APPENDIX C

Alpine Lakes Optimization and Automation Feasibility Study

FEASIBILITY STUDY

Alpine Lakes Optimization and Automation

Prepared for:
Chelan County Natural Resources Department

Project No. 120045 • April 30, 2018 Final

earth + water

Aspect CONSULTING

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This project was funded by the Washington State Department of Ecology, Office of Columbia River, Grant Number WROCR-VER1-ChCoNR-00002

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Project Overview

This feasibility study was conducted by Aspect Consulting, LLC (Aspect) and Anchor QEA, LLC (Anchor) 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 (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 lower Icicle Creek.

This project was funded by the Washington State Department of Ecology, Office of Columbia River (Grant Number WROCR-VER1-ChCoNR-00002).

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 feasibly study is to determine whether fatal flaws exist related to optimizing and automating water storage at the seven alpine lakes managed by the Icicle-Peshastin Irrigation District (IPID) and the U.S. Fish and Wildlife Service (USFWS). This included acquisition of field data (e.g., LiDAR mapping), performing pilot releases (e.g., manual optimized-release pursuant to the guiding principles), and progressing the engineering of automation improvements to a conceptual design level (10% engineering). Refined costs and permitting strategies were also explored.

Currently, release from the Alpine Lakes is manually controlled by IPID and USFWS staff hiking into the lakes to periodically manage release from existing manmade infrastructure. In drought years, water is released from all of the lakes to meet IPID and Leavenworth National Fish Hatchery (LNFH) demand. In non-drought years, partial release occurs which results in water remaining in the lakes (subject to additional drawdown periods for maintenance). Automation would allow for additional release from the lakes in non-drought years in a manner that maximizes efficiency in an optimized manner.

Two related studies are being completed concurrently with this study, including improvements and restoration of outlet controlling works at upper Snow Lake and Eightmile Lake, respectively.

Findings

Overall Findings

Based on results of the 2016 and 2017 Pilot Release Studies (Pilot Release Studies), in conjunction with refined storage estimates from LiDAR, and refined engineering developed herein, instream flow augmentation of on the order of 90 cubic feet per second (cfs)[1] and 6,670 acre-feet per year[2] may be released from the lakes in an automated fashion to improve instream flows in Icicle Creek. Water could be adaptively managed with automation but is generally expected to be available for approximately 90 days from mid-July through mid-October.

Typical improvements needed to facilitate automated release include outlet works modification (gate modification or replacement), installation of electronic motorized gate actuators, programable controls, power generation equipment (e.g., solar panels, batteries), communications equipment (e.g., radio modem, directional antennae), and enclosures consisting of modest (e.g., 6-foot square) cast-in-place reinforced concrete shed buildings with faux rock finished exteriors.

No fatal flaws related to optimization or automation were identified during the course of this study; however, continued property owner coordination and acquisition access to land for repeater sites is recommended prior to commencing design and construction. This includes coordination with a private property owner (Johnson’s), who owns the proposed Wedge Mountain repeater site, and the U.S. Forest Service (USFS), who owns the existing Icicle Repeater site. If one or both repeater sites cannot be acquired, the project may still be viable. However, this may require stronger radio signals (e.g., 25 watt in lieu of 5 watt) or alternative means of communication, which were not evaluated herein.

Feasibility level costs for automation have been estimated at $876,000,[3] which include both direct hard costs (construction) and softs costs (design and permitting).

Due to the harsh environmental conditions (extreme heat / cold), equipment design life is expected to be shorter than comparable improvements; therefore, operations and maintenance costs will be higher than usual. For example, electrical equipment and batteries will have shorter design life than customary installation and require more frequent maintenance and replacement. Annual operations and maintenance costs are estimated at approximately $35,700.

[1] Release flows of up to 90 cfs were observed during 2016 pilot release; however, significantly higher release flows may be possible during lake-full conditions. Release flows were limited to 75 cfs during the 2017 pilot release to extend the duration of benefit later into the Icicle low-flow period.

[2] 6,670 acre-feet represents the combined storage volume of Square, Klonaqua, Eightmile and Colchuck. Additional storage volume of approximately 12,730 acre-feet is available in Upper and Lower Snow Lakes. These lakes are already operated each year to augment LNFH operations. Some additional augmentation or instream flow benefit is possible with a tradeoff in refill potential if the following year is a drought.

[3] These costs include the infrastructure necessary for permanent monitoring and control of release from all lakes; however, costs associated with gate replacement and automation at Eightmile and valve replacement at Upper Snow Lakes are excluded (accounted for in separate studies).

LiDAR Mapping Findings

LiDAR data collected at each lake was processed using topographic analysis software (AutoCAD Civil3D). Stage-storage relationship curves were developed from LiDAR for each lake. A summary of active storage volumes calculated based on LiDAR analysis is provided in Table ES-1.

Table ES-1. Alpine Lakes Storage Volume Estimates

Lake Name	Maximum Normal Stage (feet)	Minimum Normal Stage (feet)	Operational Range (feet)	Active Storage Volume (acre-feet)[1]
Square	4,985	4,954	31	2,130
Klonaqua[2]	5,094	5,066	28	1,690
Eightmile	4,667	4,644	23	1,370
Colchuck	5,563	5,546	17	1,480
Upper Snow	5,433	5,273	160	12,590
Lower Snow	5,429	5,427	2	140

Notes:

1) Active storage volume represents the bathymetric volume between maximum normal stage (e.g., spillway elevation) and minimum normal stage (e.g., invert of low level outlet works). Additional dead storage is available in all lakes below manmade controlling works. Further, active storage volumes do not account for additional release volumes which may occur due to natural seepage.

2) Volumes stated represent Lower Klonaqua Lake only. Prior study indicates that approximately 2,450 acre-feet of storage may be available in Upper Klonaqua lake (which would require 50 feet of drawdown).

2016 Pilot Release Findings

The objective of the 2016 pilot release was to simulate optimized release from the IPID-managed Alpine Lakes to meet guiding principles, to the extent feasible while balancing 2016 IPID maintenance objectives and tributary fish protection issues raised by the Instream Flow Subcommittee of the IWG. Key findings are as follows:

- Flow augmentation using over 6,400 acre-feet of water stored in Alpine Lakes reservoirs can significantly enhance stream flows in the Historic Channel of Icicle Creek.
- While flow augmentation is not a total solution for achieving the IWG’s flow targets in the Historic Channel, it might account for about one-third of the solution, based on 2016 results.
- Augmentation flows up to 90 cfs extended Historic Channel flows above the 100 cfs target for 3 weeks of the 9-week low-flow period in 2016, during a period when flows would have otherwise dropped below the target.
- Augmentation flows equaled between 31 and 78 percent of late-season discharge in the Historic Channel.
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonal falling hydrograph. However, flow augmentation

can slow the rate of decline, prolonging the period of time when flows remain above the 100 cfs target.

2017 Pilot Release Findings

The objectives of the 2017 pilot release were to confirm the 2016 findings and to address data gaps. In contrast to the 2016 pilot release, the approach for the 2017 pilot release consisted of preserving water in storage longer in the season by limiting combined releases from the lakes to 75 cfs.

- Findings of the 2016 Pilot Study were generally confirmed. No fatal flaws were identified.
- Flow augmentation releases available from storage in the Alpine Lakes nearing 6,500 acre-feet were confirmed to significantly enhance stream flows in the Historic Channel of Icicle Creek.
- While flow augmentation is not a total solution for achieving the IWG's flow targets in the Historic Channel, it may account for over half the volume needed to meet the target.
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonally falling hydrograph. However, flow augmentation can slow the rate of decline, prolonging the period when flows remain above the target. Specifically, during the 2017 Pilot Study:
  - Augmentation flows of up to 75 cfs improved flows in the Historic Channel by about one half during critical low-flow periods.
  - Augmentation flows increased flows in the Historic Channel of Icicle Creek to above the 100 cfs target for about 10 days.
  - Augmentation flows equaled up to 95 percent of discharge in the Historic Channel during critical low-flow periods.
- Winter augmentation opportunities are limited by lack of sufficient inflows to replace summer and fall storage releases and, at Eightmile Lake, by seepage losses from storage.

Recommendations and Next Steps

Automating and optimizing water storage at the seven Alpine Lakes offers an efficient and 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 implement a project that includes the following:

- Install permanent 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 Snow, 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 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 Feasibility Study* (Anchor and Aspect, 2018), being prepared concurrent with this study.
- Replace the existing valve at Upper Snow Lake, as recommended in the *Snow Lakes Valve Replacement Value Engineering Draft Report* (Reclamation, 2015).

The next steps toward implementation would include:

- Improve accuracy of Icicle Creek discharge monitoring in the Historic Channel by obtaining real-time stream flow measurements at Structure 2 (located at the head of the Historic Channel).
- Determine benefits and impacts of release flows on bull trout habitat in French and Leland creeks that drain Square and Klonaqua lakes, respectively. Additionally, investigate whether release flows above the interim 10 cfs target would not be detrimental after September 15. These lakes hold nearly half the water physically available for flow augmentation, and releases above 10 cfs in late season would provide greater flexibility to manage flow augmentation to Icicle Creek.
- Improve the understanding of the fate of flow augmentation water including lag effects due to stream channel storage. Evaluate gaining/losing characteristics of tributaries draining reservoirs and mainstem Icicle Creek.
- Coordinate with USFWS to improve understanding of releases from Snow Lakes.
- Coordinate with USFWS, IPID, Cascade Orchards Irrigation Company, and the City of Leavenworth to quantify diversions occurring upstream of the Historic Channel. Perform property owner negotiation, including submitting preliminary special use permit, for USFS site.
- Completion of Programmatic Environmental Impact Study (PEIS).
- Perform additional communications testing if land associated with preferred communications radio repeaters is unsuccessful. If needed, evaluate modifications that could be made to mitigate for communications related changes if needed.
- Negotiate with landowners (Johnson's and USFS) regarding use of their lands for permanent repeater site installations.
- Perform engineering design and cost estimating of improvements.
- Negotiate trust water agreement and obtain a new secondary use permit from Ecology for instream flow benefit.

- Continue monitoring of flow and water quality in Icicle Creek and key bull trout tributaries (e.g., French Creek, Leland Creek) as part of continuing pilot release.

Introduction

The Chelan County Natural Resources Department (CCNRD), Icicle and Peshastin Irrigation Districts (IPID), and the Icicle Work Group (IWG) requested that Aspect Consulting, LLC (Aspect) and Anchor QEA, LLC (Anchor) provide an evaluation of the automation of infrastructure related to seven naturally-occurring alpine lakes (Alpine Lakes) which have been enhanced to operate as reservoirs by the U.S. Fish and Wildlife Service (USFWS)/Bureau of Reclamation (Reclamation) and IPID. The Alpine Lakes are part of the Alpine Lakes Wilderness, which is managed by the U.S. Forest Service (USFS).

This report serves to provide a feasibility-level analysis to identify potential fatal flaws and to outline future steps required to proceed with design (Project). This report summarizes recent data collection efforts, preliminary equipment selection and sizing, describes permitting strategy and describes visual impacts resulting from the potential improvements. A Project Vicinity Map is provided as Figure 1.

Icicle Work Group

The IWG has been co-convened by CCNRD and Washington State Department of Ecology (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.

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
    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)

    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
    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.

This Project is expected to meet all of the guiding principles by helping to sustain streamflows in certain reaches of Icicle Creek during key low-flow periods.

Scope of Work

The scope of work of this study includes feasibility level investigation of automation improvements at the six Alpine Lakes that are operated as reservoirs: Square, Klonaqua, Eightmile, and Colchuck lakes (IPID-managed) and Upper and Lower Snow lakes (USFWS/Reclamation-managed). A seventh lake (Nada) is related to the Alpine Lakes but was excluded from the scope of this Project because it does not contribute appreciable storage volumes and is managed differently than the other lakes.

The project scope of work was completed under the following tasks:

1. **Feasibility Level Design** – Summarize infrastructure improvements necessary for automated release (gates, actuators, measurements, telemetry, and embankment improvements).
2. **Evaluation of Infrastructure Improvements and Identification of Constraints**
3. **Create Conceptual Design Drawings** – Create conceptual design drawings, showing location and general layout of major materials and equipment in plan view.
4. **Project Cost Estimates –** Estimate probable costs for the improvements outlined in the conceptual design.
5. **Aesthetic Impacts –** Develop illustrated rendering of improvements.
6. **Permitting Strategy**

Background

The Alpine Lakes were enhanced to operate as reservoirs by Reclamation and IPID in the 1920s. The following provides background on water management of the lakes under both existing and future conditions.

Prior Studies

The *Water Storage Report, Wenatchee River Basin* (Anchor, 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 water storage in Upper and Lower Snow Lakes and automating releases.

The evaluation of water storage at Snow Lakes presented in Anchor (2011) 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 Anchor (2011) 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.

Anchor and Aspect prepared a report, *Eightmile Lake Storage Restoration Appraisal Study* (Eightmile Lake Appraisal Study; Anchor and Aspect, 2015). The evaluation provided in that report was based on initial work completed by Gravity Consulting (Gravity) and Forsgren Associates (Forsgren), 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.

Aspect and Anchor also prepared a report, *Appraisal Study Alpine Lakes Optimization and Automation* (Alpine Lakes Appraisal Study; Aspect and Anchor, 2015), concurrent with Anchor and Aspect (2015). The Alpine Lakes Appraisal Study evaluated the potential for optimizing releases by automating gates that could be operated remotely by IPID and USFWS. The report concluded that there would be high refill probability at most of the Alpine Lakes, developed conceptual cost estimates for automating lake releases, and identified the potential need for a future feasibility study (this study).

Concurrent Studies

Pilot Release

Optimized manual releases from the Alpine Lakes were performed during the summers of 2016 and 2017 to characterize the effects of releases on Icicle Creek at various control locations (Pilot Release Studies). Results of the Pilot Release Studies are appended to this report (Appendix A).

LiDAR Topographic Mapping

Following the 2016 Pilot Release Study, Light Detection and Ranging (LiDAR) was collected in October 2016 by Quantum Spatial of Corvallis, Oregon. The scope of LiDAR collected included approximately 1,500 acres encompassing Square, Lower Klonaqua, Colchuck, Upper and Lower Snow, and Nada lakes at drawn-down conditions. The LiDAR collection report is provided as Appendix B.

Eightmile Lake Storage Improvements Feasibility Study

Improvements to Eightmile Lake are being evaluated by Anchor and Aspect concurrent with this study. An existing dam consists of a concrete/rock-masonry structure and an earthen embankment. The earthen embankment has eroded at the left edge of the concrete/rock-masonry structure. Due to erosion of the embankment, the dam can now only store water to an elevation of approximately 4,667 feet and IPID can only access approximately 1,375 acre-feet of storage. Further, the current facilities are old and in need of significant repairs. The release gate is damaged and is very difficult to open and close. The low-level outlet pipeline is collapsing in multiple locations and the capacity has been limited as a result.

Improvements planned for Eightmile Lake include replacement of the existing dam with a new dam, spillway, and low-level outlet facilities that meet the following objectives:

- Allow for IPID to store water to the historical spillway elevation of 4,671 feet and access the full capacity allowed by IPID’s water right (2,500 acre-feet of storage);
- Improve operation of the facilities; and
- Replace the existing facilities with facilities that that meets current requirements of the Washington State Department of Ecology Dam Safety Office (DSO).

Water Management Strategy Overview for Alpine Lakes

There are various water management strategies (both existing and proposed) associated with operation of the Alpine Lakes. Release strategies involve both release period (time of year) and release quantities.

Release Period

Under existing conditions, IPID manages the lakes in a manner that meets their operational needs and reduces drought-related risk. This generally involves releasing water from at least one lake per year and alternating between lakes amongst years. During drought years, IPID may release water from two or more lakes, as needed to maintain diversions from Icicle Creek during the late part the irrigation season or when needed for maintenance.[4] A detailed characterization of current operation is provided in Aspect and Anchor (2015).

To meet the IWG Guiding Principles, two enhanced release strategies have been identified to make additional use of combined lake storage and associated release in the future. With both strategies, water management includes drawdown of all lakes each year to the extent that they may be reliably refilled. The Seasonal Release strategy would provide for release from Alpine lakes during the driest period only with release commencing in July and ending in late September or early October.[5] The Year-round Release strategy would include multiple release and refill periods throughout the year. The various release period scenarios are illustrated in Table 1 below.

Table 1. Release Period Scenarios

<table>
<tr><th>Lake</th><th>Existing</th><th>Optimized Seasonal Release</th><th>Optimized Year-round Release</th></tr>
<tr><td>Square</td><td rowspan="4">one release per lake every 4 years, on average</td><td rowspan="6">one release per lake per year</td><td rowspan="4">one to two releases per lake per year</td></tr>
<tr><td>Klonaqua</td></tr>
<tr><td>Eightmile</td></tr>
<tr><td>Colchuck</td></tr>
<tr><td>Upper Snow</td><td rowspan="2">one release per year</td><td rowspan="2">one release per year</td></tr>
<tr><td>Lower Snow</td></tr>
</table>

Release Flows

Square, Klonaqua, Colchuck and Eightmile (IPID-Managed Lakes)

Each lake has various limitations on release flow quantity at various stages. The controlled range of flow releases from the four IPID-managed lakes is approximately 5 to 25 cfs for most lakes, with as high as 50 cfs possible.

Based upon the Pilot Release Studies, release quantities observed at various lakes and stages are shown in Table 2.

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[4] IPID typically performs maintenance on lakes once they are drawn down. Periodic needs for special maintenance may dictate the need for special operation of lakes out of sequence.

[5] Individual lakes would have different exact release periods within this general window.

Table 2. Observed Release Quantities

Lake	Peak Observed Lake Full (cfs)[1]	Drawdown Conditions		
		Observed Flow (cfs)[2]	Stage (ft H_2O)	Estimated Gate Position
Square	35[3]	10	-27.5	Partially Open
Klonaqua	37	1	-23.5	Fully Open
Eightmile[4]	22	2.5[5]	-19.0	Fully Open
Colchuck	28	2	-11.0	Fully Open

Notes:

Higher release flows may be possible during lake-full conditions. Release flows were limited to for stream gauging / safety purposes during pilot releases.

[2] Observed flows at lake discharge during drawdown conditions with gate near maximum degree of open during pilot releases.

[3] Flows as high as 35 cfs were estimated by extrapolating values beyond rating of section (25-cfs limit on measured flows).

[4] IPID has observed that the release capacity from Eightmile Lake was recently reduced over the historical capacity due to partial or full collapse of the low-level outlet pipe at multiple locations.

[5] The release flow of 2.5 cfs is entirely attributed to seepage (i.e., not flowing through the gate, but rather seeping through the ground under the dam.)

During the Pilot Release Studies, observed conditions indicate that relatively modest initial gate settings (e.g., 6-inch gate adjustment) were necessary to achieve flows approaching 25 cfs (or higher). As lake levels dropped, larger gate adjustments were necessary to maintain flows at those levels. As expected, lake levels ultimately dropped sufficiently that peak flows could no longer be maintained with gates fully open. Results of the Pilot Release Studies, including flow release quantities by month, are provided in Figures 6 and 7 of Appendix A.

The primary conclusion from the 2016 Pilot Release Study was that a wide range of controlled flow release is achievable (e.g., 0 cfs to 25 cfs or higher from each lake) within the first 3 to 4 weeks of releases. After that period, the upper limit of releasable flow decreases as the lake level drops.

The results of the 2016 Pilot Release Study were confirmed during the 2017 Pilot Release Study. A key conclusion of the 2017 Pilot Release was that while quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonally falling hydrograph, flow augmentation slowed the rate of decline and prolonged the period when flows remained above the target. Augmentation flow during the 2017 release slowed the rate of the seasonally falling hydrograph by an average of about 1 cfs per day, delaying the date when Icicle flows would otherwise diminish to below the 100 cfs target by approximately 10 days.

Upper and Lower Snow (USFWS/Reclamation-Managed Lakes)

USFWS, in association with Reclamation, manages releases from Snow Lakes to enhance water supply to the Leavenworth National Fish Hatchery (LNFH). LNFH is operated by the USFWS under an agreement with Reclamation as mitigation for impacts from the operation of Grand Coulee Dam. Currently, the USFWS releases water from Upper Snow Lake through a controlled low-level outlet tunnel and pipe to Nada Lake during the late summer. Water flows through Nada Lake and eventually merges with Snow Creek, a tributary to Icicle Creek.

Under full lake level conditions, water from Upper Snow Lake spills over or passes through a small dam structure (Upper Snow Lake Dam) to Lower Snow Lake, and from Lower Snow Lake over a small dam structure (Lower Snow Lake Dam) to Snow Creek. During the late summer, when controlled releases draw down Upper Snow Lake, the water from Lower Snow Lake can be higher than the water level in Upper Snow Lake. As a result, water can flow the opposite direction from Lower Snow Lake through the Upper Snow Lake Dam and into Upper Snow Lake.

Controlled releases from Upper Snow Lake to Nada Lake are limited to approximately 55 cfs by the size of the existing butterfly valve that is used to control those releases. The USFWS and Reclamation are currently exploring options for replacement of the existing valve and related appurtenances to restore flows to historic release conditions. This would allow for full access of water rights that authorize a release of up to 85 cfs by both the USFWS and IPID.

Existing Conditions

Existing conditions were characterized in the Alpine Lakes Appraisal Study (Aspect and Anchor, 2015). Since the completion of that study, new information has been collected (e.g., additional site visits, topographic mapping, etc.). A summary of pertinent information related to existing conditions at each of the Alpine Lakes considered for automation and optimization is provided below.

LiDAR Results, Stage-Storage Summary

LiDAR data collected at each lake was processed using topographic analysis software (AutoCAD Civil3D). Stage-storage relationship curves were developed from LiDAR for each lake and are provided as Figure 2. A summary of active storage volumes calculated based on LiDAR analysis is provided in Table 3 below.

Table 3. Alpine Lakes Storage Volume Estimates

Lake Name	Maximum Normal Stage (feet)	Minimum Normal Stage (feet)	Operational Range (feet)	Active Storage Volume[1] (acre-feet)
Square	4,985	4,954	31	2,130
Klonaqua[2]	5,094	5,066	28	1,690
Eightmile	4,667	4,644	23	1,370
Colchuck	5,563	5,546	17	1,480
Upper Snow	5,433	5,273	160	12,590
Lower Snow	5,429	5,427	2	140

Notes:

1) Active storage volume represents the bathymetric volume between maximum normal stage (e.g., spillway elevation) and minimum normal stage (e.g., invert of low level outlet works). Additional dead storage is available in all lakes below manmade controlling works. Further, active storage volumes do not account for additional release volumes which may occur due to natural seepage.

2) Volumes stated represent Lower Klonaqua Lake only. Prior study indicates that approximately 2,450 acre feet of storage may be available in Upper Klonaqua lake (which would require 50-feet of drawdown).

Existing Infrastructure Summary

Lake / Reservoir Infrastructure

Existing operational infrastructure at each lake is described in the Alpine Lakes Appraisal Study (Aspect and Anchor, 2015) which has been updated with new information. A summary of pertinent infrastructure is provided in Table 4.

Table 4. Alpine Lakes Infrastructure Summary

Lake Name	Dam / Embankment Type		Outlet Works / Control	
Square	Concrete/Rock-Masonry Dam and Spillway	Approx. 85 ft Length x 2 ft Width	5 ft Wide x 7 ft Tall Tunnel	30-inch Circular Gate mounted in Tunnel
Lower Klonaqua	Concrete/Rock-Masonry Dam and Spillway and Earthen / Rock Embankment	Approx. 100 ft Length x 8 ft Crest Width	30-inch Pipe	30-inch Circular Gate mounted in Vertical Gate Chamber
Eightmile Lake	Concrete/Rock-Masonry Dam and Spillway and Earthen / Rock Embankment	Approx. 95 ft Overall Length, width / composition varies	Buried Piped, Various Size / Material	30-inch Circular Gate mounted on Rock Masonry Tower (collapsed)
Colchuck	Concrete Dam and Spillway	Approx. 40 ft Length	Buried Piped	30-inch Rectangular Gate mounted on Rock Masonry Tower
Upper Snow	Rubble Masonry	Approx. 110 ft Length	Tunnel	Gate Valve, 24-inch Butterfly Valve[1]
Lower Snow	Embankment	Approx. 40ft Length	Flap Gate at Upper Snow Lake Dam, Spill at Lower Snow Lake Dam	

USFWS is exploring options which may increase butterfly valve to 36-inch diameter.

Repeater Sites

IPID operates several base stations and repeater sites under two FCC licenses (call signs WQKS355 and WQKR961). An existing radio repeater at Blag Mountain (approximately 7 miles east of Leavenworth, elevation 4,500 feet) is frequently used by IPID. This repeater is identified as Location 2 under FCC Call Sign WQKR961 and is listed with an estimated signal strength of 45 watts.[6] This repeater has line of sight to several key points including:

- IPID Peshatin Headworks
- Icicle Ridge Repeater
- Wedge Mountain Site

[6] IPID District staff has stated that they can typically receive signals from Blag mountain at Eightmile Lake and Colchuck due to the high power signal (45 watt) of the transceiver – despite line-of-sight not being available. At times, IPID is able to transmit signals from Colchuck to the Blag mountain repeater using small handheld radios (5 watt).

The IPID Peshastin Headworks is located several miles up US Route 97 / Peshastin Creek. According to IPID, this facility is relevant due to the main connection to the IPID supervisory control and data acquisition (SCADA) system. This facility could be used to transmit data to other locations within the District or to an internet connection if desired.

The Icicle Ridge Repeater (MGRS 10TFT6856772797) is owned and operated by the USFS and is located approximately 4 miles west of Leavenworth and approximately 7 miles northeast of Eightmile Lake, at an elevation of approximately 6,800 feet. This station is equipped with a 50-watt collinear antenna with a listed height of 6 meters (~20 feet). The site includes onsite power generation (400-watt solar), 500 watt-hours of batteries, and a storage shed. The site is inaccessible by vehicle; however, there is a helipad at the site.

According to Mr. Howard Banks of the USFS (Icicle Repeater facility manager), the equipment has limited capacity for expansion; however, there may be room at the site for additional towers, etc.[7] This site is a candidate location for a new repeater to send and receive signals from the four IPID-managed lakes. It may also be possible to send and receive signals from Snow Lakes and LNFH at this location, although this has not been evaluated.

Wedge Mountain is located approximately 5 miles southwest of Leavenworth and approximately 3 miles northeast of Snow Lakes, at elevation of 5,000 feet. Property at this site (Parcel ID 231703000050) is owned by Robert and Nancy Johnson of Leavenworth, and is a candidate location for a new repeater to Snow Lakes and LNFH. This site may also be conducive to sending and receiving communications from more distant lakes (e.g., Square, Klonaqua, Colchuck and Eightmile) if more powerful signals (e.g., 25 watt signals rather than 5 watt signals) are transmitted from those locations.

Radio repeater sites, including base stations, are identified on Figure 3. Background information related to existing repeater sites is provided in Appendix C.

Site Investigation

A site investigation was performed on October 7, 2016, by Aspect, Anchor, and IPID personnel. The purpose of this investigation was to observe each lake during drawn-down conditions and collect additional data and measurements necessary for completing this feasibility study. Data collected during site investigation included gate operation force measurements. This was performed to establish a baseline for actuator torque and provide as a check on existing gate condition.

The amount of force required to lift or lower gates during drawdown conditions at each lake varies dramatically and is provided in Table 5. The gates at Square, Klonaqua, and Colchuck currently operate using a manual hand wheel operator attached to the gate stem. The estimated torque applied to each of these gate stems to operate the gate was developed based on gear ratios and leverage available at each manual actuator.

[7] Personal communications, telephone conversation, Tony Jantzer and Howard Banks, March 8, 2017.

Table 5. Gate Actuator Force Measurements

Lake Name	Approximate Operating Force (lbs)	Gear Ratio / Description	Estimated Torque Applied to Stem (ft-lbs)
Square	40	18-inch hand crank 3.5-gear 10-inch gear 6-inch gear 18-inch gear to stem	457
Klonaqua	12	24-inch hand crank 5-inch gear 19-inch gear to stem	115
Colchuck	6	28-inch handwheel	7

The stem and hand-wheel operator used to open and close the gate at Eightmile Lake were damaged by ice when the rock-masonry gate tower was destroyed. The damaged hand-wheel operator has since been removed. As a result, opening and closing the gate requires the use of a log as a come along, which is physically challenging.

Eightmile Lake was not visited as part of the October 2016 site investigation since improvements to that structure are being considered under a separate feasibility study. Thsee improvements will likely include replacement of the existing gate and low-level outlet pipe with a new pipeline and valves. Flow from through the low-level outlet will be controlled by a plug valve near the pipe outlet. A gate valve on the pipeline at the dam will allow for isolation of the pipeline below the dam. Additionally, Upper and Lower Snow lakes were not visited as part of the October 2016 site investigation since the USFWS is working directly with Reclamation to replace the outlet control valve as part of maintenance activities.

The gates at Klonaqua, Colchuck, and Eightmile are likely due for replacement; however, IPID's preference is to perform additional inspection of the gate at Square Lake before proceeding with replacement of that gate.

Conceptual Design for Automation

Automation will be accomplished through installation of motorized actuators with onsite power generation (e.g., solar panels). Due to the remote setting in a federally-designated wilderness area, special design criteria and constraints must be considered.

Design Constraints

Various constraints limit the degree and frequency to which adjustments to gates via motorized actuators are made:

Construction Access

The Alpine Lakes are all located in the Alpine Lakes Wilderness Area, so access is limited to foot trails (i.e., there are no roads) and helicopter. Eightmile and Colchuck lakes are accessible by trails that can be hiked within a half-day (less than 5 miles), while Square and Klonoqua lakes are much further (more than 10 miles) from the nearest road or parking area.

In addition to their remote location, gates at Klonoqua and Square lakes are physically constrained: the gate at Klonaqua is located inside a narrow access vault and the gate at Square is located inside a tunnel. The operators are more accessible than the gates themselves. The design of the project will have to consider relatively tight access constraints and limit impact of the proposed improvements on the Wilderness Area.

According to their easement agreement with the USFS, IPID can access the lakes via helicopter for maintenance activities. The USFS completed an Environmental Assessment in 1981 evaluating this access and finding no conflict with the environment (USFS, 1981). In order to limit the cost of constructing the proposed improvements, equipment and materials needed for this Project will likely need to be hauled in via a relatively small helicopter, or by foot.

Construction Equipment

The installation of automating equipment, replacement of gates, placement of solar panels and batteries or other power supply equipment, and installation of enclosures will all likely be completed with hand tools and/or light equipment. Due to the construction access constraints described above, we expect that all work will be completed without the aid of heavy construction equipment.

Construction Timing

Work required to automate the release equipment at each lake is expected to occur when the lakes are fully drawn down, at the end of the summer or early in the fall. The lakes are at high elevations where snow and freezing temperatures typically occur as early as late October and last until May. Therefore, we expect the work window for completing the improvements will be limited to late September and early October.

Power Supply

The remote setting of the lakes in a wilderness area dictates that alternative power supply options be considered for automatic gate operation. At a minimum, battery power is anticipated in conjunction with onsite power generation (e.g., solar, micro-hydropower). Constraints on solar power generation include seasonal direct sunlight (southern exposure) including likely excessive snow cover for much of the year. Constraints on other forms of energy, such as micro-hydropower, include seasonal freezing potential and release period constraints coupled with adequate driving head. Reliability considerations related to power supply should be accounted for commensurate with industry standards (e.g., providing sufficient level of amp-hours supply at adequate voltage to meet certain conditions in the event of onsite power generation failure).

Communications and Controls

The purpose of the Project is to provide for automated and optimized releases from the lakes to enhance the benefit of the releases to instream flows and downstream uses. Therefore, some measure of programable control and logic is necessary. Onsite manual operation of gates is also necessary independent of automation along with a programmed fail-close system. Furthermore, to meet the IWG Guiding Principles, the magnitude and timing of releases from the lakes will depend on Icicle Creek flow conditions, which are monitored outside the wilderness area. For this reason, some frequent measure of communications is necessary to maintain optimized release.

Remote communication options include radio, cellular, and satellite. Constraints related to cellular include poor, weak, or non-existent signal; these constraints cannot be mitigated economically.[8] Satellite communications is constrained by commercial satellite availability and coverage, particularly with respect to obstructions relative to horizon, weather, and other factors. Radio communications is constrained by signal strength / frequency, FCC licensing, relative line of sight, and distance.

Security

Although access to the release sites is limited, security concerns (e.g., vandalism, attractive nuisance) should be considered. At a minimum, facilities should be designed such that equipment cannot be easily adjusted (e.g., actuators and associated controls are either inaccessible or reasonably locked out) or damaged.

Durability

Dramatic climatic conditions are present, including extreme high and low temperatures, deep snow and freezing conditions, high flow and runoff conditions, and wood debris. At a minimum, facilities should be designed to withstand anticipated natural events in addition to a reasonable amount of human tampering.

Aesthetics

Existing visible features associated with manual release from the lakes includes cast iron manual actuators (e.g., Square, Klonaqua, Colchuck), dams (all lakes), concrete / rock-masonry structures (all lakes) and small shed buildings (Snow Lakes). While no discrete minimum measure of aesthetic quality has been established as criteria, aesthetic considerations related to environmental impacts are included under the scope of this

[8] Cellular was tested during Appraisal Study and was deemed infeasible at that time. Additional cellular towers within the project vicinity may be necessary to accommodate cellular service which cannot be predictably expected within the lifespan of this project.

study. It is anticipated that aesthetic modifications to new or replaced infrastructure should be as natural looking as is feasible. Visual impacts should be similar in nature and magnitude to existing improvements, or otherwise concealed from view or camouflaged to look natural.

Design Criteria for Release Automation

Operations and Maintenance

To justify capital expenditures of this Project, operations and maintenance costs should be minimized to the extent feasible. For example, operations and maintenance costs associated with new infrastructure should not approach the alternative cost needed to achieve the same goal with manual labor (i.e., performing manual periodic adjustments on the lakes in lieu of automation). Mechanical/electrical elements (e.g., actuator, controls, communications equipment) should operate with limited repair and maintenance for at least 10 years, with replacement of equipment not necessary sooner than 15 years.

The existing gates have operated for approximately 50 to 60 years.[9] It is reasonable to expect that new comparable gates or valves would have a design life this long with periodic maintenance (at least every 5 years). Batteries are only expected to last 3 to 5 years with lifespan highly dependent on frequency and manner of use; batteries are expected to be a recurring maintenance expense. Due to the remote setting, ease of repairs of faulty/failed equipment is low, particularly during the winter months as many of the lakes are practically inaccessible between November and May.

Reliability

Automated releases will contribute to increased instream flow quantities in Icicle Creek during the late summer low-flow period, which is intended to mitigate for existing and future water uses as part of the IWG guiding principles. Therefore, the need for reliability of automated releases is relatively high. Reliability risk may be mitigated by redundancy (e.g., redundant batteries, alternative controls).

Release Scenarios

Four operational scenarios are being considered amongst two operational alternatives and two release schemes (Table 6). Within each alternative, two operational schemes were considered (daily adjustment vs. weekly adjustment). These scenarios were primarily developed to establish bookends for the purpose of identifying potential infrastructure sizing / configuration ramifications. Operational Alternative 1 includes seasonal release only whereas Operational Alternative 2 includes the option s for multiple releases year-round.[10]

[9] It is estimated that gates may have been last replaced in the 1960s or 1970s.
[10] It is anticipated that only one or two lakes may be operated during a multiple release operational alternative (e.g., wintertime release) and that release flow quantity may be minimal (e.g., 5 to 10 cfs)

Table 6. Operational Scenarios

Operational Scheme	Alternative 1 (Single Release)	Alternative 2 (Multiple Release)
Operational Scheme A (Daily Adjustment)	Scenario 1A	Scenario 2A
Operational Scheme B (Weekly Adjustment)	Scenario 1B	Scenarios 2B

Ramifications of the two operational scenarios include potential tradeoffs in cost vs benefits and anticipated risk. For example, Scenarios 1A and 1B (single release) would involve higher refill probabilities than Scenarios 2A and 2B (multiple release), which would involve releasing water closer to the end of the refill season. Scenarios 1A and 2A (daily adjustment) will require greater power considerations than Scenarios 1B and 2B (weekly adjustment).

Automation Infrastructure Improvements

It is anticipated that automation is feasible within the prescribed criteria and constraints with adequately sized and configured infrastructure. Typical automation improvement concepts have been developed and are shown in Figure 4. Conceptual design of automation improvements for individual lakes has also been developed, as described below and illustrated in the conceptual engineering drawings (10% design level) in Appendix D. Preliminary equipment selections included in the design are described below[11] and sample equipment information (vendor resources) is provided for reference as Appendix E.

Monitoring Equipment

Automation will rely on automated monitoring of conditions (lake stage and discharge flow). Options for monitoring equipment were explored in the *Appraisal Study Alpine Lakes Automation and Optimization* and have not been progressed as part of this study. Improvements will generally consist of installation of pressure transducers, staff gages, and rated release channel sections.[12] Costs associated with these improvements vary by lake and are included in cost estimates as part of this Project.

Outlet Works Improvements

The outlet works at the lakes being considered for automation and optimization of releases typically consist of some type of low-level outlet conveyance (pipeline or tunnel)

[11] Final equipment selections will be made at time of construction based upon engineering design specifications. Vendor cut sheets provided herein are intended to provide examples of products which may meet preliminary criteria.

[12] Temporary monitoring equipment (staff gates and pressure transducers) were installed during the 2016 pilot release however more permanent solutions will be required in conjunction with automation improvements.

and control infrastructure (gates / valves) needed to manage releases.[13] In some cases, existing outlet works are in suitable operating condition; cost for upgrade or replacement of the equipment is likely to exceed the benefit of replacing the equipment. In other instances, modest improvement to outlet works infrastructure is warranted to improve operation and make the facilities compatible with automation improvements.

Square

Square lake has a well-functioning outlet tunnel and gate. The tunnel was constructed through bedrock and appears to be stable. The gate and operator appear to have been installed within the last 40 to 50 years and are still in very good condition. It is not anticipated that major improvements will be necessary to these facilities to accommodate automation; however, the gate has not been fully inspected. A full inspection of outlet gate should be performed during preliminary design phase, when the lake is fully drawn down, so that full operation of the gate can be observed and both sides of the gate can be inspected.

Three options are available to facilitate automation:

- **Option 1**: equipping the existing manual operator with new motorized actuator. The advantages of this option includes minimal capital cost and utilization of existing gears and leveraging available.
- **Option 2:** replacement of existing manual actuator and stem with new stem and motorized actuator. One advantage of this option includes removal of existing cast iron gears which may be more maintenance intensive. One disadvantage of this option is that the new actuator would likely have to be larger to lift the gate without the use of existing gears and leveraging equipment. New equipment would need to be capable of providing approximately 500 ft-lbs of torque.
- **Option 3:** full gate replacement with new motorized actuator. The challenge to this option is that the existing gate is mounted in a tunnel that is difficult to access. The gate stem extends to the actuator through a small opening drilled in the bedrock above the tunnel. Replacement of the gate and stem could be very difficult, but additional inspection is needed to determine whether replacement is warranted.

We expect that the IPID and IWG would select Option 2, replacement of stem and actuator only, as the preferred option based on IPID’s stated assessment that the existing gate is in satisfactory working condition.

Klonaqua

Klonaqua outlet works consist of a 30-inch diameter concrete pipe (inferred from asbuilt), low-level outlet pipeline, and a positive seating circular canal-style gate installed in a reinforced concrete vertical gate chamber. The condition of this infrastructure is variable with much of the conduit and gate chamber in satisfactory condition. The gate

[13] Two parallel studies are being performed to explore outlet works improvements at both Eightmile Lakes and Snow Lakes; therefore, upgrades to outlet works associated with those lakes have not been included in this study.

itself does not seal and should be replaced with a similar style gate. IPID has indicated that approximately 20 feet of the outlet pipe (nearest the outlet channel) has partially collapsed and is due for maintenance and repair. IPID has plans to repair the collapsed section of the low-level outlet pipe.

Eightmile

Eightmile lake outlet works consist of a 30-inch diameter low level outlet pipeline constructed of a variety of materials and a circular canal-style gate installed at the inlet to the pipeline. During most conditions, the gate is submerged in the lake and is exposed to ice, floating debris, and other potentially damaging conditions. The gate and low-level outlet pipe inlet are protected by a debris rack. The gate stem was originally supported by a rock-masonry gate tower. A hand-wheel operator mounted on top of the gate tower, above the water surface of the lake, was used to open and close the gate. However, the gate tower was sheared off by ice within the last 20 years. The damaged hand-wheel operator was removed. The gate is now operated by a long chain attached to the gate stem ad a come along. Fully opening and closing the gate is a challenge. In addition, the existing low-level outlet pipe, which consists of segments of corrugated metal, log stave, and wood stave pipe are collapsing. The collapse of portions of wood stave pipe has reduced the capacity of releases from the lake and is a major concern for IPID.

Improvements to the dam, outlet works, and controls at Eightmile Lake are being studied concurrently and recommendations for these facilities will be identified in the *Eightmile Lake Restoration Project Feasibility Study* (Anchor and Aspect, 2018). Recommended improvements will include:

- A new reinforced concrete and earthern/rock embankment dam with a spillway constructed with concrete and rock-filled gabions.
- A new 30-inch diameter low-level outlet pipe constructed of high-density polyethylene pipe that will extend from a point deeper in the lake to an outlet location further down the outlet channel. The low-level outlet pipe will operate by gravity during the early part of the season and will operate as a siphon in the later part of the season, when the water level is drawn down below the elevation of the high point in the pipeline at the dam.
- The pipe will neck down to 24 inches in diameter at the dam and an isolation valve, air-release valve, and vacuum pump/priming equipment will be installed in a valve chamber at the high point in the pipeline on the downstream side of the new dam structure.
- Releases from the pipe will be controlled by a 24-inch plug valve, located in a valve enclosure near the pipe outlet. The plug valve will be throttled to control the release rate. Locating the control valve near the pipe outlet will allow for the pipeline to remain primed when lake levels are low. The valve will include an electronic actuator that will be powered by batteries and a solar panel, similar to power for automation at the other lakes.

Colchuck

The outlet works at Colchuck Lake consist of two segments of low-level outlet pipe of variable size and material (assumed to be corrugated metal pipe based on visible features) with a rectangular style gate positioned in the lake adjacent to a free-standing gate tower. The first segment of pipe extends from a deeper part of the lake to the gate tower, which is installed in a relatively shallow part of the lake adjacent to the dam structure. The rock-masonry gate tower includes a rock-masonry well at the bottom which connects the first segment of low-level outlet pipe to the gate. The gate controls flow to the second segment of outlet pipe, which conveys water from the gate to an outlet in the channel downstream of the lake. The gate is fully submerged in the lake under most operating conditions. When the lake is fully drawn down, the gate tower, gate, and lake bottom around the tower and gate are fully exposed. A manual hand-wheel gate actuator is mounted on top of the gate tower and is accessible by a wooden plank or footbridge from the shoreline of the lake.

Because the gate is positioned in the lake, it is exposed to ice, floating debris (such as logs which often accumulate), and other potentially damaging conditions. Existing conditions do not support winter-time operation as the gate stem is typically encased in ice when the lake freezes over. In spite of the exposure to potentially damaging conditions, the gate is still in relatively good operating condition.

Recommended improvements to the outlet works at Colchuck Lake include:

- Replacement of the gate with a new gate of similar size and operation with an electronic actuator.
- Replacement of the gate tower with a new riser or manhole type structure that will protect and provide access to the new gate, actuator, and controls. The structure could consist of pre-cast manhole sections or a riser pipe with a cast-in-place concrete base and a weathertight, locking lid. The riser or manhole structure would also connect the two segments of low-level outlet pipe.

Upper Snow

Upper Snow Lake controlling works consist of a tunnel (estimated 160 foot deep), an outlet pipe that extends from a block plugging the tunnel to a discharge point on a rocky slope above Nada Lake, a valve house built into the hillside at the end of the tunnel above Nada Lake, and several valves that control flow from the tunnel through the pipeline to Nada Lake. The primary control valve is a 24-inch butterfly valve that is throttled to control flow through the pipeline to Nada Lake. The outlet works are generally in good operating condition; however, the control valve and associated pipe at the discharge end of the system are currently limited to release flows of approximately 55 cfs, which is less than the combined release rights for the lake held by Reclamation and IPID.

The USFWS and Reclamation are exploring options to replace the existing butterfly valve to increase flows to 85 cfs. Additional improvements recommended for automation and optimization of releases from Upper Snow Lake would include installing an electronic actuator with the new valve, control equipment, batteries, and solar power to enable remote control of the valve by the USFWS[14].

[14] Improvements to Snow Lakes controlling works (valve, mechanical actuator, controls, power supply and communications) are being planned by Bureau of Reclamation, Technical Service Center in Denver, Colorado. The scope of improvements considered by Reclamation are generally consistent

Lower Snow

When the low-level outlet from Upper Snow Lake is closed and the water level in Upper Snow Lake is near the full level, water is released from upper Snow Lake to Lower Snow Lake over and through a dam structure between the two lakes. The dam structure includes a flap gate that was originally designed to allow water to flow from Upper Snow Lake to Lower Snow Lake, but prevent flow in the reverse. Water also spills over the dam structure at Upper Snow Lake to Lower Snow Lake. The flap gate is no longer water tight and allows for water to flow through the dam in both directions. When Upper Snow Lake is lowered by opening the low-level outlet to Nada Lake, the water in Lower Snow Lake can be higher than the water level in Upper Snow Lake and water can flow backwards through the dam from Lower Snow Lake to Upper Snow Lake.

Lower Snow Lake also has a small rock-masonry dam at its outlet. No low-level outlet facilities are functioning at this dam, so the water level in Lower Snow Lake is generally controlled by spilling over the dam crest. Under current operation, water levels in Lower Snow Lake only vary a few feet from the dam crest elevation. Consequently, the active storage volume in Lower Snow Lake is small and is really only accessible when Upper Snow lake is drawn-down sufficiently to allow back flow through the existing flap gate at the Upper Snow Lake Dam. No discrete automation or improvement to outlet works is proposed for Lower Snow Lake as part of this Project.

Gate Actuators and Automation

Automation would consist of installing motorized actuators on the release gates and/or valves at each lake. Motorized actuators would be controlled by programable control equipment capable of communicating with a computer or telephone from a remote location.[15]

Actuators

Due to the remote conditions and other power constraints, direct current (DC)-powered actuators would be required. As identified in the Appraisal study, several manufacturers are available, including Auma, Limitorque and Rotork. For the purpose of this study, Rotork actuators were considered; however, a final manufacturer and model would be selected during the detailed design and construction phases. Features associated with Rotork actuator include a self-contained waterproof enclosure, integrated datalogger, manual handwheel actuator (backup), oil bath lubrication, position control, and encapsulated stem.

Conceptual actuator sizing was performed using Rotork design resources. Based upon a 30-inch diameter circular canal style gate with 30 feet of effective head, a thrust of approximately 6,000 lbs thrust was calculated. Required torque (torque applied to gate stem) of approximately 70 ft-lbs was calculated by applying a stem factor of 0.012 (based

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with those presented herein however additional coordination is required to ensure consistency between planning efforts.

[15] Local motorized operator interface manual control override would be provided in addition to remote capabilities.

on 1.5 inches diameter stem, 4 threads per inch and frictional factors provided by manufacturer).

A variety of DC powered actuators are available ranging in voltage, horsepower, torque, speed, etc. The smallest actuator available is 24-volt, 1/3 hp which applies 20 ft-lbs of torque at 18 rpm. Typically, gearboxes ranging from 1:1 ratio up to 6:1 ratio can be added, thereby increasing torque delivered (at lower overall speeds).

Rotork model IQD10 at 48 rpm provides 20 ft-lbs of torque which is increased to 102 ft-lbs with Rotork model IB4 gearbox (6:1 ratio), which would be sufficient for any of the lakes including Square (assuming gate replacement), Klonaqua, Colchuck and Eightmile. The Rotork ID10 actor has a motor horsepower of 1/3 hp with 7 amps motor load.

At 48 rpm, 6:1 gear ratio, and 1/4-inch thread spacing (4 threads per inch), it is estimated that an operation duration of 30 seconds per inch of gate adjustment would be required to adjust the gates. Based upon the results of the 2016 Pilot Release Study, daily adjustments of up to 6 inches may be required (Scenarios 1A and 2A) or weekly adjustment of up to 12 inches for Scenarios 1B and 2B.

An exception to the required sizing may exist at Square Lake, should the existing gate be left in place. Field measurements indicate that approximately 40 ft-lbs of force applied to the handwheel operator is required to raise the gate during lake-empty conditions. Considering current gearing and mechanical advantage, this force translates to approximately 460 ft-lbs of torque, which exceeds the limits of 24V actuators provided by Rotork. In order to provide torque of that magnitude, a 110V model would be necessary, which may be excessive from a power budget perspective (i.e., ten 12V batteries would be required in parallel).

If the gate is left in place, it is recommended that a 24V actuator be selected in conjunction with either the existing gears or with replacement gears that provide similar mechanical advantage. The tradeoff with this approach is significantly longer run-time per adjustment. For example, under this scenario, a 24V, 48 rpm motorized actuator could be installed with standard 6:1 gearbox on existing manual actuator. The existing actuator requires approximately 32 revolutions per inch of stem rise, hence the actuator would operate for approximately 4 minutes per inch of stem adjustment which is within limits of power budget assumptions.

Calculations associated with motorized actuator sizing are provided in Appendix F.

Programable Dataloggers / Controllers

The motorized actuator at each valve or gate would be controlled by a programable data logger/controller. The logger/controller would send and receive signals from the actuator and be connected to external communications, such as a phone or computer modem, as well as other monitoring equipment (e.g., water level/pressure transducers). For the purpose of this Project, Campbell Scientific equipment is being evaluated including a Model CR1000 Controller which provides for logging and control of multiple connected devices, including transducers and actuators. The programmable data logger/controller would be operated through an interface (e.g., RTU) which would include additional logic and programming function.

Operator Interface

Several operator interface options will be available for gate adjustments. The primary method for this application would be remote operation through a remote personal computer positioned at a base station (e.g., remote terminal unit (RTU) at IPID or LNFH). Campbell Scientific Loggernet software (or similar) provides for simplified configuration and programming for CR1000 Controllers and could be used in this application.

Other options for gate operation include the following:

- Automated direct adjustment of each gate using an on-site actuator remote in close proximity (e.g., Rotork remote control);
- Automated direct adjustment of each gate using an on-site terminal unit connected to the data logger/controller. (e.g., laptop computer or tablet wired to the data logger); and
- Manual handwheel adjustment/override.

Communications

Available options for communications include both satellite and radio. A radio repeater analysis was performed by Aspect in 2015 and is considered feasible. No satellite coverage analysis has been performed, but it is anticipated that satellite may also be viable.[16] For the purpose of this study, it has been assumed that communications for remote control of automated valves and gates would be via radio. Radio communications includes the use of base stations at each lake, IPID, and LNFH, and repeater stations.

The primary radio communications method considered for this Project is high frequency (UHF / VHF) radio at IPID and USFS established frequencies, which were evaluated as part of the 2015 Alpine Lakes Appraisal Study (See Figure 3). In general, direct radio communications coverage from the lakes to base stations are inconsistent without benefit of repeaters. IPID often sends and receives radio signals from some lakes, including Colchuck and Eightmile, using their existing repeater at Blag Mountain. However, limitations of this practice have not been explored. As evaluated in the 2015 Alpine Lakes Appraisal Study, radio repeater stations could be installed at intermediate high points outside the Wilderness area but within the Project vicinity to offer line-of-sight communications between lake locations and base station(s).

Radio repeater stations are very common in remote areas and are relatively inexpensive to install. Infrastructure consists of tower (anchored mast or structural frame), omni-

[16] Iridium Communications operates the Iridium satellite constellation which includes 66 active satellites to provide voice and data communications form satellite phones and transceiver units around the globe. In this case, the Iridium transceiver unit 9522B would be used. There would be a required data plan with ongoing fees – however benefits include potential greater flexibility and lower power use than radio options. An alternative vendor (Hughes / Immersat) may also be explored. Iridium is IP based whereas Hughes is not. The primary consideration related to satellite is coverage which, at minimum requires limited obstructions below 30-degree horizon. Sites could also have their own IP address allowing for login from any internet capable workstation.

directional antenna, radio transceiver (estimated 50 watt) and onsite power generation (solar panel and battery).

From a technical perspective, the preferred arrangement of new radio repeater stations includes a new radio repeater station at the Icicle Ridge site, a new radio repeater station at the Wedge Mountain site, and retention of existing IPID radio repeater infrastructure at Blag Mountain. Each new radio repeater station could be operated by IPID and added to the existing IPID FCC license. In addition to radio repeater station(s), a new radio base station could be added to USFWS facilities at LNFH to allow for independent communications and control of Snow Lakes release by USFWS.[17] Use of an IPID repeater at Wedge Mountain could be arranged through inter-agency agreement between USFWS and IPID for joint use of a new Wedge Mountain Repeater for operation of USFWS-managed lakes.[18] As an alternative, a new Wedge Mountain repeater could be owned and operated by the USFWS and licensed under National Telecommunications and Information Administration (NTIA) processing.

While not anticipated, permitting and property ownership constraints may limit the construction of radio repeaters at either of the preferred locations. In this case, radio communications may still be possible to / from the lakes with either repeater using strong base station transmitters (e.g., 25 watt radio transceivers).

It is recommended that additional field radio survey be conducted to test high power (e.g., 25 watt) signals between the more distant lakes and Wedge Mountain and between Snow Lakes and the Icicle Repeater, in conjunction with the Blag Mountain repeater and Peshastin base station.[19]

Power Supply

Due to remote site conditions, onsite power generation (DC) will be necessary. Readily available communications and controls equipment is typically provided in 12V DC, however the smallest DC motorized actuator considered as part of this study is available in 24V DC. This will require power regulation to step down from 24V to 12V which is inefficient but satisfactory.

A power budget was performed to conduct preliminary solar panel sizing and battery bank configuration. Power needs increase as a function of gate adjustment frequency and duration, communications frequency and other factors. Assumptions included in the power budget consist of the following:

- Gate adjustments may be limited to 5 minutes.
- Solar panels may be unavailable or unreliable during winter months.

[17] Other configurations may be possible. For example, base station at LNFH could be avoided through internet connection and agreement between IPID, or USFW could own / operate the Wedge mountain repeater in lieu of IPID.
[18] IPID and USFW have shared rights associated with Snow Lakes. Currently USFW is performing mainteancne activities on existing release form Snow lakes to resort flows from 55 cfs to 85 cfs historical flows such that both IPID and USFS can have access to existing storage rights in Snow Lakes.
[19] If additional communications survey are performed, scope should include coordination with USFW and possibly be expanded to test satellite communications.

A summary of power loads by equipment type for both active and quiescent are provided in Table 7.

Table 7. Equipment Power Loads

Equipment	Active Draw (A)	Quiescent Draw (A)
Datalogger	0.01	0.0006
Pressure transducer	0.08	0.00008
RotorQ Actuator	7	0
24Vdc to 12Vdc regulator		0.00093
Crydom Solid State Relay	0.01	0
RF320 VHF radio transciever	1.2	0.025
RF500M radio modem	0.015	0.00035

Power consumption varies by the duration of operation of each unit, which varies dependent upon whether daily or weekly gate adjustments are performed. Equipment runtime duration is provided in Table 8.

Table 8. Equipment Runtime Duration

	Daily Adjustment (seconds / day)		Weekly Adjustment (seconds / week)	
Equipment	active	quiescent	active	quiescent
Datalogger	7.08	292.92	5.3	294.7
Pressure transducer	1.5	298.5	1.5	298.5
RotorQ Actuator	300	86100	300	604500
24Vdc to 12Vdc regulator		86400		86400
Crydom Solid State Relay	300	86100	300	604500
RF320 VHF radio transciever	600	85800	600	604200
RF500M radio modem	600	85800	600	604200

Power supply will be provided through onsite solar generation stored in 12V batteries. Power requirements for both daily and weekly adjustments were evaluated for both summer-only and year-round operations. Solar panel sizing was determined by daylight hours available (per month based on latitude, solar exposure, obstructions) and power draw. Further, a power reduction factor was applied to account for reducing rated battery amp-hours due to temperature drop in the winter months.

Daily solar resource availability (kWh/m2/Day) was determined from us of Photovoltaic Solar Resource provided by National Renewable Energy Laboratory (U.S. Department of Energy, 2008), see Figure G1 of Appendix F. Daily average solar resource value by month is provided in Figure 5.

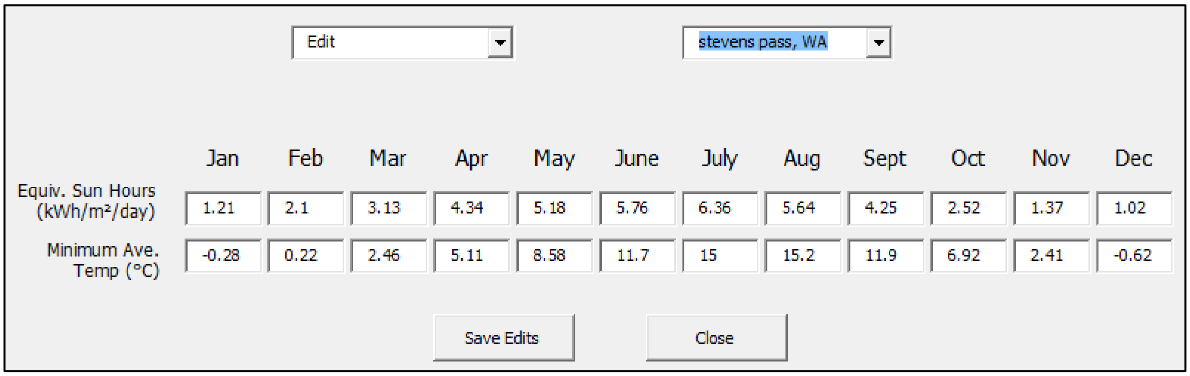

Figure 5. Solar Exposure Analysis

The combination of solar power generation and power consumption based on four scenarios is provided in Table 9.

Table 9. Solar and Battery Sizing for Summer/Fall Operation

Coms/Adjust Frequency	Daily		Weekly	
	Solar Size (Watts)	**Battery Size** (Ahr)	**Solar Size** (Watts)	**Battery Size** (Ahr)
Summer Only	13	29	7	16
Year-round	52	207	27	117

Capital Cost Estimates

Capital Costs

Opinions of probable costs were developed for implementation of the proposed Project and includes both hard costs (costs related to construction) and soft costs (costs related to engineering, planning, and administration). A detailed opinion of probable implementation costs or capital costs with quantities is included in Appendix G.

Hard costs include direct construction costs such as capital improvements and sales tax. Hard costs were estimated at approximately $875,000[20] using detailed quantities in conjunction with unit pricing from several available resources including RS Means (Costworks), APWA/SPU data, WSDOT unit bid tabulation (parametric estimating), experience with similar projects (analogous estimating), and engineering judgement. The following assumptions were made in development of hard costs for this Project:

- Washington state sales tax = 8.2 percent (Washington State Department of Revenue, based on location of project site); and
- Construction Contingency = 25 percent

[20] Costs associated with gate improvements and automation at Eightmile lake are excluded from this study and are covered in the *Feasibility Study Eightmile Lake Improvements (expected 2017).* Furthermore, control valve improvements at Snow Lakes are excluded from these costs – however, automation improvements at Snow Lakes are included in this estimate.

Soft costs include planning, engineering, permitting, miscellaneous overhead, and other administrative and non-construction costs. For purposes of this project, soft costs were estimated as 20 percent of the hard costs.

Operations and Maintenance Costs

Average annual ongoing operations and maintenance (O&M) costs of $37,500 have been estimated based on periodic routine maintenance and replacement of mechanical equipment, staff time required to operate equipment, electrical/power costs needed to operate pump infrastructure. While some O&M costs would be relatively consistent on a yearly basis (e.g., routine exercise of isolation valves), some mechanical items have relatively short life expectancy compared to the design life of the project and will require periodic repair/refurbishment or replacement (e.g., 25-year design life of mechanical equipment). Other equipment is epected to have relatively short life expectancy (e.g., 10 years for electrical equipment and 5-years for batteries). For the purpose of this estimate, O&M costs have been converted to average annual dollar amounts despite likely year over year variations in costs as indicated. The opinion of probable long-term O&M costs is included in Appendix G.

Environmental Considerations, Permitting Strategies and Potential Project Impacts

Property Ownership

Discussions regarding use of both repeater stations have commenced; however, no formal negotiations have taken place. The two repeater sites under consideration are the USFS site and the Johnson's for Icicle Ridge and Wedge Mountain, respectively.

On February 21, 2017, Aspect met with Rob Johnson and Robin John of Post Hotel, who own the Wedge Mountain property. They expressed willingness to engage in future discussions about the use of the property and stated that they are not opposed to the concept. Conditions they expressed consist of access security, market compensation for use of land, aesthetics and not unreasonably encumbering future use of the site. If they choose to utilize the site in the future for another purpose (e.g., a guest amenity such as a lookout), they may request that the radio equipment be installed on any new permeant structure rather than as a standalone site appurtenance.

On March 8, 2017, Tony Jantzer spoke with Howard Banks of the USFS supervisory electronics tech of Region 6. According to Mr. Banks, the existing Icicle Ridge repeater equipment is fully built-out and there is likely no extra room for equipment on the existing mast. The USFS may be open to IPID using adjacent space for a new repeater under a Special Use Permit. Tony is working with Kevin Smith, who is the special use permit writer for Region 6 to discuss permitting. A copy of the special use permit application is provided in Appendix C.

Aesthetic Impacts

Project impacts related to aesthetics are expected with automation improvements. Some impacts may be mitigated through enclosures with natural appearance (e.g., faux rock or decorative enclosures) whereas other improvements may be visible but concealed with natural features (e.g., solar / radio antenna concealed in tree). Improvements are illustrated in Figures 6 through 10.

Communications Equipment

Onsite remote power and communications will be provided by a combination of solar panels and a directional antenna which must remain exposed (thereby visible) to maintain functionality. The most dramatic power supply scenario includes a 50-watt solar panel, which is relatively modest in size (approximately 30 x 24 inches). In most cases, 20-watt solar panels will be sufficient, which are less than half that size. Radio signal will rely on directional yagi antenna which are relatively small in size (approximately 36 inches in length and 12 inches tall). Both the radio antenna and solar panels have an industrial appearance which is unavoidable; however, it is anticipated that both units could be tree mounted, which will aid in concealment.

Enclosure

Many enclosure options are feasible, and consist of a wide variety of materials and configurations. Criteria involved in selection of enclosure type include security, durability, aesthetic value, and fire resistance.

Typical remote site enclosures for monitoring equipment could follow the USGS measurement and computation of streamflow manual which consists of vertical corrugated metal pipe with silo roof. This would be an economical solution for most sites with an appearance that is familiar to outdoors enthusiasts. This configuration however would have an industrialized appearance which may be less favorable than other options.

Another option that may provide high aesthetic value would be decorative stamped reinforced concrete which would provide maximum benefit from multiple perspectives, including security and fire protection. Many modern concrete techniques are available to help create natural appearance including stamping, pigment, and acid stain.

Permitting

A variety of state, local, and federal agency permit authorizations will be required to facilitate construction of automation improvements. These permits are being coordinated through programmatic environmental impact study (PEIS) which is scheduled for comment period in 2018. A summary of key permits is provided below.

Clean Water Act Section 404 review

Work within jurisdictional waters of the US requires a U.S. Army Corps of Engineers (Corps) Nationwide Permit (NWP) / NEPA Categorical Exclusion (CatEx) are the likely level of regulatory compliance for this project. Compliance with General Conditions 20 would require completion of a preconstruction notification (PCN), acknowledging potentially eligible resources pursuant to the National Historic Preservation Act; however, given the nature of the activities, it is anticipated that minimal review would be required and would most likely apply only to activities proposed at Eightmile Lake. PCN is fulfilled by filling out the Washington State Joint Aquatic Resources Permit Application (JARPA).

Corps permit evaluation will address consistency with Endagered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, National Historic Preservation Act, and Fish and Wildlife Coordination Act (federal action) – which are triggerd by Federal action. Review is anticipated to be relatively straightforward for the proposed project activities. USFS would most likely serve as the federal lead agency responsible for demonstrating applicable compliance with federal regulations at lakes where a special use permit is deemed necessary.

USFS Special Use Permit

Work on USFS lands not covered by easement requires special use permit by USFS which is likely required at Snow Lake and Square Lake, use of Icicle Ridge Repeater site and possibly Colchuck Lake.

IPID has requested and obtained copies of special use permit applications regarding use of the Icicle Ridge Repeater site and is in contact with local Forest Service staff who maintain this facility.

CWA Section 401 Water Quality Certification

Project may be subject to Section 401 of CWA. There is a streamlined review process (e.g., approval letter issued when Clean Water Act NWP conditions are adhered to).

Federal Communications Commission

Federal Communications Commission (FCC) approval may be required for radio repeater placement. Federal review consistency likely to be addressed by work completed by Corps or USFS as indicated in Note 3. IPID currently operates existing repeater and base stations under FCC licensure. Relocating existing and adding new repeater and base sites to existing licenses is permissible and processed through

Ecology Water Right Permit

A new water right permit issued by Department of Ecology will be required for adding instream flows as secondary uses.

WDFW Hydraulic Project Approval

Hydraulic Project Approval is required for any work affecting bed/flow of state waters. Jurisdiction and permitting authority is with Washington State Department of Fish and Wildlife.

WDNR Aquatic Use Authorization

Work within state aquatic lands. Compliance handled through the JARPA review process and expected to be minimal.

Chelan County Shoreline Substantial Development Permit/Conditional Use Permit

Work within state shorelands). May not be required. Need to confirm with Chelan County. IPID would be the applicant, but presumably PEIS and related federal permits/approvals would provide information needed to make permit decision if required.

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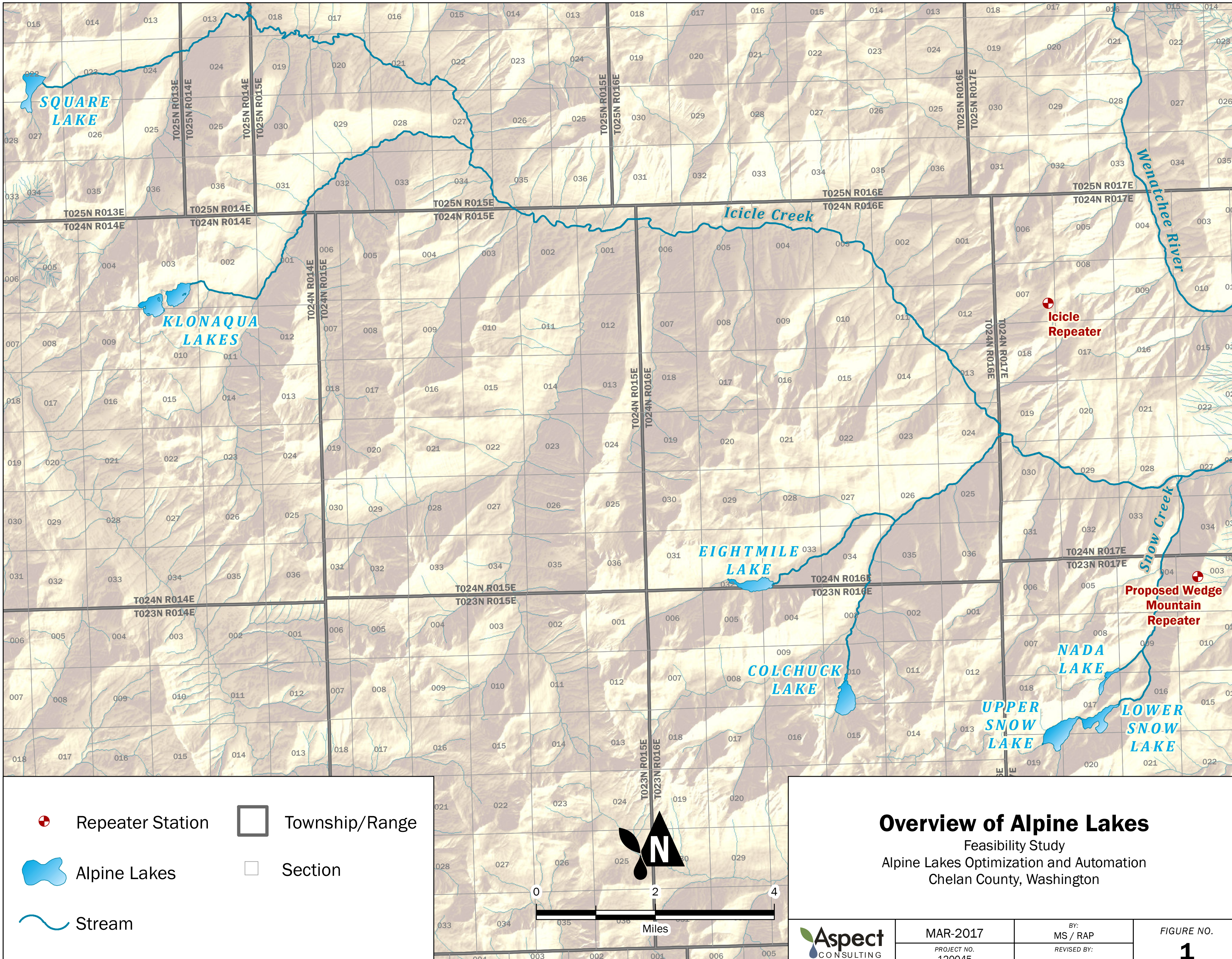
Limitations

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.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

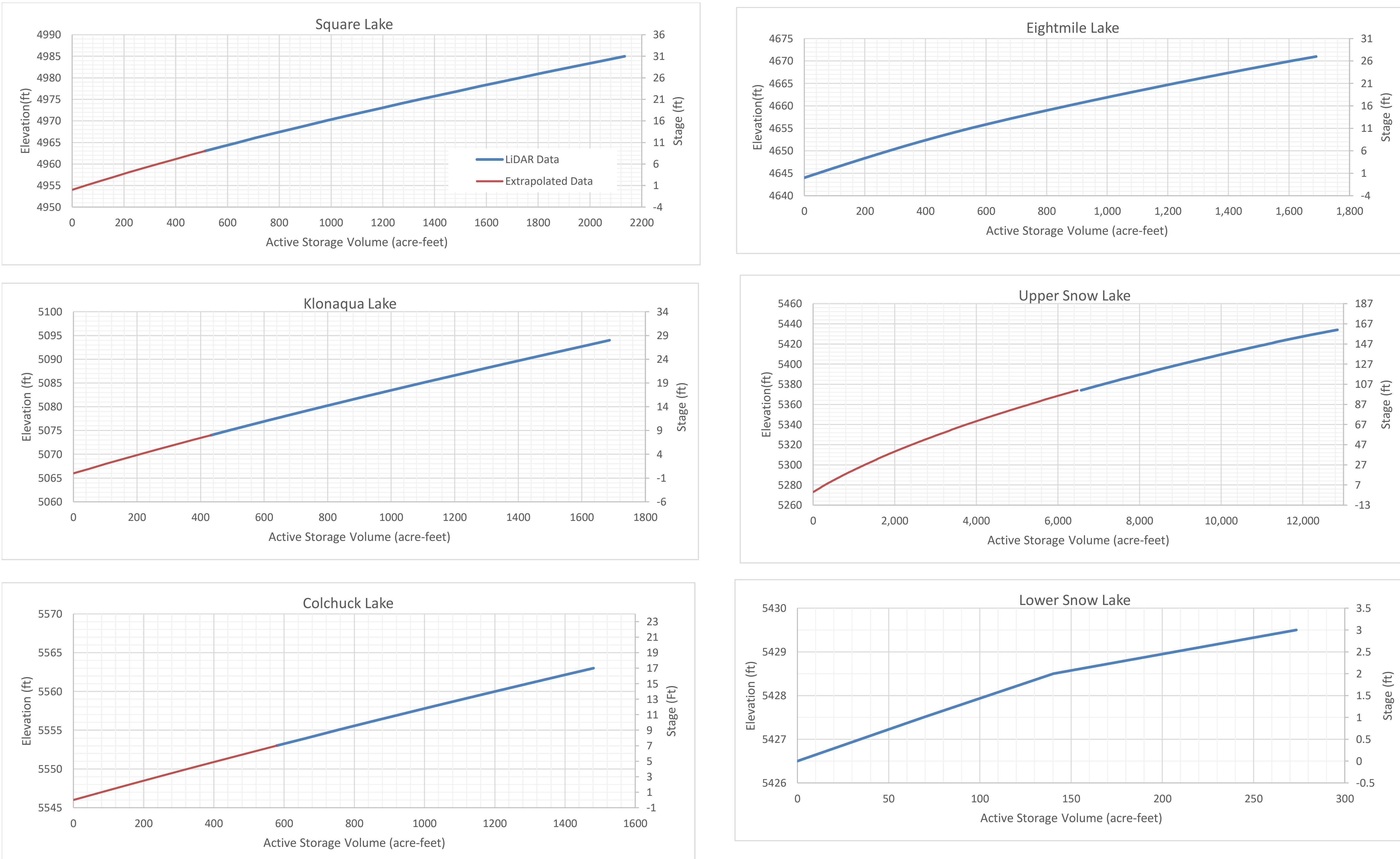
FIGURES



Overview of Alpine Lakes

Feasibility Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	MAR-2017	BY: MS / RAP	FIGURE NO. 1
	PROJECT NO. 120045	REVISED BY: - - -	



Aspect Consulting
4/30/2018
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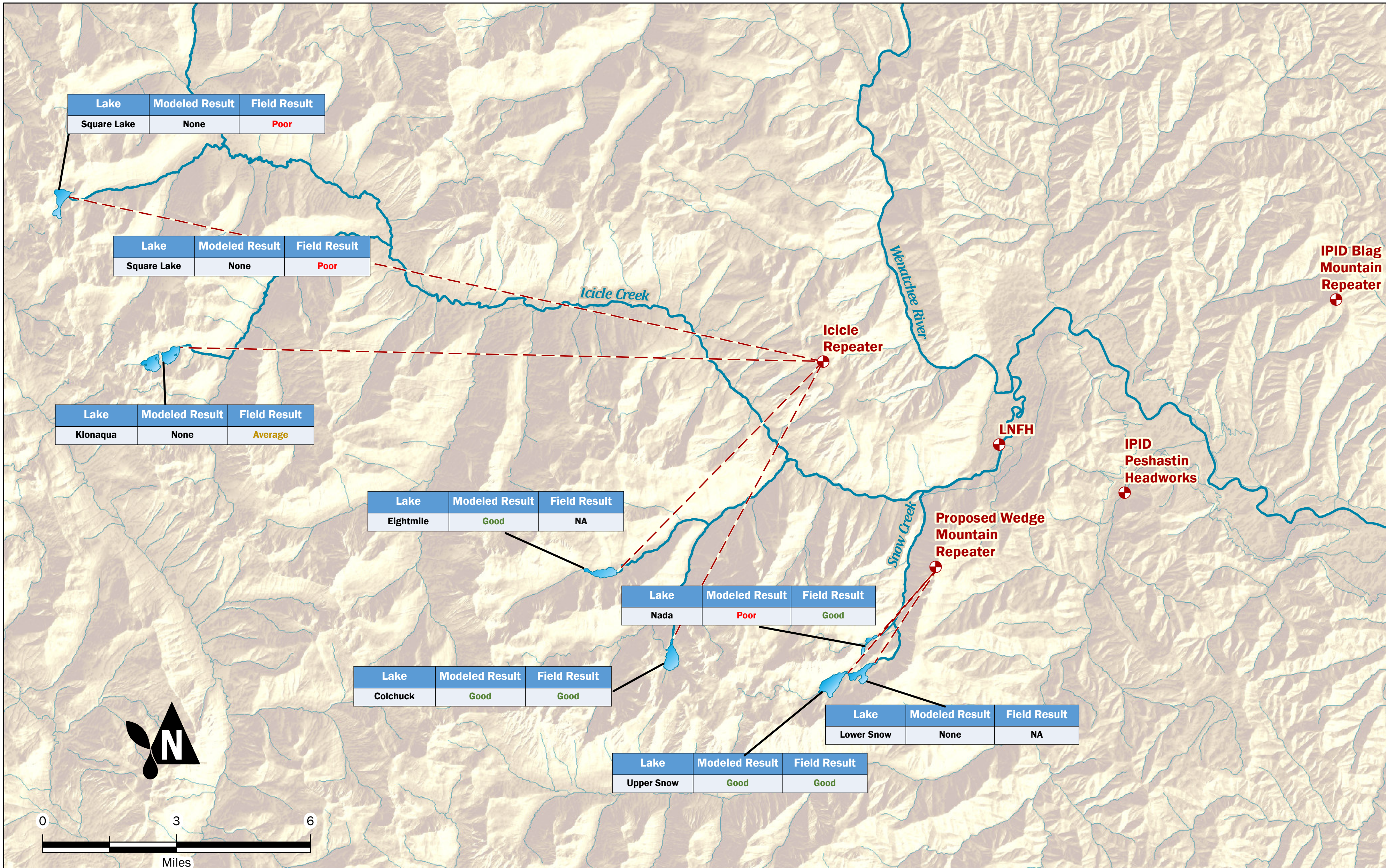
Figure 2
Stage-Storage Relationships
Alpine Lakes Automation Feasibility
Chelan County, WA



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

Feasibility Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	MAR-2017	BY: MS / RAP	FIGURE NO.
	PROJECT NO. 120045	REVISED BY: JRB / RAP	3

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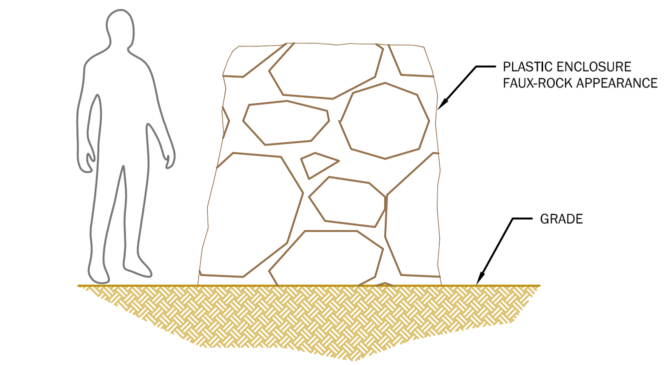
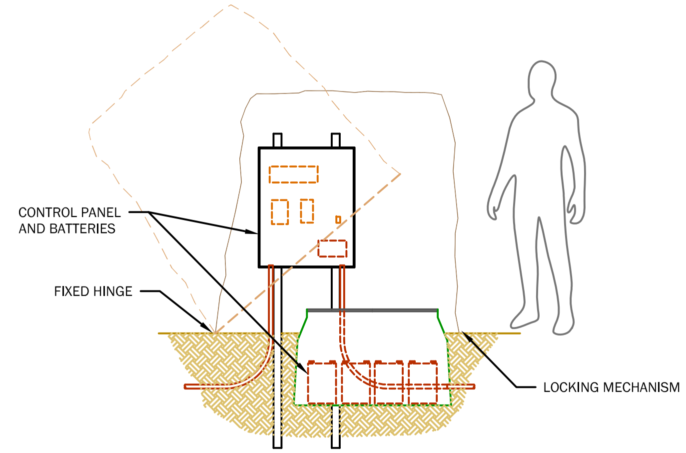
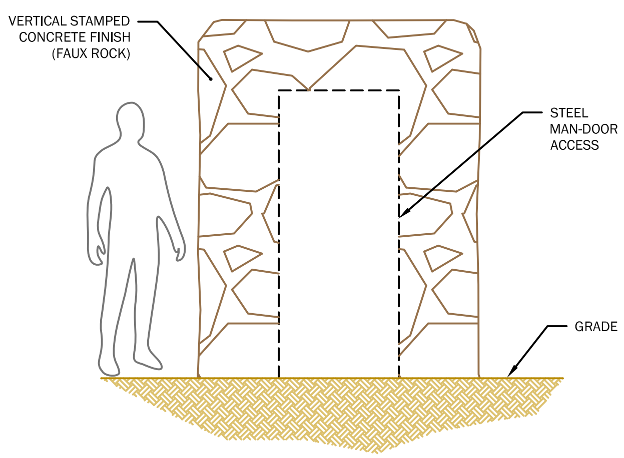


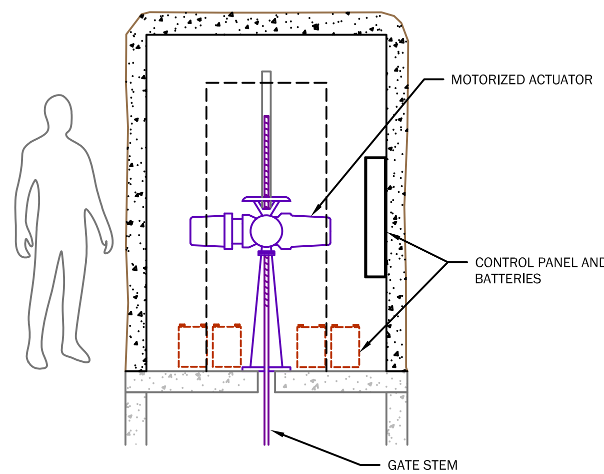
Molded Plastic Rock Enclosure
(FRONT VIEW)



Molded Plastic Rock Enclosure
(SECTION VIEW)



Stamped Concrete Enclosure
(FRONT VIEW)



Stamped Concrete Enclosure
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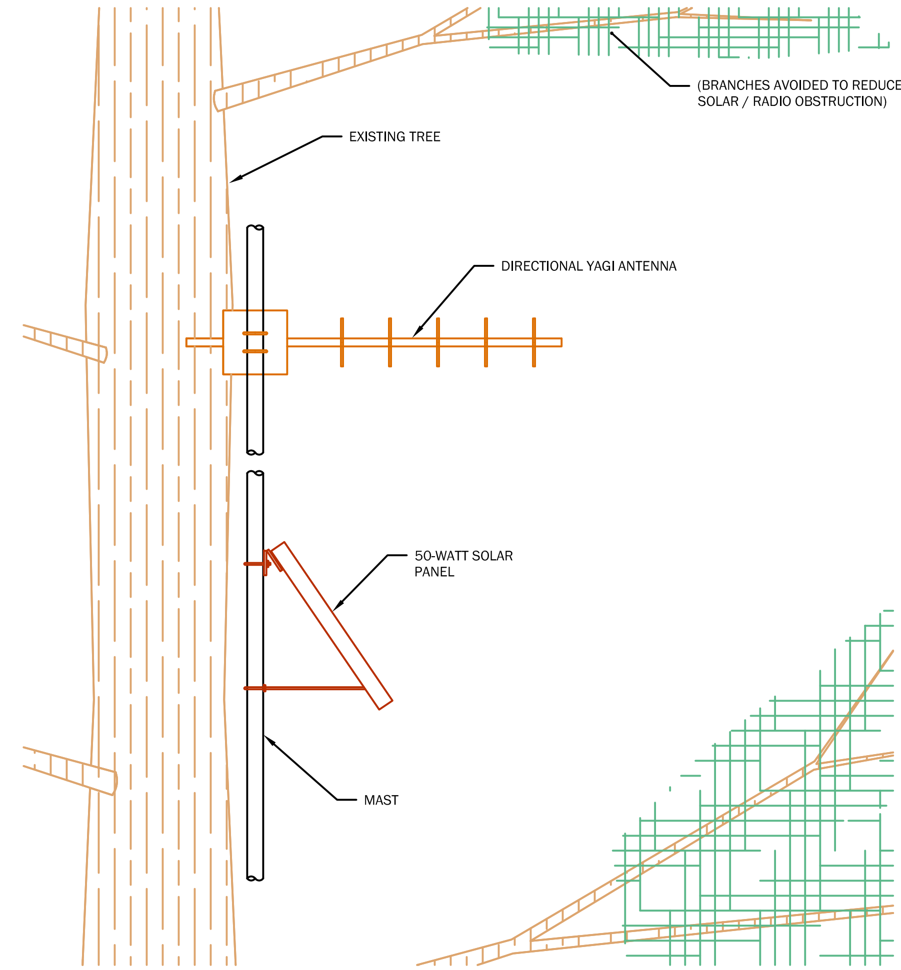

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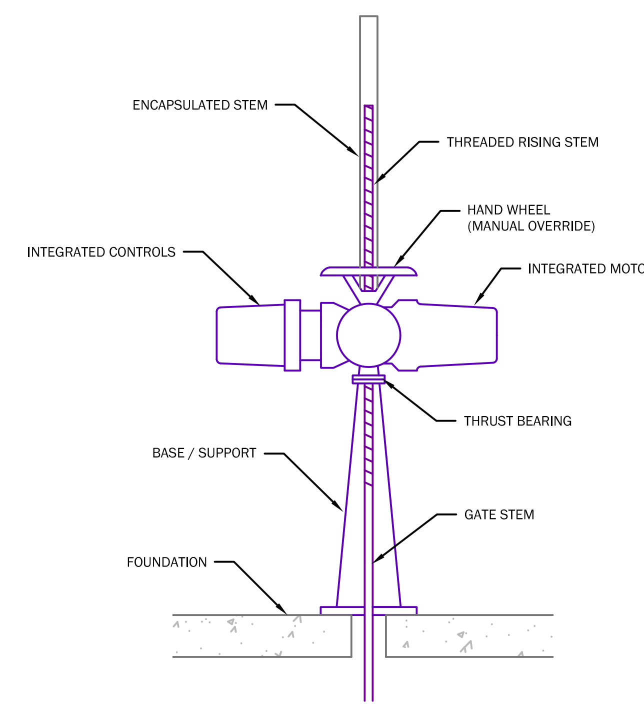
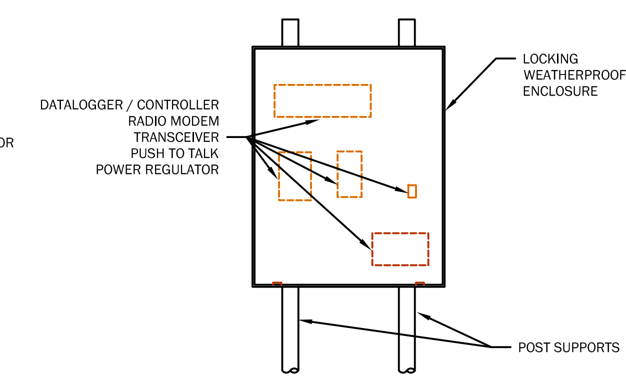


Motorized Actuator



Control Panel

REV. | DESCRIPTION | DATE | APPR.

DATE: JUL 2016
REVISION: -
PROJECT NUMBER: 000000
DESIGNED BY: -
DRAWN BY: SCC
REVISED BY: -

Aspect CONSULTING

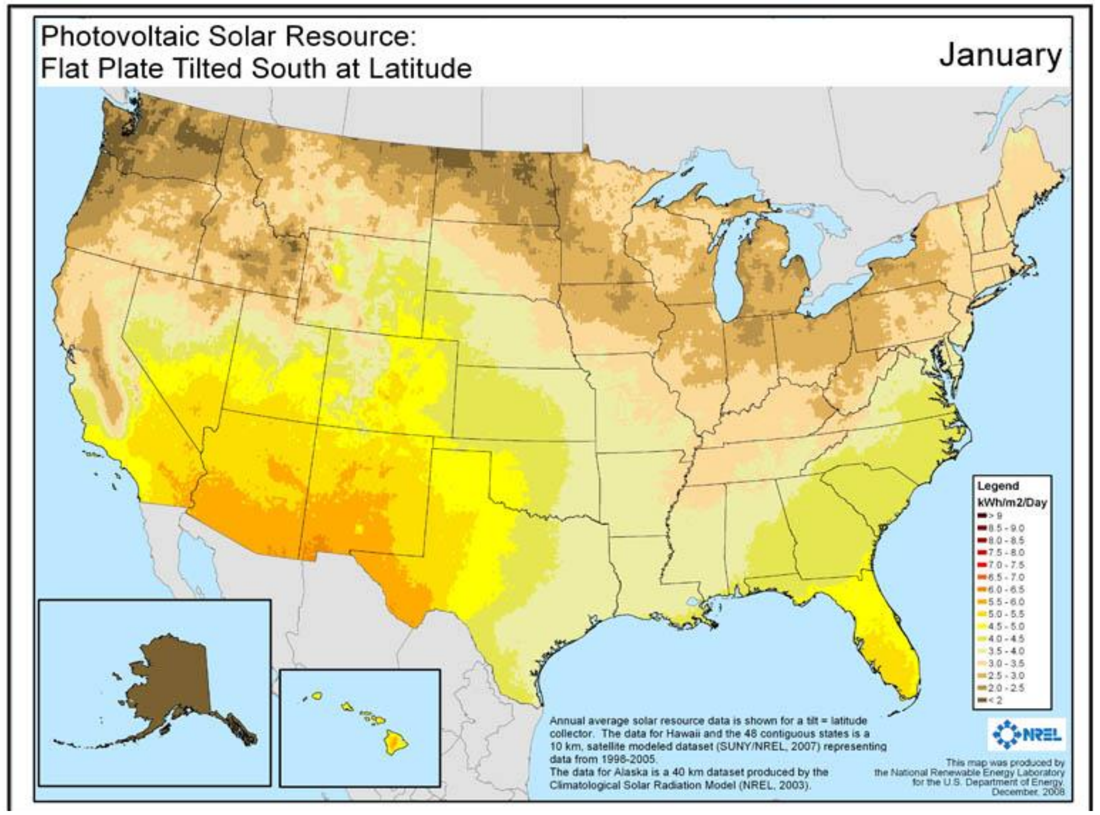
Typical Improvements

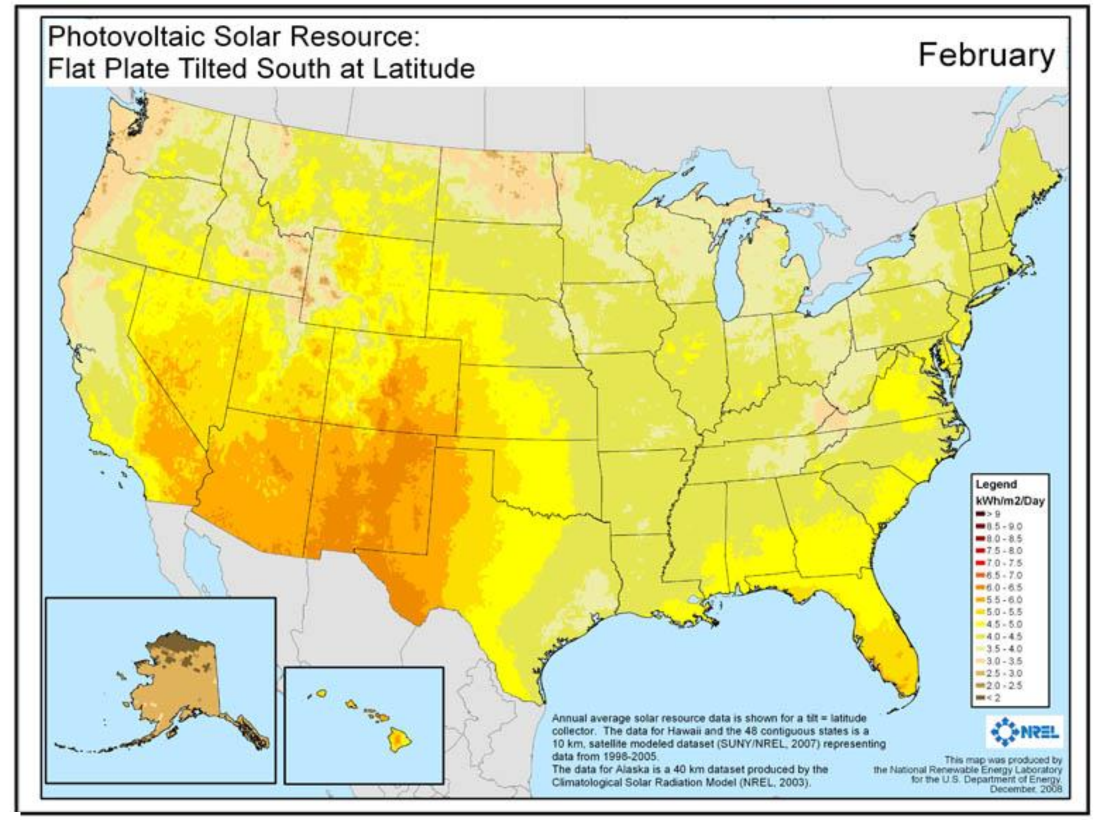
Alpine Lakes Automation
Leavenworth, Washington

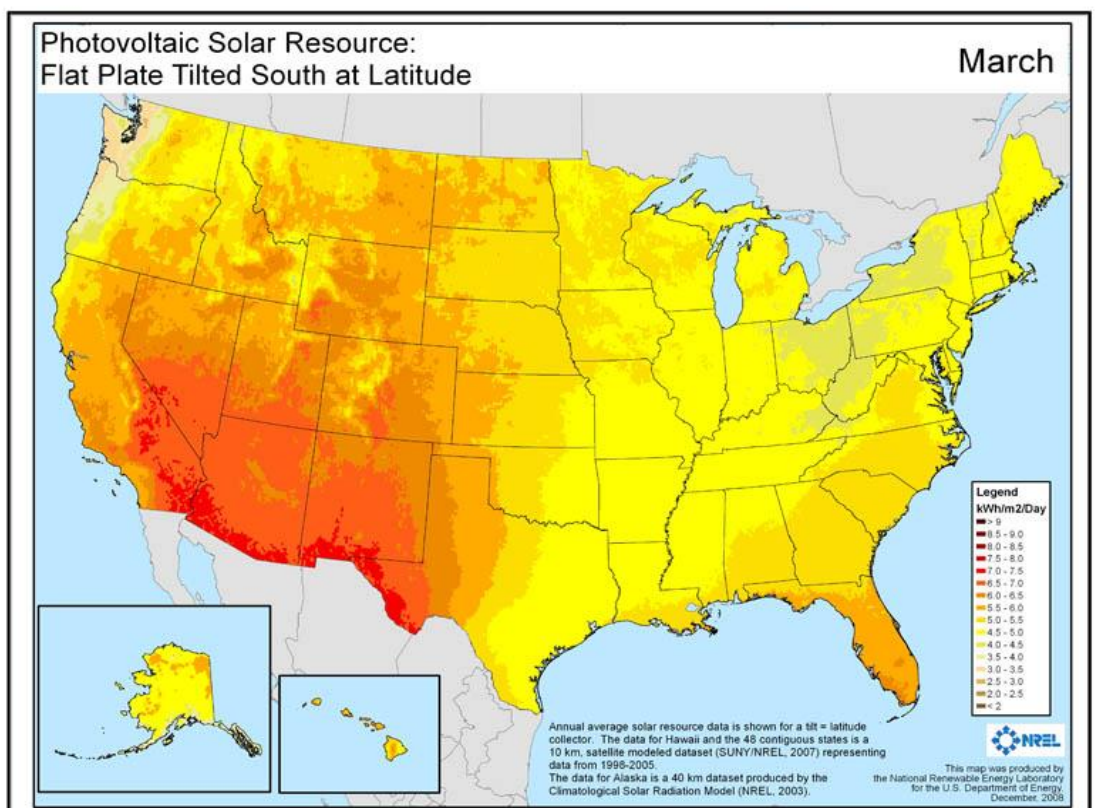
SHEET REFERENCE NUMBER:

Fig 4

SHEET OF







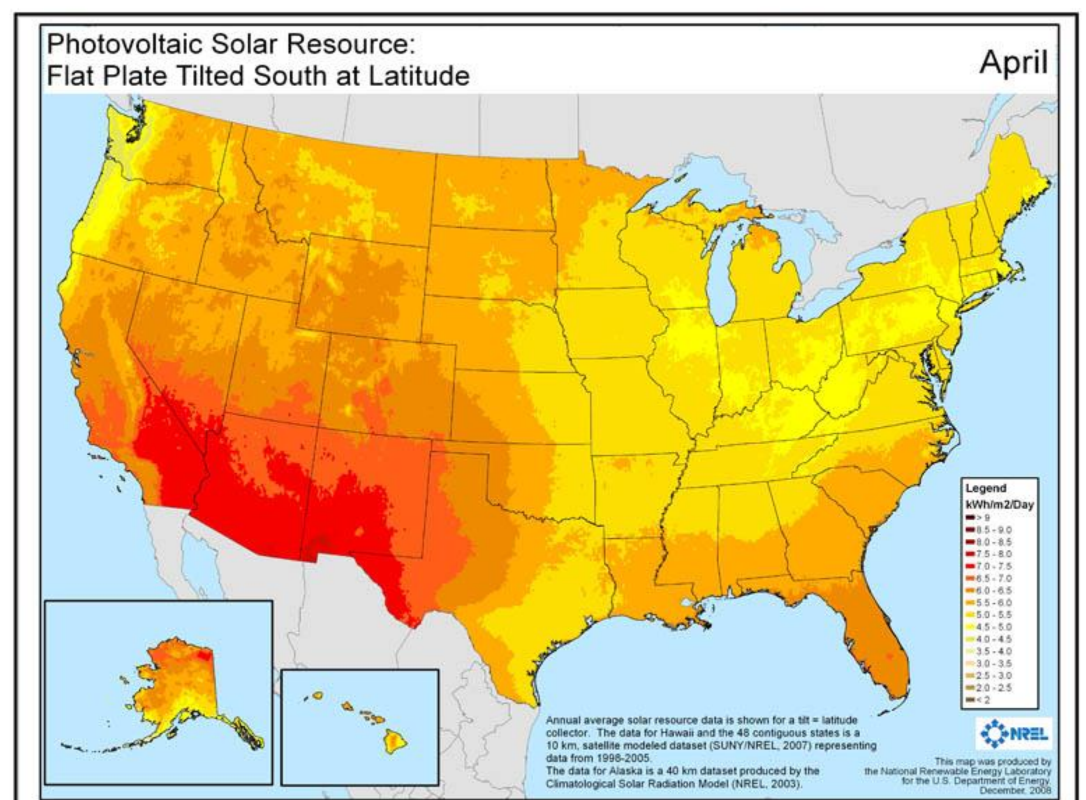
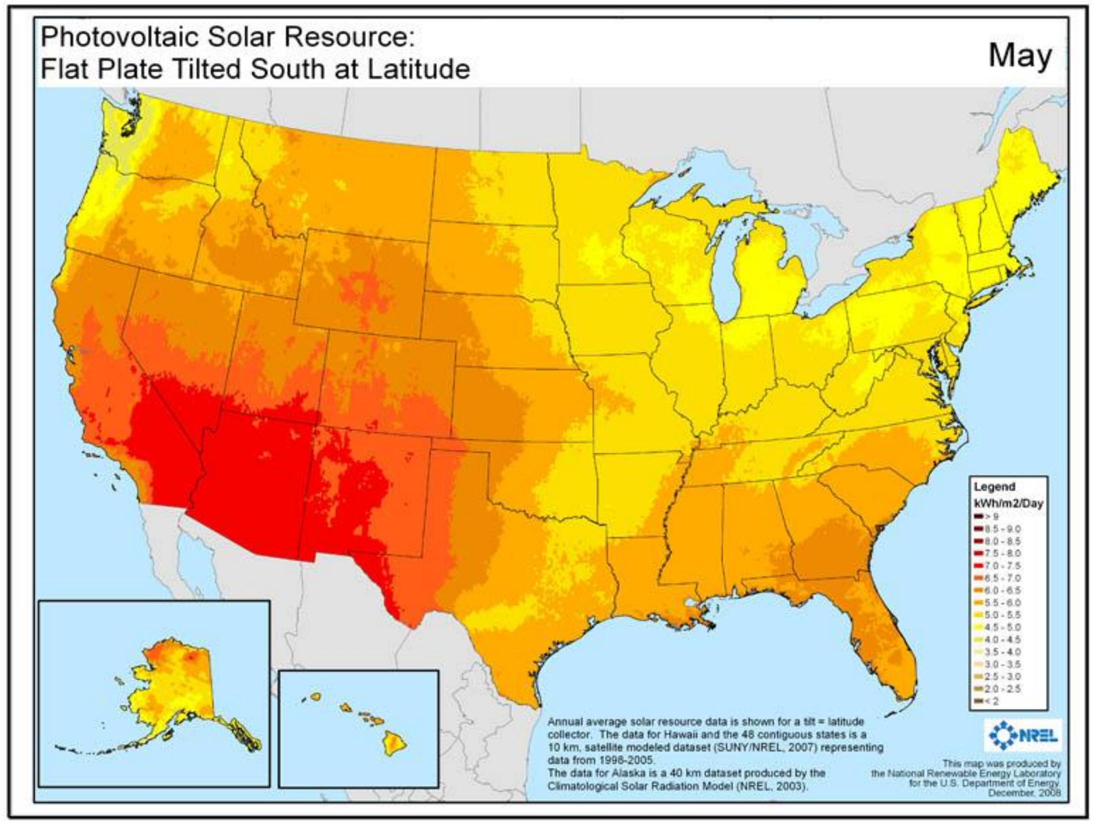
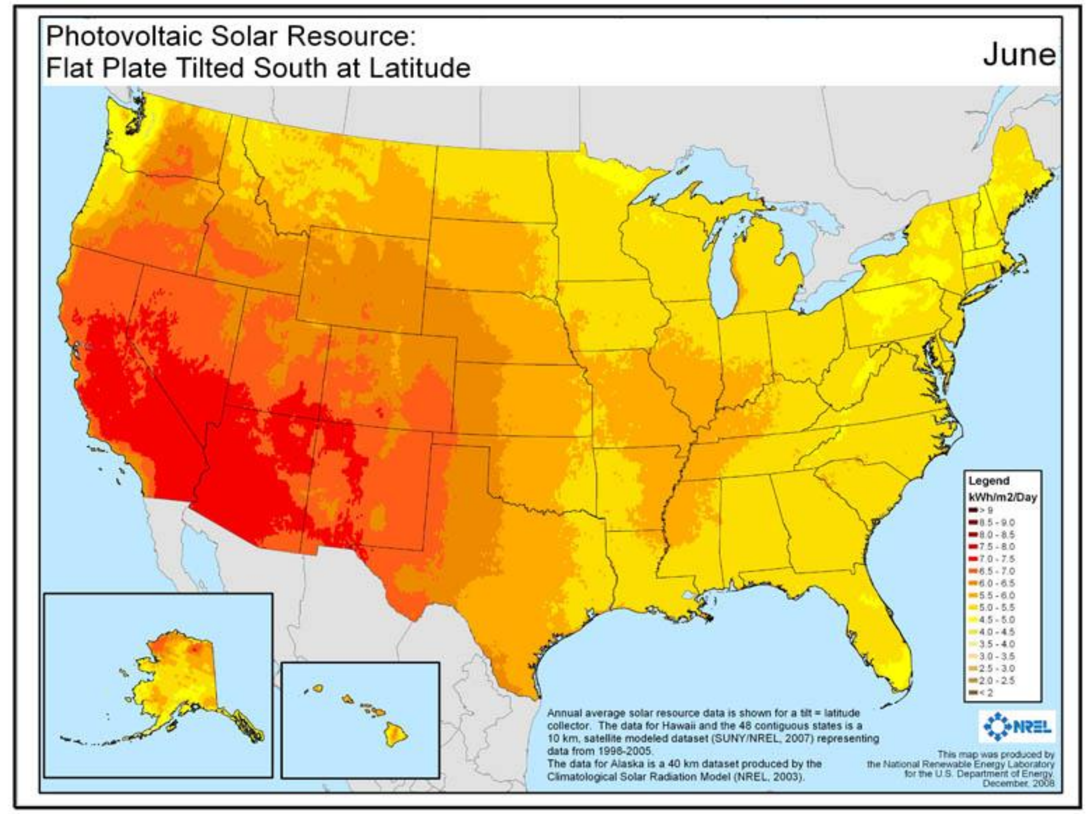
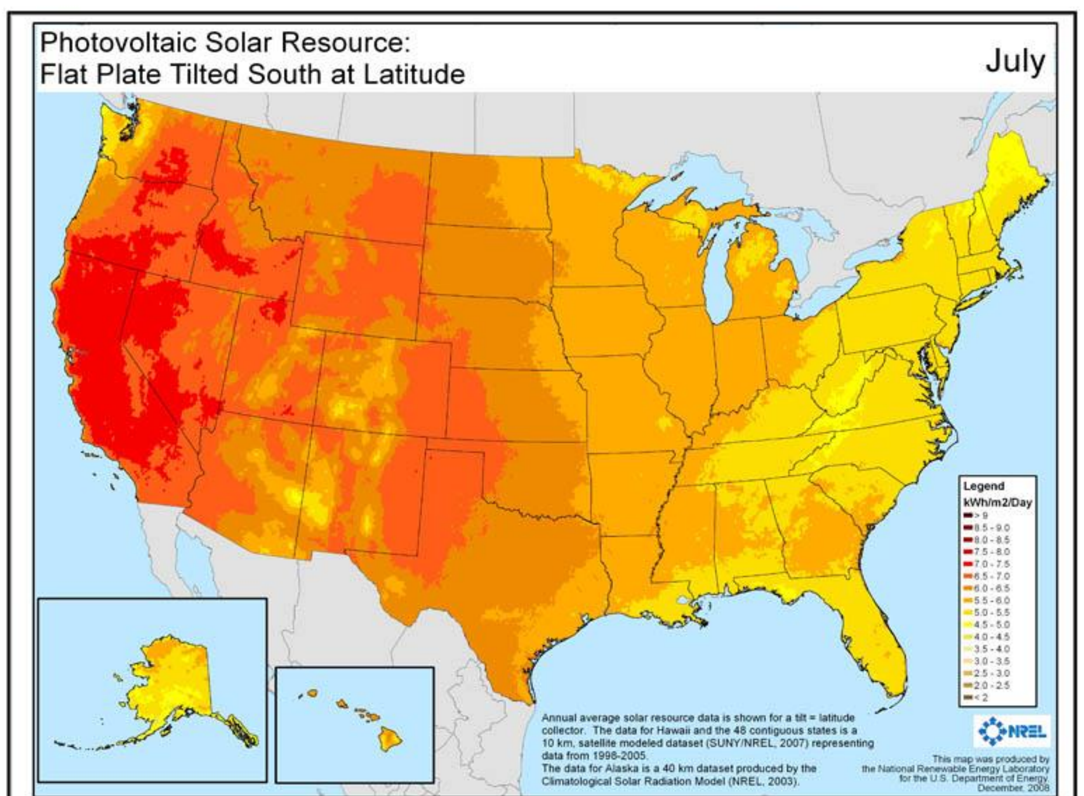


Figure 5
Photovaltaic Solar Data

Alpine Lakes Automation Feasibility
Project No. 120045, Alpine Lakes, Chelan County, WA







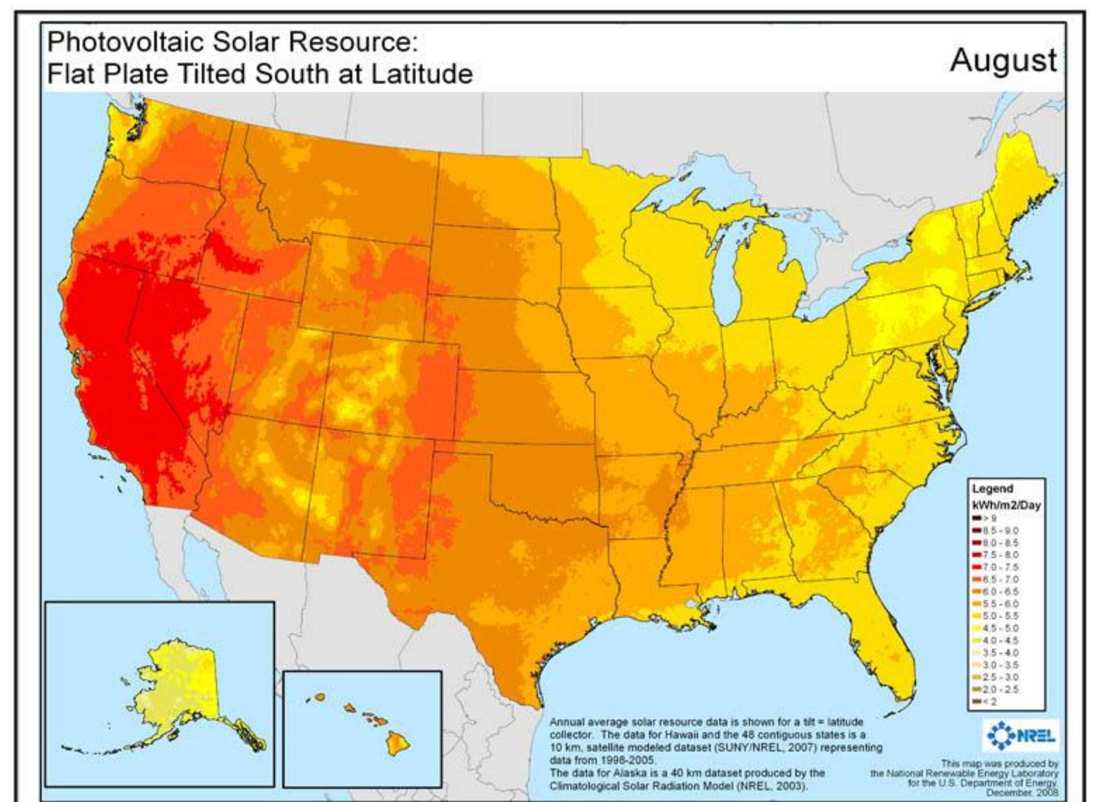


Figure 5
Photovaltaic Solar Data

Alpine Lakes Automation Feasibility
Project No. 120045, Alpine Lakes, Chelan County, WA

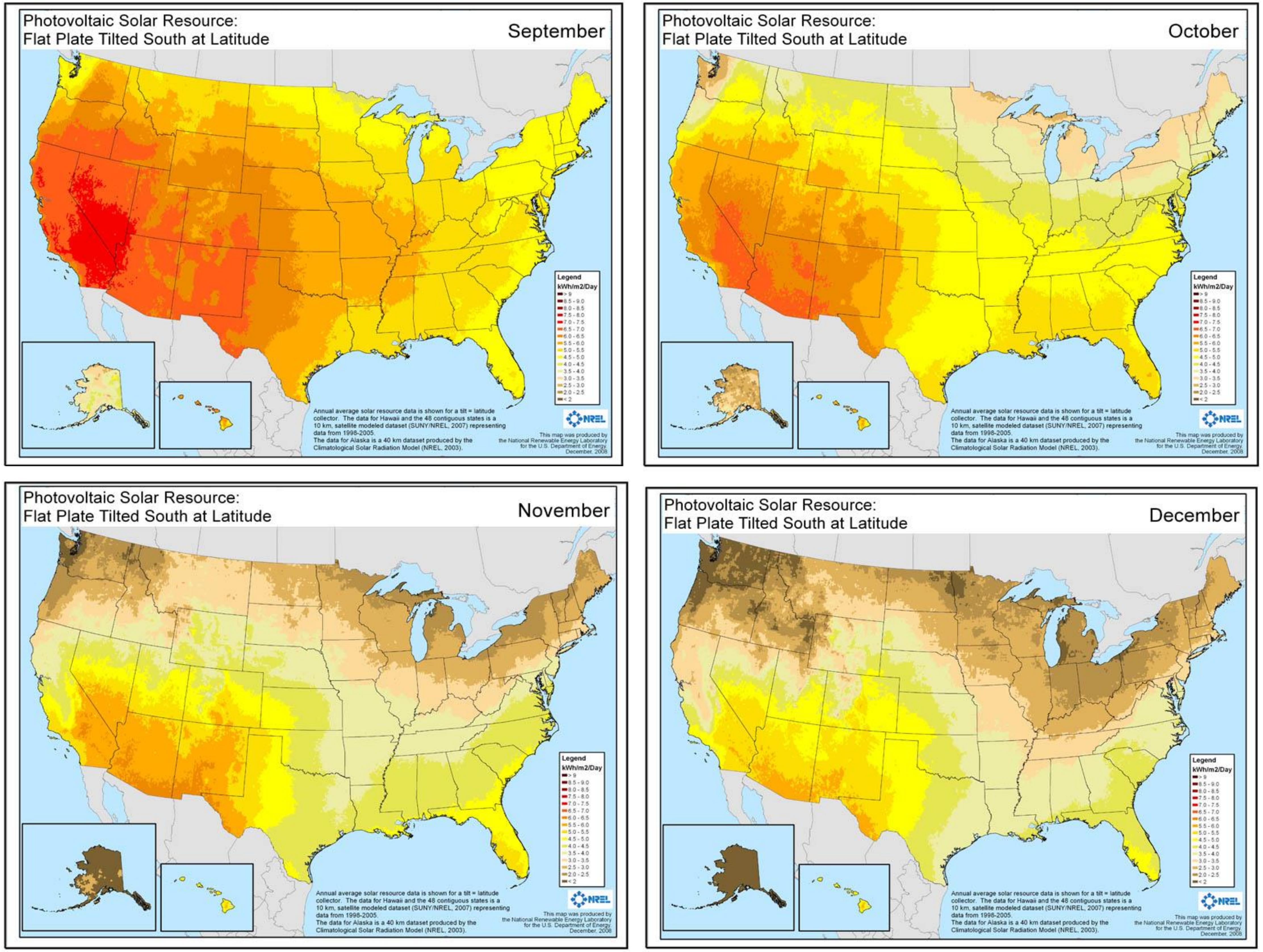


Figure 5
Photovaltaic Solar Data

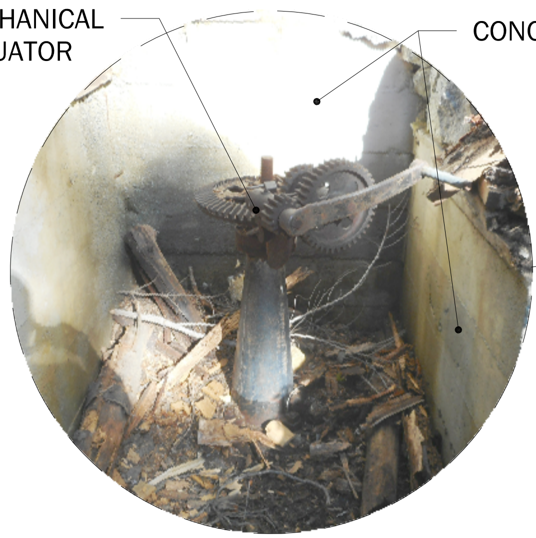
Alpine Lakes Automation Feasibility
Project No. 120045, Alpine Lakes, Chelan County, WA

EXISTING

ENCLOSURE

MECHANICAL ACTUATOR

CONCRETE



EXISTING DAM / SPILLWAY

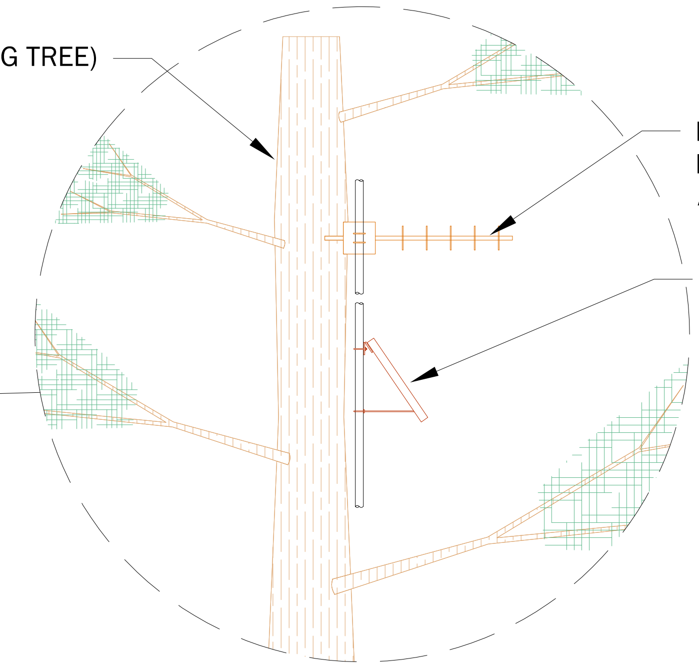
ORTHOGRAPHIC AERIAL SITE VIEW

PROPOSED

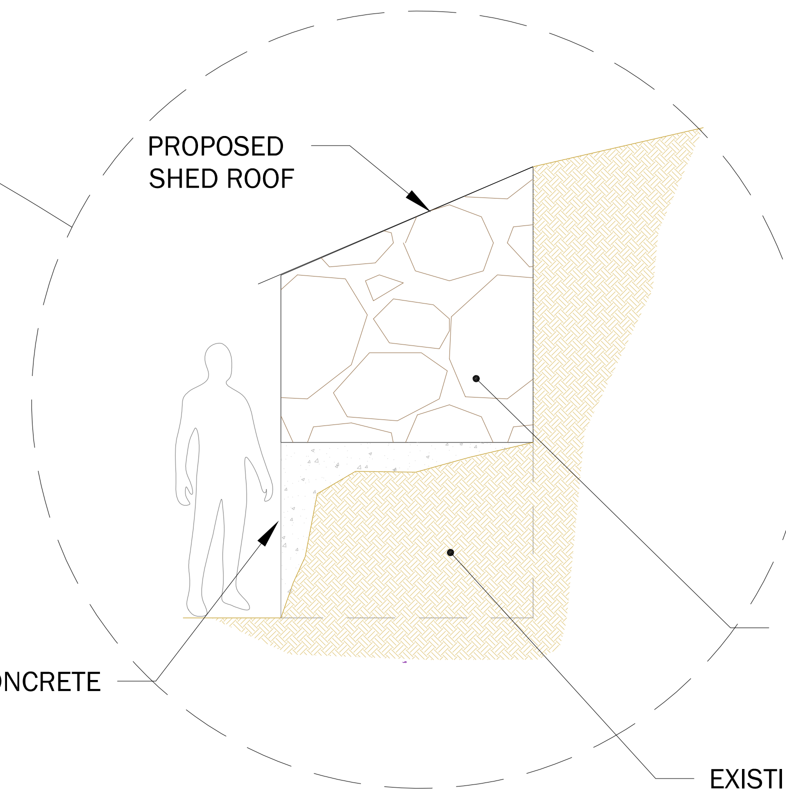
(EXISTING TREE)

PROPOSED DIRECTIONAL ANTENNA

PROPOSED SOLAR PANEL



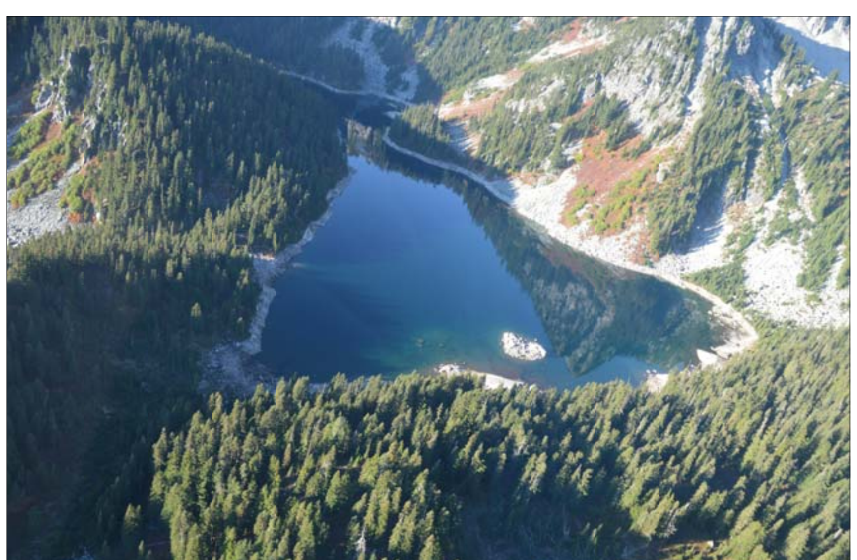
PROPOSED SHED ROOF



EXISTING CONCRETE

PROPOSED CONCRETE (FAUX ROCK APPEARANCE)

EXISTING GRADE



DRAWN-DOWN APPEARANCE

July (Full Stage)

September (Partial Stage)

August (Partial Stage)

October (Empty Stage)

Aesthetic Impacts
Square Lake Automation

Feasibility Study, Alpine Lakes Automation Improvements
Leavenworth, Washington

Aspect CONSULTING	Mar-2017	BY: JRB	FIGURE NO.
	PROJECT NO. 120045	REVISED BY: -	6

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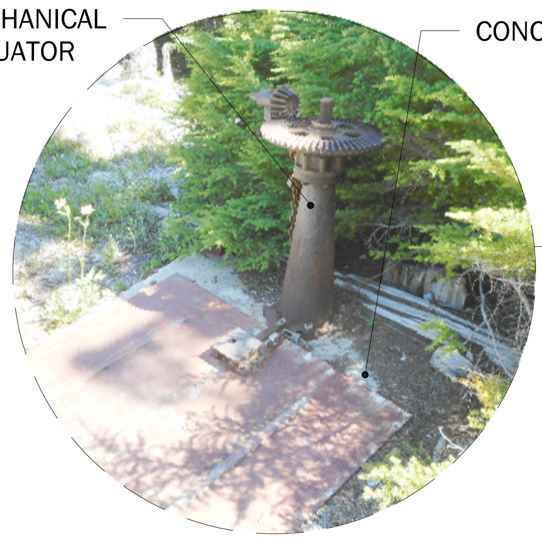
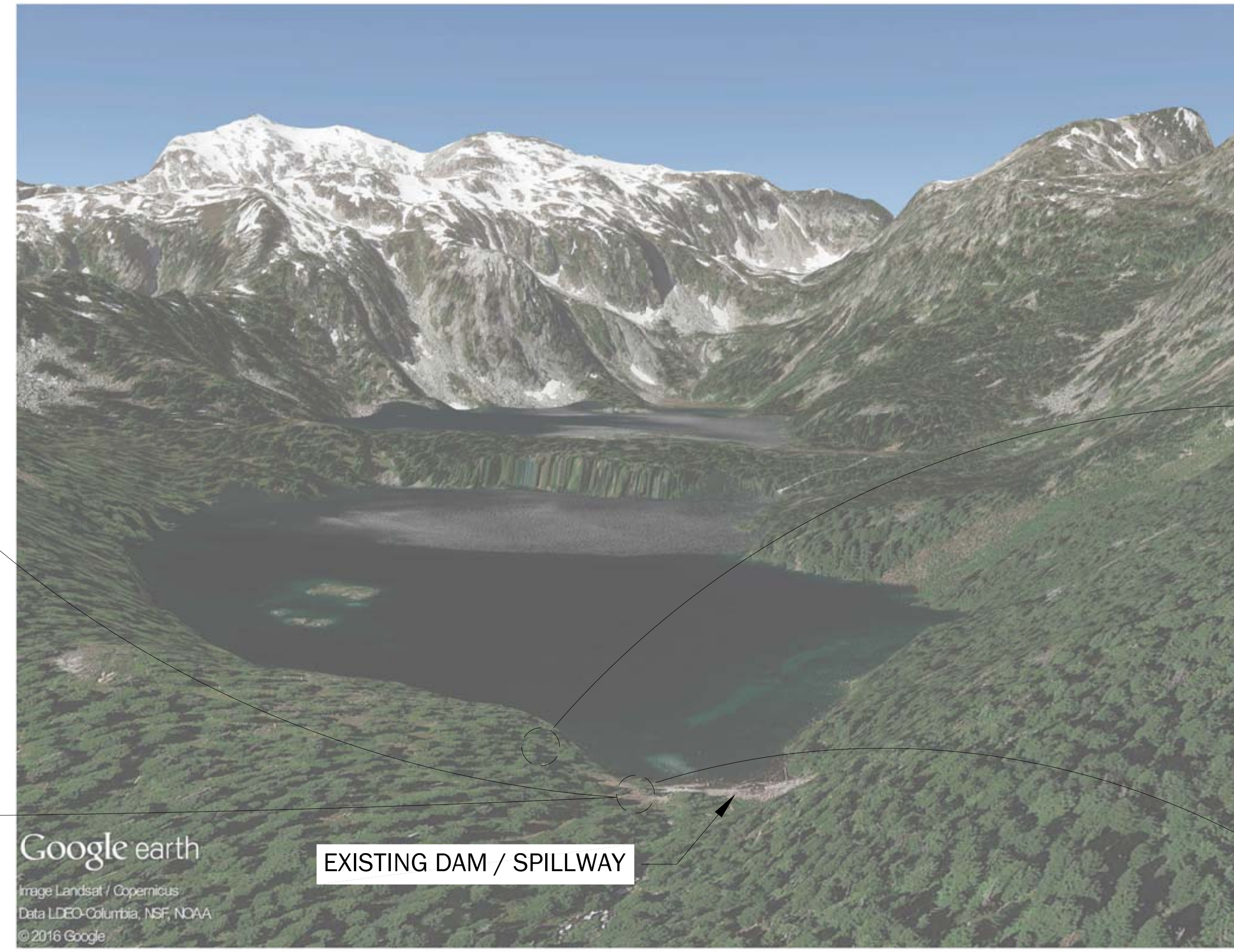
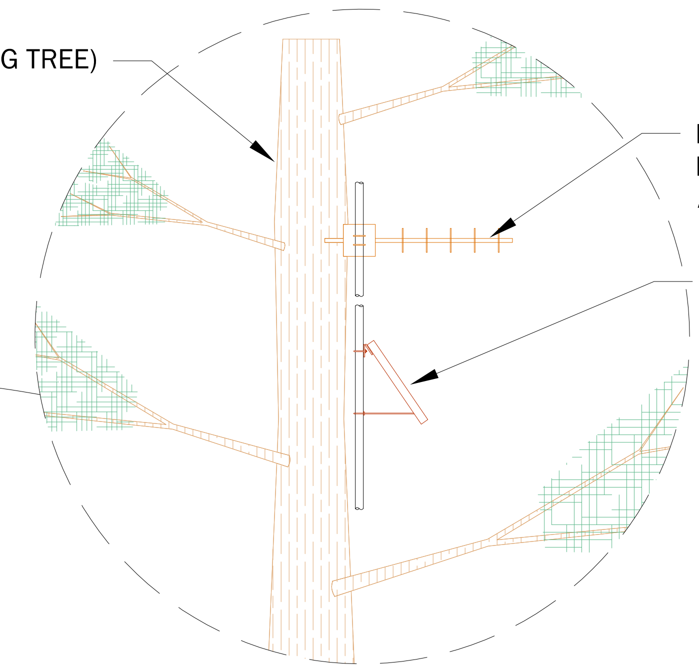
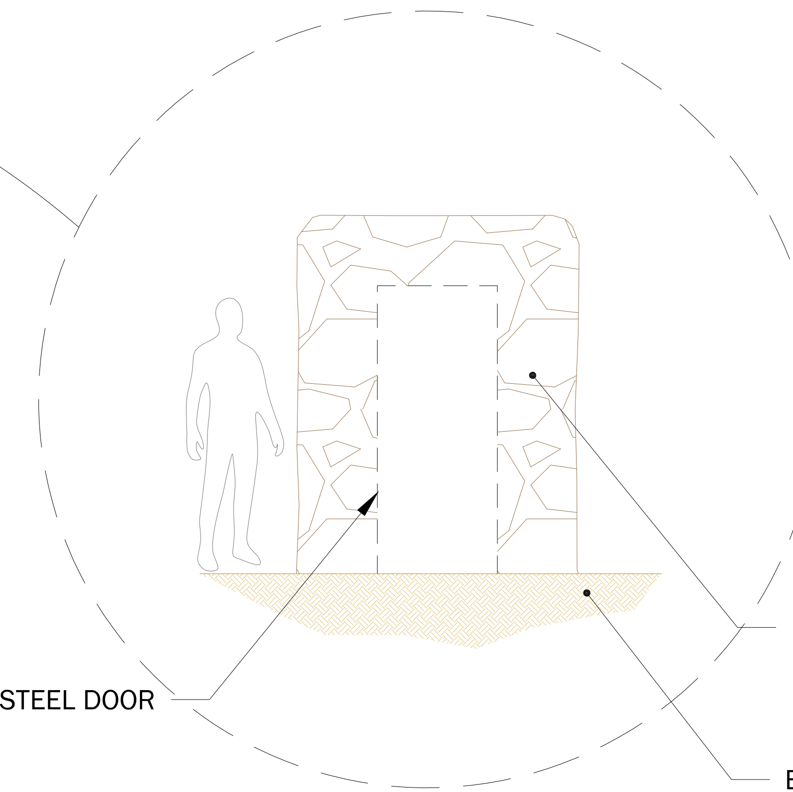




ORTHOGRAPHIC AERIAL SITE VIEW

PROPOSED





DRAWN-DOWN APPEARANCE

July (Full Stage)

September (Partial Stage)

August (Partial Stage)

October (Empty Stage)

Aesthetic Impacts
Klonaqua Lake Automation

Feasibility Study, Alpine Lakes Automation Improvements
Leavenworth, Washington

Aspect CONSULTING	Mar-2017	BY: JRB	FIGURE NO.
	PROJECT NO. 120045	REVISED BY: -	7

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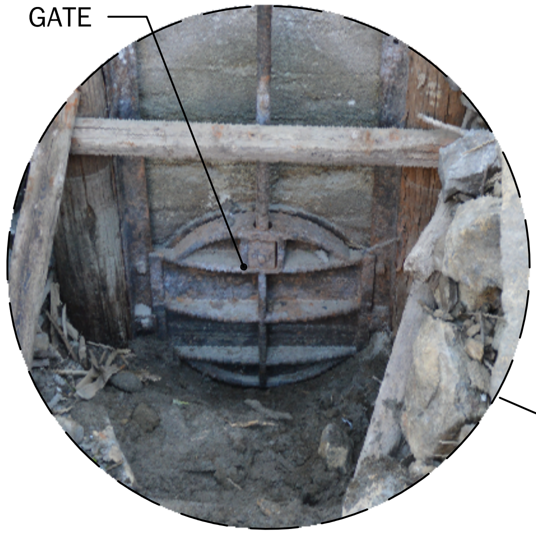
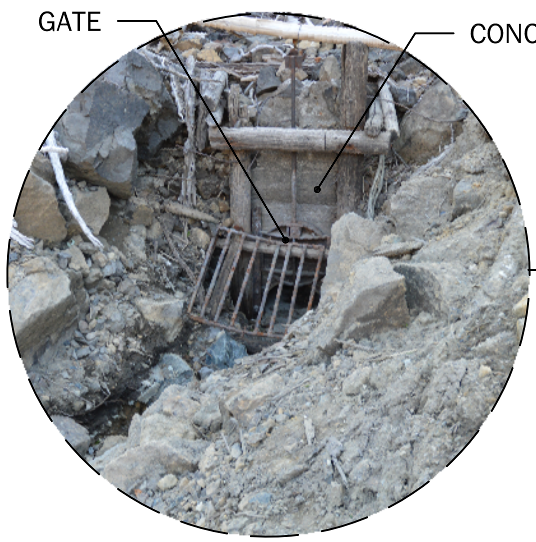
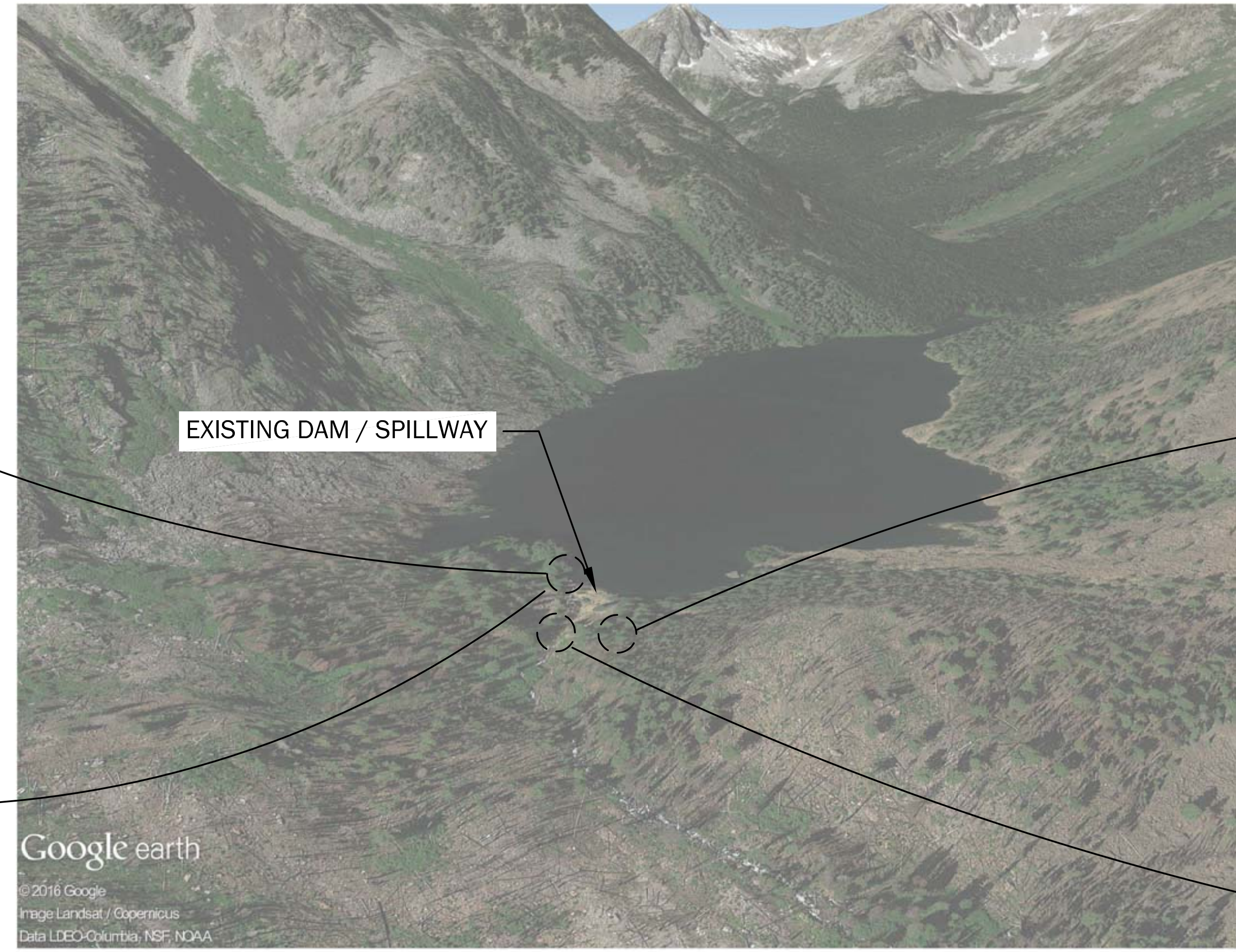
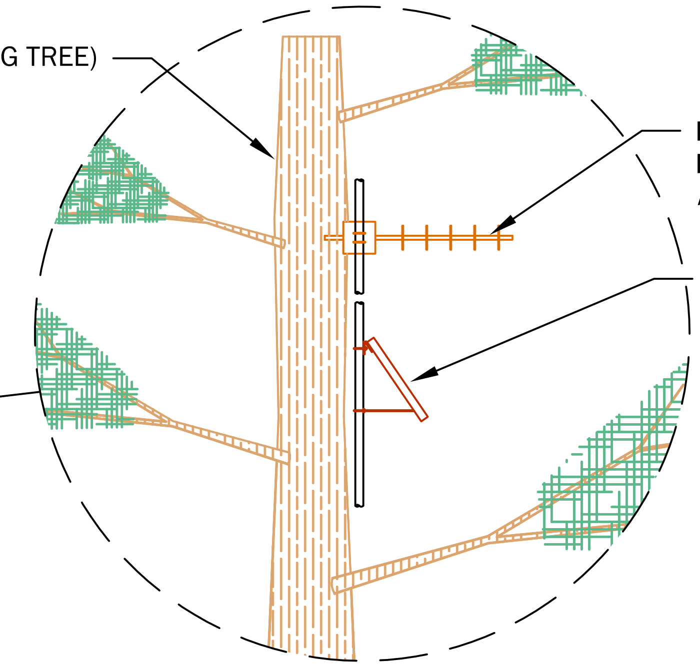


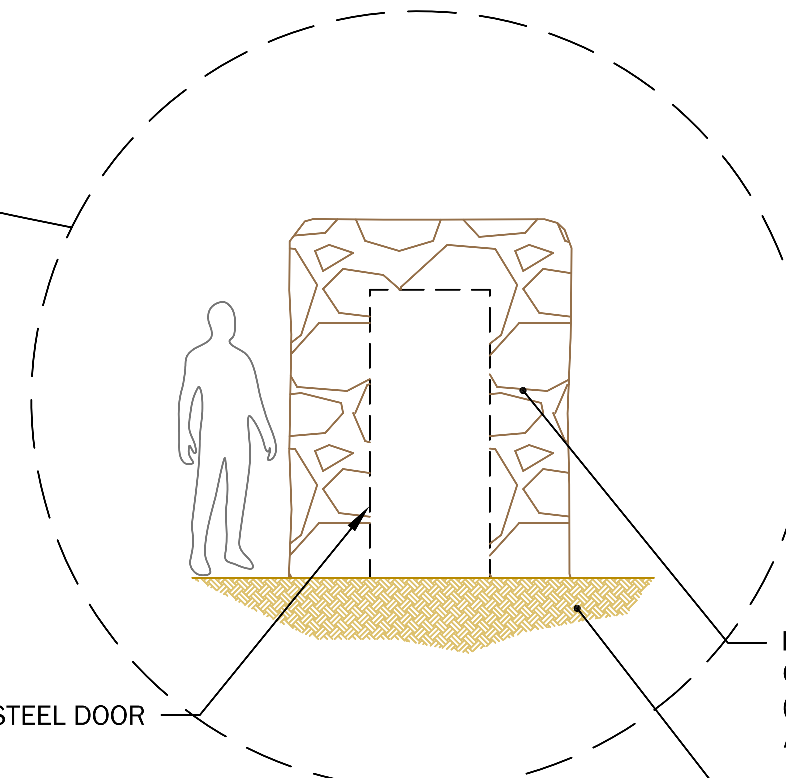


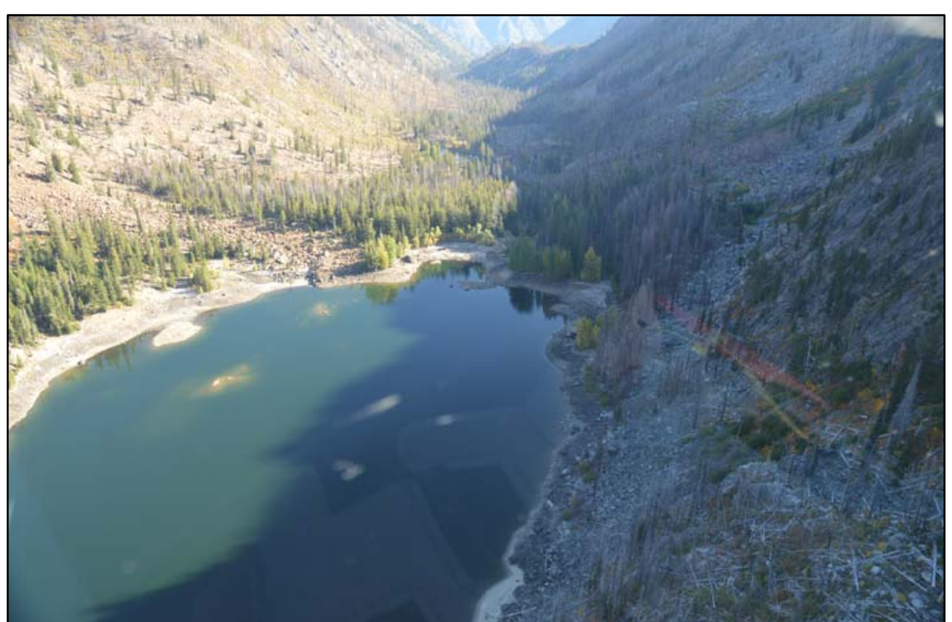


ORTHOGRAPHIC AERIAL SITE VIEW

PROPOSED







DRAWN-DOWN APPEARANCE

July (Full Stage)

September (Partial Stage)

August (Partial Stage)

October (Empty Stage)

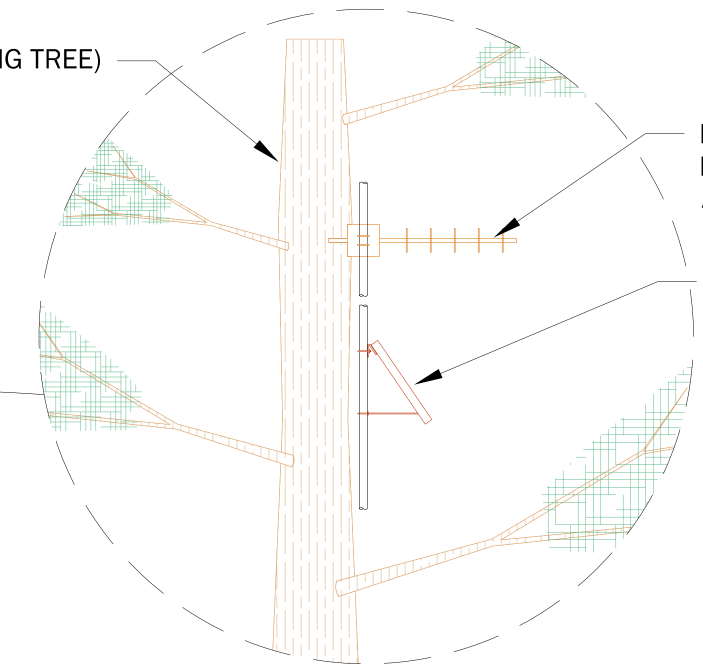
Aesthetic Impacts
Eightmile Lake Automation
Feasibility Study, Alpine Lakes Automation Improvements
Leavenworth, Washington

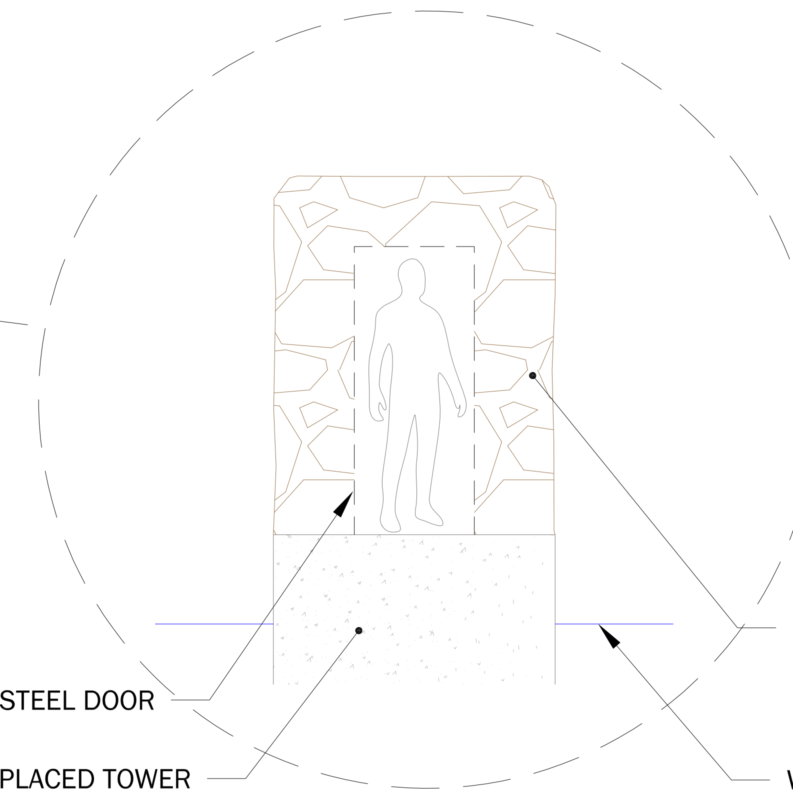
Aspect CONSULTING	Mar-2017	BY: JRB	FIGURE NO.
	PROJECT NO. 120045	REVISED BY: -	8

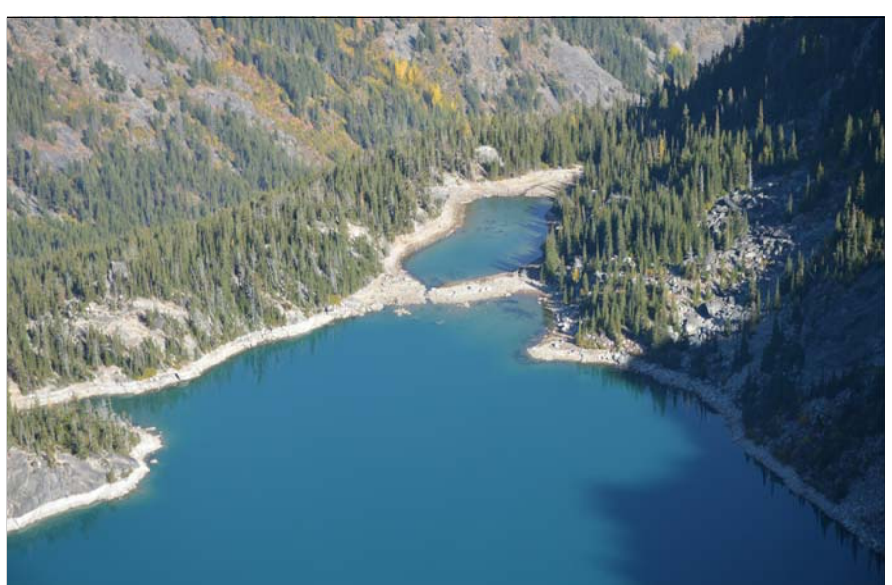
EXISTING

ORTHOGRAPHIC AERIAL SITE VIEW

PROPOSED







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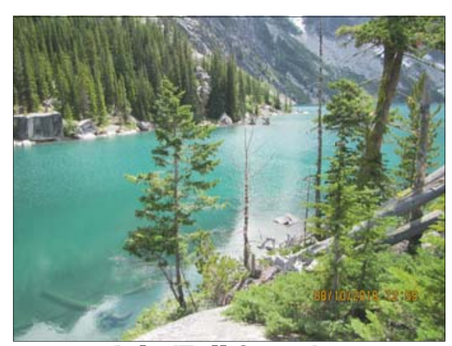

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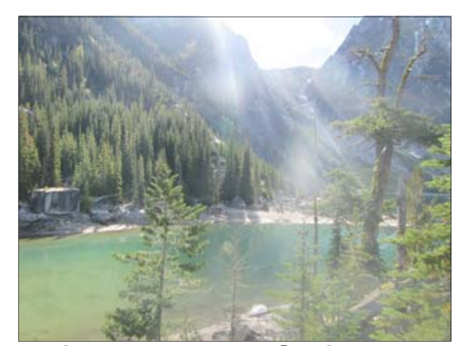

September (Partial Stage)

August (Partial Stage)

October (Empty Stage)

Aesthetic Impacts
Colchuck Lake Automation

Feasibility Study, Alpine Lakes Automation Improvements
Leavenworth, Washington

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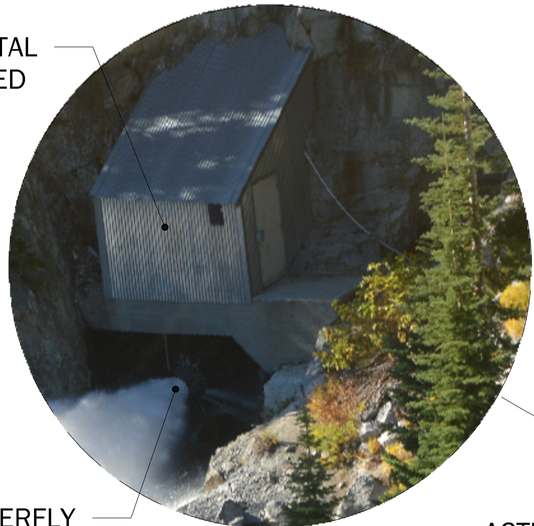

ORTHOGRAPHIC AERIAL SITE VIEW

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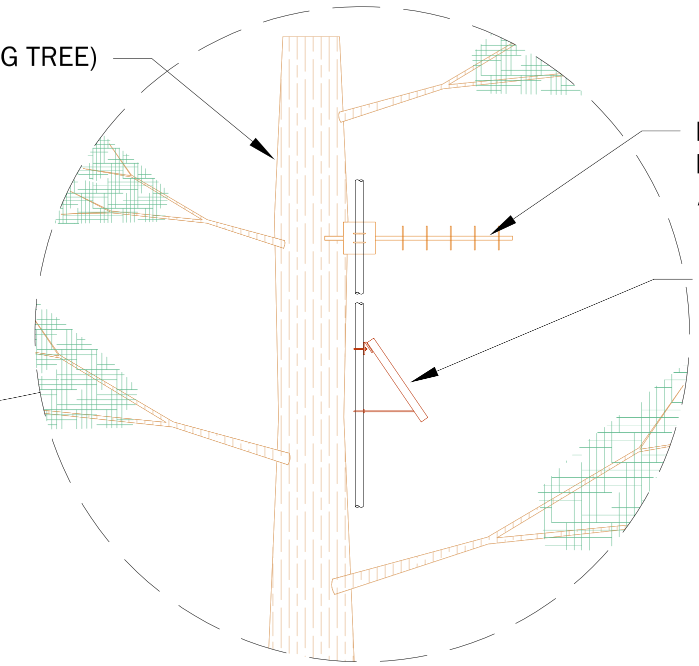

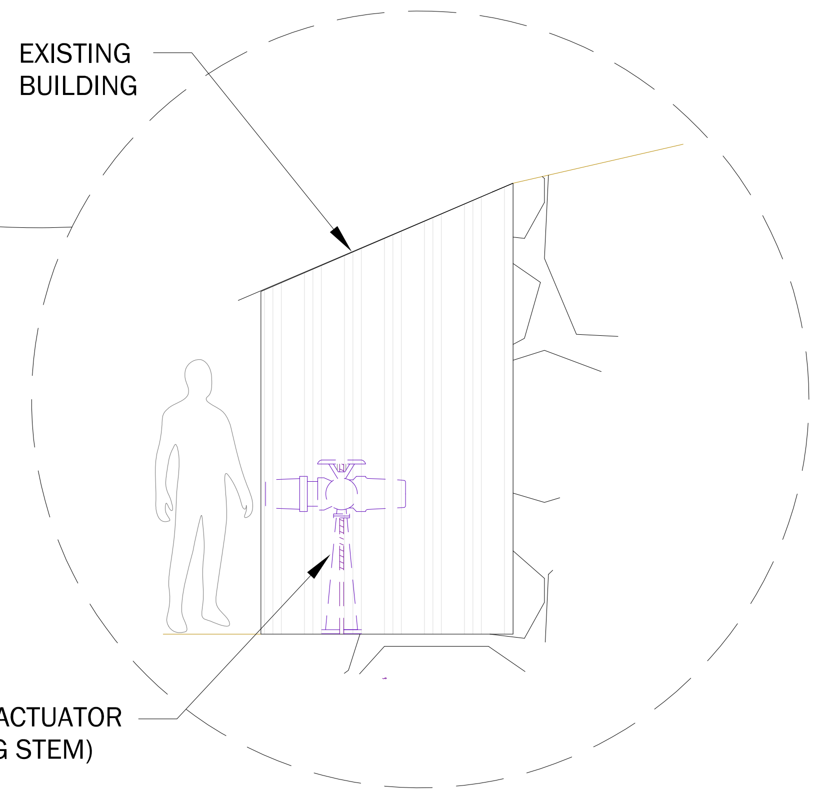

DRAWN-DOWN APPEARANCE

Aesthetic Impacts
Snow Lakes Automation

Feasibility Study, Alpine Lakes Automation Improvements
Leavenworth, Washington

Aspect CONSULTING	Mar-2017	BY: JRB	FIGURE NO.
	PROJECT NO. 120045	REVISED BY: -	**10**

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APPENDIX A

Technical Memorandums:
2016 and 2017 Alpine Lakes Flow Augmentation Pilot Studies

MEMORANDUM

Project No.: 120455

May 11, 2017

To: Mike Kaputa, Director, Chelan County Natural Resources Department

From:

Bill Sullivan, LHG, CWRE
Senior Hydrogeologist
bsullivan@aspectconsulting.com

Re: **Alpine Lakes 2016 Flow Augmentation Pilot Study**

Executive Summary

Aspect Consulting, LLC (Aspect) conducted the Alpine Lakes 2016 Flow Augmentation Pilot Study (Study) to assess the effects of augmenting stream flows in Icicle Creek using water stored by the Icicle-Peshastin Irrigation District (IPID) in five mountain reservoirs. It was launched in response to discretionary trust water donations of stored water by IPID coinciding with planned reservoir maintenance activities. The Study was coordinated by Chelan County Natural Resources Department to understand benefits and impacts and potential fatal flaws associated with the proposed Alpine Lakes Optimization, Modernization, and Automation Project (Project).

The Project is being developed by the multi-stakeholder Icicle Work Group's (IWG) as part of the Icicle Creek Water Resource Management Strategy (Strategy) to achieve diverse benefits in the Icicle Creek drainage. A Guiding Principle of the Strategy is achieving adequate stream flows in the Historic Channel of lower Icicle Creek with the goal of maintaining flows in the Historic Channel of at least 100 cubic feet per second (cfs) during average years and 60 cfs during drought years.

The Study included installation of stage and outflow monitoring equipment at four reservoirs to support management of water release from storage to augment stream flows, as well as coordination with the U.S. Fish and Wildlife Service (USFWS) on their operations of Snow and Nada Lakes. Icicle Creek flows were monitored and adjustments were made to augmentation flows on a weekly basis during 14 weeks in Summer and early Fall 2016. Key findings of the Study include:

- Flow augmentation using over 6,400 acre-feet (ac-ft) of water stored in Alpine Lakes reservoirs can significantly enhance stream flows in the Historic Channel of Icicle Creek;
- While flow augmentation is not a total solution for achieving the IWG's flow targets in the Historic Channel, it might account for about one-third of the solution based on 2016 results;

- Augmentation flows up to 90 cfs extended Historic Channel flows above the 100 cfs target for 3 weeks of the 9 week low-flow period in 2016 when flows would have otherwise dropped below the target;
- Augmentation flows equaled between 31 and 78 percent of late season discharge in the Historic Channel; and
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonal falling hydrograph. However, flow augmentation can slow the rate of seasonal decline, prolonging the period of time when flows remain above the target.

No fatal flaws were identified and a follow-on study is recommended to confirm and improve on findings of the 2016 Study and to resolve data gaps. Key recommendations for follow on study include:

- Improve accuracy of Icicle Creek discharge estimates in the Historic Channel by obtaining real-time stream flow measurements collected at Structure 2 (located at the head of the Historic Channel);
- Initiate study to assess impacts of release flows on Bull Trout habitat in French and Leland creeks that drain Square and Klonaqua lakes. Determine whether release flows above 10 cfs are detrimental after September 15. These lakes hold nearly half the water physically available for flow augmentation, and releases greater than 10 cfs in late season would provide greater flexibility to manage flow augmentation in Icicle Creek; and
- Improve understanding of the fate of flow augmentation water. Evaluate gaining/losing characteristics of tributaries draining reservoirs and mainstem Icicle Creek. Coordinate with USFWS to improve understanding of releases from Snow Lakes. Coordinate with USFWS, IPID, Cascade Orchards Irrigation Company, and the City of Leavenworth to quantify diversions occurring upstream of the Historic Channel.

A detailed discussion of project background, methods, findings, and conclusions follows.

Introduction

Aspect Consulting, LLC (Aspect) conducted the Alpine Lakes 2016 Flow Augmentation Pilot Study (Study) to assess the effects of augmenting stream flows in Icicle Creek using water stored by the Icicle-Peshastin Irrigation District (IPID) in five mountain reservoirs.

The multi-stakeholder Icicle Work Group (IWG) is comprised of diverse agricultural, conservation, and recreational interests, Tribes, and local, state, and federal agencies. The IWG developed the Icicle Creek Water Resource Management Strategy (Strategy) by consensus of its members to improve instream flows in Icicle Creek. The Strategy outlines nine Guiding Principles to achieve diverse benefits. The Adequate Streamflow principle sets a target flow of 100 cubic feet per second (cfs) during low-flow periods in non-drought years and 60 cfs during drought years in a reach known as the Historic Channel of lower Icicle Creek. The flow target is intended to be measured at the Leavenworth National Fish Hatchery (LNFH) Structure 2, located at river mile (RM) 3.8 that lies at the head of the Historic Channel of Icicle Creek (described below).

One of the proposed actions identified in the Strategy is the Alpine Lakes Reservoir Optimization and Automation Project that involves releasing water from five reservoirs to augment flows in Icicle Creek. These reservoirs are Square, Klonaqua, Eightmile, Colchuck, and Snow lakes.

The Study was launched in response to discretionary trust water donations of stored water by IPID coinciding with planned reservoir maintenance activities. It was coordinated by Chelan County Natural Resources Department to understand benefits and impacts and potential fatal flaws associated with the proposed Alpine Lakes Optimization and Automation Project.

The Study was funded under Grant Number WROCR-VER1-ChCoNR-00002 sourced from the Washington State Department of Ecology (Ecology) Office of Columbia River (OCR).

Background

Basin Description

Icicle Creek drains an area of about 243 square miles of undeveloped mountainous terrain west of Leavenworth in Chelan County, Washington (Subbasin; Figure 1). Icicle Creek drains to the Wenatchee River at Leavenworth. The majority of its drainage area lies within the Alpine Lakes Wilderness Area on land managed by the U.S. Forest Service (USFS). The lowermost section is moderately developed and includes recreational and residential development, agriculture, lodging, and the LNFH.

The Icicle is a snowpack-driven watershed with high flows occurring during spring freshet and low flows in late Summer (primarily September) and Fall. Two stream gauges are present on Icicle Creek (Figure 1). The U.S. Geological Survey (USGS) operates a gauge (12458000) at RM 5.8 located upstream of Snow Creek having a period of record from 1993 to present. Ecology operates a gauge (45B070) at RM 2.2 having a period of record from 2007 to present. Additionally, the USFWS is in the process of establishing stream measurement recording at Structure 2.

Numerous mountain and alpine lakes are present in the Icicle Subbasin. These are naturally formed lakes, the largest of which were modified to store water prior to Wilderness Area designation. The Icicle's major tributaries originate from the larger lakes. These include French Creek draining Klonaqua Lake; Leland Creek draining Square Lake; Mountaineer Creek draining Eightmile Lake and Colchuck Lake; and Snow Creek draining Upper and Lower Snow Lakes. Major lakes and tributaries are shown on Figure 1.

Icicle-Peshastin Irrigation District

The IPID diverts surface water from Icicle and Peshastin Creek drainages for irrigation of lands between Leavenworth and Cashmere. IPID holds diversionary rights from Icicle and Snow Creeks at the IPID diversion located at RM 5.7 (Figure 1) during irrigation season at a rate up to 117.71 cfs under Water Right Certificates S4-35002JC, S4*35002ABBJ, having priority date of 1910 and Certificate 1082 having priority date of 1919.

IPID also has water rights to store water in the five aforementioned reservoirs located within the Alpine Lakes Wilderness Area for the purpose of providing irrigation water during times of drought or when Icicle Creek flows are insufficient to meet IPID's diversionary needs. These reservoirs are discussed below.

Reservoirs

The five naturally-formed lakes within the Alpine Lakes Wilderness Area were modified beginning in the 1920s to store water for irrigation and fish propagation. Locations of the reservoirs are shown on Figure 1.

Four of the reservoirs are operated by IPID (Square, Klonaqua, Eightmile, and Colchuck lakes) and one reservoir is operated by the USFWS and U.S. Bureau of Reclamation (USBOR). Square and Klonaqua Lakes were modified by excavating a tunnel (Square) and buried pipe (Klonaqua) to access water below the natural level of the lakes. Colchuck Lake was modified by excavating a channel connecting two natural lake basins. All four lakes have small dams (5 to 10 feet high) constructed to enhance storage. Upper Snow Lake Reservoir is operated to support the LNFH and also stores water for IPID. Water is accessed in Upper Snow Lake using a tunnel/pipe bored through rock. The outlet lies below the natural water level of Upper Snow Lake. There is no dam.

IPID and USFWS/BOR operate these facilities under easements with USFS that were established when the land was transferred to USFS during the Wilderness Area designation. These easements allow IPID and USFWS staff access and to perform maintenance activities.

Previously, only rough estimates were available for water volumes held in active storage in the reservoirs due to limited information on lake bed bathymetry and freeboard (vertical distance from invert of outlet to overflow).

Reservoir Operations

In average runoff years, water is released on a rotational basis from one of the four reservoirs operated by IPID. IPID typically only receives water from Upper Snow Lake during drought years under a partial subordination agreement with USFWS. Water is typically released from some or all the reservoirs in drought years to augment downstream water supply.

To operate these reservoirs, IPID and USFWS staff hike to their respective lakes to manually turn hand wheels and valves that operate head gates. USFWS demand from Snow Lakes ranges from about 20 cfs in July to about 50 cfs during September. The control valve at the outlet to Upper Snow Lake currently limits the release rate to about 55 cfs.

Because of the time and cost required to adjust head gates, adjustments are generally made infrequently or only at the beginning and end of the season. The hand wheel operator at Eightmile Lake was destroyed when the dam partially washed out several decades ago. Adjusting this gate requires using scuba equipment when the lake is full, which further limits IPID’s ability to adjust outflows. Stored water in Eightmile Lake also seeps through the north end of the lake where an ancient landslide serves as a natural impoundment. For this reason, IPID’s water right includes water stored in Eightmile Lake lying below the invert of the outlet pipe.

Prior to this Study, there was no instrumentation installed to measure reservoir stage or discharge rates at the four lakes managed by IPID. At Upper Snow Lake, USFWS collects reservoir stage and release flow data using existing instrumentation.

Leavenworth National Fish Hatchery

The LNFH is located in the lower section of Icicle Creek at about RM 2.7 (Figure 1). The facility was constructed in the 1930s to mitigate impacts to anadromous fish runs impacted by the construction of Grand Coulee Dam. The LNFH continuously diverts surface and groundwater at a rate of about 50 cfs for fish propagation. Surface water is diverted a rate of about 42 cfs from Icicle Creek using a diversion located at RM 4.5. The balance of water used by LNFH is withdrawn from a well field at the hatchery tapping an aquifer in hydraulic continuity with Icicle Creek.

An artificial channel known as the Hatchery Channel was constructed to periodically divert water from Icicle Creek to hydrate the aquifer supplying the well field. Water is diverted to the Hatchery Channel by a hydraulic control structure (Structure 2) that spans the width of the mainstem Creek at RM 3.8.

Effluent from the hatchery is discharged at a rate of about 50 cfs to the mainstem Icicle Creek below the outlet of the Hatchery Channel at RM 2.7, creating a bypass reach on Icicle Creek of about almost 2 miles. This bypass reach includes the natural channel of Icicle Creek downstream of Structure 2, known as the Historic Channel.

Flow Augmentation

The 2016 Pilot Study provided flow augmentation to Icicle Creek using water donated to trust by IPID for the purpose of benefitting instream flows. Methods used in the Study and findings are discussed below.

Trust Water Donations

In 2016, IPID requested to temporarily donate five of its Alpine Lakes reservoir storage water rights into Ecology's Trust Water Right Program pursuant to RCW 90.42.080 that encourages water right holders to donate water rights for instream flow purpose. In April, Ecology accepted donations for Certificate Nos. 5527, 1227, 1228, 1229, and 1591 for the purpose of benefitting instream flow from July 11 to October 15, 2016. The donated water was to be made available by releasing water from the five lakes managed by IPID and leaving it instream for environmental benefit during the 2016 low-water season. Table 1 shows quantities of water placed into trust.

Table 1. Quantities Donated to Trust Water Program for 2016*

Lake Name	Quantity of Water (acre-feet)
Square Lake	2,000
Klonaqua Lake	2,500
Eightmile Lake	1,600
Colchuck Lake	2,500
Snow Lakes	1,000
Total Donated to Trust	9,600

*Donation period July 11 to October 15, 2016 for instream flow purpose.

The timing of trust water donations was coordinated to align with planned maintenance of IPID reservoirs, which required lake levels to be drawn down by Fall 2016 for repair and inspection. This presented an opportunity to conduct the 2016 Flow Augmentation Pilot Study.

Project Objectives and Constraints

Prior to commencing this Study, IWG's Instream Flow Subcommittee developed and agreed on the following objectives and constraints for the Project:

- Meet a target flow of 100 cfs in the Historic Channel as measured at Structure 2, consistent with IWG's Guiding Principles. Meeting this target was intended to be adaptive based on actual flows verified on a weekly basis;
- Release about 700 ac-ft from Colchuck Lake by September 1 to drawdown the reservoir supporting planned IPID maintenance;
- Release the peak flow from Eightmile Lake early to accommodate design inspection of the submerged head gate structure. This was initially assumed to be about 1,350 ac-ft of storage over the period of about 1 month. The IWG estimated this would accommodate about 250 ac-ft to be released via natural seepage at a rate of about 3 cfs for remainder of season. No weekly adjustments were planned for Eightmile due to the submerged head gate control;
- Limit release flows to about 10 cfs after September 15 from Square and Klonaqua lakes to protect Bull Trout spawning habitat in Leland and French creeks;
- Limit initial flow augmentation release from Upper Snow Lake to about 5 cfs continuously due limitations of the control valve. This would ensure USFWS could release sufficient water for operations at LNFH. This was to be adaptive later in the season, depending on LNFH water needs; and
- Significant ramping changes to the rate of water released from storage at a given reservoir should be avoided and minimized to 5 to 10 cfs per week in late Summer and early Fall.

Additional Project objectives were to release as much donated trust water as possible in support of engineering inspections at each site, and for conducting bathymetric surveys of the lakes.

These criteria were followed to the extent possible during the Study.

Methods

Overview

Key elements of the Study consisted of establishing Project objectives and constraints (described above), installing monitoring instrumentation at the four lakes operated by IPID, management of flow augmentation releases to meet Icicle target flows, and analysis of data to evaluate the effects on instream flows in the Historic Reach. A detailed methodology is contained in the Quality Assurance Project Plan (QAPP) (Aspect, 2016) as submitted to Ecology.

Instrumentation and Monitoring

Prior to this Study, there was no mechanism to measure discharge rates from lakes or monitor changes in lake stage. To prepare for releasing flow augmentation water, Aspect and IPID installed reservoir stage and outflow release rate measurement instrumentation at Square, Klonaqua, Eightmile, and Colchuck lakes during the week of July 11, 2016. Because there are no roads, helicopter support was contracted to perform lifts of equipment and to ferry staff. This work was completed with IPID supervision under its easements to reservoir sites in accordance with a Work Plan submitted by IPID to the USFS.

Reservoir Stage Height Monitoring

Continuous recording instrumentation was installed in each lake to track changes in reservoir stage resulting from flow augmentation releases and inputs from precipitation and runoff. Tracking water level changes supported flow augmentation management by allowing estimates to be made for volumes remaining in storage, and supported the Project objective of ensuring reservoirs were sufficiently drawn down in time for inspection. Lake stage monitoring also enabled development of stage-volume relationships when combined with bathymetric survey data that had already been collected (Eightmile Lake) or were scheduled for collection using LiDAR in October 2016. At the beginning of the Study on July 11, all four reservoirs were full and overflowing from runoff.

Pressure transducer and temperature data loggers were installed for continuous recording. A means to visually record reservoir stage was also installed at each site. Because the pressure transducer data loggers are not barometrically compensated, recording barometer instruments were installed at two sites (Square and Eightmile).

Methods to install lake stage monitoring instruments varied by location. Colchuck and Eightmile lakes have reservoir control structures that enabled affixing a 1.25-inch-diameter galvanized pipe to the concrete head gate tower (Colchuck) and head gate vault (Klonaqua). The pipes were extended to depths at or near the bottom of the headgate. Pressure transducers were placed inside the pipes near the bottom. Holes were drilled at intervals into the pipes to allow free communication with the surrounding lake water. Staff plates were affixed to the outside of the pipes to provide a visual means of recording stage. A water level meter was also stored and used at Klonaqua Lake to manually measure water level changes in the head gate vault.

At Square and Eightmile lakes, pressure transducers were anchored to the lake bed at depths estimated to be at or below the active storage freeboard (below the invert of the outlet). These were connected to the shoreline by a communication cable encased in PVC conduit terminating in a watertight container above the high water mark. Installation of staff gauges was not possible at these lakes. Instead, a benchmark was established as a reference point to visually measure water level changes on the shoreline using a laser level and stadia rod.

Locking metal boxes were established in discrete locations to store equipment needed throughout the Study, including laser level and stadia rod, water level meter, barometer data loggers, and hand tools.

Release Flow Monitoring

Release flow monitoring equipment was installed at the four lakes managed by IPID to establish a means of measuring outflow rates. Water stored in the lakes was released using outlet pipes controlled by head gates. Because outflow rates vary with lake level for a given head-gate position, it was necessary to establish rated stream gauging sections in the outlet channels. This allowed for the head gate position to be adjusted until the desired outflow rate was achieved.

Rated stream gauging sections were established in outlet channels by installing a staff plate affixed to vertical bedrock outcrop or a rod driven into the streambed. Discharge from the lake was measured at varied rates by changing head gate positions to adjust outflow. Discharge was determined using a velocity meter and area-velocity measurement (Rantz, et al.,1982). Staff plate measurements (stage) were recorded for each measured discharge rate to create rating curves.

Rating curves developed for the outlet channels at the four lakes managed by IPID are shown on Figure 2. Rating curves predict discharge from measured stages and discharge rates based on an empirical mathematic formula. Time constraints during the installation period limited the number of measured discharge points that could be collected to three to five points per rating curve. Safety considerations limited the ability to measure high flows at some sites. Additionally, because the reservoirs were overflowing with runoff, there was no opportunity to measure low-discharge conditions at several sites. Discharge rates lying outside the range of measured data in the rating curves shown on Figure 2 were extrapolated.

Using rating curves to predict discharge, desired outflow rates were set by adjusting the head gate until the staff plate read the correct stage.

Flow Augmentation Management

Flow augmentation management followed a weekly cycle consisting of monitoring discharge in Icicle Creek and adaptively adjusting flows released from storage with the goal of maintaining Icicle Creek flows in the Historic Channel above 100 cfs.

Flows in Icicle Creek were originally intended to be measured directly at Structure 2 because it is located at the head of the Historic Channel. However, access to real-time discharge data measured by USFWS at Structure 2 was not available. Instead, real-time flows recorded at Ecology’s Gauge located downstream of the LNFH outfall were used as a proxy for flows at Structure 2. We subtracted 50 cfs from Ecology’s measurements to account for water used at LNFH that bypasses the Historic Channel.

Lake-specific discharge rates and flow augmentation release plans were developed on a weekly basis during the Study by Aspect and the Chelan County Department of Natural Resources. In setting these rates, we considered the 100 cfs target flow, water remaining in storage, other Project objectives, and constraints. Once a flow augmentation plan was developed for a given week, it was communicated to IWG stakeholders for review a few days prior to implementation. Chelan County staff spent the following week hiking into the lakes to adjust head gates to match desired outflows. Data collected at each lake included outlet channel discharge (upon arrival--before setting desired outflows—and departure), visual measurements, pressure transducer lake level data, photographs, and other observations. These data were used to determine how quickly outflow had decreased since the last head gate adjustment, estimate volumes of water released from storage, and estimate volumes remaining in storage. These data were then considered for developing flow augmentation plans for subsequent weeks.

Findings

Flow augmentation from the five lakes began on July 11 and continued to nearly the end of the trust water donation period on October 6.

Augmentation Flows and Volumes

Estimated volumes of water released from storage, and ranges of augmentation flows during the Study, are shown on Figure 3. A total of approximately 6,427 ac-ft of water was released from storage, providing cumulative augmentation flow to Icicle Creek ranging from 6 to 90 cfs. A hydrograph of cumulative augmentation flows is shown on Figure 4.

Augmentation Flows

Peak cumulative augmentation flow was limited to 90 cfs by reservoir infrastructure and the Project objective to avoid steep ramp-ups/draw-downs of water released into tributaries.

Peak discharge rates from individual lakes during the Study ranged from 12 cfs at Upper Snow Lake to 35 cfs at Square Lake (Figure 3). Peak discharge rates ranged between 20 and 25 cfs at Klonaqua, Eightmile and Colchuck lakes under lake full conditions. Higher outflow rates were temporarily observed at Colchuck Lake during development of the rated sections but were not measured, out of consideration for safety.

At Upper Snow Lake, flow augmentation discharge was limited to 5 cfs for most of the Study because the existing control valve has a capacity of about 55 cfs, of which LNFH operations require up to 50 cfs (i.e., discharge available for flow augmentation was limited to about 5 cfs). However, augmentation flows from Snow Lakes were increased in October to 12 cfs when LNFH demand decreased.

Augmentation Volumes

Volumes of water released from each lake ranged from about 950 ac-ft in Upper Snow Lake to 1,936 ac-ft in Square Lake (Figure 3).

The active storage volume in three of the lakes was nearly or completely drawn down by the end of the Study: Klonaqua (1,006 ac-ft), Eightmile (1,452 ac-ft), and Colchuck (1,083 ac-ft) lakes. Outlet structures in these lakes were exposed or nearly exposed above the water line and outflows had diminished to less than 2 cfs. Although water remained in active storage in Snow Lakes, IPID's trust water donation was exhausted by the end of the Study.

About 250 ac-ft of active storage remained in Square Lake at the end of the Study, and the outlet structure was about 4 to 5 feet below water. Active storage remained in Square Lake because late season outflows were limited, preventing use of all the water in storage. The Project objective of protecting Bull Trout habitat in Leland Creek limited outflows to 10 cfs after September 15.

Approximately 1,300 ac-ft of IPID's trust water donation remained in storage at the end of the study in Klonaqua and Colchuck lakes. Most of this volume was physically inaccessible due to elevations of outlet structures that lie above the stored water.

Lake Drawdown and Effects on Outflow Rates

Figure 5 shows lake hydrographs with stage measured by continuous recording datalogger, periodic manual measurements, and the depth of lake outlet pipe/tunnel inverts estimated from field inspection. Because the depths of outlet inverts were not known when pressure transducers were installed, one of the transducers was placed at a depth a few feet higher than the invert. Water level changes occurring at depths deeper than the transducer were not recorded by transducer dataloggers but were collected by periodic manual measurements. At Colchuck Lake, the transducer was set about 4 feet above the outlet invert due to head gate construction. The Colchuck hydrograph exhibits a flat line beginning the second week of September that is not indicative of lake stage but rather represents the period when the transducer was no longer submerged.

Drawdown characteristics of lakes were identified by examining changes in lake stage. Drawdown characteristics depend on lake bed geometry, lake volume relative to outlet discharge rate, and water inputs to the lake (runoff, groundwater). Drawdown characteristics of Snow Lakes were not assessed.

The steady declining stage drawdown curve observed for Eightmile Lake on Figure 5 was due to its head gate position, which remained fixed throughout the study and permitted continuous seepage of water through the lake bed to Eightmile Creek. Drawdown curves at Square, Klonaqua, and Colchuck lakes were much steeper and became steeper when flow augmentation releases were increased during the third week in August. At the end of the season, lake stage was seen as increasing due to heavy regional precipitation beginning the second week of October.

Table 2 shows drawdown rates for the lakes which can be used to predict how long it will take to draw down active storage. Eightmile Lake drained slowest at a constant rate of 0.2 ft/day for discharge rates between about 3 and 20 cfs. Square Lake also drained slowly at a rate of 0.3 ft/day for a discharge rate of 15 cfs (attributable to its large volume). The drawdown rate at Square lake tripled to 1.0 ft/day when flows increased to 35 cfs.

Table 2. Lake Stage Drawdown Rates

Lake Name	Drawdown Rate (ft/day)	Discharge Rate (cfs)
Square Lake	0.3	15
	1.0	35
Klonaqua Lake	0.7	15
Eightmile Lake	0.2	3 to 20
Colchuck Lake	0.6	20
Snow Lakes	Water levels not measured	n/a

If no adjustments were made to head gates, the rate of discharge from lakes declined with lake stage due to decreased driving head and lake bottom geometry. Figure 4 shows that cumulative augmentation flows began declining immediately after weekly head gate adjustments were made. Figure 4 also shows that augmentation flows declined faster as lake levels were drawn down. When lakes were nearly full in July, the cumulative augmentation flow decreased at a rate of about 0.5 cfs per day from about 27 cfs on July 14 to 17 cfs on August 2 (Figure 4). When lakes were nearly empty in late August and early September, cumulative augmentation flows decreased at a much faster rate of about 3 cfs per day.

Effects of Augmentation on Historic Channel Flows

A hydrograph for the Historic Channel during the study period is shown on Figure 6. This hydrograph includes natural and augmentation flows. Comparing 2016 to the period of record for the USGS gauge, 2016 was approximately an average runoff year. Figure 6 also contains the hydrograph showing the cumulative flow augmentation and a hyetograph for precipitation (as rainfall) occurring at the nearest weather recording station, the Fish lake SNOTEL site located in the adjacent Cle Elum River drainage.

Icicle flows in the Historic Channel were about 300 cfs when the Study began the week of July 11 and decreased to about 120 cfs by the end of the first week in August.

Flow augmentation began the week of July 11 with modest cumulative releases from storage averaging about 22 cfs through July. Flow augmentation was increased the week of August 8 to about 60 cfs and increased again during the week of August 22 to about 90 cfs. Augmentation flows then decreased for the balance of the study primarily due to diminishment of stored water. September augmentation flows that began at about 75 cfs had decreased to 20 cfs during the last two weeks in September and first week of October. Flow augmentation ceased on October 6.

Weekly averages for flow augmentation rates and Historic Channel flows during the study period are shown on Figure 7. Flow augmentation during the low flow months of August and September equaled between 31 and 78 percent of total discharge in the Historic Channel.

Augmentation Increased Historic Channel Flows

Augmentation flows increased Historic Channel flows. Increased augmentation flows are attributed to the “peaks” in the Historic Channel hydrograph seen on Figure 6 during the weeks of August 8 and August 22.

Increases in augmentation flows during the first two weeks in August did not result in a one-for-one increase in Historic Channel flows. During this period, augmentation flows were increased by about 43 cfs, yet the Historic Channel hydrograph shows only a short-lived increase of about 20 cfs occurring the week of August 8. The difference in magnitude between flow augmentation and its effect on streamflow in the Icicle is attributed to a portion of augmentation water going to storage along the miles of creek bed between the storage sites and stream gauge.

The portion of augmentation water going to stream bed storage appears to have decreased by the week of August 22 when augmentation flows were increased by 46 cfs and Historic Channel flows temporarily increased by about 70 cfs. The difference is attributed to the contemporaneous increase of water released by USFWS from Snow Lakes and a temporary decrease in IPID’s diversion rate. There was no precipitation recorded during that week.

Peaks in the Historic Channel hydrograph occurring the weeks of July 18, September 19, and October 3 were attributed to precipitation events. The peak occurring the week of August 29 was also attributed to precipitation; however, the effect on Icicle flows was magnified by the 70 cfs flow augmentation rate occurring at that time.

Augmentation Slowed the Seasonal Falling Hydrograph

Flow augmentation appears to have slowed the rate of the Icicle’s seasonal falling hydrograph.

Figure 8 shows the observed Historic Channel hydrograph, cumulative flow augmentation hydrograph, and an estimate of what the Historic Channel hydrograph might have looked like in the absence of augmentation flows. The latter was derived by subtracting the cumulative augmentation flows from the observed Historic Channel hydrograph.

In the absence of flow augmentation, the Icicle's seasonal falling hydrograph is estimated to have decreased at a rate of about 7 to 8 cfs per day through July into the first week in August. Flow augmentation is estimated to have slowed the seasonal falling hydrograph by about 1 cfs per day to about 6 to 7 cfs per day (Figure 8). The significant increase in augmentation the week of August 8 delayed the timing of when Historic Channel flows would have diminished to below the 100 cfs target by 1 week.

Augmentation Prolonged the Target Flow

Flow augmentation increased the period of time that the target flow was met by about one third.

The estimate hydrograph for Historic Channel flows without flow augmentation indicates discharge would have dropped below the 100 cfs target beginning August 8 and remained below the target until significant precipitation began about October 8—a period of about 9 weeks (Figure 8). The observed Historic Channel hydrograph indicates augmentation flows slowed the seasonal falling hydrograph by about 1 cfs per day, delaying the date when Icicle flows would have otherwise diminished to below the 100 cfs target by one week.

Data Gaps

The following data gaps were identified from the 2016 Pilot Study:

- Real time flows for the Historic Channel measured at Structure 2 were not available. Ecology's Icicle Gauge was used as a proxy by subtracting 50 cfs, estimated to represent diversions by LNFH that bypass the Historic Channel.
- Rating curves developed for lake outlet channels require more streamflow measurements to increase accuracy. Rating curves should contain at least six measured points at various stage/discharge conditions. Existing rating curves are missing measured discharge points for high and low flow conditions. This increases error when using rating curves to record and establish release flows because low flow and high flow conditions must be extrapolated from the portions of the curves that are developed using measured data.
- Interpreting effects of flow augmentation on Icicle Creek was complicated by precipitation events. The nearest precipitation recording station is the Fish Lake Snotel located in the Cle Elum River Basin, which is between 9 and 24 miles from the Study lakes.
- The fate of water released from storage is not fully understood. It appears some portion of augmentation water may be going to storage along the tributary and mainstem Icicle Creek streambeds as indicated by the lack of a one-for-one relationship between water released from storage and the Icicle Creek stream gauges. The effects of inputs from upstream sources and diversions by upstream water users are not fully understood.
- Impacts of flow releases on Bull Trout habitat in French and Leland creeks likely require additional study. The Project objective to avoid releases from storage over 10 cfs into these

creeks after September 15 limited the flow augmentation options available to meet the late season Historic Channel flow target.

Conclusions

The 2016 Pilot Study provided promising results that water stored in Alpine Lakes reservoirs can be used to effectively enhance stream flows in the Historic Channel. There were no fatal flaws identified. While flow augmentation is not a total solution for achieving the IWG's flow targets in the Historic Channel, it may account for about one third of the solution based on the results of this Study. A follow on study is recommended to confirm and improve on findings of the 2016 Pilot Study and to resolve data gaps:

- No fatal flaws were identified.
- Augmentation flows of up to 90 cfs extended Icicle Creek flows in the Historic Channel above the 100 cfs target for 3 weeks. This represents about one third of the nine-week low flow period during 2016, which is considered an average runoff year. Augmentation flows equaled between 31 and 78 percent of late season discharge in the Historic Channel.
- Increased augmentation flows during the weeks of August 8 and August 22 resulted in higher flows in the Icicle as indicated by temporary peaks in the hydrograph.
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonal falling hydrograph. However, flow augmentation can slow the rate of decline, prolonging the period when flows remain above the target. Augmentation flows slowed the seasonal falling hydrograph by about 1 cfs per day, delaying the date when Icicle flows would have otherwise diminished to below the 100 cfs target by one week.
- Over 6,400 ac-ft of water was released from storage for flow augmentation between July 11 and October 6. Nearly all physically available water was used for flow augmentation (about 250 ac-ft remained in Square Lake). About 1,300 ac-ft of trust water quantity was not physically accessible from both Klonaqua and Colchuck lakes.

Recommendations

The following are recommended for a follow-on study:

- Improve accuracy of accounting for discharge in the Historic Channel by measuring flows at Structure 2, as opposed to using the Ecology Gauge as a proxy. USFWS is currently in the process of equipping Structure 2 for access to real time flows.
- Improve rating curves. Collect additional streamflow measurements at lake outlets to increase accuracy of rating curves for rated sections at low and high flow conditions. High flows should be collected in the Spring when water is available to release from storage and low flows should be collected in the Fall when baseflows are present.
- Establish a precipitation recording station closer to the reservoirs (preferably within the Alpine Lakes Wilderness) to improve measurement of the magnitude and timing of precipitation to understand its effects on stream flows.
- Initiate study to determine impacts of release flows on Bull Trout habitat in French and Leland Creeks that drain Square and Klonaqua Lakes and whether release flows exceeding 10 cfs could be tolerated after September 15. These lakes hold nearly half the physically

available water for flow augmentation. Releases greater than 10 cfs in late season would provide greater flexibility to manage flow augmentation to Icicle Creek during the low flow month of September.

- Improve understanding of the fate of flow augmentation water. Evaluate gaining/losing characteristics of tributaries draining reservoirs and mainstem Icicle Creek. Coordinate with USFWS to improve understanding of releases from Snow Lakes. Coordinate with USFWS, IPID, Cascade Orchards Irrigation Company, and the City of Leavenworth to quantify diversions occurring upstream of the Historic Channel.
- Account for declining outflow rates from reservoirs as the lakes are drawn down. Cumulative outflow rates decreased at a rate of 0.5 cfs per day when lakes were full. This rate increased to about 3 cfs per day as the lakes neared empty. Because these lakes are remote and can reasonably be visited on foot only once per week, flow augmentation planning should consider adjusting outflow rates to account for these changes. Automating control structures to make minor adjustments to head gates every few days would mitigate decreasing outflow rates.
- In average water years, consider limiting early season releases from storage to save water for later in the season. However, more water should be released earlier from Square Lake to avoid water remaining in storage at the end of the season due to flow in Leland Creek that are limited to 10 cfs after September 15. Leakage and the inability to control the submerged head gate at Eightmile Lake limit options for retaining stored water. Repairing the Eightmile Lake dam may increase conservation of stored water allowing greater flexibility for water management to meet late season flow targets.

References

Aspect Consulting, LLC (Aspect), 2016, Quality Assurance Project Plan for Alpine Lakes Flow Augmentation, June, 2016.

Rantz, S.E. et al., 1982, Measurement and Computation of Streamflow: Volume 1, Measurement of Stage and Discharge, Geological Survey Water-Supply Paper 2175, USGS, Washington.

Limitations

Work for this project was performed for Chelan County Natural Resources Department (Client), and this memorandum 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 memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

Attachments: Figure 1 – Icicle Creek Sub-Basin
Figure 2 – Outlet Channel Rating Curves
Figure 3 – Flow Augmentation, Volumes, and Flow Rates
Figure 4 – Cumulative Augmentation Flow
Figure 5 – Lake Hydrographs
Figure 6 – Historic Channel Hydrograph
Figure 7 – Augmentation Contribution to Historic Channel
Figure 8 – Effects of Augmentation on Historic Channel Flow

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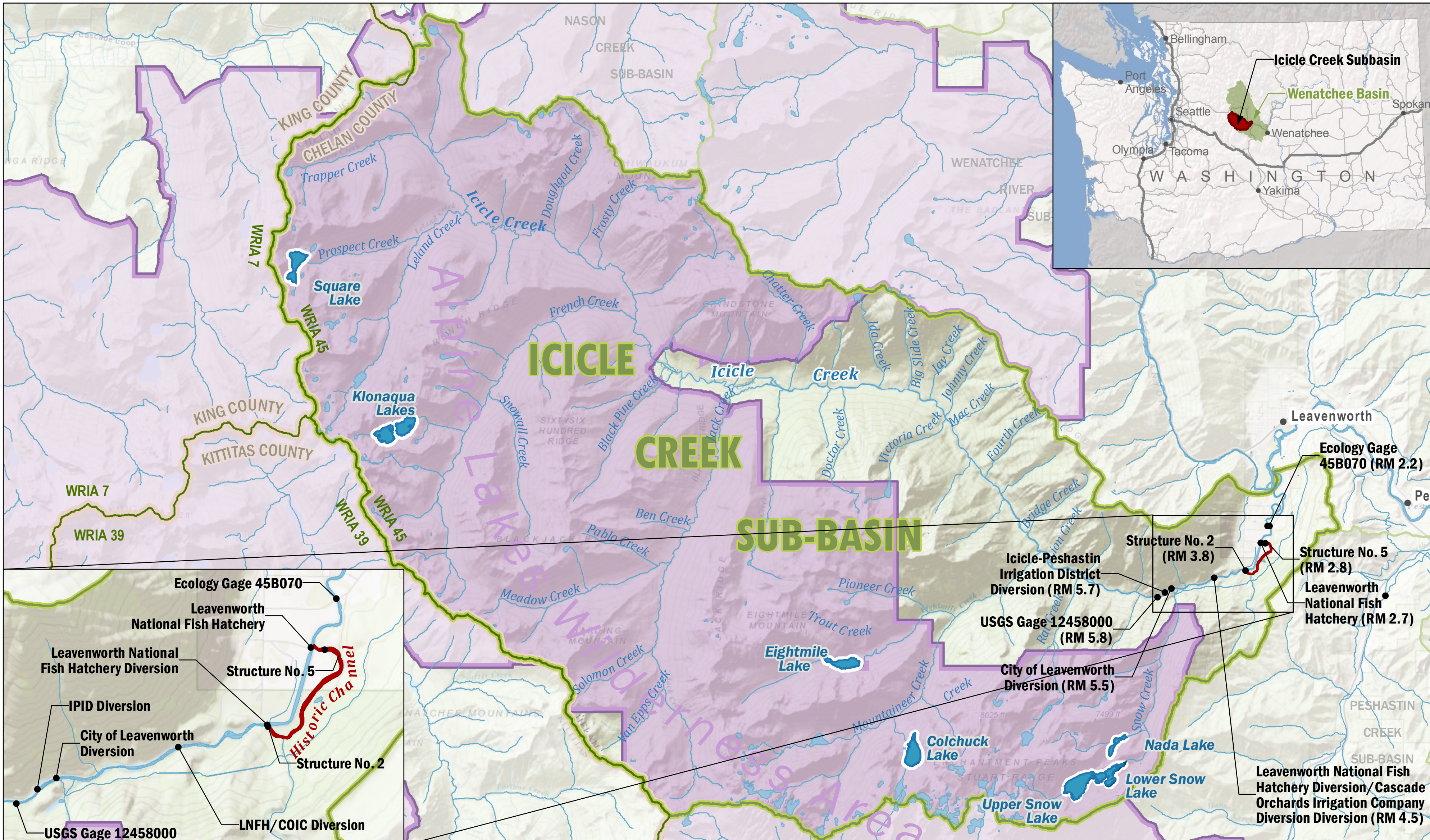
FIGURES



Icicle Creek Sub-Basin

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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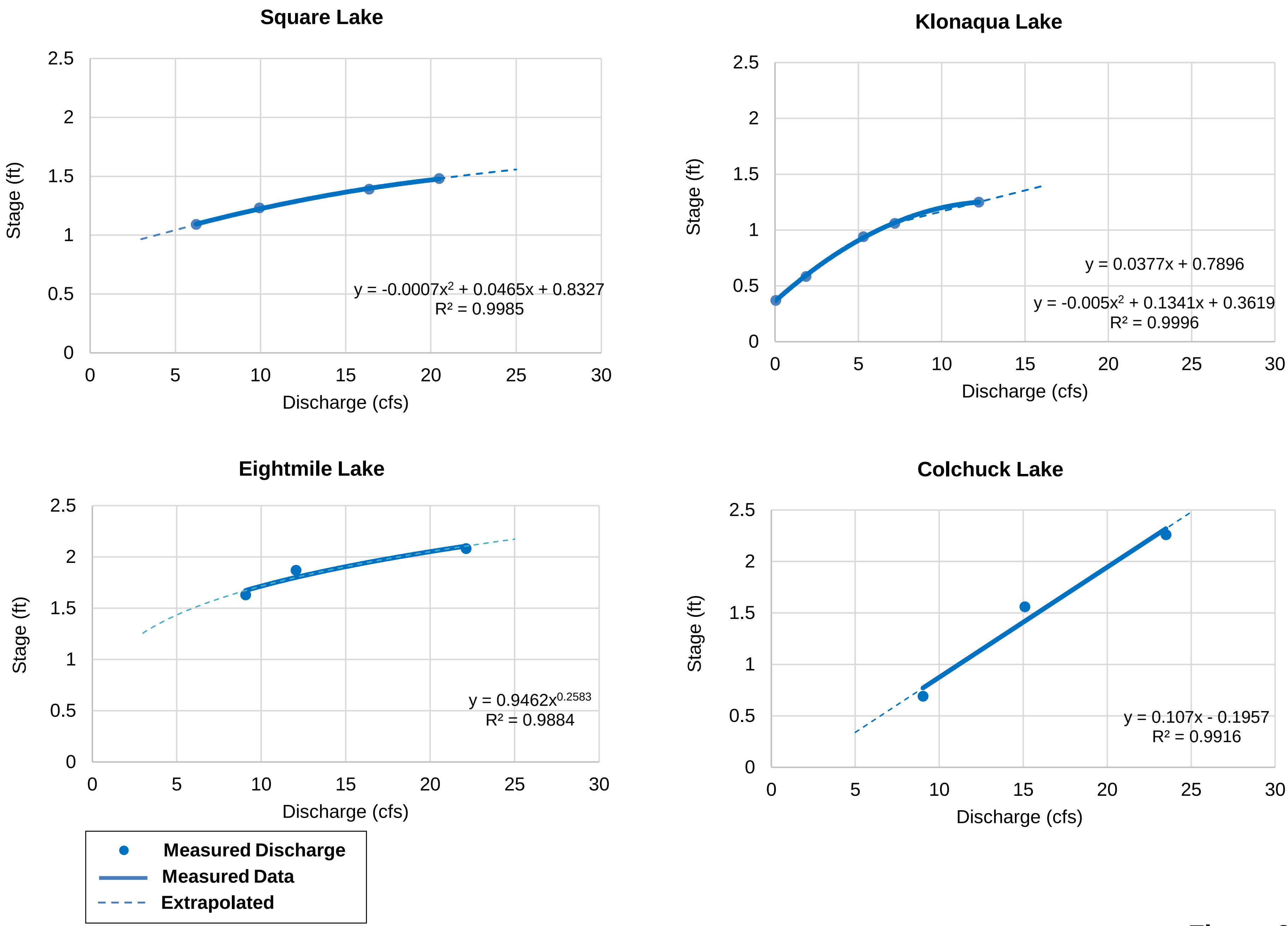
	PROJECT NO. 120045	REVISED BY: ---	1



Aspect Consulting
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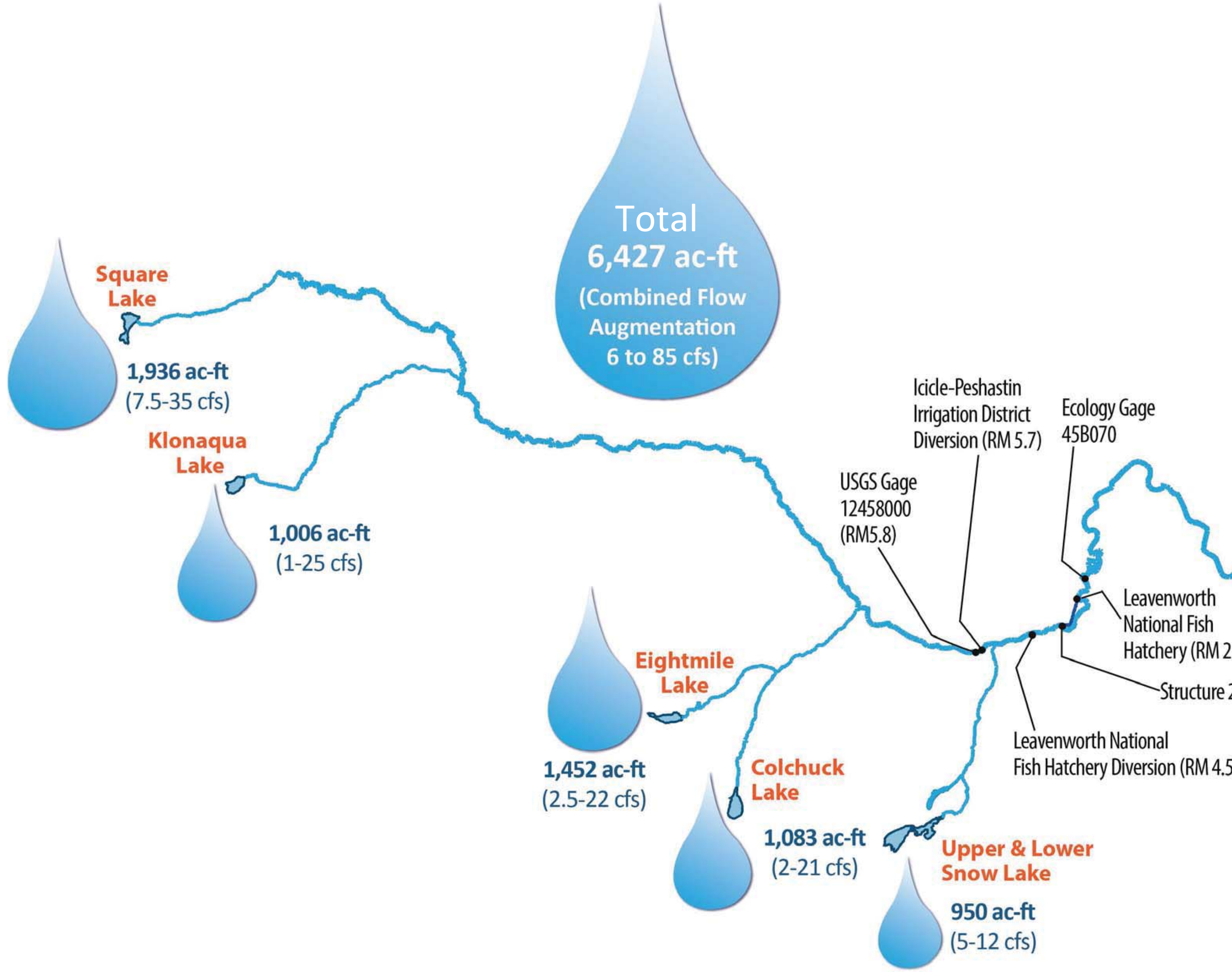
Figure 2
Outlet Channel Rating Curves
Project No. 120045, Alpine Lakes Optimization and Automation, Chelan County, WA



Flow Augmentation, Volumes, and Flow Rates

Feasibility Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	APR-2017	BY: BC / EAC	FIGURE NO. 3
	PROJECT NO. 120045	REVISED BY: ---	

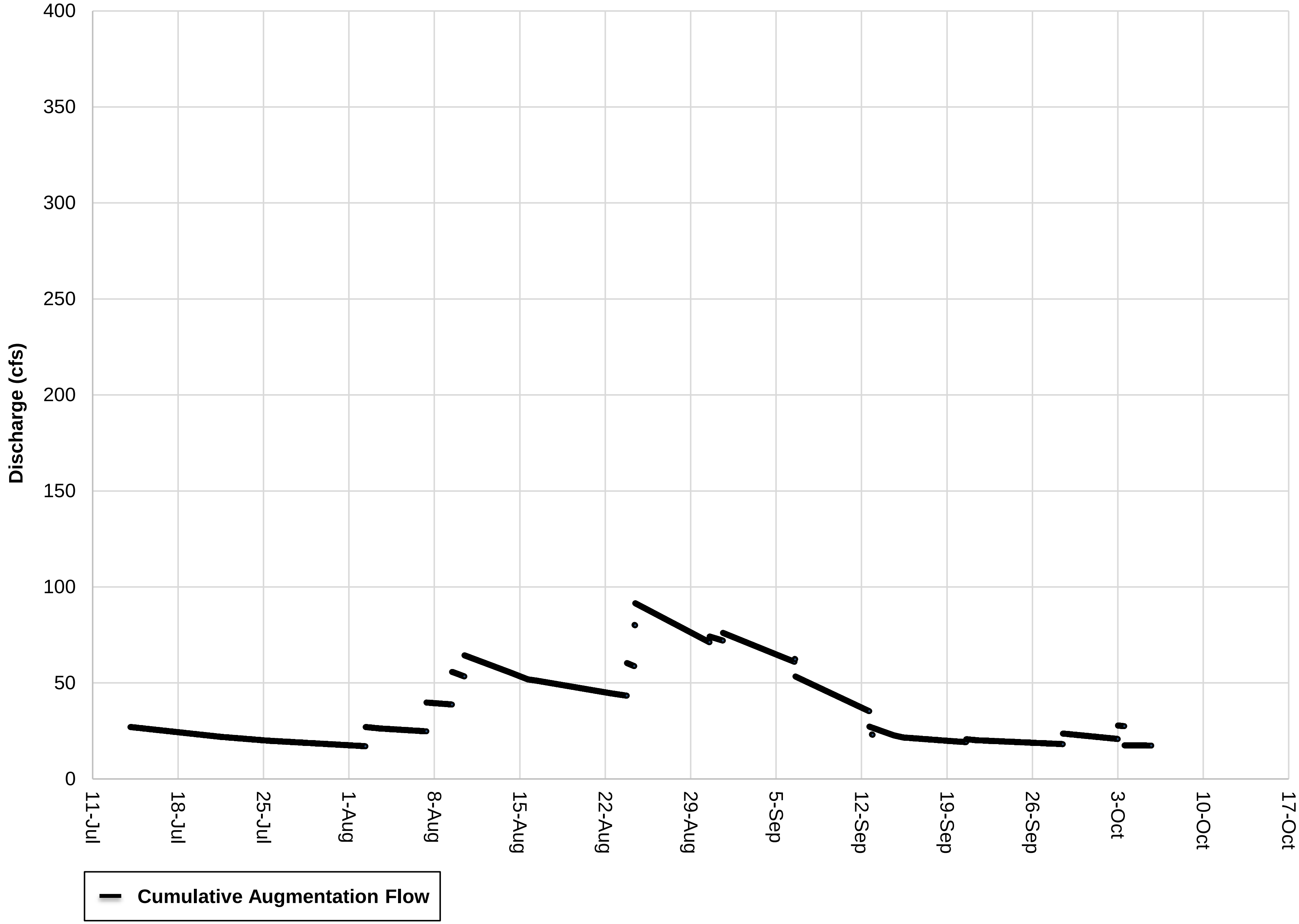


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Figure 4
Cumulative Augmentation Flow
Project No. 120045, Alpine Lakes Optimization and Automation, Chelan County, WA

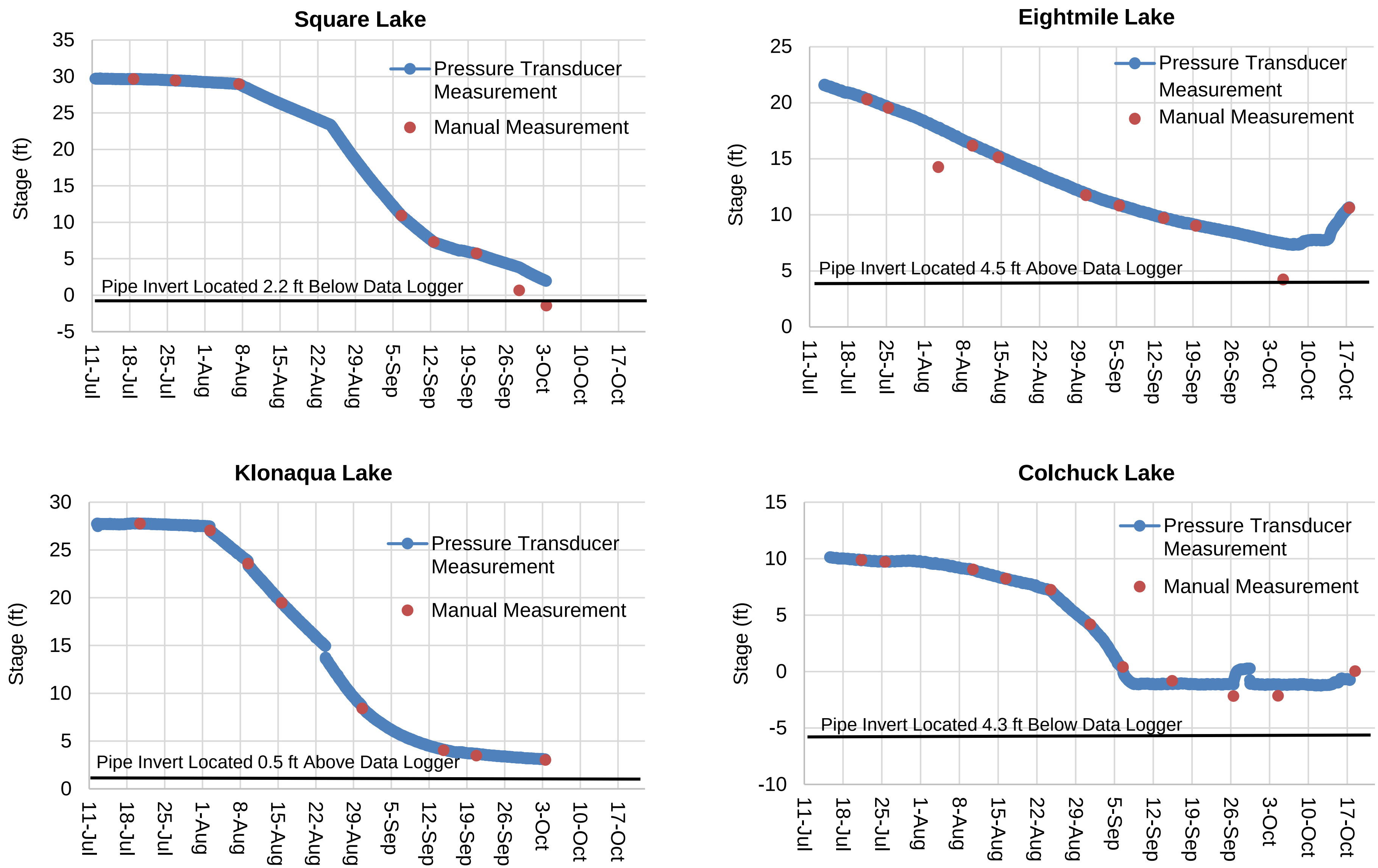

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Figure 5
Lake Hydrographs
Project No. 120045, Alpine Lakes Optimization and Automation, Chelan County, WA

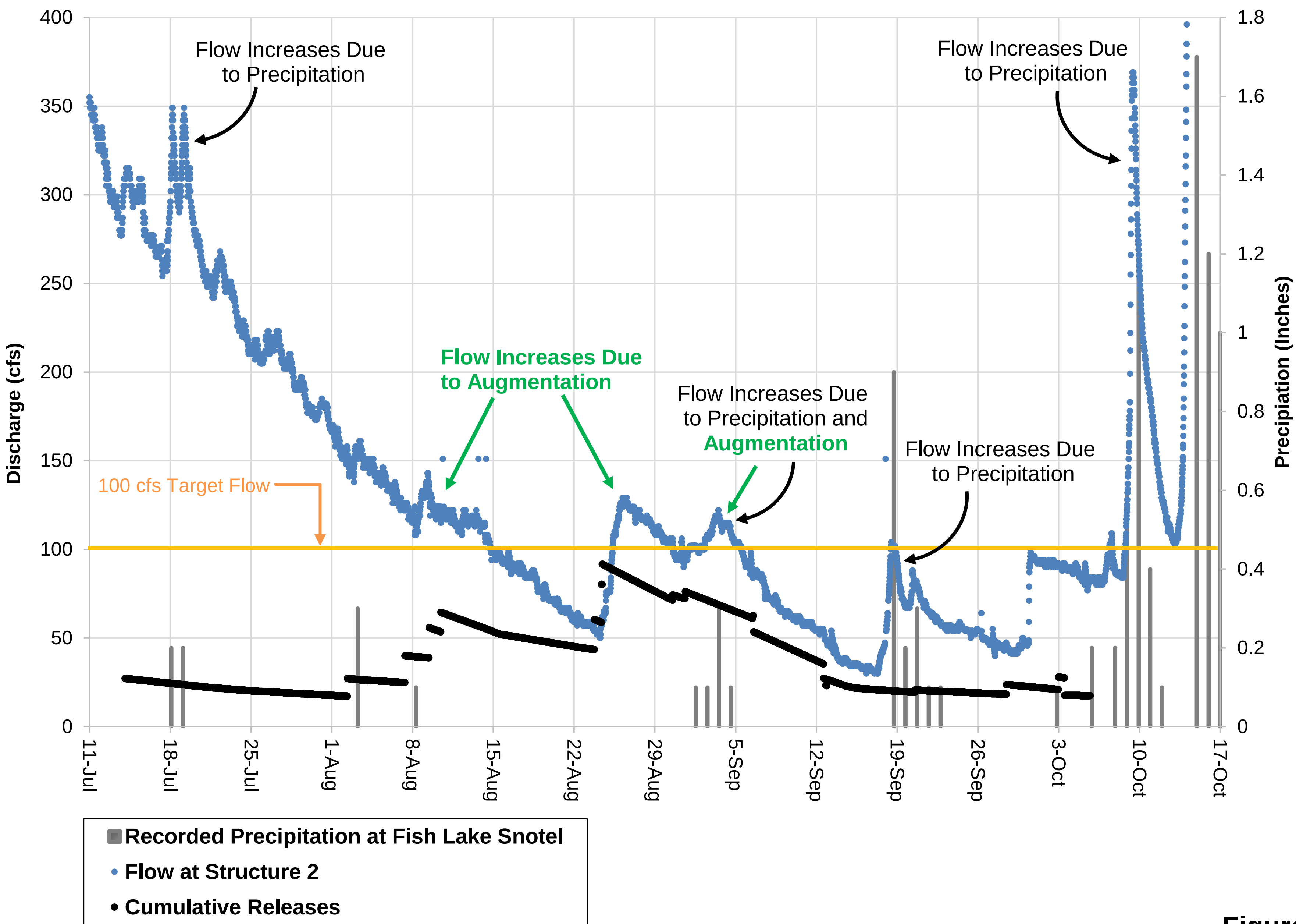

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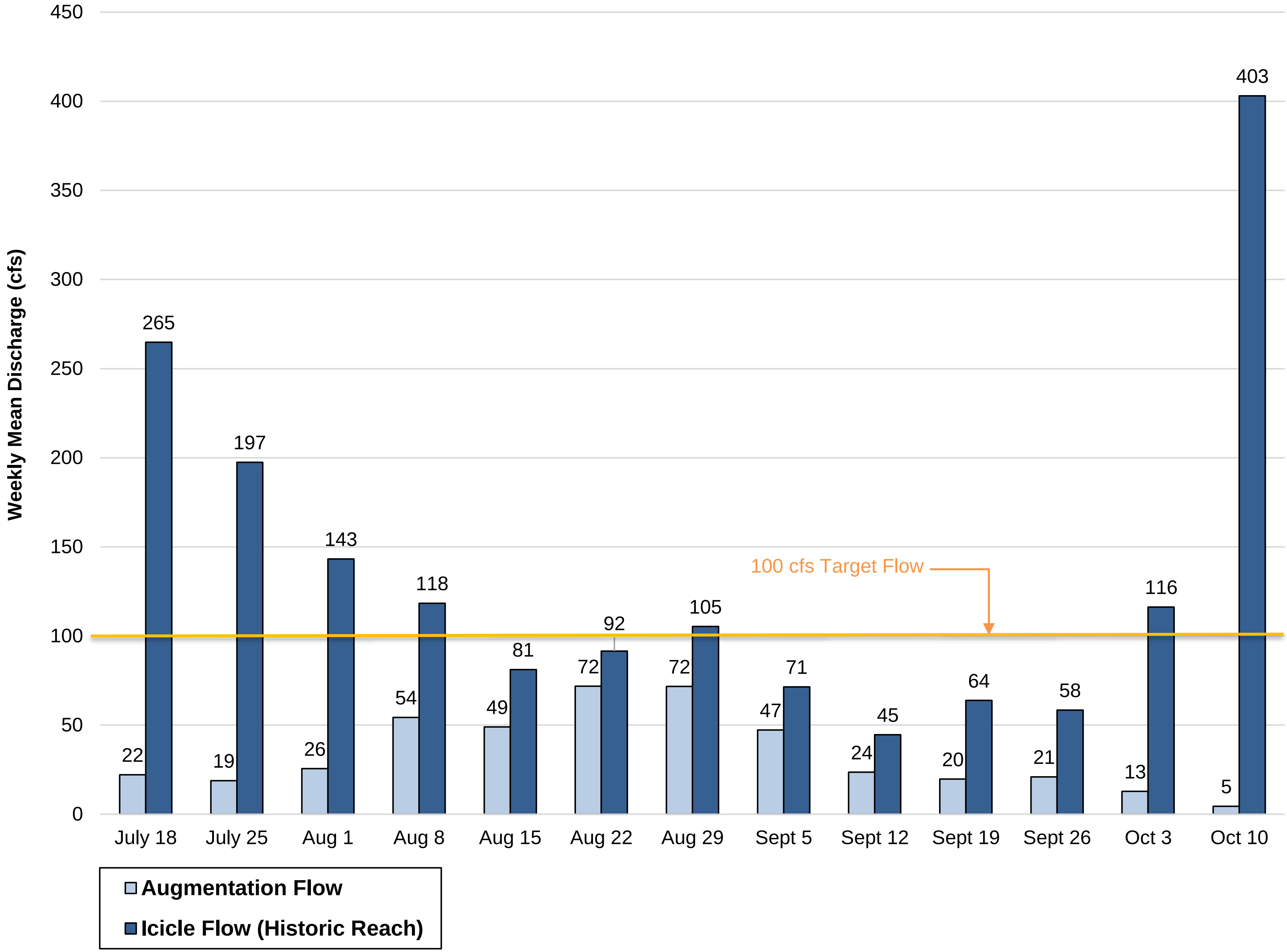
Figure 6
Historic Channel Hydrograph
Alpine Lakes Optimization and Automation Chelan County, WA



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V:\120045 Chelan County\Deliverables\Alpine Lakes Optimization and Automation\Formatted\Figure 7

Figure 7
Augmentation Contribution to Historic Channel
Project No. 120045, Alpine Lakes Optimization and Automation, Chelan County, WA

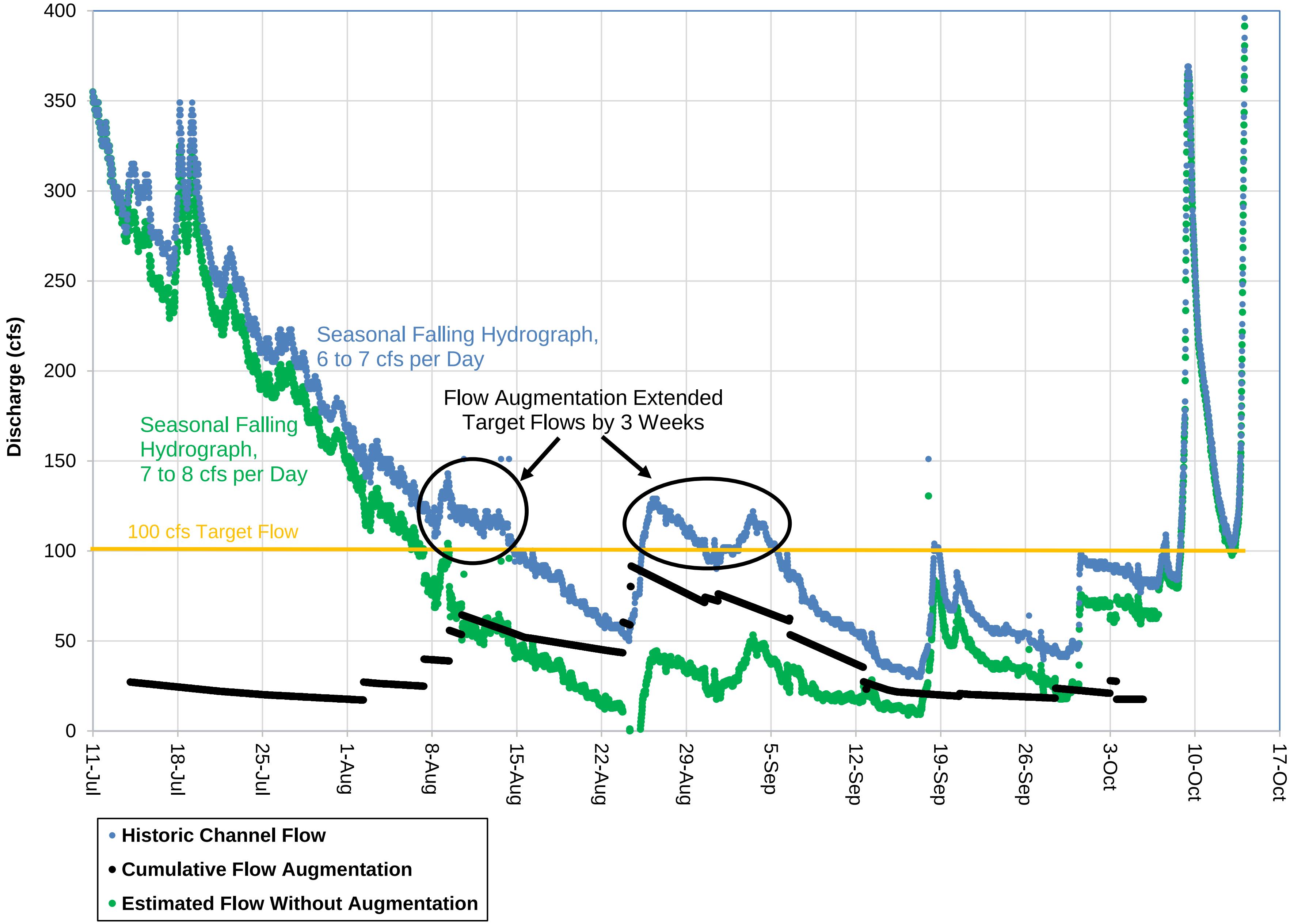

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Figure 8
Effects of Augmentation on Historic Channel Flow
Project No. 120045, Alpine Lakes Optimization and Automation, Chelan County, WA

MEMORANDUM

Project No.: 120455

April 17, 2018

To: Mike Kaputa, Director, Chelan County Natural Resources Department

From:

Bill Sullivan, LHG, CWRE
Senior Hydrogeologist
bsullivan@aspectconsulting.com

Dan Haller, PE, CWRE
Principal Water Resources Engineer
dhaller@aspectconsulting.com

Re: **Alpine Lakes 2017 Flow Augmentation Pilot Study**

Executive Summary

Aspect Consulting, LLC (Aspect) conducted the Alpine Lakes 2017 Flow Augmentation Pilot Study (2017 Pilot Study) as a continuation to the 2016 Flow Augmentation Pilot Study (2016 Pilot Study). The 2016 Pilot Study (Aspect, 2017a) demonstrated that managed release of water stored in five Alpine Lakes reservoirs substantially benefits late-season instream flows in the Historic Channel of Icicle Creek (Figure 1). The 2017 Pilot Study was conducted to confirm the benefit of flow augmentation on instream flows in the Historic Channel and to address data gaps and implement recommendations from the 2016 Pilot Study.

Both the 2016 and 2017 Pilot Studies were coordinated by the Chelan County Natural Resources Department (County) to understand benefits and impacts and potential fatal flaws associated with the proposed Alpine Lakes Optimization, Modernization, and Automation Project (Project). The Project is being developed by the multi-stakeholder Icicle Work Group (IWG) as part of the Icicle Creek Water Resource Management Icicle Strategy (Icicle Strategy) to achieve diverse benefits in the Icicle Creek drainage. A Guiding Principle of the Icicle Strategy is achieving adequate stream flows in the Historic Channel of lower Icicle Creek with the goal of maintaining at least 100 cubic feet per second (cfs) during average years and 60 cfs during drought years.

The 2017 Pilot Study was conducted in response to the Icicle-Peshastin Irrigation District (IPID) electing to donate up to 9,600 acre-feet of water stored in five Alpine Lakes reservoirs to Washington State's Trust Water Program for instream flow benefit. The Trust Water Donation period ran from July through October and coincided with planned reservoir maintenance activities.

The 2017 Pilot Study included maintenance and repair of reservoir stage and outflow monitoring equipment at four reservoirs to support management of water released from storage to augment stream flows, as well as coordination with the U.S. Fish and Wildlife Service (USFWS) on their operations of Snow and Nada Lakes and the Leavenworth National Fish Hatchery (LNFH). Icicle Creek flows were monitored and augmentation flows were adjusted on a weekly basis for 12 weeks during the Summer and early Fall of 2017.

Key findings of the 2017 Pilot Study include:

- Findings of the 2016 Pilot Study were generally confirmed. No fatal flaws were identified.
- Flow augmentation releases available from storage in Alpine Lakes nearing 6,500 acre-feet (ac-ft), were confirmed to significantly enhance stream flows in the Historic Channel of Icicle Creek.
- While flow augmentation is not a total solution for achieving the IWG's flow targets in the Historic Channel, it may account for over one half the volume needed to meet the target.
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonally falling hydrograph. However, flow augmentation can slow the rate of decline, prolonging the period when flows remain above the target. Specifically, during the 2017 Pilot Study:
  - Augmentation flows of up to 75 cfs improved flows in the Historic Channel by about one half during critical low flow periods.
  - Augmentation flows increased flows in the Historic Channel of Icicle Creek to above the 100 cfs target for about 10 days.
  - Augmentation flows equaled up to 95 percent of discharge in the Historic Channel during critical low flow periods.
- Winter augmentation opportunities are limited by lack of sufficient inflows to replace summer and fall storage releases and, at Eightmile Lake, by seepage losses from storage.

Although no fatal flaws were identified, a follow-on study is recommended to confirm and improve on findings of the 2016 and 2017 Pilot Studies and to resolve remaining data gaps. Key recommendations include:

- Improve accuracy of Icicle Creek discharge estimates in the Historic Channel by collecting manual stream flow measurements to validate/calibrate existing methods of estimating discharge. This could preclude the need to obtain real-time data from Structure 2.
- Continue providing support to the Washington Department of Fish and Wildlife (WDFW) in assessing impacts of augmentation release flows on Bull Trout habitat in French and Leland creeks, which drain Square and Klonaqua lakes. WDFW initiated a study in 2017 to assess impacts of release flows and identified several data gaps in its summary report (WDFW, 2018; Appendix A).
  - Evaluate opportunities to provide greater temperature benefits in Icicle tributaries by performing lake depth temperature profiles.
  - Conduct additional habitat and fish presence studies to create an adaptive release model that can aid in timing and magnitude of release for both tributary and mainstem Icicle Creek benefit
- Improve understanding of the fate of flow augmentation water, including lag effects due to stream channel storage:

- Evaluate gaining/losing characteristics of the tributaries draining reservoirs and the mainstem Icicle Creek.
- Coordinate with USFWS to improve understanding of releases from Snow Lakes.
- Coordinate with USFWS, IPID, Cascade Orchards Irrigation Company, and the City of Leavenworth to quantify diversions occurring upstream of the Historic Channel.

Introduction

Aspect Consulting, LLC (Aspect) conducted the Alpine Lakes 2017 Flow Augmentation Pilot Study (2017 Pilot Study) to assess the effects of augmenting stream flows in Icicle Creek using water stored by the Icicle-Peshastin Irrigation District (IPID) in five mountain reservoirs. The 2017 Pilot Study was conducted as a continuation of the 2016 Flow Augmentation Pilot Study (2016 Pilot Study; Aspect, 2017a) in response to discretionary trust water donations of stored water by IPID coinciding with planned reservoir maintenance activities.

Both the 2016 and 2017 Pilot Studies were coordinated by the Chelan County Natural Resources Department (County) to understand benefits and impacts and potential fatal flaws associated with the proposed Alpine Lakes Optimization, Modernization, and Automation Project (Project).

The Project is being developed by the multi-stakeholder Icicle Work Group (IWG), which is comprised of diverse agricultural, conservation, and recreational interests, Tribes, and local, state, and federal agencies. The IWG developed the Icicle Creek Water Resource Management Icicle Strategy (Icicle Strategy) by consensus of its members to improve instream flows in Icicle Creek. The Icicle Strategy outlines nine Guiding Principles to achieve diverse benefits. The Adequate Streamflow principle sets a target flow of 100 cubic feet per second (cfs) during low-flow periods in non-drought years and 60 cfs during drought years in the Historic Channel of lower Icicle Creek. The flow target is intended to be measured at the Leavenworth National Fish Hatchery (LNFH) Structure 2, located at river mile (RM) 3.8 that lies at the head of the Historic Channel of Icicle Creek (described below).

The 2017 Pilot Study was funded under Grant Number WROCR-VER1-ChCoNR-00002 sourced from the Washington State Department of Ecology (Ecology) Office of Columbia River (OCR).

Background

The first flow augmentation pilot study was completed in 2016 (Aspect, 2017a). As part of the 2016 Pilot Study, outflow and lake level monitoring equipment was installed at the four Alpine Lakes managed as reservoirs by IPID (Square, Klonaqua, Eightmile, and Colchuck lakes). Water released from those reservoirs, and from Snow Lakes, contributed to instream flows in Icicle Creek under IPID's trust water donation. Key findings of the 2016 study included:

- Over 6,400 ac-ft of water released from storage at peak rates up to 90 cfs.
- Augmentation flows equaled between 31 and 78 percent of discharge in the Historic Channel during critical low flow periods.
- Augmentation was found to be insufficient to keep up with the seasonally falling hydrograph and will not present a total solution for achieving the IWG's flow targets in the Historic

Channel. However, augmentation did slow the rate of seasonally decline, prolonging the period when flows remained above the target by about one third, or 3.5 weeks.

Based on the success of the 2016 Pilot Study in demonstrating beneficial impacts of augmentation on Historic Channel flows, the 2017 Pilot Study was implemented to confirm findings, address data gaps, and implement recommendations.

Basin Description

Icicle Creek drains an area of about 243 square miles of undeveloped mountainous terrain west of Leavenworth in Chelan County, Washington (Subbasin; Figure 1). Icicle Creek drains to the Wenatchee River at Leavenworth. The majority of its drainage area lies within the Alpine Lakes Wilderness Area on land managed by the U.S. Forest Service (USFS). The lowermost section is moderately developed and includes recreational and residential development, agriculture, lodging, and the LNFH.

The Icicle is a snowpack-driven watershed with high flows occurring during spring freshet and low flows in late Summer (primarily September) and Fall. Two stream gauges are present on Icicle Creek (Figure 1). The U.S. Geological Survey (USGS) operates a gauge (12458000) at RM 5.8 located upstream of Snow Creek having a period of record from 1993 to present. Ecology operates a gauge (45B070) at RM 2.2 having a period of record from 2007 to present. Additionally, the USFWS is in the process of establishing stream measurement recording at Structure 2.

Numerous mountain and alpine lakes are present in the Icicle Subbasin. These are naturally formed lakes, the largest of which were modified to store water prior to Wilderness Area designation. The Icicle's major tributaries originate from the larger lakes. These include French Creek draining Klonaqua Lake; Leland Creek draining Square Lake; Mountaineer Creek draining Eightmile Lake and Colchuck Lake; and Snow Creek draining Upper and Lower Snow Lakes. Major lakes and tributaries are shown on Figure 1.

Icicle-Peshastin Irrigation District

The IPID diverts surface water from Icicle and Peshastin Creek drainages for irrigation of lands between Leavenworth and Cashmere. IPID holds diversionary rights from Icicle and Snow Creeks at the IPID diversion located at RM 5.7 (Figure 1) during irrigation season at a rate up to 117.71 cfs under Water Right Certificates S4-35002JC, S4*35002ABBJ, having priority date of 1910 and Certificate 1082 having priority date of 1919.

IPID also has water rights to store water in the five aforementioned reservoirs located within the Alpine Lakes Wilderness Area for the purpose of providing irrigation water during times of drought or when Icicle Creek flows are insufficient to meet IPID's diversionary needs. These reservoirs are discussed below.

Reservoirs

The five naturally-formed lakes within the Alpine Lakes Wilderness Area were modified beginning in the 1920s to store water for irrigation and fish propagation. Locations of the reservoirs are shown on Figure 1.

Four of the reservoirs are operated by IPID (Square, Klonaqua, Eightmile, and Colchuck lakes) and one reservoir is operated by the USFWS and U.S. Bureau of Reclamation (USBOR). Square and Klonaqua Lakes were modified by excavating a tunnel (Square) and buried pipe (Klonaqua) to access water below the natural level of the lakes. Colchuck Lake was modified by excavating a channel connecting two natural lake basins. All four lakes have small dams (5 to 10 feet high) constructed to enhance storage. Upper Snow Lake Reservoir is operated to support the LNFH and also stores water for IPID. Water is accessed in Upper Snow Lake using a tunnel/pipe bored through rock. The outlet lies below the natural water level of Upper Snow Lake. There is no dam.

IPID and USFWS/BOR operate these facilities under easements with USFS that were established when the land was transferred to USFS during the Wilderness Area designation. These easements allow IPID and USFWS staff access and to perform maintenance activities.

The 2016 Pilot Study provided updated estimates for active storage volumes based on monitoring of discharge rates released from storage (Aspect, 2017a) and improved bathymetry derived from LiDAR data collected in Fall of 2016 after active storage in reservoirs had been drained down (Aspect, 2017b).

Reservoir Operations

In average runoff years, water is released on a rotational basis from one of the four reservoirs operated by IPID. IPID typically only receives water from Upper Snow Lake during drought years under a partial subordination agreement with USFWS. Water is typically released from some or all the reservoirs in drought years to augment downstream water supply.

To operate these reservoirs, IPID and USFWS staff hike to their respective lakes to manually turn hand wheels and valves that operate head gates. USFWS demand from Snow Lakes ranges from about 20 cfs in July to about 50 cfs during September. The control valve at the outlet to Upper Snow Lake currently limits the release rate to about 55 cfs.

Because of the time and cost required to adjust head gates, adjustments are generally made infrequently or only at the beginning and end of the season. The hand wheel operator at Eightmile Lake was destroyed due to erosion and log debris. Adjusting this gate requires using scuba equipment when the lake is full, which further limits IPID’s ability to adjust outflows. Stored water in Eightmile Lake also seeps through the north end of the lake where an ancient landslide serves as a natural impoundment. For this reason, IPID’s water right includes water stored in Eightmile Lake lying below the invert of the outlet pipe.

Prior to the 2016 Pilot Study, there was no instrumentation installed to measure reservoir stage or discharge rates at the four lakes managed by IPID. At Upper Snow Lake, USFWS collects reservoir stage and release flow data using existing instrumentation.

Leavenworth National Fish Hatchery

The LNFH is located in the lower section of Icicle Creek at about RM 2.7 (Figure 1). The facility was constructed in the 1930s to mitigate impacts to anadromous fish runs impacted by the construction of Grand Coulee Dam. The LNFH continuously diverts surface and groundwater at a rate of about 50 cfs for fish propagation. Surface water is diverted a rate of about 42 cfs from Icicle

Creek using a diversion located at RM 4.5. The balance of water used by LNFH is withdrawn from a well field at the hatchery tapping an aquifer in hydraulic continuity with Icicle Creek.

An artificial channel known as the Hatchery Channel was constructed to periodically divert water from Icicle Creek to hydrate the aquifer supplying the well field. Water is diverted to the Hatchery Channel by a hydraulic control structure (Structure 2) that spans the width of the mainstem Creek at RM 3.8.

Effluent from the hatchery is discharged at a rate of about 50 cfs to the mainstem Icicle Creek below the outlet of the Hatchery Channel at RM 2.7, creating a bypass reach on Icicle Creek of about almost 2 miles. This bypass reach includes the natural channel of Icicle Creek downstream of Structure 2, known as the Historic Channel.

Flow Augmentation

The 2017 Pilot Study provided flow augmentation to Icicle Creek using water donated to trust by IPID for the purpose of benefitting instream flows.

Trust Water Donations

In April 2017, IPID temporarily donated five of its Alpine Lakes reservoir storage water rights into Ecology's Trust Water Right Program, pursuant to RCW 90.42.080 that encourages water right holders to donate water rights for instream flow purpose. In April 2017, Ecology accepted donations for Certificate Nos. 5527, 1227, 1228, 1229, and 1591 for the purpose of benefitting instream flow through March 2018. The donated water was to be made available by releasing water from the five lakes managed by IPID and USFWS and leaving it instream for environmental benefit during the 2017 low-water season. Table 1 shows quantities of water placed into trust.

Table 1. Quantities Donated to Trust Water Program in 2017

Lake Name	Annual Quantity of Water (acre-feet)	Instantaneous Rate (cfs)
Square Lake	2,000	40*
Klonaqua Lake	2,500	25
Eightmile Lake	1,600	25
Colchuck Lake	2,500	50
Snow Lakes	1,000	25
Total Donated to Trust	9,600	-

*Increased from 10 cfs for 2017.

The timing of trust water donations was coordinated to align with planned maintenance of IPID-operated reservoirs, which required lake levels to be drawn down by Fall 2017 for repair and inspection.

The instantaneous quantities donated represent the filling rates of the certificated water rights. Water can be released by IPID at higher rates under RCW 90.03.030. Higher releases were documented during the pilot to achieve downstream flow augmentation goals.

Project Objectives and Constraints

Objectives of the **2017** Pilot Study included:

- Maintain/repair existing monitoring equipment installed at lakes for the 2016 Pilot Study to measure outflow channel discharge and lake stage.
- Collect additional stream flow measurements to improve rating curves developed for outflow channels and define maximum operational discharge rates from outlet structures.
- Download data loggers and analyze lake stage data from October 2016 to July 2017.
- Assess the assumption that flows through the Historic Channel can be reliably estimated from discharge measured at Ecology's gauge located downstream of LNFH by subtracting 50 cfs from the recorded flows to account for hatchery diversions and return flows that bypass the Historic Channel.
- Draw down active storage in Square Lake for inspection by IPID.
- Maintain County staff safety in remote and difficult environment.
- Support the Washington Department of Fish and Wildlife (WDFW) monitoring of stream flows and temperatures in French and Leland Creeks (tributaries draining Klonaqua and Square Lakes) during periods when water is released form storage to assess impacts of releases on Bull Trout habitat.

The 2017 Pilot Study adhered to the goals and constraints agreed by the IWG's Instream Flow Subcommittee, to the extent practicable:

- Meet a target flow of 100 cfs in the Historic Channel as measured at Structure 2, consistent with IWG's Guiding Principles. Meeting this target was intended to be adaptive based on actual flows verified on a weekly basis.
- Release peak flow from Eightmile Lake early to accommodate design inspection and natural seepage. No weekly discharge adjustments could be made due to the submerged headgate.
- Limit release flows to about 10 cfs after September 15 from Square and Klonaqua lakes to protect Bull Trout spawning habitat in Leland and French creeks.
- Limit initial flow augmentation releases from Upper Snow Lake to about 5 cfs continuously due to limitations of the control valve that is shared with USFWS to support operations at LNFH. This was to be adaptive later in the season, depending on LNFH water needs.
- Avoid significant ramping changes to the rate of water released from storage at a given reservoir to about 5 to 10 cfs per week in late Summer and early Fall.

Methods

Key elements of the Study consisted of establishing Project objectives and constraints (described above), maintaining monitoring instrumentation at the four lakes operated by IPID, management of flow augmentation releases, and analysis of data to evaluate the effects of augmentation on instream flows in the Historic Reach. A detailed methodology is contained in the Quality Assurance Project Plan (QAPP) (Aspect, 2017c) as submitted to Ecology. Additional details regarding monitoring equipment installation and initial streamflow rating curve development are detailed in the 2016 Pilot Study (Aspect, 2017a).

Pre-season Reconnaissance

Aspect conducted a reconnaissance trip to Eightmile and Colchuck lakes on July 8, 2017, to assess the condition of monitoring equipment installed in 2016, and to support planning for the one-day site visit.

One-Day Site Visit and Pilot Startup

On July 19, 2017, Aspect and IPID staff visited each of the four reservoirs managed by IPID. Helicopter support was contracted to perform lifts of equipment and to ferry staff. This work was completed with IPID supervision under its easements to reservoir sites in accordance with a Work Plan submitted by IPID to the USFS.

At each reservoir, monitoring equipment installed in 2016 was inspected and repaired (as needed), and onsite data loggers monitoring lake level, water temperature, and barometric pressure were downloaded and redeployed (these were left in place at the end of the 2016 Pilot Study). Discharge was measured at each lake outlet over a range of flow rates to improve rating curves developed in 2016 for the outlet channels. Maximum operational discharge rates were also estimated from manual stream flow measurements. At Square Lake, the data logger used to record lake level was relocated to a location deeper than the invert of the lake outlet. Finally, head gates were opened as needed to support flow augmentation.

Reservoir Monitoring

Water level (stage) and volume in each reservoir were recorded continuously from July 2016 to October 2017. This period includes the entire duration of the 2016 and 2017 Pilot Studies and the interval between, when active storage releases ceased and reservoir levels were allowed to recover.

Changes in reservoir stage were measured in each of the four Alpine Lakes managed as reservoirs by IPID using continuous recording pressure transducer data loggers backed up by visual measurements during the Study. Pressure transducer data loggers were located underwater, near or below the invert elevation of the lake outlets. Because the pressure transducer data loggers were not barometrically compensated, continuous recording barometers were installed at two sites (Square and Eightmile). Visual water level measurements involved reading staff gauges installed at Klonaqua and Colchuck lakes and using a laser level/stadia rod at Square and Eightmile lakes where staff gauges could not be used.

Access to Colchuck and Eightmile lakes was restricted during much of the 2017 Pilot Study due to the Jack Creek Fire. When access to the lakes was restored in October, the pressure transducer and staff gauge at Colchuck Lake were exposed above the water and a tape measure was used during the final visual measurement taken on October 14. Lake stage-volume relationships (Aspect, 2017b) were used throughout the 2017 Pilot Study to monitor volumes remaining in active storage based on lake level measurements. Tracking volumes in storage was important to balance leaving sufficient water for flow augmentation later in the Study while ensuring lake levels were drawn down for facility inspection. At the beginning of the Study on July 19, all five reservoirs were full and overflowing from runoff. To support maintenance and inspection, IPID did not install stop logs at Eigthmile Lake, resulting in an initial lake level more than 1 foot lower than 2016.

Data loggers installed in the lakes also recorded water temperature. Temperature data were provided to WDFW to better understand temperatures of water being released to tributaries from Square and Klonaqua lakes (WDFW, 2018; Appendix A). WDFW found that water temperatures recorded by these data loggers appeared to be colder than water discharging to the outlet channels. Possible explanations for this include 1) the data logger at Square Lake was about 8 feet lower than the invert to the outlet and 2) the data logger at Klonaqua Lake was located inside an access vault (i.e., shaded from the sun).

Augmentation Flow Monitoring

Water stored in the lakes was released using outlet pipes controlled by head gates. Outflow rates from storage were estimated using rated stream gauging sections at the four outflow channels managed by IPID. Rated sections consist of a staff gauge and rating curve developed from several manual streamflow measurements collected at varying discharge rates.

Rated stream gauging sections were established in each outlet channel in 2016 by installing a staff plate affixed to vertical bedrock outcrop or a rod driven into the streambed. Discharge from the lake was measured at varied rates by changing head gate positions to adjust outflow. Discharge was determined using a velocity meter and area-velocity measurement (Rantz, et al.,1982). Staff plate measurements (stage) were recorded for each measured discharge rate to create rating curves. Refer to Aspect (2017a) for further background and discussion about developing these rating curves.

Rating curves developed from the 2016 Pilot Study data were updated with additional discharge data collected during the 2017 Pilot Study (Figure 2). The staff gauge and rating curves were used to determine discharge at a given outlet. Desired outflow rates were set by adjusting the head gate until the staff gauge read the stage corresponding to the desired flow.

Flow Augmentation Management

Prior to the 2017 Pilot Study, a plan was developed to release water from storage based on stream flow conditions observed in Icicle Creek during the 2016 Pilot Study and storage volume and outflow rate characteristics at each lake. Findings from the 2016 Pilot Study indicate the total volume of water stored in the lakes was not sufficient to prevent Historic Channel flows from dropping below the 100 cfs target for most of the low flow season. With this in mind, the 2017 Pilot Study approach to flow augmentation management was focused on conserving stored water so more would be available later in the season.

Consistent with the 2016 Pilot Study, lake-specific discharge rates and flow augmentation release plans were developed on a weekly basis by Aspect and the County. In setting these rates, we considered the 100 cfs target flow, water remaining in storage, and other Project objectives and constraints. Once a flow augmentation plan was developed for a given week, it was communicated to IWG stakeholders for review prior to implementation. County staff spent the following week hiking into the lakes to adjust head gates to match desired outflows and collect data. Data collected at each lake included outlet channel discharge (upon arrival—before setting desired outflows—and departure), visual measurements, pressure transducer lake level data, photographs, and other observations. These data were used to determine how quickly outflow had decreased since the last head gate adjustment, estimate volumes of water released from storage, and estimate volumes remaining in storage. These data were then considered when developing flow augmentation plans for subsequent weeks.

In 2017, access to Square Lake was impeded by hazardous trail conditions requiring two County staff during a single trip which limited the number and timing of site visits due to staffing constraints. Additionally, access to Colchuck and Eightmile lakes were restricted during much of the study period due to the Jack Creek Fire.

Findings

Flow augmentation from the five lakes began on July 19 and continued until the planned completion date of October 11 (85 days).

Augmentation Flows and Volumes

Estimated volumes of water released from storage, and ranges of augmentation flows during the Study are shown on Figure 3. A total of approximately 6,470 ac-ft of water was released from storage during the Study, providing cumulative augmentation flow rates to Icicle Creek ranging from 8 to 75 cfs per week. A hydrograph of cumulative augmentation flows from all five lakes is shown on
Figure 4.

Augmentation Flows

Peak cumulative augmentation flow was limited to 75 cfs to conserve stored water for later in the season and to comply with the Study objective to avoid steep ramp ups/drawdowns of water released into tributaries.

Flow augmentation began on July 19 with modest cumulative releases from storage, averaging about 12 cfs through the remainder of July (Figure 4). Augmentation was increased in the first week of August to 25 and then about 46 cfs. Releases were maintained at approximately this level until the third week of August, when they were increased to a peak of 75 cfs. Augmentation flows then decreased for the remainder of the Study due to declining driving head in the lakes (lake stage) as storage depleted. Declining augmentation flows were increased twice in September. Augmentation flows declined to about 23 cfs by the end of September. Augmentation flows were accounted for through October 11.

Peak augmentation flows from each lake are shown on Figure 3. Up to 35 cfs was released at Square Lake, 25 cfs at Klonaqua Lake, 12 cfs at Eightmile Lake, and 20 cfs at Colchuck Lake.

At Upper Snow Lake, flow augmentation discharge was limited to 5 cfs for most of the 2017 Pilot Study because the existing control valve has a capacity of about 55 cfs, of which LNFH operations require up to 50 cfs (i.e., discharge available for flow augmentation was limited to about 5 cfs). After LNFH demand had ceased, flows from Snow Lakes continued for 3 days ending October 4 so that about 50 cfs was attributed to augmentation flows to allow IPID to release the full volume donated to trust (Figure 4).

Maximum Operational Discharge Rates

A goal of the 2017 Pilot Study was to estimate maximum operational discharge rates at each of the lake outlets to determine the peak rate at which flow augmentation could feasibly occur under lake-full conditions. These were used to plan augmentation release rates. Discharge rates were estimated during the site visit on July 19 by collecting a manual stream flow measurement at the highest discharge that could be safely measured given channel conditions. The maximum flow rates measured were 33 cfs at Square Lake, 37 cfs at Klonaqua Lake, and 29 cfs at Colchuck Lake. Because the initial water level was lower in 2017, the maximum discharge rate at Eightmile Lake was based on the peak discharge measured in 2016, estimated at 22 cfs.

Augmentation Volumes

The total volume of water released from storage during the Study was estimated from outflow monitoring to be 6,470 ac-ft, which was similar to the 6,427 ac-ft released during the 2016 study.

Water volumes released from each lake are shown on Figure 3. The active storage volume in each of the lakes was nearly drawn down by the end of the Study: Square Lake (2,211 ac-ft), Klonaqua Lake (956 ac-ft), Eightmile Lake (981 ac-ft), and Colchuck Lake (1,321 ac-ft). Outlet structures in these lakes were at or within several feet of the water line and individual lake outflows had diminished.

An estimated total of about 400 ac-ft remained in active storage in Square, Klonaqua, and Colchuck Lakes at the end of the 2017 Pilot Study. About half of the remaining water left in storage was in Colchuck Lake, which was inaccessible for much of the season due to the Jack Creek Fire.

Although total volumes released were similar between 2016 and 2017, volumes released from individual lakes varied. In 2017, about 275 ac-ft more was released from Square Lake (about 2 feet of additional drawdown); about 238 ac-ft more was released from Colchuck Lake, which had a higher initial water level and was drawn down about 1 foot lower than in 2016; and about 471 ac-ft less was released from Eightmile Lake, which had an initial water level more than 1 foot lower than in 2016. Additionally, a storm in October 2016 increased Eightmile Lake levels to the point where the lake discharged through the head gate, increasing the volume of water released from storage; this did not occur in 2017.

Considering active storage volumes were nearly completely drawn down in each of the lakes, results of the 2017 Pilot Study confirm the total active storage among the five lakes is in the range of about 6,500 to 7,000 ac-ft including IPID's trust donation volume of 1,000 ac-ft in Snow Lakes. The higher range of estimated volume considers about 400 ac-ft remained in storage at the end of the Study. Active storage volumes estimated using bathymetric surveys derived from LiDAR and acoustical data (Aspect, 2017b) are about 7,700 ac-ft, including the trust volume at Snow Lakes. The difference in active storage volume estimated using outflow monitoring and bathymetry is about 10 percent when water remaining in storage at the end of the Study is considered. Contributing to this difference is error associated with:

- Streamflow measurement equipment used to build rating curves
- Analytical methods used to develop rating curves
- Interpretation of rating curves
- Lake stage estimates
- Outlet pipe elevation estimates
- Bathymetry data collection methods
- Bathymetry data analysis and volumetric estimates

Despite about 400 ac-ft remaining in active storage among the lakes, cumulative augmentation flows had decreased to less than 10 cfs by the end of the Study. This suggests the instream flow benefit of accessing the final few hundred acre feet of stored water could be limited.

Assuming the five lakes contain between 6,500 to 7,000 ac-ft of active storage, about 2,600 to 3,100 ac-ft of IPID's 9,600 ac-ft trust water donation could be inaccessible in an average water year due to elevations of outlet structures that lie above the stored water. However, multiple fill opportunities in some years, or IPID options during drought years to siphon water from lower than normal inlet elevations, could increase this volume.

Lake Stage and Drawdown

At the beginning of the 2017 Pilot Study, lake levels were full, which was consistent with the start with the 2016 Pilot Study (except for Eightmile Lake, which was slightly more than one foot lower in 2017 than in 2016). Active storage in the lakes was nearly completely drawn down during the Study. Table 2 shows total drawdown levels for both study years and estimated active storage height at each lake. Active storage height was estimated by collecting manual measurements during low water at Square, Klonaqua, and Colchuck lakes and estimates from 2016 were updated as needed. Active storage height at Eightmile Lake was estimated based on information from IPID. Active storage height at Snow Lakes was not assessed.

Table 2. Maximum Drawdown During 2016 and 2017 Studies

Lake Name	Estimated Active Storage Height (ft)	Maximum Drawdown in 2016 (ft)	Maximum Drawdown in 2017 (ft)
Square Lake	32	27.9	30.0
Klonaqua Lake	28	24.7	24.7
Eightmile Lake	17	14.1	13.9
Colchuck Lake	16.5	12.0	13.1
Snow Lake	Not Measured	N/A	N/A

In 2017, Square and Colchuck lakes were drawn down by about 2 feet and 1 foot more, respectively than in 2016. The other lakes were drawn down about the same as in 2016. After the head gate becomes exposed above the water line, drawdown in Eightmile Lake is controlled by seepage only.

Figure 5 shows lake hydrographs for the 2017 Pilot Study with stage measured by continuous recording datalogger, periodic manual measurements, and the depth of lake outlet pipe/tunnel inverts estimated from field inspection. Lake hydrographs shown on Figure 6 encompass the 2016 Pilot Study, 2017 Pilot Study, and the interval between studies.

Drawdown characteristics of lakes were identified by examining changes in lake stage. Drawdown characteristics depend on lake bed geometry, lake volume relative to outlet discharge rate, and water inputs to the lake (runoff, groundwater). Drawdown characteristics of Snow Lakes were not assessed. The steady declining stage drawdown curve observed for Eightmile Lake (Figure 5) was due to its head gate position, which remained fixed throughout the study and continuous seepage of water occurring through the lake bed to Eightmile Creek.

Drawdown curves at Square, Klonaqua, and Colchuck lakes were steeper than Eightmile Lake and became steeper when flow augmentation releases were increased. Compared to 2016, lake hydrographs during the 2017 Pilot Study show a more gradual drawdown, consistent with efforts to decrease peak release flows and conserve stored water for flow augmentation later in the season (Figure 6). Unlike 2016, lake stage did not increase toward the end of the 2017 Pilot Study, as no significant precipitation occurred during this period.

At Colchuck Lake, the transducer was set about 4 feet above the outlet invert due to the head gate configuration. No data were recorded once the water level dropped below 4 feet above the outlet invert. Additionally, restricted access to Eightmile Lake due to the Jack Creek fire prevented retrieval of barometric data, which was needed to adjust continuous water level data at Colchuck Lake. This resulted in no reliable water level record at Colchuck Lake for October (Figure 5). Water level in Colchuck Lake during October was interpolated based on the last available barometrically-compensated transducer data point and the final visual measurement.

The Jack Creek Fire also resulted in less water being released from Colchuck Lake than planned, as lack of access precluded head gate adjustments needed to maintain targeted outflow rates. At the end of the study, the water level in Colchuck Lake was approximately 3.4 feet above the outlet invert.

Lake Drawdown and Effects on Outflow Rates

Table 3 shows drawdown rates for the five reservoirs, which can be used along with the 2016 study results (Aspect, 2017a) to estimate how long it will take to draw down active storage.

Table 3. Lake Stage Drawdown Rates

Lake Name	Average Drawdown Rate (ft/day)	Average Discharge Rate (cfs)
Square Lake	0.4	16
Klonaqua Lake	0.5	9
Eightmile Lake	0.2	7
Colchuck Lake	0.3	12
Snow Lakes	Water levels not measured	n/a

Eightmile Lake drew down slowest at a rate of about 0.2 ft/day with an average discharge rate of about 7 cfs. Klonaqua Lake drained fastest, at a rate of about 0.5 feet per day and an average discharge of 9 cfs.

If no adjustments were made to head gates, the rate of discharge from the lakes declined with lake stage due to decreased driving head and lake bottom geometry. Figure 4 shows that cumulative augmentation flows began declining immediately after weekly head gate adjustments were made. Following the start of peak cumulative augmentation flow on August 21, flows decreased by about 3 cfs per day. Figure 4 also shows that augmentation flows declined faster as lake levels were drawn down. When lakes were relatively full in early August, the cumulative augmentation flows decreased at a rate of about 1.0 cfs per day, from about 46 cfs on August 6 to about 40 cfs on August 12 (Figure 4). When lakes were nearly empty in mid to late September, cumulative augmentation flows initially set at about 44 cfs, similar to early August augmentation flows, decreased at a faster rate of about 1.6 cfs per day.

Year-Round Lake Stage

The pressure-transducer data loggers also recorded lake stage during the period between studies (October 2016 to July 2017; Figure 7). Following closure of the head gates in October 2016, water levels in Square, Klonaqua, and Colchuck lakes recovered gradually. The lakes did not fill to overflow levels until February (Klonaqua Lake) and May (Square and Colchuck lakes).

Lake stage in Eightmile Lake recovered more rapidly than the other three lakes in response to precipitation (increase of approximately 14 feet in 2 weeks). However, by mid-November, seepage from Eightmile Lake overcame the inflow rate and the lake level began to drop, falling about 12 feet until lake levels began to recover in February. Declining water levels during the winter are assumed to be the result of precipitation transitioning to snow, limiting runoff to the lake while seepage from the lake continued.

The potential for Eightmile Lake to draw down significantly in winter due to seepage losses despite the head gate being closed could limit its value as a source for winter augmentation flows. Square and Colchuck lakes may only fill completely after the snow melts in spring, potentially limiting the ability to use these lakes as winter flow augmentation sources, especially when below-average precipitation accumulations are expected.

Effects of Augmentation on Historic Channel Flows

A hydrograph of estimated flows in the Historic Channel at Structure 2 during the 2017 Pilot Study is shown on Figure 7. This hydrograph was developed based on recorded flow measurements at the Ecology Gauge at RM 2.2 and subtracting 50 cfs to account for LNFH withdrawals and diversions upstream of this gauge. The hydrograph reflects ambient and augmentation flows. Based on the period of record from the USGS gauge, 2017 was an average runoff year in Icicle Creek. Figure 7 also contains the hydrograph showing the cumulative flow augmentation and a hyetograph for precipitation (as rainfall) occurring at the nearest weather station, the Fish Lake SNOTEL site located in the adjacent Cle Elum River drainage.

Icicle flows in the Historic Channel were about 200 cfs when the 2017 Pilot Study began on July 19 and decreased to about 100 cfs in mid-August.

Weekly averages for flow augmentation rates and Historic Channel flows during the 2017 Pilot Study period are shown on Figure 8. Flow augmentation during the low flow months of August and September equaled between 15 and 95 percent of total discharge in the Historic Channel.

Augmentation Increased Historic Channel Flows

Consistent with the 2016 Pilot Study, augmentation flows increased Historic Channel flows in 2017. Increased augmentation flows are indicated by the small “peaks” in the Historic Channel hydrograph during the weeks of August 2, 16, and 30 (Figure 7). Although not intended for flow augmentation, the peak in the Historic Channel hydrograph of about 45 cfs occurring the week of July 26 is the result of USFWS initiating releases from Snow Lakes. Augmentation releases also contributed to Historic Channel flows by slowing the naturally-declining hydrograph, prolonging the target flow period, and improving overall discharge. This decreased the difference between the estimate hydrograph for conditions without augmentation and the 100 cfs minimum flow target.

Increases in augmentation flows in August did not result in a one-for-one increase in Historic Channel flows. For example, when augmentation flows were increased by 31 cfs the week of August 2, 36 cfs the week of August 16, and 21 cfs the week of August 30, the Historic Channel hydrograph responded with short-lived increases (peaks) of 23 cfs, 15 cfs, and 12 cfs, respectively, before returning to pre-augmentation-increase levels and gradually declining flow trends (Figure 7). The difference in magnitude between flow augmentation and its effect on streamflow in Icicle Creek is attributed primarily to a portion of augmentation water going to storage along the miles of creek bed between the reservoirs and the Ecology Gauge. Some of this water is temporarily stored in channels and wetlands and as shallow groundwater in the hyporheic zone. A portion of the water is also likely lost to evaporation and transpiration by riparian vegetation.

The peaks observed in the hydrograph for the Historic Channel during 2017 are smaller than observed during the 2016 study. This is consistent with the different augmentation management approach for 2017 that initiated smaller increases in augmentation flows to minimize significant ramp-ups, and to conserve stored water for the late season.

Late-season precipitation events had a much greater influence on the hydrograph than the August increases to augmentation flows. Peaks in the Historic Channel hydrograph occurring the weeks of September 20 and 27, and October 4, were attributed to precipitation events (Figure 7). Precipitation events increased Historic Channel flows by about 47 to 63 cfs. The hydrograph peak occurring the week of September 27 appears considerably higher than peaks resulting from the other two precipitation events; much of this increase was because IPID had ceased its approximately 100 cfs diversion in the 2 days prior to the precipitation event. As with increased augmentation flows, precipitation events had only short-term impacts to stream flows, and flows quickly returned to a low flow state. For the 2017 Pilot Study, there were no circumstances when augmentation flows were intentionally reduced to conserve stored water.

Augmentation Slowed the Seasonally Falling Hydrograph

Consistent with the 2016 Pilot Study, flow augmentation appears to have slowed the rate of Icicle Creek's natural, seasonally falling hydrograph. Figure 9 shows the observed Historic Channel hydrograph (estimated based on the Ecology Gauge minus 50 cfs), cumulative flow augmentation hydrograph, and an estimate of what the Historic Channel hydrograph might have looked like in the absence of augmentation flows (estimated hydrograph). The latter was derived by subtracting the cumulative augmentation flows from the observed Historic Channel hydrograph. While the estimated hydrograph is generally consistent with average year flows based on the Ecology gauge period of record, it appears to underestimate the lowest flows that remain above 25 cfs during average years.

In the absence of flow augmentation, the seasonally falling hydrograph is estimated, based on the estimated hydrograph to have decreased at a rate of about 13 cfs per day from July 19 through the end of July (Figure 9). This rate is estimated to have decreased to about 4 cfs per day through August as discharge approaches base flows.

With limited augmentation through the end of July, the rate of decline of the seasonally falling hydrograph was effectively unchanged from the estimated (non-augmentation) hydrograph, with decreases in augmented flows of about 13 cfs per day. As releases were progressively increased starting in August, there was an improvement in the rate of decline of the augmented flow hydrograph relative to the estimated (non-augmentation) hydrograph of about 1 cfs per day, from an estimated 4 cfs per day without augmentation to about 3 cfs per day observed with augmentation (Figure 9).

Augmentation Prolonged the Target Flow

Flow augmentation increased the period of time that the target flow was met by about 10 days, or about 15 percent of the time when flows were estimated to have otherwise been below the target.

The estimated hydrograph for Historic Channel flows without flow augmentation indicates discharge would have dropped below the 100 cfs target beginning August 5 and largely remained below the target until a week after the 2017 Pilot Study had concluded, when significant precipitation began—a period of about 10 weeks (Figure 9). The observed Historic Channel hydrograph indicates augmentation flows slowed the seasonally falling hydrograph by about 1 cfs per day, delaying the date when Icicle Creek flows would have otherwise diminished to below the 100 cfs target by 10 days.

The 10-day period that augmentation is estimated to have prolonged target flows is less than the period estimated in 2016. This difference is partly explained by a change in the approach to augmentation management that sought to conserve stored water for later in the season during the 2017 Pilot Study. Additionally, the period when flows are estimated have been below the target in 2017 (10 weeks) is longer than in 2016 (9 weeks) due to the onset of significant precipitation occurring earlier in 2016.

Augmentation Decreased the Target Flow Deficit

Augmentation improved overall discharge in the Historic Channel, decreasing the difference between the estimated hydrograph without augmentation and the 100 cfs target.

Evaluation of the estimated, non-augmentation hydrograph indicates about 10,300 ac-ft would have been required to sustain flows at the 100 cfs target during the low flow period between August 5 and the end of the Study on October 11. About 6,000 ac-ft of augmentation water flowed through the Historic Channel during this period. With flow augmentation, the deficit between observed flows and the 100 cfs target decreased to approximately 4,300 ac-ft over this period—augmentation water made up over half the volume needed to meet the flow target. This improvement to Historic Channel flows is consistent with results of the 2016 Pilot Study that estimated augmentation increased the period flows are above the target by about one third.

Further beneficial effects of augmentation on Historic Channel flows could be realized by minimizing releases from storage in July and early August that were initiated before flows dropped below the 100 cfs target. Between 400 and 500 ac-ft of augmentation water was released from storage at the start of the 2017 Pilot Study before flows dropped below the 100 cfs target on August 5. Had that 400 to 500 ac-ft been retained, augmentation releases could have been increased later in the season by 10 cfs for about 20 to 25 days.

Estimating Flows through the Historic Channel

An objective of the 2017 Pilot Study was to confirm assumptions used to estimate stream flows in the Historic Channel.

Real time flows for the Historic Channel measured at Structure 2 were not available. The Ecology Gauge at RM 2.2 was used as a proxy by subtracting 50 cfs from the recorded flow measurements, estimated to represent diversions by LNFH that bypass the Historic Channel and return downstream. Upon conclusion of the Study, USFWS provided 2017 daily mean discharge data for the Historic Channel measured through Structure 2. These data were compared to our assumption of the Ecology Gauge minus 50 cfs.

Figure 10 contains hydrographs for our estimated flows through the Historic Channel using the Ecology Gauge minus 50 cfs assumption and USFWS measurements at Structure 2. The data sets show strong agreement until flows dropped to about 130 cfs on August 10. From that point, USFWS-estimated flows were generally higher by up to about 20 cfs through August and September.

A single manual streamflow measurement was collected on August 25 in the Historic Channel, about 100 feet downstream of Structure 2 (Figure 10). The manual measurement indicated discharge of 87 cfs, compared to our estimate of 80 cfs and the USFWS estimate of 90 cfs (daily mean). These limited data suggest our assumption using the Ecology Gauge minus 50 cfs may underestimate flows in the Historic Channel, especially when flows are near or below the 100 cfs flow target. Considering that the USFWS estimates are daily mean values, include rounding error and error associated with manual streamflow measurement of at least 3 percent, our assumption appears to be sufficiently valid (and conservative) for analyzing effects of augmentation on Historic Channel flows. Additional data collection will be required to refine this conclusion and to resolve differences between the methods used to estimate flows.

Data Gaps

The following data gaps were identified based on the 2016 and 2017 Pilot Studies:

- **Real-time flows for the Historic Channel measured at Structure 2 were not available.** Ecology's Icicle Creek Gauge at RM 2.2 was used as a proxy by subtracting 50 cfs from the recorded flow, to account for estimated diversions by LNFH that bypass the Historic Channel. It is not clear why there were differences between Historic Channel flows based on our estimates using the Ecology Gauge and the USFWS measurements at Structure 2.
- **The fate of flow augmentation water is not fully understood.** Lag effects due to stream channel storage reduce the impact of augmentation flows in the Historic Channel. The effects of inputs from upstream sources and diversions by upstream water users are not fully understood.
- **The effects of augmentation water on stream flow in Icicle Creek are not fully understood.** Interpretation of the data were complicated by precipitation events and the absence of precipitation-recording stations within the Icicle Creek basin. The nearest precipitation recording station is the Fish Lake SNOTEL located in the Cle Elum River Basin, which is between 9 and 24 miles from the Alpine Lakes reservoirs.

- **Evaluation of impacts of flow releases on Bull Trout habitat** in French and Leland creeks is ongoing and will require additional study (WDFW, 2018).

Conclusions

The 2017 Pilot Study, in combination with data collected during the 2016 Pilot Study, provided promising results that water stored in the Alpine Lakes reservoirs can be used to effectively enhance stream flows in the Historic Channel. There were no fatal flaws identified. While flow augmentation from the Alpine Lakes reservoirs is not a total solution for achieving the IWG's flow targets in the Historic Channel, these studies indicate it may increase the period flows are above the target by about one third and account for over one half the volume required to meet the flow target. A follow up study is recommended to confirm and improve on findings of the 2017 Pilot Study and to resolve data gaps.

The following is a summary of conclusions from the 2017 Pilot Study, with comparisons to the 2016 Pilot Study:

- No fatal flaws were identified.
- Between 6,500 and 7,000 ac-ft are available for release from storage. An estimated total of 6,470 acre-feet was released from storage, which is about the same as that released during the 2016 Pilot Study.
- Nearly all the water in active storage was released, and active storage in all lakes was nearly drawn down. About 400 ac-ft remained in active storage amongst the lakes. Storage volumes estimated in 2016 were confirmed in 2017.
    - Storages volumes estimated by monitoring outflow rates in 2017 (~6,500 ac-ft) are within 10 percent of volumes previously estimated using bathymetric survey based on LiDAR and acoustical data (~7,700 ac-ft; Aspect, 2017b) when the volume remaining in active storage at the end of the Study (~400 ac-ft) is considered.
- The full volume in active storage may not be available for effective flow augmentation. Although about 400 ac-ft remained available in storage amongst the lakes, cumulative augmentation flows had decreased to less than 10 cfs when lake levels were drawn down at the end of the Study. This augmentation rate is not sufficient to substantially close the gap between late season low flows in Icicle Creek and the 100 cfs.
- Between 2,600 and 3,100 ac-ft of water donated to trust was not physically accessible from the lakes using existing reservoir infrastructure.
- While total volumes released in 2017 were about the same as in 2016, release volumes differed significantly at several lakes.
    - About 300 ac-ft more was released from Square Lake than in 2016 and the lake was drawn to within 2 feet of the outlet invert. Drawing down Square Lake was a priority to support inspection of the facility.
    - About 200 ac-ft more was released from Colchuck Lake primarily because a higher water level at the beginning of the study in 2017 allowed more releases.

- About 500 ac-ft less was released from Eightmile Lake than in 2016. Outflows from Eightmile in the late season are controlled by natural seepage and the headgate that was set to a fixed position at the beginning of the Study. The lower volume released in 2017 is attributed to initiating the study more than 1 week later than the 2016 Pilot Study, an initial water level 1 foot lower than in 2016, and decreased inflows (precipitation and runoff) during the study period.

- Planned augmentation was not optimized due to limited access to lakes. This delayed making adjustments, contributing to about 400 ac-ft remaining in active storage at the end of the Study. Access to Square Lake by foot was inhibited by hazardous trail conditions, and access to Colchuck and Eigthmile lakes was limited for much of the season by the Jack Creek Fire.
- Quantities of water released for flow augmentation are not adequate to reverse or even keep up with the seasonally falling hydrograph. However, flow augmentation can slow the rate of decline, prolonging the period when flows remain above the target. Augmentation flows slowed rate of the seasonally falling hydrograph by an average of about 1 cfs per day, delaying the date when Icicle flows would have otherwise diminished to below the 100 cfs target by approximately 10 days.
- Augmentation flow rates were managed to conserve stored water so more would be available later in the season than in 2016. While this approach improved late season flows, it resulted in a lower peak augmentation rate and fewer days when flows were maintained above the 100 cfs target.
  - Augmentation flows of up to 75 cfs improved flows in the Historic Channel by about one half during critical low flow periods.
  - Augmentation extended Icicle Creek flows in the Historic Channel above the 100 cfs target for about 10 days compared to 3 weeks in 2016.
  - Augmentation flows equaled between 15 and 95 percent of discharge in the Historic Channel during critical low flow periods.
  - Augmentation releases account for over one half the volume needed to meet the 100 cfs flow target in the Historic Channel. The total volume of augmentation water flowing through the Historic Channel during the low flow period of about 6,000 ac-ft made up over half the difference between the estimate hydrograph without augmentation and the 100 cfs target of 10,300 ac-ft.
- Data gaps identified in 2016 were addressed, including:
  - Rating curves for outlet channels were improved by collecting additional discharge measurements to increase the accuracy of outflow rates and volume estimates. Rating curves still require improvement, specifically at the lower end of flow ranges.
  - Informing impacts of flow releases on Bull Trout habitat in French and Leland Creeks (WDFW, 2018).
- The method used to estimate flow in the Historic Channel during 2016 and 2017 appears valid for the purpose of this Study. However, differences between flows estimated using the Ecology Gauge (minus 50 cfs) and those estimated by the USFWS at Structure 2 require further refinement, validation, and calibration.

- Lag effects due to stream channel storage reduce the effects of augmentation flows in the Historic Channel. Flows released from storage were not proportional to changes observed in the Historic Channel hydrograph, and peaks in the hydrograph resulting from significant increases to augmentation flows were relatively small. More study is needed to understand the fate and timing of water released from storage.
- Minimal head gate operation may be required to maintain augmentation flows. Precipitation events had only short-term impacts to stream flows, suggesting there may be no need to close gates to conserve water following precipitation events. Once opened, head gates remained open for the duration of the study but required periodic adjustment (opened more) to maintain augmentation flow rates.
- Winter augmentation opportunities are limited. Lake hydrographs for the winter of 2016-2017 suggest storage volumes are less than 6,500 ac-ft. After filling in response to precipitation, Eightmile Lake emptied due to seepage in mid-winter, when precipitation turned to snow, and did not fill again until spring. Square and Colchuck lakes did not fill completely until the spring snow melt.

Recommendations

The following are recommended for a follow-on study to improve confidence in findings of the 2016 and 2017 Pilot Studies:

- With additional study, our assumption for using the Ecology Gauge minus 50 cfs could be used to accurately estimate flows in the Historic Channel, precluding the need to equip Structure 2 to collect real-time data. Data collection, including LNFH surface and groundwater diversion rates and discharge rates of return flows to Icicle Creek, could be used in conjunction with additional streamflow measurements taken downstream of Structure 2 to refine our assumption, especially during low-flow periods.
- Improve understanding of the fate of flow augmentation water. Lag effects due to stream channel storage reduce the impact of augmentation flows in the Historic Channel. Evaluate gaining/losing characteristics of tributaries draining the reservoirs and of mainstem Icicle Creek. Coordinate with USFWS to improve understanding of releases from Snow Lakes. Continue coordination with USFWS, IPID, Cascade Orchards Irrigation Company, and the City of Leavenworth to quantify diversions occurring upstream of the Historic Channel.
- Establish a precipitation recording station closer to the reservoirs (preferably within the Alpine Lakes Wilderness) to improve measurement of the magnitude and timing of precipitation to understand its effects on stream flows.
- Continue improving rating curves. Increase the accuracy of outlet channel discharge rate estimates for low flows by measuring stream flows in the fall.
- Account for declining outflow rates from reservoirs due to drawdown. Flow augmentation planning should consider adjusting outflow rates to account for changes on at least a weekly basis. Automating control structures to make minor adjustments to head gates every few days would mitigate decreasing outflow rates.
- Consider limiting early season releases from storage to save water for later in the season. Both the 2016 and 2017 studies showed there is not enough augmentation water in storage to meet

the 100 cfs target for the entire low-flow season. Therefore, substantial augmentation occurring before flows drop below the 100 cfs target should be avoided to conserve water for later in the season:

  - Releases from Square Lake should be prioritized earlier in the augmentation season to avoid water remaining in storage at the end of the season. Flows in Leland Creek, which drains Square Lake, are limited to 10 cfs after September 15.
  - Leakage and the inability to control the submerged head gate at Eightmile Lake limit options for retaining stored water. Repairing the Eightmile Lake dam may increase conservation of stored water allowing greater flexibility for water management to meet late season flow targets.

- Augmentation could be increased by improving infrastructure to access the full trust donation volume. Additional study will be required to evaluate potential improvements to infrastructure.
- Continue to support WDFW in assessing impacts of release flows on Bull Trout habitat in French and Leland creeks that drain Square and Klonaqua lakes based on WDFW (2018):
  - Evaluate opportunities to provide greater temperature benefits in Icicle tributaries by performing lake depth temperature profiles.
  - Conduct additional habitat and fish presence studies to create an adaptive release model that can aid in timing and magnitude of release for both tributary and mainstem Icicle Creek benefit

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Aspect Consulting, LLC (Aspect), 2017a, Alpine Lakes 2016 Flow Augmentation Pilot Study, Memorandum, Prepared for Chelan County Natural Resources Department, May 11, 2017.

Aspect Consulting, LLC (Aspect), 2017b, Feasibility Study, Alpine Lakes Optimization and Automation, Draft, Prepared for Chelan County Natural Resources Department, May 11, 2017.

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Rantz, S.E. et al., 1982, Measurement and Computation of Streamflow: Volume 1, Measurement of Stage and Discharge, Geological Survey Water-Supply Paper 2175, USGS, Washington.

Washington Department of Fish and Wildlife (WDFW), 2018, Alpine Lakes Flow Augmentation Pilot Study 2017, Icicle Creek Tributary Monitoring Report, Washington Department of Fish and Wildlife Water Science Team Habitat Program- Science Division, January 2018.

Limitations

Work for this project was performed for the Chelan County Natural Resources Department (Client), and this memorandum 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 memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

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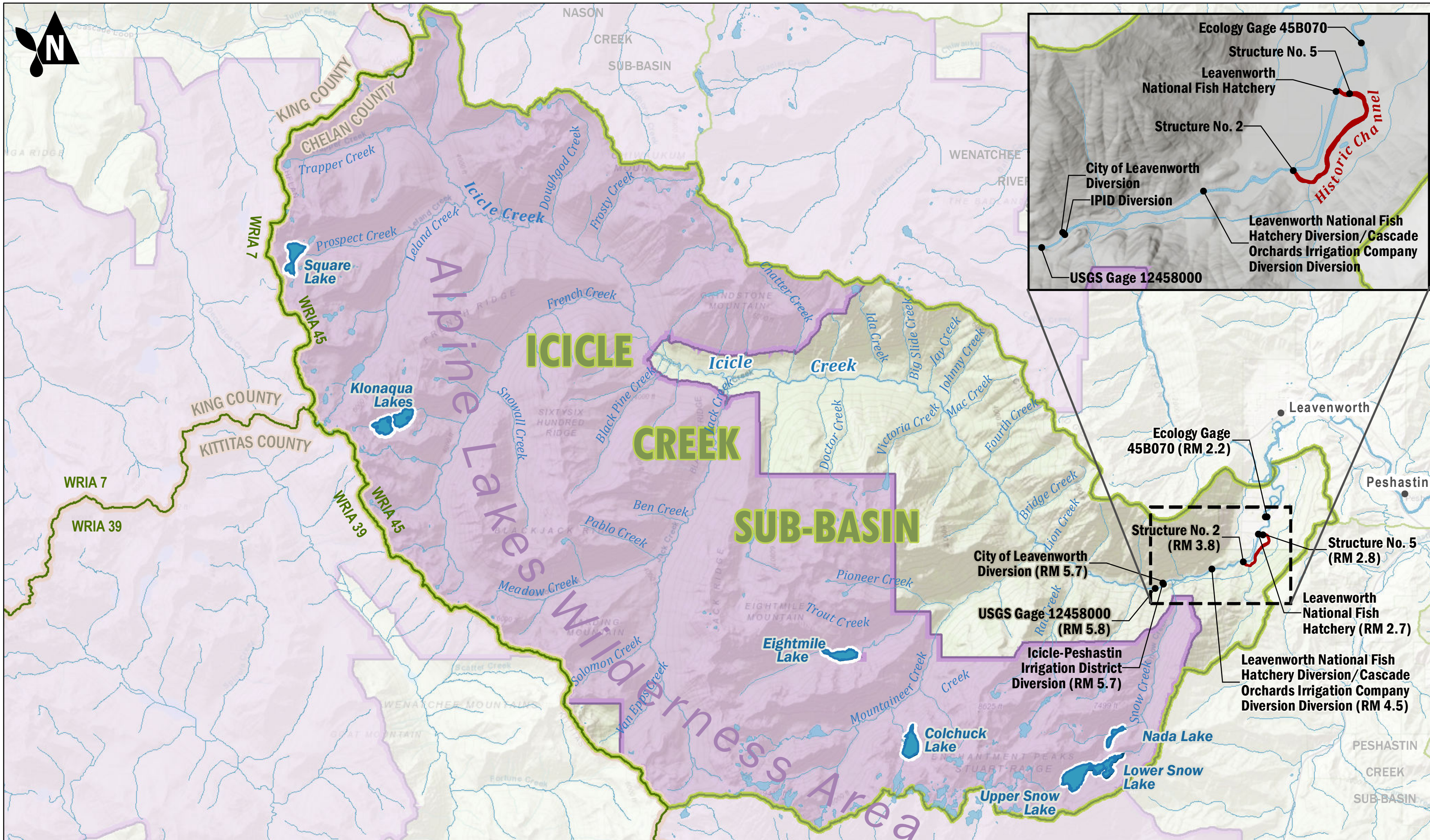
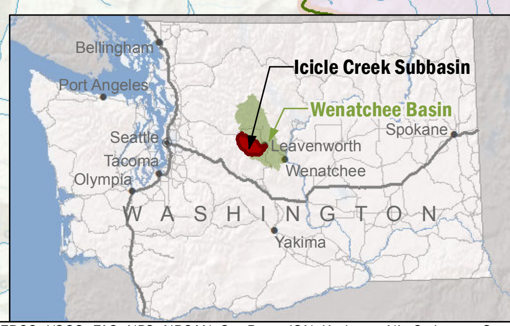
Attachments:
Figure 1 – Icicle Creek Sub-Basin
Figure 2 – Stage-Flow Curves
Figure 3 – 2017 Flow Augmentation, Volumes, and Flow Rates
Figure 4 – Cumulative Augmentation Flow
Figure 5 – 2017 Lake Hydrographs
Figure 6 – Year Round Hydrograph
Figure 7 – Historic Channel Hydrograph
Figure 8 – Augmentation Contribution to Historic Channel
Figure 9 – Effects of Augmentation on Historic Channel Flow
Figure 10 – USFWS Measured Flows at Structure 2
Appendix A – WDFW (2018) Icicle Creek Tributary Monitoring Report

V:\120045 Chelan County\Deliverables\Flow Augmentation Pilot Study\2017 Pilot Study\2017 Pilot Study Report.docx

FIGURES





Icicle Creek Sub-Basin

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	FEB-2018	BY: WMS / RAP	FIGURE NO.
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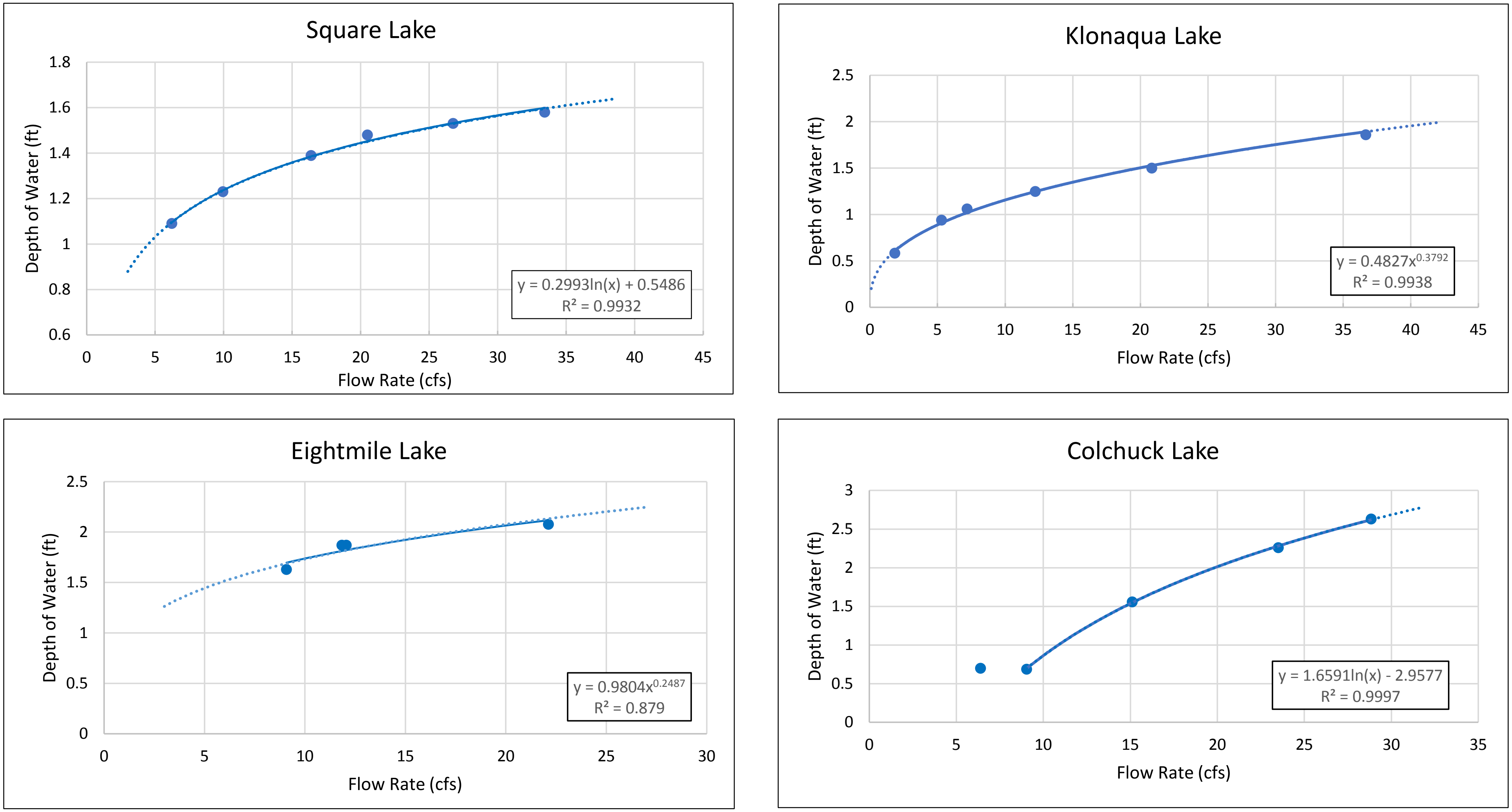

Measured Discharge — Measured Discharge Curve — Extrapolated

Stage-Flow Curves

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	FEB-2018	BY: WMS / RAP	FIGURE NO.
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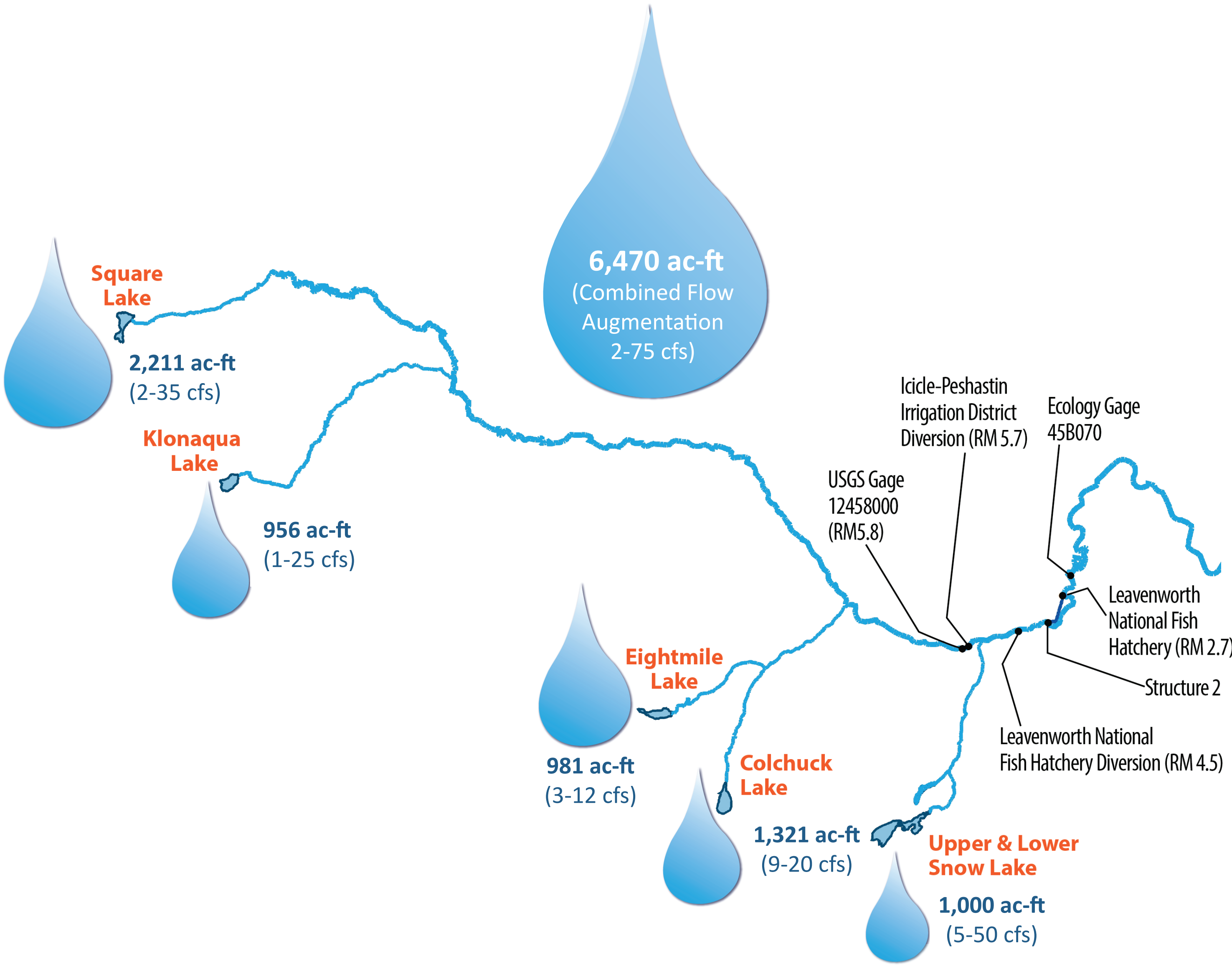

2017 Flow Augmentation, Volumes and Flow Rates

Feasibility Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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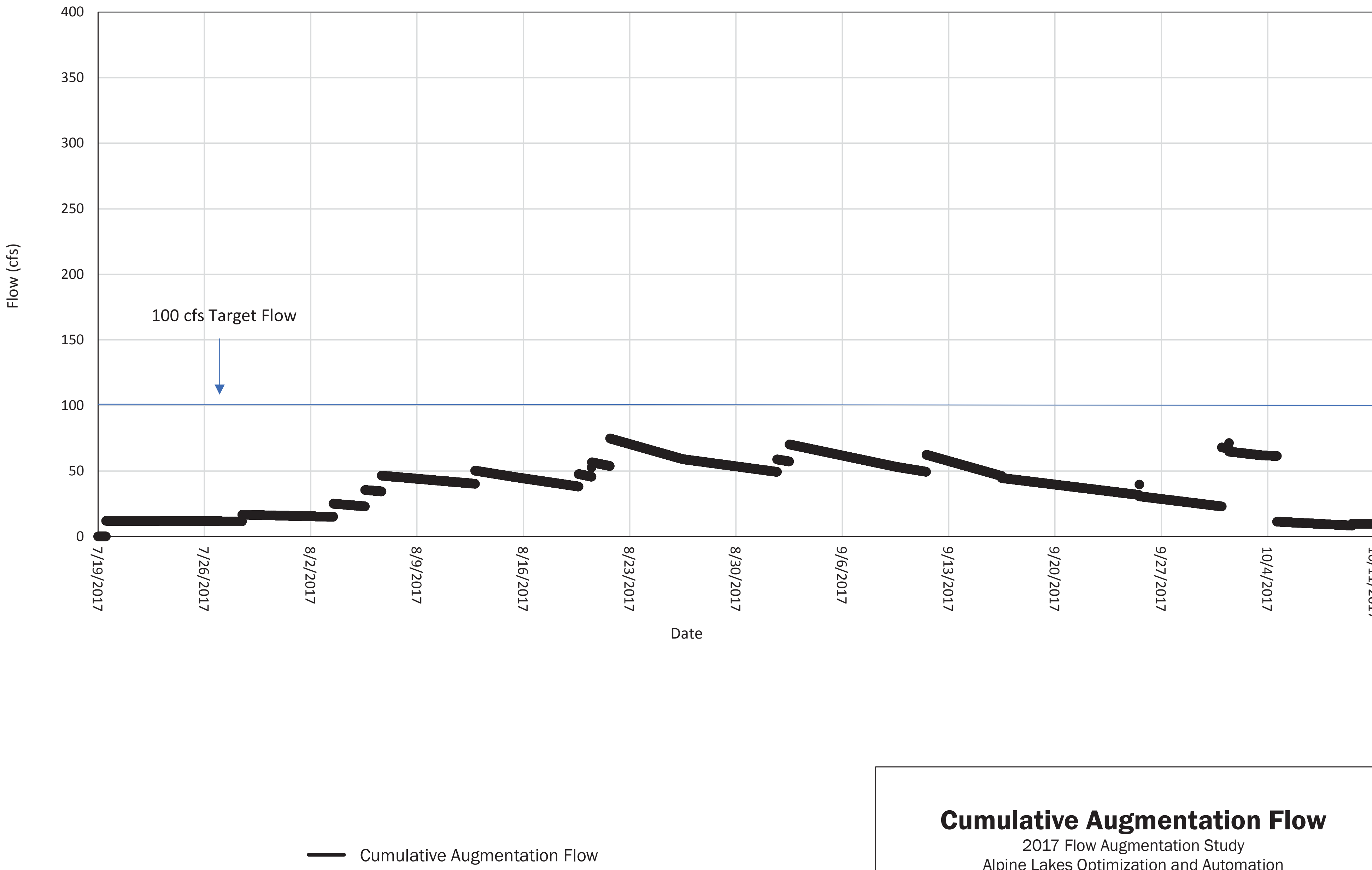

Cumulative Augmentation Flow

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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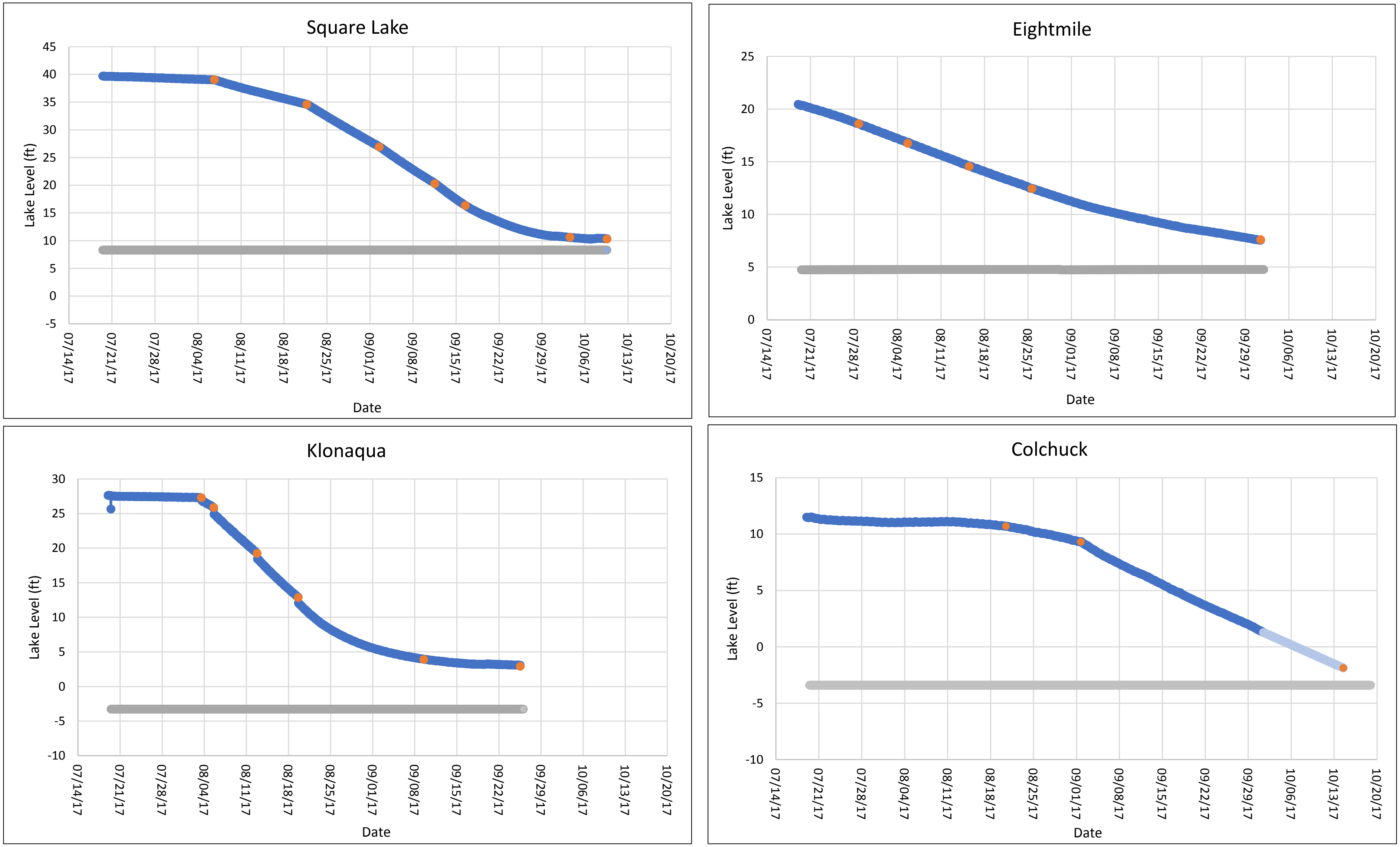

Pressure Transducer Measurement

Manual Measurement

Estimated Lake Stage

Invert

Note: Transducers are located at y = 0 for all hydrographs.

2017 Lake Hydrographs

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

Aspect CONSULTING	FEB-2018	BY: WMS / RAP	FIGURE NO.
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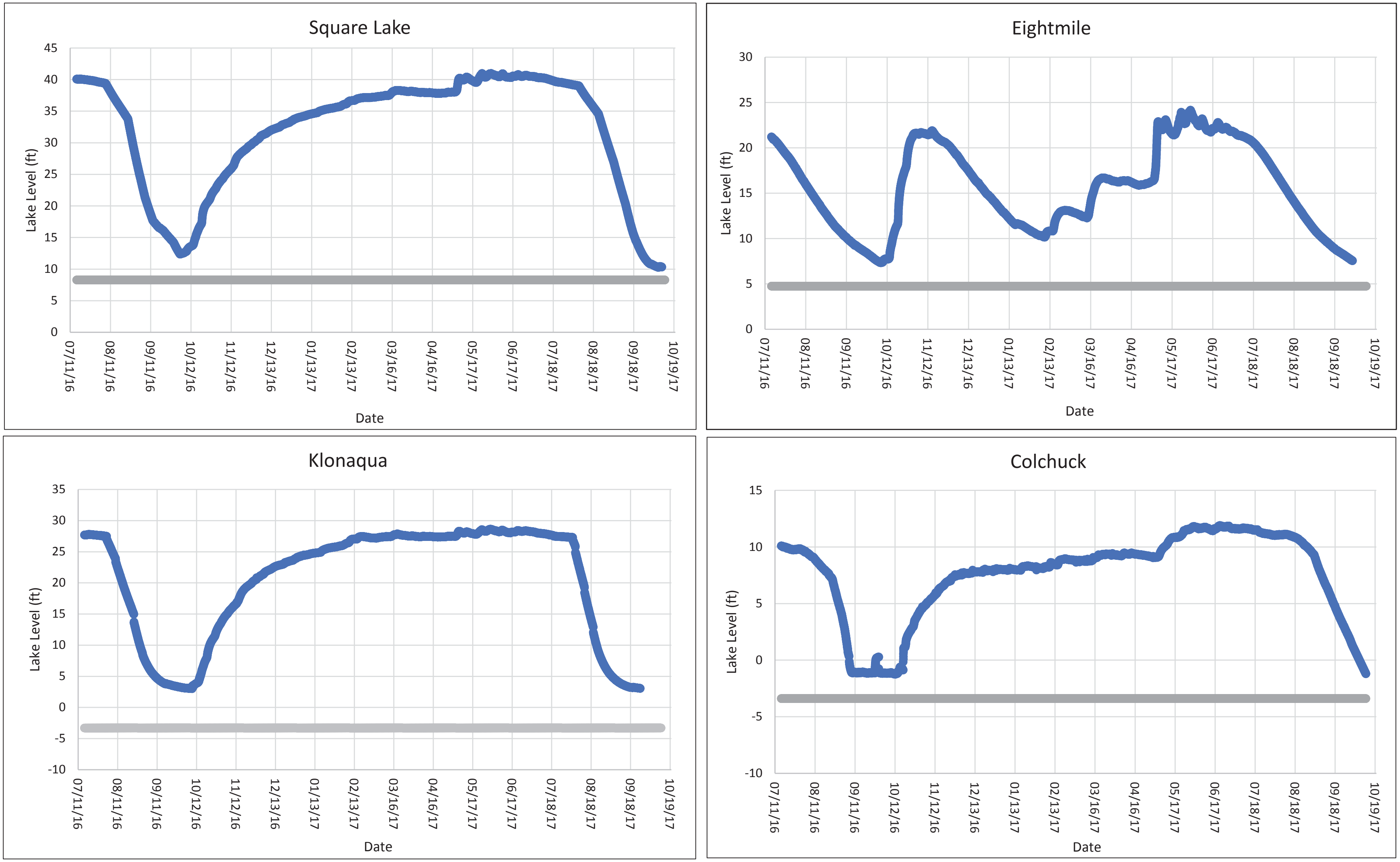

Pressure Transducer Measurement   Invert

Year Round Hydrograph

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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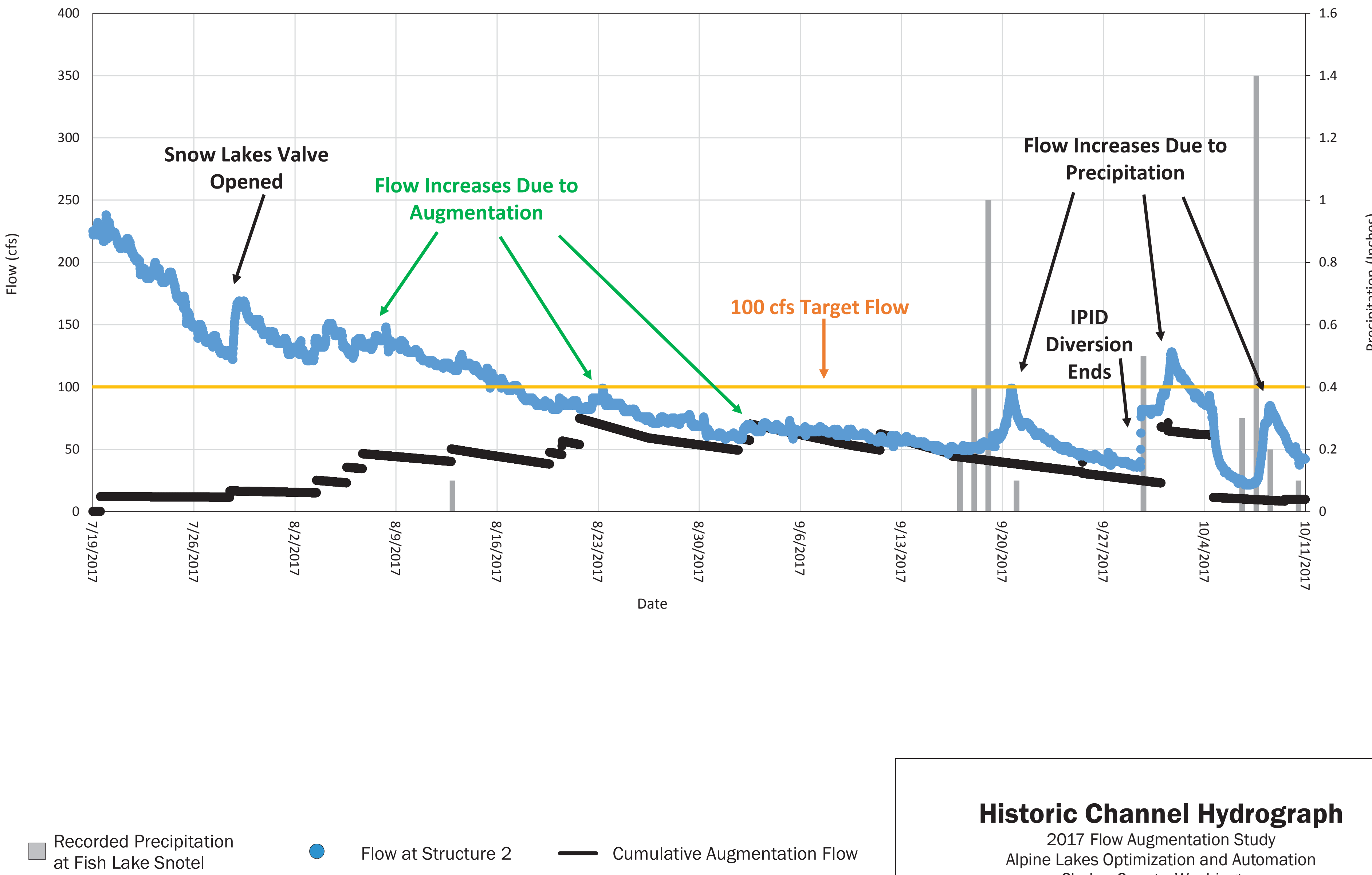

Historic Channel Hydrograph

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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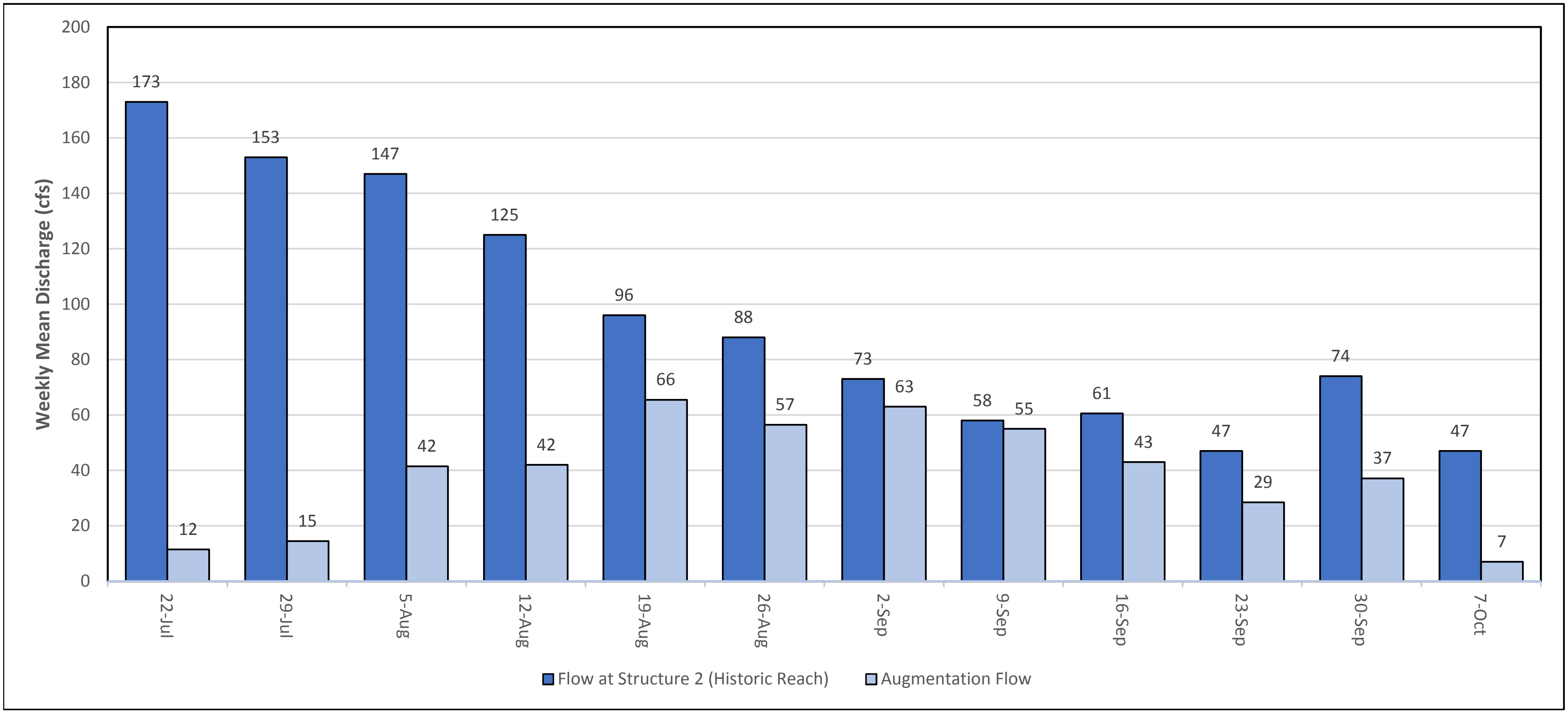

Augmentation Contribution to Historic Channel

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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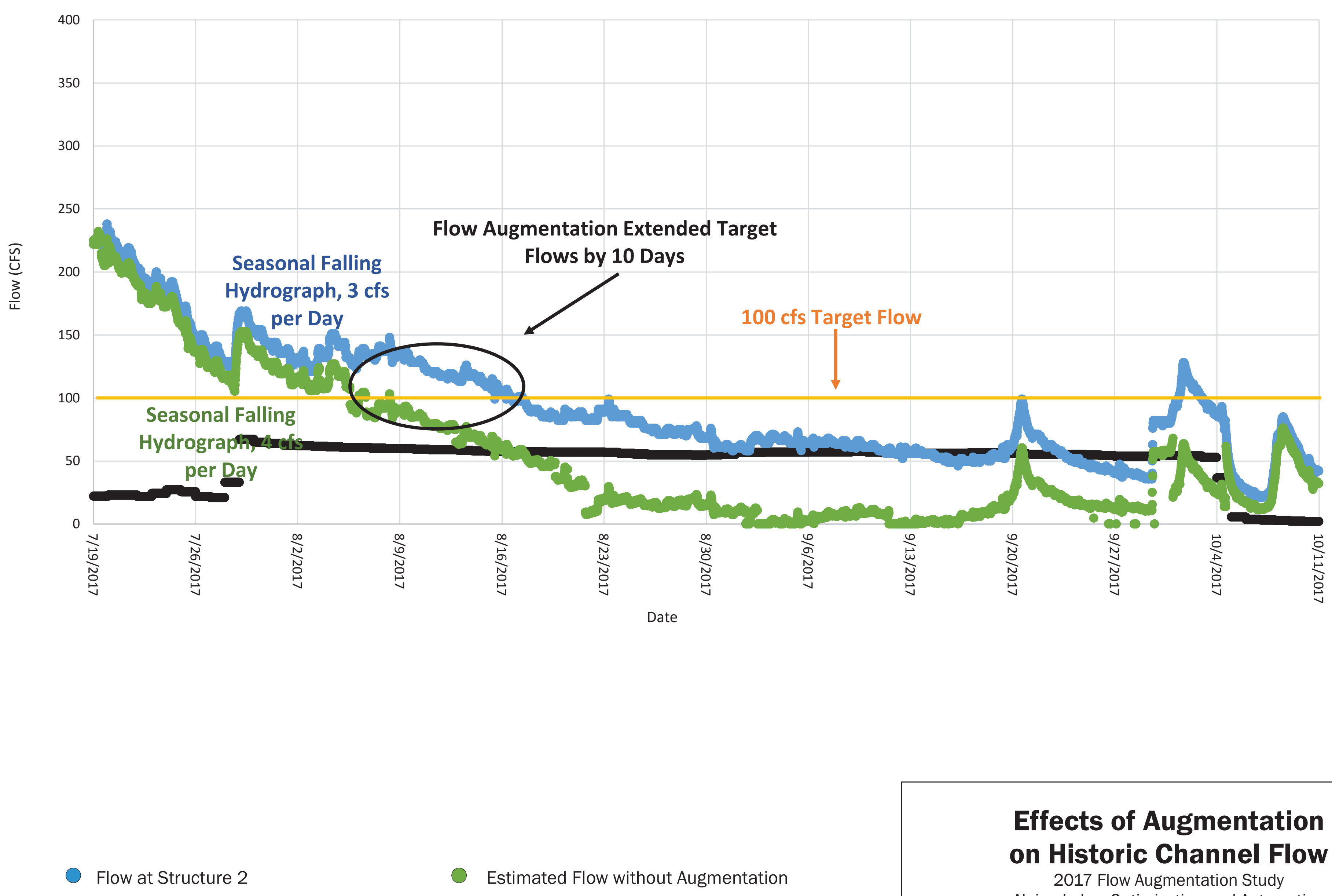

Effects of Augmentation on Historic Channel Flow

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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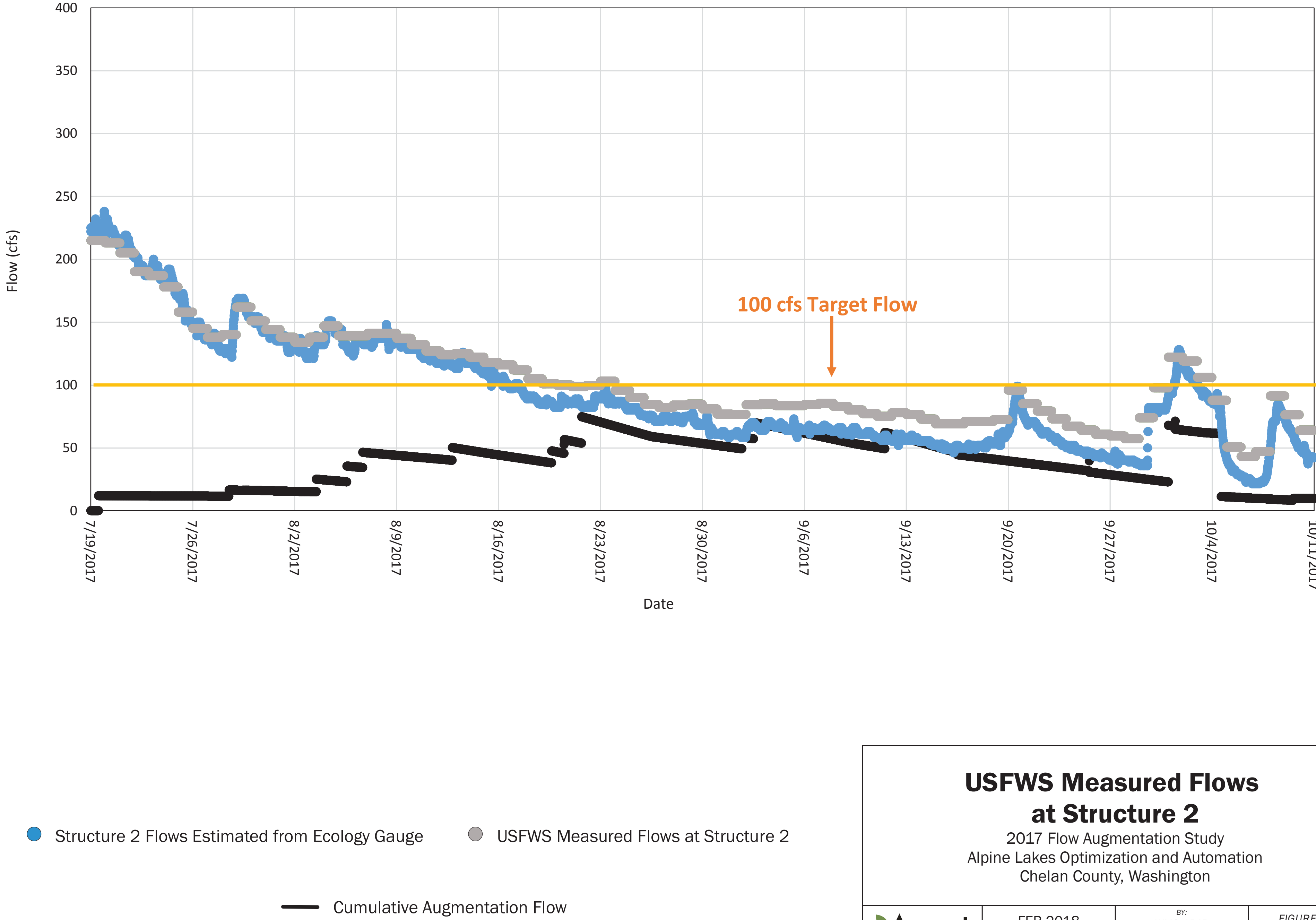

USFWS Measured Flows at Structure 2

2017 Flow Augmentation Study
Alpine Lakes Optimization and Automation
Chelan County, Washington

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	PROJECT NO. 120045	REVISED BY: - - -	10

APPENDIX A

WDFW (2018)
Icicle Creek Tributary Monitoring Report

Alpine Lakes Flow Augmentation Pilot Study 2017

Icicle Creek Tributary Monitoring Report

Washington Department of Fish and Wildlife
Water Science Team
Habitat Program – Science Division

Robert Granger

Javan Bailey, Steven Boessow, Kiza Gates, Jonathan Kohr, and Cole Provence

January 17, 2018

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Introduction

Following preliminary data collection efforts during the Alpine Lakes Flow Augmentation Pilot Study in 2016, it was determined that additional data was needed in order to gain a better understanding of the influence of augmentation flows on tributaries to Icicle Creek. Two tributaries (French and Leland Creek), which deliver flow to Icicle Creek from Klonaqua and Square Lake (respectively) were identified as priorities in the data collection effort. Prior to the 2016 augmentation effort, concerns regarding bull trout populations residing in these Icicle Creek tributaries prompted discussions regarding additional data needs to inform management decisions of flow releases from the Alpine Lakes. In response to those discussions, and preliminary monitoring and observations in 2016, a monitoring strategy was developed for the 2017 Pilot Study.

The primary goals of the monitoring strategy were to better understand the natural flow and temperature regimes in French and Leland creeks, and to identify how augmentation flows influence those regimes. To achieve this, the monitoring strategy incorporated a network of continuous flow and water temperature monitoring devices deployed at key sites intended to capture the range of conditions throughout the French and Leland creek watersheds. Additional data collection included spot measurements of various water chemistry parameters as well as manual flow and water temperature measurements.

In late-July of 2017, WDFW Water Science Team staff implemented the monitoring strategy, which began prior to augmentation releases from Klonaqua and Square lakes, and continued through mid-October after augmentation was completed for the season. Note that all River Mile (RM) estimates are approximate.

2016 Monitoring Data

In 2016 monitoring efforts were minimal, but provided initial orientation of the French and Leland Creek watersheds, and were necessary in developing a more robust monitoring strategy for the 2017 Pilot Study. Discharge, water temperature, and water chemistry data were collected at several sites in the French and Leland Creek drainages (including one site on Icicle Creek). Table 1 provides a summary of flow and water temperature data collected at transect locations. Table 2 provides water chemistry data collected at those same locations. The 2016 data are limited in nature and are not used for comparison to 2017 data in this report, however are provided for reference.

Table 1. 2016 flow data for the French and Leland Creek watersheds.

Icicle Creek Tributary Flow Monitoring 2016				
Date	**Creek Name**	**River Mile**	**Discharge (cfs)**	**Water Temp (°C)**
09/19/16	French Creek	0.10	12.56	8.70
09/19/16	French Creek	2.85	13.53	8.50
09/19/16	French Creek	5.50	6.50	8.10
09/19/16	Klonaqua Creek	0.10	2.98	8.60
09/20/16	Leland Creek	1.60	10.30	7.60
09/20/16	Prospect Creek	0.20	8.92	8.60
09/21/16	Leland Creek	0.10	19.24	5.90
09/21/16	Icicle Creek	28.0	7.86	6.00
10/25/16	French Creek	2.85	83.50	4.80
10/25/16	French Creek	4.45	47.91	5.10
11/04/16	Leland Creek	0.10	53.81	4.40
11/04/16	Icicle Creek	28.0	50.98	4.80

Table 2. 2016 water chemistry data for the French and Leland Creek watersheds.

Icicle Creek Tributary Water Chemistry Monitoring 2016								
Date	**Stream**	**River Mile**	**pH**	**Conductivity (µS)**	**Total Dissolved Solids (ppm)**	**Salinity (ppm)**	**DO %**	**DO mg/L**
09/19/16	French Creek	0.10	8.58	51.50	36.50	25.00	N/A	N/A
09/19/16	French Creek	2.85	8.16	51.60	36.60	25.00	N/A	N/A
09/19/16	French Creek	5.50	8.22	35.60	25.20	17.80	N/A	N/A
09/19/16	Klonaqua Creek	0.10	7.91	22.20	14.30	12.20	N/A	N/A
09/20/16	Leland Creek	1.60	8.24	43.80	31.10	21.10	N/A	N/A
09/20/16	Prospect Creek	0.20	8.13	27.60	19.60	14.60	N/A	N/A
09/21/16	Leland Creek	0.10	8.26	36.50	25.90	16.90	N/A	N/A
09/21/16	Icicle Creek	28.0	8.09	31.50	22.30	14.80	N/A	N/A
10/25/16	French Creek	2.85	8.16	40.20	28.60	19.50	93.60	11.98
10/25/16	French Creek	4.45	7.99	28.90	20.50	14.30	92.50	11.79
11/04/16	Leland Creek	0.10	8.98	32.30	22.90	14.10	92.00	11.93
11/04/16	Icicle Creek	28.0	8.08	21.80	15.40	9.80	89.50	11.40

2017 Study Area

French Creek Watershed

French Creek is a right bank tributary to Icicle Creek at RM 21.6. The reach of primary interest was from the confluence with Icicle Creek to just upstream of the confluence with Klonaqua Creek, which is a left bank tributary to French Creek at RM 5.35. Locations were selected for continuous flow and water temperature monitoring to capture the influence of augmentation flows delivered from Klonaqua Lake via Klonaqua Creek into French Creek, and ultimately Icicle Creek (Table 3 and Figure 1). Additional monitoring was conducted in Snowall Creek, a right bank tributary to French Creek at RM 4.35.

Table 3. French Creek watershed data logger locations.

Creek Name	Location	Data Logger Type
Icicle Creek	100 meters DS of French Creek	Water Temperature
Icicle Creek	50 meters US of French Creek	Water Temperature
French Creek	RM 0.10	Water Temperature
French Creek	RM 4.25	Water Level and Temperature
French Creek	RM 4.25	Barometric Pressure and Temperature
Snowall Creek	25 meters US of French Creek	Water Temperature
French Creek	RM 4.45	Water Temperature
French Creek	RM 5.50	Water Temperature
Klonaqua Creek	RM 0.10	Water Temperature

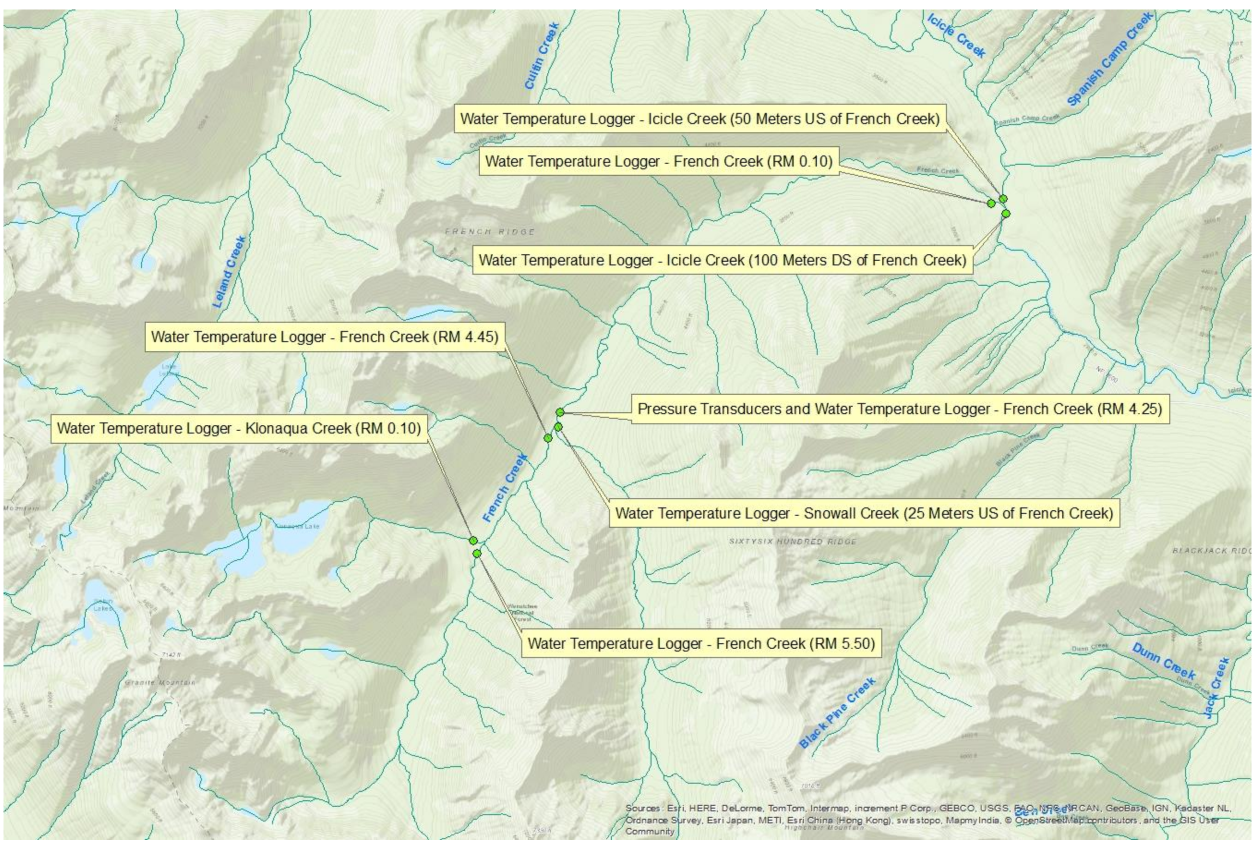

Figure 1. Map of the French Creek watershed including monitoring locations.

Leland Creek Watershed

Leland Creek is a right bank tributary to Icicle Creek at RM 27.9. The primary reach of interest was from the confluence with Icicle Creek to just upstream of the confluence with Prospect Creek, which is a left bank tributary to Leland Creek at RM 1.50. The following locations (Table 4 and Figure 2) were selected for continuous flow and water temperature monitoring to capture the influence of augmentation flows delivered from Square Lake via Prospect Creek into Leland Creek, and ultimately Icicle Creek.

Table 4. Leland Creek watershed data logger locations.

Creek Name	Location	Data Logger Type
Icicle Creek	25 meters DS of Leland Creek	Water Temperature
Icicle Creek	40 meters US of Leland Creek	Water Temperature
Leland Creek	RM 0.10	Water Level and Temperature
Leland Creek	RM 0.10	Barometric Pressure and Temperature
Leland Creek	RM 1.40	Water Temperature
Leland Creek	RM 1.60	Water Temperature
Prospect Creek	RM 0.20	Water Temperature

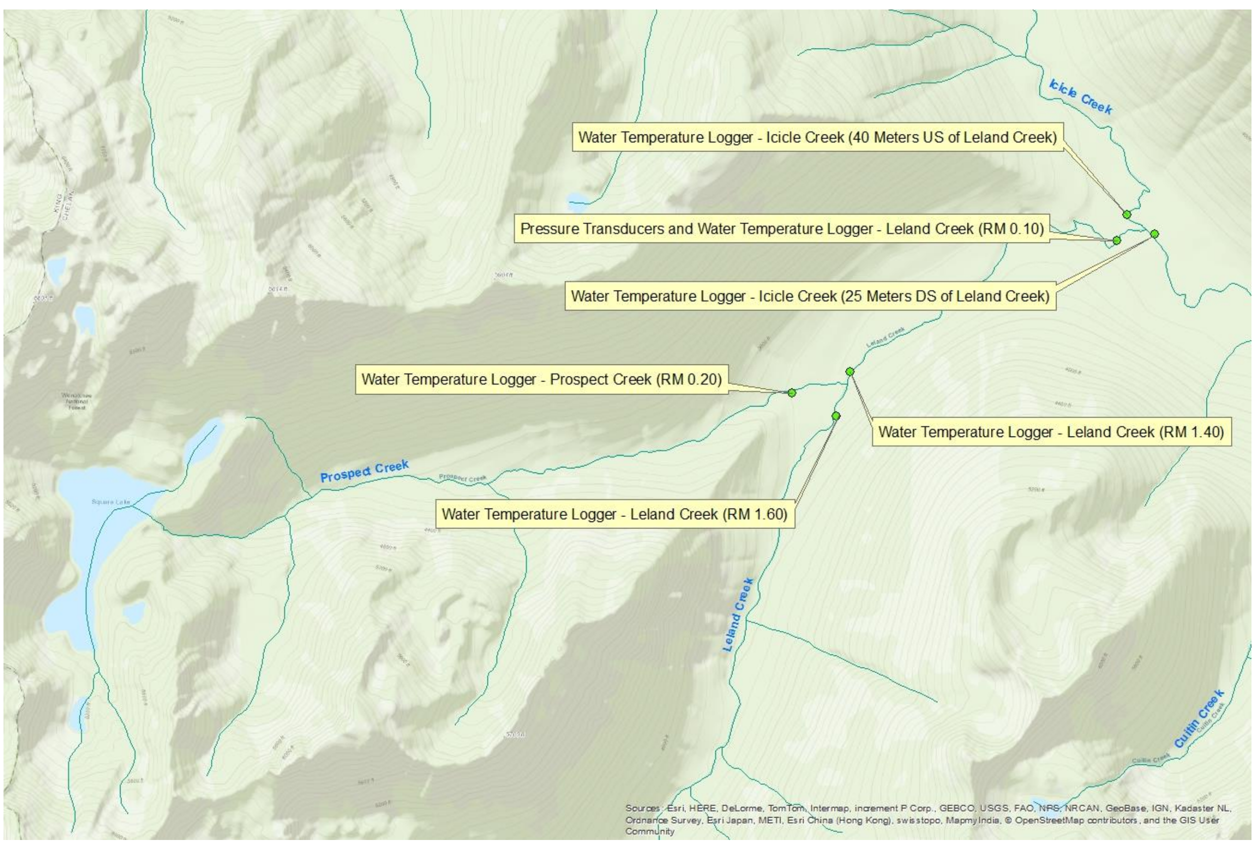

Figure 2. Map of the Leland Creek watershed including monitoring locations.

Methods

Continuous Discharge

Continuous discharge was obtained for French Creek (RM 4.25), and Leland Creek (RM 0.10). HOBO U20-001-04 Water Level Loggers (pressure transducers) were deployed instream for absolute pressure and water temperature readings (15-minute logging intervals) at locations determined to be of suitable depth, and not subject to becoming dewatered or lost to a high flow event. HOBO U20-001-04 Water Level Loggers were also deployed out of water at both locations, and adjacent to instream data loggers for barometric pressure and ambient temperature readings (15-minute logging intervals). Barometric pressure compensation was used to correct for error in water level readings associated with changes in atmospheric conditions.

Pressure transducers were deployed in French Creek during the initial site visit on July 27, and retrieved on October 17, 2017. Pressure transducers were deployed in Leland Creek on July 25, and retrieved on October 18, 2017. A total of five site visits were conducted throughout the deployment period for both French and Leland creeks to obtain manual discharge measurements. In addition, a reference water level measurement was obtained during each site visit for; 1) conversion of pressure data to water level (stage height), and 2) establishing discharge rating curves for each location.

Manual discharge measurements were obtained by extending a 100 ft. measuring tape perpendicular to the flow, and secured to both stream banks (Figures 3 and 4). Twenty-five to thirty depth and velocity measurements were collected along the transect using a HACH FH950 portable flow meter and graduated top setting wading rod. Depth and velocity measurements were then used to calculate total discharge (Cubic Feet per Second). Reference water level measurements, and the manual discharge calculations were used to obtain a stage/discharge relationship (rating curve). The rating curve was then applied to the continuous stage data to develop hydrographs for each of the two sites.

Figure 3. Cole Provence measuring discharge on French Creek (RM 4.25) October 17, 2017.

Figure 4. Kiza Gates (left) and Javan Bailey (right) measuring discharge on Leland Creek (RM 0.10) July 25, 2017.

Water Temperature Monitoring

Eight sites in the French Creek watershed were selected for continuous water temperature monitoring, and six sites were selected in the Leland Creek watershed. At each of the fourteen sites, either one or two HOBO Pro v2 water temperature loggers were deployed and programmed to record at 15-minute logging intervals. At sites where pressure transducers were deployed and already recording water temperature, an additional temperature logger was deployed as a secondary in the event of lost or failed equipment. Water temperature data was compared between each pair of data loggers deployed at a given site for reading accuracy. Only two sites had a single temperature logger deployed; Snowall Creek near the mouth and French Creek at RM 4.45.

Temperature loggers were secured to an object on the bank with a lightweight nylon rope then submerged below the water surface utilizing anything that was naturally available (Figures 5 and 6). Temperature loggers in the French Creek watershed were deployed between July 26 and 27, and retrieved on October 17, 2017. Temperature loggers in the Leland Creek watershed were deployed between July 25 and 26, and retrieved on October 18, 2017.

Figure 5. Jonathan Kohr (left) and Javan Bailey (right) deploying a water temperature logger in Icicle Creek downstream of French Creek July 26, 2017.

Figure 6. Robert Granger preparing a water temperature logger for deployment in Icicle Creek upstream of Leland Creek July 26, 2017.

Water Chemistry

Water chemistry data was collected when manual discharge measurements were conducted, and included water temperature (°C), dissolved oxygen (mg/L), pH, conductivity (µS), total dissolved solids (ppm), and salinity (ppm). Either a SPER SCIENTIFIC Dissolved Oxygen Pen – 855045, or a YSI 550A Dissolved Oxygen meter was used for DO measurements depending on availability. The other water chemistry parameters (pH, conductivity, total dissolved solids, and salinity) were collected using an Oakton PCTestr 35 Multi-Parameter pocket tester. All instrumentation was calibrated prior to collecting measurements and compared for accuracy. Single point measurements were obtained with each manual discharge measurement.

Results

French Creek Discharge

Continuous stage data was collected for French Creek (RM 4.25) from July 27 through October 17, 2017 (Figure 7). The peaks in the hydrograph during the month of August are associated with valve adjustments for augmentation flow releases from Klonaqua Lake. The first valve adjustment occurred on August 3, 2017 with additional adjustments occurring periodically throughout August and into September. Peak daily mean flow occurred on August 6 at 48.27 cfs when approximately 20.31 cfs (daily mean) was released from Klonaqua Lake. The receding limbs of the hydrograph between peaks are associated with a drop in lake levels and head pressure between valve adjustments. Peaks in the hydrograph in the months of September and October are associated with natural events and not augmentation releases.

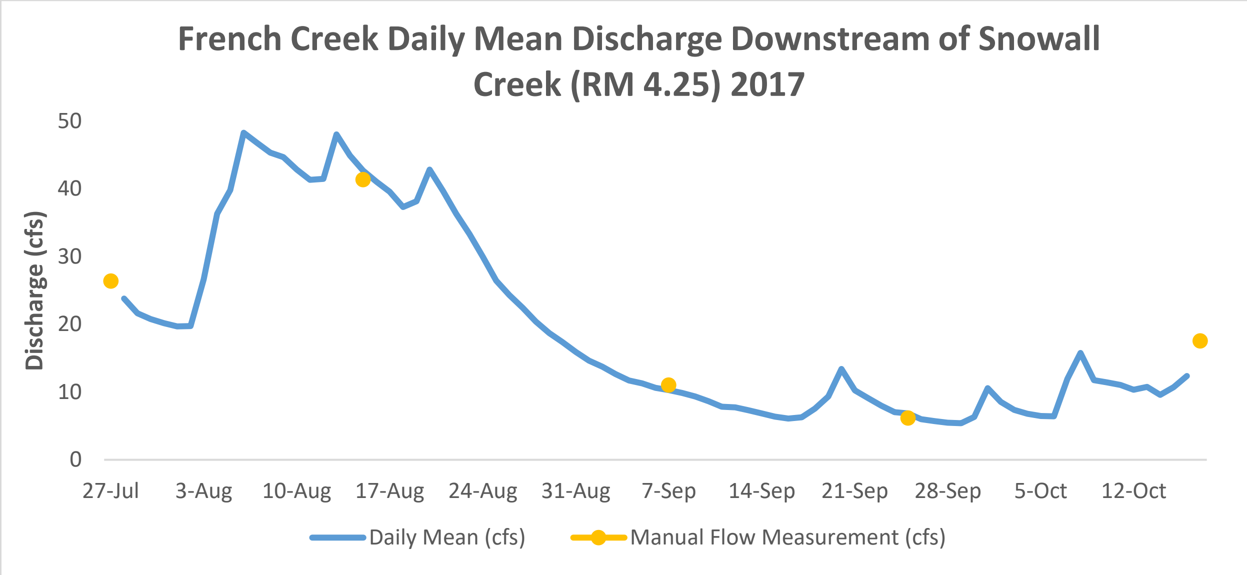

Figure 7. French Creek daily mean discharge hydrograph at RM 4.25. Manual discharge measurements used to develop the rating curve are indicated by yellow dots.

Discharge and flow rate data were provided by Aspect Consulting for augmentation releases from Klonaqua Lake in 2017 (Figure 8). Peak flow releases occurred in the month of August and tapered off into the month of September, with the greatest daily mean volume of water (24.43 cfs) being released on August 13.

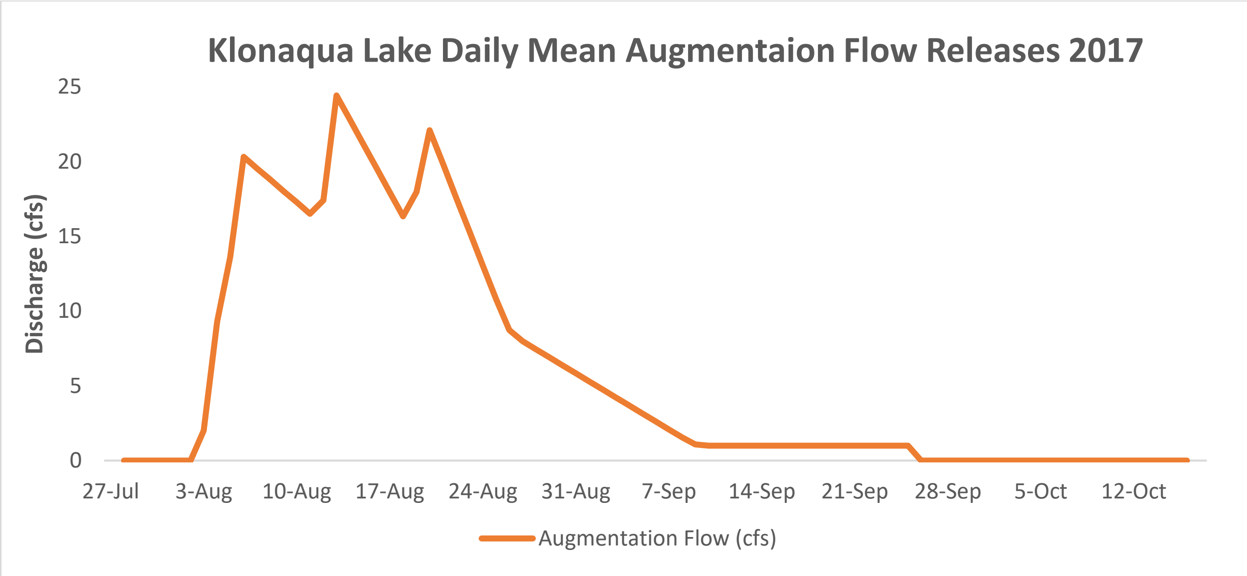

Figure 8. Klonaqua Lake daily mean augmentation flow release hydrograph (data courtesy of Aspect Consulting).

To estimate the natural hydrograph, daily mean augmentation discharge data were deducted from the daily mean discharge data collected at French Creek at RM 4.25 (Figure 9). Essentially, the estimated natural hydrograph is the expected discharge in Leland Creek without augmentation flows. Three hydrographs of daily mean discharge were developed; 1) French Creek at RM 4.25, 2) Klonaqua Lake augmentation flow releases, and 3) an estimated natural hydrograph for French Creek at RM 4.25.

As expected the estimated natural hydrograph follows a typical pattern seen in snowmelt-driven systems in which higher flows in early summer gradually taper off to base flows later in the season as snowpack declines. An estimated natural base flow of around 5.0 cfs was reached mid-September with flow increases occurring due to natural events in late-September to mid-October.

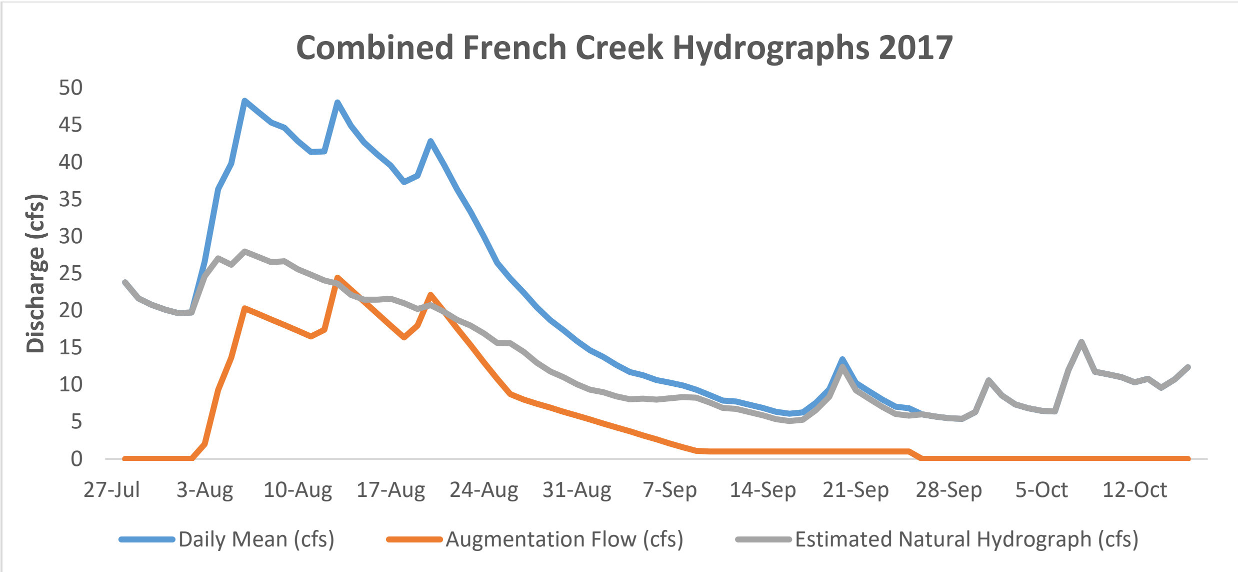

Figure 9. Combined hydrographs for French Creek (RM 4.25), Klonaqua Lake augmentation flow releases, and estimated natural hydrograph for French Creek at RM 4.25.

French Creek Water Temperature

To determine the influence of augmentation flow releases on water temperature in French Creek, water temperature data loggers were deployed within French Creek upstream and downstream of the confluence with Klonaqua Creek, as well as in Klonaqua Creek at RM 0.10. There was an increase in water temperature in French Creek downstream of Klonaqua Creek during the augmentation period (Figure 10). Although there is generally a slight warming trend in French Creek downstream of Klonaqua Creek prior to the augmentation period, the degree of warming is much greater during augmentation.

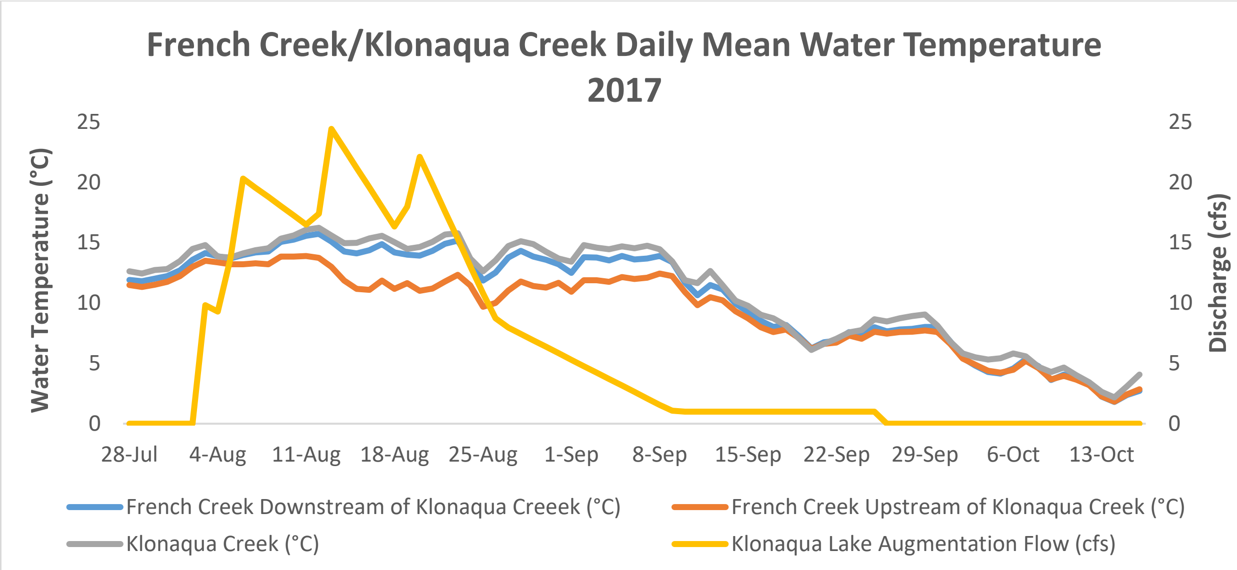

Figure 10. French Creek and Klonaqua Creek daily mean water temperature near confluence. The yellow line indicates the augmentation flow from Klonaqua Lake.

The warming trend observed in French Creek can be explained by an increase in water temperature in Klonaqua Lake during the augmentation period. Lake temperature data (provided by Aspect Consulting) suggests a relationship between lowering of lake levels associated with augmentation releases, and an increase in water temperature (Figure 11). Daily mean water temperature in Klonaqua Lake reached a high of 17.74° C in mid-August during the peak of augmentation releases. Increased water temperature in Klonaqua Lake resulted in a warming trend in French Creek downstream of Klonaqua Creek by more than 3.0° C (daily mean) at times during this period, and daily mean peaks between 15.0° and 16.0° C from August 9 through August 13.

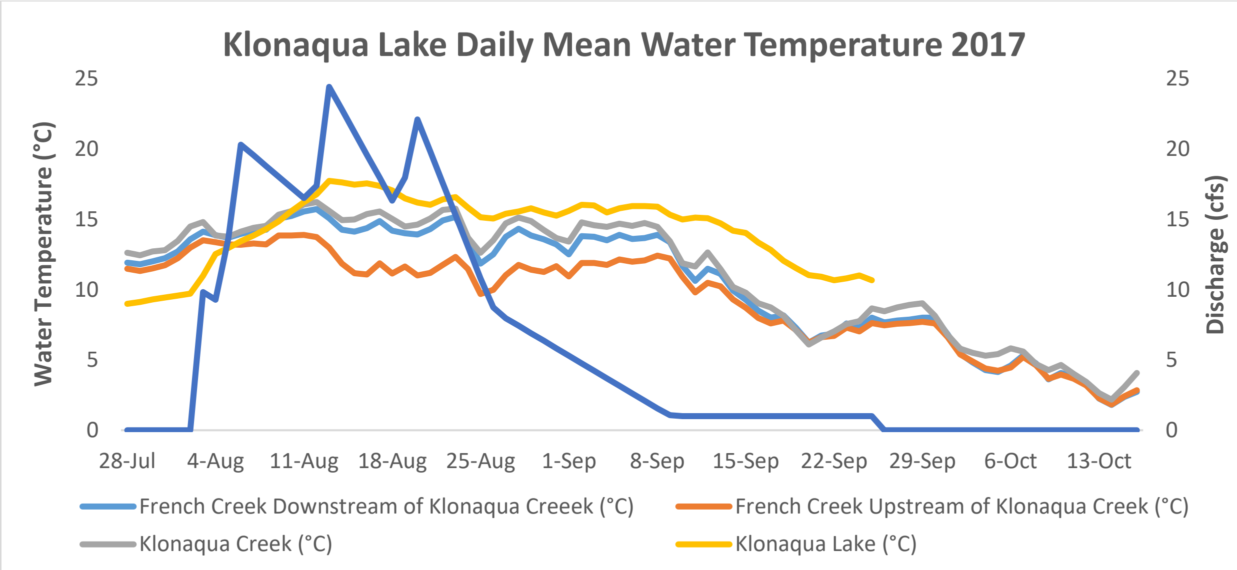

Figure 11. Water temperature of augmentation flow releases from Klonaqua Lake, French Creek, and Klonaqua Creek (lake temperature data courtesy of Aspect Consulting). The blue line indicates the augmentation flow from Klonaqua Lake.

Snowall Creek

Snowall Creek appears to contribute significant flows to French Creek. Manual discharge measurements during the 2017 monitoring period indicated, at times, more than thirty percent of the flow in French Creek at RM 4.25 could be attributed to Snowall Creek (Table 5).

Table 5. Snowall Creek and French Creek manual discharge measurements.

Date	Snowall Creek Discharge Near Mouth (cfs)	French Creek Discharge at RM 4.25 (cfs)	Snowall Creek Percent of French Creek Discharge
07/27/17	8.85	26.37	34
08/15/17	3.76	41.35	9
09/07/17	2.43	11.03	22
09/26/17	1.92	6.16	31
10/17/17	3.83	17.55	22

In addition, Snowall Creek daily mean water temperature was considerably cooler than any of the French Creek temperature monitoring sites (Figure 12). It was thought that Snowall Creek would have had a cooling effect on French Creek, compensating for the warming trend associated with augmentation flows. However, Snowall Creek had very little influence on French Creek water temperature during peak augmentation releases (Figure 12).

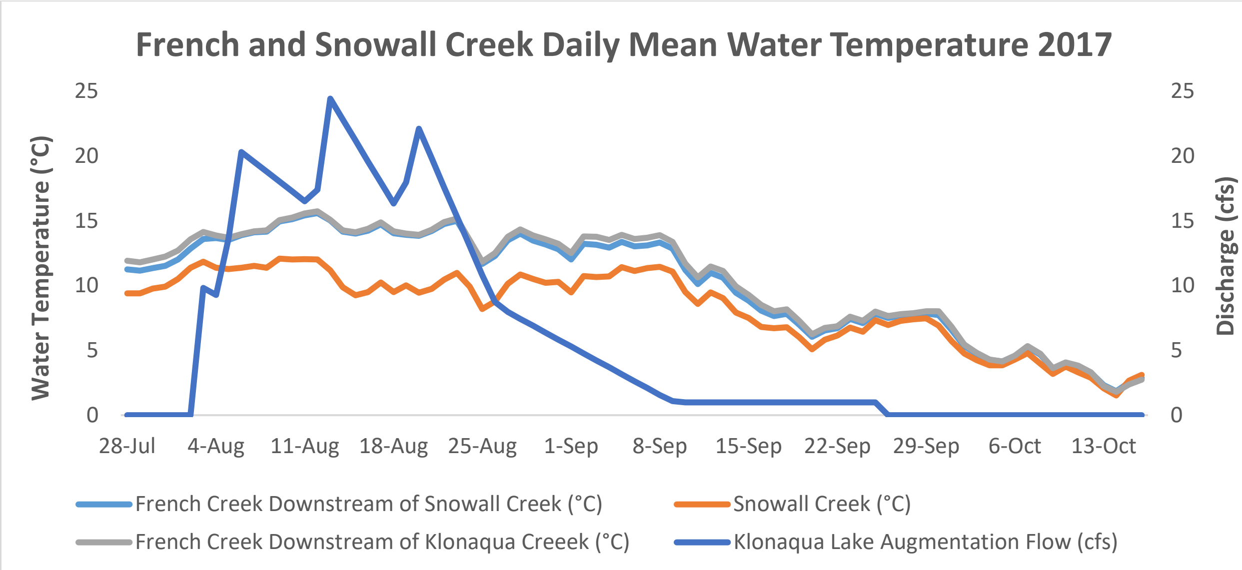

Figure 12. Klonaqua lake augmentation flow, Snowall Creek water temperature, and French Creek water temperature. The blue line indicates the augmentation flow from Klonaqua Lake.

Icicle Creek water temperature was relatively unaffected by augmentation flow releases from Klonaqua Lake (Figure 13). During peak augmentation releases (early-to-late August), water temperature remained relatively consistent among sites with around 1.0° C of variability. Outside of the augmentation period, French Creek generally remained slightly cooler than either Icicle Creek sites.

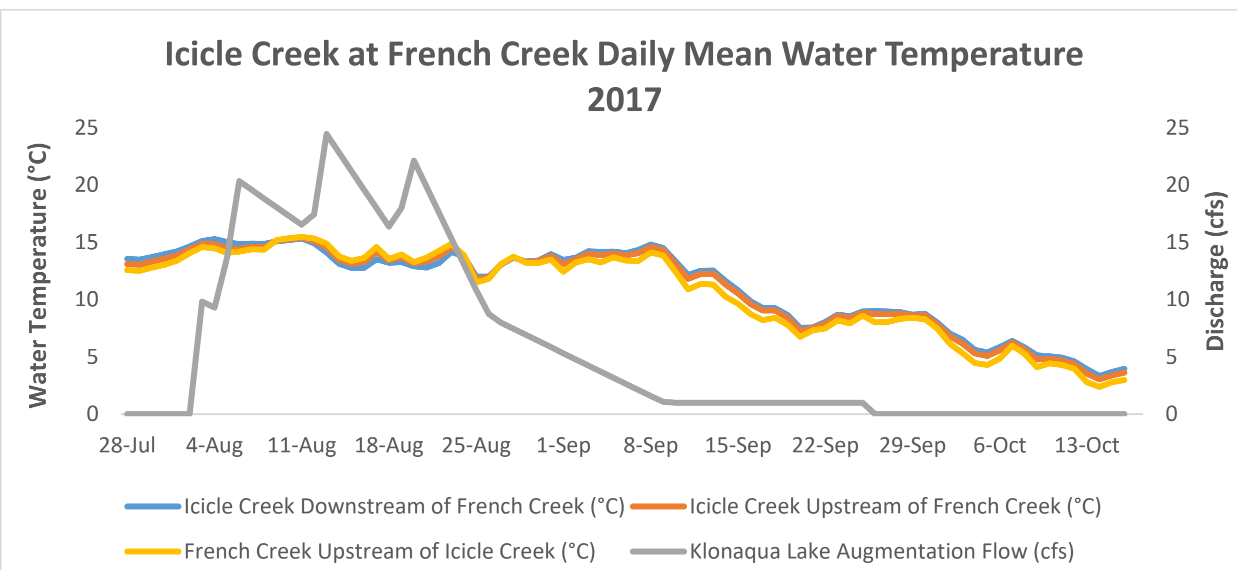

Figure 13. Icicle Creek daily mean water temperature near confluence with French Creek (RM 0.10). The grey line indicates the augmentation flow from Klonaqua Lake.

French Creek Water Chemistry

Water chemistry data collection in the French Creek watershed represents spot measurements of water chemistry and is purely informational at this time (Table 6). Water temperature data was collected in French Creek upstream of Klonaqua Creek on only one occasion (07/27/17), and this was outside of the augmentation period. To detect a change in water chemistry associated with augmentation flow releases, additional data collection is required in French Creek upstream of Klonaqua Creek during augmentation.

Table 6. French Creek watershed water chemistry.

Date	Creek Name	Location	DO (%)	DO (mg/L)	pH	EC (µS)	TDS (ppm)	Salinity (ppm)
07/27/17	French Creek	RM 4.25		11.4	8.00	36.10	25.50	20.60
07/27/17	Snowall Creek	25 meters US of French Creek		11.9	8.22	63.80	45.30	33.20
07/27/17	Klonaqua Creek	RM 0.10		11.2	7.82	22.40	15.90	15.60
07/27/17	French Creek	RM 5.50		10.3	7.78	24.80	17.60	16.10
08/15/17	French Creek	RM 4.25		10.6	7.80	33.80	23.80	20.80
08/15/17	Snowall Creek	25 meters US of French Creek		11.3	8.26	83.50	59.30	43.30
08/15/17	Klonaqua Creek	RM 0.10		9.9	7.72	13.00	9.20	12.10
09/07/17	French Creek	RM 4.25		*8.6	8.00	47.40	33.70	27.20
09/07/17	Snowall Creek	25 meters US of French Creek		10.4	8.36	93.70	66.60	49.50
09/07/17	Klonaqua Creek	RM 0.10		*9.1	7.54	18.60	13.20	14.60
09/26/17	French Creek	RM 4.25	84.5	10.1	8.02	65.50	46.60	33.60
09/26/17	Snowall Creek	25 meters US of French Creek	89.2	10.8	8.46	102.00	72.50	51.20
09/26/17	Klonaqua Creek	RM 0.10	88.3	10.4	7.99	33.80	24.00	18.40
10/17/17	French Creek	RM 4.25	91.7	11.5	6.99	51.80	36.70	23.70
10/17/17	Snowall Creek	25 meters US of French Creek	94.3	11.9	7.33	86.70	61.40	39.10
10/17/17	Klonaqua Creek	RM 0.10	88.5	11.1	6.60	39.70	28.20	18.60

*****Relatively low values are likely attributable to an un-calibrated dissolved oxygen meter.

Leland Creek Discharge

Continuous discharge data was collected for Leland Creek (RM 0.10) from July 25 through October 18, 2017 (Figure 14). The peaks in the hydrograph in the month of August through mid-September are associated with valve adjustments for augmentation flow releases from Square Lake. Peak daily mean flow occurred on August 22 at 36.98 cfs when approximately 32.28 cfs (daily mean) of augmentation flow was released from Square Lake. The first valve adjustment occurred on August 6, 2017, with additional adjustments occurring periodically through the latter part of September. The receding limbs of the hydrograph between peaks are associated with a drop in lake levels and head pressure between valve adjustments. Peaks in the hydrograph in the latter part of September and during October are associated with natural events and not augmentation releases.

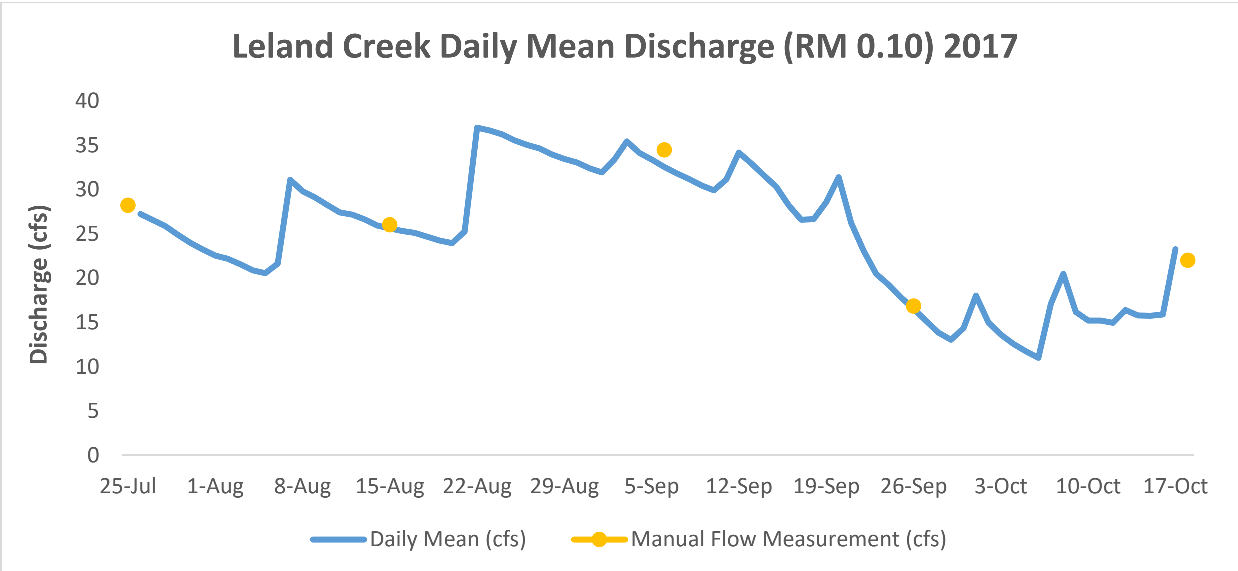

Figure 14. Leland Creek daily mean discharge hydrograph at RM 0.10. Manual discharge measurements used to develop the rating curve are indicated by yellow dots.

Discharge and flow rate data were provided by Aspect Consulting for augmentation releases from Square Lake in 2017 (Figure 15). Peak flow releases occurred during the latter part of August through mid-September, with the greatest daily mean volume of water (approximately 33.6 cfs) being released on September 3.

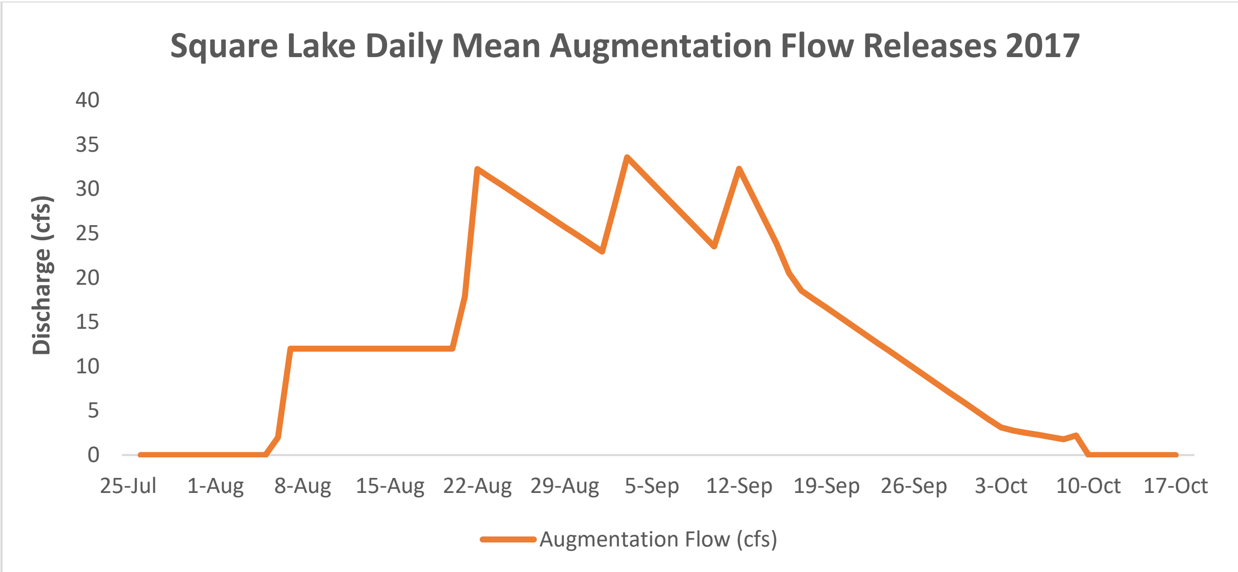

Figure 15. Square Lake daily mean augmentation flow release hydrograph (data courtesy of Aspect Consulting).

To estimate the natural hydrograph, augmentation discharge data from Square Lake were deducted from the discharge data collected at Leland Creek at RM 0.10 (Figure 16). The estimated hydrograph is the expected discharge in Leland Creek without augmentation flows. Three hydrographs of daily mean discharge were developed; 1) Leland Creek at RM 0.10, 2) Square Lake augmentation flow releases, and 3) an estimated natural hydrograph for Leland Creek at RM 0.10.

Unlike French Creek, deducting the augmentation discharge data from the Leland Creek discharge data did not produce a hydrograph representative of what is expected under natural conditions. Review of the hydrographs, and the discharge data used to develop them indicates a delay in travel time of augmentation flow from Square Lake to lower Leland Creek. A probable explanation for this is the presence of side channels and wetlands in Prospect and Leland Creek that increased retention time for the augmentation flow before it reached the downstream data logger at RM 0.10. Based on manual field measurements and known augmentation releases from Square Lake, a reasonable estimate of a natural base flow in Leland is 6 to 7 cfs occurring mid-to-late September. A manual discharge measurement on September 26 indicated 16.81 cfs in lower Leland Creek. On that date approximately 9.83 cfs (daily mean) of augmentation flow was being delivered from Square Lake, which equates to an estimated 6.98 cfs of natural flow.

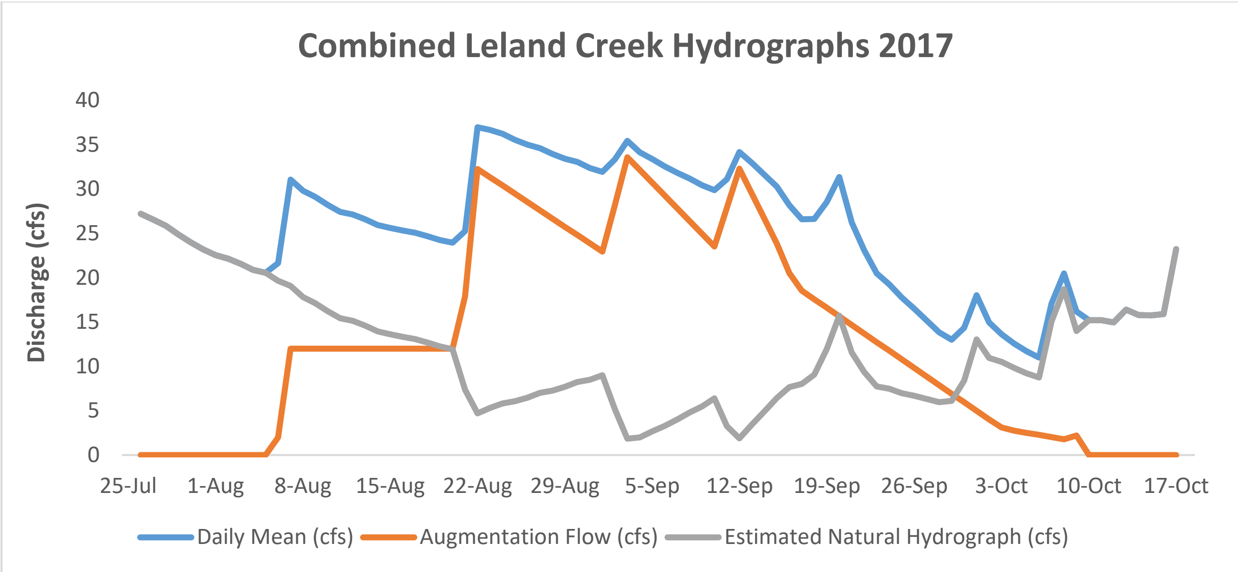

Figure 16. Combined daily mean hydrographs for Leland Creek (RM 0.10), Square Lake augmentation flow releases, and estimated natural hydrograph for Leland Creek at RM 0.10.

Leland Creek Water Temperature

To determine the influence of augmentation flow releases from Square Lake on Leland Creek water temperature, data loggers were deployed in Leland Creek upstream and downstream of the confluence with Prospect Creek, as well as in Prospect Creek at RM 0.20. There was an initial decrease in water temperature in Leland Creek downstream of Prospect Creek when approximately 12 cfs of augmentation flow was released from Square Lake on August 6 (Figure 17). Following this brief period of cooling, water temperature in Leland Creek increased considerably when augmentation flow was increased to approximately 32 cfs on August 22. This trend continued until late-September when augmentation flow began to diminish.

Although there appears to be a slight natural warming trend in Leland Creek downstream of Prospect Creek prior to the augmentation period, the degree of warming is much greater during peak augmentation. Water temperature data for Leland Creek downstream of Prospect Creek indicate an increase in water temperature (daily mean), at times, approaching 5.0° C during peak augmentation. On September 7, Leland Creek water temperature upstream of Prospect Creek was 10.78° C, while downstream at RM 0.10 the daily mean water temperature was 15.51° C.

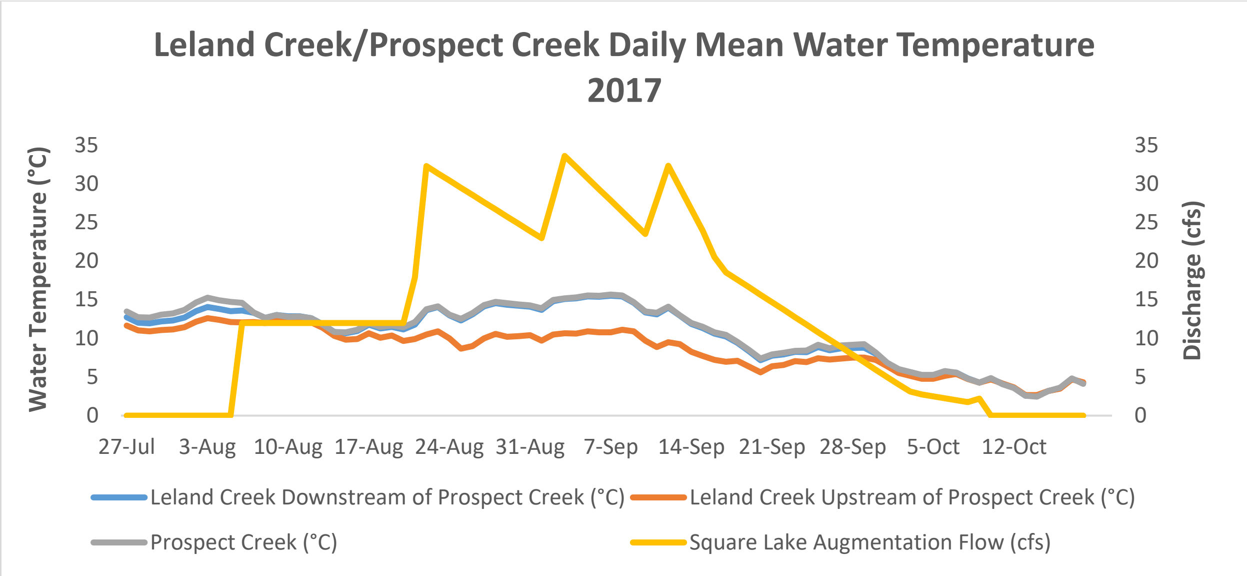

Figure 17. Square Lake augmentation flow, Leland Creek water temperature, and Prospect Creek water temperature near confluence.

Square Lake water temperature data (provided by Aspect Consulting) suggests there are questions remaining about the warming trend observed in Leland Creek during the augmentation period. Lake water temperatures were considerably cooler than either creek throughout much of the augmentation period (Figure 18). The large difference in water temperature readings between Square Lake, and Prospect and Leland creeks may be explained by the location of the temperature logger relative to the outflow of the lake.

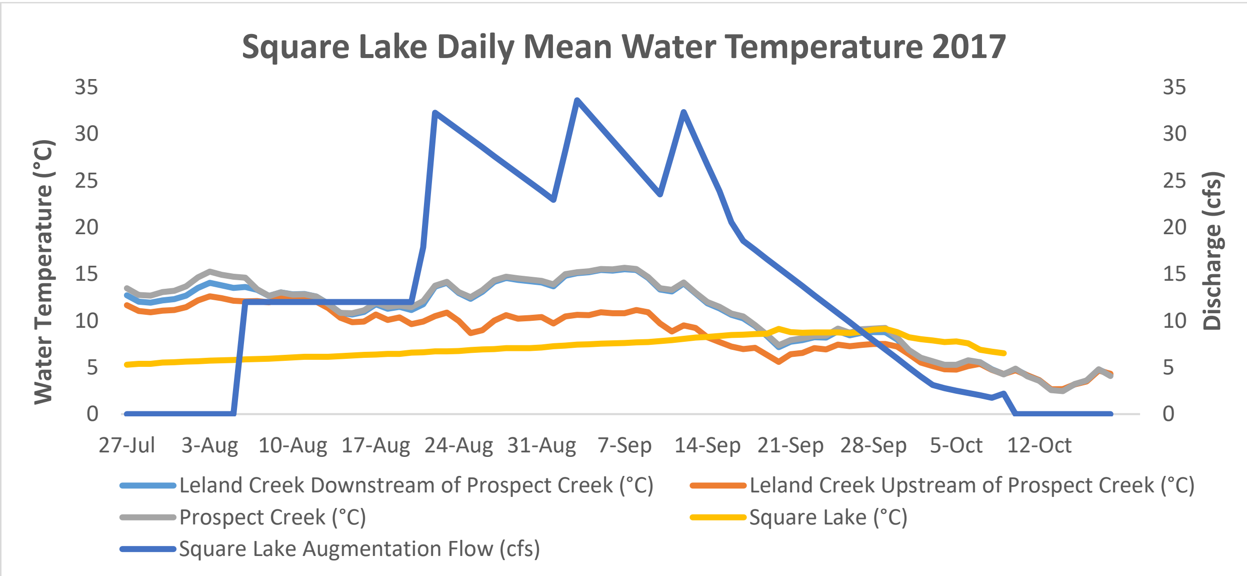

Figure 18. Augmentation flow releases from Square Lake, Leland Creek water temperature, and Prospect Creek water temperature (lake temperature data courtesy of Aspect Consulting).

Icicle Creek water temperature was relatively unaffected by augmentation releases from Square Lake, other than some initial cooling during the first two weeks of augmentation as seen in Leland Creek (Figure 19). During peak augmentation releases (late-August through mid-September), water temperature in Icicle Creek and Leland Creek remained relatively consistent among sites with around 1.0° C of variability. Near the end of the augmentation period water temperature appeared to equilibrate between sites.

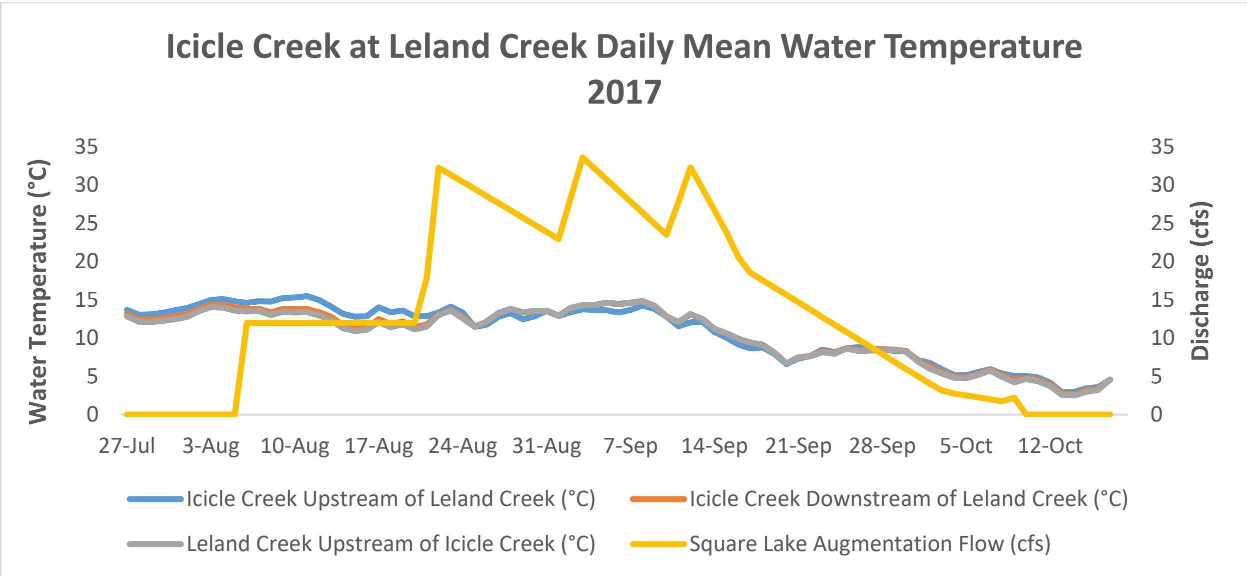

Figure 19. Icicle Creek daily mean water temperature near confluence with Leland Creek. The yellow line indicates the augmentation flow from Square Lake.

Leland Creek Water Chemistry

Water chemistry data collected in the Leland Creek watershed represents spot measurements of water chemistry and is purely informational at this time (Table 7). Water chemistry data was collected in Prospect Creek, and Leland Creek upstream of Prospect on only two dates (07/25/17 and 10/18/17), both of which were outside of the augmentation period. Additional data collection is required to perform an in-depth analysis of the effects of augmentation flow releases from Square Lake on Leland Creek water chemistry.

Table 7. Leland Creek watershed water chemistry.

Date	Creek Name	Location	DO (%)	DO (mg/L)	pH	EC (µS)	TDS (ppm)	Salinity (ppm)
07/25/17	Leland Creek	RM 0.10		11.0	8.50	33.70	23.90	21.40
07/25/17	Leland Creek	RM 1.60		9.5	7.96	37.10	26.30	22.60
07/25/17	Prospect Creek	RM 0.20		9.6	7.69	21.70	15.50	16.10
08/15/17	Leland Creek	RM 0.10	91.2	10.2	7.94	35.30	25.10	19.20
09/06/17	Leland Creek	RM 0.10		10.0	8.05	28.00	19.80	19.10
09/26/17	Leland Creek	RM 0.10		n/a	7.21	37.70	26.70	18.90
10/18/17	Leland Creek	RM 0.10		12.8	8.24	37.70	26.70	17.70
10/18/17	Leland Creek	RM 1.60		12.8	8.47	39.30	27.80	18.40
10/18/17	Prospect Creek	RM 0.20		12.4	9.68	32.90	22.80	14.90

Icicle Creek at confluence with Leland Creek

Additional measurements were obtained on Icicle Creek upstream of the confluence with Leland Creek that were not included in the initial monitoring strategy, but were collected out of relative convenience when accessing Leland (Table 8). Of particular interest is that this reach of Icicle Creek experienced extremely low flows from mid-August through late-September in 2017. On September 6 a manual flow measurement indicated less the 3.0 cfs in this reach of Icicle Creek. On the same date Leland Creek was contributing 34.47 cfs to Icicle Creek downstream of this site, with approximately 29.27 cfs (daily mean) of that value being attributed to augmentation flow from Square Lake.

Table 8. Icicle Creek discharge and water chemistry data summary upstream of confluence with Leland Creek.

Icicle Creek (upstream of Leland Creek) Discharge and Water Chemistry Data 2017							
Date	Discharge (cfs)	Water Temperature (°C)	DO (mg/L)	pH	EC (µS)	TDS (ppm)	Salinity (ppm)
07/26/17	10.32	11.3	8.9	8.00	25.30	17.90	16.00
08/15/17	4.77	11.2	10.1	8.00	30.40	21.70	17.50
09/06/17	2.87	13.8	9.7	8.00	33.70	23.90	21.10
09/26/17	3.73	9.0	n/a	7.70	34.40	24.40	18.10
10/18/17	25.64	4.4	12.6	8.62	26.70	18.80	11.90

Discussion

French Creek

Discharge from Klonaqua Lake augmentation releases, and French Creek were used to develop an estimated natural hydrograph. There may be some imprecision with volume of flow, but the general shape of the estimated hydrograph appears to follow a pattern expected in a naturally functioning snowmelt-driven system. Some general suggestions can be made of how lake releases might be managed in the future.

Sharp increases and rapid declines in the hydrograph associated with augmentation releases drove conditions away from what is expected to be a normative hydrograph, particularly in the month of August. During peak augmentation releases the estimated natural discharge was as much as doubled. This creates the potential for side channels and wetlands to be watered and subsequently dewatered as flows rapidly decline. Fish that move into these habitats may be at risk of being isolated from the main channel with the erratic behavior in the hydrograph. Augmentation releases that mimic the natural hydrograph are preferable, and may allow fish to move volitionally to and from these habitats.

An increase in water temperature in French Creek downstream of Klonaqua Creek appears to be associated with lowering of lake levels during the augmentation period. Klonaqua Lake water temperature increased dramatically during the peak of augmentation releases. This resulted in a temperature increase in French Creek downstream of Klonaqua Creek of more than 3.0° C (daily mean) at times, with daily mean peaks reaching as high as 15.7° C. Bull trout require water temperatures of less than 15.0° C (59.0° F) for rearing, and less than 9.0° C (48.0° F) for spawning (Wydoski and Whitney 2003). Future augmentation efforts will, ideally, maintain water temperatures that are well within the requirements for all bull trout life stages and not disrupt the natural temperature regime. While a temperature increase in French Creek was observed, augmentation flows appear to have had little effect on Icicle Creek water temperature at the monitoring sites.

Spot measurements of water chemistry in French Creek indicated DO and pH were maintained at levels within the tolerable range of salmonids during the augmentation period. Ideal DO levels are greater than 11 ppm (or mg/L) year-round and become lethal at levels less than 6 ppm, while the ideal range for pH is between 6.0 and 8.5 (Kidd 2011). However, with a warming trend such as seen in French Creek during augmentation, there is potential for DO levels to drop with increased water temperature. Additional data are needed to detect a change in water chemistry associated with augmentation flows, and routine water chemistry monitoring should be conducted during future augmentation releases to ensure any changes are minimal.

Leland Creek

An attempt to derive a hydrograph representing natural conditions for Leland Creek using the available discharge data was unsuccessful. However, the discharge data obtained for Square Lake augmentation releases, and lower Leland Creek provide insight into how this system functions hydrologically. There was clearly a delay in the timing of flow from the point of release at Square Lake to lower Leland Creek that can likely be explained by the presence of side channels and wetlands that increase the retention period of augmentation flows. Similar to observations in French Creek, sharp increases and rapid declines in the hydrograph associated with valve adjustments and lowering lake levels resulted in erratic flow and water level changes that may be detrimental to fish. Managing flow releases to better mimic a natural hydrograph may be a better option, and allow movement of fish freely to and from side channel habitats that can become isolated as flows decline. This may be more complex in Leland Creek as there are still questions remaining about travel time of augmentation flows and a natural hydrograph.

While Square Lake water temperature remained significantly cooler than either Leland Creek or Prospect Creek throughout much of the augmentation period, Leland Creek water temperature downstream of Prospect Creek increased by nearly 5.0° C (daily mean) at times during peak augmentation. It is possible that the water temperature logger in Square Lake was at a different depth relative to the of outflow of Square Lake resulting in temperature readings much lower than observed in Prospect and Leland creeks. Further evaluation is needed to determine the source of this warming trend and how this increase might be mitigated in the event augmentation continues in the future. As with French Creek, maintaining a water temperature regime in the Leland Creek watershed that is within the requirements for bull trout is of the utmost importance during any future augmentation efforts. The observed water temperature increase in Leland Creek associated with augmentation flows appeared to have little influence on Icicle Creek at monitoring sites near the confluence of the two creeks.

Spot measurements of water chemistry collected in the Leland Creek were limited to site visits at RM 0.10 during the augmentation period. Additional data is needed in Prospect Creek, and Leland upstream of Prospect to detect potential changes in water chemistry associated with augmentation flows. However, the water chemistry data collected indicates DO and pH levels remained within the tolerable range for salmonids. As with French Creek, water chemistry should be routinely monitored during future augmentation efforts to ensure levels remain within the tolerable range for bull trout.

References

(Kidd) Holmen, S.A., R. Beaston, and J. St. Pierre. 2011. Scappoose bay watershed water quality monitoring report 2008-2010. Scappoose Bay Watershed Council Water Quality Report June 2011, Warren, OR. www.scappoosebay-wc.org

Wydoski, R. S., and R. R. Whitney. 2003. Inland Fishes of Washington. 2nd ed. American Fisheries Society and University of Washington Press, Seattle, Washington, pp. 94-97.

APPENDIX B

LiDAR Technical Data Report, Alpine Lake, Washington

December 2, 2016

Alpine Lakes, Washington

LiDAR Technical Data Report

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Table of Contents

Cover Photo: A view looking south at Colchuck Lake in the North Cascades. The image was created from the LiDAR bare earth model overlaid with the LiDAR point cloud and colored by NAIP imagery.

INTRODUCTION

This photo taken by QSI acquisition staff shows a view of Snow Lake within the Alpine Lakes Area of Interest.

In July 2016, Quantum Spatial (QSI) was contracted by Aspect Consulting to collect Light Detection and Ranging (LiDAR) data in the fall of 2016 for four areas of interest (AOIs)comprising the Alpine Lakes project area in Washington State. Data were collected to aid Aspect Consulting in assessing the topographic and geophysical properties of the study area to support the Alpine Lakes Optimization and Automation Appraisal Study.

This report accompanies the delivered LiDAR data and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including LiDAR accuracy and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to Aspect Consulting is shown in Table 2, and the project extent is shown in Figure 1.

Table 1: Acquisition dates, acreage, and data types collected on the Alpine Lakes, Washington site

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Alpine Lakes, Washington	1,500	2,022	10/19/2016	LiDAR

Deliverable Products

Table 2: Products delivered to Aspect Consulting for the Alpine Lakes, Washington site

Alpine Lakes Products Projection: Washington State Plane North – FIPS Zone 4601 Horizontal Datum: NAD83(HARN) Vertical Datum: NAVD88 (GEOID09) Units: U.S. Survey Feet	
Points	LAS v 1.2 • All Classified Returns (Ground, Default, Water)
Rasters	3.0 Foot ESRI Grids • Bare Earth Model • Highest Hit Model
Vectors	Shapefiles (*.shp) • Project Boundary • LiDAR Tile Index • Total Area Flown Shape • Water's Edge Polygon Drawing Files (*.dwg) • Contours (2 ft)

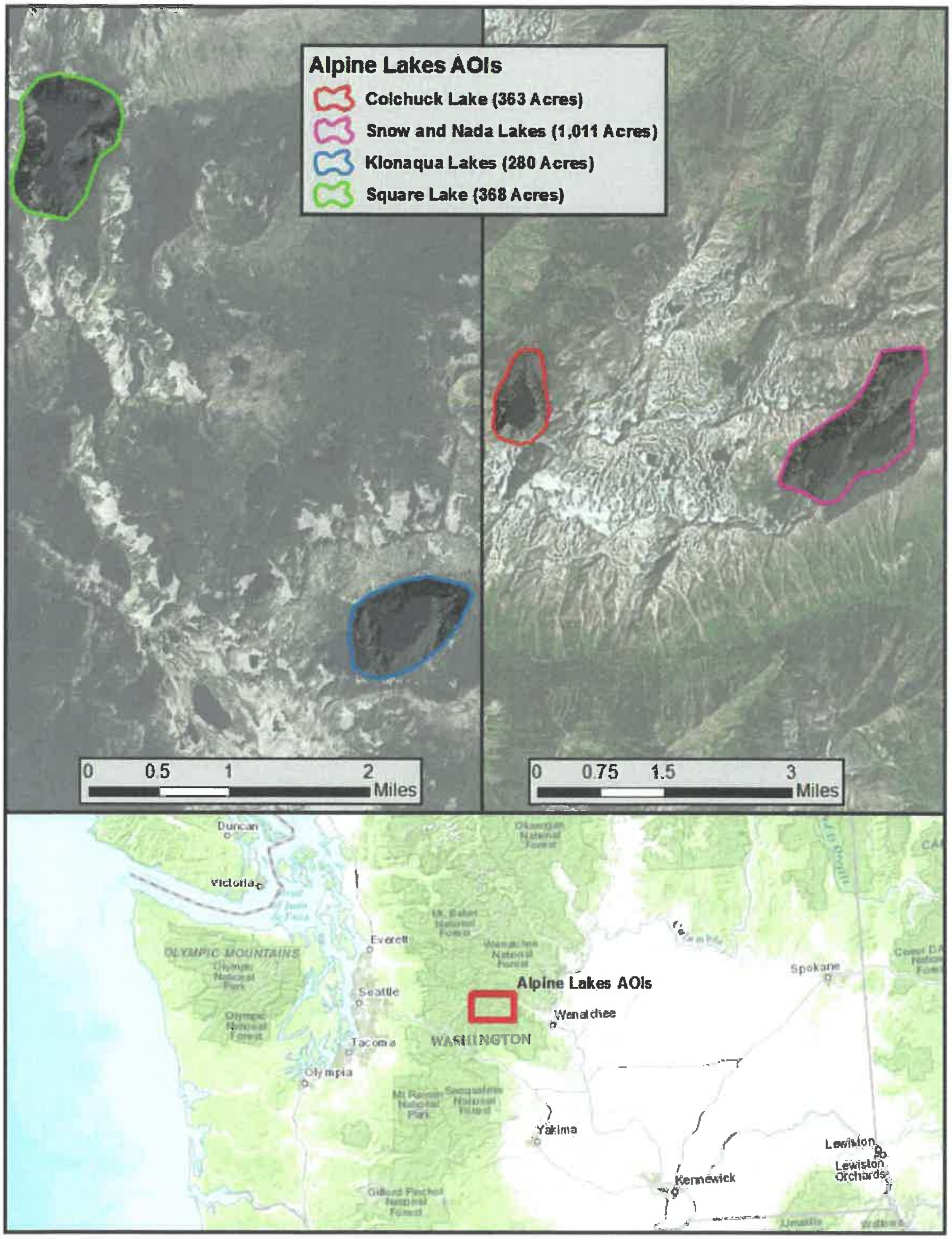

Figure 1: Location map of the Alpine Lakes site in Washington State

QSI's Cessna Caravan

Planning

In preparation for data collection, QSI reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Alpine Lakes LiDAR study area at the target point density of ≥8.0 points/m^2 (0.74 points/ft^2). Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. The survey was not conducted until late October when lakes were in full drawdown, yet before the onset of snow in the project area. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including ground survey access to the remote location, and potential air space restrictions were reviewed. Due to the extremely remote nature of the project site, QSI utilized WSRN[1] CORS station QMAR in combination with one newly established monument to achieve 13 nautical mile GPS baselines.

[1]Washington State Reference Network http://www.wsrn3.org/

Airborne LiDAR Survey

The LiDAR survey was accomplished using a Leica ALS80 system mounted in a Cessna Caravan. Table 3 summarizes the settings used to yield an average pulse density of ≥8 pulses/m^2 over the Alpine Lakes project area. The Leica ALS80 laser system can record unlimited range measurements (returns) per pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation, water, or snow) to return fewer pulses to the LiDAR sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset.

Table 3: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications	
Acquisition Dates	October 19, 2016
Aircraft Used	Cessna Caravan
Sensor	Leica ALS80
Survey Altitude (AGL)	1600 m
Swath Width	857 m
Target Pulse Rate	142.8 - 346.6 kHz
Pulse Mode	Multiple Pulses in Air (MPiA)
Laser Pulse Diameter	35 cm
Mirror Scan Rate	52.0 Hz
Field of View	40°
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Maximum Returns	Unlimited
Intensity	8-bit, scaled to 16-bit
Resolution/Density	Average 8 pulses/m^2
Accuracy	$RMSE_Z \leq 15$ cm

Leica ALS80 LiDAR sensor

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

Ground Control


QSI-Established Monument

Ground control surveys, including monumentation and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK) survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized one existing CORS station and established one new monument for the Alpine Lakes, Washington LiDAR project (Table 4, Figure 2). New monumentation was set using 5/8" x 30" rebar topped with stamped 2 ½ " aluminum caps. QSI's professional land surveyor, Evon Silvia (WAPLS#53957) oversaw and certified the establishment of all monuments.

Table 4: Monuments established for the Alpine Lakes, Washington acquisition. Coordinates are on the NAD83 (HARN) datum.

Monument ID	Latitude	Longitude	Ellipsoid (meters)
ALPINE_01	47° 28' 33.92814"	-120° 39' 18.63201"	501.273
WSRN CORS Station QMAR	47° 46' 30.34411"	-120° 57' 55.97402"	812.470

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS[2]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[3] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 5.

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[2] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions. http://www.ngs.noaa.gov/OPUS.

[3] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Table 5: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.020 m
1.96 * St Dev $_{z}$:	0.020 m

For the Alpine Lakes, Washington LiDAR project, the monument coordinates contributed no more than 2.8 cm of positional error to the geolocation of the final ground survey points and LiDAR, with 95% confidence.

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic (RTK) survey techniques. A Trimble R7 base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving Trimble R6 GNSS receiver. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK data, the rover records data while stationary for five seconds, then calculates the pseudorange position using at least three one-second epochs. Relative errors for any GSP position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Table 6 for Trimble unit specifications.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area (Figure 2).

Table 6: Trimble equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6 GNSS	Integrated GNSS Antenna R6	TRMR6	Rover
Trimble R7	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static

Lack of access and the remote nature of the project area prevented GSP collection within the project area of interest. GSPs were recorded in a nearby area meeting the requirements described above (Figure 2), and the LiDAR acquisition was adjusted to include coverage of that area. Because adjustments to ground control are generally consistent within a single mission, these GSPs could be used to vertically control the LiDAR despite being outside the project area of interest.

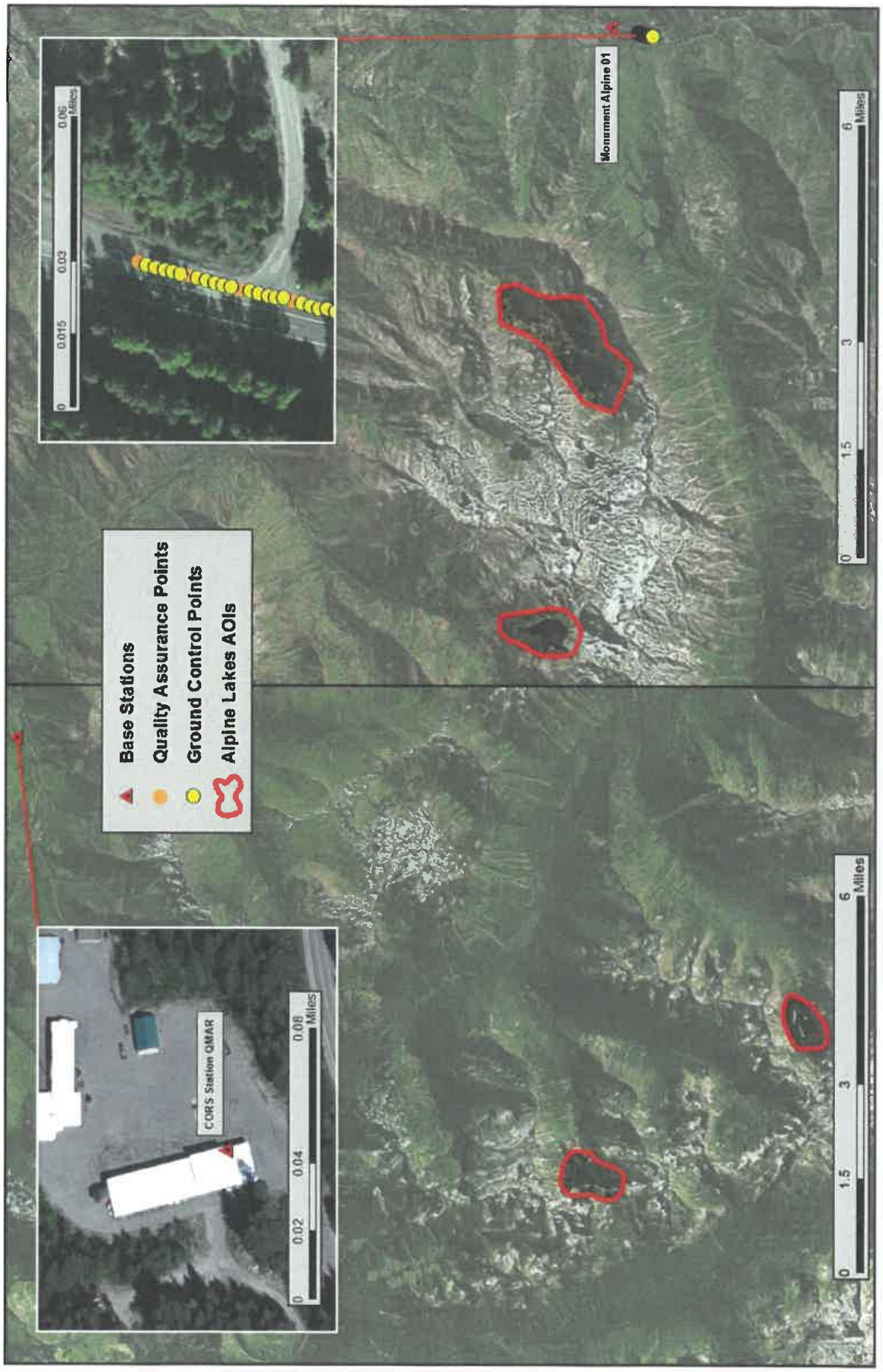
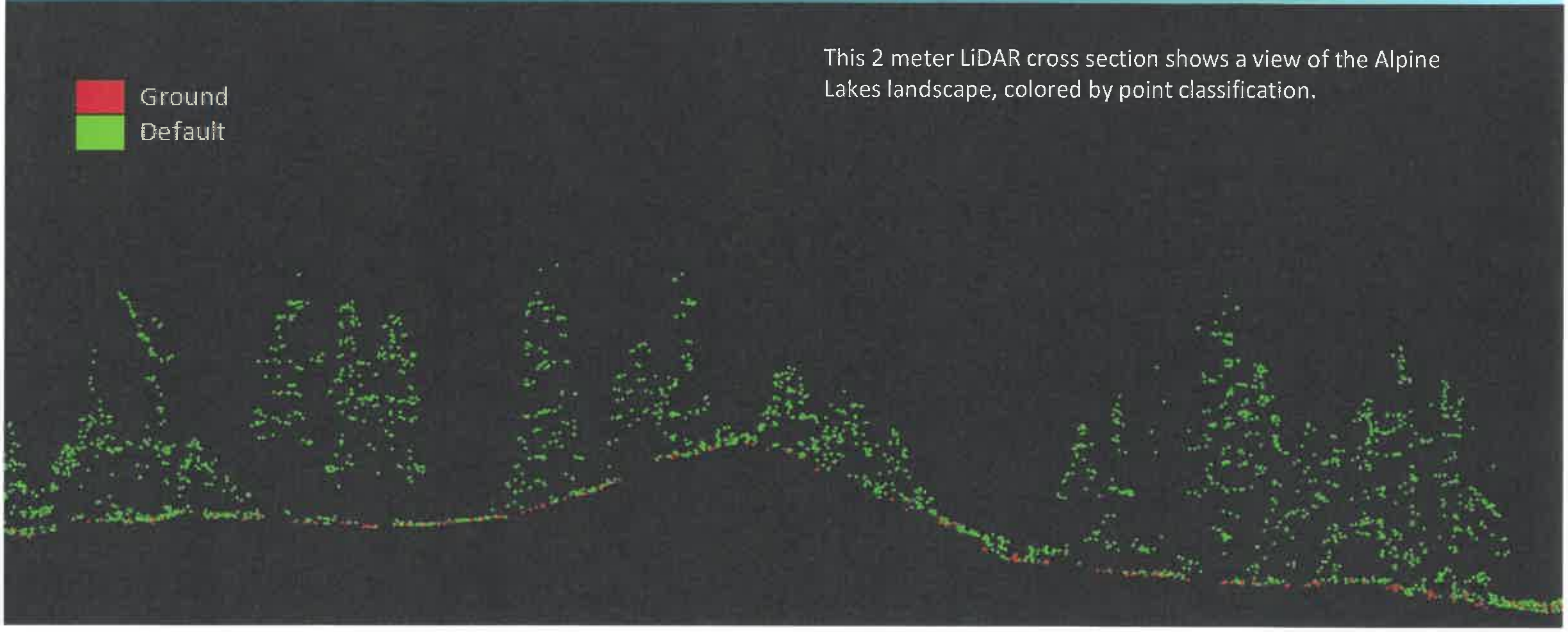


Figure 2 : Ground Survey Location Map



LiDAR Data

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and LiDAR point classification (Table 7). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 8.

Table 7: ASPRS LAS classification standards applied to the Alpine Lakes, Washington dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
9	Water	Laser returns that are determined to be water using automated and manual algorithms

Table 8: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Waypoint Inertial Explorer v.8.6
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Convert data to orthometric elevations by applying a geoid correction.	Waypoint Inertial Explorer v.8.6 Leica Cloudpro v. 1.2.2
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.16
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.16
Classify resulting data to ground and other client designated ASPRS classifications (Table 7). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.16 TerraModeler v.16
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models as ESRI GRIDs format at a 3.0 foot pixel resolution.	TerraScan v.16 TerraModeler v.16 ArcMap v. 10.2

Feature Extraction

Contours

Contour generation from LiDAR point data required a thinning operation in order to reduce contour sinuosity. The thinning operation reduced point density where topographic change is minimal (i.e., flat surfaces) while preserving resolution where topographic change was present. Contour key points were selected from the ground model every 20 feet with the spacing decreased in regions with high surface curvature. Generation of contour key points eliminated redundant detail in terrain representation, particularly in areas of low relief, and provided for a more manageable dataset. Contours were produced through TerraModeler by interpolating between the contour key points at even elevation increments.

Elevation contour lines were then intersected with ground point density rasters and a confidence field was added to each contour line. Contours which crossed areas of high ground point density have high confidence levels, while contours which crossed areas of low ground point density have low confidence levels. Areas with low ground point density are commonly beneath buildings and bridges, in locations with dense vegetation, over water, and in other areas where laser penetration to the ground surface was impeded (Figure 3). Special care was taken to exclude false contours triangulating across lakes within the project area. Water's edge breaklines were drawn to enforce contour generation up to the water's edge, as well as to classify water within the LiDAR point cloud.

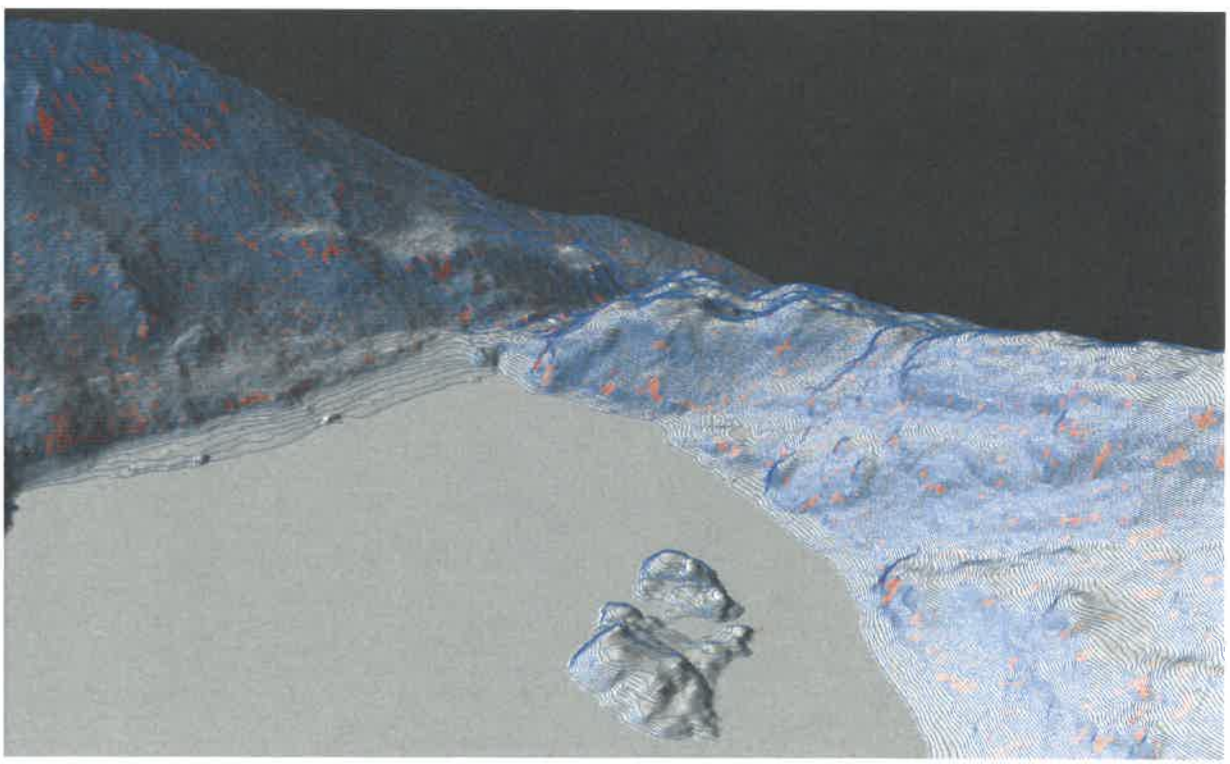
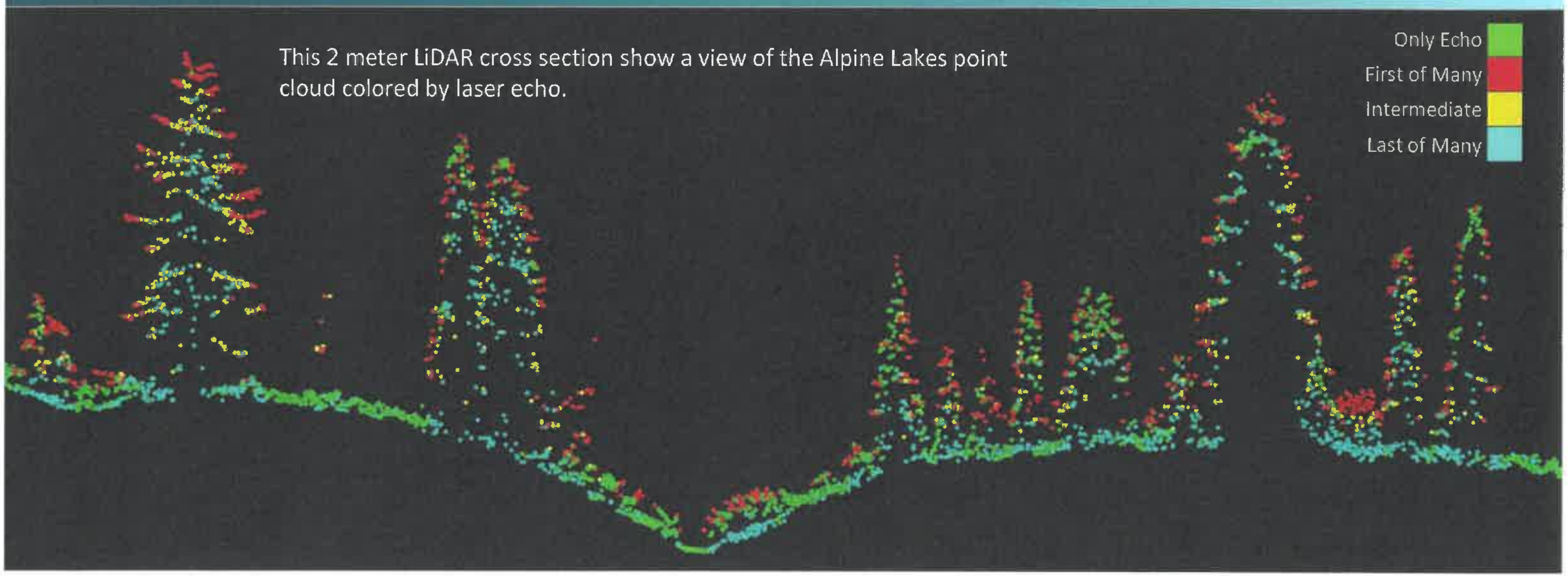


Figure 3: Contours draped over the Alpine Lakes, Washington bare earth elevation model. Blue contours represent high confidence while the red contours represent low confidence.



LiDAR Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m^2 (0.74 points/ft^2). First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser. First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The density of ground-classified LiDAR returns was also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may penetrate the canopy, resulting in lower ground density.

The average first-return point density value of LiDAR data for the Alpine Lakes project was 1.16 points/ft^2 (12.52 points/m^2) while the average ground classified point density value was 0.18 points/ft^2 (1.98 points/m^2) (Table 9). The statistical and spatial distributions of first return densities and ground classified return densities per 100 m x 100 m cell are portrayed in Figure 4 through Figure 7.

Table 9: Average LiDAR point densities

Classification	Point Density
First-Return	1.16 points/ft^2 12.52 points/m^2
Ground Classified	0.18 points/ft^2 1.98 points/m^2

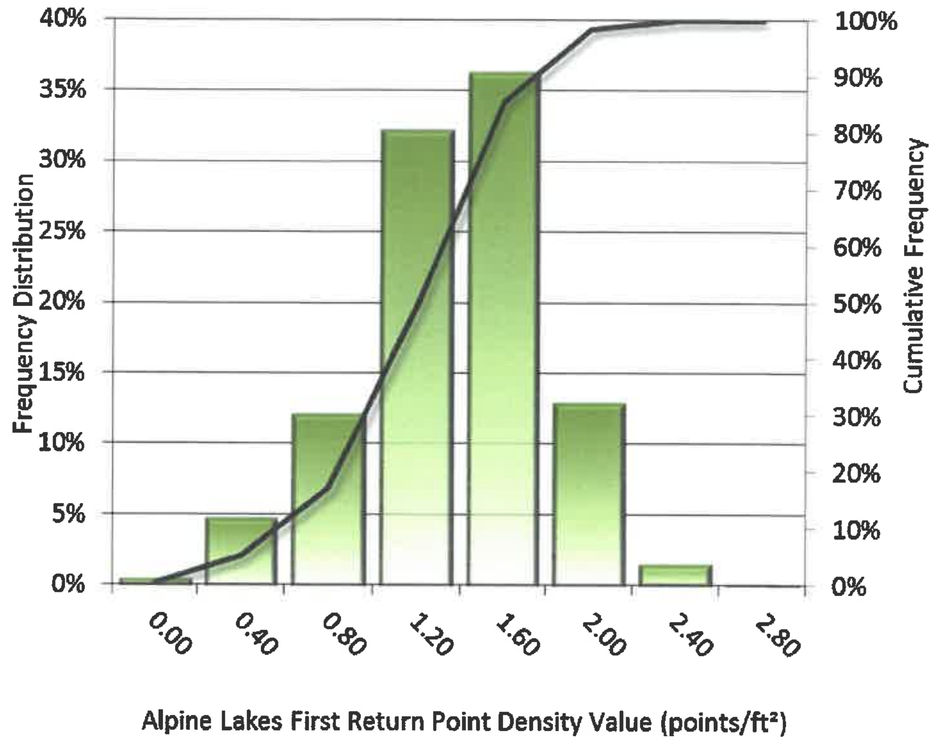


Figure 4: Frequency distribution of first return point density values per 100 x 100 m cell

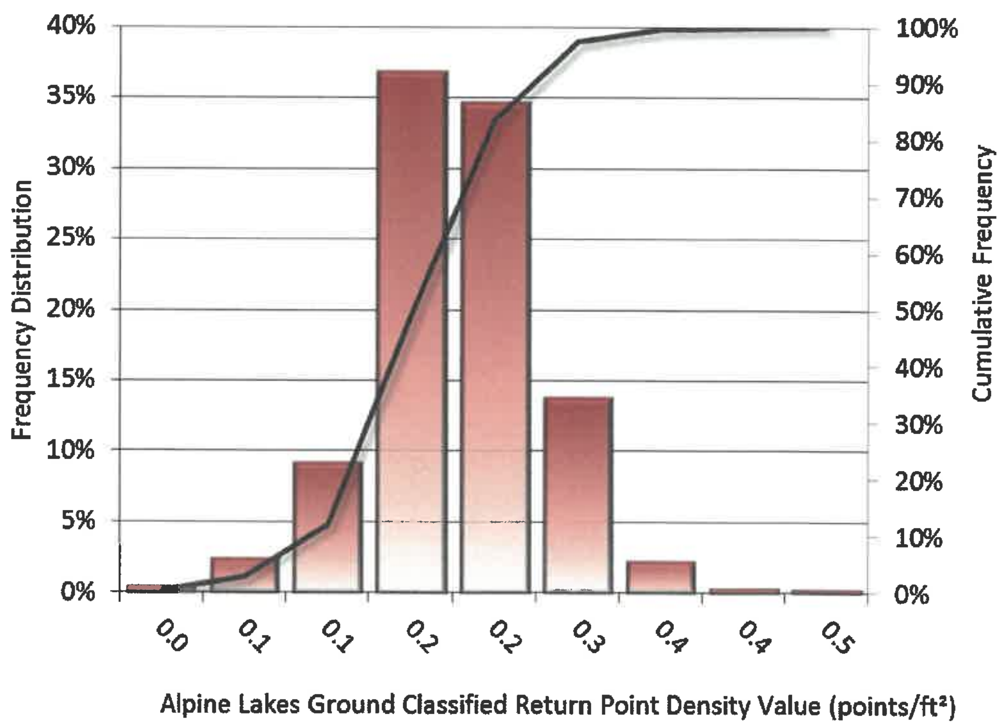


Figure 5: Frequency distribution of ground-classified return point density values per 100 x 100 m cell

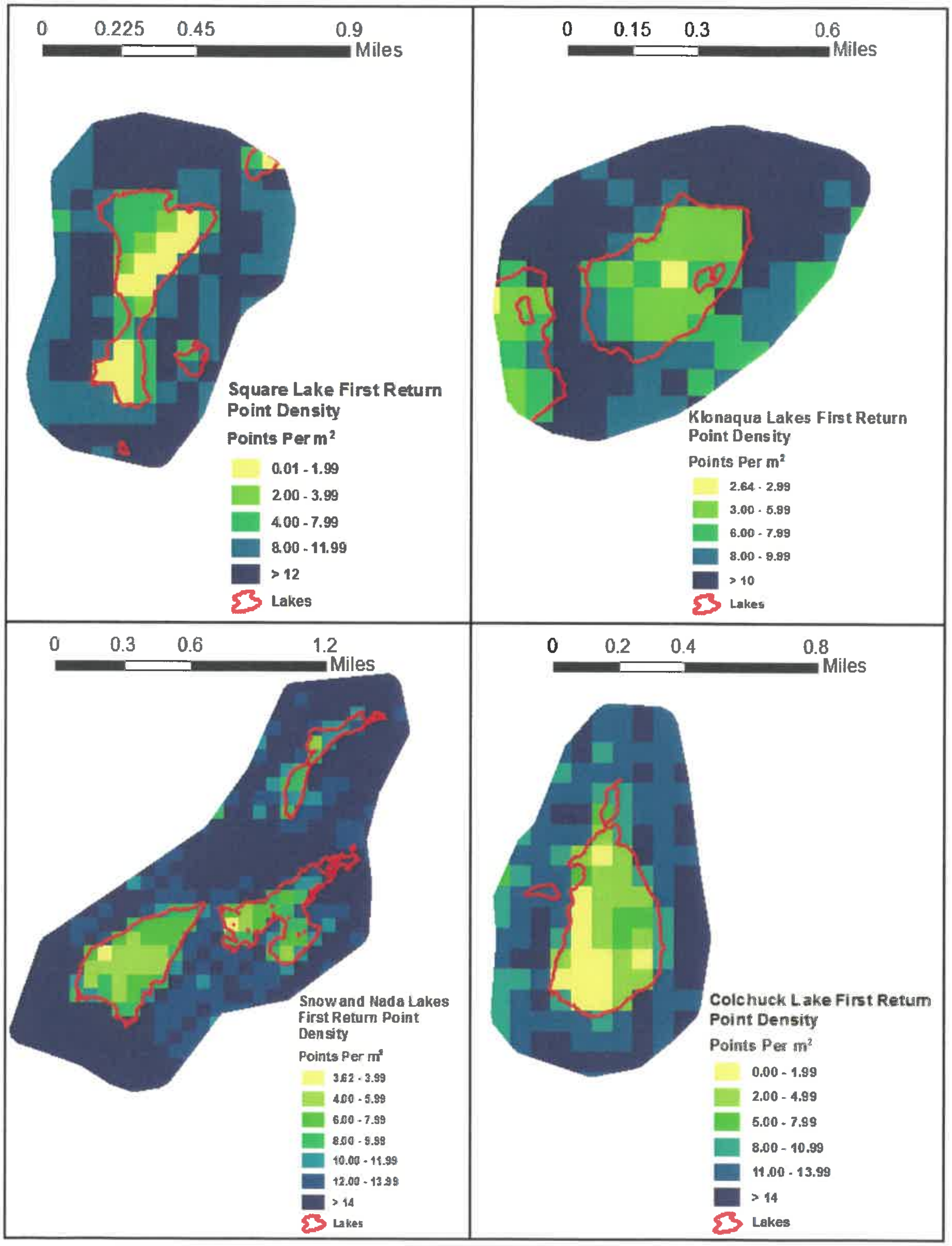


Figure 6: First return point density map for the Alpine Lakes, Washington sites (100 m x 100 m cells)

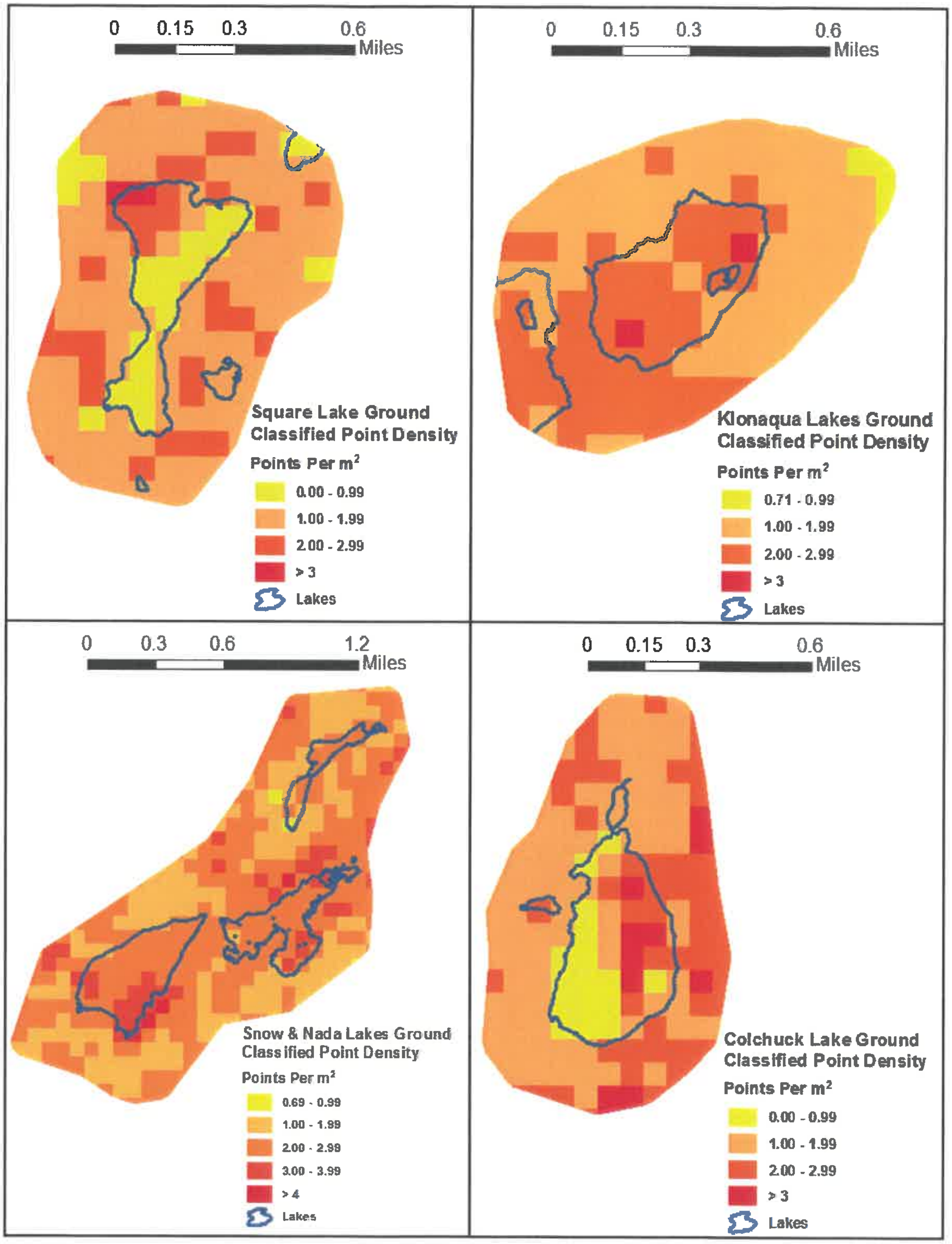


Figure 7: Ground point density map for the Alpine Lakes, Washington sites (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

LiDAR Absolute Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[4]. NVA compares known ground quality assurance point data collected on open, bare earth surfaces with level slope (<20°) to the triangulated surface generated by the LiDAR points. NVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 10.

The mean and standard deviation (sigma σ) of divergence of the ground surface model from quality assurance point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the Alpine Lakes survey, 21 quality assurance points were withheld in total resulting in a non-vegetated vertical accuracy of 0.120 feet (0.037 meters) (Figure 8).

QSI also assessed absolute accuracy using 104 ground control points. Although these points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and therefore have been provided in Table 10 and Figure 9.

Table 10: Absolute accuracy results

Absolute Accuracy		
	Quality Assurance Points (NVA)	Ground Control Points
Sample	21 points	104 points
NVA (1.96*RMSE)	0.120 ft 0.037 m	0.146 ft 0.044 m
Average	0.003 ft 0.001 m	0.011 ft 0.003 m
Median	0.000 ft 0.000 m	0.011 ft 0.004 m
RMSE	0.061 ft 0.019 m	0.074 ft 0.023 m
Standard Deviation (1σ)	0.063 ft 0.019 m	0.074 ft 0.023 m

[4] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. http://www.asprs.org/PAD-Division/ASPRS-POSITIONAL-ACCURACY-STANDARDS-FOR-DIGITAL-GEOSPATIAL-DATA.html.

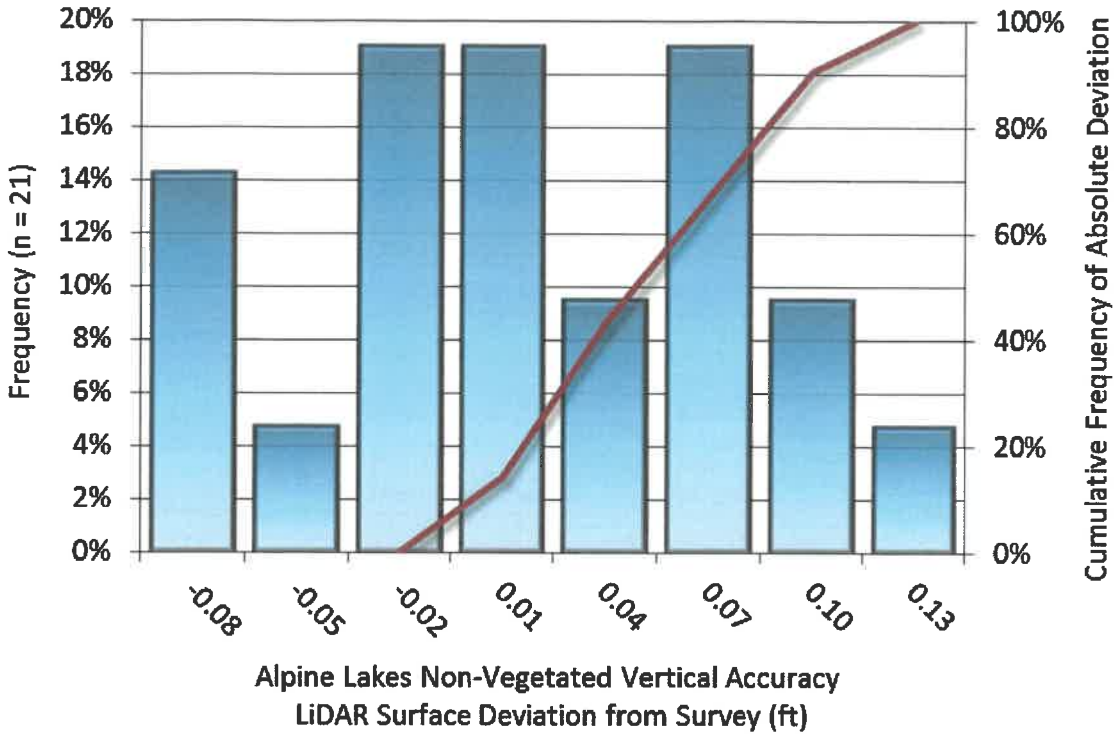


Figure 8: Frequency histogram for LiDAR surface deviation from quality assurance point values

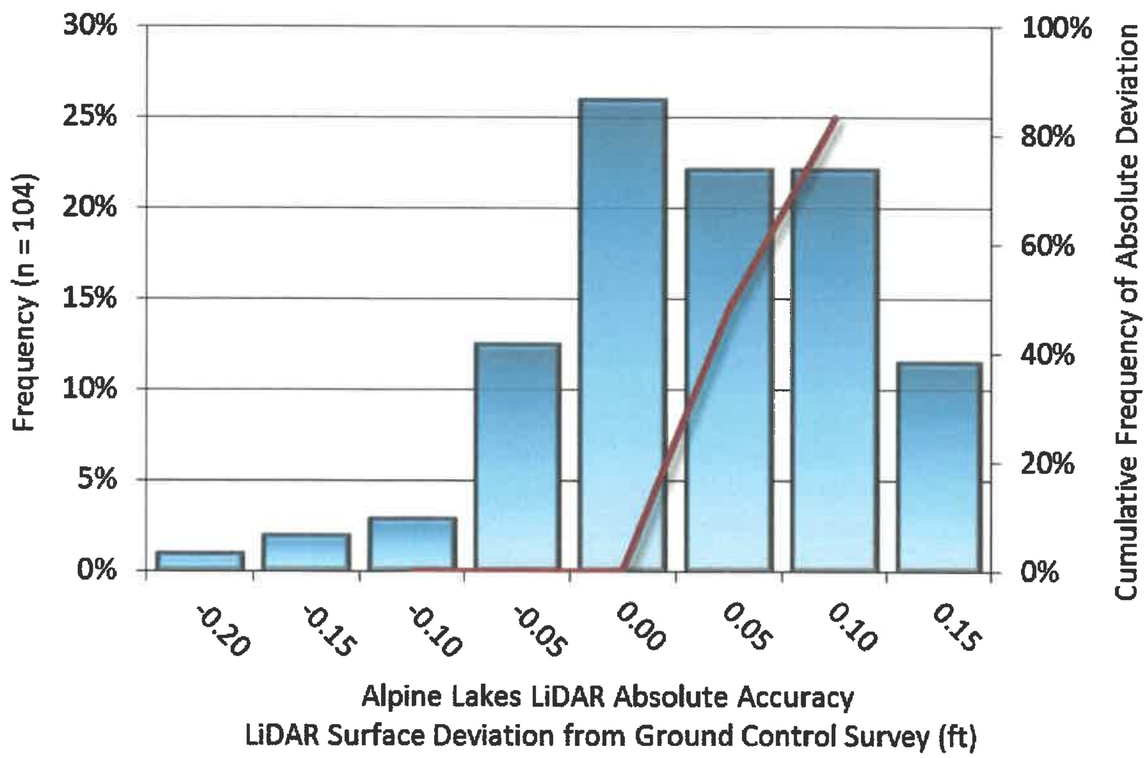


Figure 9: Frequency histogram for LiDAR surface deviation from ground control point values

LiDAR Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Alpine Lakes LiDAR project was 0.215 feet (0.066 meters) (Table 11, Figure 10).

Table 11: Relative accuracy results

Relative Accuracy	
Sample	25 surfaces
Average	0.215 ft 0.066 m
Median	0.217 ft 0.066 m
RMSE	0.216 ft 0.066 m
Standard Deviation (1σ)	0.022 ft 0.007 m
1.96σ	0.043 ft 0.013 m

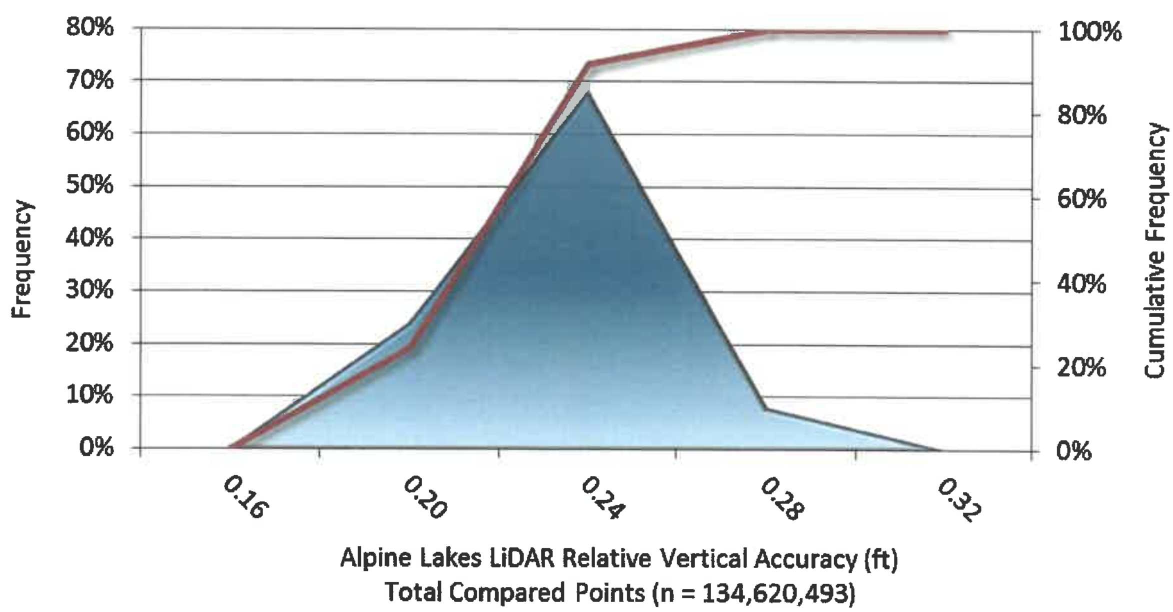


Figure 10: Frequency plot for relative vertical accuracy between flight lines

Certifications

Quantum Spatial, Inc. provided LiDAR services for the Alpine Lakes, Washington project as described in this report.

I, Adam Meyer, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

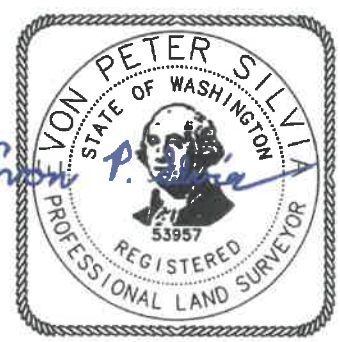
Dec 1, 2016

Adam Meyer
Project Manager
Quantum Spatial, Inc.

I, Evon P. Silvia, PLS, being duly registered as a Professional Land Surveyor in and by the state of Washington, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted on October 15, 2016.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

Dec 1, 2016



Evon P. Silvia, PLS
Quantum Spatial, Inc.
Corvallis, OR 97333

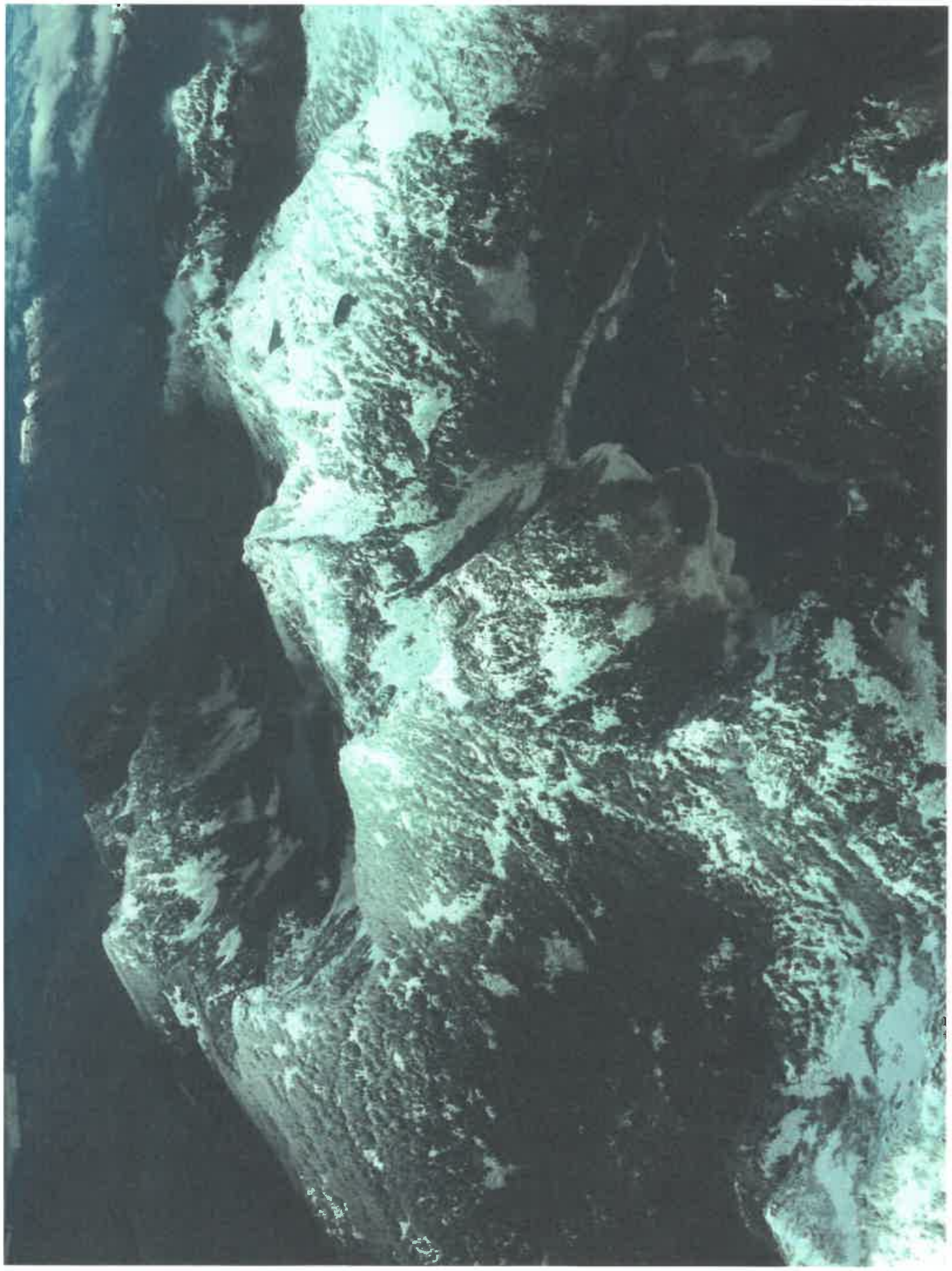


Figure 11: The above image is an aerial photo of Square Lake in the Alpine Lakes AOI. The photo was taken by QSI acquisition staff.

Figure 12: The above image is an aerial photo of Upper Snow Lake taken by the QSI acquisition team.

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Non-vegetated Vertical Accuracy (NVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Absolute Accuracy:** The vertical accuracy of LiDAR data is described as the mean and standard deviation (sigma σ) of divergence of LiDAR point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.
>
> **Relative Accuracy:** Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm).
>
> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echos) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native LiDAR Density: The number of pulses emitted by the LiDAR system, commonly expressed as pulses per square meter.

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 15^{\circ}$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

APPENDIX C

Radio Repeater Background Information

Federal Communications Commission
Wireless Telecommunications Bureau

RADIO STATION AUTHORIZATION

LICENSEE: ICICLE IRRIGATION DISTRICT

ATTN: JOEL TEELEY
ICICLE IRRIGATION DISTRICT
5594 WESCOTT DRIVE
PO BOX 371
CASHMERE, WA 98815

FCC Registration Number (FRN): 0018582478

Call Sign	File Number
WQKR961	

Radio Service
IG - Industrial/Business Pool, Conventional

Regulatory Status
PMRS

Frequency Coordination Number

Grant Date	Effective Date	Expiration Date	Print Date
08-27-2009	08-27-2009	08-27-2019	

STATION TECHNICAL SPECIFICATIONS

Fixed Location Address or Mobile Area of Operation

Loc. 1 **Address:** 5594 Wescott Drive
City: Cashmere **County:** CHELAN **State:** WA
Lat (NAD83): 47-31-09.0 N **Long (NAD83):** 120-29-47.0 W **ASR No.:** **Ground Elev:** 276.0

Loc. 2 **Address:** Blagg Mountain
City: Cashmere **County:** CHELAN **State:** WA
Lat (NAD83): 47-36-25.0 N **Long (NAD83):** 120-30-35.0 W **ASR No.:** **Ground Elev:** 1180.0

Loc. 3 **Area of operation**
Operating within a 32.0 km radius around fixed location 2

Antennas

Loc No.	Ant No.	Frequencies (MHz)	Sta. Cls.	No. Units	No. Pagers	Emission Designator	Output Power (watts)	ERP (watts)	Ant. Ht./Tp meters	Ant. AAT meter	Construct Deadline Date
1	1	000456.67500000	FX1	1		11K0F2D 11K0F3D 11K0F3E	40.000	40.000	20.0	-387.0	08-27-2010
2	1	000451.67500000	FB2	1		11K0F2D 11K0F3D 11K0F3E	45.000	45.000	40.0	395.0	08-27-2010

Conditions:
Pursuant to §309(h) of the Communications Act of 1934, as amended, 47 U.S.C. §309(h), this license is subject to the following conditions: This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term thereof nor in any other manner than authorized herein. Neither the license nor the right granted thereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934, as amended. See 47 U.S.C. § 310(d). This license is subject in terms to the right of use or control conferred by §706 of the Communications Act of 1934, as amended. See 47 U.S.C. §606.

FCC 601-LM
August 2007

Licensee Name: ICICLE IRRIGATION DISTRICT

Call Sign: WQKR961 **File Number:** **Print Date:**

Antennas

Loc No.	Ant No.	Frequencies (MHz)	Sta. Cls.	No. Units	No. Pagers	Emission Designator	Output Power (watts)	ERP (watts)	Ant. Ht./Tp meters	Ant. AAT meters	Construct Deadline Date
3	1	000456.67500000	MO	30		11K0F2D 11K0F3D 11K0F3E	6.000	6.000			08-27-2010
3	1	000451.67500000	MO	30		11K0F2D 11K0F3D 11K0F3E	6.000	6.000			08-27-2010

Control Points

Control Pt. No. 1

Address: 5594 Wescott Drive

City: Cashmere **County:** CHELAN **State:** WA **Telephone Number:** (509)782-2561

Associated Call Signs

Waivers/Conditions:

NONE

Federal Communications Commission

Wireless Telecommunications Bureau

RADIO STATION AUTHORIZATION

LICENSEE: ICICLE IRRIGATION DISTRICT

ATTN: JOEL TEELEY
ICICLE IRRIGATION DISTRICT
5594 WESCOTT DRIVE
PO BOX 371
CASHMERE, WA 98815

FCC Registration Number (FRN): 0018582478

Call Sign	**File Number**
WQKS355	

Radio Service
IG - Industrial/Business Pool, Conventional

Regulatory Status
PMRS

Frequency Coordination Number

Grant Date	**Effective Date**	**Expiration Date**	**Print Date**
08-31-2009	08-31-2009	08-31-2019	

STATION TECHNICAL SPECIFICATIONS

Fixed Location Address or Mobile Area of Operation

Loc. 1 **Address:** RTU #1 - .89 mi NE of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-34-41.8 N **Long (NAD83):** 120-35-43.8 W **ASR No.:** **Ground Elev:** 406.0

Loc. 2 **Address:** RTU #2 - 1.81 mi S of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-32-29.4 N **Long (NAD83):** 120-36-49.8 W **ASR No.:** **Ground Elev:** 354.0

Loc. 3 **Address:** RTU #3 - .98 mi SE of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-33-18.0 N **Long (NAD83):** 120-35-42.0 W **ASR No.:** **Ground Elev:** 339.0

Loc. 4 **Address:** RTU #4 - 3.69 mi E of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-31-40.8 N **Long (NAD83):** 120-32-00.6 W **ASR No.:** **Ground Elev:** 427.0

Loc. 5 **Address:** RTU #5 - 4.84 mi SE of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-31-08.4 N **Long (NAD83):** 120-31-45.6 W **ASR No.:** **Ground Elev:** 333.0

Loc. 6 **Address:** RTU #6 - 1.21 mi W of
City: Peshastin **County:** CHELAN **State:** WA
Lat (NAD83): 47-31-01.3 N **Long (NAD83):** 120-29-44.8 W **ASR No.:** **Ground Elev:** 268.0

Conditions:
Pursuant to §309(h) of the Communications Act of 1934, as amended, 47 U.S.C. §309(h), this license is subject to the following conditions: This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term thereof nor in any other manner than authorized herein. Neither the license nor the right granted thereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934, as amended. See 47 U.S.C. § 310(d). This license is subject in terms to the right of use or control conferred by §706 of the Communications Act of 1934, as amended. See 47 U.S.C. §606.

Licensee Name: ICICLE IRRIGATION DISTRICT

Call Sign: WQKS355 **File Number:** **Print Date:**

Antennas

Loc No.	Ant No.	Frequencies (MHz)	Sta. Cls.	No. Units	No. Pagers	Emission Designator	Output Power (watts)	ERP (watts)	Ant. Ht./Tp meters	Ant. AAT meters	Construct Deadline Date
1	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-428.0	08-31-2010
2	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-435.0	08-31-2010
3	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-464.0	08-31-2010
4	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-312.0	08-31-2010
5	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-393.0	08-31-2010
6	1	000456.67500000	FXO	1		11K0F2D 11K0F3D 11K0F3E	6.000	6.000	3.0	-409.0	08-31-2010

Control Points

Control Pt. No. 1

Address: 5594 Wescott Drive

City: Cashmere **County:** CHELAN **State:** WA **Telephone Number:** (509)782-2561

Associated Call Signs

Waivers/Conditions:

NONE

Location Details - ICICLE RIDGE

General | Details | Antenna | Contact | Rules | Alerts | Repeaters

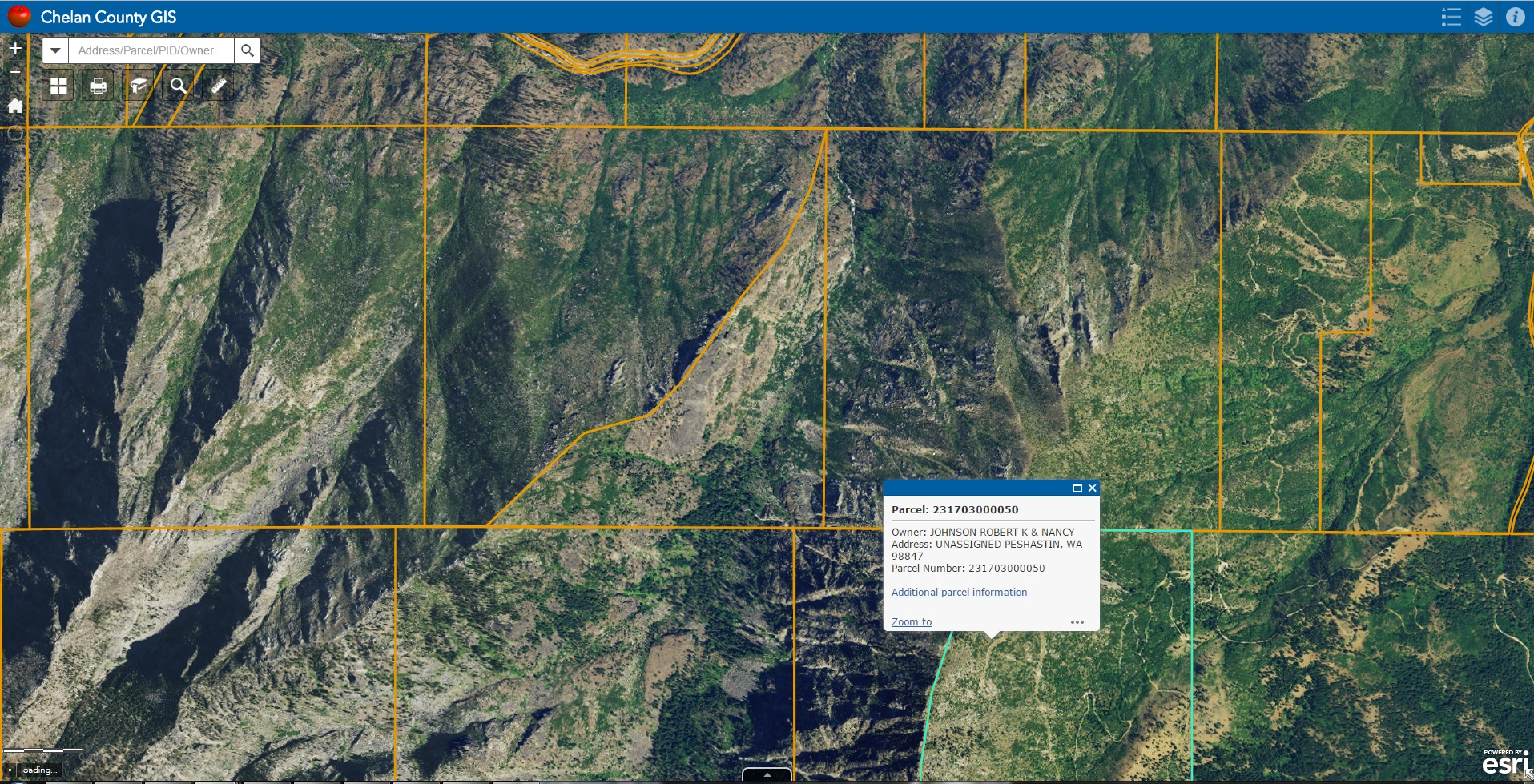
Health Status:	Auto (rules)
ID:	ICICLERIDGE
Name:	ICICLE RIDGE
ESN:	
MGRS:	10TFT6856772797
Lat / Lon:	47.586667 -120.758056
Elevation (m):	2079
Forest:	Okanogan-Wenatchee National Forest


About
Dashboard
Admin
Help
Location Summary - ICICLE RIDGE
General
Data
Repeaters
Status: UNMONITORED
Updated: 4/8/2014, 6:15:43 AM
Reasons:
Lat/Lon: 47.5866670, -120.758056
MGRS: 10TFT6856772797
Region: R6-Pacific Northwest
Forest:
Okanogan-Wenatchee National Forest
Zoom to
Show Coverage
Location Details
Fourth of July Creek
Bridge Creek
Leavenworth
Leavenworth Golf Club
Repeaters
Layers
Legend
Tools
Placemarks
Coverage
POWERED BY esri

Location Details - ICICLE RIDGE

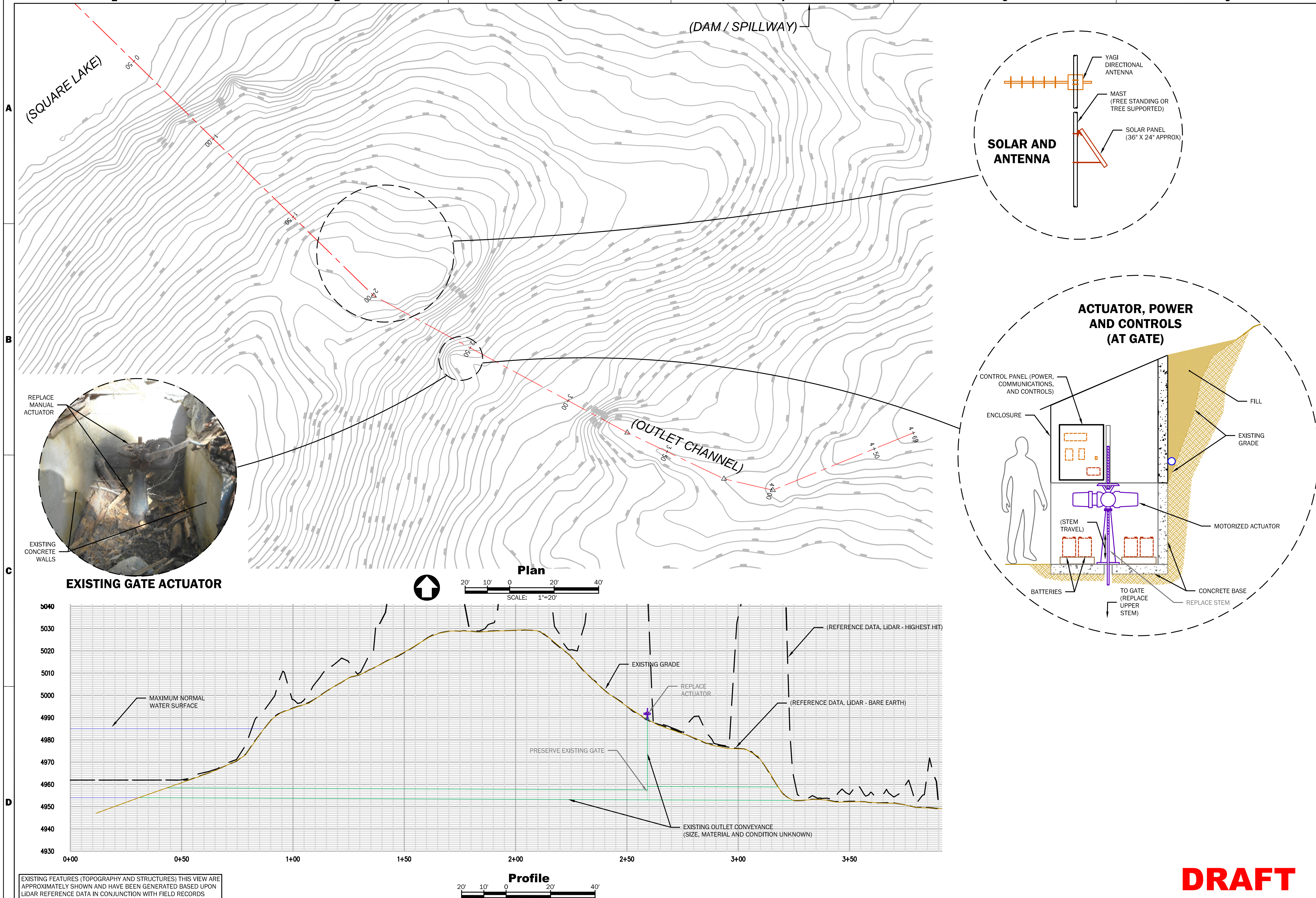
General | Details | Antenna | Contact | Rules | Alerts | Repeaters

Tx Antenna:	Collinear
Dbi:	6
Antenna Height Meters:	6
Antenna Azth:	ND
Txpo Watts:	50


Chelan County GIS
Address/Parcel/PID/Owner
Parcel: 231703000050
Owner: JOHNSON ROBERT K & NANCY
Address: UNASSIGNED PESHASTIN, WA 98847
Parcel Number: 231703000050
Additional parcel information
Zoom to
loading...

APPENDIX D

Conceptual Engineering Drawings



REV.	DESCRIPTION	DATE	APPR.
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

Aspect CONSULTING

DATE:	REVISION:	PROJECT NUMBER:	DESIGNED BY:	DRAWN BY:	REVISED BY:
FEB 2017	-	000000	-	SCC	-

Conceptual Improvements Square Lake

Alpine Lakes Automation Feasibility

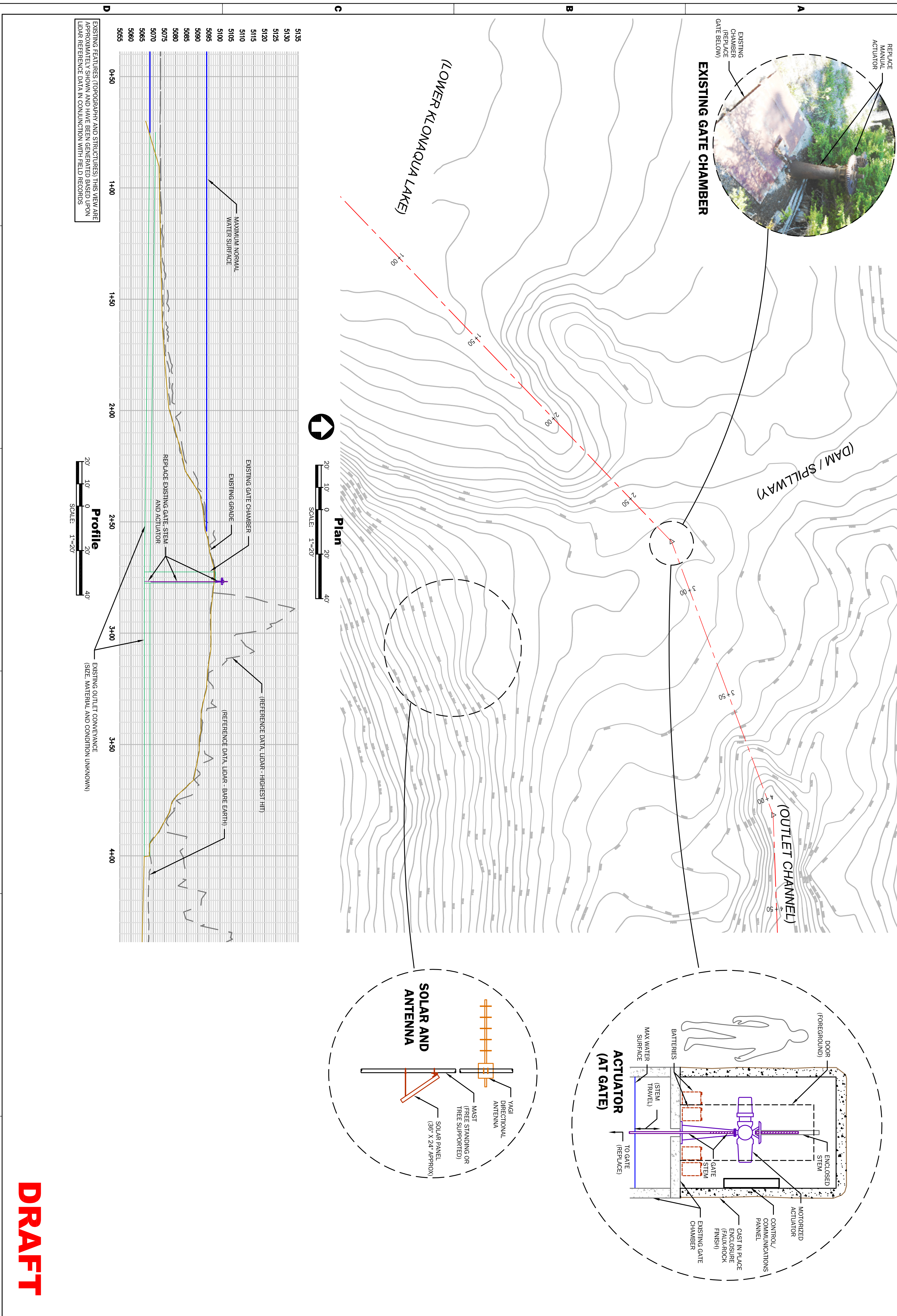
Leavenworth, Washington

SHEET REFERENCE NUMBER:

C01

SHEET 1 OF 3

CAD Path: K:\Projects\Chelan County Natural Resources-120045\Alpine Lakes\Feasibility Design\CAD\Square\square-p-civ01.dwg Square Plan || Date Saved: May 12, 2017 8:40am || User: rbrownlee



Conceptual Improvements
Klonaqua Lake

Alpine Lakes Automation Feasibility

Leavenworth, Washington

Aspect CONSULTING

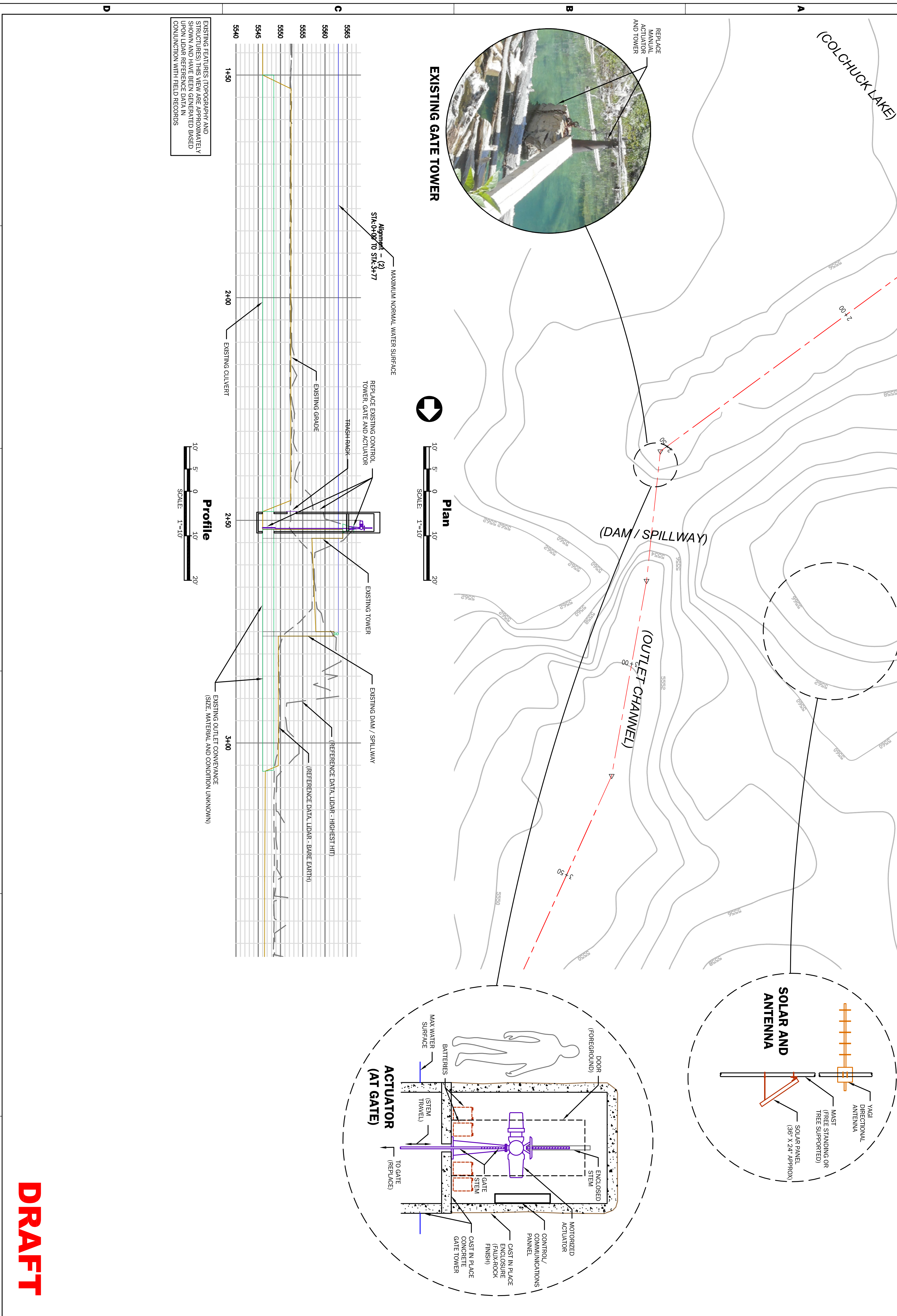
DATE:	REVISION:	PROJECT NUMBER:	DESIGNED BY:	DRAWN BY:	REVISED BY:
FEB 2017	-	000000	-	SCC	-

REV.	DESCRIPTION	DATE	APPR.
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SHEET REFERENCE NUMBER: **C02**

SHEET 2 OF 3

CAD Path: K:\Projects\Chelan County Natural Resources-120045\Alpine Lakes\Feasibility Design\CAD\Klonaqua\klonaqua-p-civ01.dwg Klonaqua Plan || Date Saved: May 12, 2017 8:37am || User: rbrownlee



Conceptual Improvements
Colchuck Lake

Alpine Lakes Automation Feasibility

Leavenworth, Washington

Aspect CONSULTING

DATE:	REVISION:	PROJECT NUMBER:	DESIGNED BY:	DRAWN BY:	REVISED BY:
FEB 2017	-	000000	-	SCC	-

REV.	DESCRIPTION	DATE	APPR.
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SHEET REFERENCE NUMBER: **C03**

SHEET 3 OF 3

CAD Path: K:\Projects\Chellan County Natural Resources-120045\Alpine Lakes\Feasibility Design\CAD\Colchuck\Colchuck-p-civ01.dwg Colchuck Plan || Date Saved: May 12, 2017 8:36am || User: rbrownlee

APPENDIX E

Preliminary Equipment Selection, Vendor Data

Controls

IQ range DC actuators

Motor data for IQ range DC actuators

Publication number E130E_DC0807
Date of issue 08/07

Electric Motor Performance Data for IQD New Generation Actuators - DC Power Supplies

Publication number E130E_DC0807
Date of issue 08/07

Introduction

This guide provides IQD motor data for standard class F, 15 minute rated actuators at the following DC supply voltages:

24V 48V 110V

Actuator performance is limited by supply voltage due to current switching limitations. Refer to motor data tables.
The IQD actuator range is generally described in publication E110E. For IQD control and monitoring refer to publication E120E

Glossary

- Rated Torque – Corresponds to 100% torque switch setting
- Locked rotor – motor starting and stalled condition
- Rated Amps – current at 100% torque switch setting
- Average (nominal) load – Corresponds to 33% of rated torque.
- Efficiency – electrical efficiency of the actuator motor.

Design criteria

Motors designed for operation of valve actuators require special consideration. As continuous running is not a requirement with isolating and "inching" or regulating duty valves, motors need only be short duty time rated. Valve load can vary dramatically across stroke and from stroke to stroke as process and valve conditions change. Varying from light running to rated torque with a facility to exceed rated in unseating "sticky" valves, actual motor loading has no constant. To apply traditional motor protection to actuator motors is therefore flawed, leading to spurious tripping or no protection at all. Rotork recognise the special nature of actuator motors and have therefore designed the IQD motor and control package with this unique duty at the forefront.

IQD Motor Design

IQD motors are of a low inertia, permanent magnet design. In its standard form they are class F insulated, rated 15 minutes at average load. The motor torque/speed characteristic has been designed to fulfill the following requirements:

- High locked rotor torque in comparison with that required to operate and seat the valve. Rotork are able to guarantee actuator performance at +/-10% of nominal voltage, however in common with all DC motors of this type, speed will vary with load and voltage.
- Low inertia, high starting torque motor combined with the lost motion drive, allows the motor to reach full speed with maximum available torque before the drive is applied to the valve, ensuring unseating for all except jammed valves.
- Maintenance free for the life of the actuator.

IQD motor protection

The primary protection for the motor is torque switch protection. By measuring the actuator output torque and comparing it to the open and close torque switch setting, the motor will be de-energised when the set torque is reached. This method provides the only comprehensive means of motor *and* valve protection.

IQD motors also incorporate over temperature protection using thermostats that will de-energise the motor if the duty cycle exceeds actuator rating. Testing has shown that using motor mounted thermostats offer better protection than traditional thermal overload relays as they respond directly to motor temperature and therefore are more closely linked to the motor thermal characteristic.

IQD control protection will prevent motor stall in the event of valve jamming *.

*If "torque switch bypass" or "Boost" open torque has been set the actuator will develop torque in excess of rated and can stall in attempting to unseat a jammed valve. If the actuator stalls, jammed valve protection will trip the motor within 4 seconds.

Power supply cable sizing

As a minimum requirement, cables must be sized to ensure volt drop does not exceed 10% of nominal supply voltage at locked rotor current.

Fuse selection

Due to the unique nature of the motor duty and taking in to account the comprehensive control protection of the IQD, sizing of fuses or trip devices should be based on protecting the power cable connected to the actuator. If required, sizing trip devices to disconnect after 5 seconds at locked rotor current may enhance protection. This will reduce the risk of severe motor heating under stall conditions while preventing spurious trips under normal operation. It should be noted that sizing trip devices in this manner may not be possible while meeting other criteria and is purely designed to meet extreme fault conditions such as jammed contactor when standard control protection cannot de-energise the motor. All other operating conditions will be catered for by the standard IQD control protection.

DC power systems

Rotork can supply failsafe charger/battery and solar powered backup systems for use with IQD and IQT-24V DC range actuators. Please apply.

Motor Options

IQD motors are available with extended duty cycles. Please apply.

24VDC

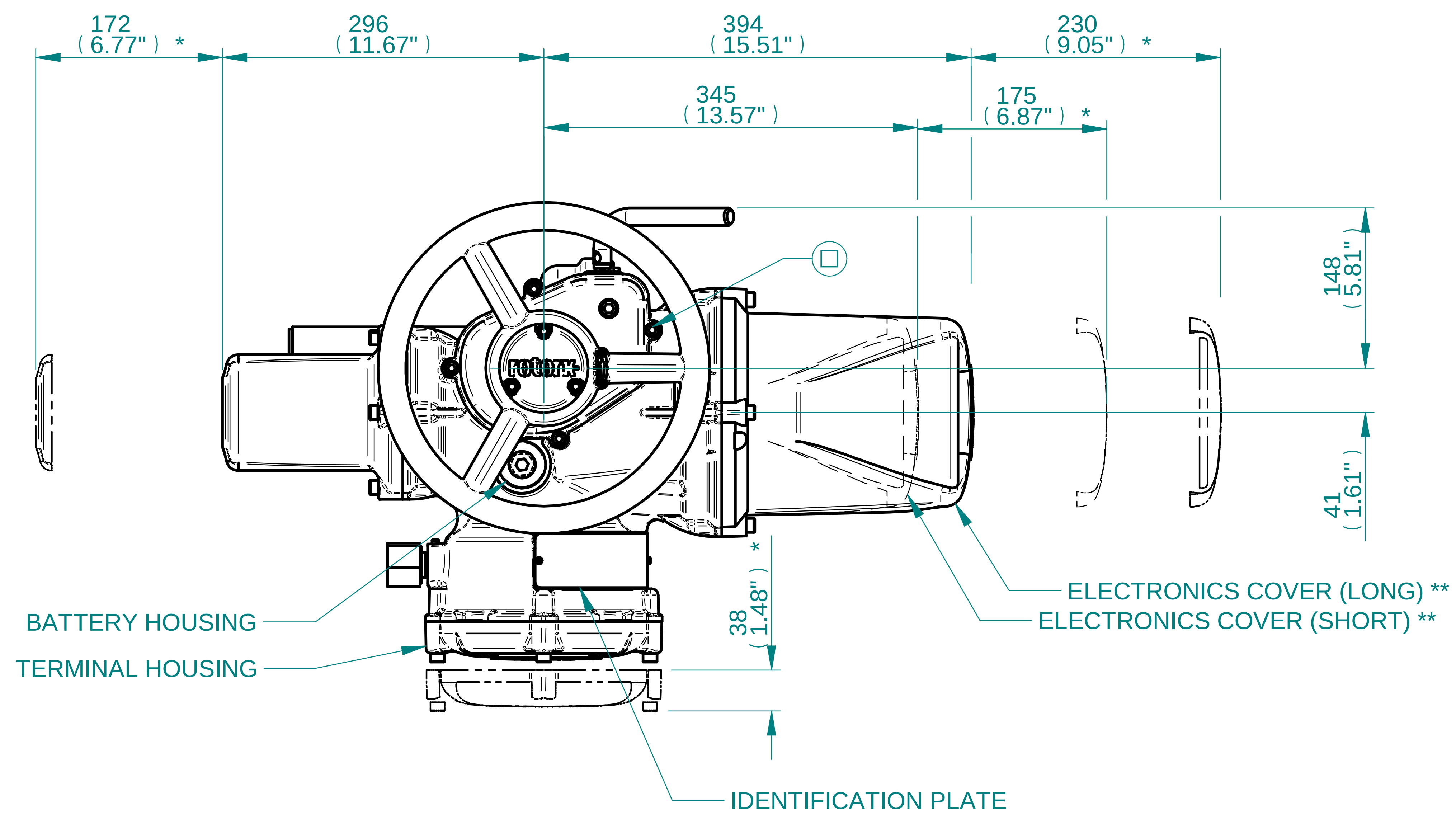
Size	Actuator	Rated Torque		Stall Current (A)	Rated Torque	Motor Average Load	
	rpm	Nm	Ft lbf	Cold Motor	Amps	Amps	KW
IQD10	18	34	25	50.5	19.2	7	0.21
	24	34	25	50.5	19.2	7	0.21
	36	31	23	50.5	19.2	7	0.21
	48	27	20	50.5	19.2	7	0.21

48VDC

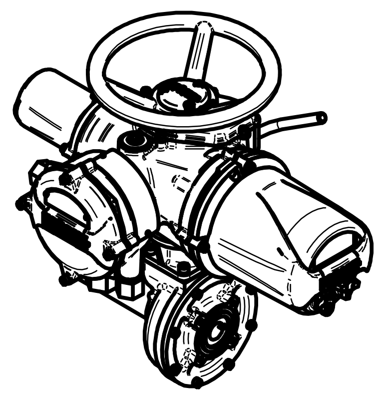
Size	Actuator	Rated Torque		Stall Current (A)	Rated Torque	Motor Average Load	
	rpm	Nm	Ft lbf	Cold Motor	Amps	Amps	KW
IQD10	18	34	25	11	5.4	1.8	0.08
	24	34	25	11	5.4	1.8	0.08
	36	31	23	11	5.4	1.8	0.08
	48	27	20	11	5.4	1.8	0.08
IQD12	18	68	50	22.4	7.5	5.1	0.2
	24	68	50	22.4	7.5	5.1	0.2
	36	61	45	22.4	7.5	5.1	0.2
	48	54	40	22.4	7.5	5.1	0.2
IQD18	24	108	80	51	29.6	10.5	0.51

110VDC

Size	Actuator	Rated Torque		Stall Current (A)	Rated Torque	Motor Average Load	
	rpm	Nm	Ft lbf	Cold Motor	Amps	Amps	KW
IQD10	18	34	25	4.7	2.1	0.9	0.08
	24	34	25	4.7	2.1	0.9	0.08
	36	31	23	4.7	2.1	0.9	0.08
	48	27	20	4.7	2.1	0.9	0.08
IQD12	18	68	50	10.9	4.7	2.3	0.2
	24	68	50	10.9	4.7	2.3	0.2
	36	61	45	10.9	4.7	2.3	0.2
	48	54	40	10.9	4.7	2.3	0.2
IQD18	24	108	80	24	12.8	4.5	0.51
IQD20	18	163	120	19	6.3	4.9	0.34
	24	163	120	19	6.3	4.9	0.34
	36	136	100	19	6.3	4.9	0.34
	48	108	80	19	6.3	4.9	0.34
IQD25	18	305	225	31.9	10.2	7	0.61
	24	305	225	31.9	10.2	7	0.61
	36	257	190	31.9	10.2	7	0.61
	48	203	150	31.9	10.2	7	0.61

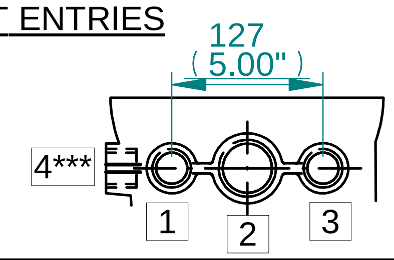


NOTES:
:DIMENSIONS WITH '*' INDICATE COVER REMOVAL ALLOWANCE
:ELECTRONICS COVER OPTION "**" WILL VARY DEPENDING ON CONFIGURATION
:NETT WEIGHT = 47kg/103lbs
: ▢ = OIL FILLER/DRAIN PLUG
:THE INTERFACE PROVIDED FOR MOUNTING THE ACTUATOR OR SECOND STAGE GEARBOX ONTO THE VALVE SHOULD CONFORM TO GOOD ENGINEERING PRACTICES, ENSURING ADEQUATELY TOLERANCED LIMITS FOR PARALLELISM, PERPENDICULARITY AND CONCENTRICITY.
:ROTORK CANNOT BE HELD LIABLE FOR DAMAGE TO OUR EQUIPMENT CAUSED BY EXCESSIVE LOADING FROM COVER TUBES. (SEE ALSO E156E)



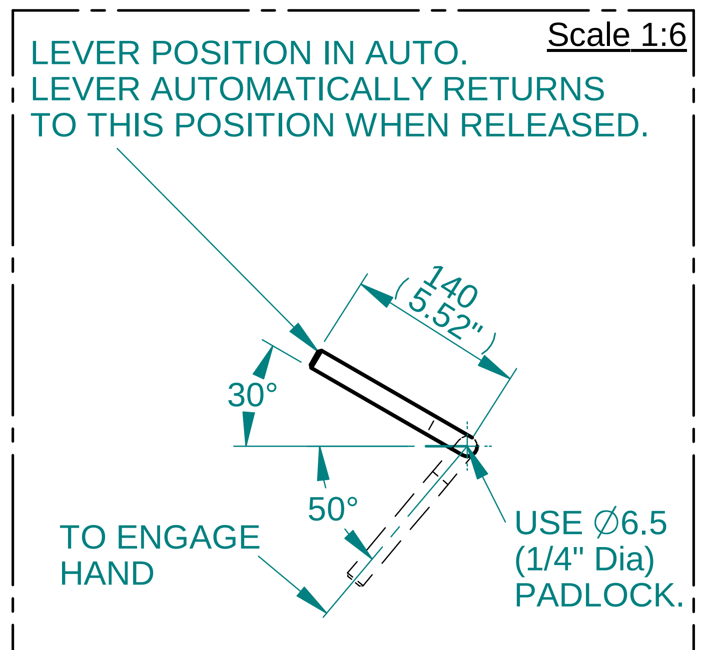
ISOMETRIC VIEW
(SCALE 1:12)

CONDUIT ENTRIES

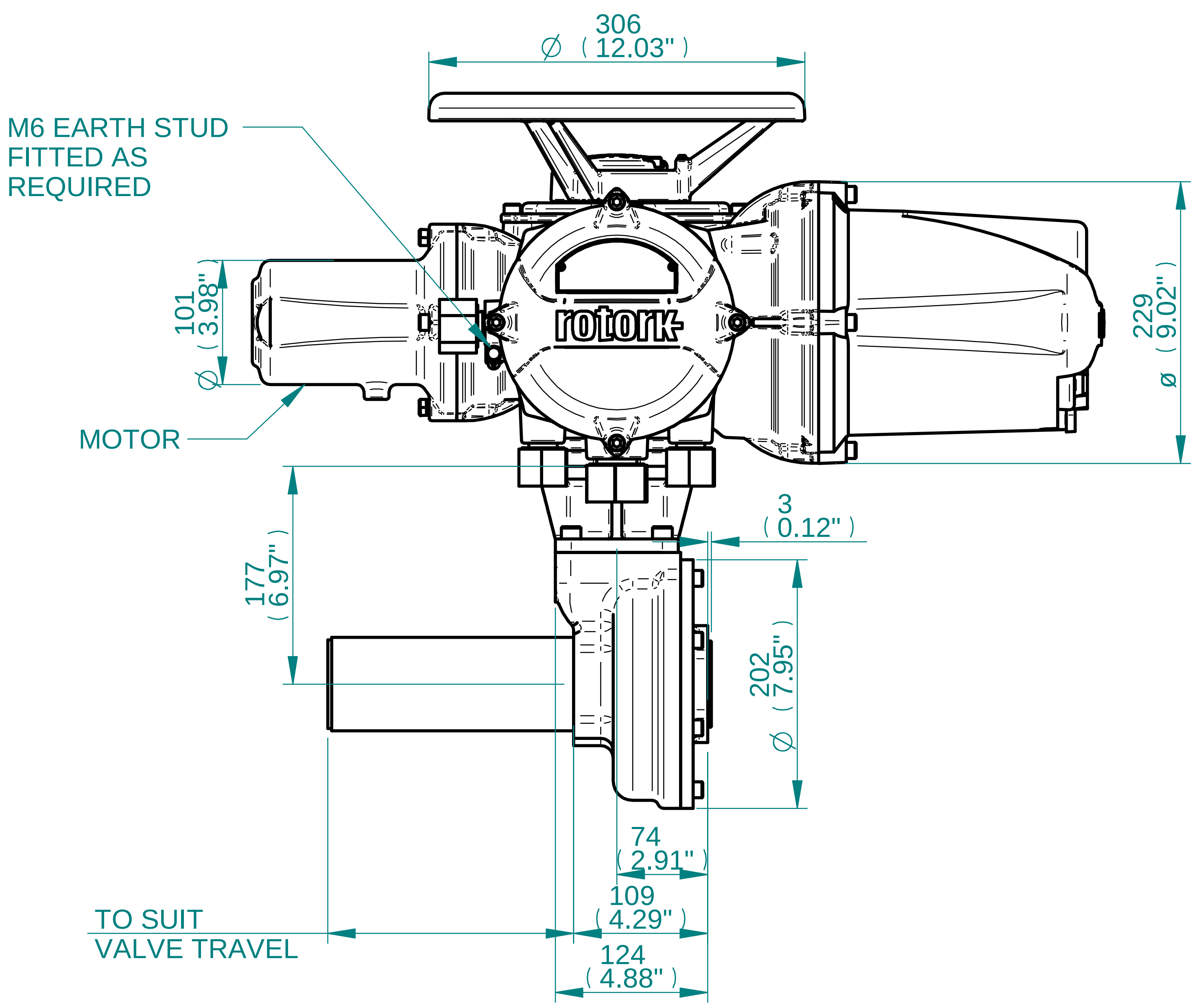


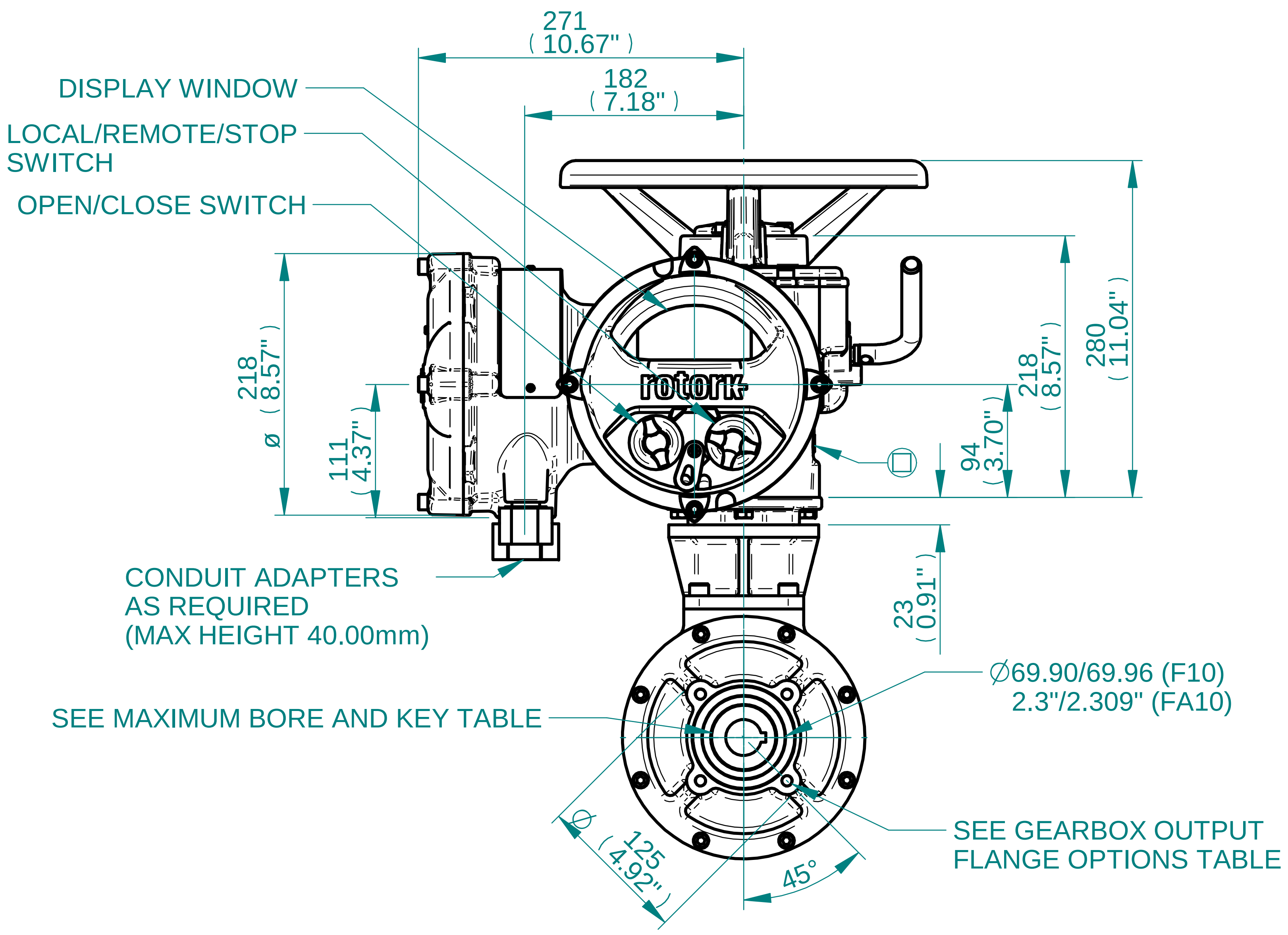
	Hole 1	Hole 2	Hole 3	Hole 4***
Size	As Required	As Required	As Required	As Required
Plugged	As Required	As Required	As Required	As Required
Gland	As Required	As Required	As Required	As Required

***HOLE 4 IS OPTIONAL



PADLOCKABLE HAND-AUTO LEVER





rotork
www.rotork.com

Rotork Controls Limited
Bath, BA1 3JQ, England.
Telephone 01225-733200

Actuator Size:	IQ10/12/18, IB4, F10/FA10
Title	IQ10/12/18, TOP HANDWHEEL, IB4, F10/FA10, Ratios 2:1,3:1,4:1 & 6:1 Installation Details
Drawn JLF	Checked NJC · Date 11-MAR-15
Ref SALES	Project Ref QUOTATION

Gearbox output flange options

Designation	F10	-	-	-	FA10	-	-	-
No. Holes	4	-	-	-	4	-	-	-
Hole size	M10	-	-	-	3/8" UNC	-	-	-
PCD	102	-	-	-	4"	-	-	-

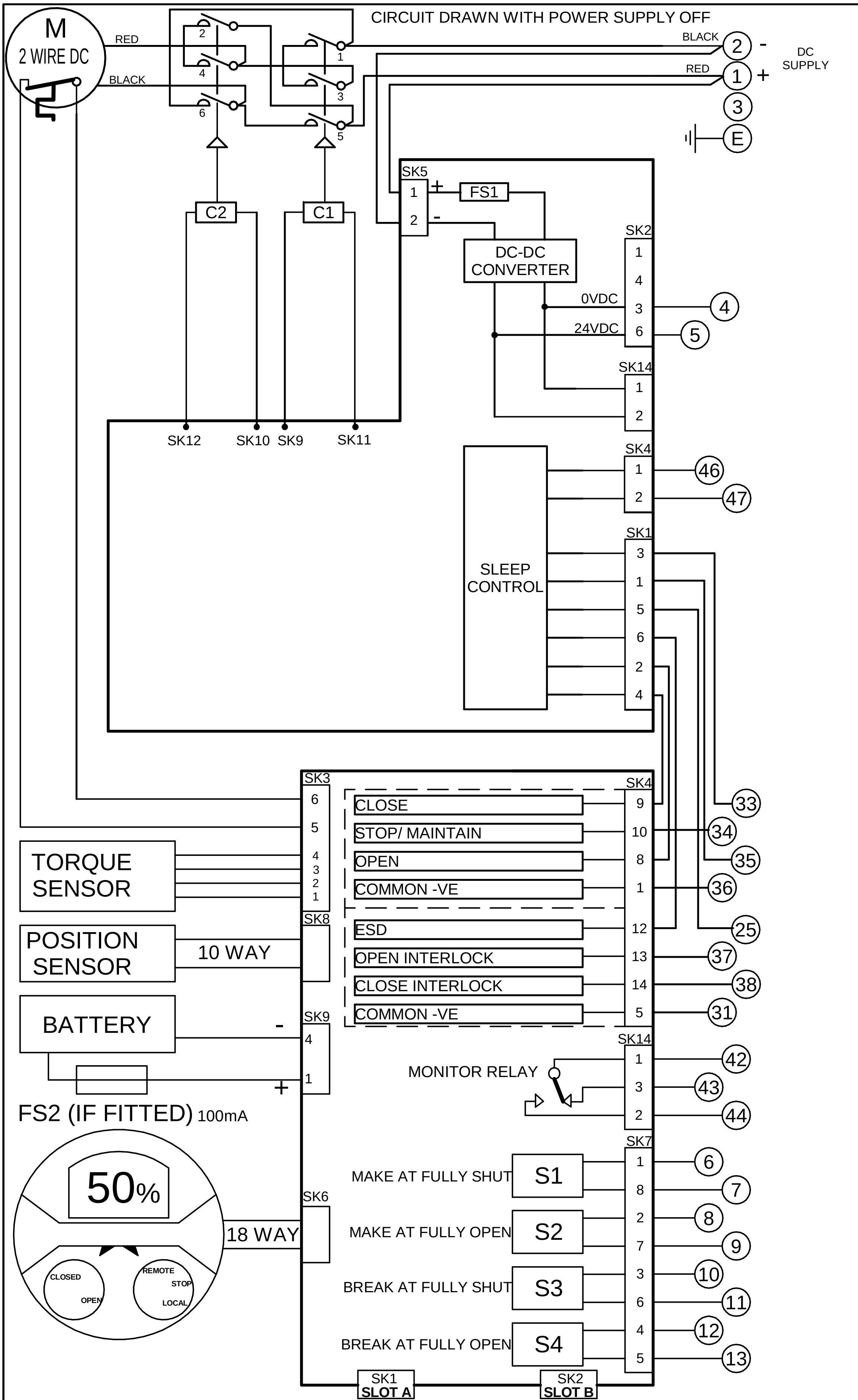
Maximum Bore & Key

Key form	∅ Bore	Key size
Rectangle (BS4235)	40	12 X 8
Rectangle (ANSI B17.1)	1-5/8"	3/8 X 1/4"
Square (ANSI B17.1)	1-1/2"	3/8"

Issue	Description
1	First Issue

Scale: 1:5 · THIRD ANGLE PROJECTION

A2	Drawing Number	Issue No	Sheet No
	II1THWIB4STD	1	1 of 1



FOR TYPICAL REMOTE CONTROL DETAILS, SEE DOCUMENT
RWS100

VOLTAGE OPTIONS	
VOLTAGE	SIZE
110VDC	10,12,18,20,25
48VDC	10,12,18
24VDC	10

REFER TO SHEET 2 FOR NOTES & OPTION PCB'S IF FITTED

Iss	Date	Chkd	Revision Details
1	240413	PJW	FIRST ISSUE
2	240614	MR	SHEET 2, NOTE 1 UPDATED

www.rotork.com

ROTORK CONTROLS LTD
BATH, BA1 3JQ
ENGLAND
Tel:01225-733200

ROTORK CONTROLS INC
ROCHESTER
NY 14624, USA
Tel:585-247-2304

IQ DC SOLAR BASIC DIAGRAM

Drawn by: JC1
Date : 240413
Base WD: 150B0000
Job No : - -
MI No : - -

Circuit Diagram Number
150B0000
B1 C1 B2 C2

Issue No: 2
Sheet 1 of 2

IQ3

CIRCUIT DRAWN WITH POWER SUPPLY OFF

NO OPTIONS FITTED

NOTES

1.FUSES:

-FS1 - 6A anti-surge

-Actuator rated voltage specified on nameplate. Voltage tolerance +/-10%, applies for rated torque performance; duty cycle and speed is not guaranteed.

2.REMOTE CONTROL:

-For typical remote control circuits refer to:
  -RWS indicated or PUB002-041.
-For DC and AC control, connect –ve/0V to terminal 36.
-(For negative switch / positive common, refer to RWS indicated).
-Control signal threshold voltages:
  -DC: “on” ≥16Vdc / “off” ≤8Vdc, max 60Vdc.
  -AC: “on” ≥60Vac / “off” ≤40Vac, max 120Vac.
-Control signal duration to be 300ms minimum.
-Maximum current drawn from remote control signals is:
  -8mA at 24Vdc or 12mA at 120Vac.
-Supply provided on terminals 4 & 5:
  -Intended for remote control.
  -Max external load 5W at 24Vdc / 5VA at 120Vac

3.INDICATION:

-For typical position, status and alarm indication see PUB002-041.
-“S” contacts are user configurable and are shown in their default setting.
-Refer to PUB002-040 for functions and configuration instructions.
-Monitor Relay indicates actuator availability for remote control (shown “unavailable”). It can be configured to exclude local/remote selection.
-Refer to PUB002-040 for monitored functions and configuration instructions.
-Voltage applied to indication contacts must not exceed 150Vac
-Individual Switch current must not exceed 3.5A inductive, 5A resistive and no more than 8A in total for all 4 contacts.

4.BATTERY:

-Battery maintains local and remote “S” contact indication only.
-Refer to installation manual for approved replacement battery types.

5.DC:

-Default for sleep mode is ENABLE.
-To disable sleep mode connect 5 to 46 & 4 to 47.
-Sleep mode can also be disabled by moving link LK1 from SOLAR to NORM.
-Actuator will remain powered up at all times while supply is present.
-24VDC will be lost when in sleep mode.
-If customer supply is needed to wake actuator link LK3 must be moved to CUST for maintained customer supply.

See Sheet 1 for all Revision details/information

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Sizing Guide Search

Seating Torque
93.55 **Nm** 69 **lbsft**

Seating Thrust
26.33 **kN** 5919 **lbsf**

Rising Stem Diameter (RS)
mm **ins**

OR

Non Rising Stem Diameter (NRS)
mm **ins**

Number of Turns
0 **Turns**

Stroke Time
0 **Secs**

Stroke Time Tolerance
50 **%+** 50 **%-**

Power Supply
DC 24V

Options
- [ ] Hazardous Area
- [ ] Watertight
- [ ] Failsafe

Output Flange
Any

Range
- [ ] ALL
- [x] IQD3
- [ ] IQ3
- [ ] IQS3

Reset Search

Output Performance

Combination	Rated Torque		Rated Thrust		Resultant Thrust		Stroke Time
	Nm	lbsft	kN	lbsf	kN	lbsf	Secs (60 Hz)
IQD10/IB4	138	102	53.00	12000	11812.27	8750	0.0

Available Output Flanges	Available Enclosures		Weight	
(ISO5210 "F" & MSS SP-102 "FA")	Hazardous	Watertight	Kg	Lbs
F10/FA10	Yes	Yes	52.66	116

Stem Acceptance	Max Bore		Min Bore		Fail Safe
	mm	in	mm	in	
Rising Stem	45	1.75	-	-	No
Non Rising Stem	40	1.63	-	-	

Actuator Performance

Size	Rated Torque		Output RPM	Rating
	Nm	lbsft	RPM (60Hz)	Starts / Hour
IQD10	27	20	48	60

Available for power supply			Available Enclosures		Weight	
1-Phase AC	3-Phase AC	DC	Hazardous	Watertight	Kg	Lbs
No	No	DC 24V DC 48V DC 110V	Yes	Yes	36.32	80

Handwheel	Type	Ratio	Turns	Rimpull	
		(:1)	(per stroke)	N	Lbsf
Standard	Direct	1.0	-	122	28
Option 1	Geared	5.0	-	87	20

Sales/Technical Information: **IQD - Direct Current (DC)**

Gearbox Performance

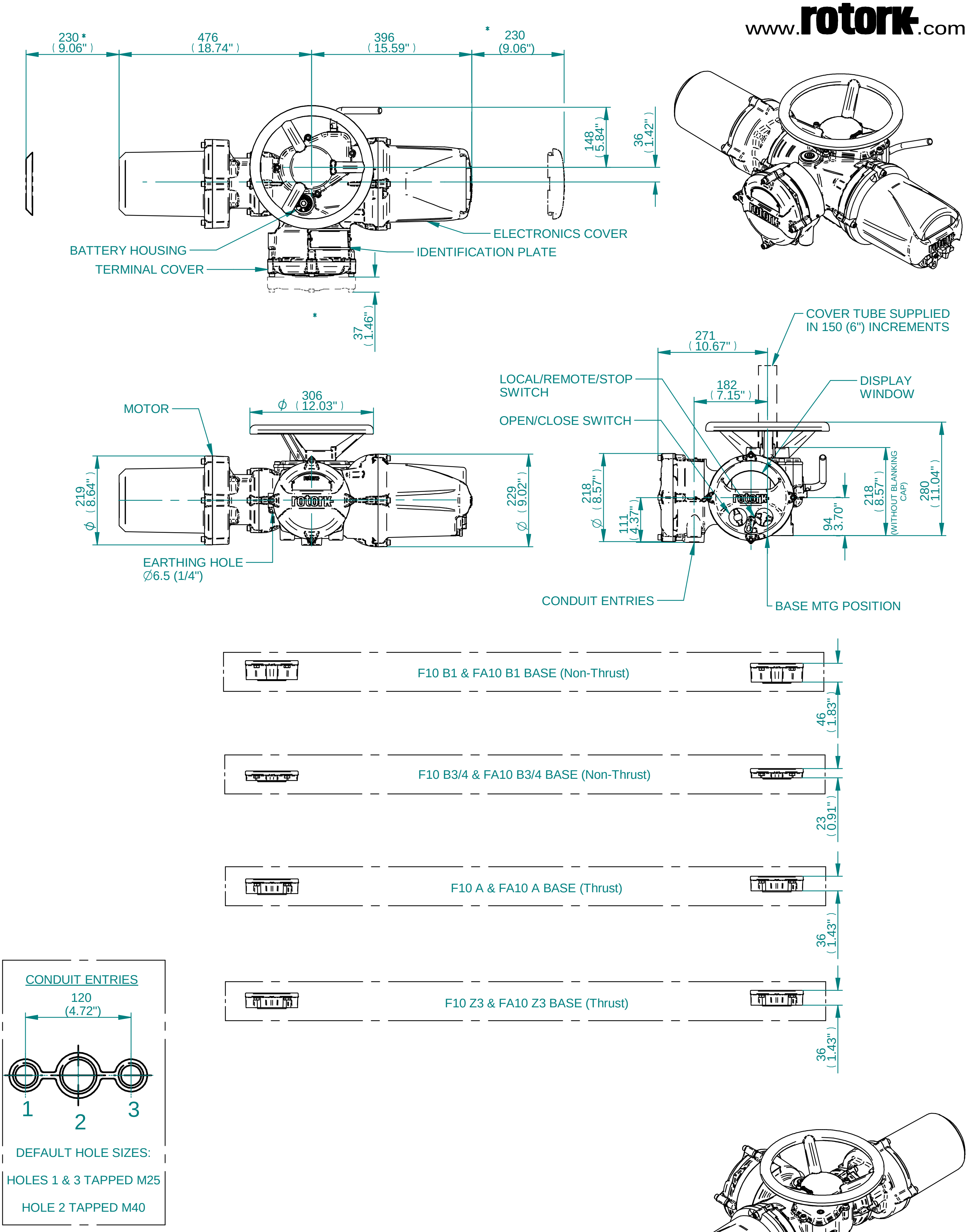
Size	Rated Torque		Ratio	MA	Weight	
	Nm	Lbsft	(:1)		Kg	Lbs
IB4	542	400	6	5.1	16.34	36

Sales/Technical Information: **IB Motorised**

Enter your specific requirements and click 'Add to enquiry'

Fields marked with an * are required.

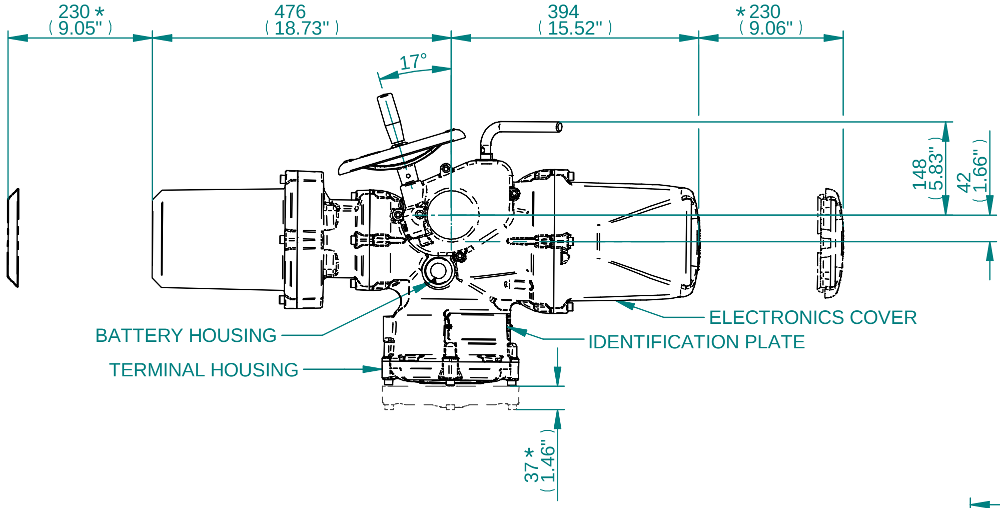
« Go Back

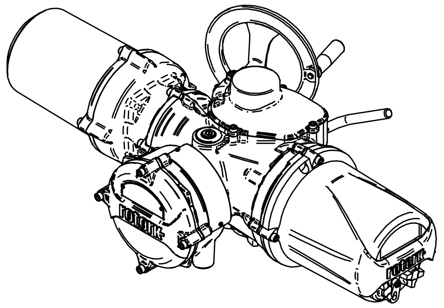


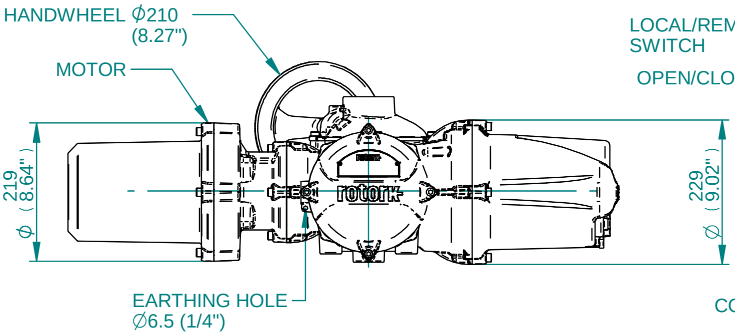
NOTES

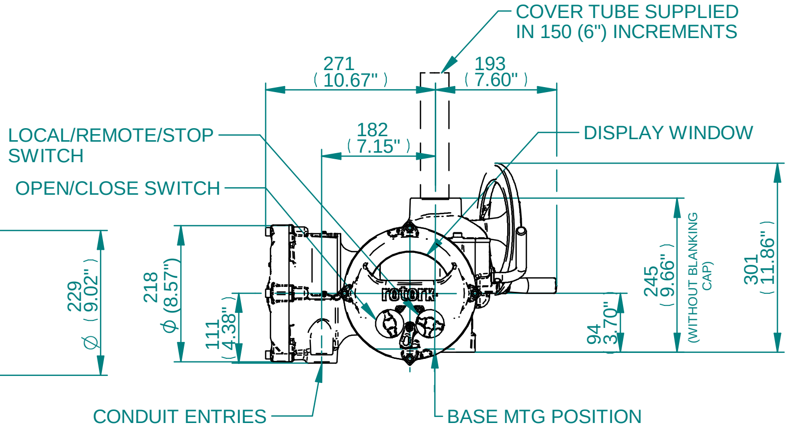
1. FOUR BASE OPTIONS ARE DETAILED TO SUIT THE RELEVANT COUPLING ARRANGEMENT.
2. THE REQUIRED BASE FOR THE SIDE & END VIEWS SHOULD BE LOADED TO MTG POSITION INDICATED.
3. '*' REMOVAL ALLOWANCE REQUIRED.

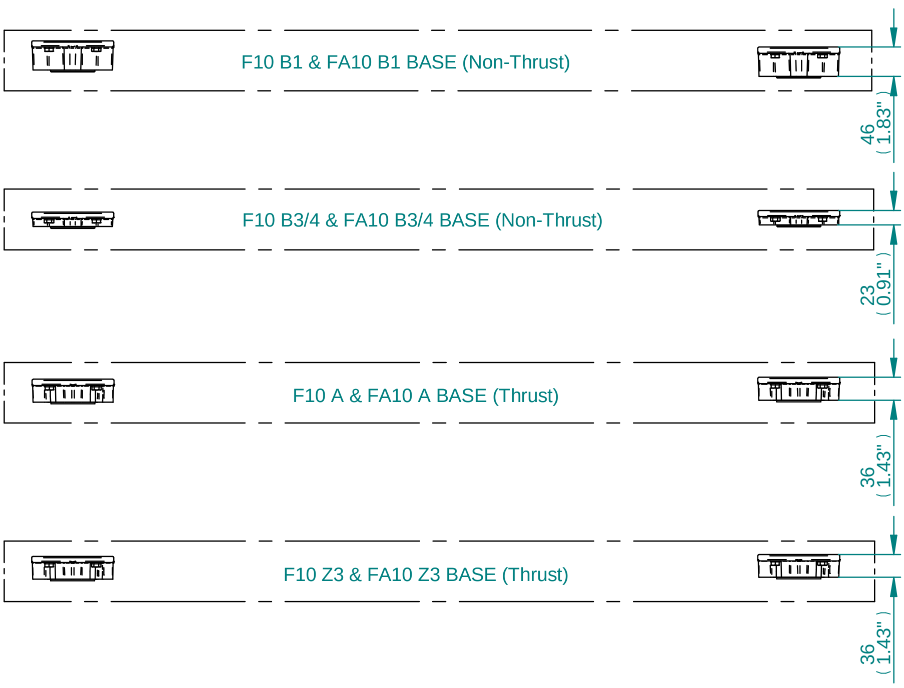
Title	Date	A4 Doc Number	Ver No	Scale	Sheet No
DIMENSIONAL DATA SHEET FOR IQD3 (Sizes 10-18) WITH TOP HANDWHEEL	030215	IQD3-1SP-BC	1	1:12	1 of 4

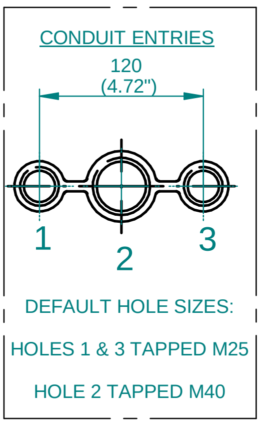


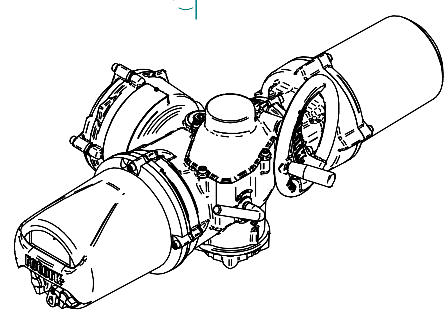








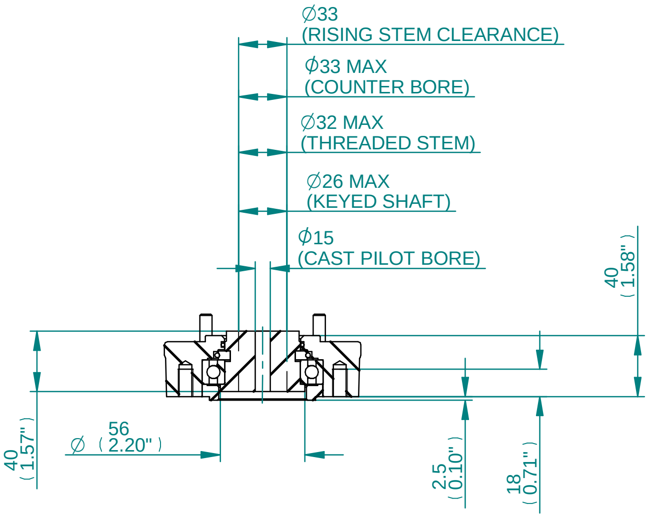




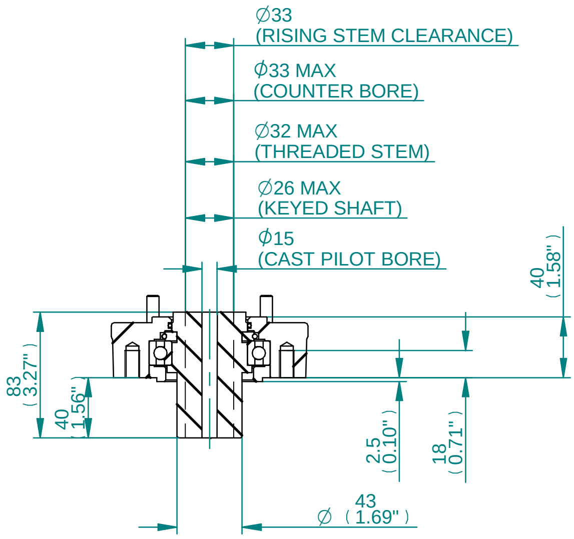
NOTES
1. FOUR BASE OPTIONS ARE DETAILED TO SUIT THE RELEVANT COUPLING ARRANGEMENT.
2. THE REQUIRED BASE FOR THE SIDE & END VIEWS SHOULD BE LOADED TO MTG POSITION INDICATED.
3. '*' REMOVAL ALLOWANCE REQUIRED.

Title	Date	A4 Doc Number	Ver No	Scale	Sheet No
DIMENSIONAL DATA SHEET FOR IQD3 (Sizes 10-18) WITH OPTIONAL SIDE HANDWHEEL	030215	IQD3-1SP-BC	1	1:12	2 of 4

www.rotork.com

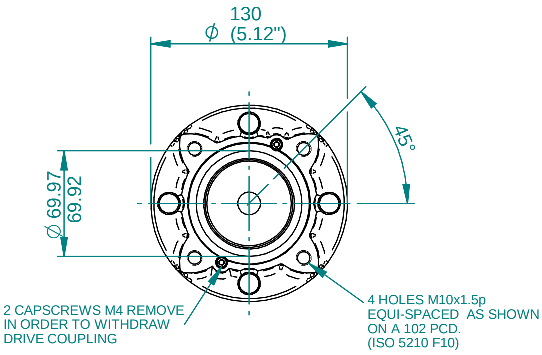


TYPE 'A' COUPLING DETAILS

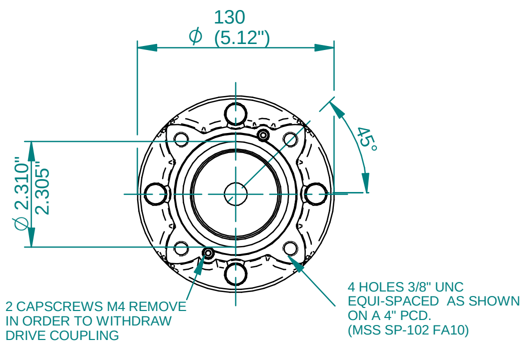


TYPE 'Z3' COUPLING DETIALS

NOTE : COUPLINGS WITHOUT PILOT BORE AVAILABLE IF SPECIFIED WITH ORDER.



F10 BASE DETAILS
FOR 'A' & 'Z3' COUPLINGS



FA10 BASE DETAILS
FOR 'A' & 'Z3' COUPLINGS

IQ3 SIZE 10-18 THRUST BASES

Title	Date	A4 Doc Number	Ver No	Scale	Sheet No
DIMENSIONAL DATA SHEET FOR F10/FA10 BASE & COUPLING OPTIONS	030215	IQD3-1SP-BC	1	1:5	3 of 4

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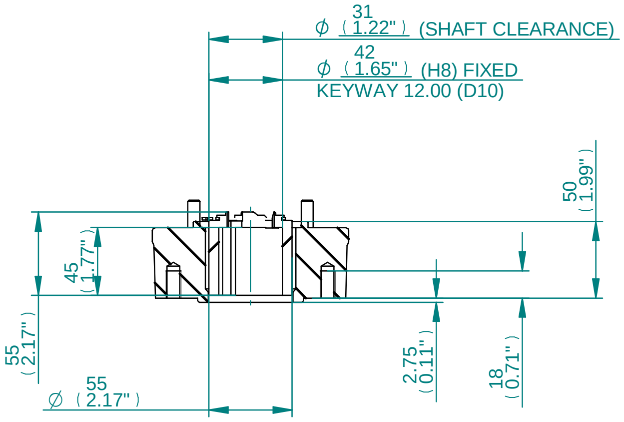
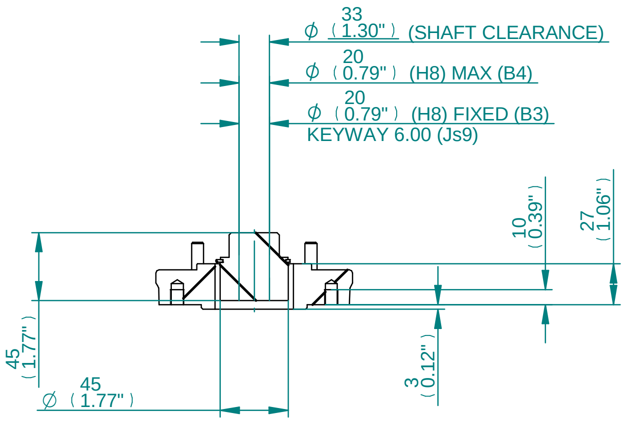
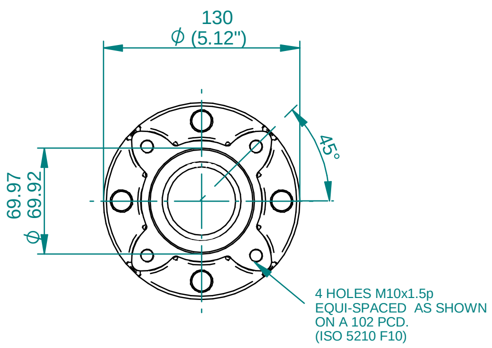


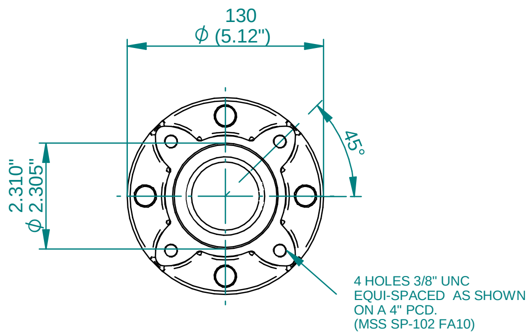
TYPE 'B1'
COUPLING DETAILS



TYPE 'B3/B4'
COUPLING DETAILS



F10 BASE DETAILS
FOR 'B1' & 'B3/B4' COUPLINGS



FA10 BASE DETAILS
FOR 'B1' & 'B3/B4' COUPLINGS

IQ3 SIZE 10-18
NON-THRUST BASES

Title	Date	A4 Doc Number	Ver No	Scale	Sheet No
DIMENSIONAL DATA SHEET FOR F10/FA10 BASE & COUPLING OPTIONS	030215	IQD3-1SP-BC	1	1:5	4 of 4

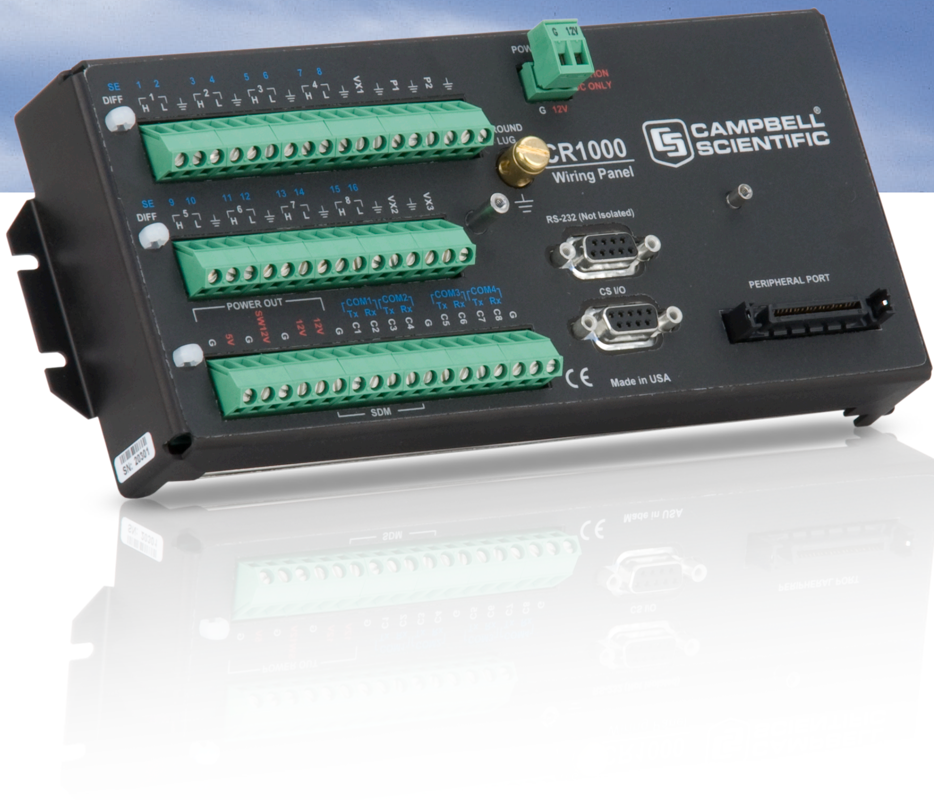
COMPONENT

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

CR1000

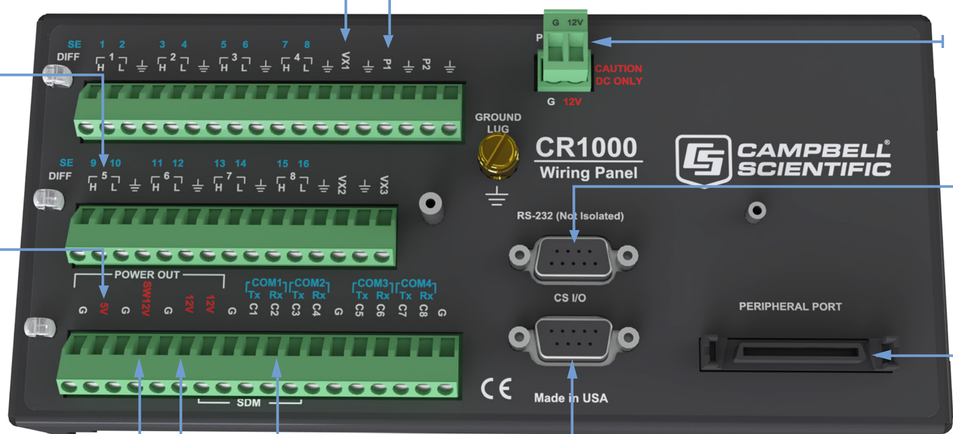
Measurement and Control Datalogger

Rugged, Reliable, and Ready for any Application



CR1000 Measurement and Control Datalogger

The CR1000 provides precision measurement capabilities in a rugged, battery-operated package. It consists of a measurement and control module and a wiring panel. Standard operating range is -25° to +50°C; an optional extended range of -55° to +85°C is available.



Switched Excitation Outputs
Provides programmable excitation for resistive bridge measurements

Analog Inputs
For differential, single-ended, and period averaging measurements

5 V Terminal
For sensor or modem power

Switched 12 V Terminal
For switching power to sensors or communication devices

12 V Terminal
For continuous sensor or modem power

Digital I/O Ports
For controlling external devices, reading SDI-12 sensors or SDM peripherals

Pulse Counters
For measuring switch closures, low-level ac sine waves, or high frequency pulses

Removable Power Terminal
Simplifies connection to external power supply.

RS-232 Port
For connecting battery-powered PCs, serial sensors, or RS-232 modems

Peripheral Port
For Ethernet communications and/or storing data on a CompactFlash card.

CS I/O Port
For connecting to ac-powered PCs and Campbell Scientific peripherals

Benefits and Features

- 4 MB memory*
- Program execution rate of up to 100 Hz
- CS I/O and RS-232 serial ports
- 13-bit analog to digital conversions
- 16-bit H8S Renesas Microcontroller with 32-bit internal CPU architecture
- Temperature compensated real-time clock
- Background system calibration for accurate measurements over time and temperature changes
- Single DAC used for excitation and measurements to give ratio metric measurements
- Gas Discharge Tube (GDT) protected inputs
- Battery-backed SRAM memory and clock ensuring data, programs, and accurate time are maintained while the CR1000 is disconnected from its main power source
- Serial communications with serial sensors and devices supported via I/O port pairs
- PakBus®, Modbus, DNP3, TCP/IP, FTP, and SMTP protocols supported

Measurement and Control Module

The module measures sensors, drives direct communications and telecommunications, reduces data, controls external devices, and stores data and programs in on-board, non-volatile storage. The electronics are RF shielded and glitch protected by the sealed, stainless steel canister. A battery-backed clock assures accurate timekeeping. The module can simultaneously provide measurement and communication functions. The on-board, BASIC-like programming language supports data processing and analysis routines.

Wiring Panel

The CR1000WP is a black, anodized aluminum wiring panel that is compatible with all CR1000 modules. The wiring panel includes switchable 12 V, redistributed analog grounds (dispersed among analog channels rather than grouped), unpluggable terminal block for 12 V connections, gas-tube spark gaps, and 12 V supply on pin 8 to power our COM-series phone modems and other peripherals. The control module easily disconnects from the wiring panel allowing field replacement without rewiring the sensors. A description of the wiring panel's input/output channels follows.

**Originally, the standard CR1000 had 2 MB of data/program storage, and an optional version, the CR1000-4M, had 4 MB of memory. In September 2007, the standard CR1000 started having 4 MB of memory, making the CR1000-4M obsolete. Dataloggers that have a module with a serial number greater than or equal to 11832 will have a 4 MB memory. The 4 MB dataloggers will also have a sticker on the canister stating "4M Memory".*

Analog Inputs
Eight differential (16 single-ended) channels measure voltage levels. Resolution on the most sensitive range is 0.67 µV.

Pulse Counters
Two pulse channels can count pulses from high level (5 V square wave), switch closure, or low level AC signals.

Switched Voltage Excitations
Three outputs provide precision excitation voltages for resistive bridge measurements.

Digital I/O Ports
Eight ports are provided for frequency measurements, digital control, and triggering. Three of these ports can also be used to measure SDM devices. The I/O ports can be paired as transmit and receive. Each pair has 0 to 5 V UART hardware that allows serial communications with serial sensors and devices. An RS-232-to-logic level converter may be required in some cases.

CS I/O Port
AC-powered PCs and many communication peripherals connect with the CR1000 via this port. Connection to an AC-powered PC requires either an SC32B or SC-USB interface. These interfaces isolate the PC's electrical system from the datalogger, thereby protecting against ground loops, normal static discharge, and noise.

RS-232 Port
This non-isolated port is for connecting a battery-powered laptop, serial sensor, or RS-232 modem. Because of ground loop potential on some measurements (e.g., low level single-ended measurements), AC-powered PCs should use the CS I/O port instead of the RS-232 port (see above).

Peripheral Port
One 40-pin port interfaces with the NL116 Ethernet Interface and CompactFlash Module, the NL121 Ethernet Interface, or the CFM100 CompactFlash® Module.

Switched 12 Volt
This terminal provides unregulated 12 V that can be switched on and off under program control.

Storage Capacity
The CR1000 has 2 MB of flash memory for the Operating System, and 4 MB of battery-backed SRAM for CPU usage, program storage, and data storage. Data is stored in a table format. The storage capacity of the CR1000 can be increased by using a CompactFlash card.

Enclosure/Stack Bracket
A CR1000 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The 31551 and 31143 stack brackets allow a peripheral to be placed under the mounting bracket, thus conserving space. The 31143 is hinged, allowing easy access to the lower component during wiring or during maintenance.

Communication Protocols
The CR1000 supports the PakBus, Modbus, DNP3, TCP/IP, FTP, and SMTP communication protocols. With the PakBus protocol, networks have the distributed routing intelligence to continually evaluate links. Continually evaluating links optimizes delivery times and, in the case of delivery failure, allows automatic switch over to a configured backup route.

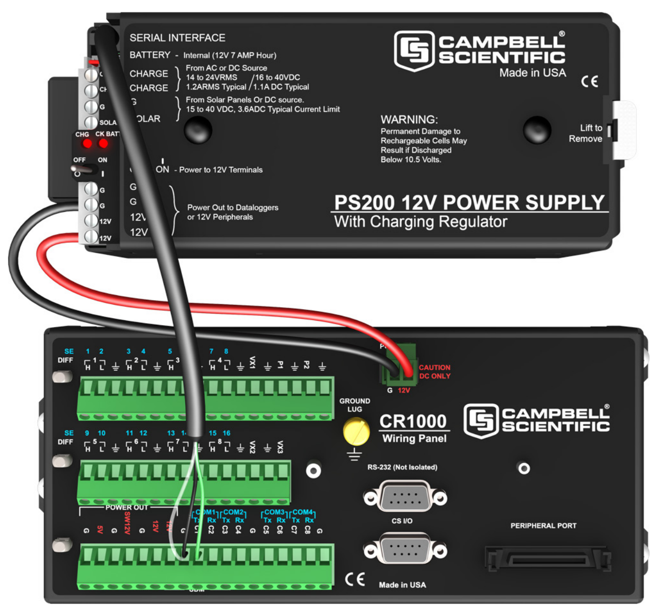
The Modbus RTU protocol supports both floating point and long formats. The datalogger can act as a slave and/or master.

The DNP3 protocol supports only long data formats. The dataloggers are level 2 slave compliant, with some of the operations found in a level 3 implementation.

The TCP/IP, FTP, and SMTP protocols provide TCP/IP functionality when the CR1000 is used in conjunction with an NL240, NL201, NL116, or NL121. Refer to the CR1000 manual for more information.

Power Supplies
Typically, the CR1000 is powered with a PS200, PS150, or BPALK. The PS200 and PS150 provide a 7 Ah sealed rechargeable battery that should be connected to a charging source (either a power converter or solar panel). The BPALK consists of eight non-rechargeable D-cell alkaline batteries with a 7.5 Ah rating at 20°C.

Also available are the BP7, BP12, and BP24 battery, which provide nominal ratings of 7, 12, and 24 Ah, respectively. The BP7 is typically used instead of the PS150 or PS200 when the battery needs to be mounted under the 31143 Hinged Stack Bracket. The BP12 and BP24 batteries are for powering systems that have higher current drain equipment such as satellite transmitters. The BP7, BP12, and BP24 should be connected to a regulated charging source (e.g., a CH200 or CH150 connected to a unregulated solar panel or power converter).



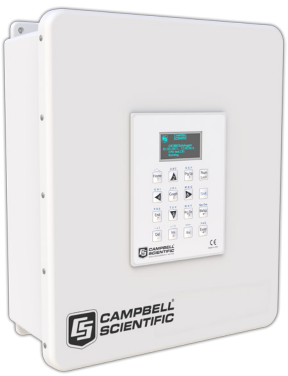
The PS200 (above) and CH200 can monitor charge input voltage, battery voltage, on-board temperature, battery current, and load current.

Communication Options

To determine the best option for an application, consider the accessibility of the site, availability of services (e.g., cellular phone or satellite coverage), quantity of data to collect, and desired time between data-collection sessions. Some communication options can be combined—increasing the flexibility, convenience, and reliability of the communications.

Keyboard Display
The CR1000KD can be used to program the CR1000, manually initiate data transfer, and display data. The CR1000KD displays 8 lines by 21 characters (64 by 128 pixels) and has a 16-character keyboard. Custom menus are supported allowing customers to set up choices within the datalogger program that can be initiated by a simple toggle or pick list. One CR1000KD can be carried station to station in a CR1000 network.

Mountable Displays
The CD100 and CD295 can be mounted in an enclosure lid. The CD100 has the same functionality and operation as the CD1000KD, allowing both data entry and display without opening the enclosure. The CD295 displays real-time data only.



The CD100 has a vacuum flourescent display for responsive use through a very wide operating temperature range.

iOS Devices and Android Devices
An iOS device or Android device can communicate with the datalogger or connect to the LoggerNet network using Apps available, at no charge, from the Apple Store or Google Play.

Direct Links
AC-powered PCs connect with the datalogger's CS I/O port using an SC32B or SC-USB interface. These interfaces provide optical isolation. A battery-powered laptop can be attached to the CR1000's RS-232 port via an RS-232 cable—no interface required.

External Data Storage Devices
A CFM100 or NL116 module can store the CR1000's data on an industrial-grade CompactFlash (CF) card. The CR1000 can also store data on an SC115 2 GB Flash Memory Drive.

Short Haul Modems
The SRM-5A RAD Short Haul Modem supports communications between the CR1000 and a PC using a four-wire unconditioned line (two twisted pairs).

Multidrop Interface
The MD485 intelligent RS-485 interface permits a PC to address and communicate with one or more dataloggers over the CABLE2TP two-twisted pair cable. Distances up to 4000 feet are supported.

Internet and IP Networks
Campbell Scientific offers several interfaces that enable the CR1000 to communicate with a PC using TCP/IP.

Radios
Radio frequency (RF) communications are supported using narrowband UHF, narrowband VHF, spread spectrum, or meteor burst radios. Line-of-sight is required for all of our RF options.

Satellite Transmitters
The CR1000 can transmit data using the Argos, Iridium, Inmarsat BGAN, GOES, or Meteosat satellite systems. Satellite telemetry offers an alternative for remote locations where phone lines or RF systems are impractical.

Telephone Networks
The CR1000 can communicate with a PC using landlines or cellular transceivers. A voice synthesized modem enables anyone to call the CR1000 via phone and receive a verbal report of real-time site conditions.

In Virginia, our RF500M Narrowband Radio Modem provides time- and event-driven ALERT data transmission.

Channel Expansion

4-Channel Low Level AC Module

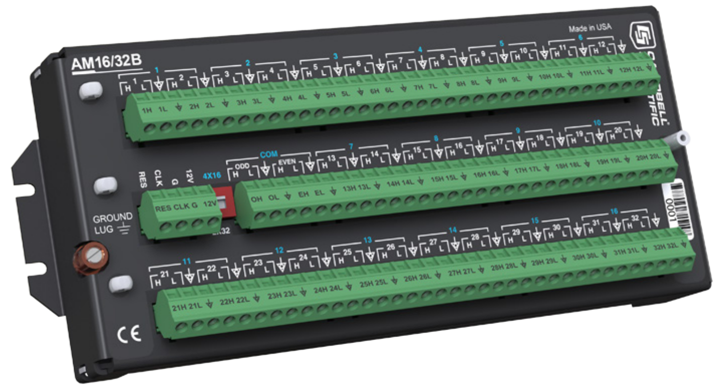
The LLAC4 is a small peripheral device that allows customers to increase the number of available low-level ac inputs by using control ports. This module is often used to measure up to four anemometers, and is especially useful for wind profiling applications.

Synchronous Devices for Measurement (SDMs)

SDMs are addressable peripherals that expand the datalogger's measurement and control capabilities. For example, SDMs are available to add control ports, analog outputs, pulse count channels, interval timers, or even a CANbus interface to the system. Multiple SDMs, in any combination, can be connected to one datalogger.

Multiplexers

Multiplexers increase the number of sensors that can be measured by a CR1000 by sequentially connecting each sensor to the datalogger. Several multiplexers can be controlled by a single CR1000.



The CR1000 is compatible with the AM16/32B (shown above) and AM25T multiplexers.

Software

Starter Software

Our easy-to-use starter software is intended for first time users or applications that don't require sophisticated communications or datalogger program editing. SCWin Short Cut generates straight-forward datalogger programs in four easy steps. PC200W allows customers to transfer a program to, or retrieve data from a CR1000 via a direct communications link.

At www.campbellsci.com/downloads, the starter software can be downloaded at no charge. Our Resource DVD also provides this software as well as PDF versions of our brochures and manuals.

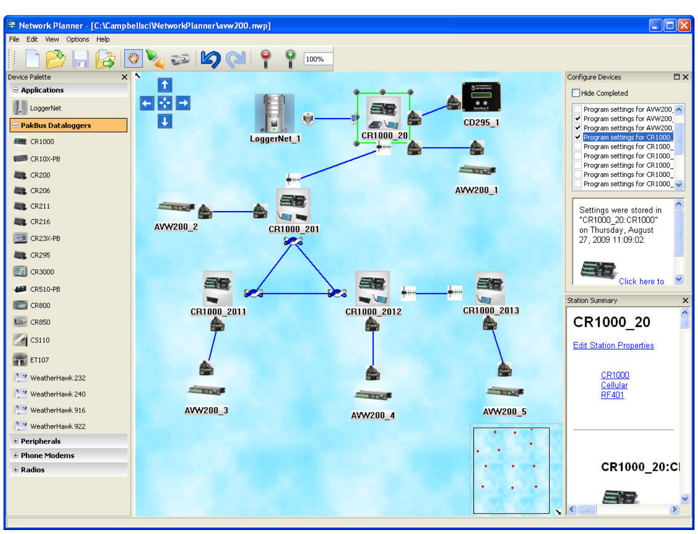
Datalogger Support Software

Our datalogger support software packages provide more capabilities than our starter software. These software packages contains program editing, communications, and display tools that can support an entire datalogger network.

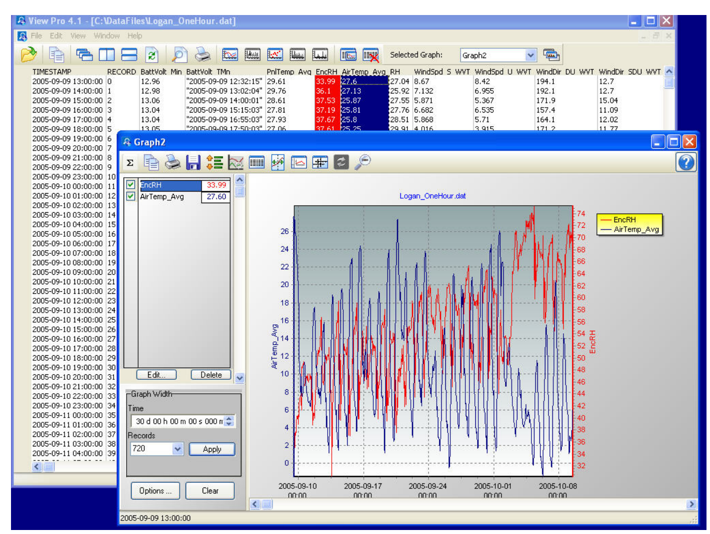
PC400, our mid-level software, supports a variety of telemetry options, manual data collection, and data display. For programming, it includes both Short Cut and the CRBasic program editor. PC400 does not support combined communication options (e.g., phone-to-RF), PakBus® routing, and scheduled data collection.

RTDAQ is an ideal solution for industrial and real-time users desiring to use reliable data collection software over a single telecommunications medium, and who do not rely on scheduled data collection. RTDAQ's strength lies in its ability to handle the display of high speed data.

LoggerNet is Campbell Scientific's full-featured datalogger support software. It is referred to as "full-featured" because it provides a way to accomplish almost all the tasks you'll need to complete when using a datalogger. LoggerNet supports combined communication options (e.g., phone-to-RF) and scheduled data collection.



The Network Planner, included in LoggerNet 4 or higher, generates device settings and configures the LoggerNet network map for PakBus networks.



Both LoggerNet and RTDAQ use View Pro to display historical data in a tabular or graphical format.

Applications

The measurement precision, flexibility, long-term reliability, and economical price of the CR1000 make it ideal for scientific, commercial, and industrial applications.

Meteorology

The CR1000 is used in long-term climatological monitoring, meteorological research, and routine weather measurement applications.

Our rugged, reliable weather station measures meteorological conditions at St. Mary's Lake, Glacier National Park, MT.

Sensors the CR1000 can measure include:

- cup, propeller, and sonic anemometers
- tipping bucket rain gages
- wind vanes
- pyranometers
- ultrasonic ranging sensor
- thermistors, RTDs, and thermocouples
- barometers
- RH probes
- Cooled mirror hygrometers

Agriculture and Agricultural Research

The versatility of the CR1000 allows measurement of agricultural processes and equipment in applications such as:

- plant water research
- canopy energy balance
- plant pathology
- machinery performance
- frost prediction
- crop management decisions
- food processing/storage
- integrated pest management
- irrigation scheduling

This vitaculture site in Australia integrates meteorological, soil, and crop measurements.

Wind Profiling

Our data acquisition systems can monitor conditions at wind assessment sites, at producing wind farms, and along transmission lines. The CR1000 makes and records measurements, controls electrical devices, and can function as PLCs or RTUs. Because the datalogger has its own power supply (batteries, solar panels), it can continue to measure and store data and perform control during power outages. Typical sensors for wind assessment applications include, but are not limited to:

- cup, propeller, and sonic anemometers (up to 10 anemometers can be measured by using two LLAC4 peripherals)
- wind vanes
- thermistors, RTDs, and thermocouples
- barometers
- pyranometers

For turbine performance applications, the CR1000 monitors electrical current, voltage, wattage, stress, and torque.

A Campbell Scientific system monitors an offshore wind farm in North Wales.

Photo courtesy npower renewables

Soil Moisture

The CR1000 are compatible with the following soil moisture measurement technologies:

- **Soil moisture blocks** are inexpensive sensors that estimate soil water potential.
- **Matric water potential sensors** also estimate soil water potential but are more durable than soil moisture blocks.
- **Time-Domain Reflectometry Systems (TDR)** use a reflectometer controlled by the datalogger to accurately measure soil water content. Multiplexers allow sequential measurement of a large number of probes by one reflectometer.
- **Self-contained water content reflectometers** are sensors that emit and measure a TDR pulse.
- **Tensiometers** measure the soil pore pressure of irrigated soils and calculate soil moisture.

Air Quality

The CR1000 can monitor and control gas analyzers, particle samplers, and visibility sensors. The datalogger can also automatically control calibration sequences and compute conditional averages that exclude invalid data (e.g., data recorded during power failures or calibration intervals).

Road Weather/RWIS

Our fully NTCIP-compliant Environmental Sensor Stations (ESS) are robust, reliable weather stations used for road weather/RWIS applications. A typical ESS includes a tower, CR1000, two road sensors, remote communication hardware, and sensors that measure wind speed and direction, air temperature, humidity, barometric pressure, solar radiation, and precipitation.

Water Resources/Aquaculture

Our CR1000 is well-suited to remote, unattended monitoring of hydrologic conditions. Most hydrologic sensors, including SDI-12 probes, interface directly to the CR1000.

Typical hydrologic measurements:

- **Water level** is monitored with incremental shaft encoders, double bubblers, ultrasonic ranging sensors, resistance tapes, strain gage pressure transducers, or vibrating wire pressure transducers. Vibrating wire transducers require an CDM-VW300-series, AVW200-series or another vibrating wire interface.
- **Well draw-down tests** use a pressure transducer measured at logarithmic intervals or at a rate based on incremental changes in water level.
- **Ionic conductivity measurements** use one of the switched excitation ports from the datalogger.
- **Samplers** are controlled by the CR1000 as a function of time, water quality, or water level.
- **Alarm and pump actuation** are controlled through digital I/O ports that operate external relay drivers

A turbidity sensor was installed in a tributary of the Cedar River watershed to monitor water quality conditions for Seattle, Washington.

Vehicle Testing

This versatile, rugged datalogger is ideally suited for testing cold and hot temperature, high altitude, off-highway, and cross-country performance. The CR1000 is compatible with our SDM-CAN interface and GPS16X-HVS receiver.

Vehicle monitoring includes not only passenger cars, but airplanes, locomotives, helicopters, tractors, buses, heavy trucks, drilling rigs, race cars, and motorcycles.

The CR1000 can measure:

- **Suspension**—strut pressure, spring force, travel, mounting point stress, deflection, ride.
- **Fuel system**—line and tank pressure, flow, temperature, injection timing.
- **Comfort control**—ambient and supply air temperature, solar radiation, fan speed, ac on and off, refrigerant pressures, time-to-comfort, blower current.
- **Brakes**—line pressure, pedal pressure and travel, ABS, line and pad temperature.
- **Engine**—pressure, temperature, crank position, RPM, time-to-start, oil pump cavitation.
- **General vehicle**—chassis monitoring, road noise, vehicle position and speed, steering, air bag, hot/cold soaks, wind tunnels, traction, CANbus, wiper speed and current, vehicle electrical loads.

Other Applications

- Eddy covariance systems
- Wireless sensor/datalogger networks
- Fire weather
- Geotechnical
- Mesonet systems
- Avalanche forecasting, snow science, polar, high altitude
- Historic preservation

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every three years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE

10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)

8 differential (DF) or 16 single-ended (SE) individually configuredinput channels. Channel expansion provided by optional analog multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single A/D conversion. A DIFF measurement with input reversal has better (finer) resolution by twice than Basic Res.

Range (mV)[1]	*DF Res (µV)*[2]	*Basic Res (µV)*
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.
[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C (-XT only)

[3]Accuracy does not include the sensor and measurement noise. Offsets are defined as:
Offset for DF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

ANALOG MEASUREMENT SPEED:

Integration Type/Code	*Integra-tion Time*	*Settling Time*	*Total Time*[4] *SE w/ No Rev*	*Total Time*[4] *DF w/ Input Rev*
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[5]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[5]	20.00 ms	3 ms	~25 ms	~50 ms

[4]Includes 250 µs for conversion to engineering units.
[5]AC line noise filter.

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range (digital resolution dominates for higher ranges).
250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

INPUT LIMITS: ±5 Vdc

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

INPUT VOLTAGE RANGE W/O MEASUREMENT CORRUPTION: ±8.6 Vdc max.

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 GΩ typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT only)

ANALOG OUTPUTS (VX1-VX3)

3 switched voltage, sequentially active only during measurement.

RANGE AND RESOLUTION:

Channel	*Range*	*Resolution*	*Current Source/Sink*
(VX 1–3)	±2.5 Vdc	0.67 mV	±25 mA

ANALOG OUTPUT ACCURACY (VX):
±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

VX FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

PERIOD AVERAGE

Any of the 16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	*Input Range (±mV)*	*Signal (peak to peak) Min. (mV)*[6]	*Signal (peak to peak) Max (V)*[7]	*Min Pulse Width (µV)*	*Max*[8] *Freq (kHz)*
1	250	500	10	2.5	200
10	25	10	2	10	50
33	7.5	5	2	62	8
100	2.5	2	2	100	5

[6]Signal centered around Threshold (see PeriodAvg() instruction).
[7]With signal centered at the datalogger ground.
[8]The maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

RATIOMETRIC MEASUREMENTS

MEASUREMENT TYPES: Provides ratiometric resistance measurements using voltage excitation. 3 switched voltage excitation outputs are available for measurement of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Optional excitation polarity reversal minimizes dc errors.

RATIOMETRIC MEASUREMENT ACCURACY:[9,10, 11]
±(0.04% of Voltage Measurement + Offset)

[9]Accuracy specification assumes excitation reversal for excitation voltages < 1000 mV. Assumption does not include bridge resistor errors and sensor and measurement noise.
[10]Estimated accuracy, ΔX (where X is value returned from the measurement with Multiplier = 1, Offset = 0):
BrHalf() instruction: $\Delta X = \Delta V_1/V_X$
BrFull() instruction $\Delta X = 1000 \cdot \Delta V_1/V_X$, expressed as mV•V⁻¹.
ΔV^{-1} is calculated from the ratiometric measurement accuracy. See Resistance Measurements Section in the manual for more information.
[11]Offsets are defined as:
Offset for DIFF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DIFF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3•Basic Res + 3.0 µV
Excitation reversal reduces offsets by a factor of two.

PULSE COUNTERS (P1-P2)

2 inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

MAXIMUM COUNTS PER SCAN: 16.7×10^6

SWITCH CLOSURE MODE:
Minimum Switch Closed Time: 5 ms
Minimum Switch Open Time: 6 ms
Max. Bounce Time: 1 ms open w/o being counted

HIGH-FREQUENCY PULSE MODE:
Maximum Input Frequency: 250 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW-LEVEL AC MODE: Internal ac coupling removes ac offsets up to ±0.5 Vdc.
Input Hysteresis: 12 mV RMS @ 1 Hz
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine Wave (mV RMS)	*Range(Hz)*
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

DIGITAL I/O PORTS (C1-C8)

8 ports software selectable, as binary inputs or control outputs. Provide on/off, pulse width modulation, edge timing, subroutine interrupts / wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), and SDI-12 communications. SDM communications are also supported.

LOW FREQUENCY MODE MAX: <1 kHz

HIGH-FREQUENCY MODE MAX: 400 kHz

SWITCH-CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1

OUTPUT RESISTANCE: 330 Ω

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kΩ with inputs <6.2 Vdc
220 Ω with inputs ≥6.2 Vdc

SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

SWITCHED 12 VDC (SW-12)

1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA at 20°C, 650 mA at 50°C, 360 mA at 85°C.

EU DECLARATION OF COMPLIANCE

https://s.campbellsci.com/documents/us/compliance/eudoc_cr1000-series.pdf
https://s.campbellsci.com/documents/us/compliance/eudoc_cr1000kd.pdf

COMMUNICATIONS

RS-232 PORTS:
DCE 9-pin: (not electrically isolated) for computer connection or connection of modems not manufactured by Campbell Scientific.
COM1 to COM4: 4 independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART
Baud Rates: selectable from 300 bps to 115.2 kbps.
Default Format: 8 data bits; 1 stop bits; no parity
Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with telecommunications peripherals manufactured by Campbell Scientific.

SDI-12: Digital control ports C1, C3, C5, and C7 are individually configured and meet SDI-12 Standard v 1.3 for datalogger mode. Up to 10 SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, AES-128 Encrypted PakBus, Modbus, DNP3, FTP, HTTP, XML, HTML, POP3, SMTP, Telnet, NTCIP, NTP, Web API, SDI-12, SDM.

SYSTEM

PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core running at 7.3 MHz)

MEMORY: 2 MB of flash for operating system; 4 MB of battery-backed SRAM for CPU usage and final data storage; 512 kB flash disk (CPU) for program files.

REAL-TIME CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

REAL-TIME CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

EXTERNAL BATTERIES: Optional 12 Vdc nominal alkaline and rechargeable available. Power connection is reverse polarity protected.

TYPICAL CURRENT DRAIN at 12 Vdc:
Sleep Mode: < 1 mA
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 6 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 20 mA
Active external keyboard display adds 7 mA (100 mA with backlight on).

PHYSICAL

DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in); additional clearance required for cables and leads.

MASS/WEIGHT: 1 kg / 2.1 lb

WARRANTY

3 years against defects in materials and workmanship.

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every three years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE
10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)
8 differential (DF) or 16 single-ended (SE) individually configuredinput channels. Channel expansion provided by optional analog multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single A/D conversion. A DIFF measurement with input reversal has better (finer) resolution by twice than Basic Res.

Range (mV)[1]	*DF Res (µV)*[2]	*Basic Res (µV)*
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.
[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C (-XT only)

[3]Accuracy does not include the sensor and measurement noise. Offsets are defined as:
Offset for DF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

ANALOG MEASUREMENT SPEED:

Integration Type/Code	*Integration Time*	*Settling Time*	*Total Time*[4] *SE w/ No Rev*	*DF w/ Input Rev*
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[5]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[5]	20.00 ms	3 ms	~25 ms	~50 ms

[4]Includes 250 µs for conversion to engineering units.
[5]AC line noise filter.

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range (digital resolution dominates for higher ranges).
250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

INPUT LIMITS: ±5 Vdc

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

INPUT VOLTAGE RANGE W/O MEASUREMENT CORRUPTION: ±8.6 Vdc max.

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 GΩ typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT only)

ANALOG OUTPUTS (VX1-VX3)
3 switched voltage, sequentially active only during measurement.

RANGE AND RESOLUTION:

Channel	*Range*	*Resolution*	*Current Source/Sink*
(VX 1–3)	±2.5 Vdc	0.67 mV	±25 mA

ANALOG OUTPUT ACCURACY (VX):
±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

VX FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

PERIOD AVERAGE
Any of the 16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	*Input Range (±mV)*	*Signal (peak to peak)* *Min. (mV)*[6]	*Max (V)*[7]	*Min Pulse Width (µV)*	*Max*[8] *Freq (kHz)*
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[6]Signal centered around Threshold (see PeriodAvg() instruction).
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MEASUREMENT TYPES: Provides ratiometric resistance measurements using voltage excitation. 3 switched voltage excitation outputs are available for measurement of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Optional excitation polarity reversal minimizes dc errors.

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Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

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Input Hysteresis: 12 mV RMS @ 1 Hz
Maximum ac Input Voltage: ±20 V
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Sine Wave (mV RMS)	*Range(Hz)*
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8 ports software selectable, as binary inputs or control outputs. Provide on/off, pulse width modulation, edge timing, subroutine interrupts / wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), and SDI-12 communications. SDM communications are also supported.

LOW FREQUENCY MODE MAX: <1 kHz

HIGH-FREQUENCY MODE MAX: 400 kHz

SWITCH-CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

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OUTPUT RESISTANCE: 330 Ω

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kΩ with inputs <6.2 Vdc
220 Ω with inputs ≥6.2 Vdc

SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

SWITCHED 12 VDC (SW-12)
1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA at 20°C, 650 mA at 50°C, 360 mA at 85°C.

EU DECLARATION OF COMPLIANCE
https://s.campbellsci.com/documents/us/compliance/eudoc_cr1000-series.pdf
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PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core running at 7.3 MHz)

MEMORY: 2 MB of flash for operating system; 4 MB of battery-backed SRAM for CPU usage and final data storage; 512 kB flash disk (CPU) for program files.

REAL-TIME CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

REAL-TIME CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS
VOLTAGE: 9.6 to 16 Vdc

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

EXTERNAL BATTERIES: Optional 12 Vdc nominal alkaline and rechargeable available. Power connection is reverse polarity protected.

TYPICAL CURRENT DRAIN at 12 Vdc:
Sleep Mode: < 1 mA
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 6 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 20 mA
Active external keyboard display adds 7 mA (100 mA with backlight on).

PHYSICAL
DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in); additional clearance required for cables and leads.

MASS/WEIGHT: 1 kg / 2.1 lb

WARRANTY
3 years against defects in materials and workmanship.

13855

Quick Links

Overview

The 13855 push-to-talk switch allows a customer an easy method for keying up a radio. The 13855 attaches to a square 10-position connector on the radio-to-modem cable that is supplied with the radio (for example, pn 29201). Pressing the button grounds the radio push-to-talk (PTT) line, which causes the radio to transmit the carrier frequency. This process is useful during radio maintenance and for troubleshooting. For example, it allows a user to sustain a transmission while measuring the forward and reflected radio transmit power with a watt meter.

Images

Specifications

Connector	Square, 10-pin (2x5), 0.100 inch pitch, male
Button	Metal dome button with overlay

Compatibility

The 13855 is compatible with the 29201, 13547, and 12160 cables.

Listed Under

Other Accessories for the following products:

- **RF304** - UHF Radio Transceiver
- **RF302** - UHF Radio Transceiver
- **RF300** - VHF Radio Transceiver
- **RF301** - VHF Radio Transceiver
- **RF303** - UHF Radio Transceiver
- **RF310** - VHF Radio Transceiver
- **RF312** - UHF Radio Transceiver
- **RF313** - UHF Radio Transceiver
- **RF323** - UHF Radio Transceiver
- **RF321** - UHF Radio Transceiver
- **RF320** - VHF Radio Transceiver
- **RF322** - UHF Radio Transceiver

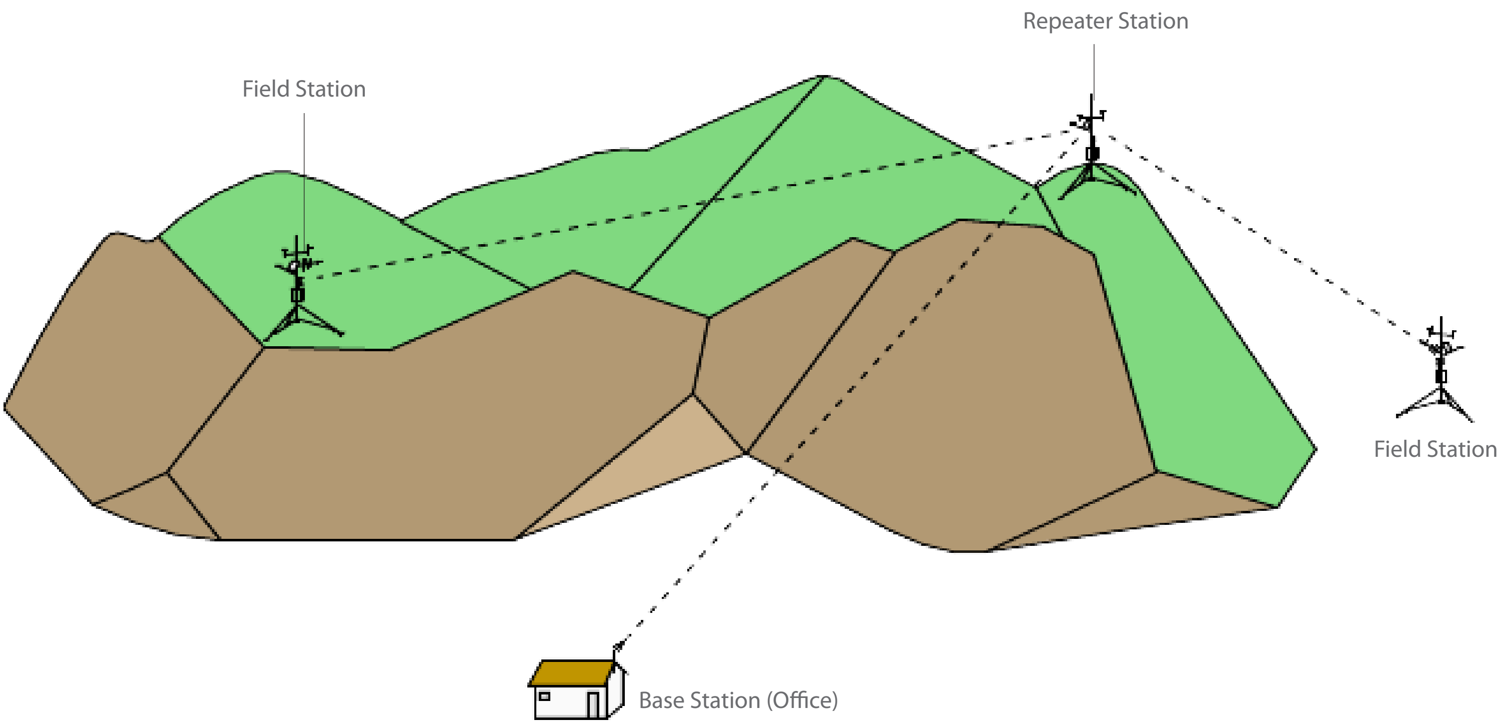
CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

Narrowband RF Networks

for remote wireless communications

Stable, long-range,wireless communication

Using narrowband, licensed, UHF/VHF radios



Overview

Campbell Scientific's radiotelemetry (RF) systems support data retrieval from moving vehicles or remote areas where communication via cables is impractical.

Data from field stations are retrieved at a computer base station. The base station can communicate with up to 254 remote stations over a single frequency. A phone modem can also access an RF network.

Field stations and repeater stations can be located to allow communication over long distances and rough terrain. The maximum distance between any two communicating stations is approximately 25 miles and must be line-of-sight (unobstructed by mountains, large buildings, etc.). Longer distances and rough terrain may require intermediate repeater station(s).

RF data transmission hardware includes radios, antennas, and radio modems. Power at the field and repeater stations is provided by sealed rechargeable batteries trickle-charged by solar or ac power.

Benefits and Features

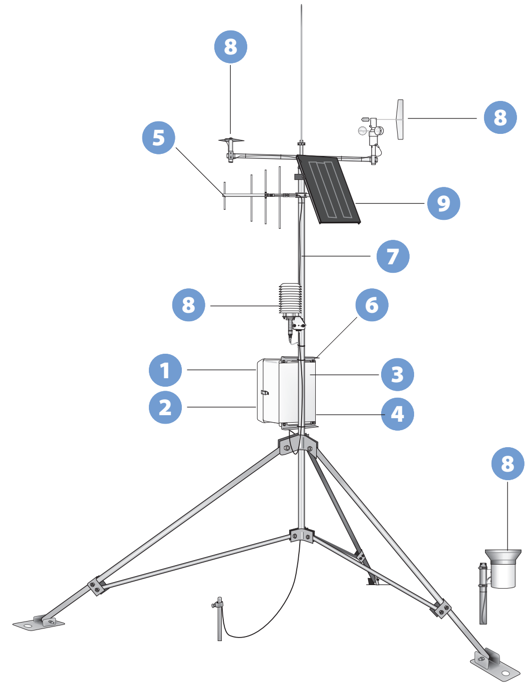
- Measurement sites can be located in areas without phone lines or cellular coverage
- Eliminates cables and cable costs
- Supports local and remote data retrieval
- Allows remote control of datalogger functions

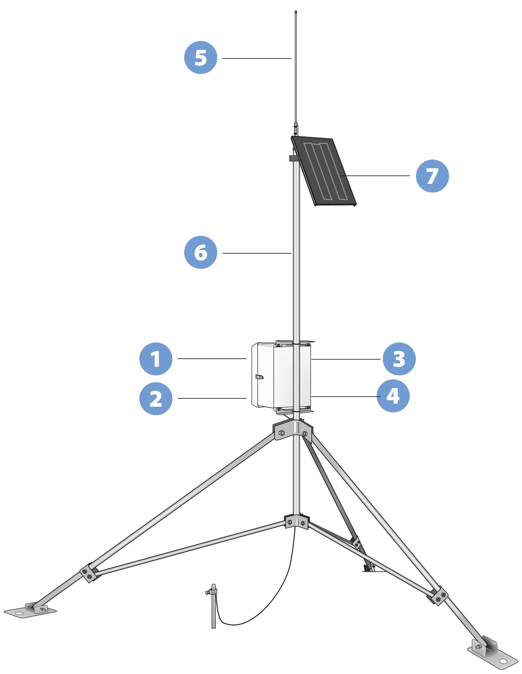
Before ordering radios and antennas, you must submit an application to the Federal Communications Commission (FCC) to acquire an FCC license and be assigned a frequency range. To file for an FCC license on-line, go to http://wireless.fcc.gov/uls and register. Canadian DOC approval is available for radios in the 138 to 174 MHz and 403 to 470 MHz frequency bands only.

Field Station Components

Field stations are located at the measurement site. They can also act as a repeater to extend the range of the network.

1. Datalogger
2. Power supply (5 Ah minimum)
3. RF500M Radio Modem
4. Radio transceiver such as the RF320, RF321, RF322, or RF323
5. Antenna (Yagi directional antenna shown) and antenna cable
6. Environmental enclosure
7. Tripod or tower
8. Sensors and sensor mounts
9. Solar Panel (optional)





Repeater Station Components

Repeater stations act as communication relays between stations that cannot communicate directly due to distance or obstacles.

1. RF500M Radio Modem
2. Radio transceiver such as the RF320, RF321, RF322, or RF323
3. Power supply with charging regulator and null modem ports such as an A100 adapter connected to a CH150 regulator and a user-supplied rechargeable battery
4. Environmental enclosure
5. Omnidirectional antenna and antenna cable
6. Tripod or tower
7. Solar Panel

Computer Base Station Components

Base stations support attended and unattended retrieval of the field station's data and provide communication error checking and data processing. AC power is required. Base stations should contain:

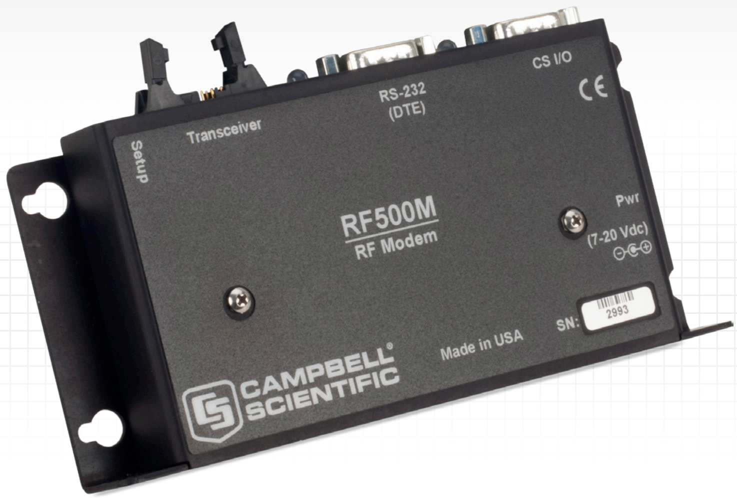
- RF500B Base Station or the RF500M modem and power supply
- Radio transceiver such as the RF320, RF321, RF322, or RF323
- PC running LoggerNet Datalogger Support Software
- Antenna (directional or omnidirectional) and antenna cable

Power Considerations

The location of your site, number of calls, and length of calls affect the power requirements of your system. Information on analyzing your system's power requirements is provided in our Power Supply Overview brochure and the Power Supply application note. You can also contact an applications engineer who will help you determine an appropriate power supply for your system.

CAMPBELL® SCIENTIFIC
WHEN MEASUREMENTS MATTER

RF500M
Radio Modem



Versatile radio modem

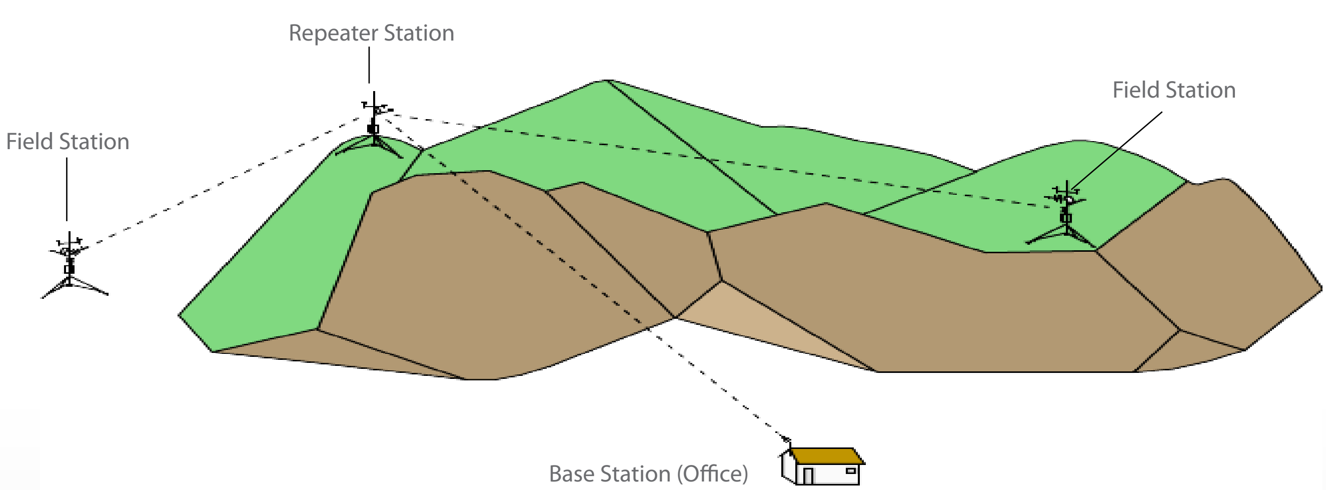
For networks with narrowband, UHF/VHF, licensed radios

Overview

The RF500M serves as a field, repeater, or base station communication interface, generally for our licensed radio applications. It provides an interface between a datalogger or computer and a radio and can be a stand-alone repeater when onsite logging is not required. The RF500M is powered from the CS I/O port or from an external power connection. This modem is software configurable, and has been designed to interface with data telemetry radios such as our RF320-, RF310-, and RF300-series VHF/UHF radios.

Benefits and Features

- Supports multiple radio configurations including our RF320-series, our RF310-series, our RF300-series, and the DataRadio DL-3400 radio
- Uses software instead of hardware modifications to upgrade the operating system (OS) and change RF ID or other settings
- Provides an RS-232 port (DTE) for modem configuration or attachment of an RS-232 radio
- Avoids all collisions within a network, thus increasing polling speeds and reducing overall current drain



Our RF networks require line-of-sight transmission. The mountain in this drawing obstructs line-of-sight with the base station. Use of the repeater station allows the base station to receive data from the field stations.

Ordering Information

Radio Modem

Must choose an OS option and a radio jumper setting option (see below).

RF500M Radio Modem.

OS Options (see discussion at right)

-PB PakBus OS.

-AL ALERT Dual Mode OS.

-DA Dial OS.

Radio Jumper Setting Options

-MJ Jumper for RF320-series or RF310-series radios.

-RJ Jumper for RF300-series radios.

-UJ Jumper for radios purchased directly from DRL.

Temperature Range Options

-ST Standard -25° to +50°C (default).

-XT Extended -55° to +85°C.

Warranty Length Options

-SW Standard one year warranty (default).

-XW Four year warranty extension.

Accessories

10873	9-pin female to 9-pin male serial data cable (6 ft); cable is required to connect RS-232 digital radios.
15966	Wall Charger 12 Vdc, 800 mA Output, 100 to 240 Vac, 50 to 60 Hz with Barrel Plug, 6 ft Cable.
14291	Field Power Cable 12 Vdc Plug to Pigtail (2 ft) connects with a 12 Vdc power supply.
14020	Field Power Cable CS I/O to 12 Vdc Barrel Plug (2 ft) connects with datalogger.

Operating System (OS) Options Descriptions

PakBus OS

Considered the standard for the RF500M, the -PB OS uses TDRF polling to quickly and efficiently move data through a network. Each station can be individually dialed by LoggerNet. This OS is compatible with -TD, -PB, and our current generation of PakBus dataloggers.

ALERT Dual Mode OS

The ALERT (Automated Local Evaluation in Real Time) OS allows for transmission, repeating, and reception of binary ALERT formatted data. It is a derivative of the -PB OS, and therefore supports both ALERT and TDRF communications (allowing true two-way communication with a station). This OS is compatible with the CR200(X)-series, CR800-series, CR1000, and CR3000 dataloggers.

Dial OS

The dial OS works with both mixed-array and PakBus/table-based dataloggers. Each station can be dialed by LoggerNet for downloading data, sending programs, and performing other tasks. Additionally, this OS allows stations to create point-to-point networks for sharing of measurement and control tasks.

Specifications

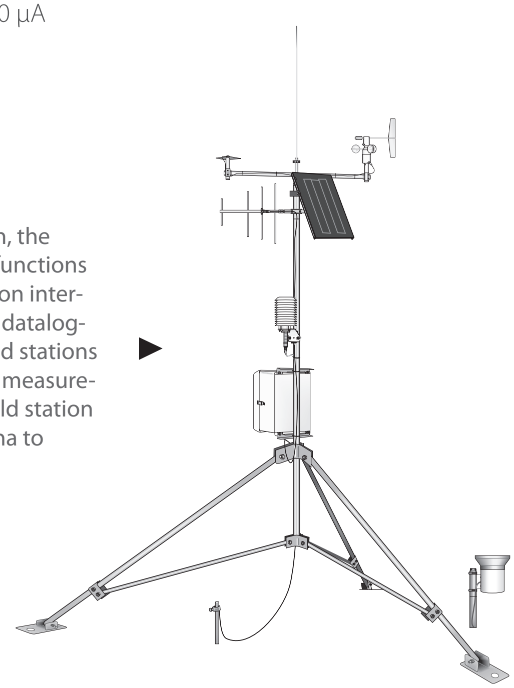
- Voltage: 7 to 20 Vdc
- Dimension: 160 x 95 x 22 mm (6.31 x 3.69 x 0.88 in.)
- Weight: 0.18 kg (0.4 lb)

Current Drain

- Active: <15 mA
- Quiescent: <350 µA

The RF500M can be used as a stand-alone repeater. Repeater stations provide a communication relay between stations that cannot communicate directly due to distance or obstacles. Repeater stations use omnidirectional antennas.

At the field station, the RF500M modem functions as a communication interface between the datalogger and radio. Field stations are located at the measurement site. This field station uses a Yagi antenna to transmit the data.



RF320

UHF / VHF Radios / RF320

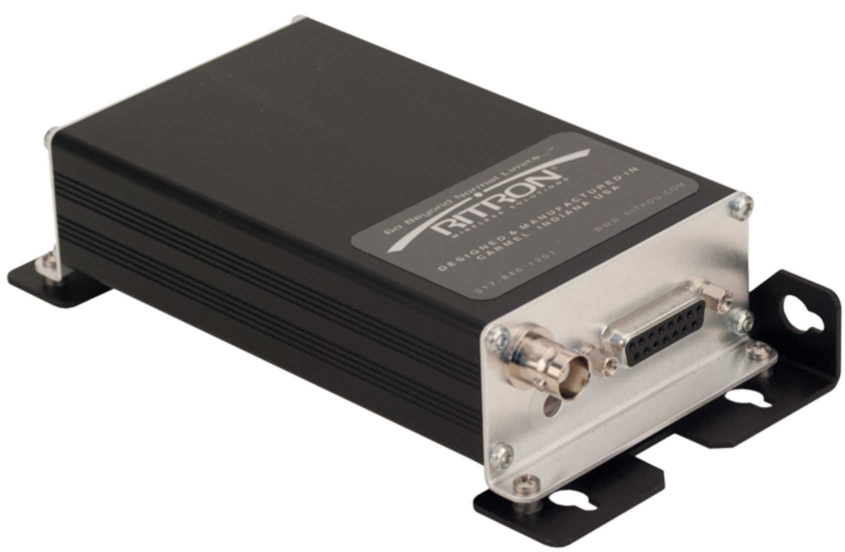
Quick Links

Overview

The RF320 is a 136 to 174 MHz radio. Campbell Scientific's RF320-series narrowband UHF/VHF radio transceivers provide a long-distance telemetry option for communicating with remote measurement stations. Each radio includes a configured Ritron DTX-L radio, a mounting bracket, and a cable for connecting the radio to a radio modem. The different models vary by the frequency ranges they support.

Read More ›

Images





Similar Products

RF321 UHF Radio Transceiver

RF322 UHF Radio Transceiver

RF323 UHF Radio Transceiver

Detailed Description

The RF320 is programmed by Campbell Scientific to the frequency that was assigned by the Federal Communications Commission (FCC). This frequency must be specified at time of order so that it can be programmed into the radio.

A user-supplied antenna is required for each radio; contact Campbell Scientific for more information about selecting the antenna and cable. Each radio must also be connected to an RF500M or RF310M radio modem.

Specifications

Ritron Module	DTX-445
FCC ID	AIERIT17-445
Industry Canada ID	1084A-RIT17145
FCC Rule Parts	90
Industry Canada Rule Parts	RSS-119
Frequency Range	136 to 174 MHz
RF Channels	8 independent Tx/Rx frequencies
Synthesizer Step	2.5 kHz
Channel Spacing	12.5 kHz
Frequency Stability	±2.5 PPM (-30° to +60°C)
Input Voltage	9 to 17 Vdc
Antenna Connector	BNC female
Dimensions	14.5 x 7.6 x 3.5 cm (5.7 x 3 x 1.375 in.)
Weight	0.2 kg (7.3 oz)

Current Drain @ 12.5 Vdc

Receive Standby	25 mA
Transmitter	› < 0.9 A (2 W output) › < 1.2 A (5 W output)

Receiver

Receiver Type	12.5 kHz narrowband
Sensitivity	0.25 µV (12 dB SINAD)
Adjacent Channel	-60 dB
Receiver Attack Time	< 10 ms (Tx to Rx)
Noise Squelch Sensitivity	PC adjustable (factory set for -121 dBm)

Transmitter

RF Power Output	2.0 W or 5.0 W (@ 12.5 Vdc)
Duty Cycle	50% (< 13.5 V, 5 W output, 25°C)
Voice Emissions Designator	10K0F3E
Data Emissions Designator	9K8F1D, 11K0F2D, 11K0F3D
Transmitter Attack Time	< 10 ms

Compatibility

Radio Modems

RF500M	RF310M	RF95A	RF95	RF95T	RF315M
✓	✓				

Radio Base Stations

RF500B	RF310B	RF232A	RF232	RF232T
✓	✓			

Radios

The RF320 is compatible with the RF310 radio.

Datalogger Considerations

Compatible Contemporary Dataloggers

CR200(X) Series	CR800/CR850	CR1000	CR3000	CR9000X
*	✓	✓	✓	

Compatible Retired Dataloggers

CR500	CR510	CR10	CR10X	21X	CR23X	CR9000	CR5000	CR7
✓	✓	✓	✓	✓	✓			✓

Note: *The CR200(X)-series dataloggers are only compatible if the RF500 radio modem is used.*

Documents

Brochures

- RF320-Series Narrowband UHF/VHF Radios
- Narrowband RF Networks
- Data Storage and Retrieval Peripherals

Manuals

- RF320-Series Ritron VHF/UHF Radios

Technical Papers

- Line of Sight Obstruction
- The Link Budget and Fade Margin

Frequently Asked Questions

Number of FAQs related to **RF320**: 2

1. Can an RF500M work with a GPS device for vehicle tracking systems?
   No. The RF500M cannot be directly interfaced with a GPS receiver. However, most Campbell Scientific dataloggers can be interfaced with the output from a GPS receiver and programmed to extract the positional information. This information can then be accessed via an RF500M/RF320 RF link.

2. Can more than one antenna be connected to a single radio?
   It is possible to connect two antennas to a single radio via a properly specified (operating frequency and power handling capability) two-way, 50 ohm RF power divider. One example of this type of power divider is offered by Pasternack. Note that using a device like this will induce additional losses into the system (3 to 4 dB, typically).


1
100V
7A
+2
OUTPUT
CRYDOM
SOLID-STATE RELAY
ASSEMBLED
IN MEXICO
D1D07
INPUT
4
3.5-32V
+3
LD7

COMPONENT

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

PS150 and CH150

Power Supply and Charge Controller

Optimized Power Performance

Manages voltage and amperage to protect battery

Overview

The PS150 and CH150 are smart charge controllers that manage amperage and voltage for safe, optimized battery charging from a solar-panel or ac power source. The PS150 includes a 12 Vdc, 7 Ah valve-regulated lead-acid (VRLA) battery, while the CH150 is for use with a separate larger battery such as our BP12, BP24, or a user-supplied battery.

Benefits and Features

- Protects against high-amperage and high-voltage damage to power supply
- Battery reversal protection
- Allows simultaneous connection of two charging sources (e.g., solar panel, ac wall charger)
- ETL listed Class 2 power supply

Technical Description

The PS150 and CH150 are micro-controller-based smart chargers with temperature compensation that optimize battery charging and increase the battery's life. Two input terminals enable simultaneous connection of two charging sources. They also incorporate a maximum power point tracking algorithm for solar inputs that maximize available solar charging resources.

The PS150 and CH150 have several safety features intended to protect the charging source, battery, charger, and load devices. Both the SOLAR – G and CHARGE – CHARGE input terminals incorporate hardware current limits and polarity-reversal protection. A 5 A fuse protects the CHARGE – CHARGE inputs in the event of a catastrophic AC/AC or AC/DC charging source failure. A 4.65 A solid-state circuit breaker protects the 12 V output terminals of the charger in the event of an output load fault. The PS150 and CH150 also have battery-reversal protection, and include ESD and surge protection on all of its inputs and outputs.

Ordering Information

Power Supplies

CH150 12 V Charging Regulator. Choose a warranty option (see below).

PS150 12 V Power Supply with Charging Regulator and 7 Ah Sealed Rechargeable Battery. Choose a warranty option (see below).

Warranty Options (choose one)

-SW Standard 1 Year Warranty. See manual for full warranty policy.

-XW 4 Year Warranty Extension (available only at the time of original product purchase).

12 Vdc Battery Packs for CH150

BP12 12 Ah Sealed Rechargeable Battery with Mounts

BP24 24 Ah Sealed Rechargeable Battery with Mounts

External Battery Cable

6186 Battery Cable for connecting an external 12 Vdc flooded battery such as a deep-cycle marine or RV battery.

Wall Chargers

29796 Wall Charger 24 Vdc 1.67 A Output, 100 to 240 Vac, 1A Input, 5 ft Cable. Must choose a power plug option (see below).

22110 Wall Charger 24 Vdc 1.67 A Output, 100 to 240 Vac, 1 A Input for prewired enclosure. Must choose a power plug option (see below).

Power Plug Options (choose one)

-US US/Canada Plug

-IP 7 International Plugs

Unregulated Solar Panels

Regulated solar panels such as the SP10R are not recommended. Must choose a cable termination option and a mounting option.

SP10 10 W Solar Panel with 15 ft cable

SP20 20 W Solar Panel with 15 ft cable

SP50-L 50 W Solar Panel with user-specified cable length (used with the CH150 only). Enter length, in feet, after the -L. A 20 ft length is typical; maximum length is 50 ft.

Cable Termination Options (choose one)

-PT Cable terminates in stripped and tinned leads for direct connection to the CH150 or PS150.

-PW Cable terminates in a connector that attaches to a prewired enclosure.

-C Cable terminates in a connector that attaches to an ET station or the CS110 Electric Field Meter (only available for the SP10).

Mounting Option (choose one)

-SM Standard Mounting Kit

-EM Extended Mounting Kit

Adapters

Only one adapter can be used at a time.

A100 Null Modem Adapter for powering peripherals and external devices at non-datalogger sites such as repeater stations.

A105 12 V Terminal Expansion Adapter that increases the number of 12 V and ground terminals available on the PS150 or CH150.

Specifications

- EU Declaration of Conformity: https://s.campbellsci.com/documents/us/compliance/eudoc_ch150-ps150.pdf
- Operational Temperature Range*: –40° to +60°C
- Dimensions:

	Height	Length	Width
PS150	10.6 cm (4.2 in)	19.3 cm (7.5 in)	7.6 cm (3 in)
CH150	10 cm (3.9 in)	7.5 cm (3 in)	3.7 cm (1.5 in)

Battery Charging

- FLOAT Charging: Vbatt(T) = 13.65–(24 mV) x (T–25) + (0.24 mV) x $(T–25)^2$
- Accuracy: ±1% accuracy on charging voltage over -40° to +60°C

CHARGE – CHARGE Terminals (AC or DC Source)

- AC: 18 to 24 V RMS internally limited to 1.2 A RMS
- DC: 16 to 40 Vdc internally limited to 0.85 A dc

SOLAR Terminals (Solar Panel or Other DC Source)

- Input Voltage Range: 15 to 40 Vdc
- Maximum Charging Current: 4.0 A dc typical; 3.1 A dc to 4.8 A dc depending on individual charger

Quiescent Current

- No Charge Source Present: 160 µA at 13.7 Vdc
- No Battery Connected: 930 µA at 30 V input voltage (ac or dc)

Power Out (+12 terminals)

- Voltage: Unregulated 12 V from battery
- 4.65 A solid state circuit breaker
- ETL Listed Class 2 power supply

**VRLA battery manufacturers state that "heat kills batteries" and recommend operating batteries ≤50°C.*

14221

Quick Links

Overview

The 14221 is a 3 dBd omnidirectional antenna for use with many of our spread-spectrum products. The 14221 is suitable for base station use where you need to communicate with multiple stations located in different directions. It is also preferred in mobile applications and in other applications in which the best radio path is not constant, including close-up applications without clear line-of-sight.

Read More ›

Images

14221 antenna with mounting hardware, disassembled

Similar Products

14205 900 MHz 6 dBd Yagi Antenna with Mounting Hardware

14201 900 MHz 9 dBd Yagi Antenna with Mounting Hardware

14203 900 MHz 3 dBd Omnidirectional Antenna without Mounting Hardware

17548 900 MHz 0 dBd Omnidirectional Antenna without Mounting Hardware

14204 900 MHz 0 dBd 1/2 Wave Omnidirectional Antenna with RPSMA Connector

15731 900 MHz 0 dBd 1/4 Wave Omnidirectional Antenna with RPSMA Connector

15730 900 MHz 0 dBd 1/4 Wave Omnidirectional Antenna with RPSMA Connector

15970 900 MHz 1 dBd Omnidirectional Dipole Antenna with Adhesive Mount

Detailed Description

The 14221 is the highest gain, omnidirectional antenna available for our 900 MHz spread spectrum radios that Campbell Scientific offers. This outdoor antenna is ideal for a base station or repeater station where you need to communicate with multiple stations located in different directions. The 14221 is also preferred in mobile applications and in applications where the best radio path is not constant, including close-up applications without clear line-of-sight.

The 14221 requires an antenna cable to connect it to the spread-spectrum radio. (See the Compatibility information for options.)

Specifications

Gain	3 dBd
Frequency Band Supported	902 to 928 MHz
Connector	Type N female
Antenna Type	Omnidirectional, outdoor antenna with mounting hardware
Manufacturer's Model Name	ANTENEX FG9023
Mounting	Mounts to pipes with outer diameters from 3.18 to 6.35 cm (1.25 to 2.5 in.).
Diameter	3.175 cm (1.25 in.) at base
Length	63.5 cm (25 in.)
Weight	383 g (13.5 oz)

Compatibility

Antenna Cables

The following cables can be used:

- COAXNTN-L—connects the antenna to the radio, datalogger, or interface via a surge protector.
- COAXRPSMA-L—connects the antenna to spread-spectrum radios other than the RF450 when surge protection is not required.
- COAXSMA-L—connects the antenna to an RF450 when surge protection is not required.

Mounting Hardware

The antenna includes a rugged FM2 antenna mounting bracket. The mounting bracket will accommodate a pipe with up to 6.5 cm (2.5 in.) outer diameter. A similar antenna, the 14203, does not have mounting hardware and is intended for customers who want to construct an antenna mounting bracket that fits their specific application.

Contemporary Devices

The 14221 is compatible with these current products:

Spread-Spectrum Radios

- RF451
- RF401A
- RF411A
- RF407
- RF412

Dataloggers

- CR206X
- CR211X
- CR6-RF451
- CR6-RF407
- CR6-RF412
- CRVW3-RF451
- CRVW3-RF407
- CRVW3-RF412
- CR300-RF407
- CR300-RF412
- CR310-RF407
- CR310-RF412

Vibrating-Wire Peripherals

- AVW206
- AVW211

Retired Devices

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

SP50-L

50 W Solar Panel

Powers Remote Systems

Useful at sites far from ac sources

The SP50 50 W solar panel is a photovoltaic power source capable of recharging batteries. It is used for our CS110 Electric Field Meter or other systems that require 50 W solar panels. The SP50 allows unattended operation of systems in remote locations, far from ac electrical sources.

This solar panel needs to be used with either a 18529 Morningstar SunSaver, CH200, or CH150 regulator. One SP50 can be connected to any of the regulators to provide a peak charge of 50 W. Two SP50 solar panels can be wired in parallel to the charge inputs of the SunSaver 18529 regulator to provide a peak charge of 100 W.

Regulators

CH150/CH200 Charge Controller
The CH150 and CH200 limit charging current to approximately 3.6 A and can precisely charge these battery families: EnerSys Genesis NP Series (BP12, BP24), EnerSys Cyclone Series, Concorde Sun Xtender Series (BP84, PS84), or a custom battery.

18529 MorningStar SunSaver
The 18529 Morning Star SunSaver limits charging current to approximately 10 A and can charge flooded batteries or sealed rechargable batteries such as our BP12, BP2, BP24, and BP84.

Mounting Hardware

The SP50 includes the 31107 Extended Mounting Kit for attaching the solar panel to a Campbell Scientific tripod or tower. The 31107 positions the solar panel approximately 25 cm (10 in) from the tripod or tower, which reduces shadows from other components and guy wires. The zenith angle indicator and the slotted supports simplify installation. The 31107 began shipping with the solar panel in October 2014. This kit may be purchased separately to retrofit existing solar panels.

Ordering Information

Solar Panel

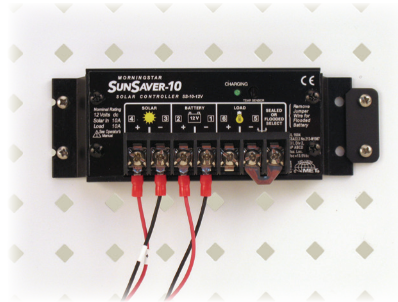
SP50-L	50 W Solar Panel with user-specified cable length. Enter length, in feet, after the -L. A 20 ft length is typical; maximum length is 50 ft. Must choose a cable termination option (see below).

Cable Termination Option (choose one)

-PT	Cable terminates in stripped and tinned leads for connection to the CH200 Smart Charge Controller or 18529 regulator.
-PW	Cable terminates in a connector that attaches to a prewired enclosure.

Regulators

CH200	12 Vdc Charging Regulator
18529	Morning Star SunSaver-10 10A 12V Regulator with 15 ft Battery Cable
CH150	12 Vdc Charging Regulator



18529 Morning Star SunSaver

CH200

Above shows two regulators available for use with the SP50. Regulators must be housed in an environmental enclosure.

Specifications[a]

- Maximum Power: 50 W (100 W peak power when two SP50s are connected to one 18529 regulator)
- Voltage at Peak: 17.5 V
- Current at Peak: 2.9 A
- Dimensions: 83.9 x 53.7 x 5 cm (33 x 21.1 x 2.0 in)
- Weight: 6 kg (13 lb)
- Maximum Wind Speed Rating[b]: 58 m s^{-1} (130 mph)
- Cable Description: 16 AWG, 1-twisted pair

[a]Solar panel characteristics assume 1 kW m^{-2} illumination and 25°C solar panel temperature. Individual panels may vary up to 10%. The output panel voltage increases as the panel temperature decreases.

[b]Assumes the 31107 Extended Mounting Kit is used to mount the SP50 to an adequately anchored tripod or tower.

14201

Quick Links

Overview

The 14201 is a high-gain (9 dBd), directional (Yagi) antenna. It is useful for making RF links over longer distances in one direction. This antenna is typically used with sub-315 mW radios such as the RF401A. The 14201 requires an antenna cable to connect it to the spread-spectrum transceiver. (See the Compatibility information for cable options.)

Read More ›

Images

Similar Products

14205 900 MHz 6 dBd Yagi Antenna with Mounting Hardware

14221 900 MHz 3 dBd Omnidirectional Antenna with Mounting Hardware

14204 900 MHz 0 dBd 1/2 Wave Omnidirectional Antenna with RPSMA Connector

15731 900 MHz 0 dBd 1/4 Wave Omnidirectional Antenna with RPSMA Connector

15730 900 MHz 0 dBd 1/4 Wave Omnidirectional Antenna with RPSMA Connector

15970 900 MHz 1 dBd Omnidirectional Dipole Antenna with Adhesive Mount

Detailed Description

The 14201 is a high-gain, Yagi antenna used with our 900 MHz spread spectrum transceivers. This outdoor antenna has a narrow beam width that requires precise aiming. It should be used to communicate with one distant station. The 14201 requires an antenna cable to connect it to the spread spectrum transceiver. (See the Compatibility information for cable options.)

Note: *Because the FCC limits the EIRP of 900 MHz spread-spectrum radios to 36 dBm, using this antenna with an RF450- or RF451-based system requires the user to reduce the radio's transmit power to a setting of 5 or less.*

Specifications

Gain	9 dBd
Frequency Band Supported	900 MHz
Connector	Type N female
Antenna Type	Yagi (directional) with mounting hardware
Manufacturer's Model Name	MAXRAD BMOY8905

Mounting	Mounts to pipes with outer diameters from 3.18 to 6.35 cm (1.25 to 2.5 in.)
Bracket Dimensions	11.5 x 9 x 0.6 cm (4.5 x 3.5 x 0.25 in.)
Overall Length	56.5 cm (22.3 in.)
Longest Element Length	16 cm (6.3 in.)
Weight	0.73 kg (1.6 lb)

Compatibility

Spread-Spectrum Transceivers

***Note:** Because the FCC limits the EIRP of 900 MHz spread-spectrum radios to 36 dBm, using this antenna with an RF450- or RF451-based system requires the user to reduce the radio's transmit power to a setting of 5 or less.*

Antenna Cables

The following cables can be used:

- COAXNTN-L—connects the antenna to the radio, datalogger, or interface via a surge protector.
- COAXRPSMA-L—connects the antenna to spread-spectrum radios other than the RF450 when surge protection is not required.
- COAXSMA-L—connects the antenna to an RF450 when surge protection is not required.

Mounting Hardware

The antenna includes mounting hardware that accommodates a pipe of up to 3.18 to 6.35 cm (1.25 to 2.5 in.) outer diameter.

Contemporary Devices

The 14201 is compatible with these current products:

Spread-Spectrum Radios

- RF451
- RF401A
- RF411A
- RF407
- RF412
- RF422

Dataloggers

- CR206X
- CR211X
- CR6-RF451
- CR6-RF407
- CR6-RF412
- CRVW3-RF451
- CRVW3-RF407
- CRVW3-RF412

Vibrating-Wire Peripherals

- AVW206
- AVW211

Retired Devices

The 14201 is compatible with these retired products:

Spread-Spectrum Radios

- RF400
- RF401
- RF430
- RF410
- RF411
- RF431
- RF450
- FGR-115RE and RC

Dataloggers

- CR205
- CR206
- CR210
- CR211

Listed Under

Replacement Parts for the following products:

- **RF400** - 900 MHz Spread Spectrum Radio/Modem
- **RF410** - 922 MHz Spread Spectrum Radio/Modem

Common Accessories for the following products:

- **AVW211** - 922 MHz Wireless 2-Channel Vibrating-Wire Analyzer Module
- **AVW206** - 900 MHz Wireless 2-Channel Vibrating-Wire Analyzer Module
- **RF401A** - 900 MHz Spread-Spectrum Radio
- **RF412** - 922 MHz Spread-Spectrum Radio
- **RF407** - 900 MHz Spread-Spectrum Radio
- **RF411A** - 922 MHz Spread-Spectrum Radio
- **CWB100A** - 922 MHz Wireless Sensor Base for Australia
- **CWB100** - 900 MHz Wireless-Sensor Base
- **CR206X** - Datalogger with 900 MHz Spread-Spectrum Radio
- **CR211X** - Datalogger with 922 MHz Spread-Spectrum Radio
- **CR310** - Datalogger with Ethernet
- **CR300** - Datalogger

Other Accessories for the following products:

- **FGR-115RC** - Freewave 900 MHz Spread Spectrum Radio
- **FGR-115RE** - FREEWAVE 900 MHz, 1 W Spread Spectrum Radio with Ethernet
- **RF401** - 900 MHz Spread-Spectrum Radio
- **RF411** - 922-MHz Spread-Spectrum Radio
- **CR206** - Datalogger with 900 MHz Spread-Spectrum Radio
- **RF431** - 922-MHz Spread-Spectrum Radio
- **RF430** - 900-MHz Spread-Spectrum Radio

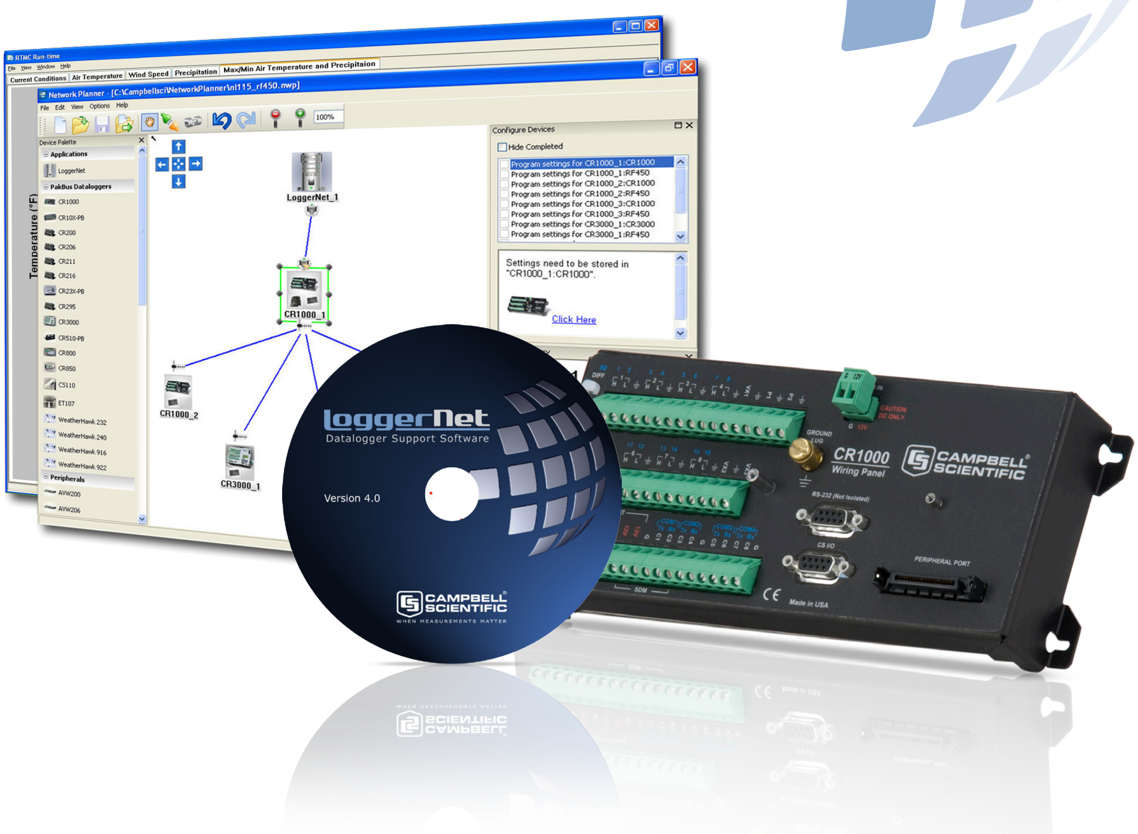
COMPONENTS

CAMPBELL SCIENTIFIC®
WHEN MEASUREMENTS MATTER

LoggerNet 4 Series

Datalogger Support Software

loggerNet
Datalogger Support Software



LoggerNet 4 Series

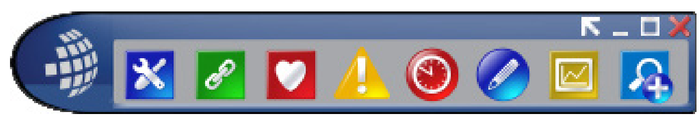
The LoggerNet family of datalogger support software

LoggerNet version 4 is Campbell Scientific's latest offering in its suite of datalogger support software packages. LoggerNet 4 is still built on a solid client/server architecture that allows data to be served to multiple LoggerNet clients simultaneously, while featuring a newly designed user-interface and new or updated clients. While the LoggerNet server does the work of communicating with the datalogger network, the client applications are used to manage the network. This includes network setup, configuration, monitoring, and backup; datalogger programming, maintenance, and data collection; and real-time or historical data display.

Toolbar and Navigation

LoggerNet's Toolbar starts the LoggerNet server and is used to navigate to all the client applications. It has been redesigned to offer quick access to all LoggerNet clients. A new Favorites category has been added to the Toolbar. With the click of a button the Toolbar can be restored down to Favorites view, allowing easy access to those clients most important to your application.

The Toolbar's Full view is shown on top right. The Favorites view reduces the size of the toolbar and provides access to your most-used applications. ▶



LoggerNet Packages

LoggerNet *offers a complementary suite of client applications for datalogger programming, data collection, network monitoring and troubleshooting, and data display. This standard package is recommended for those who have datalogger networks that do not require the more advanced features offered in LoggerNet Admin. LoggerNet 30-day Trial version is available for download.*

LoggerNet Admin *includes tools that are useful for those with large datalogger networks. It provides all the capabilities of LoggerNet, plus it adds network security, network management from a remote PC, LoggerNet service, data export to third party applications, and the ability to launch multiple instances of the same client (for instance, two Connect windows).*

LoggerNet Remote *is the full suite of LoggerNet Admin client applications that lets you manage an existing datalogger network from a remote PC. LoggerNet Remote does not include the LoggerNet server or the service.*

LoggerNet for Linux *provides a solution for those who want to run the LoggerNet server in a Linux environment. The package includes a Linux version of the LoggerNet server. At least one copy of LoggerNet Remote must be purchased to use LoggerNet for Linux. LoggerNet Remote's Windows-based clients are used to manage the LoggerNet Linux server and the datalogger network. LoggerNet Linux includes a Debian distribution and two RPM distributions—Red Hat and SUSE.*

Setup and Network Configuration

Setup

Setup and EZSetup have been combined into one application, providing you with a choice in setting up the datalogger network. EZSetup walks you through the process for each station step-by-step, while Setup allows you more flexibility and access to more advanced features. You can toggle between the two by pressing a button. When in Setup mode, you can choose to view all devices in the network or the datalogger stations only, to make finding a particular station easy.

New features for Setup include the ability to configure a scheduled datalogger network backup, the File Retrieval tab for scheduling retrieval of image or other files from a datalogger, the Notes tab for creating custom notes for a station, and the ability to cut and paste single devices or a branch of the network to another location in the network map. New file output options include support for CSIXML and incrementing file names with each data collection from a datalogger.

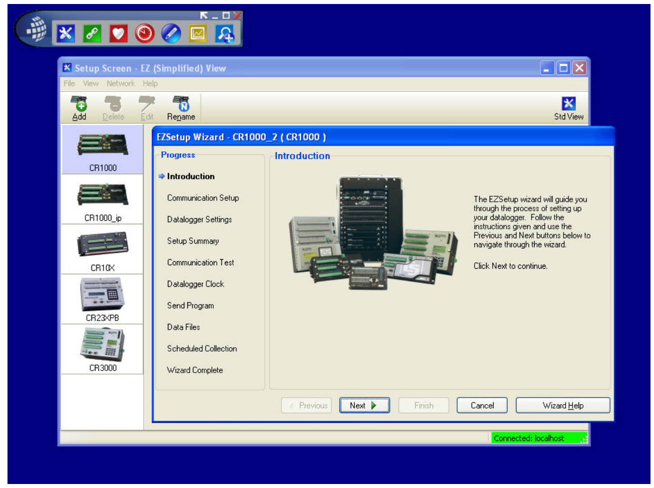
Task Master

The Task Master allows you to set up events (e.g., running a batch file) that occur on a schedule (interval or calendar) or based on some trigger event such as a successful or failed data collection attempt to a datalogger. LoggerNet 4 Task Master now supports sending files via FTP/SFTP and the new "After File Closed" and "After File Retrieved" trigger events.

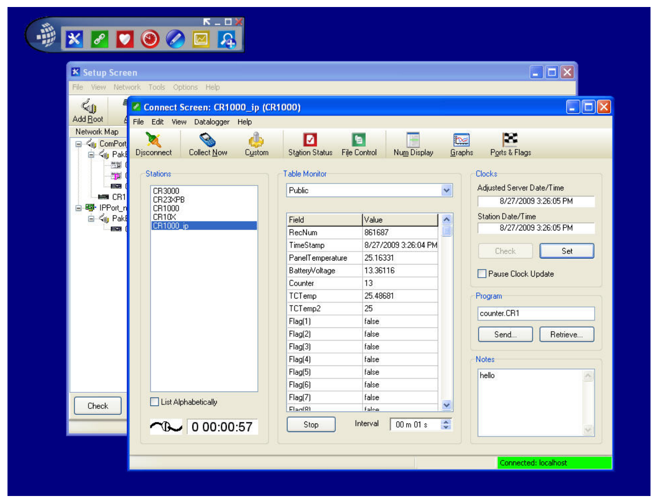
Network Planner

LoggerNet 4 includes the Network Planner, a new tool for designing your PakBus datalogger network. First, PakBus devices are selected from a list and placed on the network design palette. You then use a link tool to draw lines indicating the physical communication links between devices, and an activity tool to indicate activities that will take place between devices (scheduled data collection, call-back, one-way data messages, or get/set variable transactions between dataloggers).

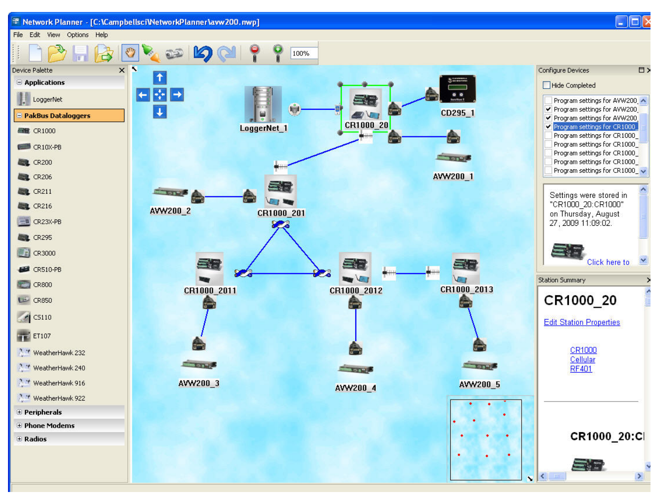
The Network Planner calculates the optimum settings for each device in the network and then allows you to send these settings to the device, or save them for later download via the Network Planner or the Device Configuration Utility. If any change is made to a device in the network, that change is propagated to any other devices in the network that are affected. The configuration can then be imported into LoggerNet's network map, providing a start-to-finish solution for PakBus network setup.



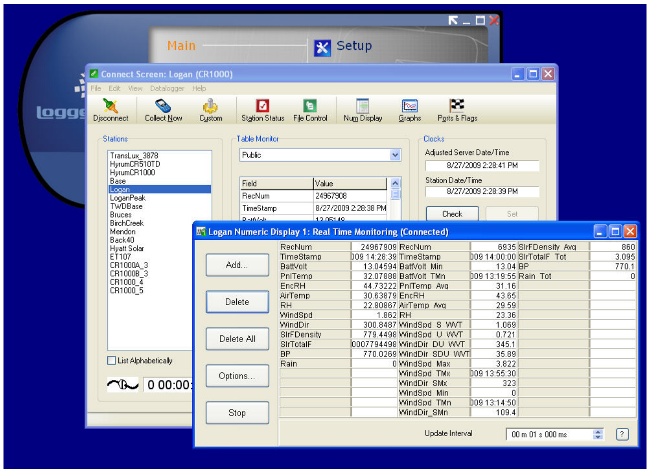
Select the EZSetup to walk through datalogger setup step-by-step.



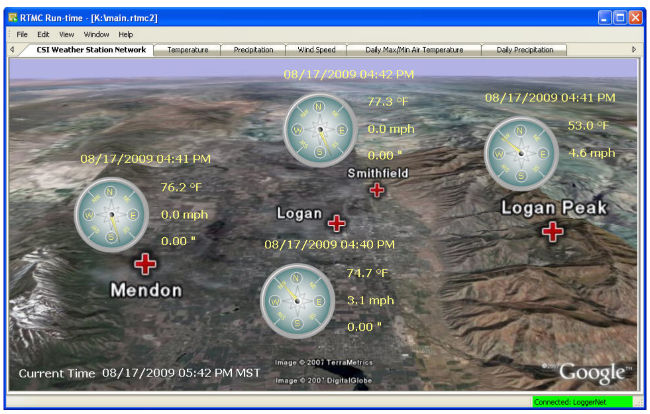
The standard Setup screen along with the Connect screen are shown above. Notes entered in the Setup screen are displayed in the Connect screen (lower right corner).



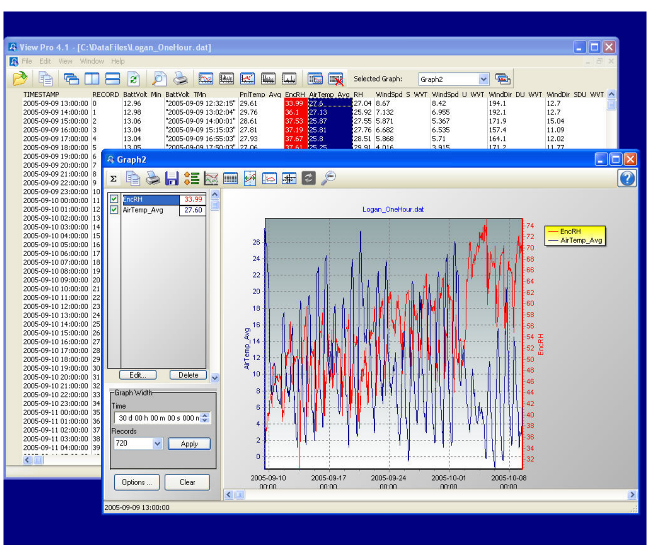
The Network Planner generates device settings and configures the LoggerNet network map for PakBus networks.



The Connect window's numerical monitor displays real-time and historical data.



RTMC simultaneously displays data from any number of dataloggers on one display.



View Pro displays historical data in a tabular or graphical format.

Connect and Datalogger Status

Connect

Connect allows you to perform maintenance on a station (including sending a program and setting the clock) while also viewing important datalogger status information, managing program and other files on a datalogger's CPU, and displaying numerical and graphical data. A new Table Monitor has been designed within the Connect window so that a table can be quickly selected from a drop-down list, and all values from that table displayed. The numerical and graphical displays are fully configurable and now allow saving a configuration that can then be reloaded for the original station or a different station. Any notes that have been added for a station during Setup will be displayed at the bottom right of the Connect window.

Status Monitor

The Status monitor is used to view the communication and data collection status of the overall datalogger network.

Advanced Data Display and File Viewing

RTMC Development, RTMC Run-Time

RTMC is used to create custom displays of real-time data, flags, and ports. It provides digital, tabular, graphical, and Boolean data display objects, as well as alarms. You can combine data from multiple dataloggers on one display. Complex displays can be organized on multi-tabbed windows.

View Pro

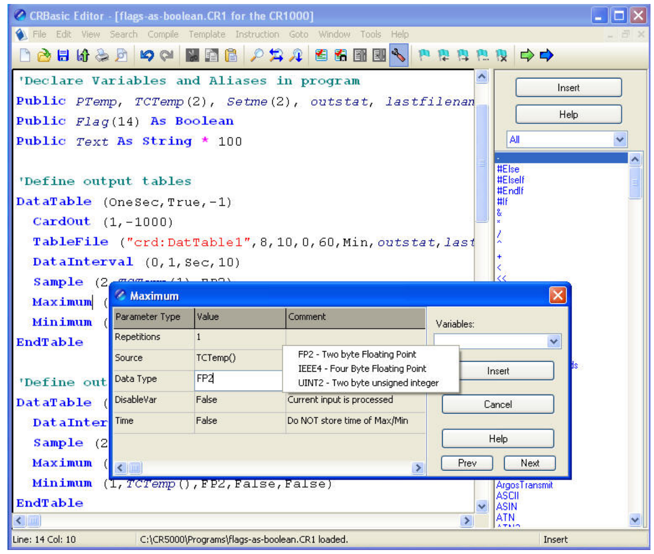
View Pro is our newly designed data file viewer. Beginning with LoggerNet 4.1, View Pro can also be used to view data from a LoggerNet database table. Data can be viewed in numeric format or in one of several graphical layouts, including a line graph, X/Y plot, histogram, rainflow, and 2D/3D FFTs. Multiple data files can be opened at once, allowing side-by-side comparison of the data. There is no limit to the number of traces that can be displayed on a graph.

The Zoom feature offers a closer look at important data, and the Statistical window provides the average, standard deviation, minimum, and maximum for all points displayed on a graph. Graphs can be saved to a file (BMP, JPG, WMF, EMF, or PCX). View Pro supports all Campbell Scientific data file types (including the new CSIXML format).

Programming

Full-featured Programming Tools

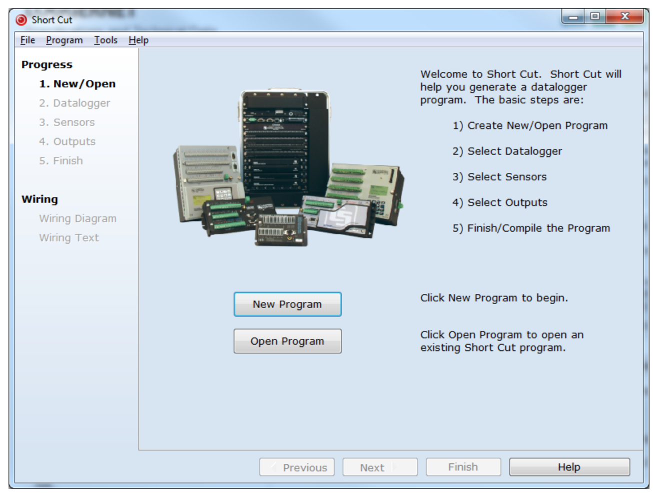
LoggerNet offers two full-featured programming tools—the CRBasic Editor and Edlog. The CRBasic Editor uses syntax similar to BASIC programming language to provide sophisticated programming capabilities for our CR6, CR300, CR200-series, CR800/CR850, CR1000, CR3000, CR5000, and CR9000(X) dataloggers. The CRBasic Editor in LoggerNet 4 includes new functionality to support encrypting a file prior to sending it to the datalogger and support for user-defined functions. Edlog provides programming capabilities for our CR500, CR510, CR10(X), 21X, CR23X, and CR7 dataloggers.



CRBasic Editor offers keyword and other syntax highlighting and a parameter dialog box with drop-down lists for CRBasic programming.

Simple Program Generator

For those who prefer a simpler means of programming their dataloggers, LoggerNet 4 includes Short Cut for Windows (SCWin). SCWin provides a wizard-like interface for generating programs for all Campbell Scientific dataloggers and supports all of the popular sensors we offer, as well as user-created custom sensor files (using an existing sensor file as the starting point). You can use a program as generated by SCWin, or open it in the CRBasic Editor for further editing (for CR6, CR300, CR200-series, CR800, CR850, CR1000, CR3000, CR5000, and CR9000(X) dataloggers).



Short Cut provides a wizard-like interface for generating datalogger programs.

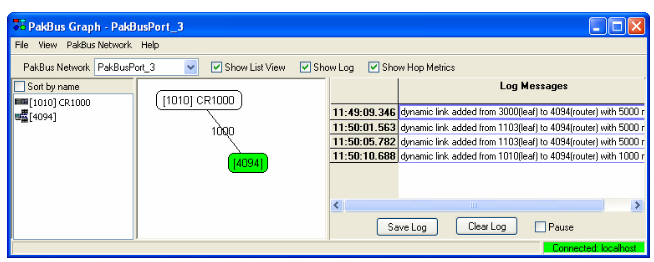
Troubleshooting

Troubleshooter

Troubleshooter helps you discover the cause of communication problems. Troubleshooter can be customized to display only the warnings of interest. In addition, you can click on any highlighted warning to bring up a menu that allows you to go to the Setup Screen or Status Monitor to fix the problem, bring up help describing the problem, or, in some cases, fix the problem directly.

PakBus Graph

PakBus Graph provides a graphical display of a PakBus network as known by the LoggerNet server, and quick access to the PakBus settings in LoggerNet and other PakBus devices.



LogTool

The LogTool application is available to view operational log messages for the server as well as the low-level communication between the datalogger and the server.

Troubleshooter, PakBus Graph (shown above), and Log Tool are tools available for monitoring the status of a datalogger network and troubleshooting communication problems within that network.

DevConfig is used to configure dataloggers, communication devices, and programmable sensors.

The RWIS Administrator supports communication with RWIS weather stations such as the one shown above.

Other Applications

Device Configuration Utility (DevConfig)

DevConfig allows you to send new operating systems to dataloggers and other devices with flash memory, configure various PakBus® settings in dataloggers, and edit settings for communication peripherals such as the MD485 and RF401A. DevConfig can now be launched from within LoggerNet, without conflict with the remainder of the datalogger network. The latest DevConfig can be downloaded from our website.

RWIS Administrator

New in LoggerNet 4 is the RWIS Administrator. With the RWIS Administrator, LoggerNet is able to communicate with any station that implements the NTCIP (National Transportation Communications for ITS Protocol) Environmental Sensor Station interface.

Card Convert

CardConvert is used to convert and save binary data from a microSD card, CompactFlash® (CF) card, or PC Card. It can also perform other conversions. MicroSD cards are compatible with the CR6 datalogger. CF cards are compatible with our CR1000, CR3000, CR5000, and CR9000X dataloggers. PC Cards are compatible with our CR5000 and CR9000X dataloggers.

Split

Split is used to post-process data files and create printed reports. It sorts and combines data based on time or conditions, performs calculations on data values, converts between mixed-array "day of year" calendar dates and more traditional date/time stamps, and generates simple HTML-formatted reports.

Transformer

The Transformer tool converts Edlog programs to CRBasic programs. Specifically, it can convert a CR510 or CR10X program to a CR1000, CR800, or CR850 program, or a CR23X program to a CR3000 program.

Data Filer (LoggerNet Admin and LoggerNet Remote only)

Data Filer is an application used to retrieve data from the LoggerNet server's data cache and save that data to a file. It provides a way to manually retrieve data from a remote LoggerNet server and store the data on the local computer.

Data Export (LoggerNet Admin and LoggerNet Remote only)

Data Export is an application used to export data from the LoggerNet server's data cache to a third party computer program. Data Export "listens" for a request from another application and sends the requested data via a socket connection.

Service Manager (LoggerNet Admin only)

Service Manager is used to install LoggerNet as a service, and to manage the service on the PC. When run as a service, after a power failure, LoggerNet will resume data collection and scheduled task activities when power is restored to the computer—regardless of whether or not a user logs on to the computer.

Security Manager (LoggerNet Admin and LoggerNet Remote only)

Security Manager is used to set up security within the LoggerNet application to restrict access to certain functions. Individual user accounts are set up and assigned one of five levels of security, with different user privileges assigned to each level.

.

LoggerNet Server Monitor (LoggerNet Admin and LoggerNet Remote only)

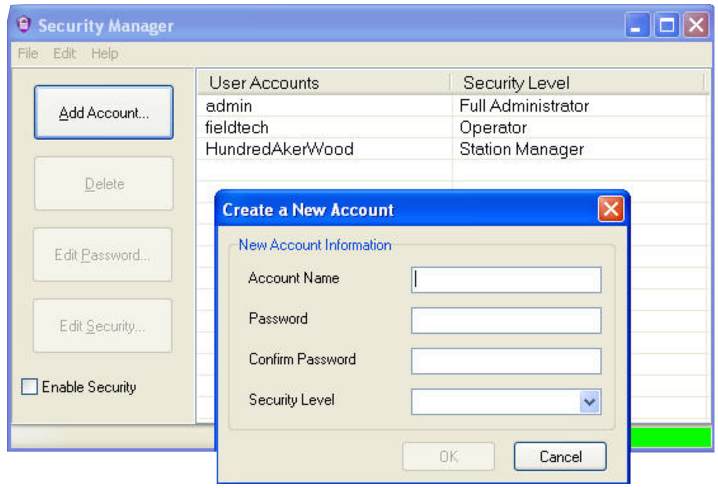
The LoggerNet Server Monitor is a utility that runs minimized with an icon in the Windows Status Area. It monitors the status of a LoggerNet server when it is being run as a service or being run on a remote computer. Multiple instances of the LoggerNet Server Monitor can be launched to monitor more than one server running on remote computers.

Hole Monitor (LoggerNet Admin and LoggerNet Remote only)

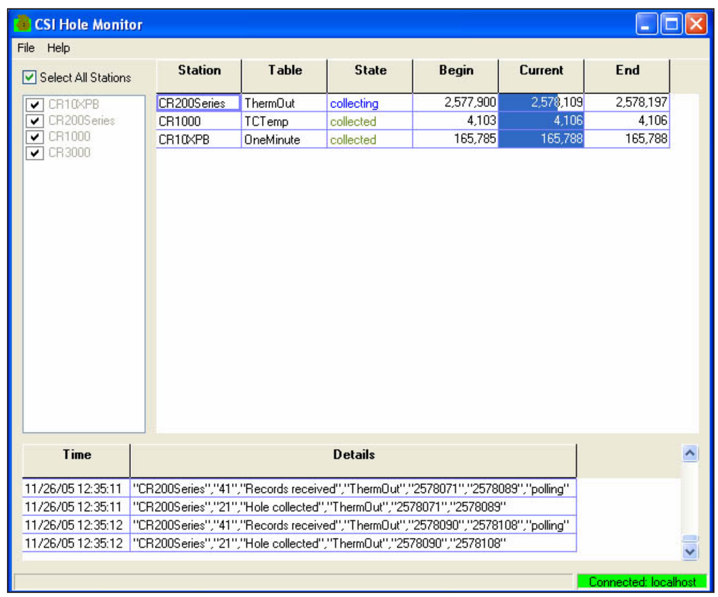
The Hole Monitor is used to monitor the hole collection activity for the dataloggers in a LoggerNet network. Holes are most often encountered with data collected from table-based dataloggers via data advise (data advise is used for data collection in large table-data RF networks). A hole occurs when there are missing records of data in the LoggerNet server's data cache for a datalogger.

CoraScript

CoraScript is a command line scripting tool, which can be used to configure the datalogger network from a command prompt.



Security Manager lets you set up multiple security accounts for access to the datalogger network.



The Hole Monitor lists datalogger stations and collection status for missing records in LoggerNet's data cache.

Requirements and Certificates

- PC Operating System: Windows 10, 8, 7, Vista, or XP (both 32- and 64-bit versions supported)
- Military Certificate of Networthiness (CoN):
  - LoggerNet 4.0 is certified as Cert #201004872
  - LoggerNet 4.x is certified as an upgrade to 4.0 and has ASC CoN ID 12274
  - Expires 1/13/2017

Related Products

Upgrades

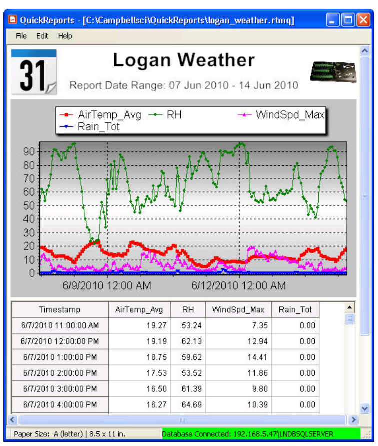
Upgrade pricing is available for current licenses of any version of LoggerNet. Contact Campbell Scientific for details.

Software Developers Kits

LoggerNet-SDK and LoggerNet Server-SDK allow software developers to create custom applications that communicate with the LoggerNet server and through the server to one or more dataloggers. Refer to the Software Development Kit product brochure for more information.

Separately Purchased Clients

Several clients may be purchased to add functionality to our LoggerNet and LoggerNetAdmin software packages. To use the clients, a licensed copy of the datalogger support software needs to be running on a PC. Functions supported by these clients include distributing data to remote files, OPC interface, PC displays, and web browsers. For more information, refer to: www.campbellsci.com/loggernet-clients



LNDB is one of the client application available for use with LoggerNet.

License for Use

LoggerNet is protected by United States copyright law and international copyright treaty provisions. Installation of LoggerNet (including the trial version) constitutes an agreement to abide by the provisions of its licensing agreement. The agreement grants the user a non-exclusive license to use the software in accordance with the following:

(1) The purchase of this software allows you to install and use a single instance of the software on one physical computer or one virtual machine only.

(2) This software cannot be loaded on a network server for the purposes of distribution or for access to the software by multiple operators. If the software can be used from any computer other than the computer on which it is installed, you must license a copy of the software for each additional computer from which the software may be accessed.

(3) If this copy of the software is an upgrade from a previous version, you must possess a valid license for the earlier version of software. You may continue to use the earlier copy of software only if the upgrade copy and earlier version are installed and used on the same computer. The earlier version of software may not be installed and used on a separate computer or transferred to another party.

(4) This software package is licensed as a single product. Its component parts may not be separated for use on more than one computer.

(5) You may make one (1) backup copy of this software onto media similar to the original distribution, to protect your investment in the software in case of damage or loss. This backup copy can be used only to replace an unusable copy of the original installation media.

LoggerNet software or its trial may not be sold, included, or redistributed in any other software or altered in any way without prior written permission from Campbell Scientific.

CAMPBELL SCIENTIFIC®
WHEN MEASUREMENTS MATTER

ENC24/30, ENC24/30S

Large Steel Enclosures

Rugged, Versatile

Campbell components mount easily and securely

Overview

The ENC24/30 and ENC24/30S are large steel enclosures that provide additional wiring room. They include a prepunched backplate with one-inch-on-center holes suitable for attaching the datalogger, power supply, communication device, and measurement and control peripherals. The enclosures can be mounted to a building, tower, or other structures, but the users must provide their own mounting. The ENC24/30 is a painted mild-steel version, and the ENC24/30S is a stainless-steel version.

Benefits and Features

- Weather resistant to protect instruments
- Backplate designed so that Campbell Scientific components mount easily and securely

Cable-Entry Options

The ENC24/30 and ENC24/30S can be ordered with one to four 1.5-in. conduit openings or 12 individual cable-entry seals.

Conduit(s)

Multiple cables can be routed through one conduit. A plug included in the 7363 enclosure supply kit can reduce the conduit's internal diameter to 0.5 in. (1.3 cm). The enclosure supply kit also contains the putty used to seal each conduit.

Entry Seals

Entry seals have a more water-tight seal than the conduits. Each entry seal is compressed around one cable. A small vent is included to equalize pressure with the atmosphere. Theses enclosures are fitted with four large, four medium, and four small cable entry seals.

The acceptable cable diameters are:

- Large—0.236 to 0.512 in. (6 to 13 mm)
- Medium—0.231 to 0.394 in. (5.8 to 10 mm)
- Small—0.187 to 0.312 in. (4.75 to 8 mm)

Enclosure Supply Kit

The enclosure supply kit is included with our enclosures, but can be purchased separately. The assembled equipment aids in mounting your equipment inside the enclosure as well as monitoring relative humidity and sealing the enclosure. It includes desiccant packs, humidity indicator card, cable ties, putty, screws, grommets, and a Phillips-head screwdriver.

Ordering Information

Steel Enclosures

ENC24/30	Weather-Proof 24 x 30 Mild Steel Enclosure
ENC24/30S	Weather-Proof 24 x 30 Stainless-Steel Enclosure

Enclosure Hole Options

-SC	One Conduit for cable entry.
-DC	Two Conduits for cable entry.
-TC	Three Conduits for cable entry.
-QC	Four Conduits for cable entry.
-ES	12 individual-Cable Entry Seals for cable entry.

Accessories

27814	CD100 Mountable Display with Keypad Installed in Enclosure Lid. The CD100 provides the same operation and functionality as the CR1000KD keyboard display.
31551	Enclosure Leg Stack Mounting Kit
31143	Hinged Stack Bracket Kit
10525	Two-pack desiccant holder that mounts to the inside of the enclosure lid.
CS210	Enclosure Humidity Sensor.
6714	Desiccant Four-Unit Bag (Qty 20).

Antenna Cable/Bulkhead Installations

These accessories are offered for enclosures that will house a cellular phone, satellite transmitter, or radio. They allow an antenna to be connected to the outside of the enclosure.

31327	Compatible with the type N-to-type N antenna cable used with the GOES satellite transmitters.
31312	Compatible with the type N-to-RPSMA antenna cable used with the RF401-series spread spectrum radios, CR200(X)-series dataloggers, AVW200-series Interfaces, or CWB100-series wireless bases..
31315	Compatible with the type N-to-SMA antenna cable used with the RF450 radio, LS300G cellular modem, RavenXT-series cellular modems, or Iridium9522 satellite modem.
31330	Compatible with the type N-to-BNC antenna cable used with the ST-21 Argos Satellite Transmitter, RF320-series radios, RF310-series radios, or RF300-series radios.
31321	Compatible with the type N-to-TNC antenna cable used with the HUGHES9502 Inmarsat-BGAN transmitter.
31324	Compatible with the type SMA-to-SMA antenna cable used with the GPS device included with our GOES satellite transmitters, AL200 ALERT transmitter, and Iridium9522B satellite modem.

Specifications

- Dimensions: 61 x 76 x 20 cm (24 x 30 x 8 in)
- Weight: 21 kg (46 lb)

ENC24/30

- Construction: painted, 14-gauge, mild steel with door gasket and stainless steel hinges
- Enclosure Classification: NEMA Type 3R, 4, and 12 (before being modified for cable entry

ENC24/30S

- Construction: formed, 14-gauge, 304 stainless steel with door gasket and stainless steel hinges
- Enclosure Classification: NEMA Type 3R, 4, 12, and 13 (before being modified for cable entry)

MODEL 114 APPLICATION MEASUREMENTS:

Usable dimensions at incremental heights. Diameter is for circular shaped objects at listed heights. The length and width measurements are for rectangular shaped objects at listed heights. When choosing a rock enclosure for an application, note the shape of the rock as well as the application measurements. Measurements are listed in inches.

Height at	Length (max)	Width (max)	Diameter (max)	Notes
4	58	42.5	44	
4	72	4	44	Diagonal measurement; more width available at middle
8	58	41.5	43	
8	71	4	43	Diagonal measurement; more width available at middle
12	57	39.5	42	
12	70	4	42	Diagonal measurement; more width available at middle
16	57	38.5	41	
16	68	4	41	
20	56	37.5	41	
20	67	4	41	Diagonal measurement; more width available at middle
24	53	37.7	40	
24	66	4	40	Diagonal measurement; more width available at middle
28	52	36	39	
28	64	4	39	Diagonal measurement; more width available at middle
32	48	36	38	
32	57	4	38	Diagonal measurement; more width available at middle
36	46	35	38	
36	56	4	38	Diagonal measurement; more width available at middle
40	42	33	36	
40	53	4	36	Diagonal measurement; more width available at middle
44	42	32	35	
44	52	4	35	Diagonal measurement; more width available at middle
48	40	32	34	
48	50	4	34	Diagonal measurement; more width available at middle
52	38	31	34	
52	48	4	34	Diagonal measurement; more width available at middle
56	38	28	28	
56	45	4	28	Diagonal measurement; more width available at middle
58	39	28	28	
58	40	4	28	Diagonal measurement; more width available at middle

OUTDOOR CONCRETE STYLES

OLD WORLD PALETTE

Distressed finishes, stone surfaces and warm, masculine colors evoke the Old World style. Concrete gives you the ability to imitate the timeworn appeal of the pathways and patios of Tuscan and Mediterranean-style homes, while conveying a sense of New World permanence.

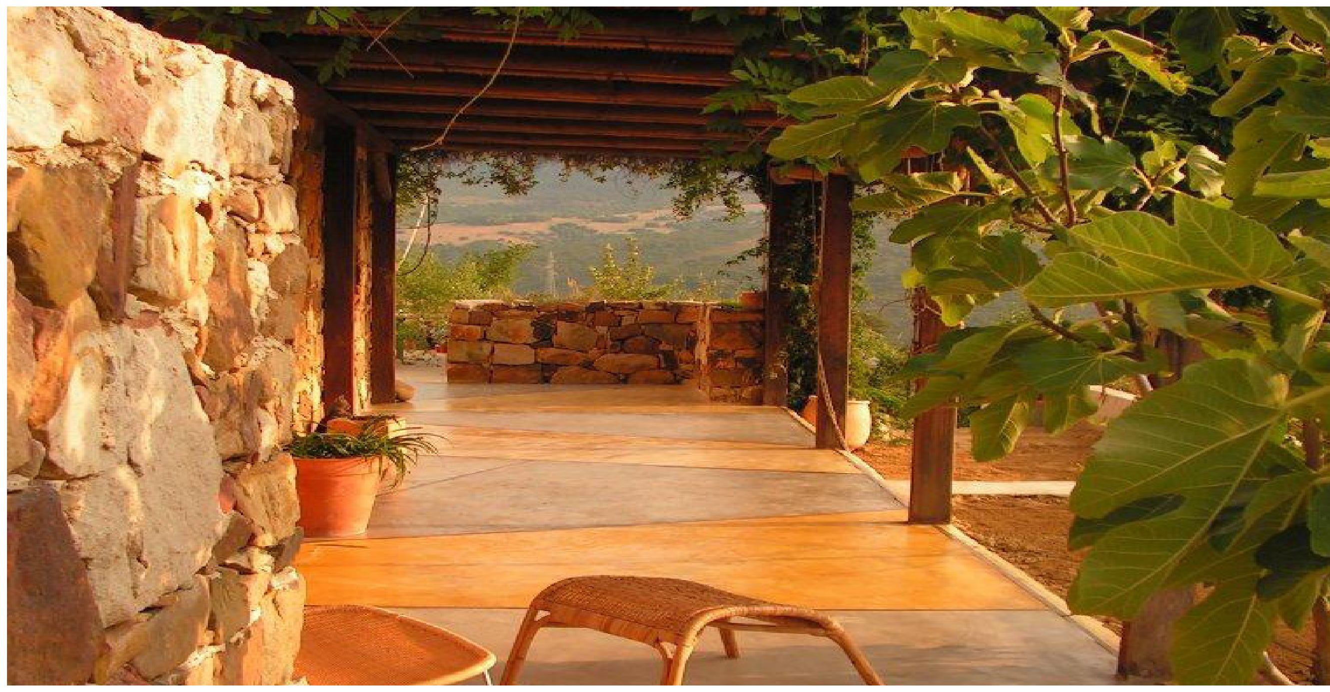
COLORS + FINISHES

Marsh Brown

Spicy Mustard

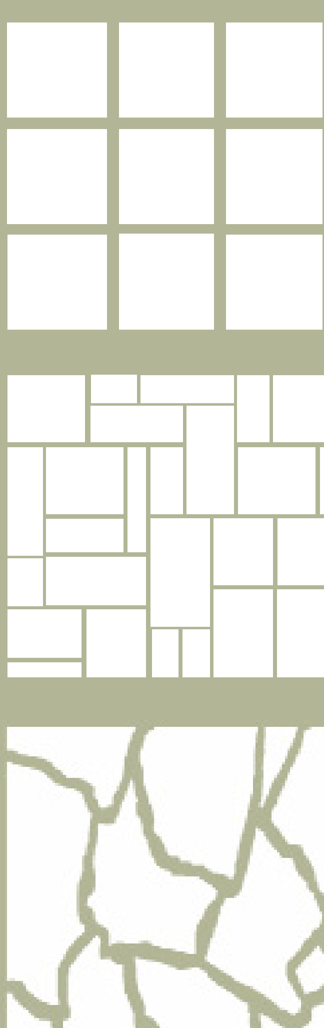
Urban Nature

Baked Terra Cotta

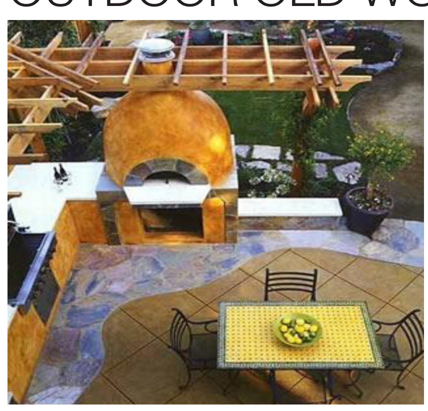


SHAPES & PATTERNS

You can achieve an Old Word style using concrete by incorporating small tiles or stone-like patterns for hardscape surfaces.



OUTDOOR OLD WORLD ELEMENTS


Patios


Driveways


Walkways

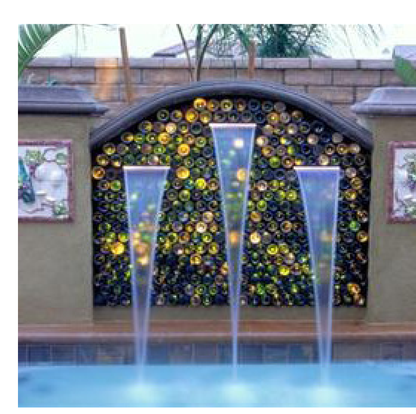

Walls


Outdoor kitchens


Fire pits


Steps


Fireplaces


Fountains

TEXTURES


Fractured Earth Seamless Stamp


European Fan Paver

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www.concretenetwork.com/outdoor

ConcreteNetwork.com

PHOTO: www.estudioarque.com; COLORS: www.benjaminmoore.com; ELEMENTS: www.tomralstonconcrete.com, www.gkrete.com, www.brickform.com, California Decorative Concrete, www.tomralstonconcrete.com, www.greenscenelandscape.com, www.ozarkpatternedconcrete.com, www.greenscenelandscape.com, www.greenscrenelandscape.com; TEXTURES: www.scofield.com

OUTDOOR CONCRETE STYLES

RANCH/RUSTIC PALETTE

Concrete in rich earth-tone colors and rough stonelike textures contributes to the rustic charm of ranch, farmhouse and country home styles. Using stains and dyes, it's also possible to "antique" existing concrete and give it an aged, weathered look.

COLORS + FINISHES

Rio Rancho Clay

Van Buren Brown

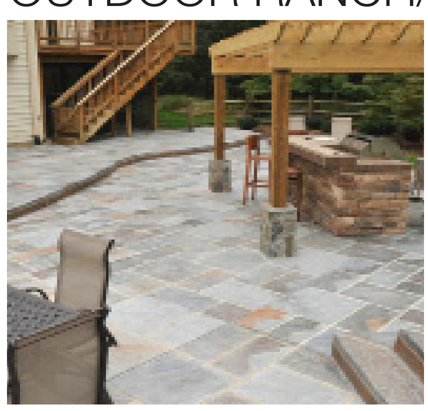
Glacial Till

Morning Light

SHAPES & PATTERNS

You can achieve a ranch or rustic style using concrete by incorporating irregular stone-like patterns or large organic spaces for hardscape surfaces.

OUTDOOR RANCH/RUSTIC ELEMENTS


Patios


Driveways


Walkways


Walls


Outdoor kitchens


Fire pits


Steps


Fireplaces


Water features

TEXTURES


Ashlar Stone


Vermont Slate

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ConcreteNetwork.com

PHOTO: www.progressiveconcrete.com; COLORS: www.benjaminmoore.com; ELEMENTS: www.salzanoconcrete.com, Pizzazz Painting, Verlennich Masonry and Concrete, www.flex-c-ment.com, www.nehardscapes.com, www.matrixrock.com, www.nehardscapes.com.com, www.progressiveconcrete.com, www.elementsofconcrete.com; TEXTURES: www.scofield.com

OUTDOOR CONCRETE STYLES

TRADITIONAL PALETTE

Formal brick-lined and stone pathways often grace the exteriors of traditional homes. This same classic, unfussy style can be replicated in concrete by incorporating formal details such as scalloped edges, brick-patterned borders and symmetrical lines.

COLORS + FINISHES

Brick Red

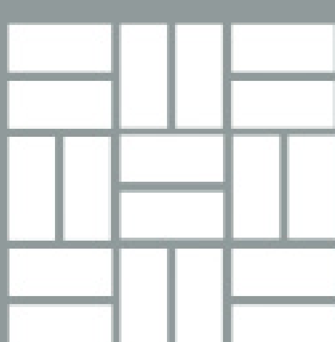
Midnight Oil

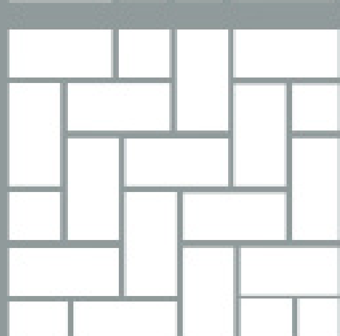
Gibraltar Cliffs

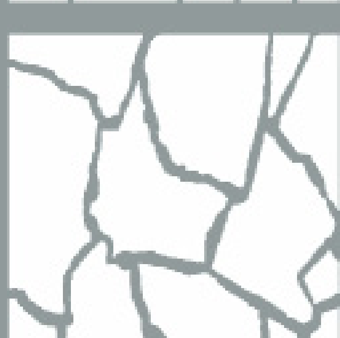
Gray Lake

SHAPES & PATTERNS

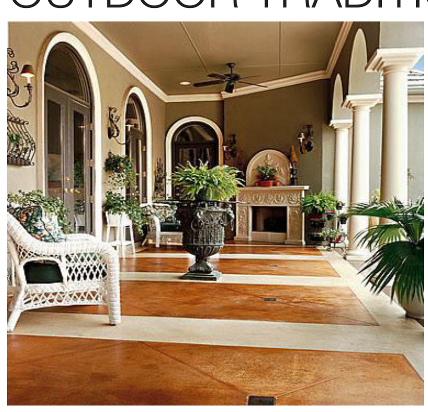
You can achieve a traditional style using concrete by incorporating repeating brick and natural cut patterns for hardscape surfaces.







OUTDOOR TRADITIONAL ELEMENTS

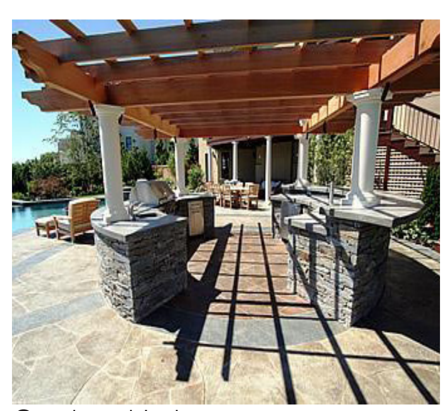


Patios

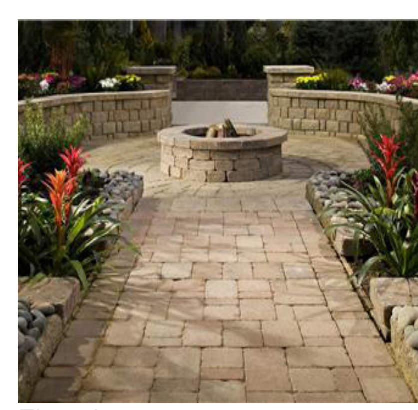
Driveways

Walkways

Walls



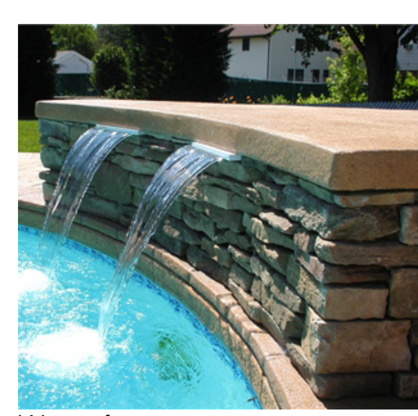
Outdoor kitchens



Fire pits

Steps

Fireplaces



Water features

TEXTURES

English Yorkstone

London Slate

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www.concretenetwork.com/outdoor

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PHOTO: www.actionconcreteservices.com; COLORS: www.benjaminmoore.com; ELEMENTS: www.bomanite.com, www.ozarkpatternedconcrete.com, www.actionconcreteservices.com, www.flex-c-ment.com, www.nehardscapes.com, www.belmanpaversandconcrete.com, www.ozarkpatternedconcrete.com, www.greenscenelandscape.com, www.uniqueconcretenj.com; TEXTURES: www.scofield.com

OUTDOOR CONCRETE STYLES

TROPICAL PALETTE

Concrete is a natural fit for the beachy sand-and-sea vibe of an oceanside home. Colored in natural browns and sandy hues, concrete complements the vibrant turquoise blues and palm-tree greens of a tropical setting.

COLORS + FINISHES

Green Thumb

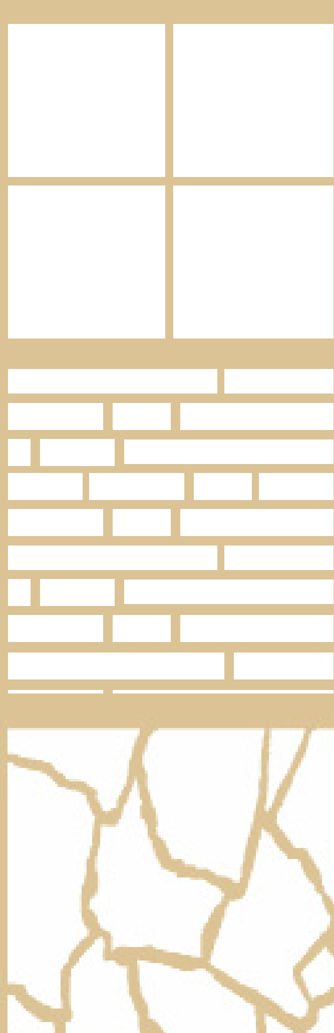
Tropical Oasis

Shortbread

Gotham

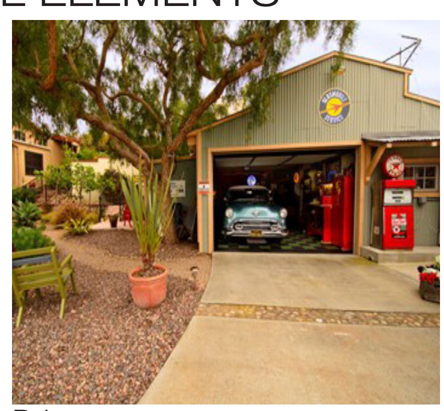
SHAPES & PATTERNS

You can achieve a tropical style using concrete by incorporating subtle geometric-shaped or random stone patterns for hardscape surfaces.



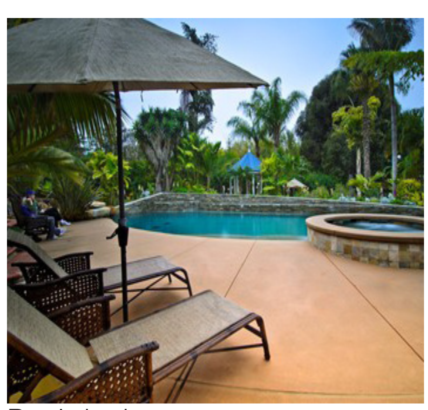
OUTDOOR TROPICAL ELEMENTS

Patios



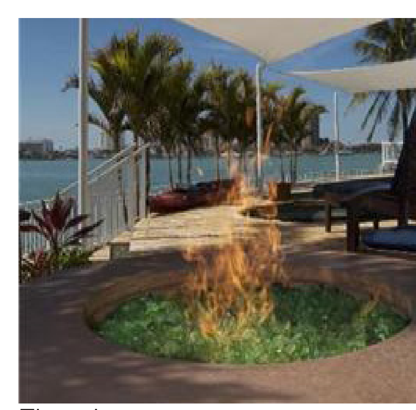
Driveways

Walkways



Pool decks

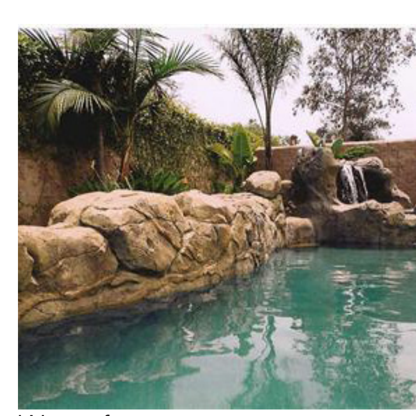
Outdoor kitchens



Fire pits

Steps

Fireplaces



Water features

TEXTURES

Pine Interlocking

Canyon Stone

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APPENDIX F

Equipment Sizing Calculations

Table G-1 - Alpine Lakes Power Consumption

Project No. 120045, Alpine Lakes, Chelan County, WA

System	Communication interval (days)	Gate adjustment interval (days)	Daily power drawdown (Ahr)	Summer Battery size (Ahr)	Summer Solar Size (W)	All Year Battery Size (Ahr)	All Year Solar Size (W)	Radio Repeater daily drawdown (Ahr)	Summer Battery size (Ahr)	Summer Solar Size (W)	All Year Battery Size (Ahr)	All Year Solar Size (W)
VHF Telemetry	1	1	1.654	28.95	13	206.76	52	1.812	31.72	13	226.54	52
Hughes Immarsat	1	1	0.871	15.25	6	108.92	25					
Iridium Satellite	1	1	0.788	13.80	6	98.55	23					
VHF Telemetry	2	2	1.237	21.65	9	154.62	35	1.218	21.32	9	152.25	35
Hughes Immarsat	2	2	0.468	8.20	4	58.55	14					
Iridium Satellite	2	2	0.424	7.42	3	53.03	12					
VHF Telemetry	7	7	0.939	16.43	7	117.38	27	0.793	13.88	6	99.14	23
Hughes Immarsat	7	7	0.181	3.16	2	22.57	6					
Iridium Satellite	7	7	0.164	2.87	2	20.51	5					

Notes

For this latitude Campbell Scientific recommends 336 hr battery reserve, this is used for Summer sizing

all year sizing assumes solar panel is burried in the snow for 100 consecutive days

All estimates are for 24Vdc systems except repeater, which is 12Vdc

ROTORK CONTROL SLUICE GATE SIZING CALCULATIONS

Customer	Aspect Consulting - Taylor Dayton
Gate Location	Wenatchee 24" C-10 Canal Gate

Required Data | Computed Data

1 CALCULATE TOTAL LIFTING FORCE F (THRUST)

F = 62.4 * A * P * f + W

f = Coefficient of Friction (0.6 for sluice gates)

H=	21.25	in.	Length of gate in inches
W =	21.25	in.	Width of gate in inches
A =	3.14	sq ft.	Area of gate in square feet
P =	30.00	ft	Efective head of water in feet
W =	300	lb	Total weight of gate and stem in pounds
Thrust	3,822	lbs	

2 CALCULATE TORQUE REFER TO ROTORK PUB. NO.AE 2/0.2 8/93

TORQUE = STEM FACTOR X F (THRUST)

Stem Type	Rising=R Non-Rising=NR	R
Rotating Stem	Y=Yes N=No	N
Stem Diameter -- in.		1.50
Stem -- TPI		4
Number of Starts		1
Lead		1/4
Stem Factor		0.012

TORQUE = 45 ftlb

3 DATA FOR ROTORK SIZING CD

TORQUE	45	ftlb	
THRUST	3,822	lb	
STEM DIA	1.50	in	
STROKE	300	sec	12 inches/minute
TURNS	85		
TOLERANCE	50	?+ / - stroke time %	

ROTORK CONTROL SLUICE GATE SIZING CALCULATIONS

Customer: Aspect Consulting - Taylor Dayton

Gate Location: Wenatchee 30" C-10 Canal Gate

Required Data | Computed Data

1 CALCULATE TOTAL LIFTING FORCE F (THRUST)

F = 62.4 * A * P * f + W

f = Coefficient of Friction (0.6 for sluice gates)

H=	26.60	in.	Length of gate in inches
W =	26.60	in.	Width of gate in inches
A =	4.91	sq ft.	Area of gate in square feet
P =	30.00	ft	Efective head of water in feet
W =	400	lb	Total weight of gate and stem in pounds
Thrust	5,919	lbs	

2 CALCULATE TORQUE REFER TO ROTORK PUB. NO.AE 2/0.2 8/93

TORQUE = STEM FACTOR X F (THRUST)

Stem Type	Rising=R Non-Rising=NR	R
Rotating Stem	Y=Yes N=No	N
Stem Diameter -- in.		1.50
Stem -- TPI		4
Number of Starts		1
Lead		1/4
Stem Factor		0.012

TORQUE = 69 ftlb

3 DATA FOR ROTORK SIZING CD

TORQUE	69	ftlb	
THRUST	5,919	lb	
STEM DIA	1.50	in	
STROKE	300	sec	12 inches/minute
TURNS	106		
TOLERANCE	50	?+ / - stroke time %	

APPENDIX G

Opinions of Probable Cost

Table H-1 - Opinion of Probable Costs

Project No. 120045, Alpine Lakes, Chelan County, WA

ITEM	UNIT	UNIT COST	SQUARE LAKE QUANTITY	SQUARE LAKE COST	KLONOQUA LAKES QUANTITY	KLONOQUA LAKES COST	EIGHTMILE LAKE QUANTITY	EIGHTMILE LAKE COST	COLCHUCK LAKE QUANTITY	COLCHUCK LAKE COST	SNOW LAKES QUANTITY	SNOW LAKES COST
Install Monitoring Equipment												
Install Staff Gage / Lake Level Monitoring	EA	$5,000	1	$5,000	1	$5,000	1	$5,000	1	$5,000	0	$0
Install Staff Gage / Discharge Monitoring and Develop Rating	EA	$6,500	1	$6,500	1	$6,500	1	$6,500	1	$6,500	0	$0
Subtotal - Install Monitoring Equipment				**$11,500**		**$11,500**		**$11,500**		**$11,500**		**$0**
Gate Modifications												
Remove Existing Gate	LS	(Varies)	0	$0	1	$5,000	0	$0	1	$2,500	0	$0
Modify Existing Gate Appurtenances	LS	(Varies)	1	$3,500	0	$0	0	$0	0	$0	0	$0
Gate Tower	LS	(Varies)	0	$0	0	$0	0	$0	1	$24,000	0	$0
Install 30-inch Diameter Slide Gate	EA	$25,000	0	$0	1	$25,000	0	$0	1	$25,000	0	$0
Subtotal - Existing Control Gate Modifications				**$3,500**		**$30,000**		**$0**		**$51,500**		**$0**
Automate Gates/Valves to Optimize Releases												
Motorized Valve or Gate Actuator	EA	$20,000	1	$20,000	1	$20,000	0	$0	1	$20,000	1	$20,000
Power, Controls and Communications	EA	$25,000	1	$25,000	1	$25,000	0	$0	1	$25,000	1	$25,000
Controls Enclosure	LS	(Varies)	1	$11,000	1	$11,000	0	$0	1	$11,000	0	$0
Repeater Station	EA	$20,600	0.25	$5,150	0.25	$5,150	0.25	$5,150	0.25	$5,150	1	$20,600
Base Station	EA	$18,400	0.25	$4,600	0.25	$4,600	0.25	$4,600	0.25	$4,600	1	$18,400
Subtotal - Automate Gate to Optimize Releases				**$65,750**		**$65,750**		**$9,750**		**$65,750**		**$84,000**
		`										
Subtotal - All Work				**$80,750**		**$107,250**		**$21,250**		**$128,750**		**$84,000**
Mobilization Costs (Assumes Use of Helicopter)				**$31,056**		**$33,044**		**$26,594**		**$34,656**		**$11,300**
Miscellaneous Mobilization/Demobilization	7.5%			$6,056		$8,044		$1,594		$9,656		$6,300
Helicopter Mobilization/Demoblization/Rental				$25,000		$25,000		$25,000		$25,000		$5,000
Construction Subtotal				**$111,806**		**$140,294**		**$47,844**		**$163,406**		**$95,300**
Contingency	25.0%			$27,952		$35,073		$11,961		$40,852		$23,825
Engineering, Permitting and Administration	20.0%			$22,361		$28,059		$9,569		$32,681		$19,060
Sales Tax	8.2%			$13,294		$16,681		$5,689		$19,429		$11,331
Total Project Cost				**$175,413**		**$220,107**		**$75,062**		**$256,368**		**$149,516**

Table H-2 - Operations and Maintenance Cost Estimate

Project No 120045, Alpine Lakes, Chelan County, WA

O&M Element	Unit Cost	Unit	Qty	Total Cost	Notes
Actuators				**$7,700**	
Preventative Maintenance				**$1,700**	
Labor	$7,500	year	0.20	$1,500	100 hours labor @ $75 / hr, Once every 5-years
Equipment	$100	year	1.00	$100	nominal hand toolls and equipment / year
Materials	$500	year	0.20	$100	$500 materials, Once every 5-years
Operations				**$2,000**	
Labor	$50	hr	40.00	$2,000	40 hours of operational labor (system), yearly
Repair / Replacement (Labor, Equipment, Materials)				**$4,000**	
Actuators	$100,000	year	0.04	$4,000	Replacement cost of actuator, 25-year estimated life
Electrical Equipment (Controls and Communications)				**$20,450**	
Preventative Maintenance				**$2,200**	
Labor	$10,000	year	0.20	$2,000	100 hours labor @ $100 / hr, Once every 5-years
Equipment	$100	year	1.00	$100	nominal hand toolls and equipment / year
Materials	$500	year	0.20	$100	$500 materials, Once every 5-years
Operations				**$1,000**	
Labor	$50	hr	20.00	$1,000	40 hours of operational labor (controls troubleshooting), yearly
Repair / Replacement (Labor, Equipment, Materials)				**$17,250**	
Controls and Communications Equipment	$125,000	year	0.10	$13,000	Replacement cost of equipment, 10-year estimated life
Solar Panel Replacement	$2,500	year	0.10	$250	Replacement solar panel, 10-year estimated life
Batteries	$20,000	year	0.20	$4,000	Replacement battery banks, 5-year estimated life
Monitoring Equipment				**$1,550**	
Preventative Maintenance				**$1,000**	
Labor	$5,000	year	0.20	$1,000	40 hours labor @ $125 / hr, Once every 5-years
Repair / Replacement (Labor, Equipment, Materials)				**$550**	
Transducer Replacement	$5,000	year	0.10	$500	Transducer replacement, every 10-years
Staff Gage Replacement	$1,000	year	0.05	$50	Repair / Replace Staff Gage, Every 20-years
Miscellaneous				**$6,000**	
Operations and Maintenance				**$6,000**	
Labor (Misc System Operation)	$50	hr	40.00	$2,000	40 hours misc labor @$50, yearly
Equipment (Helicopter Support)	$15,000	year	0.20	$3,000	3-days misc. helicopter support, every 5-years
Materials and Equipment (Misc.)	$1,000	year	1.00	$1,000	$1,000 materials and equipment, yearly
Total				**$35,700**	