

Rocky Reach Reservoir

Evaluation of Reservoir Operations and Adult Pacific Lamprey Migration

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September 2017

Background

The Rocky Reach Fish Forum (RRFF), Priest Rapids Fish Forum (PRFF) and Well Aquatic Settlement Work Group (ASWG) met jointly at Douglas County PUD on April 13, 2017. The group met to review adult Pacific lamprey passage studies and results, future studies and adult translocation. During the meeting Chelan PUD heard suggestions that Rocky Reach Reservoir may be the cause of very low adult lamprey passage at Wells Dam for the past 10 years. No hypotheses about this condition or mechanisms that might create this condition were discussed. Rocky Reach Reservoir is used by adult Pacific lamprey for overwintering in their first fresh-water year (Blue Leaf Environmental 2017), and for upstream migration to the Entiat River and to Wells Dam. Adult lamprey passage studies are ongoing at Rocky Reach Dam. Passage efficiency was measured at 98.8% in 2016 using Full Duplex PIT tags (Blue Leaf 2017, Draft Final Report).

Annual counts of Pacific lamprey at Wells Dam declined significantly in 2006 (Table 1, Figure 1) and have not increased commensurately with annual counts at Rocky Reach since that time (Source: Fish Passage Center 2017). Rocky Reach counts have increased, reaching an in-progress count of 23,652 adult lampreys as of September 30, 2017. The 2017 in-progress count at Wells Dam is 275 lampreys as of September 30 (Table 1).

Comparison of annual fishway counts between Rocky Reach Dam and Wells Dam from 2006 to 2016 shows an average annual count conversion of only 0.77% (Table 1; Figure 1). In prior years 2000-2005, the six-year mean count conversion from Rocky Reach Dam to Wells Dam was 36.2% and ranged from 18.3% to 55.9% (Table 1). This “count conversion rate” is a ratio, calculated using number of fish enumerated at Wells Dam divided by the number enumerated at Rocky Reach Dam in the same year. The conversion is not adjusted for the number of lamprey that cross Rocky Reach, enter Entiat River, and do not move upstream to Wells. It also not adjusted for the number of lampreys that may overwinter in Rocky Reach and then pass Wells Dam in the following migration year.

In the latest four-year period at Rocky Reach (2014-2017), 33,179 adult lampreys have been counted passing through the fishway. Although not complete, the 2017 count of 23,652 fish is the highest since lamprey enumeration began at Rocky Reach Dam in 1983 (second highest 3,799 in 2014). The 2017 in-progress count at Wells Dam is 275 lampreys.

After the initial joint meeting in April 2017, the RRFF discussed possible reasons for the ongoing low passage counts of adult lamprey at Wells Dam. Broad hypotheses include operations of Rocky Reach Reservoir or changes in operations since 2006, fires in the Methow River Basin causing loss of pheromone cues, Chelan PUD’s white sturgeon stocking program and presence of white sturgeon in the Wells Dam tailrace, Wells Fish Hatchery effluent (sturgeon rearing water) discharging into Wells Dam tailrace, changes in Wells Dam project operations, poor entrance efficiency at Wells fishways, and lamprey spawning in Rocky Reach Reservoir.

Rocky Reach Reservoir Operating Conditions

Chelan PUD prepared this document to describe the past daily and seasonal operation of Rocky Reach Reservoir. Reservoir operations consist of several measurable metrics: Minimum and maximum licensed forebay elevations, a licensed vertical operating range between these elevations, and the frequency and duration of time the reservoir is operated within this vertical operating elevation range. We analyzed these metrics to describe reservoir operations over six years of time, determine what factors affect Rocky Reach Reservoir surface elevations and whether any controllable operation could affect or block lamprey migration through the Rocky Reach Reservoir to Wells Dam.

The Rocky Reach Pacific Lamprey Management Plan (PLMP) requires the Rocky Reach Fish Forum to develop initial hypotheses regarding ongoing Project operational effects. This document provides an analysis of reservoir operations as a potential effect on lamprey migration through Rocky Reach Reservoir.

Table 1. Counts of adult Pacific lamprey at Rocky Reach Dam and Wells Dam, 2000-2017, and the average count-conversion percent between the two dams (*9/30/17 counts still in progress). (Source: Fish Passage Center)

YEAR	ROCKY REACH COUNT	WELLS COUNT	AVG CONVERSION %
2000	767	155	20.21
2001	805	262	32.55
2002	1842	338	18.35
2003	2521	1408	55.85
2004	1043	291	27.90
2005	404	215	53.22
2006	370	21	5.68
2007	541	35	6.47
2008	368	7	1.90
2009	278	9	3.24
2010	268	2	0.75
2011	618	1	0.16
2012	805	3	0.37
2013	1625	21	1.29
2014	3799	7	0.18
2015	2133	0	0.00
2016	3595	5	0.14
2017*	23,652	275	1.16
Total 2000-2005	7,382	2,669	36.16
Total 2006-2016	14,400	111	0.77
Avg All Years	45,434	3,049	6.72

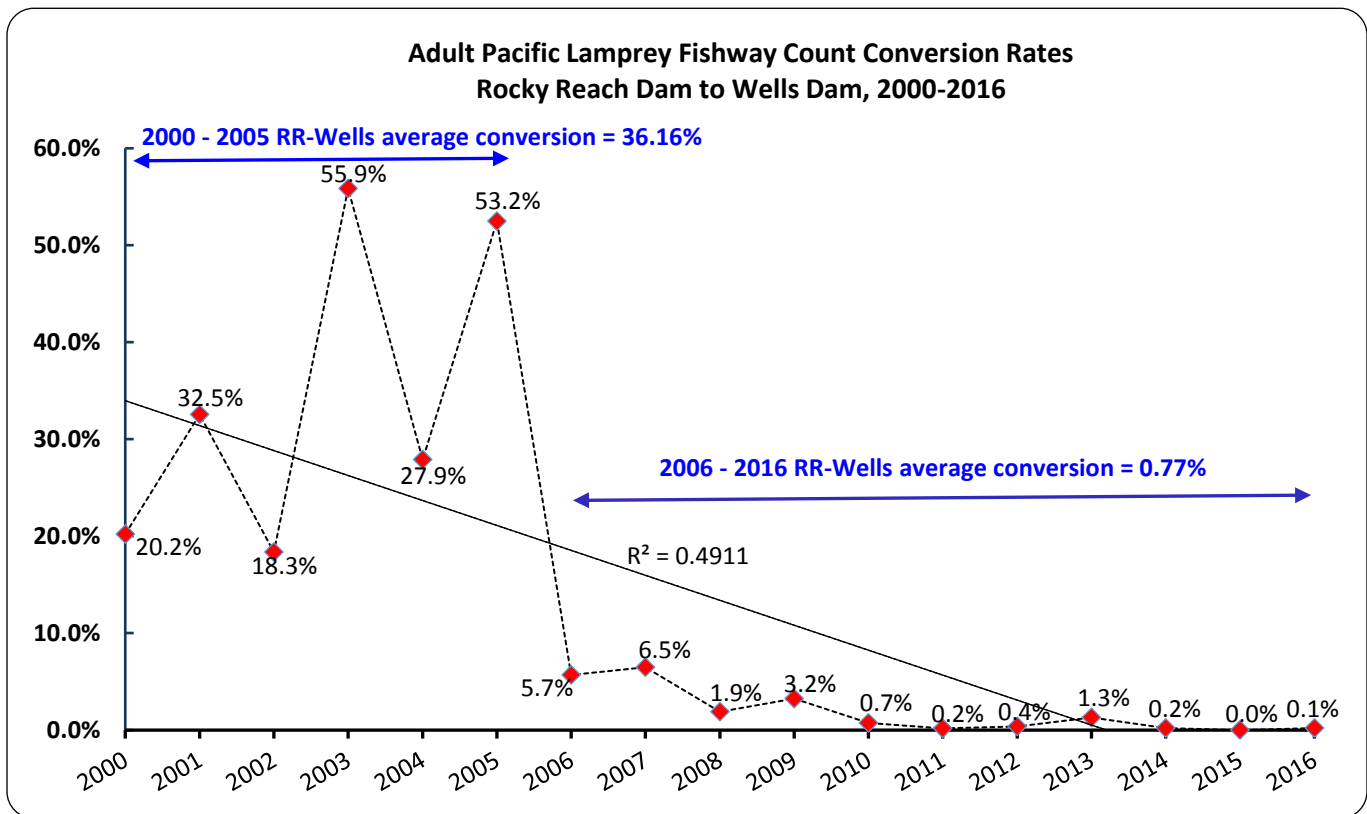


Figure 1. Adult Pacific Lamprey count conversion rates between Rocky Reach Dam and Wells Dam, 2000-2016.

Table 2 shows Rocky Reach Reservoir’s maximum and minimum licensed operating elevations, its allowable operating range (vertical draft range), and its useable storage volume in comparison to other Columbia River reservoirs. Rocky Reach has four feet of maximum usable vertical draft. Only Ice Harbor Dam’s reservoir on the Snake River has a smaller vertical operating range.

Rocky Reach Reservoir’s maximum surface elevation is 707.0 feet above mean sea level (msl). Its minimum elevation is 703.0 feet msl. The reservoir has a small allowable draft range and its elevations do not change significantly for long periods of time (no fall draft for flood control operations). The reservoir contains a small amount of useable stored water volume compared to other Columbia River reservoirs. “Useable storage” means the amount of water available between the licensed (FERC Projects) maximum and minimum reservoir operating elevations.

Table 2. Columbia River Hydroelectric Project Reservoir elevations and useable storage volumes.

Project	Max Resv Elev (ft msl)	Min Resv Elev (ft msl)	Max Vertical Draft (ft)	Useable Storage (thousand acre-ft*)	Useable Storage (thousand cfs-day**)
Grand Coulee	1290.0	1208.5	81.5	5,185.0	2,613.0
Chief Joe	956.0	930.0	26.0	116.0	58.5
Wells	781.0	771.0	10.0	74.0	37.3
Rocky Reach	707.0	703.0	4.0	36.0	18.1
Rock Island	613.0	609.0	4.0	9.5	4.8
Wanapum	571.5	560.0	11.5	161.0	81.1
Priest Rapids	488.0	481.5	6.5	44.0	22.6
Ice Harbor	440.0	437.0	3.0	25.0	12.6
McNary	340.0	335.0	5.0	185.0	12.6
John Day	268.0	257.0	11.0	534.0	269.1
The Dalles	160.0	155.6	4.4	53.0	26.7
Bonneville	77.0	70.0	7.0	138.0	69.5

* One acre-foot of water equals 43,560 cubic feet of water

** cfs-day is a water volume equal to a water flow rate in cubic feet per second each second of one day.

Reservoir Characteristics, Operations and Elevations

We evaluated Pacific Lamprey run-timing into Rocky Reach Reservoir (Figure 2) and concurrent operations of the reservoir to determine if operating conditions exist that could affect adult lamprey movement through the reservoir any time of year, and during the primary adult lamprey migration period July through October.

We evaluated hourly reservoir elevation data from 2005 to 2007 (Figure 3) to compare elevations in years that bookend the precipitous drop in lamprey counts that occurred at Wells Dam in 2006. We also analyzed operating elevation data from 2014 to 2016 to demonstrate that Rocky Reach Reservoir operating conditions did not change between the two periods. We compared surface elevation differences between Rocky Reach Forebay (FB) and Wells Tailwater (TW) to determine causal mechanisms of water surface elevation changes. We analyzed the relationship between the Wells Project’s total discharge rates and Rocky Reach forebay elevations (Table 3). We plotted hourly elevation data for the Rocky Reach forebay (annually 8,760 hours) to construct hourly elevation duration curves, and separately for each hour during the period July 1 through October 31 (2,952 hours) coinciding with the lamprey migration timing (Figure 2). Rocky Reach Reservoir elevations are measured every four seconds of the day using a system of electronic monitors in the forebay. Water surface elevation data used in this document are top-of-the-hour measurements.

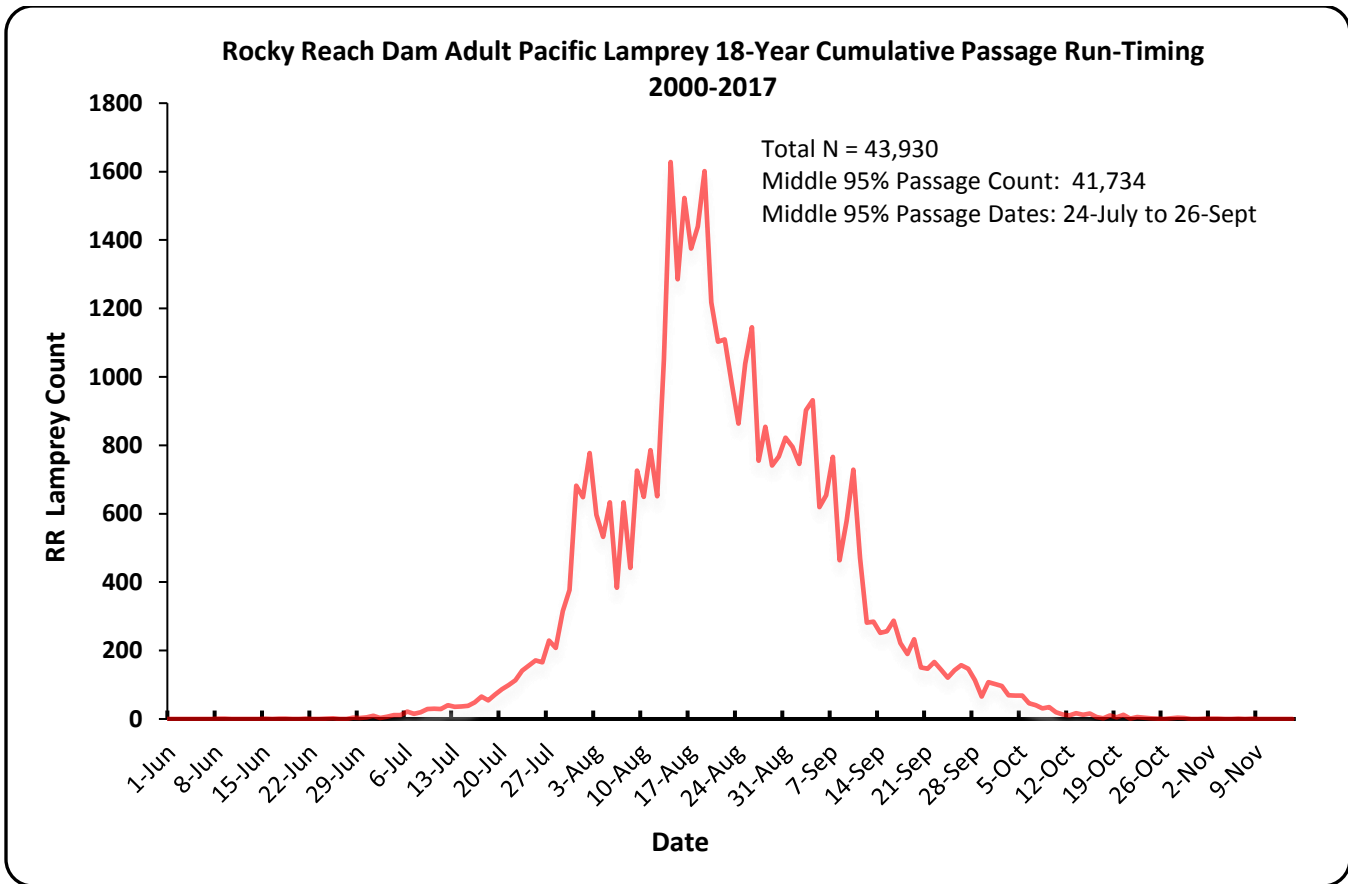


Figure 2. Rocky Reach Dam adult Pacific lamprey 18-year cumulative fishway count run-timing, 2000-2017.

Rocky Reach Reservoir’s licensed operating limits (2009) have not changed from the Project’s previous FERC license. Chelan PUD’s 2005 license application to FERC (second license) proposed no changes to the reservoir’s size, operations, or the upper and lower operating elevation limits; 707 ft msl (mean sea level) maximum and 703 ft msl minimum still remain in the new 2009 Project license. No other operating changes are in effect.

Rocky Reach Reservoir is 41.4 miles (66.6 km) in length. It extends upstream from Rocky Reach Dam at Columbia River mile 473.7 to 1000 feet below Wells Dam located at river mile 515.1. Rocky Reach Reservoir is “run-of-river” (ROR). Run of river means the reservoir contains no seasonally stored water volume. The reservoir has no fall draft or spring refill operation typical of storage reservoirs (i.e., Grand Coulee, Dworshak, Brownlee, and Hungry Horse). Rocky Reach Reservoir contains only 36,000 acre-feet of useable water within four feet of available vertical draft. One acre-foot of water is equal to 43,560 cubic feet of water. The reservoir has no significant flood control ability. For example, the allowable water volume stored in Rocky Reach Reservoir would be completely gone in a single day if the reservoir began full (707.0 feet msl) and the dam discharged 18,100 cfs all day with no inflow (Table 2). Inflow sources to Rocky Reach are Wells Dam discharge, the Entiat River, and the Chelan River.

Having minimal water storage available, Rocky Reach Dam uses primarily daily inflow for power generation and stored water secondarily to meet power demand. Discharge from Rocky Reach Dam closely approximates daily inflow into the reservoir (Wells discharge plus tributary inputs). This results in continuous flow through the reservoir, making it more riverine-like with relatively consistent reservoir surface elevations all year (Figures 3-5).

In the six years analyzed, Rocky Reach Reservoir operated primarily on a daily draft and same day refill cycle. Daily fluctuations were generally between 0.5 and 1.5 feet. Rocky Reach used stored reservoir water mainly during the day, and the reservoir refilled during the night. Daily outflow rates from the dam closely approximated daily inflow rates to the reservoir each day of the year.

Forebay surface elevations (“headwater elevations”) demonstrate the nature of Rocky Reach Reservoir operating conditions. Rocky Reach Dam operations control reservoir forebay elevations. Inflow rates to Rocky Reach Reservoir are estimated hourly (every four seconds in the Districts SCADA Program). In general, discharge rates from Rocky Reach Dam are balanced with inflow rates (Wells discharge, plus Entiat R, plus Chelan R) to keep the reservoir within operating limits. The reservoir is maintained as stable and high as possible to maximize power generation. Figures 3-8 show hourly surface elevations of the Rocky Reach Reservoir (forebay) for all hours of 2005-2007 and 2014-2016, and all hours from 1 July through 31 October of the same years.

In all years prior to and after 2006, Rocky Reach reservoir elevations remained at or above 705.0 feet msl 90% of all hours (8,760 hours per year). This illustrates stable and consistent reservoir elevations and dam operations. Figure 9 demonstrates the 24-hour operation of Rocky Reach forebay elevations that occurred on August 20 of all six years evaluated. August 20 was used because it is the approximate 50th percentile passage date of adult lampreys that cross Rocky Reach Dam and move into the reservoir.

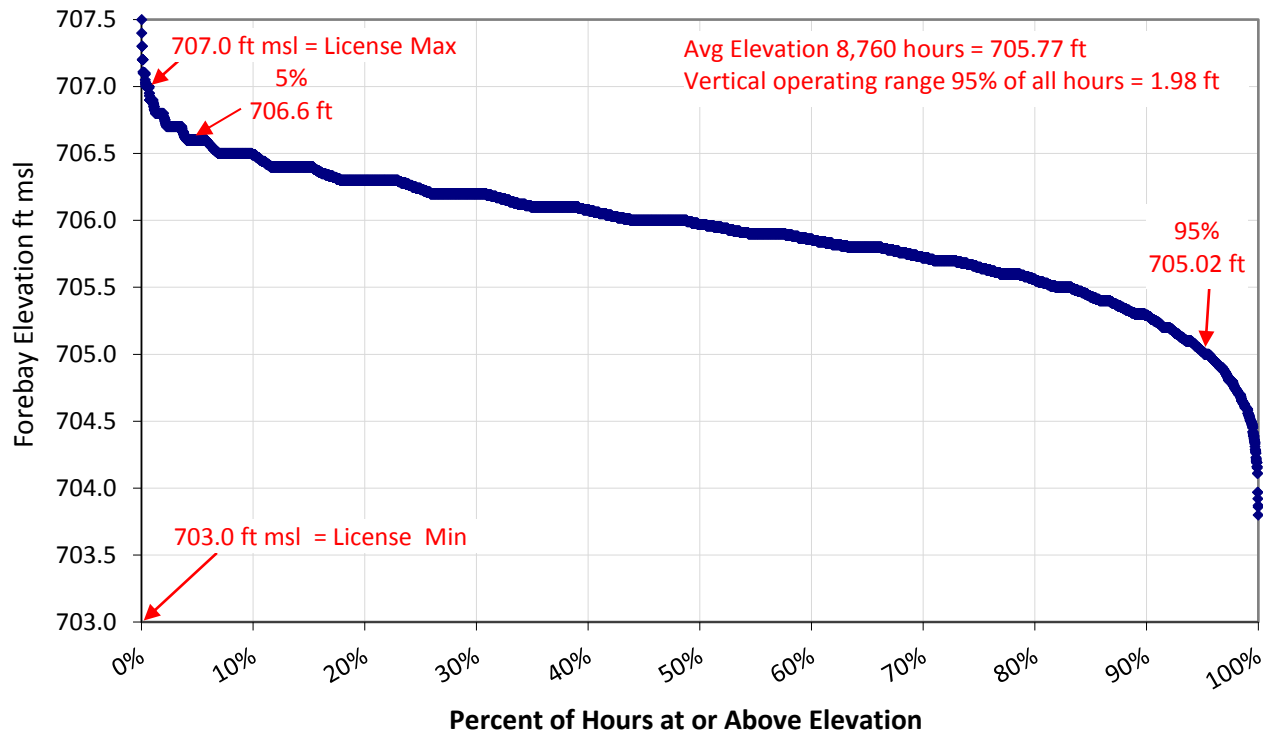
Adult Pacific lamprey migrate through seven hydroelectric dams and reservoirs prior to Rocky Reach. The distance from Bonneville Dam to Rocky Reach Dam is 327.6 river miles. Rocky Reach Reservoir is similar to the other reservoirs downstream, except it is smaller, has a smaller vertical draft range, and less useable water storage. Generally, it is more stable and more riverine-like, with higher daily mean water velocities (Appendix 1). Peak annual inflows into the reservoir and outflows from Rocky Reach Dam occur in the months of May and June.

Rocky Reach Reservoir is confined within a relatively narrow canyon. The reservoir narrows even further upstream of Beebe Bridge, towards Wells Dam. River flow below Wells Dam conveys downstream quickly (Chelan PUD 2017, Appendix 1). Mean Rocky Reach Reservoir water velocities from June through September are 2.27, 1.80, 1.37, and 0.88 feet per second, respectively (Appendix 1).

Rocky Reach Dam controls forebay elevations through discharge of water for generation and fish spill (April-August). Surface elevations are measured hourly (electronically) at the forebay of the dam. Rocky Reach Dam cannot control inflows into its reservoir from Wells Dam, and cannot control Wells Dam tailrace elevations. Wells Dam controls both of these metrics. Any significant operational change at Rocky Reach Dam would be visible as changes in Rocky Reach Dam forebay (reservoir) surface elevations.

Hourly surface elevation duration curves (Figures 3-8) developed for this analysis show the percent of time (hours) that Rocky Reach Reservoir operated at or above a given surface elevation within its four-foot vertical operating range between 703.0 feet and 707.0 feet msl.

**2005 Rocky Reach Reservoir Hourly Forebay Operating Elevations
January 1 - December 31 (8,760 hours)**



**2005 Rocky Reach Reservoir Hourly Forebay Operating Elevations
July 1 - October 31 (2,952 hours)**

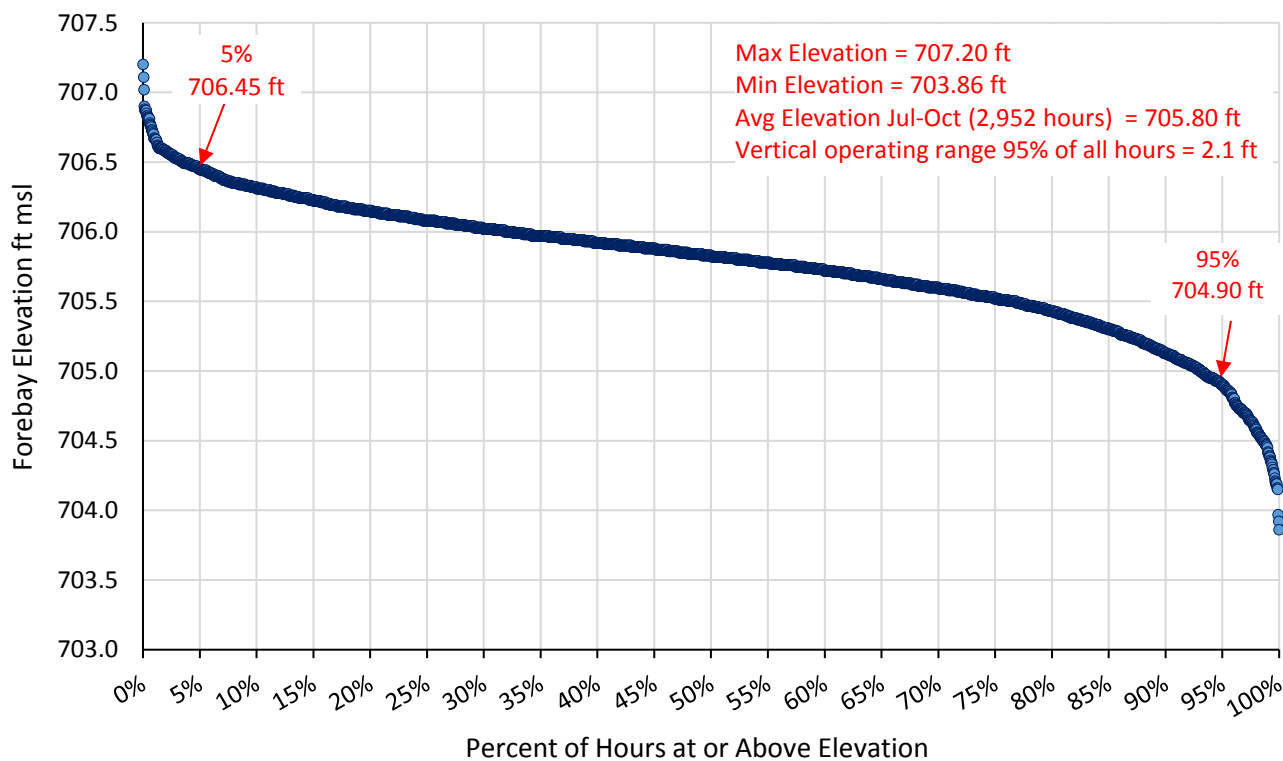
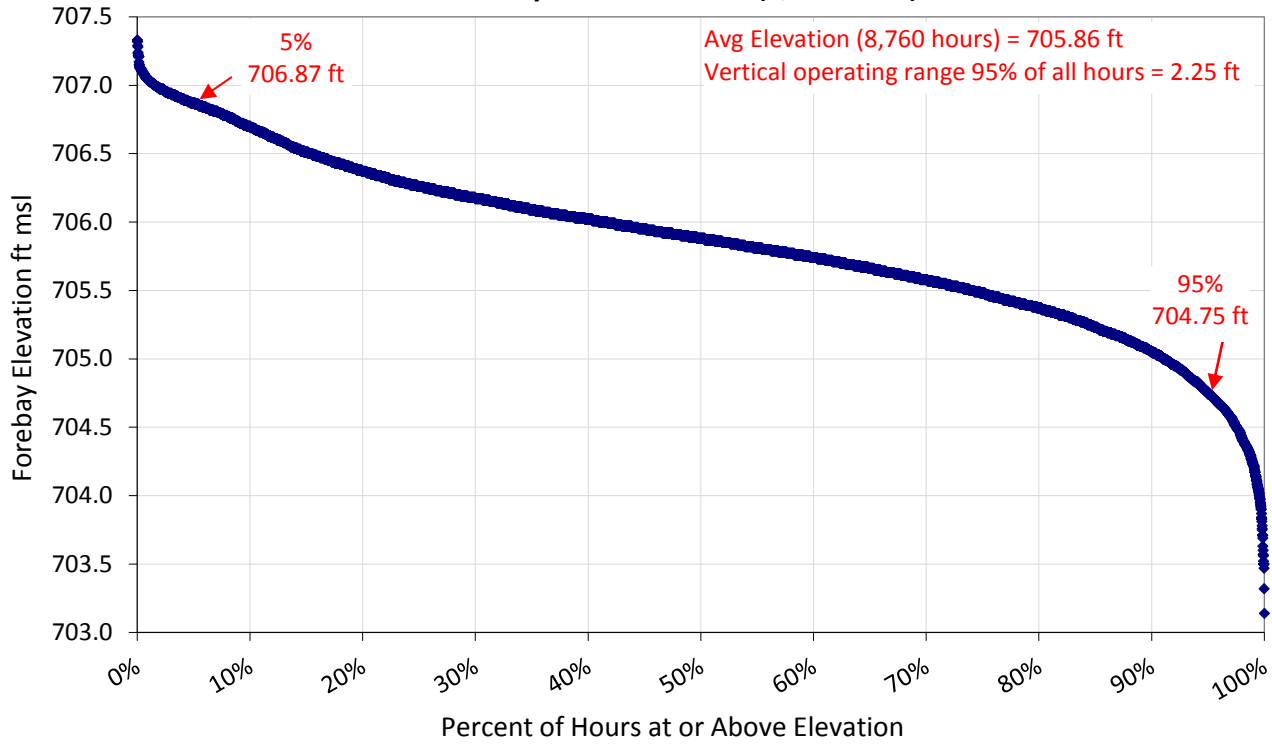


Figure 3. 2005 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 October 31, 2005 during the adult lamprey migration period.

**2006 Rocky Reach Reservoir Hourly Forebay Operating Elevations
January 1 - December 31 (8,760 hours)**



**2006 Rocky Reach Reservoir Hourly Forebay Operating Elevations
July 1 - October 31 (2,952 Hours)**

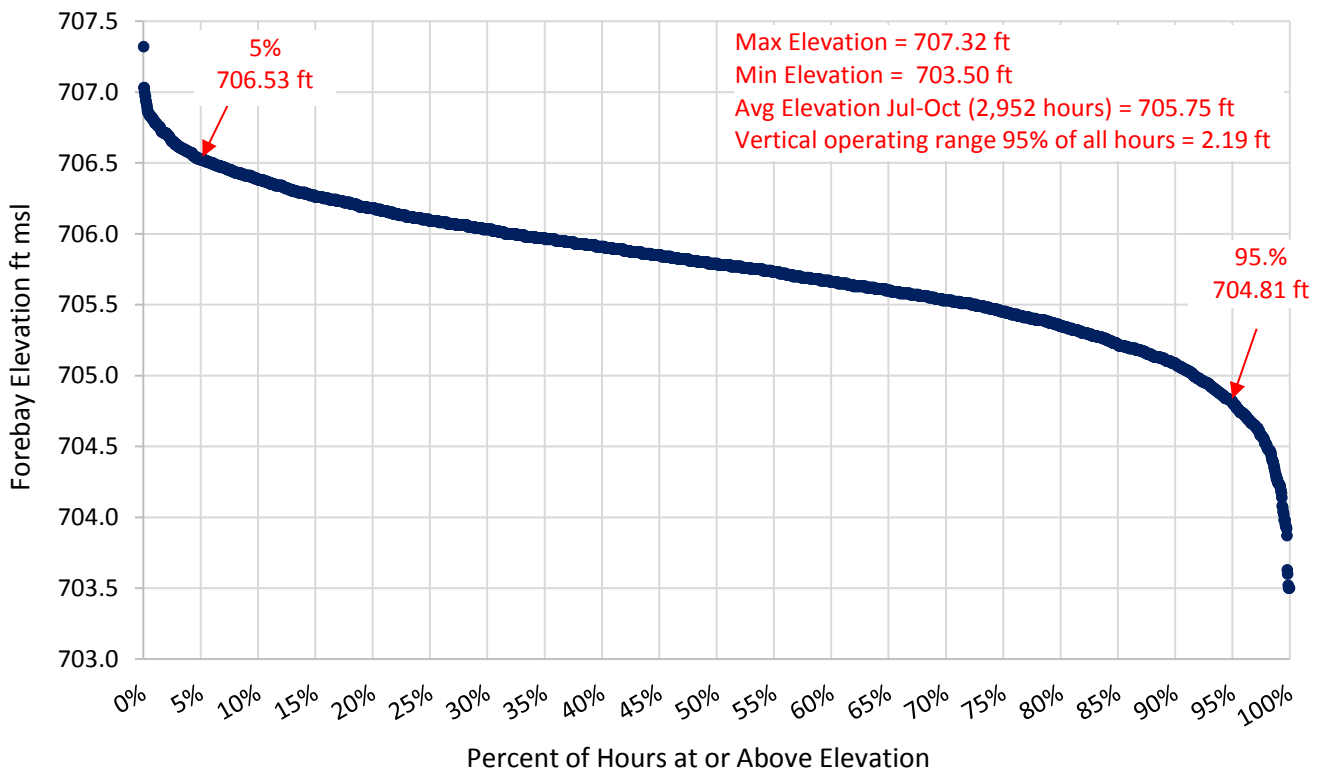


Figure 4. 2006 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 – October 31, 2006 during the adult lamprey migration through the reservoir.

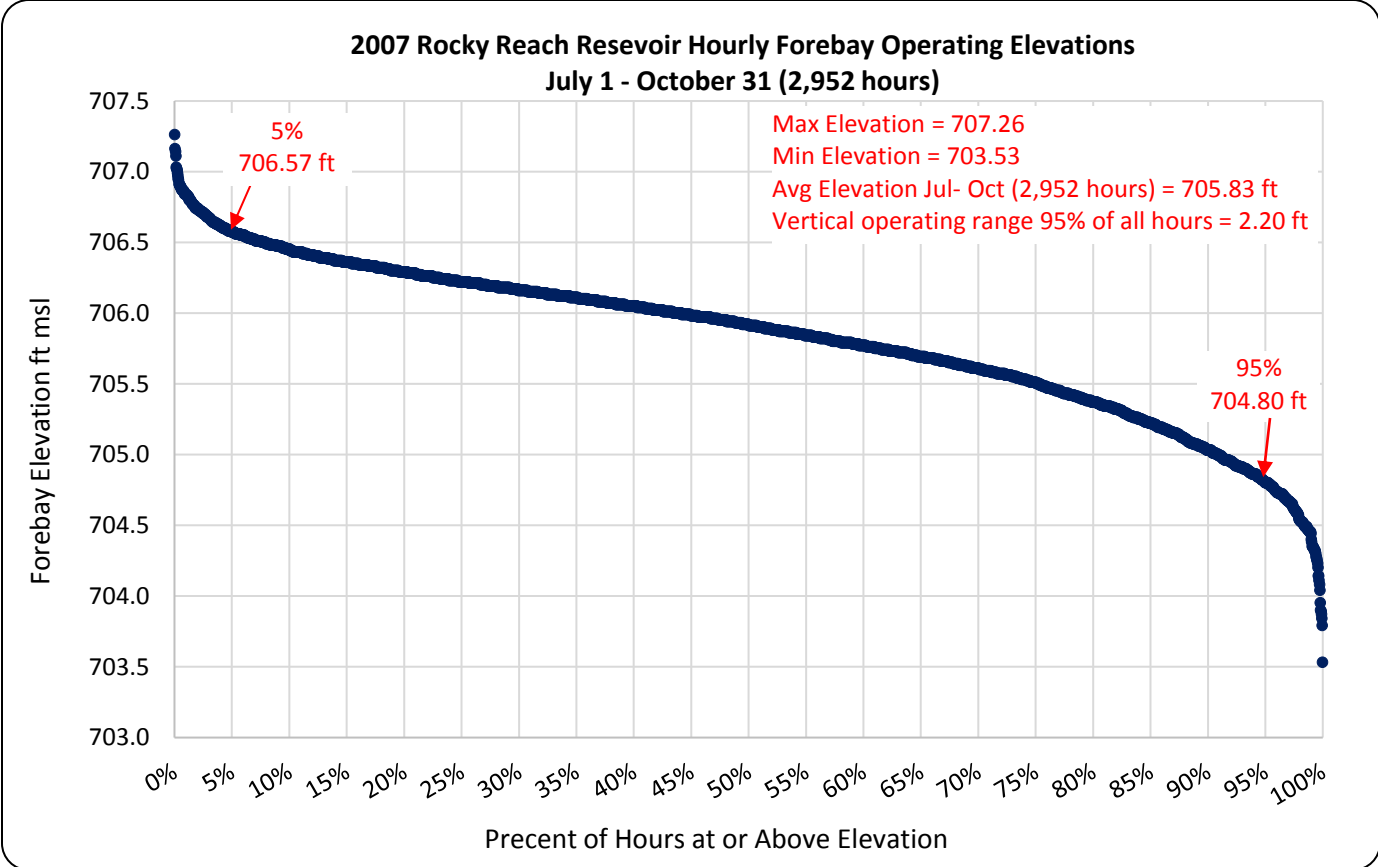
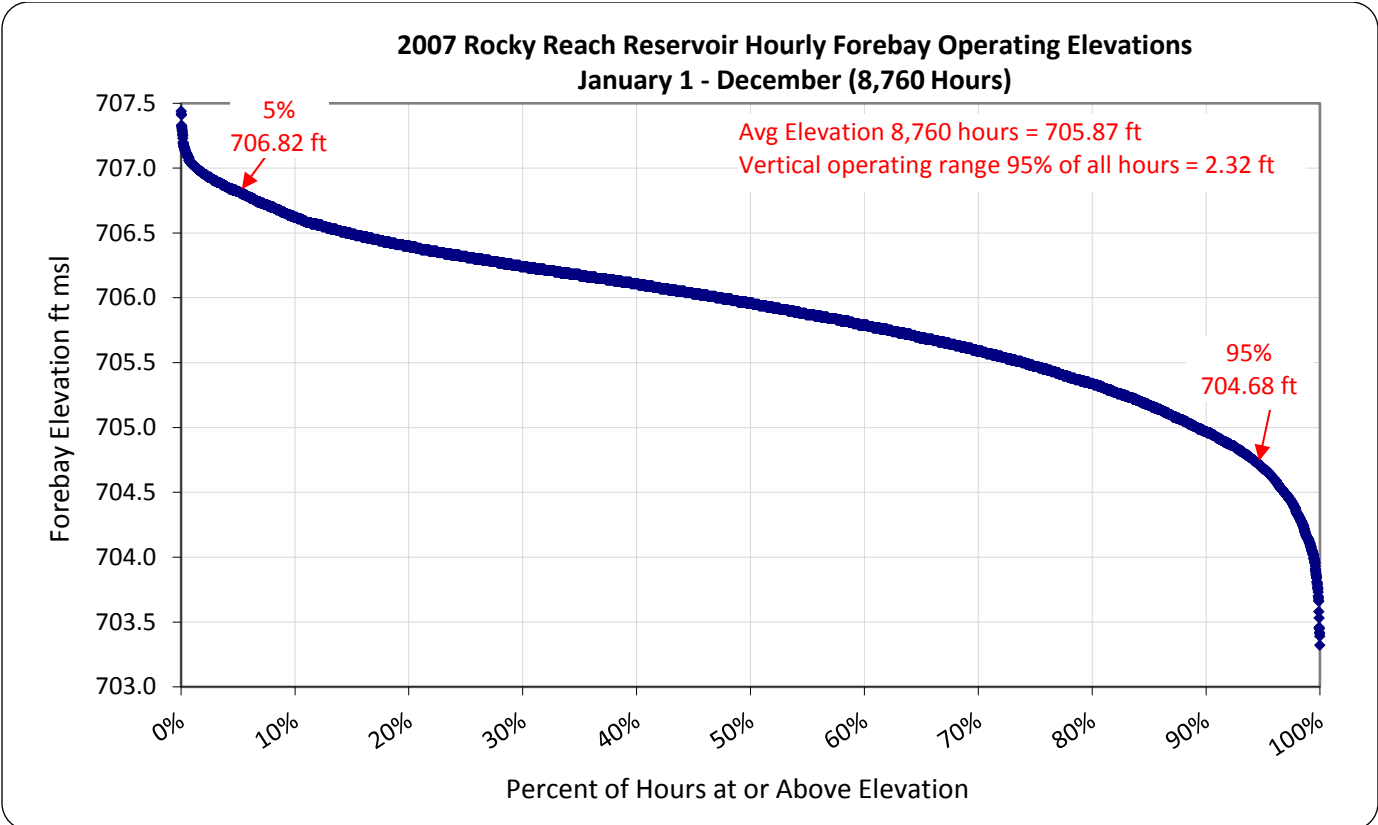
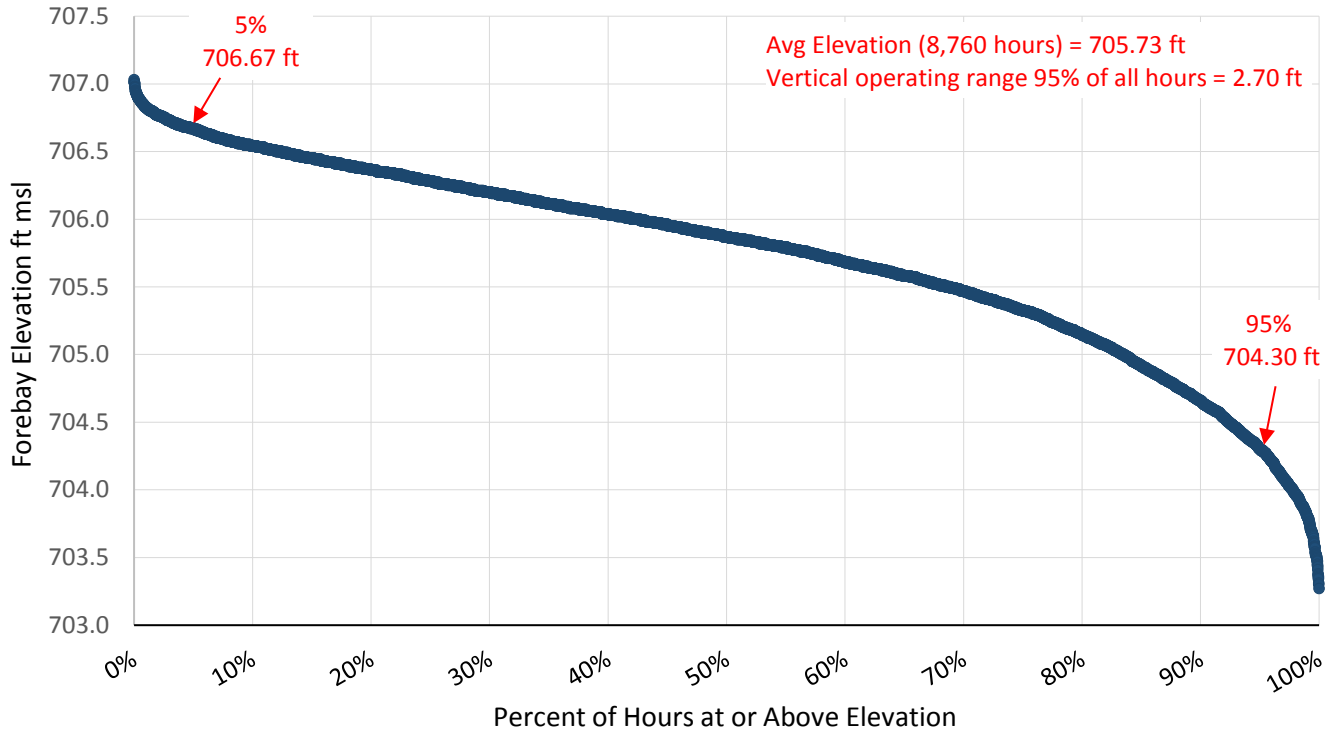


Figure 5. 2007 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 – October 31, 2007 during the adult lamprey migration period.

**2014 Rocky Reach Reservoir Hourly Forebay Operating Elevations
January 1 - December 31 (8,760 hours)**



**2014 Rocky Reach Reservoir Hourly Forebay Operating Elevations
July 1 - October 31 (2,952 hours)**

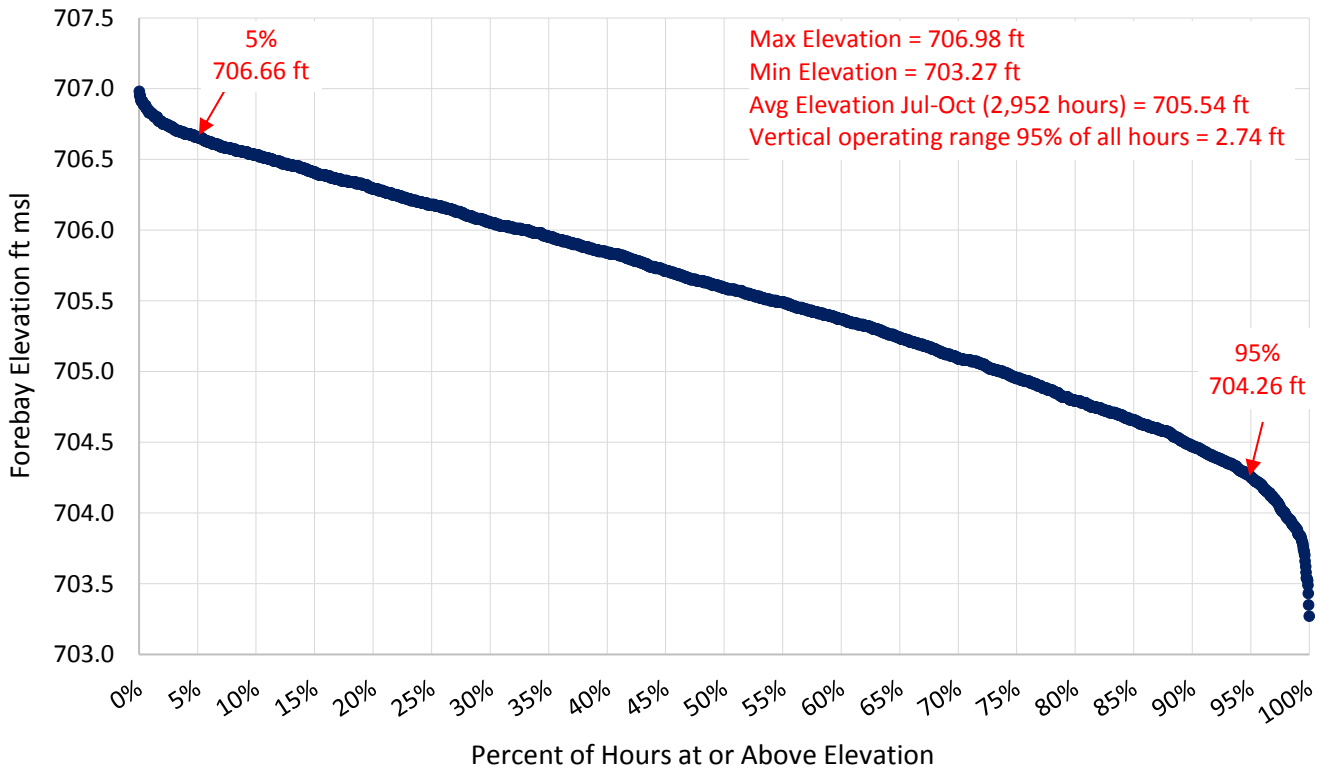
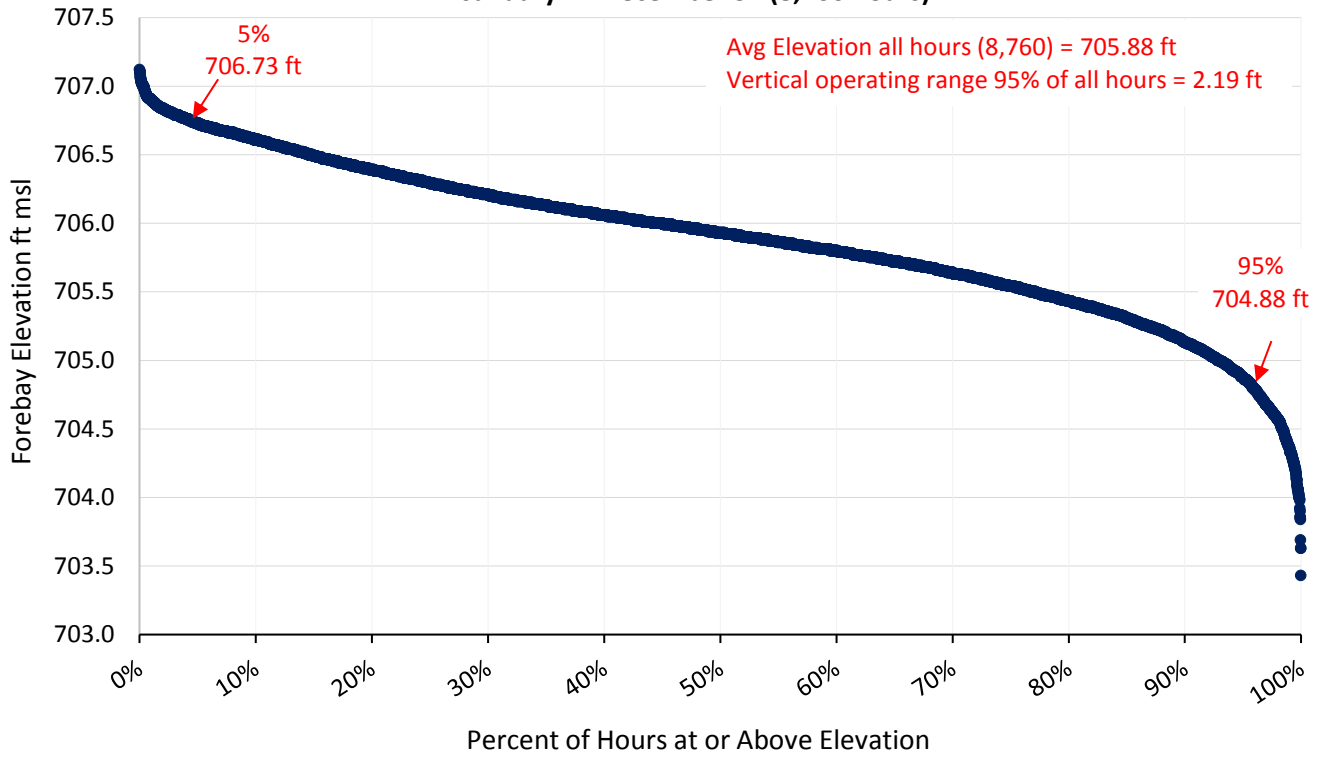


Figure 6. 2014 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 - October 31, 2014 during the adult lamprey migration period.

**2015 Rocky Reach Reservoir Hourly Forebay Operating Elevations
January 1 - December 31 (8,760 hours)**



**2015 Rocky Reach Reservoir Hourly Forebay Operating Elevations
July 1 - October 31 (2,952 hours)**

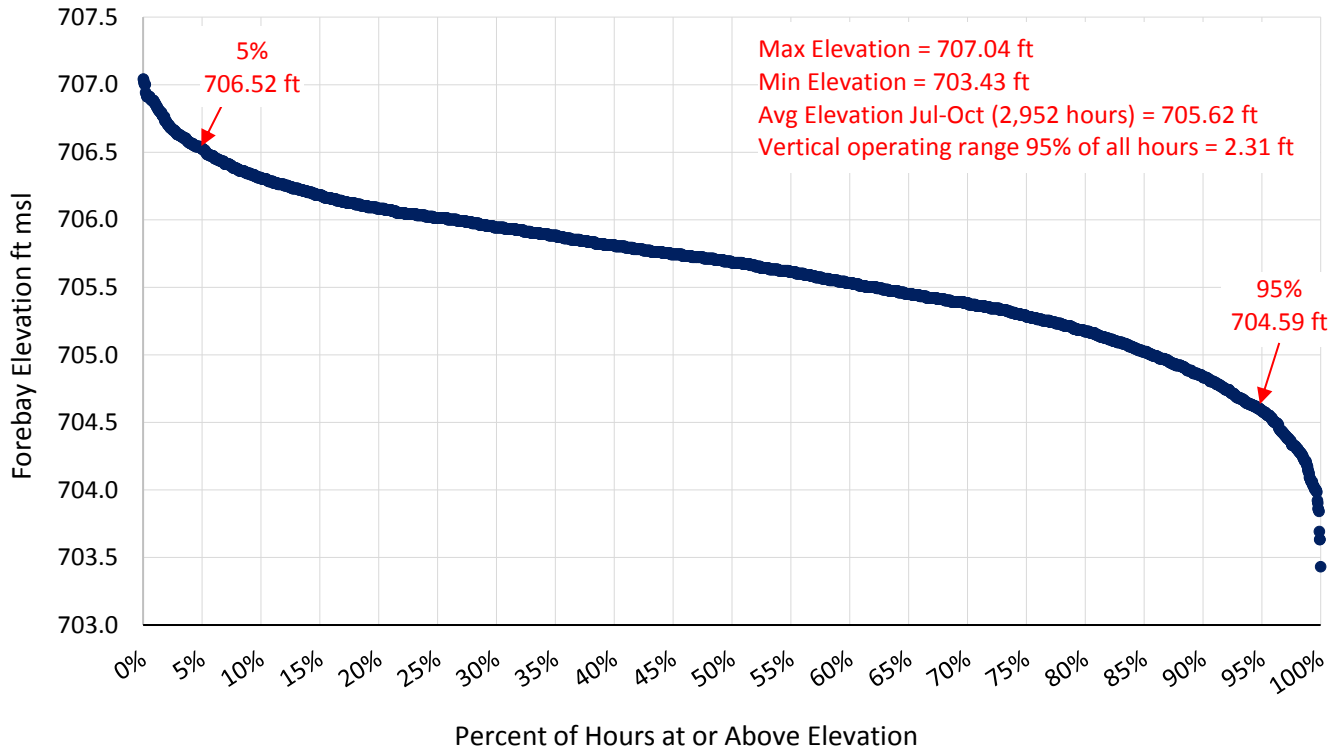
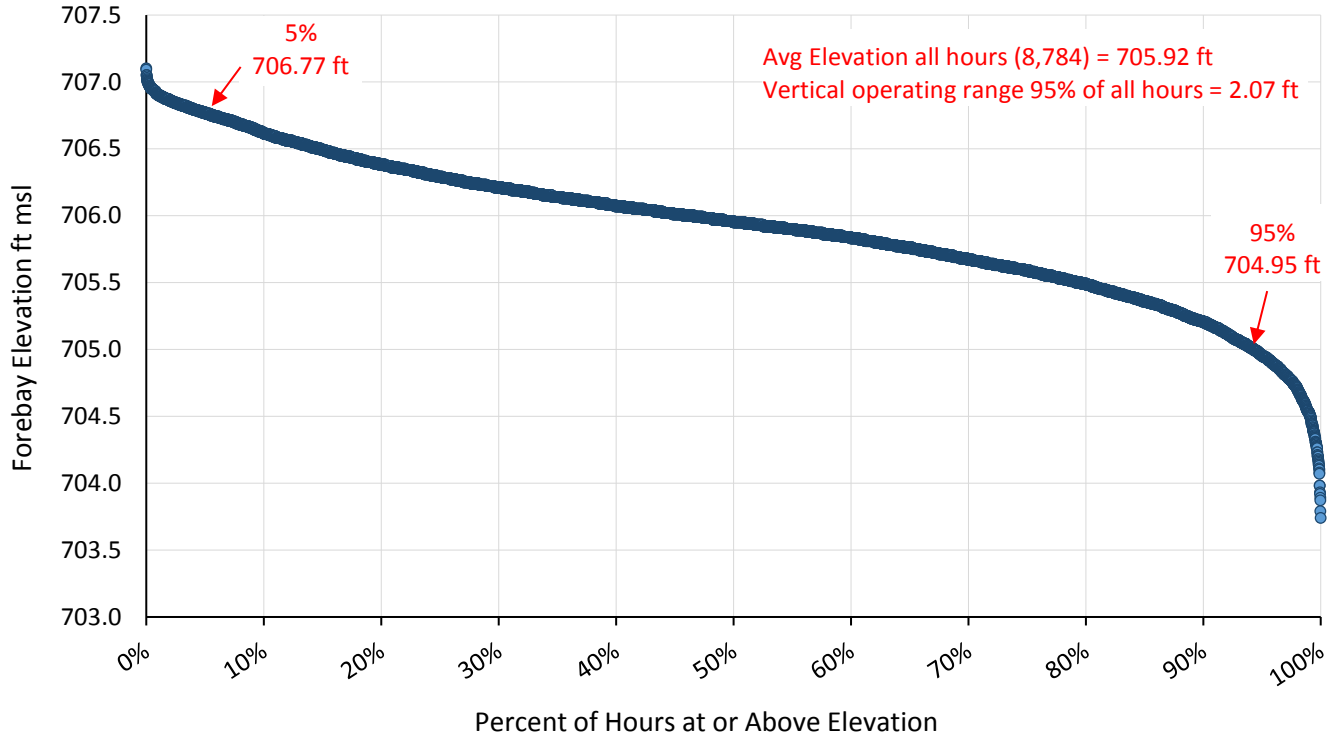


Figure 7. 2015 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 - October 31, 2015 during the adult lamprey migration period.

**2016 Rocky Reach Reservoir Hourly Forebay Operating Elevations
January 1 - December 31 (8,760 hours)**



**2016 Rocky Reach Reservoir Hourly Forebay Operating Elevations
July 1 - October 31 (2,952 hours)**

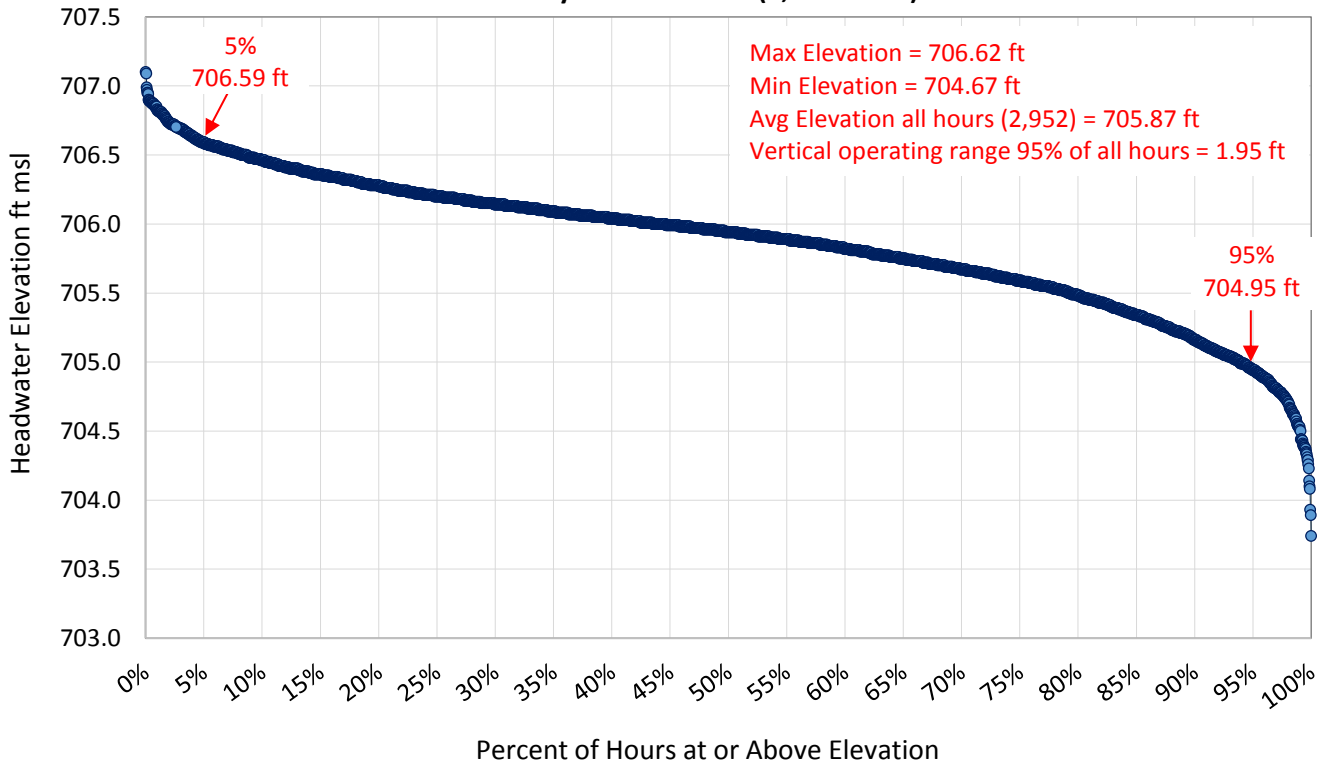


Figure 8. 2016 Rocky Reach Reservoir annual hourly forebay operating elevations and hourly elevations July 1 - October 31, 2016 during the adult lamprey migration period.

Figure 9 shows Rocky Reach Reservoir operations on August 20, 2005-2007 and 2014-2016 to illustrate daily maximum vertical operating ranges for the reservoir during the peak of lamprey migration. In 2005, the reservoir’s vertical operating range for the day was 1.61 feet. The operating range for August 20 in 2006 was 1.12 feet. In 2016, the reservoir’s vertical operating range was 0.89 feet for that day.

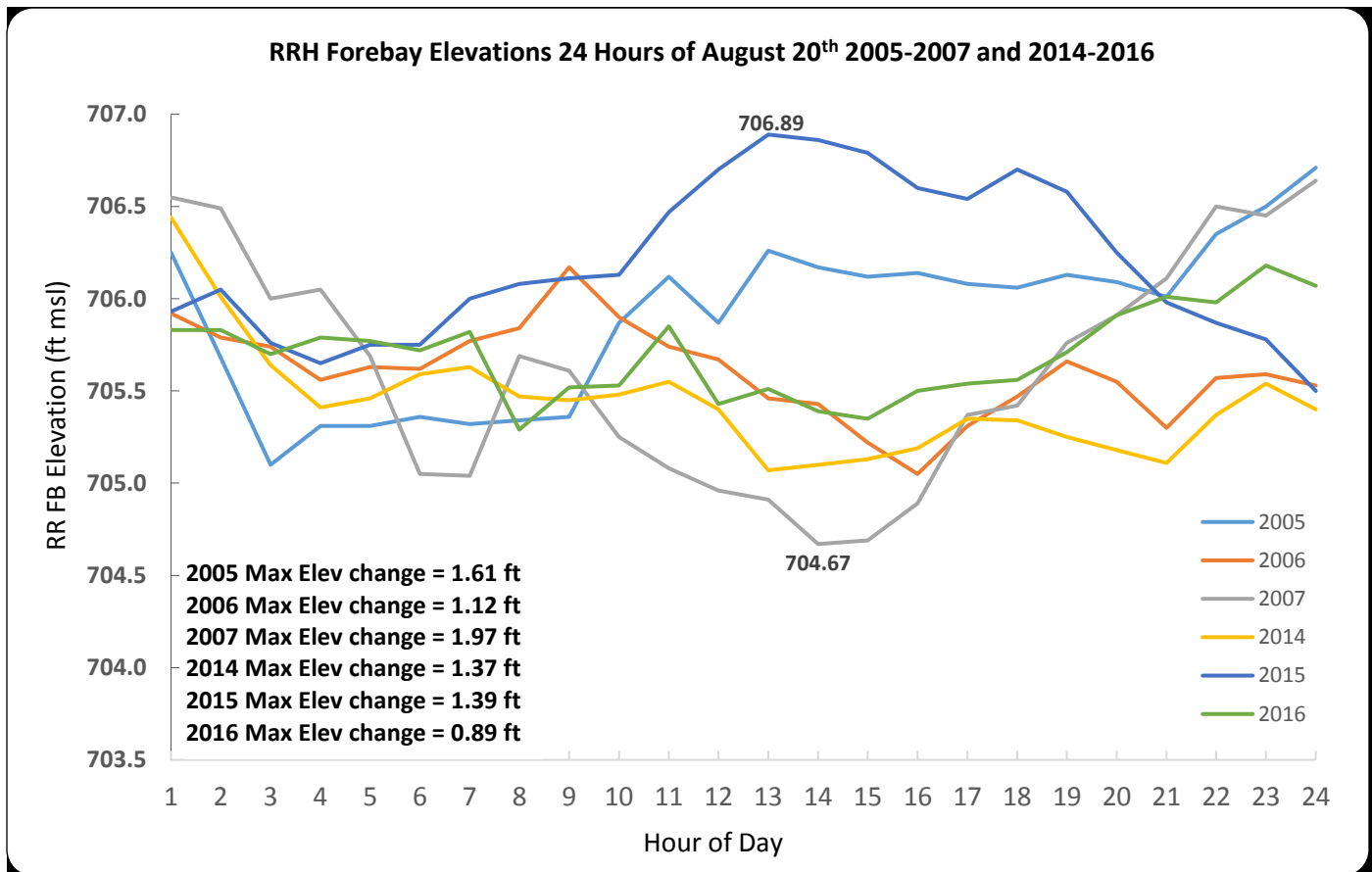


Figure 9. Rocky Reach forebay hourly operating elevations and maximum elevation changes of August 20th, 2005-2007 and 2014-2016.

Data in Table 3 and Table 4 shows that discharge from Wells Dam drives the changes in Wells tailwater elevations, regardless of Rocky Reach forebay operations and elevation. Wells Dam minimum and maximum day-average discharge rates correspond directly with minimum and maximum elevations differences between Rocky Reach forebay and Wells tailwater. On average, the annual elevations differences between Rocky Reach forebay and Wells tailwater range from 5.66 ft to 6.67 feet. During the lamprey migration period July through October under lower river Columbia River flows and lower Wells discharges, elevations differences between the Wells tailwater and Rocky Reach forebay are also less, ranging from 4.38 feet to 5.56 feet.

Rocky Reach day-average forebay elevations are included in Table 4 with the corresponding dates of Wells maximum day-average discharge and forebay-tailwater elevation differences. Rocky Reach forebay elevations have no apparent effect on Rocky Reach forebay-Wells tailwater elevation differences. Backwater curves also show Wells Dam discharges are the primary driver of upper Rocky Reach Reservoir elevations (Chelan PUD 1980).

Table 3. Wells Dam mean, maximum, and minimum annual daily discharges 2005-2007 and 2014-2016, with corresponding surface water elevations differences between Rocky Reach forebay and Wells Dam tailwater.

Wells Discharge and Rocky Reach Forebay to Wells Tailwater Elevation Differences							
Year	Wells Day Avg Q (cfs)	RR-Wells Day Avg Elevation Diff (ft)	Wells Max Day Avg Discharge (cfs) and Date	RR-Wells Max FB-TW Elevation Diff (ft) and Date	Wells Min Day Avg Q (cfs) and Date	RR-Wells Min FB-TW Elevation Difference (ft)	July-Oct RR-Wells Avg Elev Diff (ft)
2016	106,974	5.79	205,880 (4/17)	12.21 (4/17)	51,620 (9/12)	1.84 (9/12)	4.38
2015	105,211	5.81	170,180 (2/23)	10.34 (2/23)	42,450 (10/10)	1.42 (10/10)	4.59
2014	114,973	6.67	216,270 (6/1)	13.18 (6/1)	38,250 (2/17)	1.28 (2/17)	5.56
2007	110,472	6.31	197,720 (5/8)	12.14 (5/8)	35,400 (10/6)	1.16 (10/6)	5.03
2006	111,100	6.32	250,270 (5/28)	14.51 (5/28)	38,700 (9/24)	1.24 (9/24)	4.95
2005	101,139	5.66	177,070 (5/27)	10.89 (5/27)	37,360 (9/10)	1.35 (9/10)	5.42

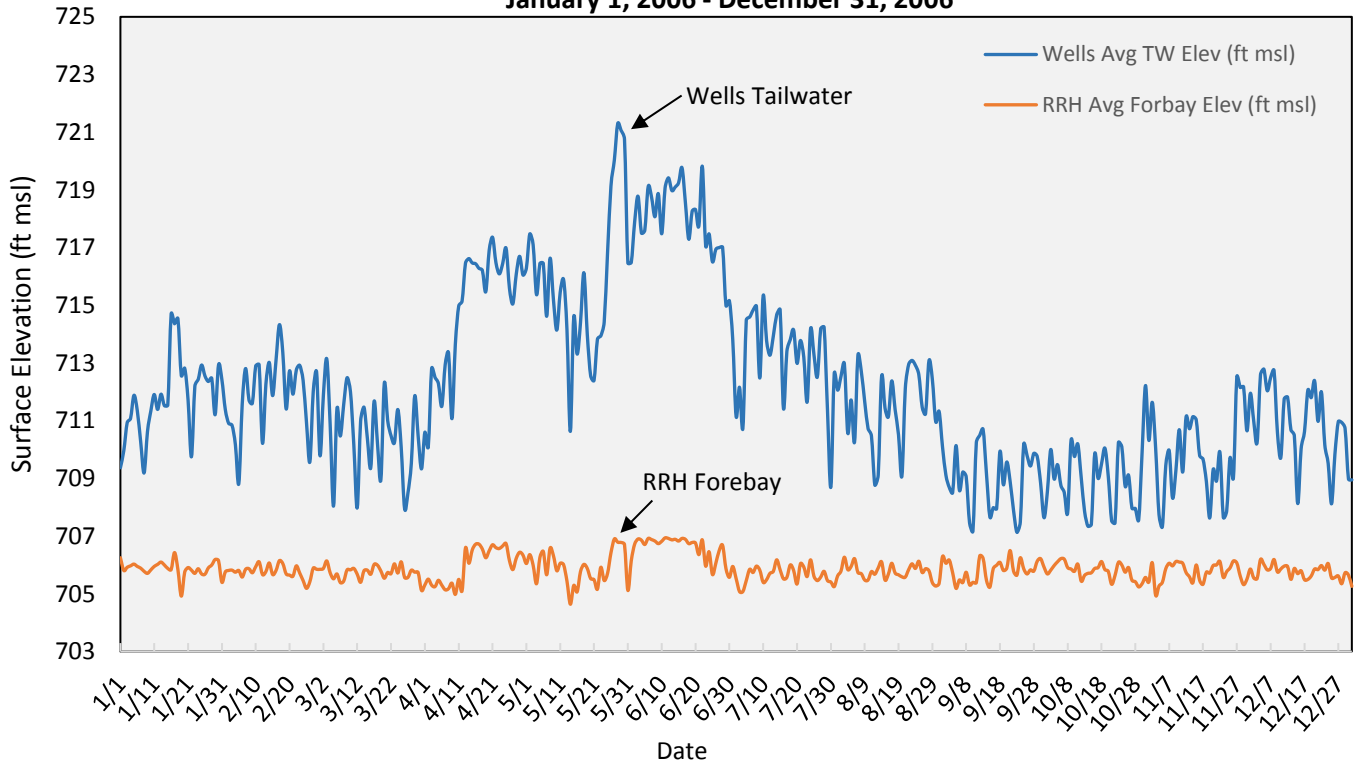
Table 4. Wells Dam single-day maximum average discharges, corresponding maximum elevation differences from Rocky Reach forebay to Wells tailwater, and the corresponding Rocky Reach day-average forebay elevations with day of occurrence.

Year	Wells Day-Avg Maximum Q (cfs)	Day of Occurrence	RR FB-Wells TW Maximum Day-Avg Elevation Difference (ft)	Day of Occurrence	RR Forebay Day-Avg Operating Elevation (ft msl)	Day of Occurrence
2016	205,880	Apr 17	12.21	Apr 17	706.58	Apr 17
2015	170,180	Feb 23	10.34	Feb 23	706.77	Feb 23
2014	216,270	Jun 1	13.18	Jun 1	706.08	Jun 1
2007	197,720	May 8	12.14	May 8	706.38	May 8
2006	250,270	May 28	14.51	May 28	706.79	May 28
2005	177,070	May 27	10.89	May 27	705.64	May 27

Figure 10 below compares the annual, day-average elevations for Wells tailwater and Rocky Reach forebay in years 2005 and 2006. Data in Table 4 and Figure 10 show the relationship between Wells Dam Discharge, resulting Wells tailwater elevations, and coinciding Rocky Reach forebay elevations.

Wells tailwater undergoes considerable fluctuations, up to 14 feet or more based on Wells' discharge rates. This effect is not influenced by Rocky Reach Dam or reservoir. Under significant Wells tailwater fluctuations, Rocky Reach forebay elevations remain relatively constant, generally operating within 1.5 vertical feet regardless of Wells Dam discharge or tailwater fluctuations.

**Wells Dam Tailwater Elevations and Rocky Reach Forebay Elevations
January 1, 2006 - December 31, 2006**



**Wells Dam Daily Tailwater Elevations and Rocky Reach Forebay Elevations
January 1 - December 31, 2005**

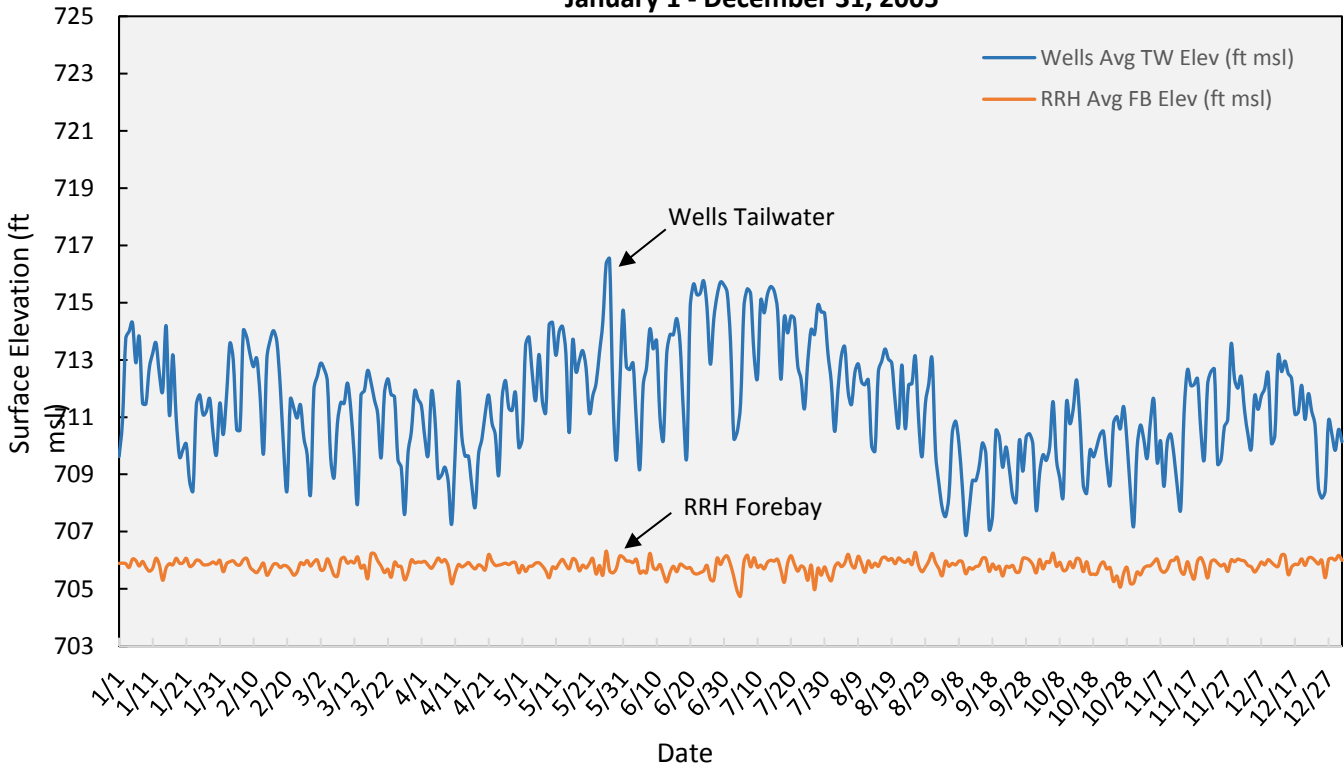


Figure 10. Comparison of day-average Wells Dam tailwater elevations and Rocky Reach forebay elevations, 2005 and 2006.

Entiat River and Connection with Rocky Reach Reservoir

The Entiat River flows into Rocky Reach Reservoir at Columbia River mile 483.7, approximately 10 miles upstream of Rocky Reach Dam. The mean daily discharge at the USGS Entiat gauge over 21 years of record is 137 cfs. The minimum Entiat River flow recorded at the gauge was 78.2 cfs in 2005. The confluence of the Entiat River has never been dewatered and has never lost flow connectivity with Rocky Reach Reservoir because reservoir elevations are maintained between 703.0 ft and 707.0 ft msl. During 2001, one of the lowest Columbia River flow years on record, the Entiat River remained fully connected to the reservoir. Based on reservoir backwater curves (Chelan PUD 1980), Rocky Reach elevations do not affect the Entiat River confluence and therefore it is not probable that the reservoir has any operational influence on adult Pacific lamprey entering the Entiat River

Discussion and Summary

The intent of this analysis was to identify any possible operational effects of Rocky Reach Reservoir that could block or stop migrating adult Pacific Lamprey from reaching Wells Dam.

Forebay elevation data in the six years analyzed demonstrate consistent Rocky Reach operations and reservoir elevations. In years evaluated, Rocky Reach Reservoir generally operated within a daily vertical maximum draft range of 2.75 feet or less, 95% of all hours. Operating elevations during the key adult lamprey migration months of July-October are very similar, with the reservoir operating at 705.0 feet or above most hours.

In this analysis, we found no operating condition for Rocky Reach Reservoir that indicates existence of a Project effect, or operating scenario that could negatively affect lamprey migration to Wells Dam. While Rocky Reach Dam clearly maintains the reservoir forebay at very stable levels, the upper portion of Rocky Reach Reservoir near Wells tailrace fluctuates widely due to Wells Dam discharge. These fluctuations cannot be controlled by any operation of Rocky Reach Dam or its reservoir.

Most importantly, Rocky Reach Reservoir operations and elevations were very consistent during the key adult migration months (July-October) across years when lamprey passage numbers decreased significantly at Wells Dam. Therefore, factors or mechanisms other than Rocky Reach operations are likely causing low passage rates of adult Pacific Lamprey at Wells Dam.

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Appendix 1 References

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