expected adverse impacts on fish and wildlife resources in the project area. With respect to fishery resources, the license order requires that VEPCO submit a plan for improving:

> "the fishery habitat for warm water species (and put-and-take trout fishing) for a distance along Back Creek below the lower dam which would not exceed the length of that stream to be inundated by the lower reservoir, and the acquisition of lands, to be included within the project boundary, to provide public access thereto" (FPC 1977).

The license order also reserves FPC's right, after notice and the opportunity for hearing, "to require such reasonable changes in the plan, the construction of the project and/or the operation of the project works as are found necessary and appropriate to avoid or to mitigate adverse impacts on fish or wildlife" (FPC 1977).

The license order concludes that the fisheries plan for Back Creek should focus on enhancing habitat for warm water species, rather than creating habitat for cold-water species as suggested by some intervenors, because construction and operation of the project would further reduce Back Creek's viability as a potential cold-water fishery:

> "Impoundment of the water in an otherwise free-flowing stream tends to modify the temperature extremes that would naturally occur. Construction of the lower reservoir, in other words, will produce water temperatures that are cooler than the natural stream temperatures in the spring and early summer. During the rest of the year, the temperature of the water in the reservoir will be warmer than the stream temperature, and release of the water in the reservoir will, in the absence of thermal stratification (which is unlikely owing to the mixing action of pumping and release of reservoir water during project operation), produce warmer temperatures in Back Creek than would otherwise be the case. The planned recreational ponds will have a similar effect. Thus, construction of the project will exacerbate the existing condition of Back Creek as a cold-water fishery: the temperature regime will be, as it is now, lethal to trout and other cold-water species during large portions of the year and it will be unable to support cold-water fish species on a year-round basis" (FPC 1977).

C.6.3 Big Creek Project Nos. 2A, 8, and Eastwood

Big Creek Project Nos. 2A, 8, and Eastwood (FERC No. 67) comprise an existing 373-MW open-loop project located in Fresno County, California. Nos. 2A, 8, and Eastwood are three separate developments within the larger Big Creek System, a complex, integrated hydropower operation of seven separate developments (listed below) with six major dams and reservoirs, numerous small diversions and reservoirs, various conveyance facilities, nine major powerhouses, access roads, electrical transmission lines, and appurtenant facilities owned and operated by SCE. SCE operates the entire Big Creek System in a tightly coordinated manner to maximize the value of hydropower produced from the available water supply (FERC 2009a).

Big Creek Project Nos. 2A, 8, and Eastwood are located within the South Fork San Joaquin River, Big Creek, and Stevenson Creek watersheds, which all flow into the San Joaquin River. Their diversions and reservoirs (described below) are capable of impounding approximately 201,700 acre-feet of water. Their project features are located on 2,388.8 acres within the Sierra National Forest. No. 2A was constructed between 1920 and 1928, with additional features added between 1944 and 1948. Its two generating units (Units 1 and 2) were placed into service in 1928. No. 8 was constructed between 1921 and 1929, and its two generating units (Units 1 and 2) were placed into service in 1921 and 1929. Eastwood was constructed between 1983 and 1987, and its generating unit was placed into service in 1987 (FERC 2009a).

Nos. 2A, 8, and Eastwood are licensed together as FERC Project No. 67. They were originally licensed in 1978, and their original license expired in 2009. They have been operating under FERC annual licenses since 2009. In November 2005, SCE filed an application for a new FERC license for the Mammoth Pool Project within the Big Creek System. In February 2007, SCE filed an application for a new FERC license for Big Creek Nos. 2A, 8, and Eastwood; Big Creek Nos. 1 and 2; and Big Creek No. 3. In 2009, FERC issued a combined FEIS for all the Big Creek Project license applications: *Final Environmental Impact Statement for Hydropower Licenses: Big Creek Nos. 2A, 8, and Eastwood (FERC Project No. 067), Big Creek Nos. 1 and 2 (FERC Project No. 2175), Mammoth Pool (FERC Project No. 2085), and Big Creek No. 3 (FERC Project No. 120), California* (FERC 2009a).

FERC has not, however, issued a new license for any of the Big Creek Project developments because it has been waiting for the State of California to complete its review of the proposed relicensing under the California Environmental Quality Act (CEQA) and to issue its water quality certification under Section 401 of the federal Clean Water Act. SCE combined its water quality certification applications for the separate Big Creek developments into one application and filed its most recent certification application with the State Water Board in November 2017. In May 2019, the State Water Board issued the final water quality certification (California State Water Resources Control Board 2019).

Project Facilities. The Big Creek Project Nos. 2A, 8, and Eastwood's primary hydropower features are described below for each development.

Big Creek No. 2A. The No. 2A development consists of two large dams, 11 smaller diversion dams, several water conveyances, and a powerhouse. The first dam, Florence Lake Dam, is 3,156 feet long and 149 feet high. Florence Lake is a high elevation reservoir that stores water from the South Fork San Joaquin River and other small tributaries. The lake has a maximum pool elevation of 7,327.5 feet msl, a surface area of 962 acres at maximum pool, and a usable storage capacity of 64,406 acre-feet at maximum pool. Florence Lake storage is kept near its minimum level (1,000 acre-feet) during the winter months to avoid damage due to freezing water on the dam face. Storage usually begins to increase in late April. After the peak storage level is reached in late spring/early summer, the reservoir elevation gradually declines until it again reaches its minimum storage level in late fall (FERC 2009a).

The second No. 2A dam, Shaver Lake Dam, is 1,760 feet long and 185 feet high. Shaver Lake is a moderate elevation reservoir that stores water from Huntington Lake, local inflows from North Fork Stevenson Creek, and other small tributaries. Shaver Lake has a maximum pool elevation of 5,370 feet msl, a surface area of 2,184 acres at maximum pool, and a usable storage capacity of 135,568 acre-feet at maximum pool. Water storage at Shaver Lake is not noticeably altered on a daily basis by pump-back operations at Eastwood powerhouse, which usually occur during the late-night/early-morning hours from spring through fall, depending on water availability (FERC 2009a).

During spring through fall, Shaver Lake is generally kept at a high surface elevation to enable the use of pump-back capability. In pump-back mode, the Eastwood powerhouse pumps water from Shaver Lake and returns it to Balsam forebay. This water is used again the following day for generation through Eastwood powerhouse, and then returned to Shaver Lake (FERC 2009a).

Big Creek No. 8. The No. 8 development consists of Big Creek Dam 5, conveyance, penstocks, and a powerhouse. Big Creek Dam 5 is 224 feet long and 60 feet high and creates a reservoir with a maximum pool elevation of 2,943 feet msl. The Big Creek Dam 5 reservoir has a surface area of 3.3 acres and a usable storage capacity of 47 acre-feet at maximum pool (FERC 2009a).

Eastwood. The Eastwood development consists of the Balsam Meadows forebay dam, spillway, two water conveyances, a surge chamber, powerhouse, tailrace tunnel, and a transmission line. Balsam Meadows Dam is 1,325 feet long and 12 feet high. Balsam Meadows Lake has a maximum pool elevation of 6,670 feet msl, with a surface area of 60 acres and usable storage capacity of 1,570 acre-feet at maximum pool (FERC 2009a).

Environmental Impacts and Mitigation. SCE, the affected state and federal agencies, and other stakeholders signed a Settlement Agreement regarding the Big Creek Project relicensing and submitted it to FERC in 2007. The Settlement Agreement and the FERC FEIS identify a number of ongoing environmental impacts, as well as protection, mitigation, and enhancement measures to address them. Many of the impacts identified would not be unique to an open-loop project and would also occur with the construction and operation of a closed-loop project. Therefore, this discussion focuses on those impacts that would result from the continued operation of Big Creek Project Nos. 2A, 8, and Eastwood developments as an open-loop system, primarily impacts related to aquatic ecological resources and aquatic-based recreation.

C.6.3.1 Aquatic Ecological Resources

Regarding project operations at the Big Creek Project, one of the primary issues identified during the EIS scoping was “establishment of appropriate flow regimes in project-affected stream reaches.” Current project operations affect aquatic habitats and sediment transport in the stream reaches, so the Settlement Agreement and FERC FEIS include measures focused on the ecological health and suitability of reaches downstream of project dams to support native fish, amphibian, and reptile populations (FERC 2009a). These measures are discussed below.

Minimum Instream Flows

The FERC FEIS states that, prior to construction of the Big Creek Project, many of the now bypassed reaches were naturally fishless, but most currently support self-sustaining populations of introduced rainbow, brown, and/or brook trout because of stocking efforts by the California Department of Fish and Game (now called the California Department of Fish and Wildlife, or CDFW). In many of the project reaches, low flows due to project operations create barriers to fish passage, limit the quantity of available fish habitat, and contribute to daily mean and maximum water temperatures that exceed optimal levels for trout growth (FERC 2009a).

Under the Settlement Agreement, SCE proposes to implement increased MIF in 21 of the Big Creek Project bypassed reaches downstream of project diversion dams, including those at Nos. 2A, 8, and Eastwood. In most cases, the MIF vary by season and by water type, and include both minimum daily average and instantaneous minimum flows. In the FEIS, FERC staff conclude that the proposed MIF would enhance aquatic conditions and benefit fisheries for naturally produced and stocked trout in each of the 21 reaches where MIF would be implemented. Overall, the benefits would mainly improve conditions for cold-water species such as brook, rainbow, brown, and rainbow/golden trout hybrids by increasing rearing habitat, spawning habitat, and invertebrate production, and by improving water temperatures, passage for spawning migrations, and habitat connectivity during the rearing season (FERC 2009a).

Channel and Riparian Maintenance Flows

The FERC FEIS states that construction and operation of the Big Creek System has substantially altered the flow regime in the South Fork San Joaquin River and in the bypassed reaches of its tributary streams. Project bypassed reaches have been affected by disruption of natural geomorphic processes including sediment retention behind dams and diversion, altered floodplain connectivity, and flow regulation that alters the timing, magnitude, and duration of peak flows and base flows. These alterations affect aquatic habitat conditions including the condition of spawning gravels and the extent and condition of riparian vegetation (FERC 2009a).

Under the Settlement Agreement, SCE would implement channel and riparian maintenance flows in the South Fork San Joaquin River and six of its tributaries. The proposed channel and riparian maintenance flow releases would occur during the peak spring hydrograph to maximize the channel’s ability to mobilize and transport sediment and increase riparian vegetation regeneration. Spring channel and riparian maintenance flow releases would also contribute flow to the South Fork San Joaquin River to benefit spring spawning trout (FERC 2009a).

Channel and riparian maintenance flows would increase the magnitude and duration of spring peak flows compared to current project operations and would make sure that overbank flows would occur during most wet water years. In the FEIS, FERC staff conclude that these increased peak flows would benefit riparian habitats by helping to (1) scour encroaching upland and riparian vegetation in the formerly active channel and on the channel bars; (2) deposit fresh alluvium; (3) regenerate and/or establish riparian vegetation; (4) provide higher soil moisture and water table to support riparian vegetation; and (5) discourage continued encroachment of upland species on the channel bars (FERC 2009a).

FERC staff also conclude that the higher peak flows would have a greater capacity to mobilize and transport accumulated sediments; increase the recruitment of large woody debris (LWD) to the channel; contribute to the formation of physical habitat features such as riffles, pools, runs, and point bars; support dynamic geomorphic processes over time; and decrease spawning gravel embeddedness. As spawning substrate conditions improve and LWD increases over time, FERC staff expect that trout recruitment would increase, benthic macroinvertebrate productivity would increase, and young-of-the-year trout would have increased access to spaces within the substrate, which provide cover during floods. Overall, FERC staff conclude that implementing channel and riparian maintenance flows in the South Fork San Joaquin River and in the six tributaries would provide a substantive benefit to recreational fisheries for naturally produced trout, aquatic ecosystems, and riparian-dependent wildlife species (FERC 2009a).

Riparian Monitoring

The FERC FEIS states that quantitative and qualitative riparian studies completed for the Big Creek Project identified potential riparian or meadow resource issues along certain bypassed streams associated with Nos. 2A, 8, and Eastwood. Under the Settlement Agreement, SCE would implement a Riparian Monitoring Plan to determine the effectiveness of channel and riparian maintenance flows for maintaining channels and riparian and meadow ecosystems. Specific objectives for the plan include monitoring riparian and meadow vegetation composition in selected reaches; riparian vegetation age class structure, including regeneration, in selected bypassed reaches; and trends in riparian and meadow health in selected reaches over the length of the new license. FERC staff conclude that the proposed monitoring effort would provide information to determine whether or not the proposed channel and riparian maintenance flows and MIF promote healthy riparian and meadow communities; result in successful establishment of native species on alluvial surfaces in reaches with identified age class resource issues; support native riparian or meadow species; and discourage the establishment of mature woody vegetation and upland species on lower surfaces within the channel causing channel encroachment (FERC 2009a).

Large Wood Debris Management

The Bear Creek diversion dam at Big Creek No. 2A blocks the transport of LWD (i.e., dead or dying wood at least 10 feet long and at least 4 inches in diameter) from the upper watershed to the Bear Creek bypassed reach. Under the Settlement Agreement, SCE would return LWD to Bear Creek by allowing it to pass over the Bear Creek diversion spillway during spill. SCE would also collect LWD from the impoundment in the vicinity of the intake gates and dam for placement in the bypassed reach (FERC 2009a).

In the FEIS, FERC staff conclude that LWD contributes to productive aquatic ecosystems and is an important component in the formation of complex aquatic habitat units and channel maintenance. FERC staff recommend that the LWD management proposal be included as a license condition because it would increase the amount of available trout habitat by creating deep pools that provide thermal refugia and increasing habitat complexity. Further, LWD creates high flow velocity breaks and provides cover from predators, and the velocity breaks retain and sort substrate to create gravel bars and spawning habitat for salmonids (FERC 2009a).

Temperature Monitoring and Management

Under the Settlement Agreement, SCE would implement a *Temperature Monitoring and Management Plan* to document the effects of proposed MIF on water temperatures and allow for adaptive management where needed. SCE would monitor water temperatures during, at least, the first three to five years that new MIF are released, including at least one dry or critically dry water year. The plan includes measurement of water temperatures at 19 sites in six bypassed stream reaches where daily mean water temperatures exceeded 20°C (68°F) or daily maximum water temperatures exceeded 22°C (71.6°F) in 2000 or 2001, based on criteria supplied by the State Water Board to protect coldwater beneficial uses. The monitoring results would be used to develop interim and long-term water temperature control programs including measures that may be feasibly implemented by SCE to maintain water temperatures below target temperatures (FERC 2009a).

FERC staff conclude that the proposed *Temperature Monitoring and Management Plan* would benefit coldwater fisheries for trout by documenting how project operations affect water temperatures so that flows could be adjusted through adaptive management based on monitoring results. The program would help to determine the effectiveness of proposed MIF in attaining temperature objectives, and in conjunction with SCE's proposed fish monitoring program, would help to determine associated fish population responses (FERC 2009a).

Sediment Management

The FERC FEIS states that Big Creek Project dams impede or interrupt the flow of sediments, spawning gravels, and other materials beneficial to fish and wildlife from continuing downstream through the affected stream reaches. Sediment retention behind project dams has resulted in depletion of spawning gravels in the bypassed reaches. To address this impact, SCE would implement sediment management measures to pass accumulated sediment through project facilities (followed by flushing flows to redistribute passed sediments), remove accumulated sediment from behind dams, if needed, and monitor turbidity and pool filling (FERC 2009a).

FERC staff conclude that the benefits of restoring sediment passage into downstream reaches would include increasing the volume of spawning gravels, improving benthic macroinvertebrate production, creating greater quality and diversity of aquatic habitat to benefit native fishes, and fostering point bar development to enhance riparian habitat. Sediment removal activities would help to prevent MIF release structures from becoming blocked by sediment and would reduce the transport of fine sediments into downstream reaches, which could prevent potential adverse effects from fine sediment such as reducing the permeability of spawning gravels and smothering incubating trout eggs (FERC 2009a).

Dam Decommissioning and Removal

Under the Settlement Agreement, SCE would decommission and remove four small diversions at Big Creek No. 2A: Crater Creek, Tombstone Creek, North Slide Creek, and South Slide Creek. Removing these dams would enhance fish habitat and water temperature by restoring the affected stream reaches to essentially natural flow conditions (FERC 2009a).

Fish Monitoring

The FERC FEIS states that trout populations in a number of the Big Creek Project bypassed reaches have low densities, fragmented distributions, or skewed age class distributions. The FEIS states that fish populations are constrained by the effects of flow diversions and project structures on stream flows, water temperatures, fish passage, and the transport and supply of spawning gravel and LWD. The Settlement

Agreement includes measures that would enhance fish populations by addressing many of these project-related effects. SCE would monitor fish populations in the specified bypassed reaches to measure the effects of the new MIF and other enhancement measures on fish populations and would apply adaptive management as needed based on monitoring. SCE would monitor species composition, relative abundance, size and age distribution, biomass, density, and condition factor in several locations during the months of August and September in license years 3, 8, 18, 28 (and 38, if a 50-year license is granted) (FERC 2009a).

C.6.3.2 Aquatic-Based Recreation

To mitigate ongoing project impacts and enhance aquatic-based recreation, SCE would construct new recreational facilities at areas where specific needs were identified during its studies and consultations with stakeholders. At Big Creek Nos. 2A, 8, and Eastwood, SCE would develop an accessible fishing platform on the South Fork San Joaquin River and an accessible boat loading facility on Florence Lake. In the FEIS, FERC staff conclude that these new recreational facilities would provide public access, especially for those with disabilities, and “alleviate informal recreational use that can lead to adverse environmental effects and unsafe conditions associated with crowding” (FERC 2009a).

SCE also proposed to provide resources to match fish stocking of Big Creek Project reservoirs and stream reaches conducted by CDFW. SCE proposed to provide this match by either acquiring fish directly or by reimbursing CDFW for half the cost of annual stocking. In the FEIS, FERC staff agree that enhanced stocking would improve the recreational experience of visitors to the Big Creek Project but recommend that SCE be solely responsible for ensuring that the Big Creek Project reservoirs and stream reaches are stocked. Therefore, FERC staff recommend that SCE, after consultation with CDFW, file with FERC an annual fish stocking report detailing the quantity, species, size, location, and frequency of stocking efforts in Big Creek Project reservoirs and stream reaches (FERC 2009a).

SCE proposes to provide channel and riparian maintenance flows from Florence Lake during wet and above average water years so that the descending portion of the flow release is timed to facilitate whitewater boating opportunities. At Florence Lake, SCE proposes to implement more specific minimum water surface elevations. SCE’s proposed measure would result in higher water levels in Florence Lake during July and August, about 20 percent more often than currently occurs. As such, associated flatwater boating opportunities would be enhanced by SCE’s proposed measure to maintain a minimum water surface elevation of 7,276 feet during July and August. FERC staff recommends that these measures be included in a new license for Big Creek Nos. 2A, 8, and Eastwood because they would mitigate project impacts and enhance recreational opportunities (FERC 2009a).

C.6.4 Smith Mountain

The Smith Mountain Project is a 636-MW project located on the headwaters of the Roanoke River in Bedford, Campbell, Franklin, and Pittsylvania counties, Virginia. The project is a combination of PSH and conventional hydropower, with two developments: the upper, PSH portion is the Smith Mountain development and the lower, conventional portion is the Leesville development. The project encompasses about 25,600 acres of land and water, none of which is located on federal lands (FERC 2009b).

The Federal Power Commission (FPC) (the predecessor of FERC) issued the original license for the Smith Mountain Project in 1960, and the project began operations in 1966. Appalachian Power Company (Appalachian Power) filed an application for a new license for the continued operation and maintenance of the project in 2008, and FERC issued the new 30-year license in 2009 (FERC 2009b).

Project Facilities. The Smith Mountain Project's primary hydropower features are described below for the two developments.

Smith Mountain. The Smith Mountain development consists of a 235-foot-high, 816-foot-long concrete arch dam with a crest elevation of 812.0 feet National Geodetic Vertical Datum (NGVD); a 20,260-acre reservoir (Smith Mountain Lake) with a normal water surface elevation of 795.0 feet NGVD; and a powerhouse with five generating units located immediately downstream from the toe of the dam. The Smith Mountain development operates as a peaking facility, generating electricity during peak demand periods. During off-peak periods, the Smith Mountain development does not generate electricity, and water is pumped back into Smith Mountain Lake from Leesville Lake (see the next paragraph) (FERC 2009b).

Leesville. The Leesville development, which serves as the lower reservoir for the Smith Mountain development, consists of a 94-foot-high, 980-foot-long concrete gravity dam with a crest elevation of 615.67 feet NGVD; a 3,260-acre reservoir (Leesville Lake) with a water surface elevation of 613.0 feet NGVD; and a powerhouse containing two turbine-generating units. The Leesville development operates as a conventional facility in an auto-cycling mode, whereby the units are run for nine minutes every hour to provide flow to the Roanoke River downstream from the project. During off-peak periods when the Smith Mountain development is not generating, water that passed through the Smith Mountain development to Leesville Lake is pumped back into Smith Mountain Lake to be used again for generation during the next on-peak demand period (FERC 2009b).

When inflows permit, Appalachian Power maintains Smith Mountain Lake at its normal operating level of 795.0 feet NGVD for power generation and recreation. Generation at the Smith Mountain development results in a daily 2-foot drop in the level of Smith Mountain Lake. This volume of water flowing into Leesville Lake increases the operating level for the Leesville development by 13 feet, from the minimum level of 600.0 feet to 613.0 feet NGVD. Generation at Leesville results in a 5.4-foot fluctuation in the development's tailwater elevation, from 531.5 feet to 536.9 feet NGVD. Depending on generation needs and inflows to the project, the levels of both lakes and the number of units operating at any one time can vary (FERC 2009b).

Environmental Impacts and Mitigation. FERC issued the *Final Environmental Impact Statement for Hydropower Relicensing: Smith Mountain Pumped Storage Project (FERC Project No. 2210-169), Virginia* in 2009 (FERC 2009c). The FEIS analyzes the potential impacts of continued operations at the project, the environmental measures proposed by Appalachian Power, and additional measures proposed by federal and state agencies and recommended by FERC staff.

The 2009 FEIS identifies a number of ongoing environmental impacts, and the license order includes numerous protections, mitigations, and enhancement measures to address them. Many of the impacts identified would not be unique to an open-loop project and would also occur with the construction and operation of a closed-loop project. Therefore, this discussion focuses on those impacts that have resulted from the project's operation as an open-loop system, including impacts to geology and soils, surface water quality and quantity, and aquatic ecological resources.

C.6.4.1 Geology and Soils

The 2009 FEIS identifies two primary impacts to geology and soils from continued operation of the Smith Mountain Project: 1) shoreline erosion and 2) sedimentation at the project reservoirs. The FEIS found that reservoir shoreline erosion would continue with ongoing project operations, with wind-driven waves and boat wakes being the two predominant sources of erosion. The FEIS concludes that while water-level fluctuations associated with pumping operations increase the shoreline’s susceptibility to wave-based erosion, they are not a significant source of erosion (FERC 2009c).

To address ongoing shoreline erosion, the FERC license order requires Appalachian Power to implement an *Erosion Monitoring Plan* through which erosion is monitored in shoreline areas of Smith Mountain Lake and Leesville Lake with scarp heights of less than 5 feet (scarp is defined as a relatively continuous cliff or steep slope produced by erosion between two relatively level surfaces). Following an initial survey, Appalachian Power is required to prepare a report to be filed with the Commission every five years that: (a) documents the locations of the monitored sites; (b) compares the monitoring results with data collected during pre-filing studies; (c) assesses effects and identifies any project-related effects; and (d) proposes actions with an implementation schedule to address project-related effects. In addition, Appalachian Power must develop demonstration projects that use natural methods for stabilizing eroding shoreline, while also enhancing shoreline habitat. The project sites must be monitored to assess the effectiveness of the methods chosen (FERC 2009b).

Regarding sedimentation, the 2009 FEIS reports that since the project was constructed in the 1960s, sediment has accumulated in Smith Mountain Lake and Leesville Lake, decreasing the lakes’ storage volume by about six percent at Smith Mountain and about 11 percent at Leesville. The FEIS concludes that the sedimentation would continue with ongoing project operations, but that most of the sedimentation is due to land use practices in the watershed outside the project boundary. The sedimentation is not uniform but is concentrated in inlets and coves where tributary rivers and streams enter the lakes, with little sedimentation occurring in the main body of the lakes. In areas where sedimentation occurs, it affects recreational access (FERC 2009c).

To address ongoing sedimentation, the FERC license order requires Appalachian Power to implement a *Sedimentation Monitoring Plan* that includes monitoring “areas of concern” every five years and periodic reporting. In addition, Appalachian Power is required to dredge an area in Smith Mountain Lake where sediment impedes access at the Hardy Ford Public Boat Launch and to remove, as necessary, sediment that affects the use of other public boat ramps. The *Sedimentation Monitoring Plan* includes the types of actions Appalachian Power would implement (e.g., methods for dredging), and under what conditions Appalachian Power would propose dredging at a project recreation site (FERC 2009b).

C.6.4.2 Surface Water Quality and Quantity

Surface Water Quality

The Virginia Department of Environmental Quality issued a Clean Water Act, Section 401 water quality certification for the Smith Mountain Project in 2008, and FERC incorporated the conditions of the certification into the new project license (FERC 2009b).

The 2009 FEIS reports that the primary water quality issues at Smith Mountain Lake and Leesville Lake are related to nutrients and bacteria. The FEIS concludes, however, that the source of these nutrients and bacteria is not related to project operations, but rather to shoreline development around the lakes and overall watershed development (FERC 2009c).

Regarding the impact of project operations on water quality, the FEIS reports that water discharged from Smith Mountain Dam can have low temperatures and low DO concentrations under certain generation conditions. When Smith Mountain Lake is stratified (late spring to early fall), releasing colder, less-oxygenated water from Unit 1, which has its intake located in the deepest part of the lake, can result in DO levels below Virginia’s standard of 4.0 mg/L in Leesville Lake (FERC 2009c).

To address this impact to water temperature and DO, the FERC license order requires Appalachian Power to implement a *Water Quality Monitoring Plan* that includes: (a) modifying operations at Smith Mountain from July through September to bring units on- and off-line in a manner that prioritizes withdrawing water from higher in the lake's water column; (b) monitoring DO and water temperature in both project lakes for the first five years of the new license (with continuous monitoring during the first two years); and (c) establishing a Water Quality Technical Review Committee to review the monitoring results. The *Water Quality Monitoring Plan* includes a process for determining the need for additional measures to ensure that Virginia's water quality standards are met (FERC 2009b).

Surface Water Quantity

The FEIS describes how water management at the Smith Mountain Project affects water uses within the project reservoirs and downstream. The project's effects are most evident during low-flow conditions, where maintaining sufficient flow for aquatic resources and recreational uses downstream of the project can lead to a drawdown of Smith Mountain Lake, or, conversely, where ensuring that lake levels are adequate for recreation can require a reduction in flows from Leesville that could harm downstream resources (FERC 2009c).

To address these water management issues, the FERC license order requires Appalachian Power to use an Operations Model to forecast future Smith Mountain Lake levels and adjust downstream flow releases based on the probability of Smith Mountain Lake elevations reaching certain levels in the future. The license order also requires Appalachian Power to modify its auto-cycling operation at the Leesville development from 18 minutes every 2 hours to 9 minutes every hour. This operation protocol is included in the project's *Water Management Plan*, which specifies that the project will continue to operate as a PSH facility, utilizing up to a 2-foot drawdown in Smith Mountain Lake and a 13-foot drawdown in Leesville Lake. The *Water Management Plan* also includes:

a. monthly minimum flows for aquatic organisms, habitat, and recreation in the Roanoke River downstream from Leesville, measured at Brookneal, Virginia;

b. operational restrictions during droughts, including absolute minimum flows;

c. a variance process for the operational provisions;

d. flood control operations;

e. a monitoring and reporting component to make sure that the project is operated in accordance with the license; and

f. an adaptive management component with a 5-year review and update cycle (FERC 2009b).

C.6.4.3 Aquatic Ecological Resources

The 2009 FEIS reports that the primary impact of continued project operations on aquatic ecological resources are those to fish in the project reservoirs and downstream due to changes in water quality (reduced temperature and DO) and water quantity (reduced instream flows). The FEIS concludes that the operational parameters included in the *Water Management Plan* would provide higher annual lake levels in Smith Mountain Lake, particularly during low-inflow conditions, which would benefit aquatic habitat in the lake, the lake's fish populations, and recreational use. Implementing the new operational protocol of bringing the Smith Mountain units on- and off-line in a manner that prioritizes withdrawing water from higher in the water column would reduce the amount of low DO water passing through the development and enhance DO levels in the Smith Mountain discharge, thereby benefiting aquatic life in portions of Leesville Lake. Similarly, the FEIS concludes that the downstream flows below Leesville Dan included in the *Water Management Plan* would provide nearly optimal habitat for the fish species of concern in the Roanoke River, mainly black bass and striped bass (FERC 2009c).

C.7 Appendix C References and Bibliography

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