APPRAISAL STUDY

Alpine Lake Optimization and Automation

Prepared for: Chelan County Natural Resources Department

Project No. 120045-007-007A • March 20, 2015

earth + water

Aspect CONSULTING

ANCHOR QEA

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Executive Summary

Project Overview

This appraisal study has been conducted by the Aspect Consulting, LLC (Aspect) and Anchor QEA, LLC (Anchor QEA) team under contract with the Chelan County Natural Resources Department (CCNRD) in close coordination with the Icicle Work Group (IWG). The IWG has been co-convened by CCNRD and the Washington State Department of Ecology's (Ecology) Office of Columbia River (OCR) to identify and evaluate projects that will improve management of water in the Icicle Creek Sub-basin and improve instream flow conditions in the lower Icicle Creek. This project has been funded under (Grant No. G1400161) from Ecology's OCR.

The nine Guiding Principles related to implementation of water resource projects within the Icicle Basin adopted by the IWG include: 1) broad benefits to streamflow, 2) promotion of sustainable hatchery system, 3) fulfillment of tribal treaties, 4) improvement to municipal and domestic supplies, 5) improvement to agricultural reliability, 6) protection of aquatic and terrestrial habitat, 7) legal compliance, 8) protection of non-treaty harvest, and 9) compliance with wilderness acts and management plans.

The intent of this appraisal study is to determine whether optimizing and automating water storage at the seven alpine lakes managed by Icicle-Peshastin Irrigation District (IPID) and the U.S. Fish and Wildlife Service (USFWS) can meet these principles. IPID manages Square, Upper and Lower Klonaqua Lakes, Colchuck and Eightmile Lakes. USFWS manages Upper and Lower Snow Lakes, and Nada Lake. Flows released from Snow Lakes and Nada Lake supply water to Leavenworth National Fish Hatchery (LNFH; operated by the USFWS) and allow the USFWS to meet instream flow obligations. These seven lakes (collectively referred to in this report as the Alpine Lakes) each have a small dam and low-level outlet that can be controlled to allow for release of some of the storage capacity in the lakes to meet IPID and LNFH diversion needs on Icicle Creek. The Alpine Lakes have a combined estimated usable storage capacity of 20,015 acre-feet. That total usable storage volume is not typically released during a given year due to the difficulty of accessing the more remote lakes and due to the reliability of recharge in the Upper and Lower Snow Lakes basin.

Presently, these lakes are managed in a way that provides the highest level of certainty for drought protection for IPID and LNFH interests; meaning that limited release is performed each year to maximize refill potential of the lakes. A question that this report seeks to answer is: how much additional water could be released from these lakes each year, with a high degree of certainty for refill such that IPID and LNFH are satisfied that their needs during drought years are still met? A governing premise of this project is that: provided there is a high degree of certainty that IPID's needs for release from the lakes will be met in drought years, IPID will be willing to release more water from the lakes during critical periods to address competing water supply needs in the Icicle Creek Sub-basin. These needs include instream flows and out-of-stream water supply for irrigation, hatchery operation, and municipal supply for the City of Leavenworth.

This report also evaluates modernization, optimization and automation of releases from these lakes, such that lake release is performed with the highest possible benefit-to-cost ratio. Finally, conclusions from contemporary reports that look into increasing storage potential in some of the lakes (Upper and Lower Snow Lakes, and Eightmile Lake) have been incorporated into the results of this study.

Project Findings

An analysis of lake operations was performed by the Aspect/Anchor team to evaluate potential increases in release that would occur assuming existing operation conditions, maximizing use of the usable storage in each lake through full manual operation or automation of releases, and modifying existing facilities to maximize use of storage at each lake. Four potential project alternatives were identified for further analysis that included the following:

- **Alternative 1a –** This alternative would maximize the use of the storage available in each lake through manual operation and release of the usable storage in each lake. Additional personnel would need to be employed to manually open and adjust the control gates or valves at each lake over the course of the release period to optimize storage releases. Basic monitoring equipment would be installed and data would be manually downloaded periodically to allow for review of lake levels and release rates.

- **Alternative 1b –** This alternative would maximize the use of the storage available in each lake through automation and remote control of releases from each lake. Existing control gates and valves would be upgraded or replaced as needed to allow for automated control. Basic monitoring equipment would be installed. Telemetry systems would also be installed to allow for remote monitoring and operation of the lakes.

- **Alternative 2a –** This alternative includes all the components of Alternative 1b and would also rebuild the dams at Eightmile Lake, Upper Snow Lake, and Lower Lake to increase the usable storage volume. At Eightmile Lake, a siphon would also be installed to increase the drawdown in the lake. At Upper and Lower Snow Lakes, the rebuilt dams would be raised 5 feet in elevation and, at Lower Snow Lake, the outlet would lowered 3 feet.

- **Alternative 2b –** This alternative would be similar to Alternative 2b, with a minor variation on the storage modifications at Eightmile Lake. Under this alternative, the dam at Eightmile Lake would be rebuilt and raised 1 foot in elevation and the drawdown would be reduced. Both Alternative 2a and 2b would increase the usable storage volume in Eightmile Lake to the maximum annual release allowed by the water right, 2,500 acre-feet.

Key findings of the optimization analysis and evaluation of alternatives include the following:

- Existing operations were simulated to estimate the volume of water that is reliably released from the IPID- and USFWS- managed lakes. This baseline scenario estimated that, under existing operations, approximately 8,200 acre-feet of water are released per year on average during the late summer and early fall (equal to and average release rate of 45 cubic feet per second [cfs] for a 92-day period). Releases in the baseline scenario have been modeled to have 100% refill reliability in the Square, Klonaqua, Eightmile, and Colchuck (the western lakes), and 97% chance to refill at Snow Lakes.

- For Alternatives 1a and 1b that do not propose changing storage-related infrastructure, an additional 5,500 acre-feet could be available for release into Icicle Creek with 100% refill reliability in the western (IPID managed) lakes. In this scenario, reliability of refill from Snow Lakes would reduce from 97% down to 93%. The equivalent benefit to the stream in this scenario is an additional 30 cfs for a 92-day period. Preliminary opinions of probable cost were developed which indicate that the capital cost to implement this scenario would range from $86,000 to $680,000 depending upon whether release from the lakes is performed manually or whether releases are modernized and automated (Alternatives 1a and 1b, respectively).

- For Alternatives 2a and 2b that propose changes to infrastructure, an additional 2,204 acre-feet of water could be released into Icicle Creek with nearly 100% refill reliability in the western lakes. Releases of this quantity would further reduce the refill reliability of Snow Lakes; however, an additional 12 cfs for a 92-day period could be released (in aggregate) in most years with a total potential release of 87 cfs for a 92-day period. The capital cost to implement this scenario range from $3.2 million to $3.5 million and would require major retrofit to both Eightmile Lake and Upper and Lower Snow Lakes.

- A summary of cost and benefits related to improvement alternatives considered are provided in the following table ES-1:

Table ES-1 – Cost/Benefit Summary

Cost Category	Existing (Baseline)	Alternative 1a	Alternative 1b	Alternative 2a	Alternative 2b
Total Project Cost		$86,000	$680,000	$3,187,800	$3,467,200
Usable Storage Capacity (acre-feet):					
• Square Lake	2,400	2,400	2,400	2,400	2,400
• Klonaqua Lakes	1,920	1,920	1,920	1,920	1,920
• Eightmile Lake	1,375	1,375	1,375	2,500	2,500
• Colchuck Lake	1,570	1,570	1,570	1,570	1,570
• Upper and Lower Snow Lakes	12,600	12,600	12,600	13,679	13,679
• Nada Lake	150	150	150	150	150
Total Usable Storage Capacity (acre-feet)[1]	**20,015**	**20,015**	**20,015**	**22,219**	**22,219**
Additional Usable Storage Capacity (acre-feet)		0	0	2,204	2,204
Release Capacity (acre-feet)	8,200	13,700	13,700	15,904	15,904
Additional Release (acre-feet)		5,500	5,500	7,704	7,704
Additional Release (cfs, 92-day Release)		30	30	42	42
Cost/Additional Acre-foot of Release		**$16**	**$124**	**$422**	**$435**
Cost/Additional cfs of Release (92-day Release)		**$2,850**	**$22,600**	**$76,900**	**$79,300**

Data Gaps

- Should this project progress to future stages of development, the Aspect/Anchor team recommends addressing the following data gaps:
- Refining stage-storage information;
- Incorporating potential impacts related to Klonaqua Lakes storage capacity;
- Performing additional hydrologic review; and
- Performing geologic review.

Recommendations and Next Steps

Automating and optimizing water storage at the seven Alpine Lakes offers an efficient and relatively cost-effective way to improve management of water in the Icicle Creek Sub-basin. It is recommended that IPID and the USFWS continue to work with the IWG to evaluate the projects identified in this study and work toward implementing a project that includes the following:

- Install monitoring equipment to improve monitoring of lake levels and release rates from the lakes managed by IPID and USFWS.
- Repair existing gates and control structures at Square, Lower Klonaqua, and Colchuck Lakes.
- Automate releases by installing motorized actuators on the valve on the penstock at Upper Snow Lake and the gates at Square Lake, Lower Klonaqua Lake, Eightmile Lake, and Colchuck Lake.
- Install repeater stations and telemetry equipment needed to provide for remote control of valves and gates.
- Replace existing dams, low-level outlets, and control gates at Upper and Lower Snow Lakes.
- Replace the existing dam at Eightmile Lake and replace the existing low-level outlet and gate with a siphon and gate, as recommended in the *Eightmile Lake Storage Restoration Appraisal Study* (Anchor QEA and Aspect, 2015), being prepared concurrent with this study.

The next steps toward implementation would include:

- Perform feasibility level analyses and design of automation. This would include additional modeling of reservoir operations and releases, additional evaluation of telemetry and controls, additional evaluation of gate and valve retrofits, and development of feasibility level control diagrams and design drawings.
- Perform feasibility level analyses and design of dam replacements. This would include additional topographic and bathymetric survey, a fatal flaw analysis of environmental impacts and permitting, a geologic analysis, preliminary coordination with Ecology Dam Safety, more detailed hydrologic and hydraulic analyses, and development of feasibility-level design drawings.
- Identify and investigate funding opportunities for these projects.

1 Introduction

1.1 Background and Prior Studies

Background and Purpose

The Icicle and Peshastin Irrigation Districts (IPID) and the U.S. Fish and Wildlife Service (USFWS) operate seven alpine lakes (collectively referred to as the Alpine Lakes in this report) in the Icicle Creek Sub-basin. The Alpine Lakes are located in the Icicle Creek sub-basin of WRIA 45 (Wenatchee River Basin) and are used to augment water supply for IPID and the USFWS. IPID operates Klonaqua, Square, Eightmile, and Colchuck Lakes, and the USFWS manages Upper and Lower Snow Lakes and Nada Lake. The lakes are all natural lakes. A small dam with a low-level outlet and control gate was installed at the outlet of each of the lakes in the early part of the 20th Century to allow IPID and the USFWS to capture and store additional runoff during the winter and spring for release during the late summer low flow period. Flows released from Square, Klonaqua, Eightmile, and Colchuck Lakes allow IPID to maintain irrigation diversions and meet instream flow obligations. Flows released from the Snow Lakes and Nada Lake supply water to Leavenworth National Fish Hatchery (operated by the USFWS) and allow the USFWS to meet instream flow obligations. The location of the lakes are shown on Figure 1.

Release gates on the lakes are operated manually and are accessed by hiking in or by helicopter; therefore, they are adjusted infrequently and are not optimized to meet water demands. The purpose of this study is to:

1. Evaluate annual recharge to each lake over a range of historical and future climate scenarios;
2. Evaluate the different lake management scenarios to optimize water releases; and
3. Evaluate the potential to automate the lake discharges so that they can be operated remotely.

There are multiple competing demands for water in the Icicle Creek Sub-basin. These include out-of-stream water supply needed for irrigation, operation of the Leavenworth National Fish Hatchery (LNFH), and municipal use by the City of Leavenworth. Instream flows are also needed to support habitat and passage needs for the endangered species act (ESA) listed fish species. Treaty harvest by the Yakama Nation and the Colville Confederated Tribes, and non-Treaty harvest are important parts of the Icicle fishery. During the late summer and early fall, when natural flows in Icicle Creek are lowest, it is a challenge to supply water for out-of-stream uses, while meeting instream flow targets needed to maintain adequate passage and habitat conditions for ESA-listed fish species. Improvements related to automation and optimization of release from the Alpine Lakes have the potential to provide more reliable instream flows during the late summer and early fall, which would benefit a broad stakeholder group, including IPID, the City of Leavenworth, and local, state, federal, and tribal interests.

The Aspect Consulting, LLC (Aspect) and Anchor QEA, LLC (Anchor QEA) team have conducted this appraisal study under contract to the Chelan County Natural Resources Department (CCNRD) in close coordination with the Icicle Work Group (IWG). The IWG has been co-convened by CCNRD and Washington State Department of Ecology's (Ecology) Office of Columbia River (OCR) to identify and evaluate projects that will improve management of water in the Icicle Creek Sub-basin and improve instream flow conditions in the lower Icicle Creek. Automation and optimization of the Alpine Lakes is one of several projects being considered by the IWG. This study was funded under a grant (Grant No. G1400161) from Ecology's OCR.

The IWG has adopted nine Guiding Principles intended to guide the identification of water management solutions that lead to implementation of high-priority water resource projects within the Icicle Creek drainage. The nine Guiding Principles include:

1. Streamflow that:
    a. Provides passage,
    b. Provides healthy habitat,
    c. Serves channel formation function,
    d. Meets aesthetic and water quality objectives, and
    e. Is resilient to climate change.
2. Sustainable hatchery that:
    a. Provides healthy fish in adequate numbers,
    b. Is resource efficient,
    c. Significantly reduces phosphorus loading,
    d. Has appropriately screened diversion(s), and
    e. Does not impede fish passage.
3. Tribal Treaty and federally protected fishing/harvest rights are met at all times.
4. Provide additional water to meet municipal and domestic demand.
5. Improved agricultural reliability that:
    a. Is operational,
    b. Is flexible,
    c. Decreases risk of drought impacts, and
    d. Is economically sustainable.
6. Improves ecosystem health including protection and enhancement of aquatic and terrestrial habitat.
7. Comply with state and federal law.
8. Protect Non-Treaty Harvest.

9. Comply with the Wilderness Act of 1964, the Alpine Lakes Wilderness Act of 1976, and the Alpine Lakes Wilderness Management Plan.

The intent of this appraisal study to determine if optimization and automation of Alpine Lakes water storage can help meet the Guiding Principles. One key element of the water storage optimization and automation scenarios being considered in this report is IPID's willingness to consider annual flow releases from all lakes, instead of IPID's current practice where a single lake is released each year.

This study is part of a broader package of projects under development designed in part to meet IPID's needs through the Guiding Principles. If IPID agrees with these integrated projects being developed, we understand IPID is willing to retain use of all water from the Alpine Lakes in drought years, but allow for more robust annual releases for non-IPID purposes in non-drought years so long as there is a reasonable certainty that the lakes will refill the following year. These additional flows could benefit several Guiding Principles, including enhancing instream flows, helping to meet municipal supply, enhancing Treaty and non-Treaty harvest, and providing habitat benefits.

Scope of Work

The project scope of work under this study includes the following tasks:

1. **Lake Recharge Evaluation –** Development of water balance to evaluate recharge for each lake under a range of meteorological conditions, including historical and climate change-induced water years. This task builds upon prior studies developed by Montgomery Water Group, Inc. (now Anchor QEA) and the USFWS. The result of this task includes estimates of annual recharge volumes to each lake for typical (50% exceedance), wet (10% exceedance), and dry (90% exceedance) years.

2. **Lake Optimization Evaluation –** Development of various operational scenarios to determine optimal water yield benefits. Operational scenarios consider existing constraints including physical/infrastructure constraints, water rights constraints, and basin yield/hydrologic constraints. For this evaluation, a spreadsheet-based water balance model has been developed.

3. **Automation Feasibility –** Evaluation of feasibility of remote automation of release from the lakes. This feasibility includes evaluating remote telemetry systems automated data logging of lake levels and flows, motorized gate actuators, and power supply options such as solar rechargeable batteries.

Prior Studies

The *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011), provided a summary of potential water storage projects and conservation projects intended to increase water supply and instream flows in the Wenatchee River Basin. One of the projects that was identified and evaluated as part of that study was the potential for increasing storage in Snow Lakes and automating releases.

The evaluation of water storage at Snow Lakes presented in the *Water Storage Report, Wenatchee River Basin* relied on information provided in the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006). That report provided an assessment of inflows, storage, and releases from Upper Snow Lake. Recommendations were provided regarding the timing and duration of releases to optimize flow benefits with the reliability of refill in Upper Snow Lake.

The *Multi-purpose Storage Assessment in the Wenatchee River Watershed* (Montgomery Water Group, 2006), preceded the *Water Storage Report, Wenatchee River Basin* and provided a broad scale overview of storage opportunities in the Wenatchee River Basin. This study identified the various Alpine Lakes (Klonaqua, Square, Colchuck, Eightmile, Snow, and Nada) as potential opportunities for additional storage.

The Anchor/Aspect team is also preparing a report concurrent with this study to evaluate potential improvement options for infrastructure at Eightmile Lake that will allow for restoration of storage capacity and will enable automation and optimization of storage releases. The results of that report, the *Eightmile Lake Storage Restoration Appraisal Study* (Anchor QEA and Aspect, 2015), have been incorporated into this report, to the extent possible.

The evaluation provided in that report was based on initial work completed by Gravity Consulting and Forsgren Associates, summarized in the draft *Icicle Irrigation District Instream Flow Improvement Options Analysis Study* (Forsgren, 2014). The work completed by Forsgren and Gravity included bathymetric and topographic surveys of the lake, adjacent shoreline, and dam facilities and an evaluation of storage volumes based key control elevations.

1.2 Overview, Water Management Strategies for Alpine Lakes

Several strategies were considered for creating new storage and/or more reliable supply from the Alpines Lakes. Those evaluated as part of this study include: 1) modernizing and automating storage release, 2) increasing storage capacity, and 3) optimizing available storage.

Modernization/automation involves retrofitting existing infrastructure to allow for motorized operation of existing outlet works (slide gates and valves) from a remote location. Improvements also include installation of monitoring equipment such as pressure transducers to monitor lake levels and discharge flows.

Storage capacity could be increased by lowering existing outlets to provide greater potential drawdown, increasing maximum pool elevation through replacing/retrofitting existing dams, or both. Accessing storage in additional lakes (e.g., Upper Klonaqua[1]) may also be a possibility.

Optimization of available storage involves coordinating the timing and quantity of water released from the Alpine Lakes to provide additional water beyond what is currently being released for existing water demands and other beneficial use. The volume of releases from the lakes is then balanced against annual inflows to the lakes to provide a high certainty of refill. During the course of this study, it became apparent that, with the

[1] Concurrent with this report, Aspect prepared a technical memorandum summarizing bathymetry work by Gravity Consulting on Upper Klonaqua Lake and flow improvements that could be achieved under various operating scenarios (Aspect, 2014).

exception of the Snow/Nada Lakes system, the majority of the Alpine Lakes can be operated to the limits of current and proposed infrastructure.

The following alternatives were identified for evaluation in this study:

Alternative 1a

- Maximize use from each lake with existing maximum pool level.
- Use manual release to operate the release gates and valves (requires human access to the lakes—assumed to be gained via hiking, rather than helicopter).
- Install basic monitoring equipment (i.e., staff and stream gages and data loggers). Data would be manually downloaded.

Alternative 1b

- Maximize use from each lake with existing maximum pool level.
- Replace release gates as needed.
- Retrofit all release gates and valves with motorized actuators for automated releases.
- Install basic monitoring equipment (i.e., staff and stream gages and data loggers).
- Install telemetry system and automated controls to allow remote operation of release gates and valves.

Alternative 2a

- Includes all Alternative 1b components.
- Increase usable storage volume at Eightmile Lake to 2,500 acre-feet, by completing the following improvements:
    - Rebuild the dam at Eightmile Lake to raise the full water level to the historical overflow level, an elevation of approximately 4,671.0 feet.
    - Add a siphon at Eightmile Lake to allow the water level to be drawn down approximately 22.4 feet below the existing maximum drawdown level, an elevation of approximately 4,621.6 feet.
- Implement additional improvements identified in the *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011) to increase storage and automate releases from the Snow Lakes, including:
    - Replace Upper and Lower Snow Lake dams and increase the dam crest elevation by 5 feet at both locations.
    - Install a new low-level outlet at Lower Snow Lake that will allow for 3 additional feet of drawdown.
    - Replace the low-level outlet pipes and gates at both lakes.

- Automate the low-level outlet gate at Lower Snow Lake and the existing valve on the penstock that discharges water from Upper Snow Lake to Nada Lake.
- Install telemetry to allow for remote operation of the automated gate and valve.

Alternative 2b

- Includes all Alternative 2a components, but with the following variations to the proposed improvements at Eightmile Lake, which would also result in an increase in usable storage volume to 2,500 acre-feet:
  - Rebuild the dam at Eightmile Lake to raise the full water level approximately 5 feet to an elevation that is one foot above the historic overflow level, or approximately 4,672.0 feet.
  - Add a siphon at Eightmile Lake to allow the water level to be drawn down approximately 19.0 feet below the existing maximum drawdown level, to an elevation of approximately 4,624.6 feet.

2 Existing Conditions

2.1 Area Ownership

The Alpine Lakes are situated in the Alpine Lakes Wilderness Area that is jointly administered by Okanogan-Wenatchee and the Mt. Baker-Snoqualmie National Forest managed by the US Forest Service (USFS). However, both Upper and Lower Snow Lakes and Nada Lake are owned and operated by the USFWS, and IPID owns easements that encompass Klonaqua, Square, Colchuck, and Eightmile Lakes.

IPID and the USFWS have existing water rights and access agreements with the USFS that allow the lakes to be used for storage and release of water. These agreements include the right to conduct maintenance activities within the Alpine Lakes Wilderness Area.

2.2 Water Rights Summary

This section provides a summary of storage water rights for the Alpine Lakes and diversionary rights for Snow and Icicle Creeks held by IPID and USFWS. This summary is based on information gathered from Ecology’s water rights and Dam Safety Office files; Washington State Department of Natural Resources (DNR); the USFS and the United States Bureau of Land Management; water right adjudication files from Chelan County Superior Court; and the Chelan County Auditor.

Attributes of the water rights are provided in Table 1. Storage rights for Colchuck Lake, Eightmile Lake, and Klonaqua Lakes, as well as IPID’s diversionary rights to Icicle and Snow Creeks, were subject to the 1927 Icicle Creek water rights adjudication filed in Chelan County Superior Court. The storage rights for Square Lake and Snow Lakes and the USFWS diversionary right to Icicle Creek were established after the adjudication began, and were not subject to the adjudication.

IPID holds diversionary rights to Snow and Icicle Creeks totaling 117.71 cubic feet per second (cfs), while USFWS holds diversionary rights to Icicle Creek, originally issued to U.S. Bureau of Reclamation (Reclamation), for 42 cfs. In total, 12,500 acre-feet of storage rights were certificated by IPID, with an additional 16,000 acre-feet of storage certificated by Reclamation and now held by the USFWS.

Current storage capacity may be less than the quantities listed on the certificates. Based on current records, total storage in Alpine Lakes may be on the order of 8,200 acre-feet in Colchuck, Eightmile, Klonaqua, and Square Lakes under IPID’s water rights, and 12,000 acre-feet in the Snow Lakes under the USFWS’s water rights, of which IPID is entitled to 750 acre-feet.

These capacities need further verification during the feasibility stage of this project. With the exception of Eightmile and Upper Klonaqua Lakes, stage-drawdown relationships based on bathymetry data do not exist. For example, IPID recently learned that Eightmile Lake actually impounds approximately 3,000 acre-feet.

The water right record is unclear whether IPID’s water rights are single-fill storage rights, or whether they can rely on additional natural flows to augment storage, which would further enhance the beneficial use history of the water right. In dry years, it is possible for

IPID to augment its usable storage volume by drawing down the lake further than the normal outlet elevation through additional mechanical or gravity means. If additional water right authority were needed to augment storage from the Alpine Lakes to meet Guiding Principles under an Icicle Integrated Plan, it is possible that additional spring filling water rights could be granted by Ecology, since water is routinely available in excess of adopted instream flows during this time period. IPID's overall water right authority should be considered further in the feasibility stage of this project.

The following sections provide additional information on the adjudicated storage rights; the water right certificates for Square Lake and Snow Lake; and the diversionary water rights.

Table 1 – Alpine Lakes Water

Rights Summary Water Source	Certificate Number	Owner Listed on Certificate	Priority Date	Certificated Qi (cfs)	Certificated Qa (afy)	Adjudicated Qi (cfs)	Adjudicated Qa (afy)
Icicle and Snow Creek[1]	S4-35002JC	IID	1910 (Class 2)	1.7525	---	83.33	---
Icicle and Snow Creek[1]	S4*35002ABBJ	IID/PID	1910 (Class 2)	81.5775	---	83.33	---
Icicle Creek	1082	PID	1919 (Class 5)	34.38	---	34.38	---
Icicle Creek	1824	USBR	1942	42	---	---	---
Klonaqua Lakes	1227	IID	1926 (Class 5)	25	---	25	2,500
Eightmile Lake	1228	IID	1926 (Class 5)	25	---	25	2,500
Colchuck Lake	1229	IID	1926 (Class 5)	50	---	50	2,500
Square Lake	5527	IID	1926	10	2,000	NA	NA
Snow Lake	1591	IID	1929	25	---	NA	NA
Snow Lake	1592	IID	1929	---	1,000	NA	NA
Snow Lake	1825	USBR	1942	---	16,000	NA	NA

Notes:

Qi – instantaneous quantity

Qa – annual quantity

cfs – cubic feet per second

afy – acre-feet per year

IID – Icicle Irrigation District

PID – Peshastin Irrigation District

USBR – United States Bureau of Reclamation

--- not listed

NA – not applicable, these rights were not subject to the 1929 adjudication.

[1] Right confirmed for 83.33 cfs through adjudication. The right was subsequently split and a change to place of use was completed for 1.7525 cfs.

[2] Documented total storage constructed at Snow Lake is 12,000 acre-feet, shared by USFWS and IPID. Under a separate agreement, IPID is entitled to 750 acre-feet of the Snow Lake storage.

Klonaqua, Eightmile, and Colchuck Lakes Storage Rights

In 1926, Icicle Irrigation District (IID) filed applications with the state Office of Supervisor of Hydraulics (an Ecology predecessor agency) requesting to divert water from Klonaqua, Eightmile, and Colchuck Lakes for seasonal irrigation. Petitions were also filed with the Washington State Department of Public Lands (a Department of Natural Resources [DNR] predecessor) to procure the shore and overflow rights to the three lakes. The Office of Supervisor of Hydraulics issued permits to develop the lake sources and the Department of Public Lands issued an order granting “the right to overflow and perpetually inundate said lands”.

In 1927, water rights to Icicle Creek and its tributaries were adjudicated in Chelan County Superior Court. The 1929 Final Court Decree affirmed IID’s water right permits for the lakes in the amounts of 25 cfs, 2,500 acre-feet per year at Eightmile Lake and Klonaqua Lakes and 50 cfs, 2,500 acre-feet per year at Colchuck Lake. The decree noted that the water rights represented by the permits are “inchoate but may be perfected by compliance with provisions under which the permits were issued; that these rights for storage of water under said permits do not affect the water rights of any other claimant herein reported.”

These rights were subsequently certificated by the Office of Supervisor of Hydraulics for 25 cfs (50 cfs at Colchuck Lake) for the purpose of irrigation of 7,000 acres; no annual quantities were specified on the certificates. The Proof of Appropriation (PA) filed to support certificating the storage right to Colchuck Lake indicates that, because of conditions at the site, the reservoir was not raised to the full height planned, that 1,200 acre-feet per year of water was used, and that “utilization of full storage rights necessitate pumping unit during extreme low flow on Icicle water sheds.”

Square Lake Storage Right

An application requesting to divert water from Square Lake for the purpose of irrigation was filed with the state Office of Supervisor of Hydraulics in 1926. A second application, under the same application number, was filed in 1939 to construct a reservoir and store water at Square Lake. A PA was filed in 1953, asserting completion of construction of the reservoir and distribution system in 1952 and use of up to 40 cfs for “supplementing water supply for total area embraced in Icicle and Peshastin Irrigation Districts… as adjudicated in the Icicle Water right adjudication proceedings”. A single certificate was issued for 10 cfs, 2,000 acre-feet per year for irrigation of lands lying within the Icicle Peshastin Irrigation Districts.

Snow and Nada Lakes Storage Right

In 1929, IID filed separate applications to appropriate water from Snow Creek and to store water in Snow Lakes. Construction of the storage project was completed in 1940 when Reclamation drove a tunnel between Nada Lake and Snow Lakes to provide water for what is now the LNFH. In 1941, IID received two certificates authorizing 25 cfs, 1,000 acre-feet per year for irrigation of 7,000 acres lying within the lands of the Icicle and Peshastin Irrigation Districts. In 1942, Reclamation received a water right certificate for Snow Lakes in the amount of 16,000 acre-feet per year to supplement the water supply for the hatchery and holding ponds.

Information filed in support of IID’s water right included a private agreement between IPID and Reclamation. This agreement established that Reclamation would build the control works and provide storage at Snow Lakes and in return IPID would reduce its rights to Snow Lakes from 1,000 to 750 acre-feet per year and would not call on storage from Snow Lakes until water stored in IPID’s other reservoirs have begun to be used. File information also indicates that only approximately 12,000 rather than 16,000 acre-feet of storage was constructed by Reclamation. Based on this, it appears that the current combined storage rights for Snow and Nada Lakes are approximately 12,000 acre-feet of which IPID is entitled to 750 acre-feet per year.

Snow and Icicle Creeks Diversionary Rights

IPID holds three diversionary water rights to Snow and Icicle Creeks that were affirmed through the 1927 adjudication. The certificated quantities of these rights total 117.71 cfs for irrigation of 7,000 acres. USFWS holds a diversionary right to Icicle Creek for 42 cfs to supply the LNFH. No annual quantities are specified on these rights.

2.3 Infrastructure and Current Operations

Existing infrastructure was observed by the Aspect/Anchor team on July 30, 2014. Access to the lakes and the prospective radio repeater stations was accomplished through the use of a Hughes 500D helicopter piloted by Tony Reece of HiLine Helicopters of Darrington, WA. Present during the site visit were Ryan Brownlee and Michael Scrafford of Aspect, David Rice of Anchor QEA, and Tony Jantzer of IPID. Sites visited include Square Lake, Upper and Lower Klonaqua Lakes, Colchuck Lake and Nada Lake. Other lakes including Eightmile Lake, and Upper and Lower Snow Lakes were visited by low elevation fly-over but were not accessed on the ground. Michael Scrafford also visited the Icicle Repeater Station, and proposed Wedge Mountain Repeater site to test radio signal.

Very limited stage-storage relationship information is available for the lakes with the exceptions of Eightmile Lake and Upper Klonaqua Lake (which are being studied concurrently including completion of bathymetric surveys). Approximate stage-storage relationships were obtained for each of the lakes from Ecology’s Dam Safety Office; these relationships were calculated using a combination of the Inventory of Dams Report and lake surface areas from the Lakes of Eastern Washington Report (Ecology, 2014).

Square Lake

Overview

Square lake is situated within the South 1/2, Section 22, T25N, R13E with a surface area of approximately 79.6 acres, a maximum water surface elevation of 4,989 feet and a tributary basin area of 1,010 acres. The existing active storage capacity has been estimated by IPID staff to be approximately 2,400 acre-feet, providing approximately 400 acre-feet of usable storage in excess of the existing water right.

Infrastructure

Gate Actuator

The outlet works gate actuator is located approximately 150 feet south of existing spillway and is built into a hillside with a 3-sided concrete retaining wall enclosure (approximately 4 feet square, each side). Thin steel plates have been placed over the concrete wall to cover and protect the actuator in place of an original wooden cover that has deteriorated.

The existing actuator, shown in Photo 1 and Photo 2, is cast iron geared mechanically and operated with a hand lever. The actuator communicates with a threaded rising stem connected to the slide gate below (accessible from tunnel below). Operation is clockwise to raise the stem and open gate below. During the site visit on July 30, 2014, the gate was opened briefly to two positions (approximately 2-inch stem raise and 4-inch stem raise). Details of existing actuator are as follows:

- Threaded Stem: Approximately 1 – 5/8-inch diameter (inclusive of threads), approximately 4 threads per inch, approximately 1/8-inch width of thread (width and depth).
- Gear-1: Largest gear. Approx. 18-inch diameter. Communicates with stem; corresponds to stem rise.
- Gear-2: Medium-small gear. Approx. 6-inch diameter. Communicates with Gear-1 at 90-degrees.
- Gear-3: Medium gear. Approx. 10-inch diameter. Same axle as Gear-2 (same rotation).
- Gear-4: Smallest gear. Approx. 3.5-inch diameter. Communicates with Gear 3. Same axle as hand-crank.
- Hand Crank: Approx. 18-inch length (not measured).

Upon operation, approximately 8 cranks of the handle equates to one full rotation of the main gear around the stem, which results in approximately ¼-inch stem raise. A moderate level of force is required to operate the gate; however, the gate does not stick.

Photo 1 - Square Lake Gate Actuator

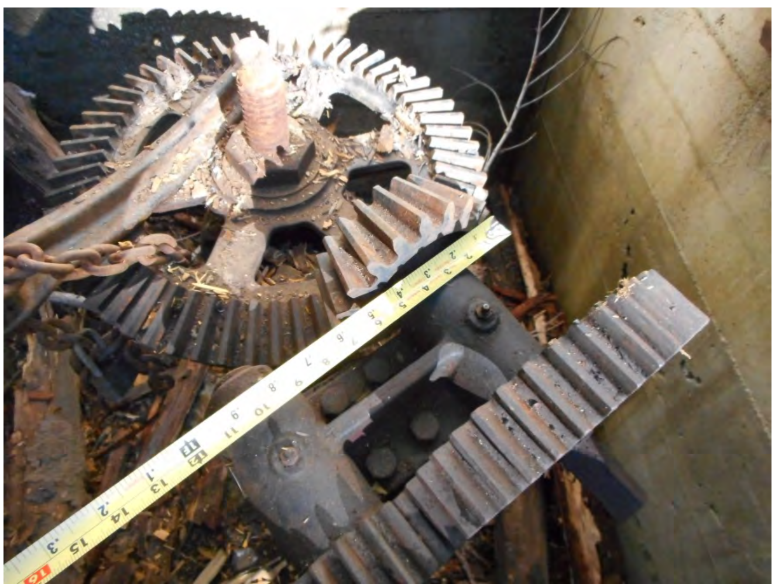

Photo 2 - Square Lake Gate Actuator

Slide Gate

The slide gate is positioned in a tunnel between lake and the outlet channel (Photo 3 and Photo 4). The outlet tunnel was quarried through bedrock with approximate dimensions of 72 inches high x 56 inches wide. The slide gate is a positive seating type, upward opening, metal construction. At the time of visit on July 30, there was no observable leakage around gate (channel outside of tunnel dry). Approximately 1 foot of rubble accumulation near the outlet of the tunnel may limit total drawdown of lake available; however, IPID crews can easily remove the rubble to restore capacity. Based upon rough field measurements using a stationary optical level and stadia rod, current available drawdown is approximately 31 feet from the top of the spillway to the invert of the outlet channel.

Photo 3 - Square Lake Entrance to Outlet Works Tunnel

Photo 4 - Square Lake Inside Outlet Works Tunnel (Gate Visible)

Due to limited time and resources during the site visit, detailed flow measurements of outlet discharge were not performed; however, limited channel velocity measurements were taken using a pygmy meter and Swoffer equipment. Flow velocity was measured at approximately 60% flow depth (average velocity depth) during operation of the slide gate to 2-inch and 4-inch stem raise. The following notes were taken:

- **Test #1;** Approx. 2-inch Stem Rise;
    - Channel Width: 74-inch
    - Flow Depth: 13-inch
    - Mid-Channel Velocity at 60% Flow Depth: 1.5 fps
    - Channel Geometry: semi rounded section
    - Approximate Flow Rate Based on Measurements: 5 to 6 cfs
- **Test #2;** Approx. 4-inch Stem Rise;
    - Channel Width: 74-inch
    - Flow Depth: 23-inch
    - Mid-Channel Velocity at 60% Flow Depth: 2.6 fps
    - Channel Geometry: semi rounded / triangular section
    - Approximate Flow Rate Based on Measurements: 15 to 20 cfs

These measurements were taken to better understand the order of magnitude flow that is achievable given various degrees of gate operation. These results indicate that even with nominal operation of the gate, flows in excess of 20 cfs are likely easily achievable and that incremental operation of the gate results in reasonable modulation of flow rate.

Weir

The original site construction included a masonry rock in-channel weir for flow measurement, as shown in Photo 5. The in-channel portion of the weir has since been eroded and would need to be replaced or reconstructed to re-establish its function.

Photo 5 - Square Lake Flow with Gate Open (Destroyed Weir Visible)

Dam / Spillway

The original dam/spillway at Square Lake was constructed of rock-masonry and is still intact (Photo 6 and Photo 7). The profile of the spillway tapers from south to north, and it is unclear whether this is the result of settlement over time or was intended to concentrate overflow to one area. The dimensions of the existing spillway are approximately 2 feet wide with a maximum freeboard at the southern limit of approximately 2 feet. Debris consisting of fallen logs have accumulated both above and below spillway.

Photo 6 - Square Lake Dam and Spillway (From Lake)

Photo 7 - Square Lake Dam along Crest

Operation

Square Lake is one of four storage sites in the Alpine Lakes Wilderness managed by IPID. The operation of Square Lake was reviewed with IPID manager during the site visit in July 2014. IPID indicated that during a typical year, only one or two of the lakes is actively managed to increase late summer releases to the Icicle Creek Sub-basin. During drought years, water is withdrawn from most of the lakes. Because Square Lake is more remote and difficult to access, it is operated less frequently than Colchuck and Eightmile Lakes.

The gate is operated to control low-level releases through the tunnel to the discharge channel. During the years when Square Lake is actively managed, IPID personnel hike approximately 13 miles (one way) to the lake to open the gate to start releasing water in July. IPID personnel return in October to close the gate after the lake has been drawn down and the irrigation season is over. Water flows from the tunnel and discharge channel to Prospect Creek, which flows to French Creek, which is a tributary to Icicle Creek. The lake refills during the spring when the gate is closed. When the lake is full, water flows over the dam to Prospect Creek. Water continues to flow through the lake and over the spillway uncontrolled until the gate is opened again.

Klonaqua Lakes

Overview

Lower Klonaqua Lake is situated within the SE 1/4, Section 3, T24N, R14E with a surface area of approximately 66.0 acres, maximum water surface elevation of 5,102 feet and a tributary basin area of 800 acres. The existing active storage capacity is estimated at 1,920 acre-feet. The basin area tributary to Lower Klonaqua Lake also includes Upper Klonaqua Lake, which is located just west of Lower Klonaqua Lake and has a maximum water surface elevation that is approximately 97 feet higher than the maximum water surface at Lower Klonaqua Lake.

Upper Klonaqua Lake is just west of Lower Klonaqua Lake and overflows through a short stream channel down a steep granite or rock slope to Lower Klonaqua Lake. Releases from the Upper Klonaqua Lake are not currently controlled. Bathymetry and topographic survey was completed at Upper Klonaqua Lake in October 2014 by Gravity Consulting to better understand the volume of water stored in Upper Klonaqua Lake. The survey measured the water surface elevation difference between Upper and Lower Klonaqua Lakes at approximately 115.8 feet. The survey estimated the difference in high water surface elevations between the two lakes at approximately 97 feet.

Infrastructure

Gate Actuator

At Lower Klonaqua Lake, the outlet works gate actuator (Photo 8 and Photo 9) is located approximately 40 to 50 feet southeast of the existing rock fill dam (spillway). The actuator configuration is similar to that at Square Lake with the actuator present on the surface adjacent to/over a vertical concrete shaft gate-house.

The actuator is connected to the rising stem slide gate below (accessible from the vertical shaft adjacent to actuator). The operation of the actuator is clockwise rotation to stem open gate below. All material is cast iron. During the site visit on July 30, 2014, the gate was operated to two positions (approximately 2-inch stem raise and 4-inch stem raise) similar to the operation at Square Lake. Details of existing actuator are as follows:

- Threaded Stem: Approximately 2-inch diameter (inclusive of threads), approximately 3 threads per inch, approximately 3/16” width of thread (width and depth).
- Gear-1: Largest gear. Approx. 19-inch diameter. Communicates with stem; corresponds to stem rise. Gear-1 positioned approximately 33” above ground surface.
- Gear-2: Small gear. Approx. 5-inch diameter. Communicates with Gear-1 at 90 degrees.
- Hand Crank: Approx. 24-inch length (not measured).

During operation, approximately 4-cranks of the handle equates to one full rotation of the main gear around the stem, which results in approximately 1/3-inch stem raise. A moderate level of force is required to operate the gate; however, the gate does not stick.

Photo 8 – Lower Klonaqua Lake Gate Actuator (Gate Chamber Access Lid Visible)

Photo 9 - Lower Klonaqua Lake Gate Chamber Open with Gate Actuator

Gate

The slide gate is located within a vertical shaft gatehouse between the lake and outlet channel. As-built sketches of the dam on file with water right documentation for the lake indicate that the gate controls flow from the lake through a 30-inch-diameter concrete pipe. The 30-inch-diameter, low-level outlet pipe is connected to and open at the shaft adjacent to the actuator, so that the water level in the shaft rises to match the water level in the lake when the gate is closed. The gate is positive seating and accessible from the vertical shaft. During the site visit, the gate was not observable due to the depth of water in the shaft. The gate chamber is at least 25 feet deep based upon field measurements and as-built sketches. The current available drawdown in Lower Klonaqua Lake is approximately 23 feet, which corresponds to the elevation difference between the spillway crest and the invert of the discharge channel, as measured with stationary survey level and stadia rod.

During gate operation, flow velocity in mid-channel was measured at 60% flow depth at outlet of tunnel using a Swoffer/pygmy type meter.

- **Test #1;** Approx. 2-inch Stem Rise;
    - Channel Width: 56-inch
    - Flow Depth: 24-inch
    - Mid-Channel Velocity at 60% Flow Depth: 2.75fps
    - Channel Geometry: semi rounded section
    - Approximate Flow Rate Based on Measurements: 12 to 13 cfs
- **Test #2;** Approx. 4-inch Stem Rise;
    - Channel Width: 56-inch
    - Flow Depth: 30-inch
    - Mid-Channel Velocity at 60% Flow Depth: 3.85 fps
    - Channel Geometry: semi rounded / triangular section
    - Approximate Flow Rate Based on Measurements: 20 to 25 cfs

These results indicate that even with nominal operation of the gate, flows in excess of 30 cfs are likely easily achievable and that incremental operation of the gate results in reasonable modulation of flow rate.

Photo 10 – Lower Klonaqua Outlet Works Tunnel - Collapsed (View from Channel Downstream)

Photo 11 – Lower Klonaqua Outlet Works Channel (No Flow, Backwater Present)

Dam/Spillway

The dam and spillway at Lower Klonaqua Lake was constructed of earth and rockfill embankment (Photo 12 and Photo 13). The crest of spillway is approximately 8 feet wide and there was approximately 2 feet of freeboard between the crest of the spillway and water surface elevation. Debris consisting of fallen logs have accumulated both above and below the dam.

Photo 12 – Lower Klonaqua Dam Embankment, View along Crest from South

Photo 13 – Lower Klonaqua Dam Embankment, View along Crest from North

Operation

The Klonaqua Lakes are another one of the four storage sites in the Alpine Lakes Wilderness managed by IPID. The operation of the Klonaqua Lakes was reviewed with IPID manager during the site visit in July 2014. As noted previously, during a typical year, only one or two of the IPID-managed lakes is actively managed to increase late summer releases to the Icicle Creek Sub-basin. Because the Klonaqua Lakes are more remote and difficult to access, they are operated less frequently than Colchuck and Eightmile Lakes.

Releases from Lower Klonaqua Lake are controlled by the gate, which is operated by an actuator at the crest of the embankment dam. During the years when Klonaqua Lakes are actively managed, IPID personnel hike more than 10 miles (one way) to the Lower Klonaqua Lake to open the gate in July. IPID personnel return to close the gate in late September or October when the lake is drawn down and the irrigation season is over.

When the gate is open, water discharges through the tunnel and discharge channel to an unnamed creek, which flows to French Creek, which is a tributary to Icicle Creek. Based on recent experience and observations from IPID personnel, Lower Klonaqua Lake typically refills by the summer following the irrigation season when the lake is drawn down. When the lake is full, water flows over the dam. Water continues to flow through the lake and over the spillway uncontrolled until the gate is opened again.

Eightmile Lake

Overview

Eightmile Lake is situated within Sections 32 and 33, T24N, R16E with a surface area of approximately 76.6 acres, maximum water surface elevation of 4,671 feet and a tributary basin area of 3,804 acres. The existing active storage capacity is estimated at 1,375 acre-feet.

Infrastructure

Infrastructure and operation of Eightmile Lake were reviewed with IPID during a site visit on November 1, 2013. Infrastructure and operation of Eightmile Lake are being evaluated in detail by the Aspect/Anchor team as part of a concurrent study, the *Eightmile Lake Storage Restoration Appraisal Study* (Anchor QEA and Aspect, 2015). Additional work at Eightmile Lake was also completed recently by Forsgren Associates and Gravity Consulting. That work included a survey of bathymetry and topography in and along the shoreline of Eightmile Lake and evaluation of storage volumes in the lake. The results are summarized in the draft *Icicle Irrigation District Instream Flow Improvement Options Analysis Study* (Forsgren, 2014).

The infrastructure at Eightmile Lake includes the following:

Dam/Spillway

The dam and spillway at Eightmile Lake consists of a masonry rock and concrete wall structure with an earthen embankment section (Photo 14 and Photo 15). The portion of the earthen embankment closest to the rock and concrete structure has eroded to an elevation that is several feet below the original dam crest and overflow elevation.

An opening in the masonry rock and concrete wall forms the primary spillway outlet for the lake. Stop logs or flashboards were once installed at the spillway opening to control the overflow elevation of the lake. No stop logs or flashboards are currently installed and water spills over large woody debris and rock that have collected at the spillway opening. Water spills through the opening into a spillway well that is filled with rock and debris. The IPID manager indicated that when the gate is closed on the low-level outlet and water spills over the spillway crest to fill the spillway well, the water flows out the discharge pipeline and into Eightmile Creek below the dam. If the spillway well fills, excess water then spills over the downstream wall of the well and into the spillway channel.

Photo 14 - Eightmile Lake Dam (Submerged Gate Not Visible)

Photo 15 - Eightmile Lake Dam, View from Lake

Gate

A gate and low-level outlet pipeline control releases from Eightmile Lake to Eightmile Creek (Photo 16). The gate is submerged in the lake just upstream of the dam and can be opened to release water from the lake through the low-level outlet pipeline to Eightmile Creek. It appears that a concrete control tower was once in place to protect the gate stem and support a manual operator above the water surface of the lake, similar to the equipment currently in place at Colchuck Lake. The tower appears to have completely deteriorated and the manual gate operator has been removed and is in the shed at the IPID office. The gate now has to be operated by inserting a come-along into a square metal loop welded to the stem just above the gate (below the water surface). This makes gate operation very challenging. The IPID manager indicated that rock has also settled above and against the bottom of the gate, making it impossible to completely close the gate.

The gate controls releases through a 36-inch-diameter corrugated metal pipe (CMP). Most of the pipe is buried under large rock. The pipe outlet is submerged. The bottom of the pipe is filled with debris. During the site visit, the IPID manager measured the outlet from the top of pipe to the top of the debris at the invert at approximately 32 inches.

Photo 16 – Submerged Gate Location

Lake Storage Capacity

An aerial view of Eightmile Lake is shown in Photo 17. The survey and lake volume evaluation completed by Gravity and Forsgren (Forsgren, 2014) estimated the volume of the lake at key water surface elevations. The current high water surface elevation was estimated at approximately 4,667 feet. This high water surface elevation reflects the current configuration of the dam and controls, including the absence of stop logs or flashboards in the spillway opening. The total estimated volume of the lake at that elevation is estimated to be approximately 2,706 acre-feet. The current usable storage in the lake is the volume of water storage between the invert of the low-level outlet gate, which was estimated to be approximately 4,644 feet, and the current high water surface elevation at 4,667 feet. The current usable storage volume was estimated to be approximately 1,375 acre-feet. The historical high water surface elevation, corresponding to the dam spillway crest elevation at the lake, was measured at 4,671 feet.

Photo 17 - Eightmile Lake Dam - Aerial View

Operation

Eightmile Lake is another one of the four storage sites in the Alpine Lakes Wilderness managed by IPID. The operation of Eightmile Lake was reviewed with the IPID manager the site visit in November 2013. As noted previously, during a typical year, only one or two of the IPID-managed lakes is actively managed to increase late summer releases to the Icicle Creek Basin. Because of its proximity to Icicle Creek and relative ease of access, the controls at Eightmile Lake are operated more frequently than the controls at the more remote lakes.

The gate on the low-level outlet pipe controls releases from the lake. To actively manage the storage in Eightmile Lake, IPID personnel hike approximately 4 miles (one-way) to the lake to open the gate on the discharge pipeline in July. IPID personnel return to close the gate in late September or October, when the lake is drawn down and the irrigation season is over.

Field observations and discussions with IPID indicate that the gate once had a concrete tower around a gate stem that was attached to a manual actuator above the surface of the lake. The tower appears to have deteriorated and the gate operator has been removed and needs to be repaired. Current gate operation requires that IPID personnel insert a come-along into a submerged metal loop welded to the gate stem to open and close the gate. IPID also indicated that rock has settled above and against the bottom of the gate, making it very difficult to open and close. When the gate is open, water discharges through the low-level outlet to Eightmile Creek, which is a tributary to Icicle Creek. Based on recent experience and observations from IPID personnel, the lake typically refills by the summer following the irrigation season when the lake is drawn down. The active storage capacity available for release and the equivalent volume that has to be refilled is limited by the condition of the dam at the outlet, as described earlier. When the lake is full, water flows over a deteriorated dam spillway outlet to Eightmile Creek. Water continues to flow through the lake uncontrolled, until the gate is opened again.

Colchuck Lake

Overview

Colchuck Lake is situated within the West 1/2, Section 10, T23N, R16E with a surface area of approximately 87.8 acres, maximum water surface elevation of 5,570 feet and a tributary basin area of 941 acres. The existing active storage capacity is estimated at 1,570 acre-feet.

Infrastructure

Gate and Gate Actuator

The outlet works gate actuator is located approximately 20 feet south of the concrete dam and spillway. The actuator is accessible only by water or make-shift wooden plank footbridge (Photo 18 and Photo 19) and is supported by a concrete pedestal that extends from the bottom of the lake to approximately 2 feet above the surface of the lake. The actuator operation is strictly by hand wheel.

The actuator is associated with a rising stem slide gate below (accessible from lake). The actuator operates in a clockwise rotation to raise the stem and open gate below. All material is cast iron. The diameter of stem is approximately 1.5-inch (inclusive of threads). There are approximately 3.5 threads per inch of stem. The gate is operable and was operated to one position (approximately 4-inch stem raise) during our site visit on July 30, 2014. Flow was not measured. IPID completed maintenance and repairs to the gate and concrete pedestal in 2012.

Photo 18 - Colchuck Lake Gate Actuator and Tower

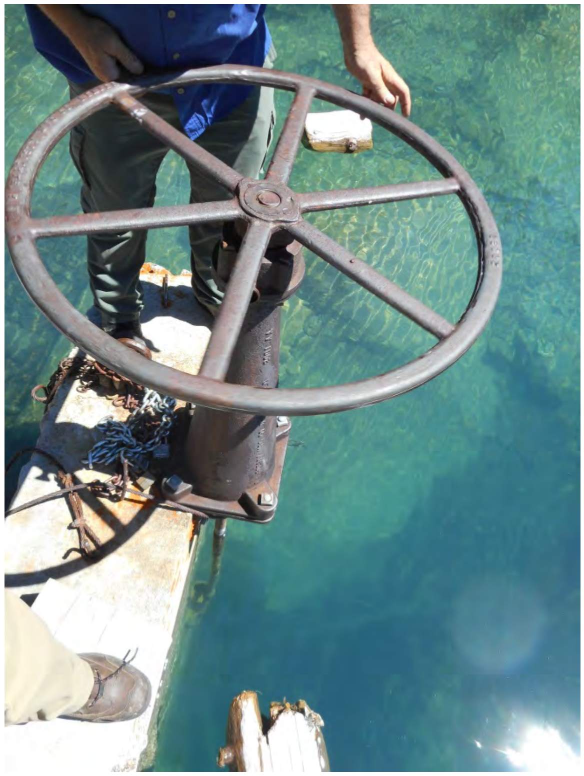

Photo 19- Colchuck Lake Gate Actuator

Photo 20 - Colchuck Lake Gate Actuator Stem (After Operation)

Photo 21 - Colchuck Lake Gate Actuator (After Operation)

Operation of the gate is moderately difficult for one person, but the gate does not stick. The gate operates relatively easily with two people. The depth to the gate from top of concrete pedestal is approximately 16 feet. Several submerged logs are encroaching on the gate opening and there is some risk of the gate being stuck open if logs/sticks were to migrate into the opening.

The submerged stem associated with gate is bent, but operable. One previous segment of stem that had been discarded was observed in debris pile nearby. The discarded stem was 1.5 inches in diameter.

The elevation variance between water surface at outlet (in channel) and lake water surface is 15.9 feet as measured by survey level and stadia rod, which represents maximum available drawdown. The horizontal distance from the gate to low-level outlet at the creek was measured at 55 feet.

Dam/Spillway

The dam/spillway is constructed of concrete (Photo 22 and Photo 23). A spillway opening in the center of the dam controls overflow from the lake. The lake level is controlled with stop logs installed in the spillway opening. During the site visit on July 30, 2014, there was continuous spill over and through spillway. Water seepage around both abutments was observed. IPID attempted to repair the dam in 2012 by patching holes in the dam foundation with concrete, but the repairs have not completely eliminated seepage. Woody debris including downed logs are present both upstream and downstream of dam.


Photo 22 - Colchuck Lake Dam, View from West Abutment


Photo 23 - Colchuck Lake Dam Spillway with Stop-Logs in Place

Photo 24 - Colchuck Lake Spillway

Operation

Colchuck Lake is another one of the four storage sites in the Alpine Lakes Wilderness managed by IPID. The operation of Colchuck Lake was reviewed with IPID manager during a reconnaissance visit to the site in July 2014. As noted previously, during a typical year, only one or two of the IPID-managed lakes is actively managed to increase late summer releases to the Icicle Creek Sub-basin. Colchuck Lake has historically been the first lake that IPID operates during a typical year, because it relatively close to Icicle Creek and is easier to access than the other lakes.

The configuration of the dam and infrastructure at Colchuck Lake is similar to Eightmile Lake. The gate, which is located at the inlet to a corrugated metal low-level outlet pipe, controls releases from the lake. To actively manage the storage in Colchuck Lake, IPID personnel hike approximately 4 miles (one-way) to the lake to open the gate on the discharge pipeline in July. IPID personnel return to close the gate in late September or October when the lake is drawn down and the irrigation season is over.

In the fall of 2012, IPID lowered the lake level at Colchuck Lake sufficiently to perform maintenance on the dam and the control gate. Concrete was added to repair the dam and plug holes in the foundation, which had been leaking. Debris and logs that had built-up on the upstream side of the dam were removed. Maintenance was performed on the control gate and a plank was installed to improve access to the gate.

When the gate is open, water discharges through the low-level outlet pipe to an unnamed creek, which flows to Mountaineer Creek, which is a tributary to Icicle Creek. Based on recent experience and observations from IPID personnel, the lake typically refills by the summer following the irrigation season when the lake is drawn down. When the lake is full, water flows over the dam spillway outlet to the unnamed creek. Water continues to flow through the lake uncontrolled until the gate is opened again.

Snow Lakes

Upper and Lower Snow Lakes

Overview

Upper and Lower Snow Lakes are situated within Sections 17, 18, and 19, T23N, R17E with a combined surface area of approximately 189.3 acres, maximum water surface elevation of 5,420 feet (Upper Snow Lake) and 5,415 feet (Lower Snow Lake), and a tributary basin area of 3,060 acres. The combined existing active storage capacity in these lakes is estimated at 12,900 acre-feet. Water released from Upper Snow Lake is conveyed through a tunnel to Nada Lake.

Infrastructure

A detailed description of infrastructure at Upper and Lower Snow lakes has been provided in past studies, including the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006) and the *Wenatchee River Basin Water Storage Report* (Anchor QEA, 2011).

Upper Snow Lake Dam

The Upper Snow Lake dam (Photo 25 and Photo 26) is a small masonry structure that appears to have been constructed out of cement and locally derived rock at the natural outlet of Upper Snow Lake. The *Upper and Lower Snow Dams Screening Level Risk Assessment* (Reclamation, 2010) indicates that the Upper Snow Lake dam has a maximum height of approximately 10 feet and a crest length of 119 feet. The crest elevation is 5,428 feet. The entire dam functions as an overflow spillway for Upper Snow Lake.

Photo 25 - Upper Snow Lake Dam and Spillway during Spill, Aerial View

Photo 26 - Upper Snow Lake Dam and Spillway

Upper Snow Lake Flap Gate

At the end of the summer when Upper Snow Lake has been drained, the water level is lower in Upper Snow Lake than in Lower Snow Lake and water flows from Lower Snow Lake to Upper Snow Lake through a small (approximately 9-square-foot) hole at the base of Upper Snow Lake Dam. A flapper gate on the opening in Upper Snow Lake Dam is designed to pass water only from Lower Snow Lake to Upper Snow Lake. However, the USFWS indicated that the gate leaks. In 2005, it was estimated that approximately 200 acre-feet of water passed through the opening.

Lower Snow Lake Dam

The Lower Snow Lake dam (Photo 26 and Photo 27) is a small masonry structure that appears to have been constructed out of cement and locally derived rock at the natural outlet of Lower Snow Lake where it discharges to Snow Creek. The *Upper and Lower Snow Dams Screening Level Risk Assessment* (Reclamation, 2010) indicates that the Lower Snow Lake Dam has a maximum height of approximately 6 feet and a crest length of 112 feet. The crest elevation is 5,423 feet. The dam consists of a 42-foot long overflow section with a 2-foot wing dike extending to right abutment.

Photo 27 - Lower Snow Lake Dam, View from Lower Snow Lake Side

Photo 28 - Lower Snow Lake Dam, View from Lower Snow Lake Side

Upper Snow Lake Tunnel and Release to Nada Lake

Water is released from Upper Snow Lake to Nada Lake through a tunnel (Photos 27 through 36). The tunnel captures water from Upper Snow Lake at a depth of approximately 150 feet and discharges to Nada Lake through a 36-inch penstock. Operation of flow through the penstock is controlled by 3 valves. The valve furthest upstream is a 30-inch gate valve, which is primarily used to cut off flow when not in use. The second valve, an 8-inch valve, provides a bypass around the gate valve in order to equalize pressure prior to operation of the valve. The third valve, a 20-inch butterfly valve, is located at the end of the penstock and is used for throttling to control releases from Upper Snow Lake to Nada Lake.

The actuator for the butterfly valve is situated in a corrugated metal shack above the valve adjacent to the tunnel entrance. USFWS monitors the flow rate discharged from

Upper Snow Lake to Nada Lake through use of a pressure transducer and data-logger in the tunnel.

Photo 29 - Upper Snow Lake Outlet Works - Butterfly Valve Actuator

Photo 30 - Upper Snow Lake Outlet Works - Butterfly Valve

Photo 31 - Upper Snow Lake Outlet Works - Gate Valve Actuator

Photo 32 - Upper Snow Lake Outlet Works - Gate Valve, View looking Towards Snow Lake


Photo 33 - Upper Snow Lake Outlet Works - Gate Valve Pressure Equalization Bleed-Bypass Valve


Photo 34 - Upper Snow Lake Outlet Works - 30" Diameter Pipe in Tunnel, View Looking Downstream

Photo 35 - Upper Snow Lake Outlet Works - Pressure Monitoring Equipment

Photo 36 - Upper Snow Lake Outlet Works – Discharging to Nada Lake

Operation

Upper and Lower Snow Lakes and Nada Lake are operated by the USFWS as part of their management of the LNFH. The operation of these facilities was reviewed in the following recent studies:

- The *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006).
- The *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011).

The lakes are operated jointly to increase late summer flows in Snow Creek, which is a tributary to Icicle Creek. The increased flows to Icicle Creek help supply the LNFH's operational requirements (approximately 40 cfs between June and October) and supplement flow in Icicle Creek.

Upper Snow Lake

Upper Snow Lake is actively managed by the USFWS. Water is released from Upper Snow Lake to Nada Lake through the tunnel and penstock. LNFH personnel hike to the shed above Nada Lake to open the valve in July each year. The valve remains open during the late summer months, typically between mid-July and mid-October. LNFH personnel may return to the lake to adjust the valve during that time to increase the rate of release. Operation and adjustment of the valve requires a hike of more than 6 miles into the site. According to the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006), the valve was open an average of 77 days each year between 1998 and 2005, with an average annual release of 3,700 acre-feet. LNFH personnel hike to the shed above Nada Lake to open the valve in July each year. The valve remains open during late summer months, typically between mid-July and mid-October. LNFH personnel may return to the lake to adjust the valve during that time to increase the rate of release. Operation and adjustment of the valve requires a hike into the site of more than 6 miles. According to the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006), the valve was open an average of 77 days each year between 1998 and 2005, with an average annual release of 3,700 acre-feet.

The USFWS currently operates Upper Snow Lake in accordance with the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster, 2006). The USFWS releases approximately 7,000 acre-feet from Upper Snow Lake to Nada Lake from late July to early October. Releases start around 30 cfs in late July and increase to 60 cfs as natural flows in Icicle Creek drop. After the valve on the outlet is closed in the fall, Upper Snow Lake refills. For six of the seven years (1998 to 2005, excluding 2000) that were evaluated in the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery*, Upper Snow Lake was full by the time the valve was opened the following summer. The only year when Upper Snow Lake did not fully refill was 2001, which was a drought year.

As noted previously, at the end of the summer when Upper Snow Lake has been drawn down, the water level in Upper Snow Lake is typically lower than the water level in Lower Snow Lake. Water flows from Lower Snow Lake to Upper Snow Lake through a small (approximately 9-square-foot) hole at the base of Upper Snow Lake Dam. In 2005, it was estimated that approximately 200 acre-feet of water passed through the opening.

Lower Snow Lake

Lower Snow Lake is not actively managed by USFWS. When Lower Snow Lake is full, water spills over the dam or discharges to Snow Creek through a breach that was identified on the east side of the dam during the 2008 *Safety Evaluation of Existing Dams (SEED) Inspection* (WW Wheeler and Associates, 2009a). Water was observed in the channel downstream of dam during a site visit on September 25, 2009. During that site visit, the water level behind the dam was 2 to 3 feet lower than the crest of the dam, which indicates that water still flows from the lake through a breach or through leaks in the dam, even when the water level is below the crest of the dam.

Hydrologic Monitoring

The USFWS monitors flows at four sites within the Snow Creek Sub-basin. Flows are monitored on Snow Creek at the inflow to Upper Snow Lake, at the penstock that discharges from Upper Snow Lake to Nada Lake, at flume at the outlet of Nada Lake, and at the confluence with Icicle Creek. The USFWS has actively monitored these sites since 2004 using data loggers to collect data over extended periods of time. This data helps the USFWS manage releases from the lakes.

Nada Lake

Overview

Nada Lake is situated within Section 17B/G, T23N, R17E with a surface area of approximately 8.8 acres, maximum water surface elevation of 4,989 feet and a tributary basin area of 981 acres. The existing active storage capacity is estimated at 150 acre-feet.

Infrastructure

Dam

A dam reconstruction project was completed at Nada Dam, downstream of Upper and Lower Snow Lakes, in 2009. The new dam structure and challenges related to its construction were described in *Nada Dam: Reconstructing a Concrete Dam in the Wilderness* (WW Wheeler Associates, 2009b).

The new dam at the outlet from Nada Lake is not currently being used to control the water level in the lake. The dam is a concrete structure, as shown in Photo 37 and Photo 38. Two vacant bays are available for stop-logs or future slide gates. No controls were in place during the site visit in July 2014. A Parshall flume was recently constructed below the dam for flow measurement and monitoring (Photo 39 and Photo 40). Flow depth is recorded by battery powered monitoring equipment in a stilling well adjacent to the flume (Photo 41). A solar panel is used for recharging the batteries of the monitoring equipment (Photo 42).


Photo 37 - Nada Lake Dam (Recently Reconstructed by USFW)

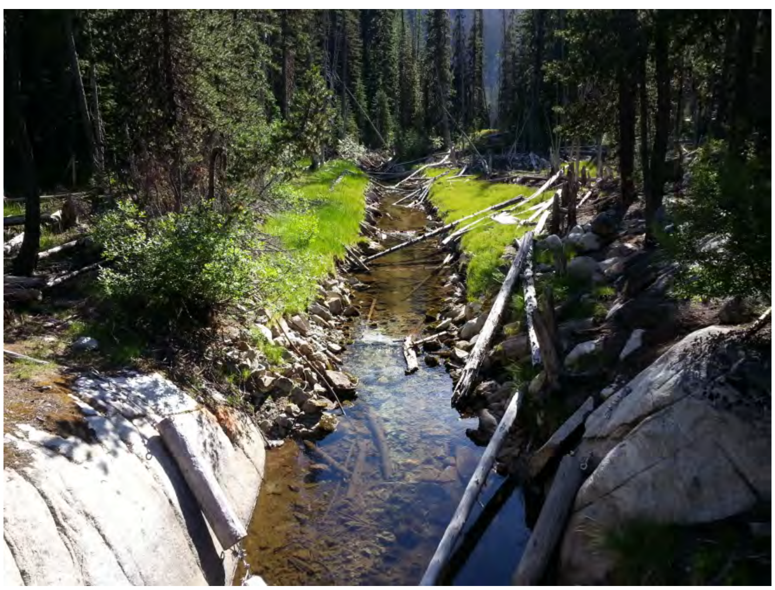
Photo 38 - Nada Lake - View Upstream from Dam toward Nada Lake

Photo 39 - Nada Lake Parshall Flume, View from South Looking North (Flow Left-Right)

Photo 40 - Nada Lake Parshall Flume Stilling Well / Monitoring Equipment Housing (View of South Side from Upstream / North Side)

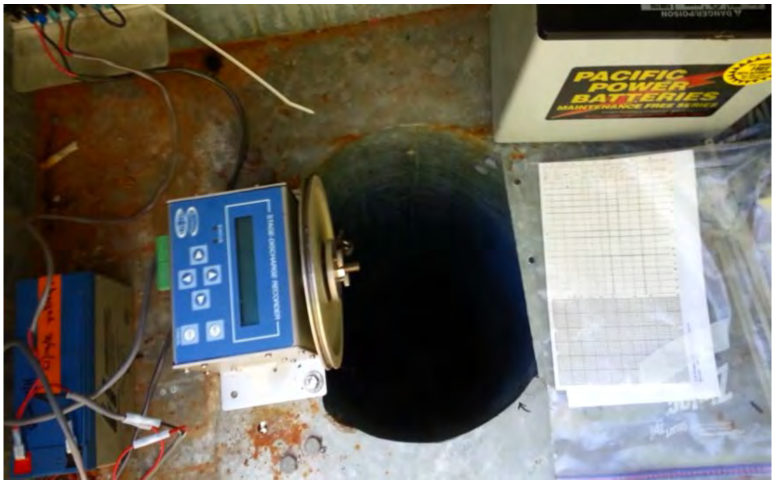

Photo 41 - Nada Lake Parshall Flume Stilling Well and Monitoring Equipment


Photo 42 - Nada Lake Solar Panel Installation for Monitoring Equipment

Operation

As noted previously, Upper and Lower Snow Lakes and Nada Lake are operated jointly to increase late summer flows in Snow Creek, which is a tributary to Icicle Creek. The increased flows to Icicle Creek help supply the LNFH’s operational requirements (approximately 40 cfs between June and October) and supplement flow in Icicle Creek.

The reinforced concrete dam structure at the outlet of Nada Lake was repaired and refurbished in 2009. The USFWS has the ability to raise the water level in Nada Lake by placing stop logs in the structure. During a reconnaissance site visit in July 2014, no stop logs were placed in the structure to control the lake level. During a typical year, the USFWS does not control flow or lake levels at the outlet from Nada Lake.

2.4 Available Water Supply and Lake Refill

Available water supply was estimated for each of the Alpine Lakes using lake drainage basin areas, average monthly precipitation rates, data from nearby Snow Telemetry (SNOTEL) stations operated by the U.S. Natural Resource Conservation Service (NRCS), and data from nearby evaporation stations.

The following describes the methodology used to estimate the water supply available from the drainage basins tributary to each of the Alpine Lakes:

- The drainage basin for each of the Alpine Lakes was delineated using geographic information system (GIS) software and digital elevation model (DEM) data from the U.S. Geologic Survey (USGS). Basin boundaries and the resulting drainage areas are shown in Figures 3 through 7.
- The approximate water surface elevation of each lake was determined using GIS and data from USGS topography maps.
- Daily precipitation and snow-water equivalent data were downloaded from seven SNOTEL stations near the Alpine Lakes. The monthly runoff, in inches, was estimated at each SNOTEL station based on daily precipitation and snow-water equivalent data.
- The average monthly precipitation in each of the Alpine Lakes drainage basins was estimated in GIS from the 1981 to 2010 average precipitation dataset from the Oregon State University PRISM Climate Group.
- The locations, elevations, and precipitation data from Water Years 1985 to 2013 of the SNOTEL sites was compared with the locations, elevations, and estimated precipitation for the Alpine Lakes drainage basins. Based on the comparison, the Stevens Pass SNOTEL site was identified as the most appropriate site for determining runoff for the Alpine Lakes.
- A precipitation ratio was developed for each of the Alpine Lakes that represents the ratio of the average annual precipitation in each lake’s drainage basin, as estimated from the PRISM precipitation data. PRISM data was checked against the average annual precipitation at the Stevens Pass SNOTEL site to confirm that the average annual precipitation for both datasets was comparable.
- Monthly runoff, in inches, was estimated for each of the Alpine Lakes drainage basins, by multiplying the estimated runoff at the Stevens Pass SNOTEL site by the precipitation ratio developed for each lake for Water Years 1985 to 2013.
- The total monthly runoff volume, in acre-feet, was estimated for each lake by multiplying the estimated runoff, in inches, by the area of the lake’s drainage basin for Water Years 1985 to 2013.
- Evaporation was estimated for each of the Alpine Lakes using estimated evaporation from nearby stations. The two stations closest to the Alpine Lakes are Wenatchee and Bumping Lake. It was determined that the Bumping Lake evaporation station would be more appropriate for determining evaporation for

the Alpine Lakes because the elevations are similar. Monthly evaporation rates were determined by multiplying the monthly pan evaporation rate for Bumping Lake by 75% to convert pan evaporation to lake evaporation. The lake evaporation was then multiplied by the lake area to get an estimated monthly evaporation volume for each Alpine Lake for Water Years 1985 to 2013.

- Available water supply was estimated for each of the Alpine Lakes by subtracting the monthly evaporation volume from the monthly runoff volume.

Statistics of available annual water supply, or net annual inflow, were developed for each of the Alpine Lakes, including

- 10% Exceedance – Represents the annual inflow during a 1 in 10-year wet cycle.
- 50% Exceedance – Represents the median annual inflow.
- 90% Exceedance – Represents the annual inflow during a 1 in 10-year drought
- Minimum – Represents the inflow projected based on 2001 precipitation, which was the most significant drought year during the period of record that was used for this analysis.

These values are summarized in Table 2.

Table 2 – Alpine Lakes Annual Water Supply Statistics

Lake	Lake Water Surface Elevation (feet)	Drainage Area (acres)	10% Exceedance Annual Inflow (acre-feet)	50% Exceedance Annual Inflow (acre-feet)	90% Exceedance Annual Inflow (acre-feet)	Estimated Annual Inflow – Minimum (acre-feet)
Upper and Lower Snow	5,420/ 5,415	3,060	12,610	9,478	7,254	5,663
Nada	4,989	981	3,310	2,497	1,920	1,507
Square	4,989	1,010	8,158	6,148	4,722	3,701
Klonaqua	5,090	800	5,093	3,808	2,895	2,243
Eightmile	4,671	3,804	18,713	14,141	10,896	8,575
Colchuck	5,570	941	4,883	3,665	2,800	2,182

To check the accuracy of this method for estimating available water supply, estimates of runoff at the inflow to Upper Snow Lake provided by the USFWS in the *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* for Water Years 1994 to 2005 were compared to runoff from the Upper Snow Lake drainage basin estimated above. The estimates provided by the USFWS are for the 2,515-acre basin tributary to Upper Snow Lake. The runoff estimated above is for the combined drainage basin for both the Upper and Lower Snow Lakes, which is 3,060 acres. To compare the runoff to Upper Snow Lakes, the estimated runoff was scaled to the size of the Upper Snow Lakes drainage basin. Table 3 presents a comparison between the analyses of estimated inflow to Upper Snow Lake.

Table 3 – Upper Snow Lake Inflow Comparison

Water Year	Inflow to Upper Snow Lake – Estimated by USFWS (acre-feet)	Inflow to Upper Snow Lake – Estimated by this Analysis (acre-feet)	Difference (%)
1994	5,600	5,469	-2.3%
1995	8,900	8,150	-8.4%
1996	13,000	10,365	-20.3%
1997	11,600	12,073	4.1%
1998	8,200	7,323	-10.7%
1999	10,900	10,672	-2.1%
2000	8,600	7,910	-8.0%
2001	4,400	4,655	5.8%
2002	9,900	9,725	-1.8%
2003	6,400	5,962	-6.8%
2004	8,300	7,803	-6.0%
2005	6,900	6,122	-11.3%
Average	**8,558**	**8,019**	**-6.3%**

As shown in Table 3, the analysis completed for this report slightly underestimated the annual volume of inflow for most of the years from 1994 to 2005. This indicates that the estimated inflows shown in Table 2 are likely a somewhat conservative estimate of water availability.

Climate Change Evaluation

An analysis of potential climate change impacts on inflows was also completed to estimate impacts of potential climate change scenarios on future water supply availability. For this analysis, three climate change scenarios were considered; a less adverse future condition, a moderate future condition, and a more adverse future condition. The climate change scenarios are based on modeling that forecasts climate conditions to 2040, as used by Reclamation and Ecology as part of the *Yakima River Basin Study* (Reclamation and Ecology, 2011). The work completed for that study projected the impact of these climate change scenarios on flow rates in various Yakima Basin tributaries. Because of proximity and similarities in climate and elevation within the watershed, climate change projections for flows in the Cle Elum River at the inflow to Lake Cle Elum were selected as a basis for estimating climate change impacts on the available water supply in the Alpine Lakes drainage basins. The predicted change in inflows to Lake Cle Elum for each of the three climate change scenarios was applied, as a percentage change, to monthly runoff values for each of the Alpine Lakes.

Assumptions and conclusions for the three levels of climate change are as follows:

Climate Change Projection: CGCM B1 Model (Less Adverse)

Under this climate projection, recharge and baseline flows in the Alpine Lakes Basin are expected to be approximately 1.4% higher annually than historically, with considerably higher flows in the winter months, and slightly reduced summer flow. This distribution is expected to have a minimal impact on lake operations, as it further increases the lake input during the period of typical refilling. This projection forecasts that Icicle Creek flows will drop in the summer months, though the average 50% exceedance flows will still exceed 100 cfs at USGS Station 12458000 for the month of September. The current average 50% exceedance flow at that gage for the month of September is 130 cfs.

Climate Change Projection: HADCM B1 Model (Moderate)

Under this climate projection, annual recharge and baseline flows in the Alpine Lakes Basin are expected to be approximately 11% lower than historically, with most significant deviations from historical flow in the late summer. This shift in flows is expected to have minimal impact to lake operations, but significantly increases the need for lake releases during the low flow period. This projection forecasts that Icicle Creek flows will drop considerably in the summer months, with the average 50% exceedance flows expected to drop to just over 50 cfs at USGS Station 12458000 for the month of September.

Climate Change Projection: HADGEM A1B Model (More Adverse)

Under this climate projection, annual recharge and baseline flows in the Alpine Lakes Basin are expected to be approximately 23% lower that historically, with most significant deviations from historical flow in the late summer. The shift in flows is expected to slightly impact lake operations, and increase the need for both additional release flows and careful management of release timing to offset the impact of climate change. This projection forecasts that Icicle Creek flows will drop significantly in the summer months, with the average 50% exceedance flows expected to drop to just over 50 cfs at USGS Station 12458000 for the months of August and September.

Table 4 presents the median (50% exceedance) annual inflow predicted based on the climate change scenarios for each of the Alpine Lakes.

Table 4 – Alpine Lakes Climate Change Scenarios Water Supply Availability

Lake	Existing Annual Inflow (acre-feet)	Less Adverse Future Annual Inflow (acre-feet)	Moderate Future Annual Inflow (acre-feet)	More Adverse Future Annual Inflow (acre-feet)
Upper and Lower Snow	9,478	9,610	8,426	7,283
Nada	2,497	2,531	2,224	1,928
Square	6,148	6,233	5,474	4,741
Klonaqua	3,808	3,862	3,376	2,907
Eightmile	14,141	14,335	12,606	10,939
Colchuck	3,665	3,716	3,256	2,812

The change in median annual inflows resulting from the climate change scenarios range from an increase of 1.4%, for the Less Adverse scenario, to a decrease of 23%, for the More Adverse scenario. Although there would be a slight increase in annual inflow for the less adverse climate change projection, monthly inflows would change such that there would be more inflow in winter months and less inflow in summer months. See Figure 8 for a hydrograph comparing monthly inflows between different climate projections.

Table 5 provides a comparison of the annual water right withdrawal volume and the annual inflow estimated for each lake based on historical precipitation data and various climate change scenarios. The available usable storage for each of the lakes is also listed. The estimates indicate the following:

- At Upper and Lower Snow Lakes, the annual water right and usable storage capacity will exceed the estimated annual lake recharge during all but the wettest years.
- At Square Lake, Klonaqua Lakes, Eightmile Lake, and Colchuck Lake, annual lake recharge is estimated to exceed the existing usable storage capacity, even under drought conditions.
- At Square Lake and Eightmile Lake, annual lake recharge is estimated to exceed the annual water right, even under drought conditions.
- At Klonaqua Lakes and Colchuck Lake, annual lake recharge is estimated to exceed the annual water right under most conditions, except in the most extreme drought conditions.

Table 5 – Comparison of Water Right, Inflow Estimates, and Usable Storage Capacity

Lake	Annual Water Right Withdrawal Amount (acre-feet)	10% Exceedance Annual Inflow (acre-feet)	50% Exceedance Annual Inflow (acre-feet)	90% Exceedance Annual Inflow (acre-feet)	Estimated Annual Inflow – Minimum (acre-feet)	50% Exceedance Less Adverse Future Annual Inflow (acre-feet)	50% Exceedance Moderate Future Annual Inflow (acre-feet)	50% Exceedance More Adverse Future Annual Inflow (acre-feet)	Usable Storage Capacity (acre-feet)	Source of Usable Storage Capacity Estimate
Upper and Lower Snow	12,000 (Reclamation) 750 (IPID)	12,610	9,478	7,254	5,663	9,610	8,426	7,283	12,600	Ecology Dam Safety File No. CH 45-0643[1]
Upper Snow Only									12,450	USFWS[2]
Nada	N/A	3,310	2,497	1,920	1,507	2,531	2,224	1,928	150	Ecology Dam Safety File No. CH 45-0664[1]
Square	2,000 (IPID)	8,158	6,148	4,722	3,701	6,233	5,474	4,741	2,400	IPID Estimate[3]
Klonaqua	2,500 (IPID)	5,093	3,808	2,895	2,243	3,862	3,376	2,907	1,920	Ecology Dam Safety File No. CH 45-0225[1]
Eightmile	2,500 (IPID)	18,713	14,141	10.896	8,575	14,335	12,606	10,939	1,375	Forsgren report[4]
									1,610	Ecology Dam Safety File No. CH 45-0228[1]
Colchuck	2,500 (IPID)	4,883	3,665	2,800	2,182	3,716	3,256	2,812	1,570	Ecology Dam Safety File No. CH 45-0227, CH 45-0226[1]

Notes:

1. Source of Usable Storage Capacity Data: Spreadsheet calculations of estimated stage-storage relationships for Alpine Lakes attached to email communication from Martin Walther, Ecology Dam Safety Office.
2. Source of Usable Storage Capacity Data: Data summarized in *Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery* (Wurster 2006).
3. Source of Usable Storage Capacity Data: Estimate based on review of dam construction and field inspection by IPID.

   Source of Usable Storage Capacity Data: Data from *Draft Icicle Irrigation District Instream Flow Improvement Options Analysis Study* (Forsgren, 2014).

3 Potential Alternatives for Storage Optimization

3.1 Optimization Analysis

Modeling Overview

An optimization model was developed to evaluate the effects of different lake operation scenarios on the amount of water released and probability of refilling each year. To allow for evaluation of a range of potential climate conditions, the model uses both historical and simulated future conditions. The period of historical conditions is water years 1985 to 2013. The climate change-impacted conditions include three described in Section 2.4.1.

The model was developed as an Excel spreadsheet simulating the water balance of each lake on a monthly time step. Each lake has been simulated individually in the model, taking into account its particular natural setting, physical construction, and potential use. The water balance is based on calculating change in storage in a given lake as the net of inflows to the lake and outflows, such as releases from the lake, leakage, and evapotranspiration. Every timestep includes a calculation of initial storage plus the net effect of lake inputs and outputs. The following approaches were used for estimating the individual inputs and outputs from each lake:

- For inputs, basin recharge is calculated on a monthly basis, as described in Section 2.4.
- For outputs:
  - Modeled releases in each scenario occur over a 92-day period (August, September, October), coinciding with the period of lowest flow in Icicle Creek only if water is available in the lake. Release rates are determined by the scenario parameters.
  - Evapotranspiration (ET) is calculated from pan ET results from Bumping Lake and the surface area of the lake. Each lake has a storage/area curve that is used to estimate surface area based on the volume stored in the lake.
  - Leakage/losses are built into the model, but not estimated at this time due to their temporal nature and difficulty in providing a reasonable estimate.
  - Overflow is calculated whenever lake inputs exceed active storage in the lake.

The optimization model was used to look at three specific scenarios that represent the range of potential lake use, described in the following section.

Storage and Release Scenarios Considered

Three storage and release scenarios were developed as a range of potential operational strategies for the Alpine Lakes. Scenarios and results are based on releases during

August, September, and October, which are the lowest flow periods within the Icicle Creek historical record. Longer and shorter periods of releases were considered during scenario development, but simulations indicated they had little effect on the reliability of lake refill because the most refill occurs outside low flow periods. Actual release cycles have and will vary in length from year to year in both the IPID- and USFWS-controlled lakes; however, the length of the release cycle is not expected to have an effect on refill reliability.

The three scenarios evaluated are:

- **Scenario A (Baseline):** This is a baseline scenario incorporating historical operational practices for all lakes. Square, Klonaqua, Eightmile, and Colchuck Lakes have historically been operated on a rotating basis with usable storage release from one lake per year. This has been modeled assuming full drawdown of active storage at each lake on its scheduled year. Releases from the Snow Lakes are based on the average historical records. Nada Lake is assumed to not have been used, given its relatively low storage capacity.

- **Scenario B (Maximize existing infrastructure through implementing Alternatives 1a and 1b):** This scenario represents optimization based upon current physical constraints of the lakes. It assumes that all lakes are used to maximize existing storage and recharge. Square, Klonaqua, Eightmile, Colchuck, and Nada Lakes are all used to their maximum storage capacity. Snow Lakes are used to approximately half of the available capacity to ensure reliable refill. This scenario reflects the conditions that would be achieved through implementation of Alternative 1a or Alternative1b.

- **Scenario C (Maximize water rights):** This scenario reflects conditions that are beyond the reach of the improvement alternatives considered in this report, but was evaluated to understand what flows would be available if infrastructure was in place to maximize the use of existing water rights during any given year. This scenario considers maximizing existing water rights coupled with storage and/or operational improvements. It assumes that lakes can be used to the full extent of the water rights. Siphoning, pumping, or other operational changes would be required to utilize the stored water beyond the currently usable active storage in Square, Klonaqua, Eightmile, and Colchuck Lakes to see higher utilization. Nada Lake is assumed to be already maximizing its potential storage. Snow Lakes are assumed to increase utilization but to remain below the water right threshold to maintain refill reliability.

Storage and Release Scenario Results-No Climate Change

Results of the modeling of the three storage and release scenarios (described in Section 3.1.2 above) in the ‘No Climate Change’ projection are discussed below and presented on Figure 9.

- **Scenario A (Baseline):** Historical operations are estimated to have released approximately 8,200 acre-feet per year on average during the summer months. This includes the operation of Square, Klonaqua, Eightmile, and Colchuck Lakes, each on a staggered four-year release cycle. Snow Lakes have historically been utilized to release approximately 4,500 acre-feet per year. Nada Lake is not believed to have been used for historical storage and releases. Releases in the baseline scenario have been modeled to have 100% refill reliability in the western lakes (Square, Klonaqua, Eightmile, and Colchuck), and 97% chance to refill at Snow Lakes. The modeled historical benefits have averaged approximately 42 cfs for a 92-day period.

- **Scenario B (Maximize existing infrastructure through implementing Alternatives 1a and 1b):** Maximizing current physical infrastructure provides approximately 5,500 additional acre-feet of water that could be released into Icicle Creek, 67% more than the baseline scenario. The western lakes (Square, Klonaqua, Eightmile, and Colchuck) were utilized to their full capacity each year, as opposed to a staggered schedule. Sufficient recharge exists to ensure 100% refill reliability in the lakes, even when utilizing the full amount of available storage. Snow Lakes can increase their utilization by 37% (from 4,500 af up to 6,200 af) with a modest reduction in refill reliability - from 97% under the baseline down to 93%. This scenario benefits streamflow by providing for additional release of approximately 30 cfs for a 92-day period above the baseline scenario. Upper and Lower Snow Lakes still have additional active storage (over 6,000 acre-feet) that is not utilized due to the limited recharge available to those lakes.
- **Scenario C (Maximize water rights):** Maximizing storage and release to the extent allowed by existing water rights would result in approximately 4,300 acre-feet of additional water that could be released into the Icicle Creek, a 31% increase relative to Scenario #2. This additional water is the result of releases from the western lakes (Square, Klonaqua, Eightmile, and Colchuck) where recharge exceeds water rights. In this scenario, only extreme drought conditions cause Colchuck and Klonaqua Lakes to not refill completely. Annual recharge at Snow Lakes is insufficient to allow for maximizing its water rights, but 1,800 acre feet of additional water could be released (from 6,200 acre-feet up to 8,000 acre-feet) at the expense of refill reliability. Additional storage is still available for release, but further reduces the chances of refill if used on an annual basis. This scenario (if implementable) would provide an additional release of approximately 23 cfs for a 92-day period above Scenario #2.

Storage and Release Scenario Results-With Climate Change

The future climate change projections were evaluated for their effect on the three storage and release scenarios described in Section 3.1.2. The projections used are based on estimates in 2040 from the CGCM B1 Model (Less Adverse), HADCM B1 Model (Moderate), and HADGEM A1B Model (More Adverse). These three climate change projections were selected from a larger set of projections to provide a likely range of future climate scenarios. Each climate model provides a projected difference from historic recharge and baseline flows on a monthly timestep. Climate projection results are discussed below and presented on Figures 10 through 12.

Climate Change Projection: CGCM B1 Model (Less Adverse)

In this projection, there’s a slight increase in annual recharge to the lakes, with a greater portion occurring in the winter and spring, and less occurring during the summer months.

The chance to refill the lakes is nearly 100% in all three operational scenarios, and this slightly improves that refill chance. Detailed results are presented in Figure 10.

Climate Change Projection: HADCM B1 Model (Moderate)

The moderate climate projection reduces annual recharge, with a smaller increase in winter and spring inflows, and greater reduction in summer flows. Lake recharge is largely maintained, but summer baseflow in Icicle Creek is diminished, increasing the need for lake releases. Detailed results are presented in Figure 11.

Climate Change Projection: HADGEM A1B Model (More Adverse)

The more adverse climate projection results in an annual reduction of recharge by over 20%, as winter and spring flows are increased and summer flows are greatly reduced. Lake recharge is still largely maintained due to increased spring inflows, but the summer baseflow in Icicle Creek is significantly diminished. Detailed results are presented in Figure 12.

3.2 Infrastructure Improvement Options

There are four main categories of infrastructure improvements that may be considered for optimization of storage release from the lakes. They include monitoring improvements, outlet works automation improvements, storage improvements, and remote communication improvements.

Monitoring improvements include installation of equipment for monitoring lake level (stage) and lake discharge (release). These types of improvements will allow for better understanding of the storage quantities available in the lake and the amount of flow being released at any given time.

Outlet works improvements include upgrades to existing gate and valve actuators to allow for remote operation from a centralized location using telemetry/SCADA. This would allow for more cost effective operation and better timing of release.

Storage improvements involve physical improvements to storage infrastructure to increase physical storage capacity.

Monitoring Improvement Options

There are several options for monitoring of both stage and release. With respect to stage, two of the most feasible options would be to install either a pressure transducer system or a bubble water level sensor. Either of these systems could be solar-rechargeable battery powered with remote-reading capability through radio telemetry.

There are at least four options for discharge measurement and monitoring at the various Alpine Lakes.

1. **Lake Stage and Gate Limit Monitoring.** This method requires a correlation between stage, degree of openness of outlet gate, and flow rate. This option would require monitoring of both stage and limit states of outlet works gates in order to determine flow rate through calculations. Presently, the release from Upper Snow Lake to Nada Lake is monitored using this method.
2. **Flume.** This method requires the construction of an in-channel fixed hydraulic structure, such as a Parshall flume, that allows the conversion of depth of flow

through the flume to flow rate. Presently, the release from Nada Lake is monitored using this method.

3. **Fixed Weir.** This method also requires the construction of an in-channel fixed hydraulic structure that allows for the conversion of depth of flow over the weir to flow rate. Presently, flow into Upper Snow Lake is monitored using this method.
4. **Stream Gaging / Rating Curve.** This method requires the identification of relatively fixed control geometry in a discharge channel, which is unlikely to change in the near future, and correlation of various depth of flows in that channel to flow rate by building a rating curve.

Outlet Works Automation Improvement Options

Currently, the outlet works at Square, Klonaqua, Eightmile and Colchuck Lakes are similar to one another and include rising stem positive seating slide gates. In contrast, release from Nada Lake is presently not mechanically controlled, and release from Lower Snow Lake is only partially controlled. The outlet works of Upper Snow Lake is the most complicated, involving three valves to operate; two of which are for seasonal startup/shut down of the system and one of which that is periodically modulated for flow control.

While the exact details of each site may vary, the main components required to provide remote automation are similar for each site and they include: 1) control mechanism, 2) motorized actuator, 3) programmable datalogger / controller, 4) communications (radio), 5) power supply, and 6) structural protection.

Control Mechanism

In the cases of Square, Klonaqua, Colchuck and Eightmile Lakes, the operational mechanisms are similar to one another (rising stem slide gates). While the stems themselves vary in diameter and condition, the mechanisms are the same in that in order to operate, the stem is raised and the gate is opened. Despite the age of the gates, they are in reasonable operating condition and replacement of the gates themselves may not be warranted in order to facilitate automation. A likely required modification to the gates includes replacement of the uppermost segments of stem with new stems fitted with modern thread pattern that would be compatible with motorized multi-turn actuators.

There is presently no control mechanism installed at Nada Lake; however, recent modifications made by USFWS could allow for new slide gates to be installed in the available bays that were cast into the outlet control structure upstream of the Parshall flume. Currently, any lake level control in Nada Lake requires manual installation of stop logs into the bays of the control structure.

Control of releases from Lower Snow Lake would require reconstruction of the Lower Snow Lake Dam to include a new controlled outlet works which would release water directly to Snow Creek.

The control mechanism associated with the Upper Snow Lake is a modern butterfly valve fitted with a multi-turn actuator. This mechanism could be easily modified to accept a motorized actuator.

Motorized Actuator

In order to automate the control mechanisms, motorized actuators compatible with direct current power supply would be required. Options include custom actuator construction or commercially available models. Custom options have been successfully implemented by Reclamation on their projects; however, at least three manufacturers now produce DC motorized actors including AUMA, Rotork and Limitorque. Custom-built installations involve the use of 12- or 24-volt direct current (DC) motors, with gear boxes, limit sensors/controls, and an enclosure. The advantage to a custom-built model is that this method may be more compatible with existing actuators and therefore may be easier to install in some cases. Other advantages include potentially easier serviceability in the field due to recognizable, readily available parts.

Commercially available options include motor, limit sensors/controls, gear reduction, and enclosure and are available in many torque ranges from as little as 20 ft-lb to over 700 ft-lb. Advantages to this option include simplicity, reliability and packaged system. Most of the commercially available motorized actuators are available with optional hand wheels for manual override operation of valves if needed.

Programmable Datalogger / Controller

The interface between the remote communication and the motorized actuator is the data-logger/controller, which translates signals received from the radio signal/modem to control signals for the actuator operation. The controller would preferably be non-volatile memory, meaning that data and programming would not be lost in the event of power failure. Many commercially available datalogger/controllers would be suitable in this application. One that has been successfully implemented by Reclamation for similar installations is the Campbell Scientific CR10X.

Communications

Assuming radio is the preferred wireless communication means; the necessary equipment consists of: 1) radio modem, 2) radio transceiver, and 3) directional radio antenna. This equipment would allow for communication of a signal from the nearby repeater station using VHF signal to the programmable datalogger/controller. See the "Radio Path Analysis" discussion in Section 3.2.4 for additional discussion on radio signal.

Power Supply

Due to remote location, power supply must be direct current (DC)/battery-operated, and it is assumed that batteries would be rechargeable with a permanently installed solar panel array. Similar installations have been successfully implemented at Alpine Lakes locations (e.g., Nada, Snow Lakes)wherein batteries are rechargeable with solar power. The following conservative assumptions were considered in evaluating power supply feasibility:

Stem Configuration	4 threads per inch / 1/4" stem rise per revolution
Stem Rise Required	4” (16 revolutions)
Operation Frequency	1 Per Day
Actuator Type	Auma SAR 14.5 Multi Turn, 24 V DC
	500 Nm (368 ft-lb), 4 rpm, 370 W motor
Battery	(2) 12 V, 100 ah connected in series (24 V)
Solar Panel	40 Watt, 12 V
Solar Exposure	4 Hours / Day

Under these assumptions, the actuator would run for 4 minutes per day at 370 Watts/24 V DC, therefore consuming approximately 1 amp-hour per day. In comparison, assuming 4 hours per day of direct sunlight, a 40 Watt Solar Panel (approx. 21-inch W x 26-inch L) could produce over 10 amp-hours to replenish batteries. In the most likely scenario, the gates would not operate every day—and it is quite possibly that there may be several days without 4 hours of direct sunlight; however, this analysis shows that with fairly reasonable assumptions solar supply is likely not a limiting factor.

Increasing Storage Options

There are two options for increasing available storage in the lakes. Those include: 1) increasing maximum water surface by raising the height of the existing dam, and 2) increasing maximum drawdown.

The concept of increasing storage in the lakes through raising existing dams/spillways has been explored in the cases of Upper and Lower Snow Lakes and Eightmile Lake. These types of improvements would involve replacing existing dams with new dam structures and increasing the overflow elevation to allow for additional storage.

Increasing drawdown in the lakes could be accomplished through a variety of means including siphoning, pumping, or reconstruction of outlets.

Siphoning involves the use of a pipe for hydraulic conveyance over an intermediate high point by gravity using differential pressure between a reservoir surface and an outlet. While it may be possible to implement a siphon to achieve some additional drawdown potential, the maximum siphon lift at the high lake elevations would likely be limited to a maximum of 20 to 25 feet because of atmospheric pressure and head losses through the siphon. However, it may be possible to slip-line or otherwise reconfigure the outlets of the lakes to include a siphon. A siphon may require pumping to prime the siphon when it is first used to release water during the season.

Pumping would require either the installation of a permanent fixed pump station or the use of portable submersible pumps. In either scenario, power supply would be required most likely consisting of gasoline- or diesel-powered portable generators (10 cfs pumping capacity, with 30 foot lift could require approximately 50 horsepower motor capacity). To power such pump(s), a minimum of a 40 kW generator would be required – which has an estimated diesel fuel consumption of 100 gallons per day.

Reconstruction of outlets could require major construction and/or tunneling, but may be possible to tap lower elevations of various lakes. Options include complete reconstruction of outlets in place or open cut/tunneling of new outlet works.

Remote Communication Options

Overview (Approach/Options Considered)

Remote communication was evaluated at each lake as a component in the optimization of release waters from the Alpine Lakes. The ability to remotely communicate allows fine tuning of releases, as well as monitoring of conditions at the lakes without time-consuming trips to inspect the lakes in person. Each lake has a unique combination of communication challenges and potential for automation.

The two primary technologies that were considered and field tested were cellular and radio wave communication. Cellular communication, where available, affords the most direct transmission of data over a cellular carrier's IP network directly to an on-site, or cloud-based server. Cell modems are an increasingly common option where coverage is available. Radio wave communication allows the use of intermediate repeater stations to accommodate greater ranges in areas where no other method of communication is available.

The Alpine Lakes are separated into lakes operated by IPID (Square, Klonaqua, Eightmile, and Colchuck), and LNFH (Upper/Lower Snow, and Nada). Due to the physical setting of the lakes, each would be serviced by a repeater station that could deliver a signal to the operating entities' facility or receiving tower. IPID has a radio communications site on Blag Mountain, reachable from the Icicle Ridge repeater. LNFH facilities are not in direct line of sight, but assumed to be close enough for communications with the proposed Wedge Mountain repeater.

Radio Path Analysis

Prior to field inspection at the lakes, a radio path analysis was performed in GIS to estimate potential line-of-sight from likely repeater locations in the Alpine Lakes Basin. Each lake was assigned an estimated radio installation site and paired to a proposed repeater site at either the Icicle Ridge, or Wedge Mountain. The proposed Wedge Mountain location was selected near the ridgeline on a private parcel owned by Mr. Rob Johnson.

Land surface elevation models (bare earth) were combined with DNR land cover data to develop a viewshed model of the Alpine Lakes Basin. Lake and repeater site locations were assumed to have a 30-foot antenna, and forested land cover was estimated to have 30-foot tree height. Results showed good potential for communication at Eightmile and Colchuck Lake from the Icicle Ridge repeater, and the Snow Lake control above Nada from the Wedge Mountain repeater. Square, Klonaqua, and the Upper and Lower Snow Lakes were all estimated to have no line-of-sight from their associated repeater locations, and significant mountains or ridgelines that separated them from their paired repeater site.

Radio/Repeater Stations Testing Methodology/Limitations

Radio path testing was performed in the field with handheld VHF radios with the assistance of the Wenatchee District USFS dispatch. Through coordination with the

USFS, Aspect was able to utilize the existing radio repeater station and USFS radio channels to verify signal at each lake. An audio call to the Wenatchee Dispatch was used to establish both a pass/fail and qualitative assessment of signal strength. Additional on-site checks were performed by attempting to bounce a signal off of the Icicle Repeater.

Cellular phones on both Verizon's and AT&T's networks were checked for signal strength at each lake. No signal was available at any of the lake sites during the field visit; however, the IPID manager has gotten cell phone reception in close proximity to Eightmile Lake.

Radio Siting/Potential Issues

Results of the radio survey are discussed below, in the order that the sites were visited in. A summary of the modeled results and field survey results are presented on Figure 13.

Icicle Repeater Station: The repeater is situated just outside of the Alpine Lakes Wilderness Area along the Icicle Ridge. A second radio repeater station could be established nearby to the existing station.

Square Lake: The signal from the landing pad at Square lake was 'scratchy, but readable' by Wenatchee Dispatch. The control structure for the lake is in a heavily wooded area away from the lake's edge, and attempts to bounce a signal off the repeater from that location were unsuccessful. Successful communication at Square Lake may require on-site communication relays or wiring, in combination with an elevated antenna mounting location. Signal quality may be an issue for communications at Square Lake, though this may potentially be mitigated by antenna placement.

Klonaqua Lakes: The signal from the control structure was considered 'good' by Wenatchee Dispatch. There appear to be no on-site issues with being able to install communication equipment in proximity to the control structure. It is not expected that there would be issues with signal quality at this lake.

Eightmile Lake: Due to high traffic at this lake, an aerial-only inspection was made. Modeled results suggest that Eightmile Lake likely has the best signal path for radio communications, and should not be an issue. The IPID manager has reported that Verizon cellular service is available near Eightmile Lake, which is the only lake believed to have cellular service as an option for telemetry.

Colchuck Lake: The signal from the control structure was considered 'loud and clear' by Wenatchee Dispatch. There appear to be no on-site issues with being able to install communication equipment in proximity to the control structure.

Upper & Lower Snow Lakes: No landing site was available during the field visit, so an aerial inspection of Upper and Lower Snow Lakes was made. Due to the configuration of Snow lakes, the main control structure that empties into Nada Lake would be the primary point of communication. This site has ideal line of site to the proposed Wedge Mountain repeater location. Point-to-Point communication was verified in the field, resulting in very clear communication. If an additional monitoring station were to be installed at Lower Snow Lake, local communication could be routed to either the communications system at the Lower Snow outlet to Nada, or to the proposed repeater on Wedge Mountain.

Nada Lake: The primary control structure for Snow Lake is at the head of Nada Lake. An automated monitoring station is installed in the flume downstream of Nada. Communications were verified to both the proposed Wedge Mountain repeater location, as well as bouncing off the Icicle Ridge repeater.

Wedge Mountain Repeater: The ridgeline along Wedge Mountain was inspected to verify the suitability for installing a repeater station. A section of the ridgeline with line-of-sight to the Snow Lakes outlet was inspected, with multiple potential sites for a repeater station. The area also has visibility to the LNFH facility below, allowing a single repeater to get communications in and out of the Snow/Nada Lakes.

3.3 Optimization and Infrastructure Improvement Alternatives Analysis

Four improvement alternatives were identified that would include combinations of the improvement options described above. Alternatives 1a and 1b are intended to maximize the use of water from each lake within existing physical and infrastructure limitations through improved control of releases. Alternatives 2a and 2b are intended to make use of additional water storage capacity, within the limitations of existing water rights, by improving infrastructure to allow for more water to be captured and released. The alternatives are summarized as follows:

Alternative 1a

- Maximize use from each lake with existing maximum pool level.
- Use manual release to operate the release gates (requires human access to the lakes, which is assumed to be via hiking, rather than helicopter).
- Install basic monitoring equipment (staff and stream gages, data loggers). These would be manually downloaded.

Alternative 1b

- Maximize use from each lake with existing maximum pool level.
- Replace release gates as needed.
- Retrofit all release gates and valves with motorized actuators for automated releases.
- Install basic monitoring equipment (staff and stream gages, data loggers).
- Install telemetry system and automated controls to allow remote operation of release gates and valves.

Alternative 2a

- Includes all of Alternative 1b components.
- Increase usable storage volume at Eightmile Lake to 2,500 acre-feet, by completing the following improvements:

- Rebuild the dam at Eightmile Lake to raise the full water level to historical overflow level, to an elevation of approximately 4,671.0 feet.
- Add a siphon at Eightmile Lake to allow the water level to be drawn down approximately 22.4 feet below the existing maximum drawdown level, to an elevation of approximately 4,621.6 feet.

- Implement additional improvements identified in the *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011) to increase storage and automate releases from the Snow Lakes, including:
    - Replace Upper and Lower Snow Lake dams and increase the dam crest elevation by five feet at both locations.

Alternative 2b

- Includes all of Alternative 2a components, but with the following variations to the proposed improvements at Eightmile Lake, which would also result in an increase in usable storage volume to 2,500 acre-feet:
    - Rebuild the dam at Eightmile Lake to raise the full water level to an elevation that is one foot above the historical overflow level, or approximately 4,672.0 feet.
    - Add a siphon at Eightmile Lake to allow the water level to be drawn down approximately 19.0 feet below the existing maximum drawdown level, to an elevation of approximately 4,624.6 feet.

Table 6 provides additional detail regarding each alternative. The full range of improvement options being considered is listed with an indication of which optional improvements are included in each alternative.

Table 6 - Summary of Alternatives				
Potential Improvement Options	**Alternative 1a**	**Alternative 1b**	**Alternative 2a**	**Alternative 2b**
Square Lake				
Install Monitoring Equipment	X	X	X	X
Replace Gate		X	X	X
Automate Gate/Optimize Releases		X	X	X
Clear Wood and Debris from Dam		X	X	X
Klonaqua Lakes				
Install Monitoring Equipment	X	X	X	X
Replace Gate – Lower Klonaqua		X	X	X
Automate Gate/Optimize Releases		X	X	X
Clear Wood and Debris from Dam		X	X	X
Eightmile Lake				
Install Monitoring Equipment	X	X	X	X
Replace Gate		X		
Automate Gate/Optimize Releases		X		
Clear Wood and Debris from Dam		X	X	X
Install Siphon Through Discharge Pipeline to Draw Lake Down an Additional 4 Feet (to 4,624 feet)			X	X
Install Automated Gate on Siphon			X	X
Repair/Rebuild Dam to Raise Storage to Historic Overflow Elevation (4,671 feet)			X	
Repair/Rebuild Dam to Raise Storage 1 Foot Above Historic Overflow Elevation (4,672 feet)				X
Colchuck Lake				
Install Monitoring Equipment	X	X	X	X
Replace Gate		X	X	X
Automate Gate/Optimize Releases		X	X	X
Clear Wood and Debris from Dam		X	X	X

Potential Improvement Options	Alternative 1a	Alternative 1b	Alternative 2a	Alternative 2b
Upper Snow Lake				
Automate Valve on Outlet of Penstock from Upper Snow Lake to Nada Lake/Optimize Releases		X	X	X
Clear Wood and Debris from Dam		X	X	X
Repair/Rebuild Dam to Raise Storage 5 Feet Above Existing Overflow Elevation			X	X
Install New Low Level Outlet Pipe at Dam at Same Elevation as Existing Low Level Outlet			X	X
Install New Flap Gate			X	X
Lower Snow Lake				
Clear Wood and Debris from Dam		X	X	X
Repair/Rebuild Dam to Raise Storage 5 Feet Above Existing Overflow Elevation			X	X
Install New Low Level Outlet Pipe at Dam 3 Feet Lower Than Existing Outlet to Allow 3 Additional Feet of Drawdown			X	X
Install Automated Control Gate on New Low Level Outlet			X	X

Potential Improvement Options	Alternative 1a	Alternative 1b	Alternative 2a	Alternative 2b
Telemetry				
Telemetry Connection to Automated Gates and Valves		X	X	X
Repeater Station for Alpine Lakes			X	X
Repeater Station for IPID Lakes			X	X

Cost Analysis

Opinions of probable construction and implementation costs and a cost/benefit summary were developed for each of the alternatives.

Probable Construction and Implementation Costs

Table 7 provides a summary of those costs. A more detailed breakdown of the cost information summarized below is included in Appendix A. The costs are summarized by the following major categories of work:

- **Install Monitoring Equipment –** This includes installation of staff gages and digital monitoring equipment, such as pressure tranducers with dataloggers, to monitor lake levels and release flow rates. As noted above in Table 6, this work would be completed as part of each of the alternatives.
- **Replace or Refurbish Existing Control Gate –** This includes all work associated with replacing or refurbishing existing control gates and assumes the following:
    - The existing gate at Eightmile Lake would be removed and replaced as part of Alternative 1b.
    - The existing gates at Square, Klonaqua, and Colchuck Lakes would be refurbished as part of Alternative 1b, 2a, and 2b.
    - Where alternatives assume replacement of dam infrastructure, including low- level outlet pipe and gates with new equipment (Eightmile and Snow Lakes, Alternatives 2a and 2b), that cost is not included in this category.
- **Automate Gates/Valves to Optimize Releases –** This includes installation of motorized actuators on release gates and valves, installation of solar panels and battery packs as power supply for motorized actuators, controls and communications equipment to be installed at each actuator, weatherproof enclosures, telemetry, and repeater stations. Gate automation and telemetry is included for releases from all lakes as part of Alternatives 1b, 2a, and 2b. Two repeater stations are included; one that would serve the Alpine Lakes and one that would serve the IPID Lakes.
- **Clear Wood and Debris from Dam –** This would include work required to remove logs, rock, and other debris that has gathered upstream or downstream of each dam prior to implementing other improvements.
- **Install New Low-Level Outlet Pipe or Siphon with Gate –** This would include work required to replace existing low-level outlet pipe with a siphon or new pipe to improve releases and increase drawdown. These improvements would only occur at Eightmile Lake, Upper Snow Lake, and Lower Snow Lake as part of Alternatives 2a and 2b. The costs assume the following:
    - The low-level outlet pipe at Eightmile Lake would be sliplined with a slightly smaller pipe. The new pipe would extend further into the lake and

operate as a siphon to increase drawdown of the lake. The drawdown would extend approximately 22 feet lower than the existing outlet for Alternative 2a and 20 feet lower than the existing outlet for Alternative 2b. A new gate would be installed at the inlet to the new siphon.

  - The low-level outlet pipe at both Upper Snow Lake would be replaced. A new flap gate would be installed at the inlet to the low-level outlet at Upper Snow Lake to allow water to flow only from Lower Snow Lake to Upper Snow Lake when Upper Snow Lake has been drawn down and is lower than Lower Snow Lake.
  - The low-level outlet pipe at Lower Snow Lake would be replaced. The low-level outlet pipe at Lower Snow Lake would be installed 3 feet lower than the existing low-level outlet to increase storage. A new slide gate would be installed on the inlet to the low-level outlet pipe at Lower Snow Lake and the gate would be automated and connected to telemetry to allow for remote control and optimization of releases.

- **Repair or Rebuild Dam –** This would include all work required to replace the existing dam structures at Eightmile Lake, Upper Snow Lake, and Lower Snow Lake. These improvements are only included in Alternatives 2a and 2b. The costs assume the following:
  - The dams would be completely replaced. Costs would include clearing and tree removal, stripping and stockpiling of soil, diversion and care of water, temporary erosion and sediment control, demolition, rock removal, waste or placement of excavated material on site, installation of reinforced concrete dams with rock/masonry facing and drilled rock anchors, and installation of a walkway and access at each dam.
  - The dam structure at Eightmile Lake, including both embankment and masonry portions, would be replaced with a reinforced concrete/masonry structure. The dam would match the height and overflow elevation of the existing dam for Alternative 2a. The dam crest elevation would be raised 1 foot for Alternative 2b.
  - The dam structure at Upper Snow Lake would be replaced as described in the *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011). The new dam would have a crest elevation 5 feet higher than the existing dam for both Alternatives 2a and 2b.
  - The dam structure at Lower Snow Lake would also be replaced as described in the *Water Storage Report, Wenatchee River Basin* (Anchor QEA, 2011). The new dam would have a crest elevation 5 feet higher than the existing dam for both Alternatives 2a and 2b.

Table 7 - Summary of Opinions of Probable Project Cost

Cost Category	Alternative 1a	Alternative 1b	Alternative 2a	Alternative 2b
Install Monitoring Equipment	$58,500	$58,500	$58,500	$58,500
Replace or Refurbish Existing Control Gate	$0	$49,000	$29,000	$29,000
Automate Gates/Valves to Optimize Releases	$0	$212,700	$212,700	$212,700
Clear Wood and Debris from Dam	$0	$27,000	$27,000	$27,000
Install New Low Level Outlet Pipe or Siphon with Gate	$0	$0	$254,200	$254,200
Repair or Rebuild Dam	$0	$0	$1,006,900	$1,051,200
Subtotal	**$58,500**	**$347,200**	**$1,588,300**	**$1,632,600**
Miscellaneous Mobilization (7.5%)	$4,388	$26,040	$119,123	$122,445
Helicopter Mobilization/ Demobilization/ Rental	$0	$125,000	$671,800	$699,000
Construction Subtotal	**$63,100**	**$498,200**	**$2,379,200**	**$2,454,000**
Contingency (30%)	$18,930	$149,460	$713,760	$736,200
Engineering, Permitting, and Administration (20%)	$3,786	$29,892	$142,752	$147,240
Sales Tax (8.2%)	$310	$2,451	$11,706	$12,074
Total Project Cost	**$86,000**	**$680,000**	**$3,247,500**	**$3,349,600**

Cost/Benefit Summary

Table 8 provides a summary of the project costs represented in terms of cost per additional acre-foot and cfs of storage that could be released to the Icicle Creek Basin during an assumed 92-day release period in late summer or early fall. The estimated usable storage available in each is listed. The Alpine Lakes managed by IPID and the USFWS have a combined estimated usable storage capacity of 20,015 acre-feet. That total usable storage volume is not typically released during a given year due to the difficulty of accessing the more remote lakes and due to the reliability of recharge in the Upper and Lower Snow Lakes basin. As a baseline, the analysis presented earlier in this report estimated that approximately 8,200 acre-feet of storage is released, on average, during the late summer and early fall. This includes 4,500 acre-feet of storage from Upper and Lower Snow Lakes and 3,700 acre-feet of storage from the IPID lakes.

The usable storage volume would not increase under Alternatives 1a and 1b, but the amount released during a typical year would increase. The analysis presented earlier in this report estimated that an additional 5,500 acre-feet could be released if the lakes were managed to maximize releases, by either hiring someone to travel between the lakes through the late summer to manually adjust the control gates and valves (Alternative 1a) or by automating releases (Alternative 1b). This equates to an average release rate of approximately 30 cfs over an assumed 92-day release period.

The active storage volume would increase under Alternatives 2a and 2b to 2,500 acre-feet in Eightmile Lake and 13,679 acre-feet in Upper and Lower Snow Lakes. This represents an overall increase in storage capacity of 2,204 acre-feet. If the additional storage was available for release during an average year, the total additional annual release over the baseline condition would be 7,704 acre feet, or approximately 42 cfs, on average, over an assumed 92-day release period.

The cost of implementing the improvements that would allow for maximizing the use of existing storage vary from $16 per acre-foot ($2,850 per cfs) for Alternative 1a to $124 per acre-foot ($22,600 per cfs) for Alternative 2a. It should be noted that Alternative 1a would require that one to two full-time employees be hired each irrigation season to manage releases. This cost for this could be on the order of $50,000 per year, assuming 2 full time employees for 16 weeks per year, 40 hours per week each, at $35 per hour loaded rate. Over 50 years of operation, this expense would be equal to $2,500,000 (in 2014 dollars). If the $2,500,000 assumption for 50 years of labor were added to the implementation cost for Alternative 1a, the cost would be approximately $470 per acre-foot ($86,200 per cfs).

The cost of implementing Alternative 2a would be approximately $422 per acre-foot ($76,900 per cfs) of additional release and the cost of implementing Alternative 2b would be approximately $435 per acre-foot ($79,300 per cfs) of additional release. These costs compare favorably to other conservation and water savings projects that have been implemented in the Wenatchee River Watershed.

Table 8 - Cost/Benefit Summary

Cost Category	Existing (Baseline)	Alternative 1a	Alternative 1b	Alternative 2a	Alternative 2b
Total Project Cost		$86,000	$680,000	$3,247,500	$3,349,600
Useful Storage Capacity (Acre-feet):					
• Square Lake	2,400	2,400	2,400	2,400	2,400
• Klonaqua Lakes	1,920	1,920	1,920	1,920	1,920
• Eightmile Lake	1,375	1,375	1,375	2,500	2,500
• Colchuck Lake	1,570	1,570	1,570	1,570	1,570
• Upper and Lower Snow Lakes	12,600	12,600	12,600	13,679	13,679
• Nada Lake	150	150	150	150	150
Total Usable Storage Capacity (Acre-feet)[1]	**20,015**	**20,015**	**20,015**	**22,219**	**22,219**
Additional Usable Storage Capacity (Acre-feet)		0	0	2,204	2,204
Release Capacity (Acre-feet)	8,200	13,700	13,700	15,904	15,904
Additional Release (Acre-feet)		5,500	5,500	7,704	7,704
Additional Release (cfs, 92-day Release)		30	30	42	42
Cost/Additional Acre-foot of Release		**$16**	**$124**	**$422**	**$435**
Cost/Additional cfs of Release (92-day Release)		**$2,850**	**$22,600**	**$76,900**	**$79,300**

1 - Alternative 1a would require that one to two full-time employees be hired each irrigation season to manage releases. Assuming two full-time employees, at $50,000/year, and 50 years of operation, this would be equal to $2,500,000 (2014 dollars). Adding this $2,500,000 assumption for 50 years of labor to Alternative 1a would result in a cost of approximately $470 per acre-foot ($86,200 per cfs

The overall project cost includes an allowance for mobilization/demobilization, including a 7.5% allowance for miscellaneous mobilization/demobilization costs plus an allowance for haul of materials and equipment to the site via helicopter. Columbia Helicopters was contacted for preliminary budget information on the cost of hauling equipment and materials to the site via helicopter. They provided the following cost estimates:

- A helicopter with a hauling capacity of 6,500 to 7,000 pounds at 5,000-foot altitude and a temperature of 70° F would cost approximately $7,000 per hour to rent plus approximately $15,000 to mobilize to the Wenatchee area.
- A helicopter with a hauling capacity of 20,000 to 30,000 pounds at 5,000-foot altitude and a temperature of 70° F would cost approximately $14,000 per hour to rent plus $20,000 to mobilize to the Wenatchee area.
- Costs may vary depending on the location and availability of helicopters at the time of the project.

Helicopter mobilization was estimated separately for work completed under each alternative at each lake, with the total for the alternative being the total for work done at all lakes under that alternative. The costs assume that the helicopter with the larger hauling capacity would be used to allow for hauling small equipment (a small excavator and a small track loader) to the site to facilitate the work, and that concrete materials would be mixed on site for the dam replacement projects at Eightmile Lake and Snow Lakes as part of Alternatives 2a and 2b. The alternative would be to haul ready-to-pour concrete via helicopter to the site, which would likely be accomplished with a smaller helicopter and additional helicopter trips. A smaller helicopter was assumed to facilitate mobilization for gate repairs, replacements, and other miscellaneous work that would occur at Square, Klonaqua, and Colchuck Lakes as part of Alternatives 1b, 2, and 3 at a cost of approximately $12,500 per day. No helicopter mobilization was assumed for the work included in Alternative 1a.

The overall project cost also includes the following allowances:

- A contingency of 30% of the construction subtotal;
- An allowance 20% of the construction subtotal for engineering, permitting, and administration; and
- An allowance for sales tax of 8.2%

Potential Challenges and Impacts Analysis

While Alternatives 1a and 1b have similar benefits, they are primarily differentiated by capital cost. Similarly, Alternatives 2a and 2b appear identical in benefit and similar in cost, however they are very different in terms of potential challenges and impacts.

Alternatives 1a and 1b

The primary difference between Alternatives 1a and 1b is the inclusion of remote automation of the release of the lakes in Alternative 1b. While the overall release benefit may be similar in terms of annual quantity, there are several differentiators that should be considered when comparing the two alternative variations.

Alternative 1a is attractive from the perspective of the lowest capital cost as well as the relative speed at which it could be implemented. However, a potential drawback would be the need for staff resources to be dedicated to accessing the lakes frequently to monitor the lake release rate, lake volume remaining as well as to physically adjust the gates. Depending upon how tight the release scheme is, some lakes may need to be visited daily to make adjustments, and it may take several seasons to further refine the optimization under a manual operation scenario.

It is likely possible to maintain an effective manual release semi-optimized scenario by employing one to two full-time seasonal employees (3 to 4 months of the year) to visit each lake one to two times per week under Alternative 1a. It is estimated that an additional labor cost to operate the optimized release in this scenario could be on the order of $50,000 per year (assuming 2 full-time employees, 16 weeks per year, 40 hours per week each, $35 per hour loaded rate).

It would also be possible to implement Alternatives 1a and 1b on a per-lake basis, allowing manual operation on some lakes with automation on other lakes. For example, there may be value in having both Square Lake and Klonaqua Lakes automated due to their significant distance, while having the release from the balance of the lakes manually operated. There is not a strict 1:1 cost savings for this as there are some shared costs in the implementation of Alternative 1b (such as repeaters) that would still be required, even if only some lakes are automated.

In the fully automated Alternative 1b, lake releases can be tailored to downstream flow requirements on an ongoing basis. Automated control to maintain flow targets, or manual remote adjustment, could be utilized on a daily basis, offering much finer control of releases to maximize the instream flow benefit. Carefully managing to instream flow needs would extend the period of release, avoiding over-releasing early in the season and allowing for longer release periods as needed in drought or climate change conditions.

A final consideration related to Alternative 1b is the potential need for periodic operations and maintenance cost, which have not been estimated. While it may be possible to design automated systems that require maintenance only once every few years, it is most likely the case that each automated system would require yearly maintenance. At a minimum, it is reasonable to assume that each lake would be visited both at startup and shut-down each year to ensure proper operation, calibration, possible replacement of batteries, etc.

Alternatives 2a and 2b

The primary difference between Alternatives 2a and 2b is the variation in minimum and maximum pool elevation associated with Eightmile Lake. Alternative 2a proposes re-establishment of water rights storage in the lake by limiting the maximum pool elevation to historical levels. This could require drawing the lake down to the point where an insufficient volume of water remains at the end of the season to promote recreational goals, support aquatic life, or support other desired uses of the lake by multiple stakeholders. Alternative 2b was developed with the goal of mitigating the potential negative impacts of such a dramatic drawdown by nominally raising the maximum pool by one-foot beyond historical levels. By raising the maximum pool 1 foot as indicated, the maximum drawdown would be reduced by approximately 3 feet. The major drawback of Alternative 2b are potential impacts to existing shoreline and the host of environmental/regulatory and administrative hurdles that would be required. Additional analysis of the Eightmile Lake options is summarized in the *Eightmile Lake Storage Restoration Appraisal Study* (Anchor QEA and Aspect, 2015).

4 Data Gaps, Recommendations, and Next Steps

4.1 Data Gaps

This appraisal study has been prepared based on information available from the following sources:

- The prior studies and references cited in this report;
- Notes and observations documented during site visits to each of the lakes;
- Descriptions and photographs showing the condition and operation of the lakes provided by IPID and USFWS;
- Stage-storage curves and as-built information for Upper Snow Lake provided by the U.S. Bureau of Reclamation;
- Flow data and management information for Upper and Lower Snow Lakes and Nada Lakes provided by the USFWS;
- Water rights documentation, including as-built sketches for selected lakes on file in Ecology's Water Rights Database;
- Stage-storage estimates provided by Ecology's Dam Safety Office;
- Surveyed bathymetry and topography for Eightmile Lake provided by Gravity Consulting under contract with Trout Unlimited;
- Evaluate of storage volumes at Eightmile Lake provided by Gravity Consulting under contract with Trout Unlimited;
- Surveyed bathymetry and topography for Upper Klonaqua Lake provided by Gravity Consulting; and
- USGS digital elevation data and other available GIS data.

Additional information should be collected to provide additional basis for further study and implementation. Additional information that may be needed includes:

- **Refined Stage-Storage Information:** Existing active storage values for Square, Lower Klonaqua, Colchuck, Nada, Upper Snow, Lower Snow, and Nada Lakes are based on historical estimates, which may be inaccurate. It is uncertain if the estimates are above or below actual active storage, and the effect of a change would be seen in both the estimated baseline releases and benefit of the proposed alternatives.
- **Bathymetry and Shoreline Topography:** Eightmile Lake and Upper Klonaqua Lake was recently surveyed by Gravity Consulting and stage storage curves were developed that should be very accurate. Additional survey data collected at the other lakes would help in refining stage-storage relationships, quantity and cost analyses, and design of improvements.

- **Analysis of Additional Storage – Upper Klonaqua Lakes:** The analysis in this study is focused primarily on automation and optimization of existing storage. Additional storage capacity may be available at Klonaqua Lakes by installing infrastructure that would allow for control and release of storage in Upper Klonaqua Lake to Lower Klonaqua Lake. The bathymetric survey indicated that, for example, approximately 1,146 acre-feet of storage could be available for release from Upper Klonaqua Lake if a controlled low-level outlet or siphon were installed 20 feet below the existing high water surface elevation. A short memo evaluating the data was prepared separately (Aspect, 2014). Additional evaluation will be needed to determine an appropriate solution.

- **Additional Hydrologic Review:** Additional review of hydrology may be needed to refine the analysis of flow and storage benefits and to provide inundation analyses needed to meet Ecology Dam Safety Office permit requirements. Modification of existing dams will require additional study to determine changes to the current hazard classification listed for the dams by Ecology Dam Safety Office. An increased hazard classification could potentially increase operational requirements and risk exposure.

- **Additional Geologic Review at Eightmile Lake and Snow Lakes:** Additional review of geologic conditions at Upper and Lower Snow Lakes and Eightmile Lake would be needed to complete the design of dam improvements at those locations.

4.2 Recommendations and Next Steps

The managed lakes in the Alpine Lakes Wilderness offer an efficient, cost-effective way to improve management of water in the Icicle Creek Sub-basin. With modest improvement, including automation and optimization of releases, USFWS and IPID could provide a significant improvement in the flow available in Icicle Creek during the critical late summer low flow period. Providing additional infrastructure improvements at Eightmile Lake, and Upper and Lower Snow Lakes will provide further operational flexibility and improvement to instream flows.

It is recommended that IPID and the USFWS continue to work with the IWG to evaluate the projects identified in this study and work toward implementing a project that includes the following:

- Install monitoring equipment to improve monitoring of lake levels and release rates from the lakes managed by IPID and USFWS.

- Repair existing gates and control structures at Square, Lower Klonaqua, and Colchuck Lakes.

- Automate releases by installing motorized actuators on the valve on the penstock at Upper Snow Lake and the gates at Lower Snow Lake, Square Lake, Lower Klonaqua Lake, Eightmile Lake, and Colchuck Lake.

- Install repeater stations and telemetry equipment needed to provide for remote control of valves and gates.

- Replace existing dams, low-level outlets, and control gates at Upper and Lower Snow Lakes.
- Replace the existing dam at Eightmile Lake and replace the existing low-level outlet and gate with a siphon and gate, as recommended in the *Eightmile Lake Storage Restoration Appraisal Study* (Anchor QEA and Aspect, 2015), being prepared concurrent with this study.

The next steps toward implementation would include:

- Perform feasibility level analyses and design of automation. This would include additional modeling of reservoir operations and releases to further define optimal operational scenarios, additional evaluation of telemetry and controls, additional evaluation of gate and valve retrofits, and development of feasibility level control diagrams and design drawings.
- Perform feasibility level analyses and design of dam replacements. This would include additional topographic and bathymetric survey, a fatal flaw analysis of environmental impacts and permitting, a geologic analysis, preliminary coordination with Ecology Dam Safety, more detailed hydrologic and hydraulic analyses, and development of feasibility-level design drawings.
- Identify and investigate funding opportunities for these projects.

5 References

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Wurster, 2006, Management Recommendations for Reservoir Releases from Upper Snow Lake: Leavenworth National Fish Hatchery. Prepared for the United States Fish and Wildlife Service, Leavenworth National Fish Hatchery. 2006.

Limitations

Work for this project was performed for the Chelan County Natural Resources Department (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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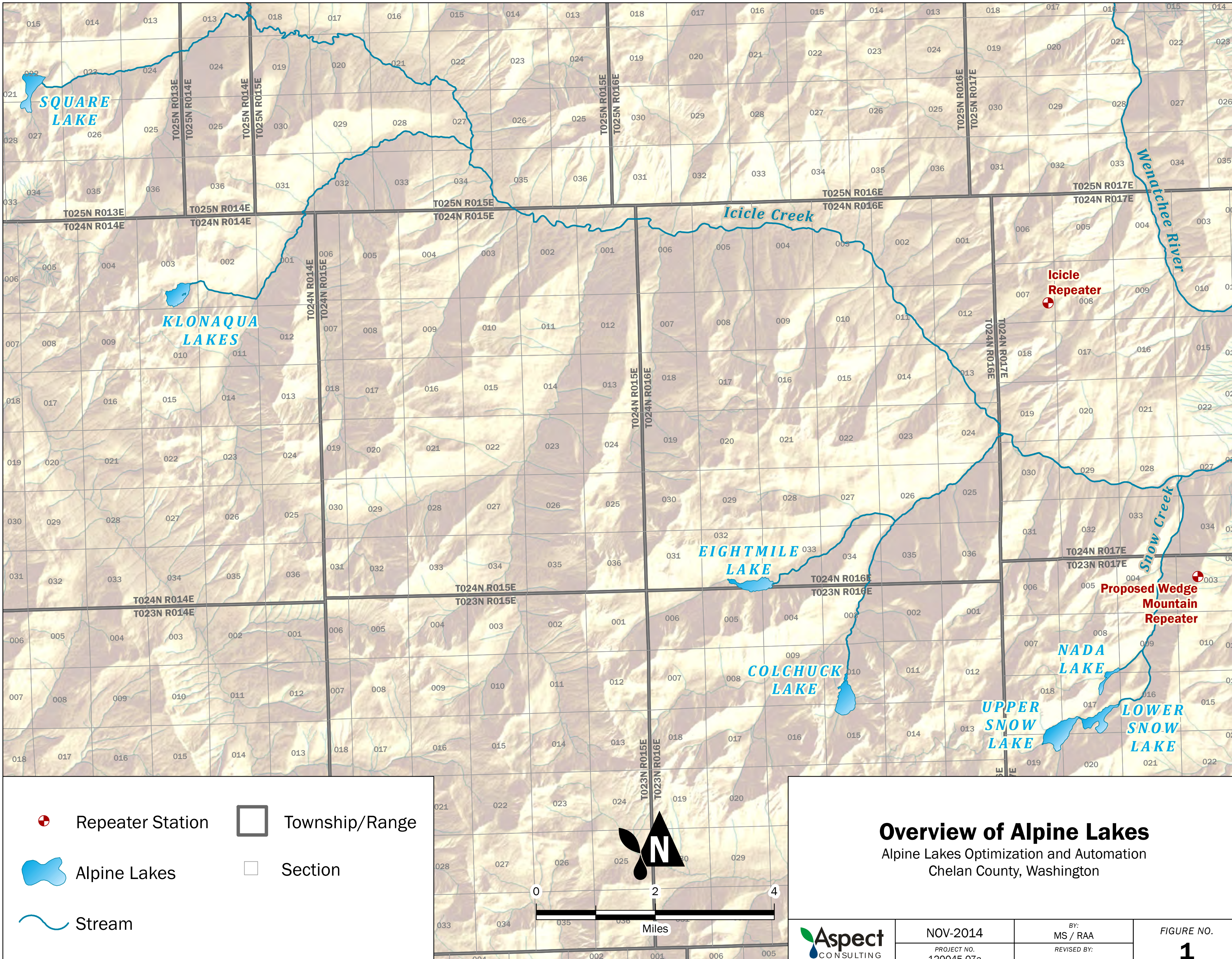
FIGURES



Overview of Alpine Lakes

Alpine Lakes Optimization and Automation
Chelan County, Washington

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NOV-2014	BY: MS / RAA	FIGURE NO.	
PROJECT NO. 120045-07a	REVISED BY: - - -	1	

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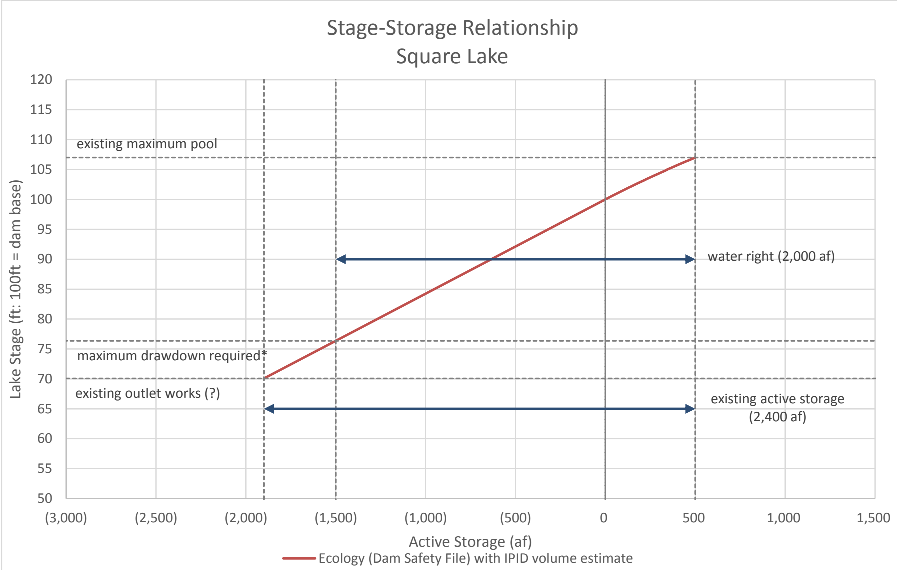
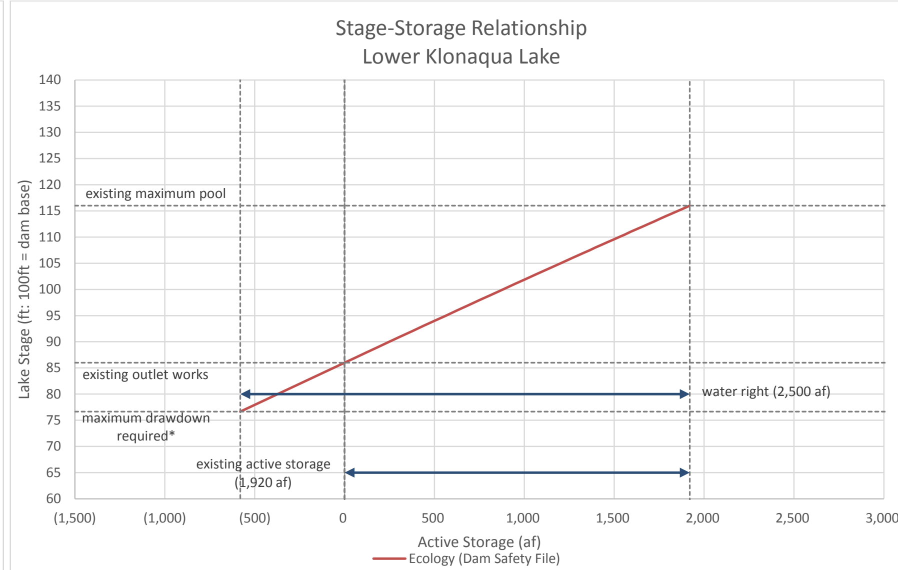
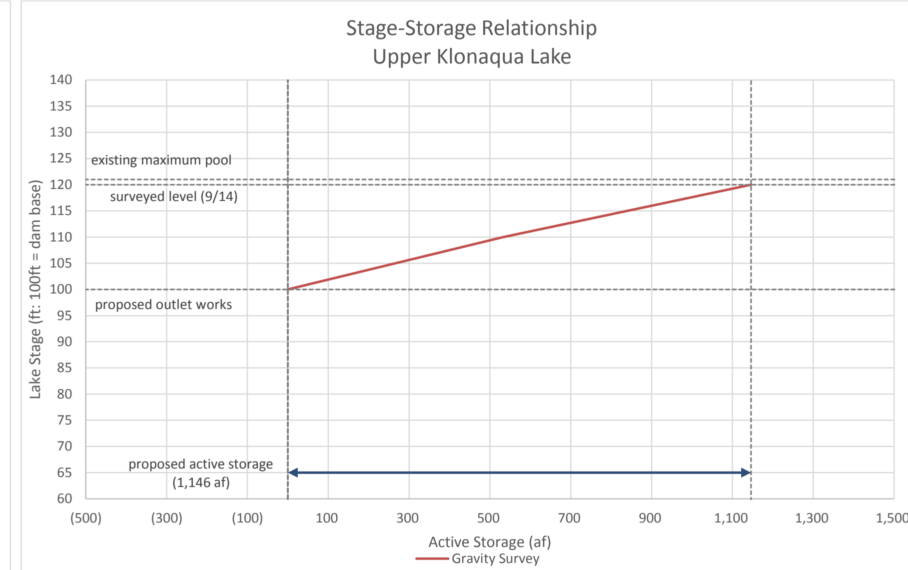
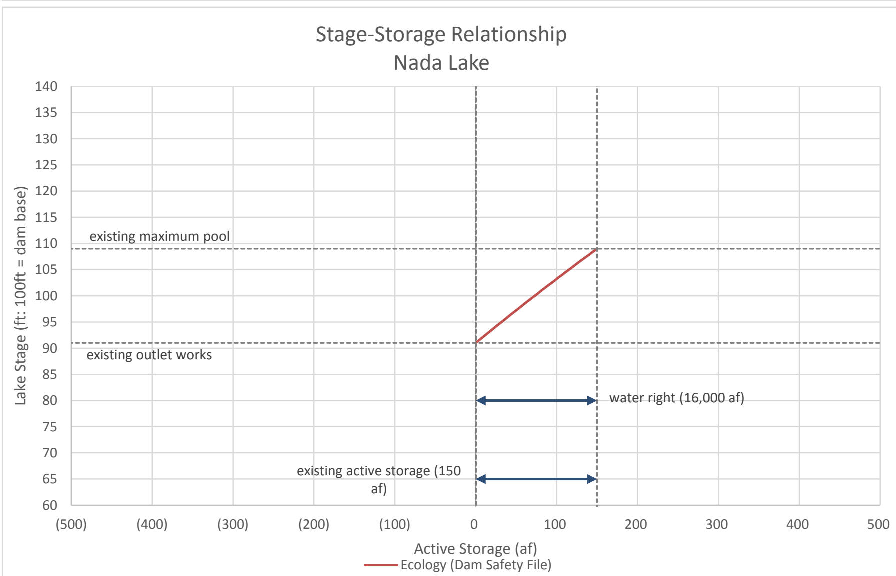
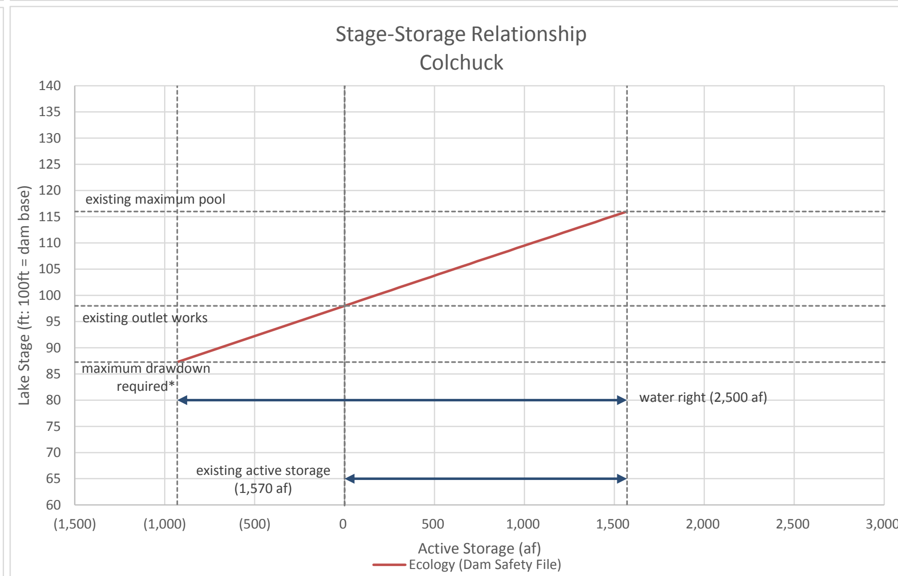
Stage/Storage Relationships

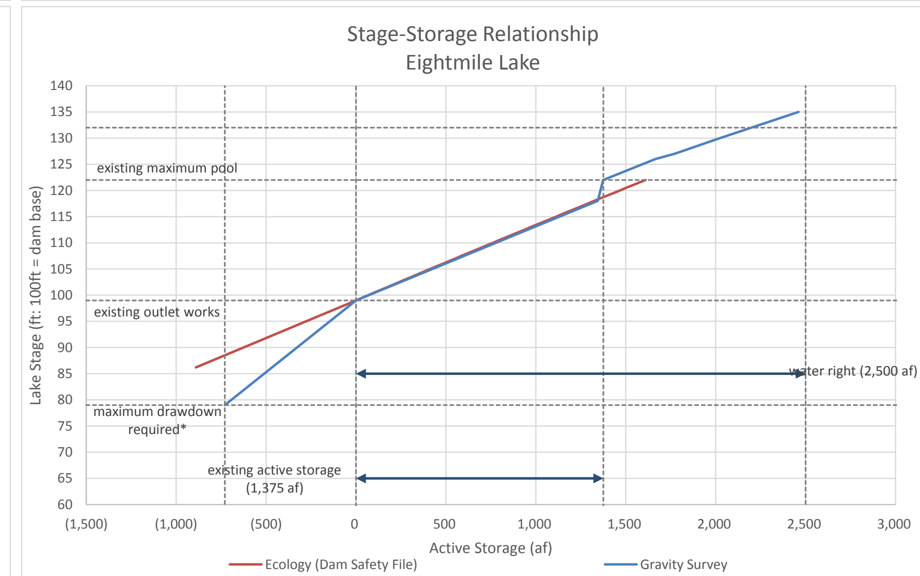


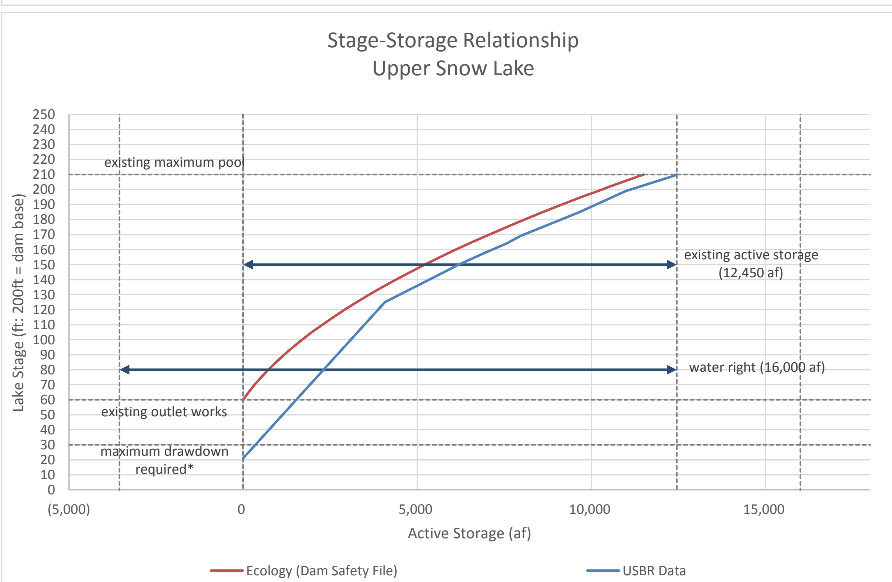












Notes: * Maximum drawdown required estimated based on existing Stage-Storage curve to achieve storage equal to the existing water right.

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2/9/2015
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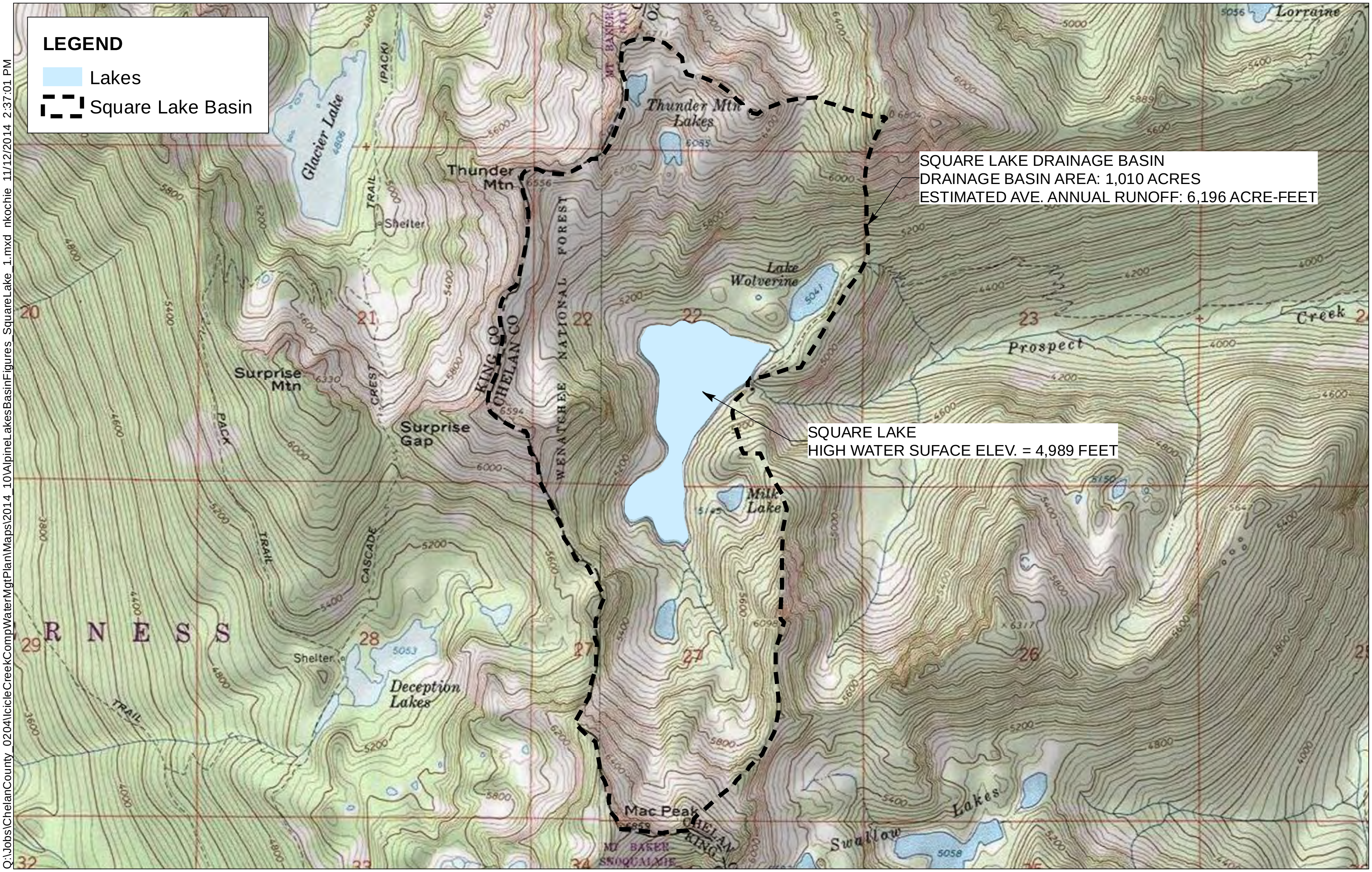
Figure 2 - Stage/Storage Relationships
Alpine Lakes Optimization and Automation



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ANCHOR QEA

Feet
0 1,100 2,200

Figure 3
Square Lake Drainage Basin
Appraisal Study
Alpine Lakes Optimization and Automation
Chelan County Department of Natural Resources

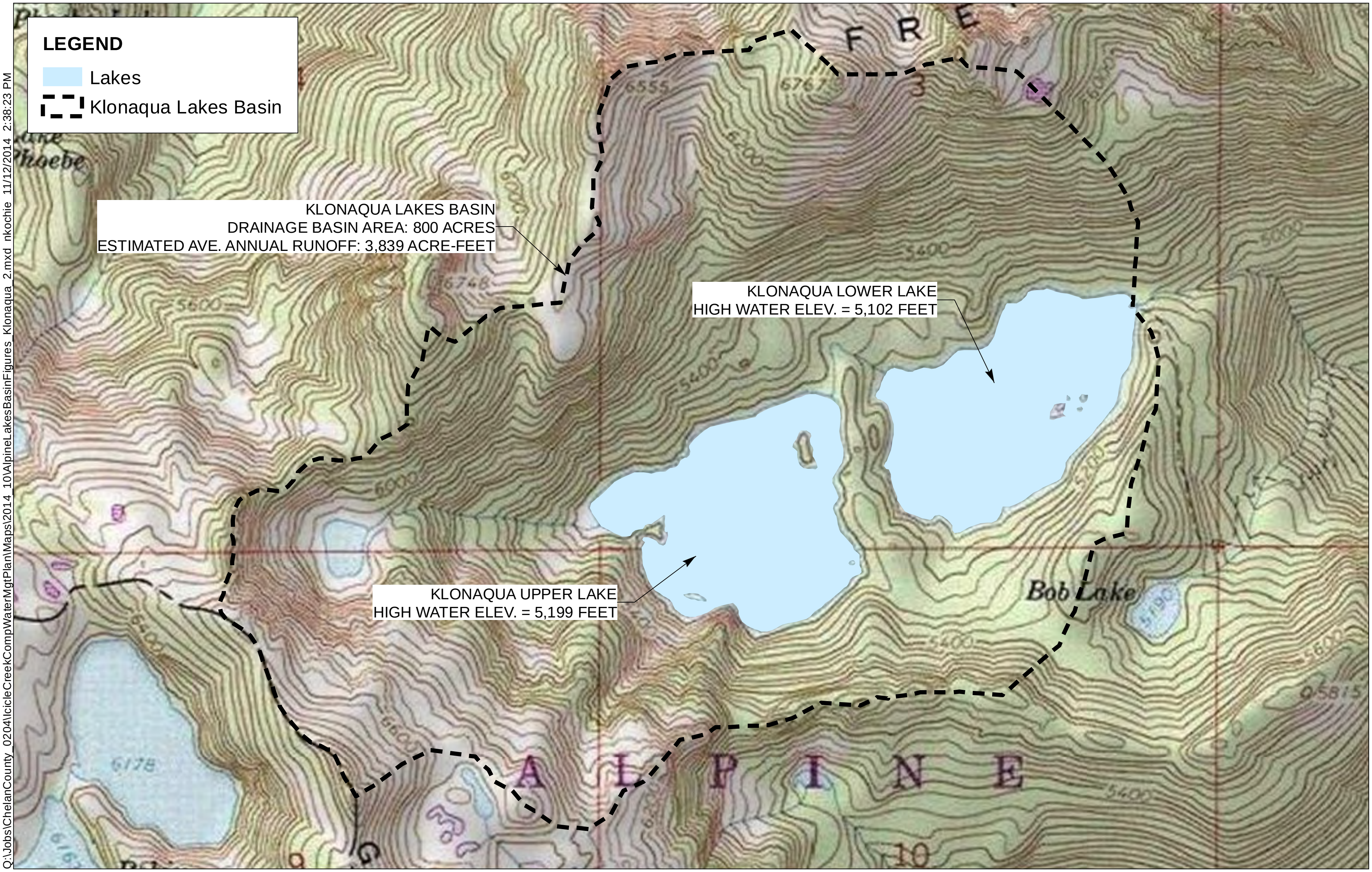

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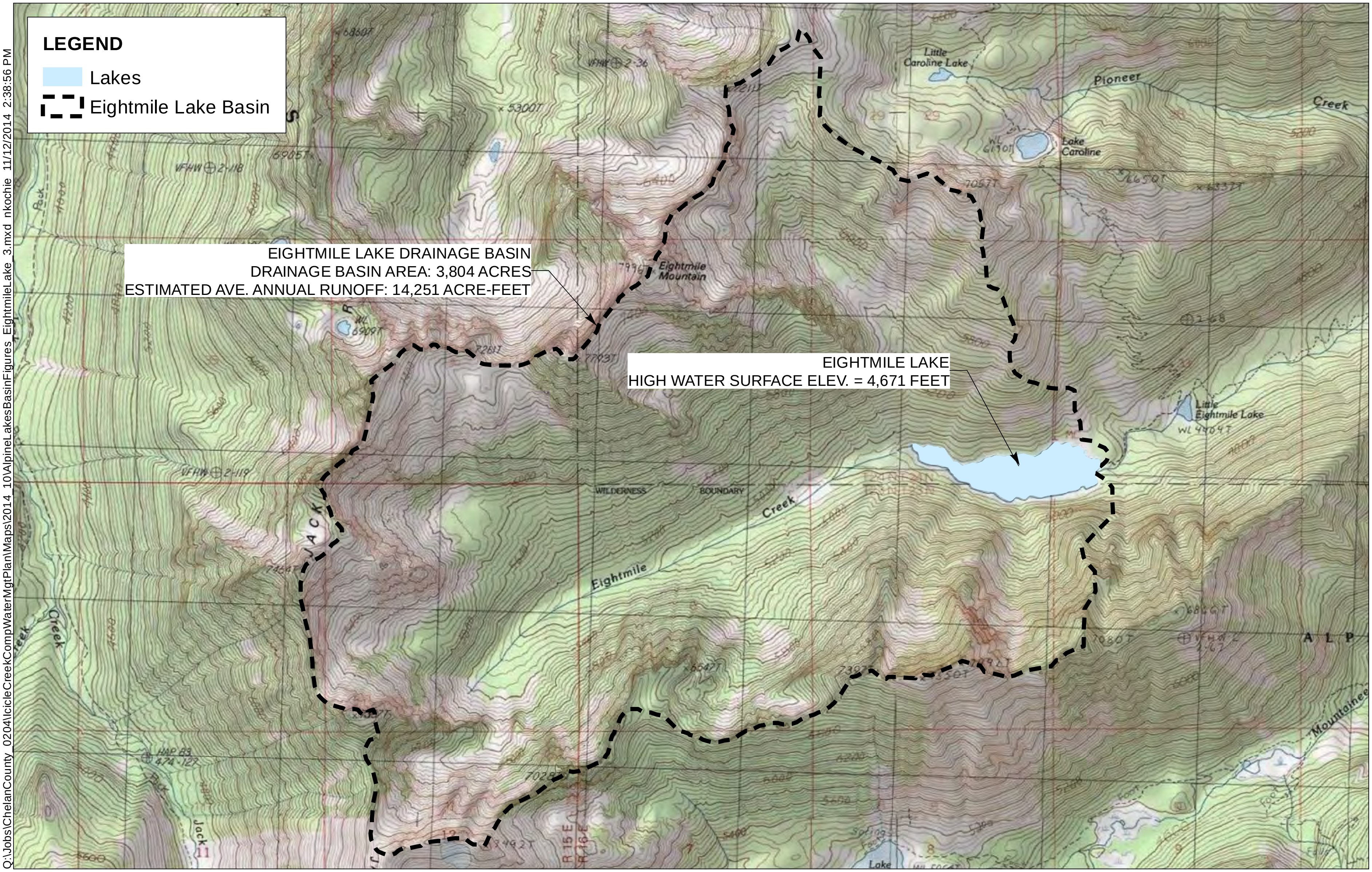
Figure 4

Klonaqua Lakes Drainage Basin

Appraisal Study

Alpine Lakes Optimization and Automation

Chelan County Department of Natural Resources



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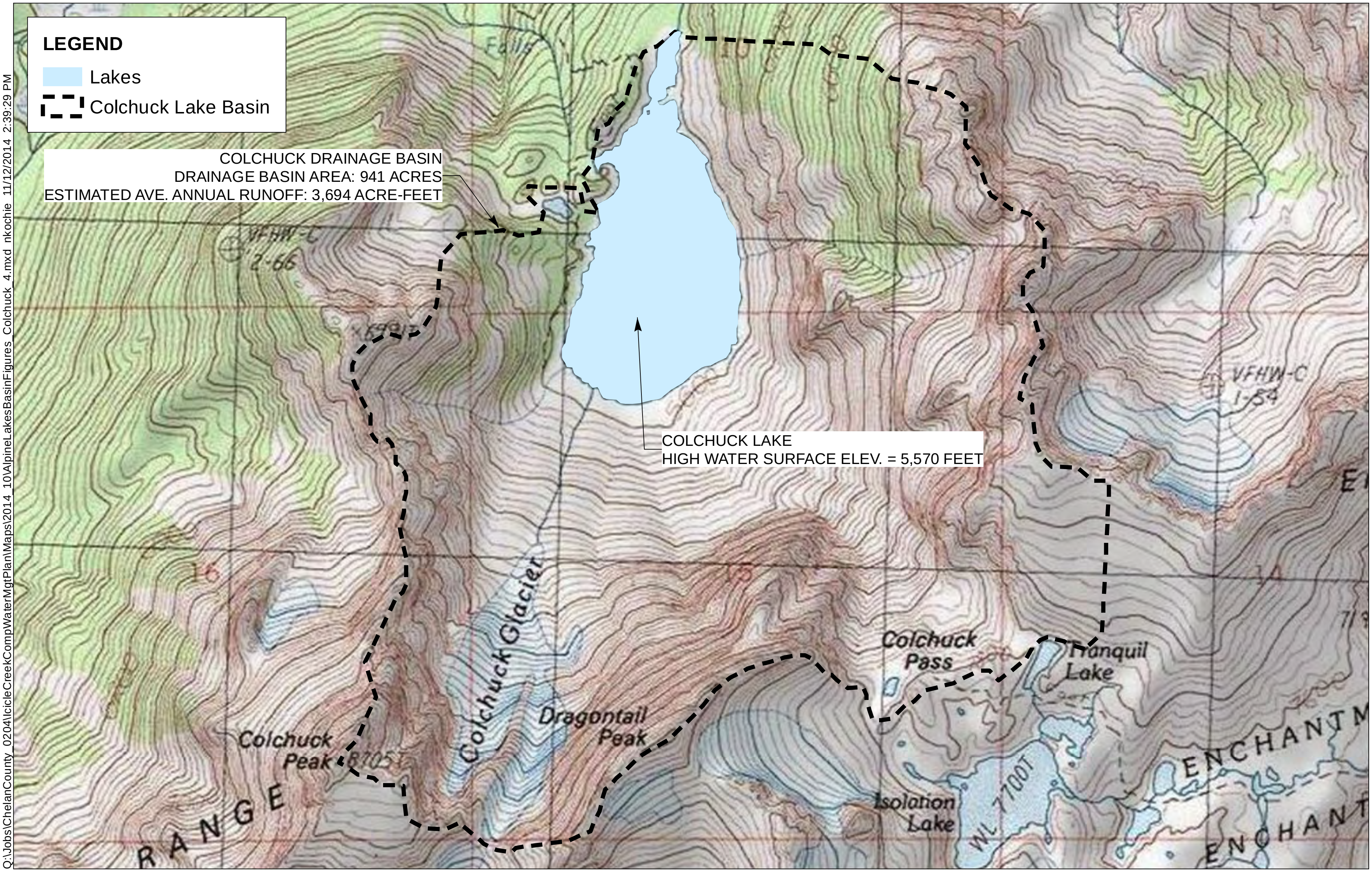
ANCHOR QEA

Feet
0 1,500 3,000

Figure 5
Eightmile Lake Drainage Basin
Appraisal Study
Alpine Lakes Optimization and Automation
Chelan County Department of Natural Resources



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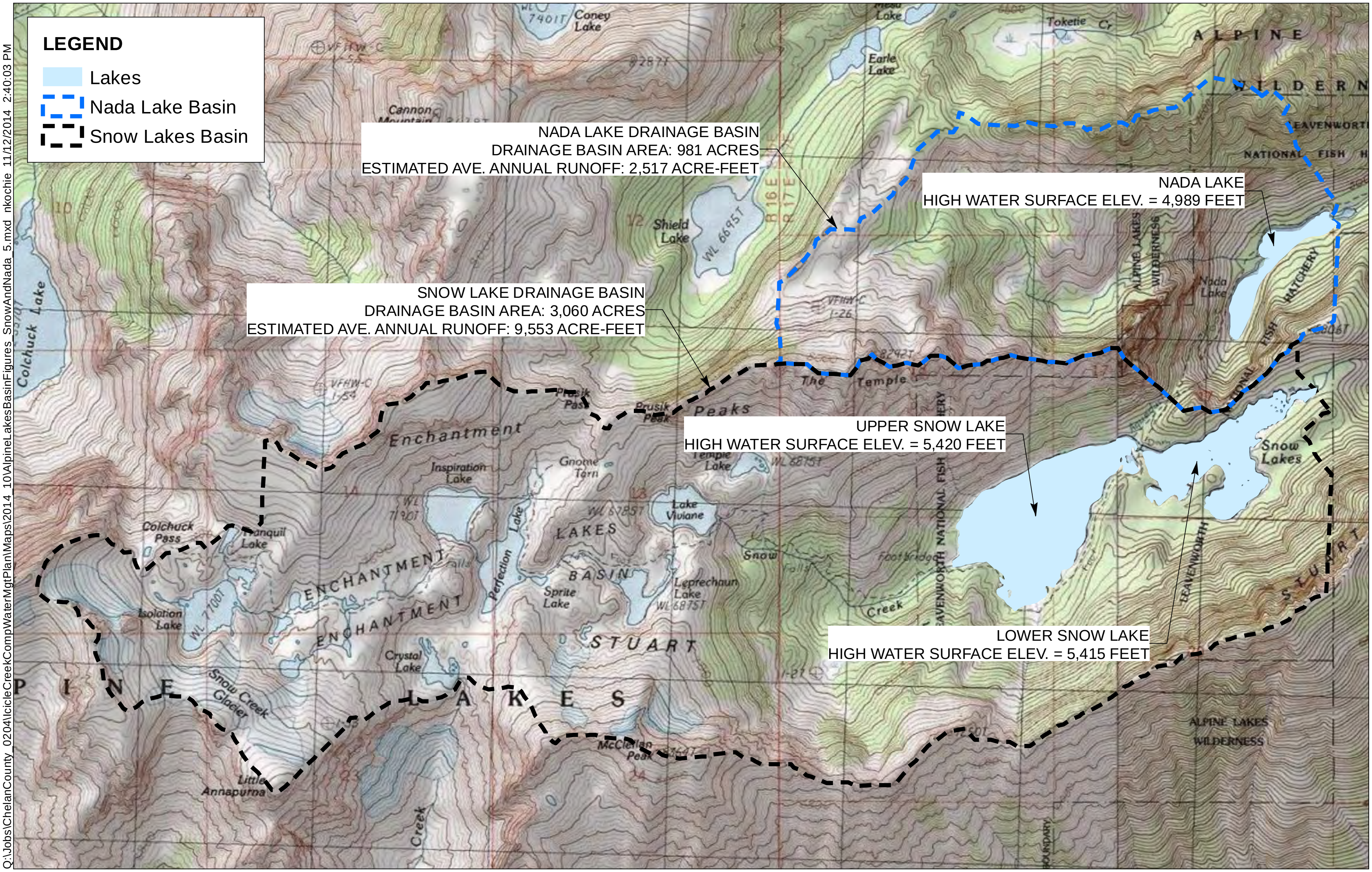
Feet
0 700 1,400

Figure 6
Colchuck Lake Drainage Basin
Appraisal Study
Alpine Lakes Optimization and Automation
Chelan County Department of Natural Resources



Feet
0 1,300 2,600

ANCHOR QEA

Figure 7
Snow and Nada Lakes Drainage Basins
Appraisal Study
Alpine Lakes Optimization and Automation
Chelan County Department of Natural Resources

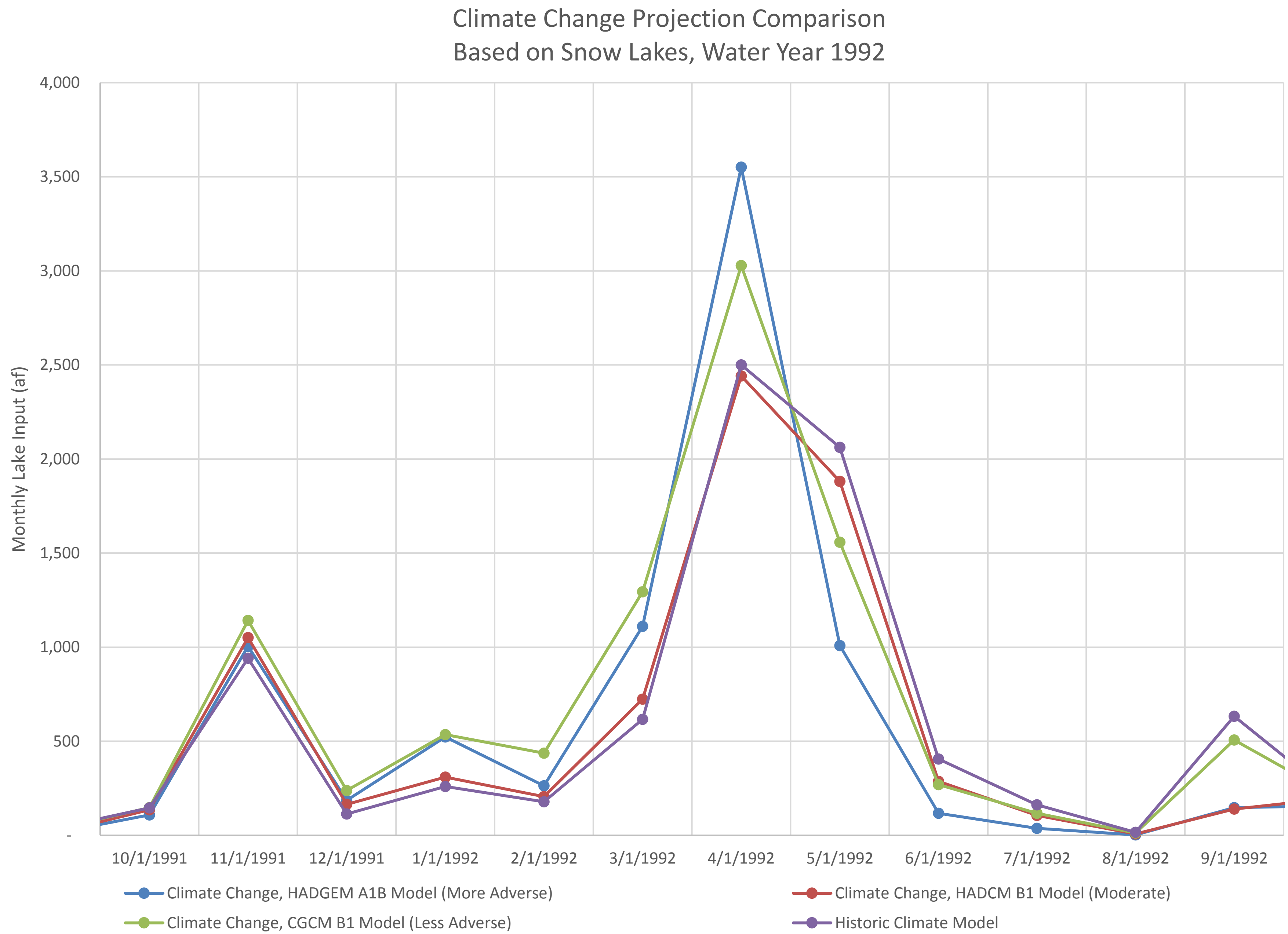


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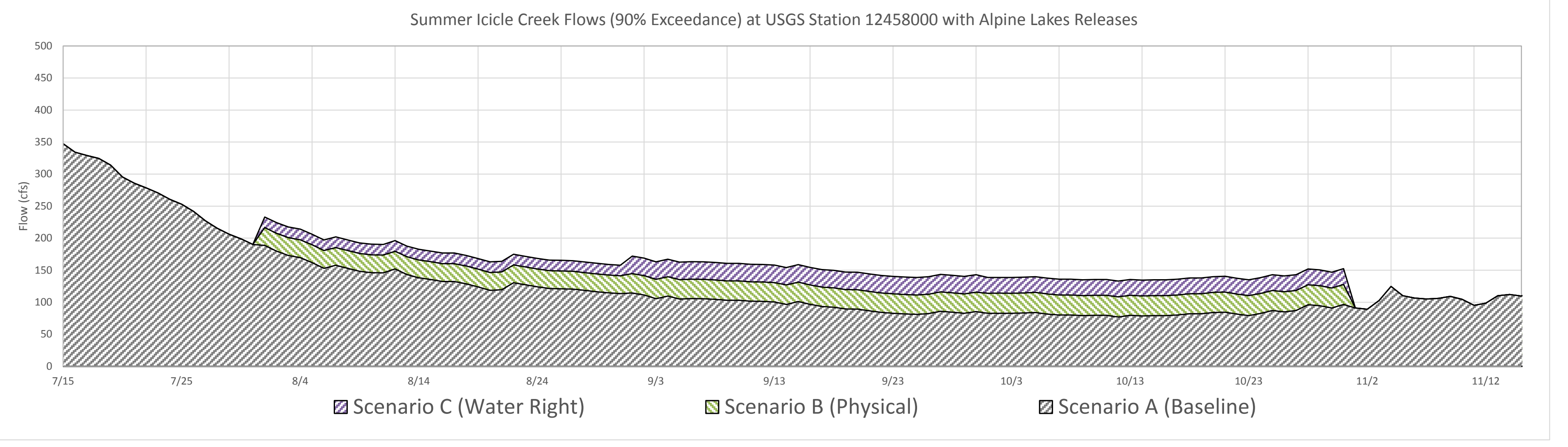
Figure 8 - Climate Change Projection Comparison
Alpine Lakes Optimization and Automation

Model Summary Results - No Climate Change

	Total System Annual Average		*Releases above USGS Station (Square, Klonaqua, Eightmile, Colchuck) (cfs)*			*Benefit Above Baseline Scenario (cfs)*			*Total Releases into Icicle Creek (Square, Klonaqua, Eightmile, Colchuck, Nada, Snow) (cfs)*			*Benefit Above Baseline Scenario (cfs)*		
Model Scenario	Releases in acre-feet (Aug-Sept-Oct)	Chance to Refill	August	September	October	August	September	October	August	September	October	August	September	October
Scenario A (Baseline)	8,228.48	99.4%	10.74	18.51	27.93	-	-	-	28.74	42.51	59.93	-	-	-
Scenario B (Physical)	13,683.58	98.9%	33.54	38.79	46.20	22.80	20.28	18.27	56.54	72.79	91.20	27.80	30.28	31.27
Scenario C (Water Right)	17,978.07	92.0%	40.12	56.10	60.85	29.38	37.59	32.92	73.12	100.10	115.85	44.38	57.59	55.92



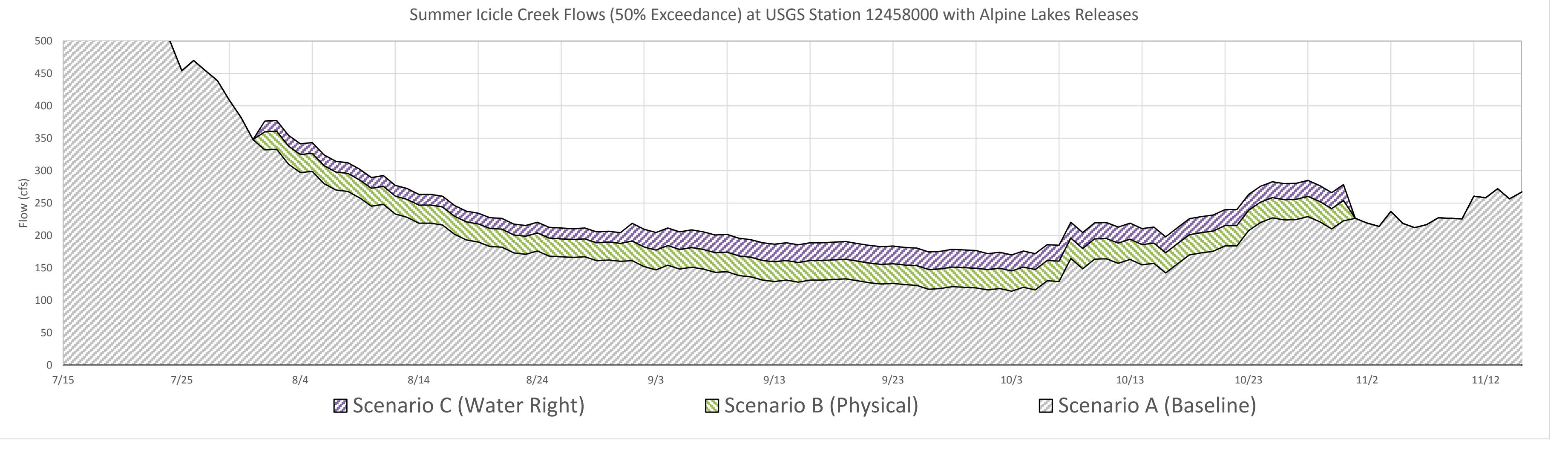
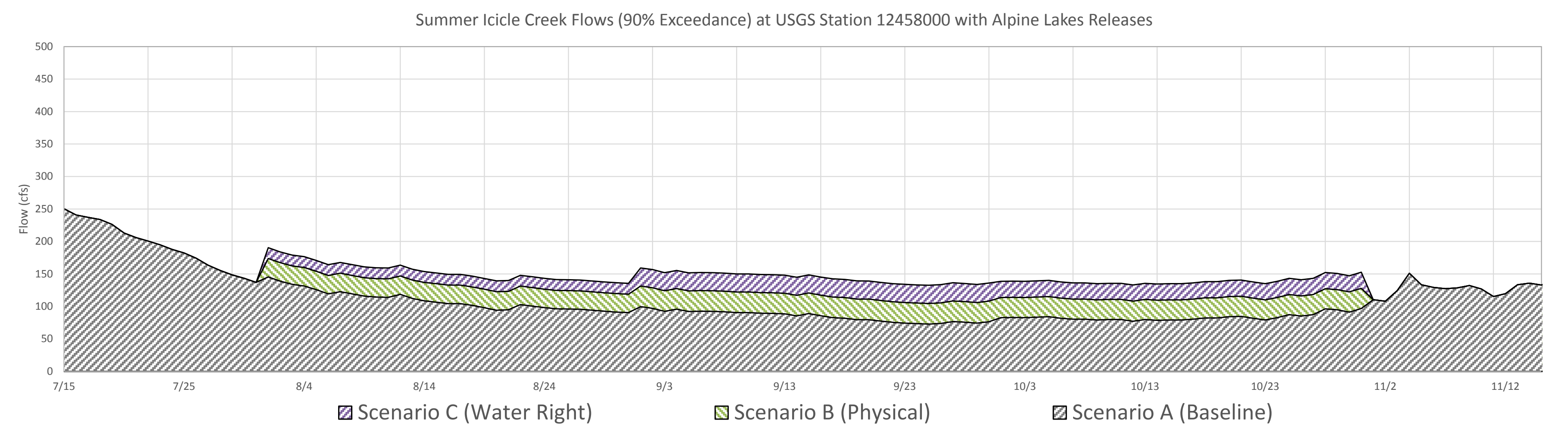


Figure 9 - Model Summary Results - No Climate Change
Alpine Lakes Optimization and Automation

Model Summary Results - CGCM B1 Model (Less Adverse)

	Total System Annual Average		*Releases above USGS Station (Square, Klonaqua, Eightmile, Colchuck) (cfs)*			*Benefit Above Baseline Scenario (cfs)*			*Total Releases into Icicle Creek (Square, Klonaqua, Eightmile, Colchuck, Nada, Snow) (cfs)*			*Benefit Above Baseline Scenario (cfs)*		
Model Scenario	Releases in acre-feet (Aug-Sept-Oct)	Chance to Refill	August	September	October	August	September	October	August	September	October	August	September	October
Scenario A (Baseline)	8,026.44	99.4%	9.92	16.41	27.80	-	-	-	27.92	40.41	59.80	-	-	-
Scenario B (Physical)	13,590.59	98.9%	33.36	38.12	45.77	23.44	21.71	17.97	56.36	72.12	90.77	28.44	31.71	30.97
Scenario C (Water Right)	17,934.30	94.8%	40.00	56.00	60.67	30.08	39.59	32.87	73.00	100.00	115.67	45.08	59.59	55.87



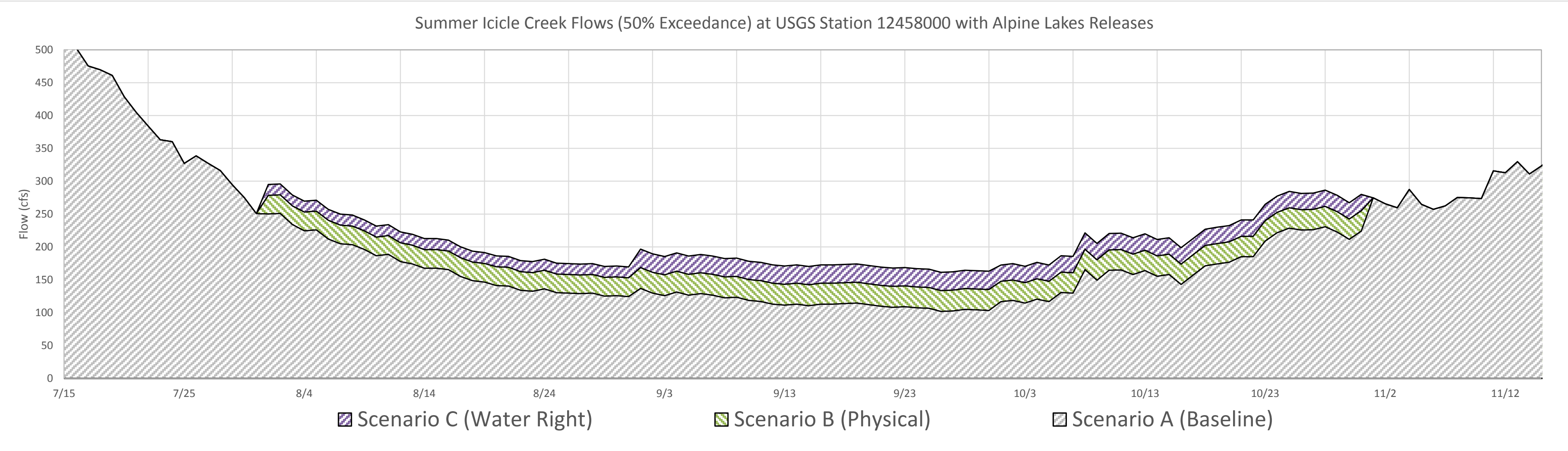


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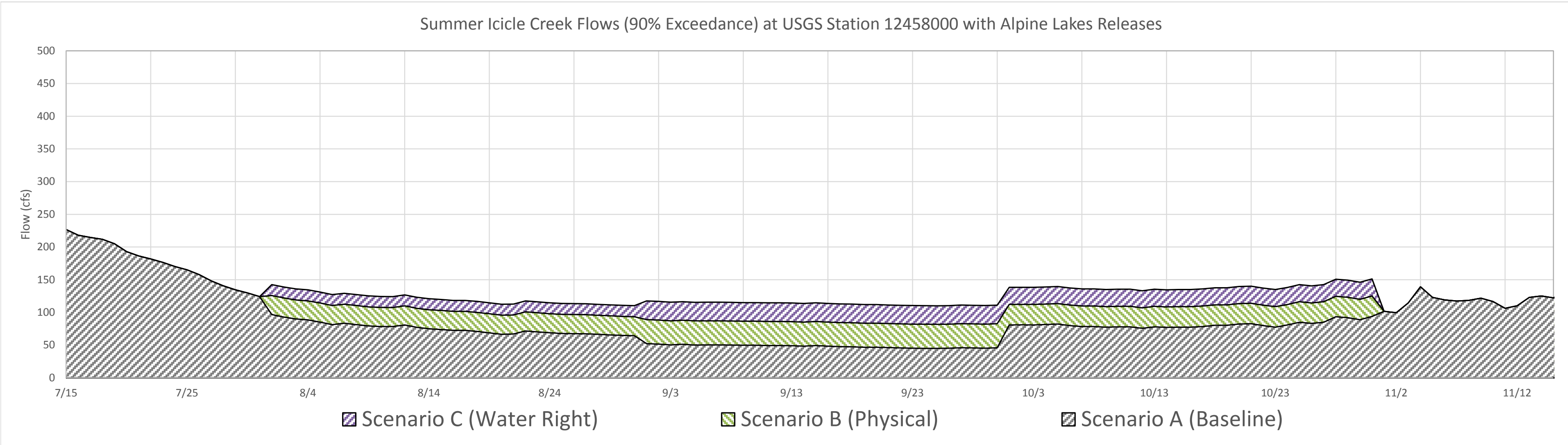
Figure 10 - Model Summary Results - CGCM B1 Model (Less Adverse)
Alpine Lakes Optimization and Automation

Model Summary Results - HADCM B1 Model (Moderate)

	Total System Annual Average		*Releases above USGS Station (Square, Klonaqua, Eightmile, Colchuck) (cfs)*			*Benefit Above Baseline Scenario (cfs)*			*Total Releases into Icicle Creek (Square, Klonaqua, Eightmile, Colchuck, Nada, Snow) (cfs)*			*Benefit Above Baseline Scenario (cfs)*		
Model Scenario	Releases in acre-feet (Aug-Sept-Oct)	Chance to Refill	August	September	October	August	September	October	August	September	October	August	September	October
Scenario A (Baseline)	7,428.23	99.4%	9.09	10.75	25.36	-	-	-	27.09	34.75	57.36	-	-	-
Scenario B (Physical)	13,372.84	98.9%	33.25	37.55	43.65	24.16	26.80	18.29	56.25	71.55	88.65	29.16	36.80	31.29
Scenario C (Water Right)	17,702.47	89.1%	40.00	56.00	59.79	30.91	45.25	34.43	73.00	100.00	114.79	45.91	65.25	57.43



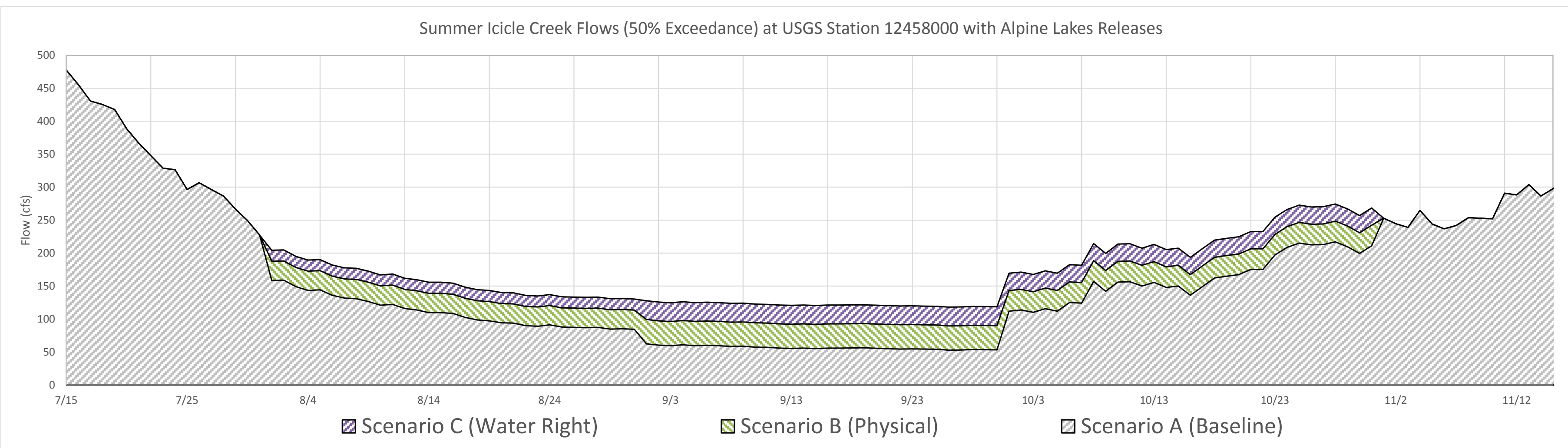
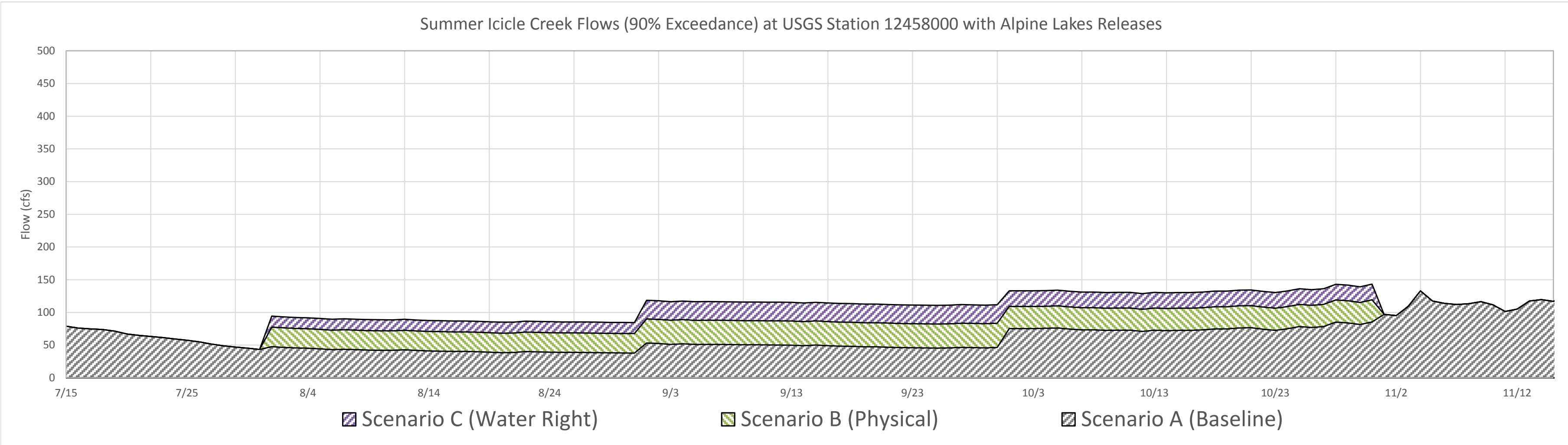
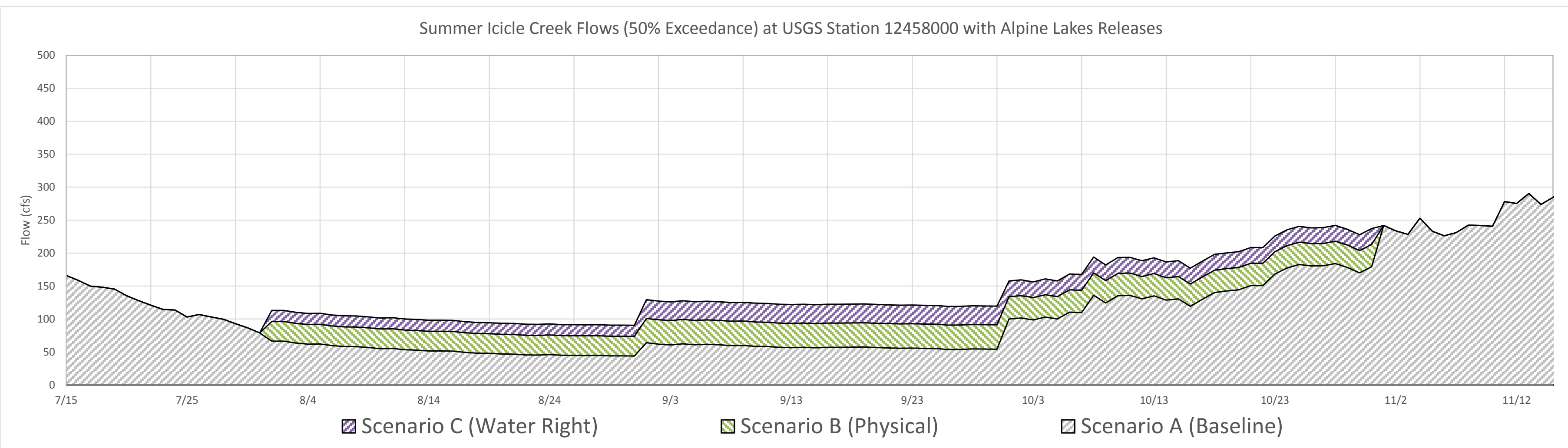


Figure 11 - Model Summary Results - HADCM B1 Model (Moderate)
Alpine Lakes Optimization and Automation

Model Summary Results - HADGEM A1B Model (More Adverse)

Model Scenario	*Total System Annual Average*		*Releases above USGS Station (Square, Klonaqua, Eightmile, Colchuck) (cfs)*			*Benefit Above Baseline Scenario (cfs)*			*Total Releases into Icicle Creek (Square, Klonaqua, Eightmile, Colchuck, Nada, Snow) (cfs)*			*Benefit Above Baseline Scenario (cfs)*		
	Releases in acre-feet (Aug-Sept-Oct)	Chance to Refill	August	September	October	August	September	October	August	September	October	August	September	October
Scenario A (Baseline)	7,099.59	99.4%	8.45	10.65	21.35	-	-	-	26.45	34.65	53.35	-	-	-
Scenario B (Physical)	13,257.18	96.0%	33.25	37.55	42.20	24.80	26.90	20.85	56.25	71.55	87.20	29.80	36.90	33.85
Scenario C (Water Right)	17,452.60	75.9%	40.00	56.00	58.85	31.55	45.35	37.51	73.00	100.00	111.15	46.55	65.35	57.80





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11/12/2014

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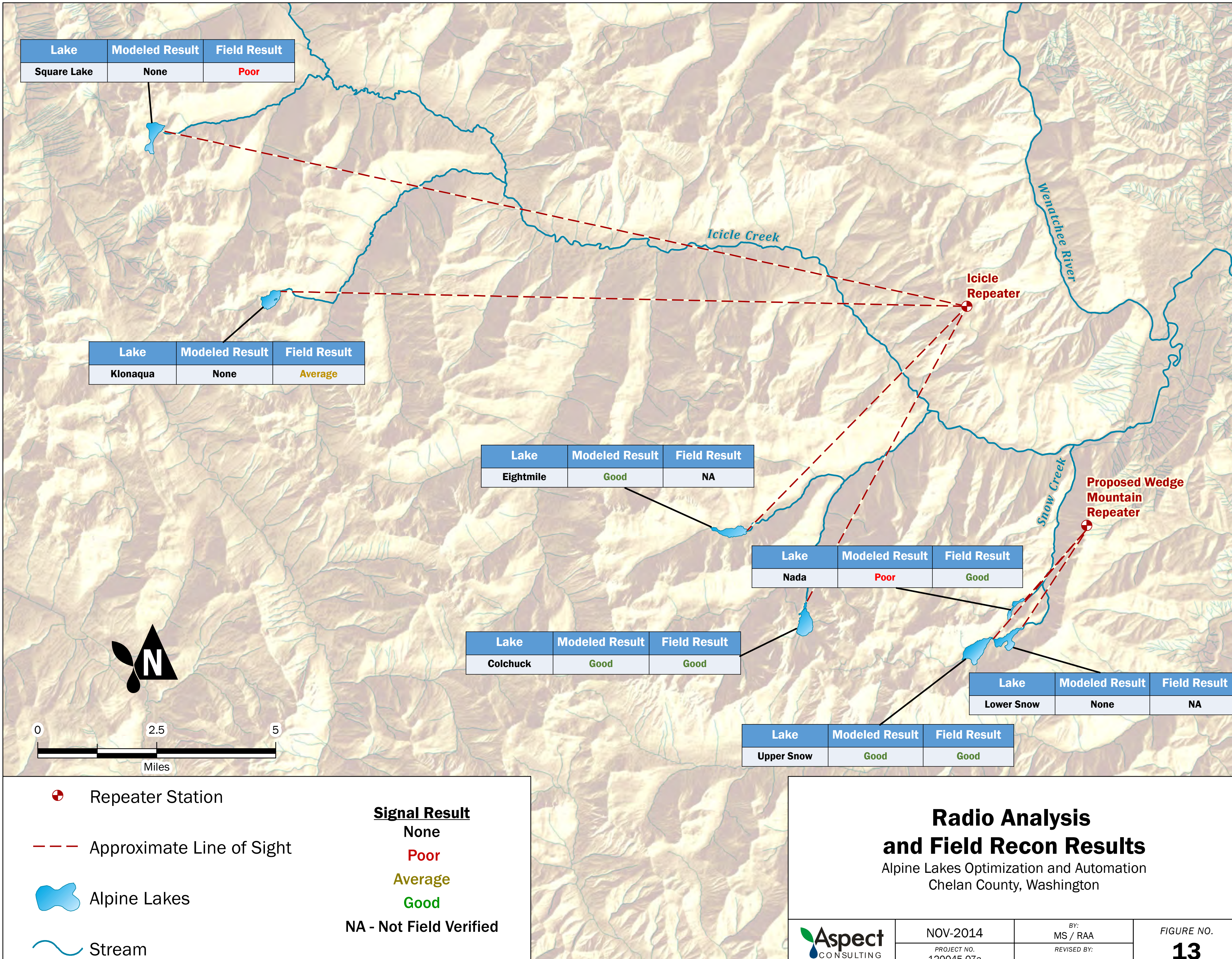
Figure 12 - Model Summary Results - HADGEM A1B Model (More Adverse)

Alpine Lakes Optimization and Automation



Lake	Modeled Result	Field Result
Square Lake	None	Poor

Lake	Modeled Result	Field Result
Klonaqua	None	Average

Lake	Modeled Result	Field Result
Eightmile	Good	NA

Lake	Modeled Result	Field Result
Nada	Poor	Good

Lake	Modeled Result	Field Result
Colchuck	Good	Good

Lake	Modeled Result	Field Result
Lower Snow	None	NA

Lake	Modeled Result	Field Result
Upper Snow	Good	Good

Repeater Station

Approximate Line of Sight

Alpine Lakes

Stream

Signal Result
None
Poor
Average
Good
NA - Not Field Verified

Radio Analysis and Field Recon Results

Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING

NOV-2014	BY: MS / RAA	FIGURE NO. 13
PROJECT NO. 120045-07a	REVISED BY: - - -	

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APPENDIX A

Opinions of Probable Costs

Opinion of Probable Costs D. Rice
Alpine Lakes Automation and Optimization Assessment 18-Nov-14
Alternative **1A**

			SQUARE LAKE		KLONAQUA LAKES		EIGHTMILE LAKE		COLCHUCK LAKE		SNOW LAKES		TOTAL
ITEM	**UNIT**	**UNIT COST**	**QUANTITY**	**COST**	**QUANTITY**	**COST**	**QUANTITY**	**COST**	**QUANTITY**	**COST**	**QUANTITY**	**COST**	**COST**
Install Monitoring Equipment													
Install Staff Gage / Lake Level Monitoring (Bubbler Type)	EA	$7,500	1	$7,500							1	$7,500	$15,000
Install Staff Gage / Lake Level Monitoring (Transducer Type)	EA	$3,500			1	$3,500	1	$3,500	1	$3,500	2	$7,000	$17,500
Install Staff Gage / Discharge Monitoring and Develop Rating	EA	$6,500	1	$6,500	1	$6,500	1	$6,500	1	$6,500			$26,000
Subtotal - Install Monitoring Equipment				**$14,000**		**$10,000**		**$10,000**		**$10,000**		**$14,500**	**$58,500**
Replace or Refurbish Existing Control Gate													
Remove Existing Gates	LS	N/A											
Install 36-inch Diameter Slide Gate, Replace Gate Tower (Eightmile Lake)	LS	N/A											
Remove Existing Mechanical Actuator, Replace Stem, Misc. Modificaitons	LS	N/A											
Replace or Refurbish Gate and Actuator Enclosures/Access	LS	N/A											
Subtotal - Replace Existing Control Gate													
Automate Gates/Valves to Optimize Releases													
Motorized Valve or Gate Actuator	EA	$20,000											
Power Supply (Solar Panels and Battery Pack)	EA	$5,000											
Controls, Communications/Telemetry and Enclosure	EA	$7,500											
Repeater Station	EA	$25,000											
Subtotal - Automate Gates/Valves to Optimize Releases													
Clear Wood and Debris from Dam													
Clear Wood and Debris from Dam	LS	N/A											
Subtotal - Clear Wood and Debris from Dam													
Install New Low Level Outlet Pipe or Siphon with Gate													
Slipline Existing Outlet with 30-inch HDPE Siphon (Eightmile Lake)	LF	$221											
Install 24-inch Low Level Outlet Pipe at New Dam (Upper Snow Lake)	LF	$190											
Install 24-inch Low Level Outlet Pipe at New Dam (Lower Snow Lake)	LF	$190											
Install Air Vent on Siphon or Outlet	EA	$2,500											
Install Intake Screen on Siphon or Outlet	EA	$12,000											
Install 30-inch Control Valve (Eightmile Lake)	EA	$5,000											
Install 24-inch Diameter Flap Gate (Upper Snow Lake)	EA	$4,200											
Install 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$4,200											
Automate New 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$32,500											
Subtotal - Install New Low Level Outlet Pipe or Siphon with Gate													
Repair/Rebuild Dam													
Clearing and Tree Removal	LS	N/A											
Stripping and Stockpiling of Organic Material	CY	$6											
Diversion and Care of Water	LS	N/A											
Temporary Erosion and Sediment Control	LS	N/A											
Demolition/Removal of Existing Dams	LS	N/A											
Loose Rock Removal for Dam Construction	CY	$45											
Hard Rock Removal for Dam Construction	CY	$110											
Waste of Excavated Material On Site	CY	$12											
Installation of Drilled Rock Anchors	LF	$120											
Place Reinforced Concrete for Dam	CY	$1,000											
Place Rock/Masonry Facing on Dam	SF	$50											
Additional Rock Removal for Dam Construction (Klonoqua, 1-foot higher)	CY	$45											
Additional Waste of Excavated Material On Site (Klonoqua, 1-foot higher)	CY	$12											
Additional Place Reinforced Concrete for Dam (Klonoqua, 1-foot higher)	CY	$1,000											
Additional Place Rock/Masonry Facing on Dam (Klonoqua, 1-foot higher)	SF	$50											
Install Wood Walkway On Dam Crest	SF	$25											
Subtotal - Repair/Rebuild Dam													
Subtotal - All Work				**$14,000**		**$10,000**		**$10,000**		**$10,000**		**$14,500**	**$58,500**
Mobilization Costs (Does Not Include Use of Helicopter)				**$1,050**		**$750**		**$750**		**$750**		**$1,088**	**$4,388**
Miscellaneous Mobilization/Demobilization	7.5%			$1,050		$750		$750		$750		$1,088	$4,388
Helicopter Mobilization/Demoblization/Rental													
Construction Subtotal				**$15,100**		**$10,800**		**$10,800**		**$10,800**		**$15,600**	**$63,100**
Contingency	30.0%			$4,530		$3,240		$3,240		$3,240		$4,680	$18,930
Engineering, Permitting and Administration	20.0%			$906		$648		$648		$648		$936	$3,786
Sales Tax	8.2%			$74		$53		$53		$53		$77	$310
Total Project Cost				**$20,600**		**$14,700**		**$14,700**		**$14,700**		**$21,300**	**$86,000**
Existing Usable Storage Capacity				2,400		1,920		1,375		1,570		12,600	19,865
Usefule Storage Capacity After Project Implementation				2,400		1,920		1,375		1,570		12,600	19,865
Existing Release Capacity[3]													8,200
Estimated Release Capacity After Project Implementation[3]													13,700
Additional Release Available Due to Project (Acre-feet)													5,500
Additional Release Available Due to Project (cfs, 92-day release period)													30
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$16**
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$2,853**

Notes:
1) This opinion of cost was developed in November 2014. Actual costs may vary depending on labor and materials costs at the time of construction.
2) Subtotals and totals are rounded to the nearest $100.
3) Estimated existing release capacity and release capacity following project implementation is from the optimization analysis and assumes reliability is maintained following a drought year (recharge inflows are sufficent to replace water released).

Opinion of Probable Costs D. Rice
Alpine Lakes Automation and Optimization Assessment 18-Nov-14
Alternative **1B**

ITEM	UNIT	UNIT COST	SQUARE LAKE QUANTITY	SQUARE LAKE COST	KLONAQUA LAKES QUANTITY	KLONAQUA LAKES COST	EIGHTMILE LAKE QUANTITY	EIGHTMILE LAKE COST	COLCHUCK LAKE QUANTITY	COLCHUCK LAKE COST	SNOW LAKES QUANTITY	SNOW LAKES COST	TOTAL COST
Install Monitoring Equipment													
Install Staff Gage / Lake Level Monitoring (Bubbler Type)	EA	$7,500	1	$7,500							1	$7,500	$15,000
Install Staff Gage / Lake Level Monitoring (Transducer Type)	EA	$3,500			1	$3,500	1	$3,500	1	$3,500	2	$7,000	$17,500
Install Staff Gage / Discharge Monitoring and Develop Rating	EA	$6,500	1	$6,500	1	$6,500	1	$6,500	1	$6,500			$26,000
Subtotal - Install Monitoring Equipment				**$14,000**		**$10,000**		**$10,000**		**$10,000**		**$14,500**	**$58,500**
Replace or Refurbish Existing Control Gate													
Remove Existing Gates	LS	N/A					1	$2,500					$2,500
Install 36-inch Diameter Slide Gate, Replace Gate Tower (Eightmile Lake)	LS	N/A					1	$20,000					$20,000
Remove Existing Mechanical Actuator, Replace Stem, Misc. Modificaitons	LS	N/A	1	$5,000	1	$3,500			1	$7,500	1	$1,500	$17,500
Replace or Refurbish Gate and Actuator Enclosures/Access	LS	N/A	1	$5,000	1	$2,500			1	$1,500			$9,000
Subtotal - Replace Existing Control Gate				**$10,000**		**$6,000**		**$22,500**		**$9,000**		**$1,500**	**$49,000**
Automate Gates/Valves to Optimize Releases													
Motorized Valve or Gate Actuator	EA	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	$100,000
Power Supply (Solar Panels and Battery Pack)	EA	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	$25,000
Controls, Communications/Telemetry and Enclosure	EA	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	$37,500
Repeater Station	EA	$25,000	0.25	$6,250	0.25	$6,250	0.25	$6,250	0.25	$6,250	1	$25,000	$50,000
Subtotal - Automate Gates/Valves to Optimize Releases				**$38,800**		**$38,800**		**$38,800**		**$38,800**		**$57,500**	**$212,700**
Clear Wood and Debris from Dam													
Clear Wood and Debris from Dam	LS	N/A	1	$5,000	1	$5,000	1	$5,000	1	$4,000	1	$8,000	$27,000
Subtotal - Clear Wood and Debris from Dam				**$5,000**		**$5,000**		**$5,000**		**$4,000**		**$8,000**	**$27,000**
Install New Low Level Outlet Pipe or Siphon with Gate													
Slipline Existing Outlet with 30-inch HDPE Siphon (Eightmile Lake)	LF	$221											
Install 24-inch Low Level Outlet Pipe at New Dam (Upper Snow Lake)	LF	$190											
Install 24-inch Low Level Outlet Pipe at New Dam (Lower Snow Lake)	LF	$190											
Install Air Vent on Siphon or Outlet	EA	$2,500											
Install Intake Screen on Siphon or Outlet	EA	$12,000											
Install 30-inch Control Valve (Eightmile Lake)	EA	$5,000											
Install 24-inch Diameter Flap Gate (Upper Snow Lake)	EA	$4,200											
Install 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$4,200											
Automate New 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$32,500											
Subtotal - Install New Low Level Outlet Pipe or Siphon with Gate													
Repair/Rebuild Dam													
Clearing and Tree Removal	LS	N/A											
Stripping and Stockpiling of Organic Material	CY	$6											
Diversion and Care of Water	LS	N/A											
Temporary Erosion and Sediment Control	LS	N/A											
Demolition/Removal of Existing Dams	LS	N/A											
Loose Rock Removal for Dam Construction	CY	$45											
Hard Rock Removal for Dam Construction	CY	$110											
Waste of Excavated Material On Site	CY	$12											
Installation of Drilled Rock Anchors	LF	$120											
Place Reinforced Concrete for Dam	CY	$1,000											
Place Rock/Masonry Facing on Dam	SF	$50											
Additional Rock Removal for Dam Construction (Klonoqua, 1-foot higher)	CY	$45											
Additional Waste of Excavated Material On Site (Klonoqua, 1-foot higher)	CY	$12											
Additional Place Reinforced Concrete for Dam (Klonoqua, 1-foot higher)	CY	$1,000											
Additional Place Rock/Masonry Facing on Dam (Klonoqua, 1-foot higher)	SF	$50											
Install Wood Walkway On Dam Crest	SF	$25											
Subtotal - Repair/Rebuild Dam													
Subtotal - All Work				**$67,800**		**$59,800**		**$76,300**		**$61,800**		**$81,500**	**$347,200**
Mobilization Costs (Assumes Use of Helicopter)				**$30,085**		**$29,485**		**$30,723**		**$29,635**		**$31,113**	**$151,040**
Miscellaneous Mobilization/Demobilization	7.5%			$5,085		$4,485		$5,723		$4,635		$6,113	$26,040
Helicopter Mobilization/Demoblization/Rental				$25,000		$25,000		$25,000		$25,000		$25,000	$125,000
Construction Subtotal				**$97,900**		**$89,300**		**$107,000**		**$91,400**		**$112,600**	**$498,200**
Contingency	30.0%			$29,370		$26,790		$32,100		$27,420		$33,780	$149,460
Engineering, Permitting and Administration	20.0%			$5,874		$5,358		$6,420		$5,484		$6,756	$29,892
Sales Tax	8.2%			$482		$439		$526		$450		$554	$2,451
Total Project Cost				**$133,600**		**$121,900**		**$146,000**		**$124,800**		**$153,700**	**$680,000**
Existing Usable Storage Capacity				2,400		1,920		1,375		1,570		12,600	19,865
Usefule Storage Capacity After Project Implementation				2,400		1,920		1,375		1,570		12,600	19,865
Existing Release Capacity[3]													8,200
Estimated Release Capacity After Project Implementation[3]													13,700
Additional Release Available Due to Project (Acre-feet)													5,500
Additional Release Available Due to Project (cfs, 92-day release period)													30
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$124**
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$22,561**

Notes:
1) This opinion of cost was developed in November 2014. Actual costs may vary depending on labor and materials costs at the time of construction.
2) Subtotals and totals are rounded to the nearest $100.
3) Estimated existing release capacity and release capacity following project implementation is from the optimization analysis and assumes reliability is maintained following a drought year (recharge inflows are sufficent to replace water released)

Opinion of Probable Costs D. Rice
Alpine Lakes Automation and Optimization Assessment 18-Nov-14
Alternative **2A**

ITEM	UNIT	UNIT COST	SQUARE LAKE QUANTITY	SQUARE LAKE COST	KLONAQUA LAKES QUANTITY	KLONAQUA LAKES COST	EIGHTMILE LAKE QUANTITY	EIGHTMILE LAKE COST	COLCHUCK LAKE QUANTITY	COLCHUCK LAKE COST	SNOW LAKES QUANTITY	SNOW LAKES COST	TOTAL COST
Install Monitoring Equipment													
Install Staff Gage / Lake Level Monitoring (Bubbler Type)	EA	$7,500	1	$7,500							1	$7,500	$15,000
Install Staff Gage / Lake Level Monitoring (Transducer Type)	EA	$3,500			1	$3,500	1	$3,500	1	$3,500	2	$7,000	$17,500
Install Staff Gage / Discharge Monitoring and Develop Rating	EA	$6,500	1	$6,500	1	$6,500	1	$6,500	1	$6,500			$26,000
Subtotal - Install Monitoring Equipment				**$14,000**		**$10,000**		**$10,000**		**$10,000**		**$14,500**	**$58,500**
Replace or Refurbish Existing Control Gate													
Remove Existing Gates	LS	N/A					1	$2,500					$2,500
Install 36-inch Diameter Slide Gate, Replace Gate Tower (Eightmile Lake)	LS	N/A											
Remove Existing Mechanical Actuator, Replace Stem, Misc. Modificaitons	LS	N/A	1	$5,000	1	$3,500			1	$7,500	1	$1,500	$17,500
Replace or Refurbish Gate and Actuator Enclosures/Access	LS	N/A	1	$5,000	1	$2,500			1	$1,500			$9,000
Subtotal - Replace Existing Control Gate				**$10,000**		**$6,000**		**$2,500**		**$9,000**		**$1,500**	**$29,000**
Automate Gates/Valves to Optimize Releases													
Motorized Valve or Gate Actuator	EA	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	$100,000
Power Supply (Solar Panels and Battery Pack)	EA	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	$25,000
Controls, Communications/Telemetry and Enclosure	EA	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	$37,500
Repeater Station	EA	$25,000	0.25	$6,250	0.25	$6,250	0.25	$6,250	0.25	$6,250	1	$25,000	$50,000
Subtotal - Automate Gates/Valves to Optimize Releases				**$38,800**		**$38,800**		**$38,800**		**$38,800**		**$57,500**	**$212,700**
Clear Wood and Debris from Dam													
Clear Wood and Debris from Dam	LS	N/A	1	$5,000	1	$5,000	1	$5,000	1	$4,000	1	$8,000	$27,000
Subtotal - Clear Wood and Debris from Dam				**$5,000**		**$5,000**		**$5,000**		**$4,000**		**$8,000**	**$27,000**
Install New Low Level Outlet Pipe or Siphon with Gate													
Slipline Existing Outlet with 30-inch HDPE Siphon (Eightmile Lake)	LF	$221					680	$150,280					$150,280
Install 24-inch Low Level Outlet Pipe at New Dam (Upper Snow Lake)	LF	$190									25	$4,750	$4,750
Install 24-inch Low Level Outlet Pipe at New Dam (Lower Snow Lake)	LF	$190									25	$4,750	$4,750
Install Air Vent on Siphon or Outlet	EA	$2,500					1	$2,500			2	$5,000	$7,500
Install Intake Screen on Siphon or Outlet	EA	$12,000					1	$12,000			2	$24,000	$36,000
Install 30-inch Control Valve (Eightmile Lake)	EA	$5,000					2	$10,000					$10,000
Install 24-inch Diameter Flap Gate (Upper Snow Lake)	EA	$4,200									1	$4,200	$4,200
Install 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$4,200									1	$4,200	$4,200
Automate New 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$32,500									1	$32,500	$32,500
Subtotal - Install New Low Level Outlet Pipe or Siphon with Gate								**$174,800**				**$79,400**	**$254,200**
Repair/Rebuild Dam													
Clearing and Tree Removal	LS	N/A					1	$3,414			1	$40,000	$43,414
Stripping and Stockpiling of Organic Material	CY	$6					213	$1,278			144	$864	$2,142
Diversion and Care of Water	LS	N/A					1	$15,000			1	$22,000	$37,000
Temporary Erosion and Sediment Control	LS	N/A					1	$15,000			1	$22,000	$37,000
Demolition/Removal of Existing Dams	LS	N/A					1	$10,000			1	$25,000	$35,000
Loose Rock Removal for Dam Construction	CY	$45					32	$1,440			64	$2,900	$4,340
Hard Rock Removal for Dam Construction	CY	$110					128	$14,080					$14,080
Waste of Excavated Material On Site	CY	$12					373	$4,476			208	$2,501	$6,977
Installation of Drilled Rock Anchors	LF	$120					150	$18,000			190	$22,800	$40,800
Place Reinforced Concrete for Dam	CY	$1,000					259	$259,000			165	$165,000	$424,000
Place Rock/Masonry Facing on Dam	SF	$50					3,120	$156,000			3,403	$170,150	$326,150
Additional Rock Removal for Dam Construction (Klonoqua, 1-foot higher)	CY	$45											
Additional Waste of Excavated Material On Site (Klonoqua, 1-foot higher)	CY	$12											
Additional Place Reinforced Concrete for Dam (Klonoqua, 1-foot higher)	CY	$1,000											
Additional Place Rock/Masonry Facing on Dam (Klonoqua, 1-foot higher)	SF	$50											
Install Wood Walkway On Dam Crest	SF	$25					570	$14,250			870	$21,750	$36,000
Subtotal - Repair/Rebuild Dam								**$511,900**				**$495,000**	**$1,006,900**
Subtotal - All Work				**$67,800**		**$59,800**		**$743,000**		**$61,800**		**$655,900**	**$1,588,300**
Mobilization Costs (Assumes Use of Helicopter)				**$30,085**		**$29,485**		**$372,525**		**$29,635**		**$329,193**	**$790,923**
Miscellaneous Mobilization/Demobilization	7.5%			$5,085		$4,485		$55,725		$4,635		$49,193	$119,123
Helicopter Mobilization/Demoblization/Rental				$25,000		$25,000		$316,800		$25,000		$280,000	$671,800
Construction Subtotal				**$97,900**		**$89,300**		**$1,115,500**		**$91,400**		**$985,100**	**$2,379,200**
Contingency	30.0%			$29,370		$26,790		$334,650		$27,420		$295,530	$713,760
Engineering, Permitting and Administration	20.0%			$5,874		$5,358		$66,930		$5,484		$59,106	$142,752
Sales Tax	8.2%			$482		$439		$5,488		$450		$4,847	$11,706
Total Project Cost				**$133,600**		**$121,900**		**$1,522,600**		**$124,800**		**$1,344,600**	**$3,247,500**
Existing Usable Storage Capacity				2,400		1,920		1,375		1,570		12,600	19,865
Usefule Storage Capacity After Project Implementation				2,400		1,920		2,500		1,570		13,679	22,069
Existing Release Capacity[3]													8,200
Estimated Release Capacity After Project Implementation[3]													15,904
Additional Release Available Due to Project (Acre-feet)													7,704
Additional Release Available Due to Project (cfs, 92-day release period)													42
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$422**
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$76,921**

Notes:
1) This opinion of cost was developed in November 2014. Actual costs may vary depending on labor and materials costs at the time of construction.
2) Subtotals and totals are rounded to the nearest $100.
3) Estimated existing release capacity and release capacity following project implementation is from the optimization analysis and assumes reliability is maintained following a drought year (recharge inflows are sufficent to replace water released)

Opinion of Probable Costs D. Rice
Alpine Lakes Automation and Optimization Assessment 18-Nov-14
Alternative **2B**

			SQUARE LAKE		KLONAQUA LAKES		EIGHTMILE LAKE		COLCHUCK LAKE		SNOW LAKES		TOTAL
ITEM	UNIT	UNIT COST	QUANTITY	COST	QUANTITY	COST	QUANTITY	COST	QUANTITY	COST	QUANTITY	COST	COST
Install Monitoring Equipment													
Install Staff Gage / Lake Level Monitoring (Bubbler Type)	EA	$7,500	1	$7,500							1	$7,500	$15,000
Install Staff Gage / Lake Level Monitoring (Transducer Type)	EA	$3,500			1	$3,500	1	$3,500	1	$3,500	2	$7,000	$17,500
Install Staff Gage / Discharge Monitoring and Develop Rating	EA	$6,500	1	$6,500	1	$6,500	1	$6,500	1	$6,500			$26,000
Subtotal - Install Monitoring Equipment				**$14,000**		**$10,000**		**$10,000**		**$10,000**		**$14,500**	**$58,500**
Replace or Refurbish Existing Control Gate													
Remove Existing Gates	LS	N/A					1	$2,500					$2,500
Install 36-inch Diameter Slide Gate, Replace Gate Tower (Eightmile Lake)	LS	N/A											
Remove Existing Mechanical Actuator, Replace Stem, Misc. Modificaitons	LS	N/A	1	$5,000	1	$3,500			1	$7,500	1	$1,500	$17,500
Replace or Refurbish Gate and Actuator Enclosures/Access	LS	N/A	1	$5,000	1	$2,500			1	$1,500			$9,000
Subtotal - Replace Existing Control Gate				**$10,000**		**$6,000**		**$2,500**		**$9,000**		**$1,500**	**$29,000**
Automate Gates/Valves to Optimize Releases													
Motorized Valve or Gate Actuator	EA	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	1	$20,000	$100,000
Power Supply (Solar Panels and Battery Pack)	EA	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	$25,000
Controls, Communications/Telemetry and Enclosure	EA	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	1	$7,500	$37,500
Repeater Station	EA	$25,000	0.25	$6,250	0.25	$6,250	0.25	$6,250	0.25	$6,250	1	$25,000	$50,000
Subtotal - Automate Gates/Valves to Optimize Releases				**$38,800**		**$38,800**		**$38,800**		**$38,800**		**$57,500**	**$212,700**
Clear Wood and Debris from Dam													
Clear Wood and Debris from Dam	LS	N/A	1	$5,000	1	$5,000	1	$5,000	1	$4,000	1	$8,000	$27,000
Subtotal - Clear Wood and Debris from Dam				**$5,000**		**$5,000**		**$5,000**		**$4,000**		**$8,000**	**$27,000**
Install New Low Level Outlet Pipe or Siphon with Gate													
Slipline Existing Outlet with 30-inch HDPE Siphon (Eightmile Lake)	LF	$221					680	$150,280					$150,280
Install 24-inch Low Level Outlet Pipe at New Dam (Upper Snow Lake)	LF	$190									25	$4,750	$4,750
Install 24-inch Low Level Outlet Pipe at New Dam (Lower Snow Lake)	LF	$190									25	$4,750	$4,750
Install Air Vent on Siphon or Outlet	EA	$2,500					1	$2,500			2	$5,000	$7,500
Install Intake Screen on Siphon or Outlet	EA	$12,000					1	$12,000			2	$24,000	$36,000
Install 30-inch Control Valve (Eightmile Lake)	EA	$5,000					2	$10,000					$10,000
Install 24-inch Diameter Flap Gate (Upper Snow Lake)	EA	$4,200									1	$4,200	$4,200
Install 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$4,200									1	$4,200	$4,200
Automate New 24-inch Diameter Slide Gate (Lower Snow Lake)	EA	$32,500									1	$32,500	$32,500
Subtotal - Install New Low Level Outlet Pipe or Siphon with Gate								**$174,800**				**$79,400**	**$254,200**
Repair/Rebuild Dam													
Clearing and Tree Removal	LS	N/A					1	$3,414			1	$40,000	$43,414
Stripping and Stockpiling of Organic Material	CY	$6					213	$1,278			144	$864	$2,142
Diversion and Care of Water	LS	N/A					1	$15,000			1	$22,000	$37,000
Temporary Erosion and Sediment Control	LS	N/A					1	$15,000			1	$22,000	$37,000
Demolition/Removal of Existing Dams	LS	N/A					1	$10,000			1	$25,000	$35,000
Loose Rock Removal for Dam Construction	CY	$45					32	$1,440			64	$2,900	$4,340
Hard Rock Removal for Dam Construction	CY	$110					128	$14,080					$14,080
Waste of Excavated Material On Site	CY	$12					373	$4,476			208	$2,501	$6,977
Installation of Drilled Rock Anchors	LF	$120					150	$18,000			190	$22,800	$40,800
Place Reinforced Concrete for Dam	CY	$1,000					259	$259,000			165	$165,000	$424,000
Place Rock/Masonry Facing on Dam	SF	$50					3,120	$156,000			3,403	$170,150	$326,150
Additional Rock Removal for Dam Construction (Klonoqua, 1-foot higher)	CY	$45					2	$80					$80
Additional Waste of Excavated Material On Site (Klonoqua, 1-foot higher)	CY	$12					18	$218					$218
Additional Place Reinforced Concrete for Dam (Klonoqua, 1-foot higher)	CY	$1,000					23	$23,000					$23,000
Additional Place Rock/Masonry Facing on Dam (Klonoqua, 1-foot higher)	SF	$50					420	$21,000					$21,000
Install Wood Walkway On Dam Crest	SF	$25					570	$14,250			870	$21,750	$36,000
Subtotal - Repair/Rebuild Dam								**$556,200**				**$495,000**	**$1,051,200**
Subtotal - All Work				**$67,800**		**$59,800**		**$787,300**		**$61,800**		**$655,900**	**$1,632,600**
Mobilization Costs (Assumes Use of Helicopter)				**$30,085**		**$29,485**		**$403,048**		**$29,635**		**$329,193**	**$821,445**
Miscellaneous Mobilization/Demobilization	7.5%			$5,085		$4,485		$59,048		$4,635		$49,193	$122,445
Helicopter Mobilization/Demoblization/Rental				$25,000		$25,000		$344,000		$25,000		$280,000	$699,000
Construction Subtotal				**$97,900**		**$89,300**		**$1,190,300**		**$91,400**		**$985,100**	**$2,454,000**
Contingency	30.0%			$29,370		$26,790		$357,090		$27,420		$295,530	$736,200
Engineering, Permitting and Administration	20.0%			$5,874		$5,358		$71,418		$5,484		$59,106	$147,240
Sales Tax	8.2%			$482		$439		$5,856		$450		$4,847	$12,074
Total Project Cost				**$133,600**		**$121,900**		**$1,624,700**		**$124,800**		**$1,344,600**	**$3,349,600**
Existing Usable Storage Capacity				2,400		1,920		1,375		1,570		12,600	19,865
Usefule Storage Capacity After Project Implementation				2,400		1,920		2,500		1,570		13,679	22,069
Existing Release Capacity[3]													8,200
Estimated Release Capacity After Project Implementation[3]													15,904
Additional Release Available Due to Project (Acre-feet)													7,704
Additional Release Available Due to Project (cfs, 92-day release period)													42
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$435**
Total Project Cost ($/Acre-foot of Additional Usable Storage)													**$79,340**

Notes:
1) This opinion of cost was developed in November 2014. Actual costs may vary depending on labor and materials costs at the time of construction.
2) Subtotals and totals are rounded to the nearest $100.
3) Estimated existing release capacity and release capacity following project implementation is from the optimization analysis and assumes reliability is maintained following a drought year (recharge inflows are sufficent to replace water released)