Relicensing Study 3.3.20

ICHTHYOPLANKTON ENTRAINMENT ASSESSMENT AT THE NORTHFIELD MOUNTAIN PUMPED STORAGE PROJECT

Addendum 1

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

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1 INTRODUCTION

On December 28, 2016, FirstLight Hydro Generating Company (FirstLight) filed the findings of Study No. 3.3.20. *Ichthyoplankton Entrainment Study at the Northfield Mountain Pumped Storage Project* (Northfield Project). The report included the findings of a second year of Ichthyoplankton study at the Northfield Project; the report for the first year of study was filed with FERC on March 1, 2016. FirstLight held its Study Report Meeting on March 16, 2017 and filed its meeting summary on April 3, 2017. The second Ichthyoplankton Study was discussed at the March 16, 2017 meeting. Comments on the second year Ichthyoplankton Study were filed by the Massachusetts Division of Fisheries and Wildlife- Natural Heritage and Endangered Species Program (MDFW-NHESP), United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS) and the Connecticut River Conservancy (CRC). On May 30, 2017, FirstLight filed its response to comments.

Relative to the Ichthyoplankton Study, CRC comment labeled as CRC-2 had the following comment:

"CRC recommendation: The Report on page 1-3 states that a future filing will include an estimate of ichthyoplankton entrainment for FirstLight's proposal to expand the Upper Reservoir's Operating Range. As part of that filing, CRC recommends that FirstLight include the flow analysis as required by FERC. Otherwise, we have two data points from 2015 and 2016, and we will have to make our own conservative assumptions on impact of project operations and flows."
In its reply to the above comment, FirstLight stated:

"*This information will be submitted as an addendum by July 28, 2017*."

Thus, the purpose of this addendum is to estimate American shad ichthyoplankton entrainment under potential future expanded Upper Reservoir storage at the Northfield Mountain Project (hereinafter termed "expanded operations"). To estimate potential increases in pumping and generating due to expanded operations the existing operations model, which relied on the software called HEC-ResSim, was used. Note that in March 2017, FirstLight filed Study No. 3.8.1 *Evaluate Impacts of Modes of Operation on Flow, Water Elevation and Hydropower Generation*, which included a discussion of the operations model.

FirstLight has already simulated expanded operations in the operations model as part of the Study No. 3.1.2 *Northfield Mountain/Turners Falls Operations Impact on Existing Erosion and Potential Bank Instability* (also called the Erosion Causation Study). On April 3, 2017, FirstLight filed a report with FERC entitled "*Evaluating the Impact of Increasing the Upper Storage Volume of the Upper Reservoir on Streambank Erosion in the Turners Falls Impoundment"*. As part of that report, and as described in further detail later in this report, FirstLight developed two model runs reflecting baseline conditions (existing operations) and expanded operations. The model runs were used to compare the volume of water used for pumping and generating under baseline and expanded operations. The same two model runs used for Study No. 3.1.2 were used to assess changes in ichthyoplankton entrainment at the Northfield Mountain Project resulting from expanded operations.

2 OPERATIONS MODEL BACKGROUND

As noted in the introduction, FirstLight used the existing operations model of the Project to evaluate the changes in the volume of water used for pumping and generating under baseline (existing) and expanded operations. Much of the text in this section is from the report filed on April 3, 2017 "*Evaluating the Impact of Increasing the Upper Storage Volume of the Upper Reservoir on Streambank Erosion in the Turners Falls Impoundment"*, which explains how the operations model was used to estimate pumping and generating volumes under baseline and expanded operations.

The first step was to identify a representative year to analyze. For the purpose of this report, the 2002 hydrology and the 2009 pump and generation (pump/gen) schedule for Northfield Mountain were selected[1]. The 2002 hydrology was selected as flows at the United States Geological Survey (USGS) gage on the Connecticut River at Montague, MA for this year are generally lower than average as compared to the recent period of record (i.e. between 1975 and 2015)[2], as shown in Figure 2.0-1.

The HEC-ResSim software model was then run using the input parameters from 2002 (hydrology) and 2009 (pump/gen) and the operating equipment that is currently in-place. The results of this run represented the baseline condition or existing operations. FirstLight operations personnel then modified the 2009 pump/gen schedule (with the benefit of hindsight) to determine how the Northfield Mountain Project would have operated in this time period if the additional Upper Reservoir storage capacity had been available. The modified 2009 schedule, combined with the actual 2002 hydrology, was then run through HEC-ResSim; the results of this run represented expanded operations. Table 2.0-1 provides a summary of the modeling scenarios.

Table 2.0-1: Summary of Modeling Scenarios

Modeling Scenario	Input Hydrology	Input Pump/Gen
Baseline Condition	2002	2009
Expanded Operations	2002	Modified 2009

The model outputs for the baseline and expanded operations—specifically the hourly pumped cfs -- was subsequently used to estimate changes in ichthyoplankton entrainment. Figure 2.0-2 shows the difference in the amount flow pumped (in cfs) under baseline and expanded operations. The figure is based on hourly pumped flows over the entire year (8,760 hourly pump values) hence there is a high percentage of the time when no pumping occurs.

[1] In addition to the reasons listed above, the 2002 hydrology and 2009 pump/gen schedule were also selected to ensure consistency with past analyses which have been conducted (i.e., winter 2014/2015 temporary amendment)

[2] While the USGS Gage at Montague provides daily flows starting in 1903, the period of record used for this analysis begins in 1975 due to changes in regulation in the Connecticut River Basin (e.g. construction of flood storage facilities, implementation of minimum flow requirements, etc.).

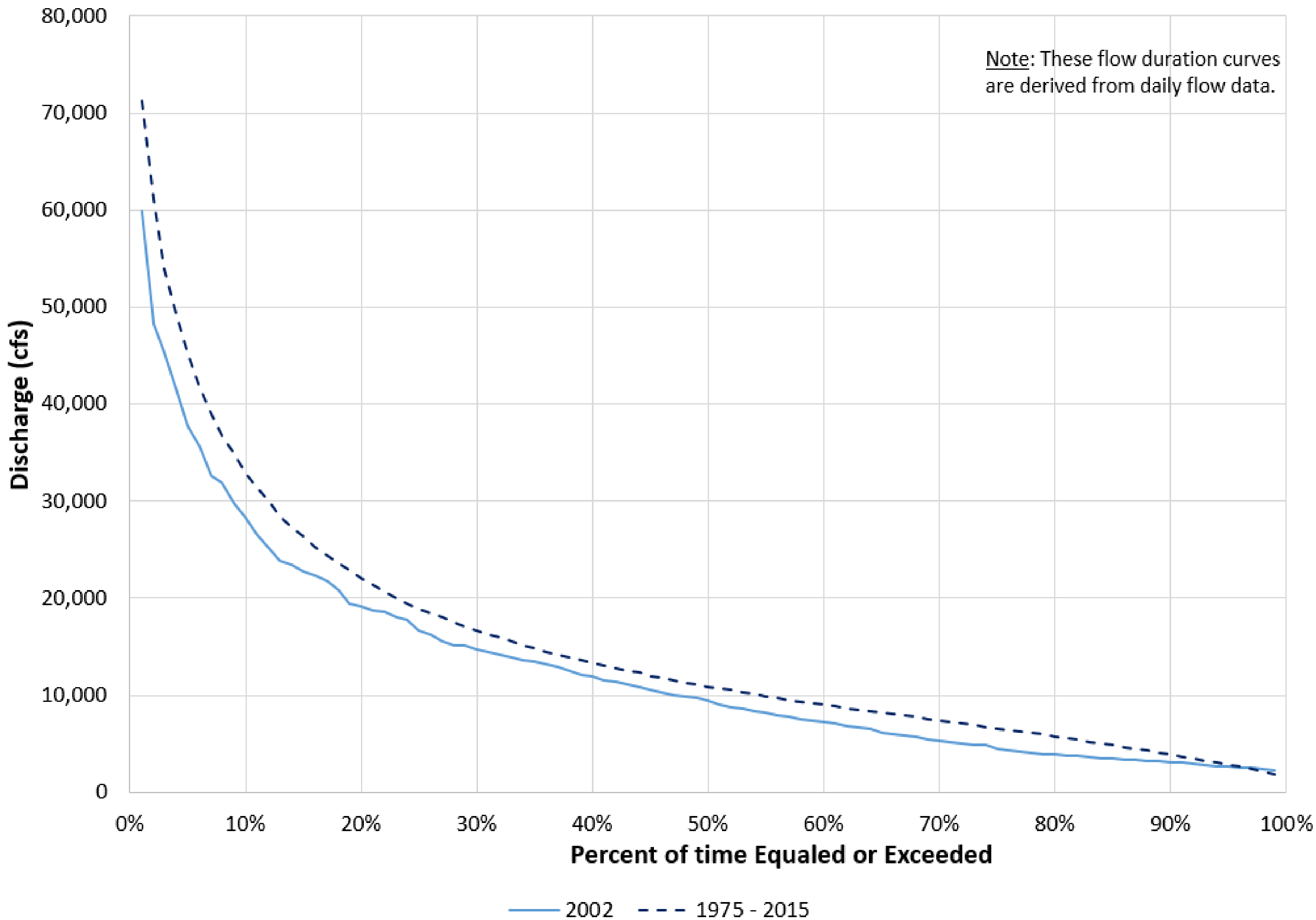

Figure 2.0-1: Montague USGS Gage – Comparison of Annual Flow Duration Curves

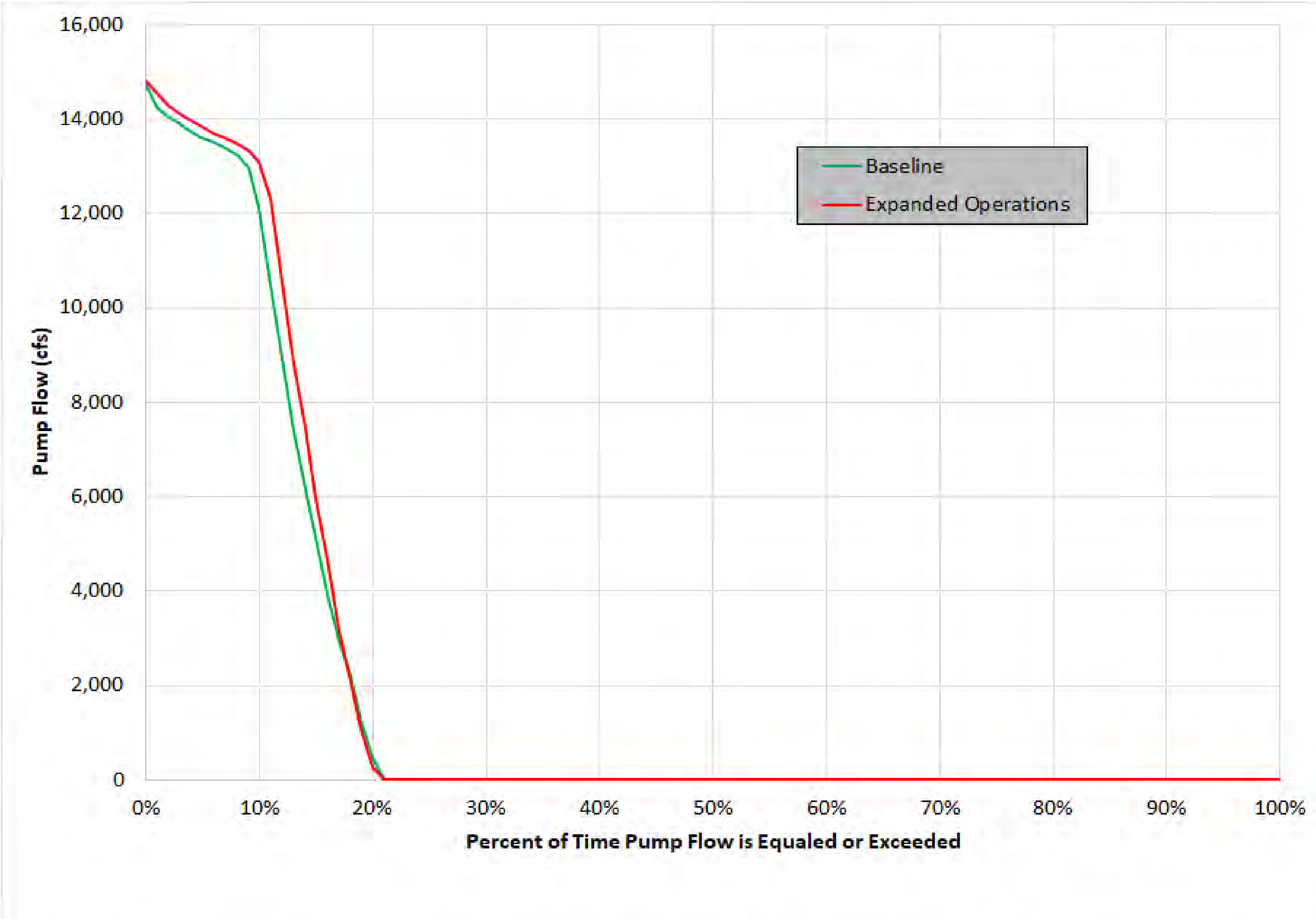

Figure 2.0-2: Percent of Time Pump Flow is Equaled or Exceeded under Baseline and Expanded Operations

3 METHODS

3.1 Data

To estimate the increase in ichthyoplankton entrainment due to expanded operations, the pumped flow data for the baseline and expanded operations was used for the period when shad eggs and larvae would be present in the Turners Falls Impoundment. Specifically, the increase in the volume of water pumped (in cubic meters, m^3) under expanded operations was compared against baseline conditions. The percent increase (or decrease in some cases) in pump flows was subsequently used, along with the observed data collected in 2016, to estimate the increase in eggs/larvae due to expanded operations.

First, the modeled hourly pump flow (in cfs) was converted to a pump volume (in cubic meters, m^3) over the time interval. The percent change (increase or decrease) in pumping on a given day was then applied to the observed data. For example, if the pump volume increased by 2% on say May 25, 2002 (the model year) due to expanded operations, the same 2% increase was subsequently applied to the observed data for the same date—in this case May 25, 2016.

Prior to extrapolating count data, d the daily percent change in pump volume was calculated with Equation 1:

$$\lambda_d = (Q_d^e - Q_d^b)/Q_d^b \qquad 1$$

Where λ_d is the percent change in pumped water on day d, Q_d^e is the expanded volume of water in m^3 pumped on day d, and Q_d^b is the baseline amount of water pumped in m^3 on day d. Each daily percent change was grouped into a calendar week using the MS Access function "DatePart", which returns the week of the year associated with the date. By grouping on the week, uncertainty can be quantified in the percent change in expanded operations over baseline conditions within a week.

3.2 Entrainment Estimate

FirstLight constructed a simple weekly volumetric extrapolation, where a measure of organism density (org/m^3) is multiplied by a volume of water (m^3) to estimate the number of entrained organisms per unit of time (week). To account for variability in the number of organisms impacted and the potential future operations, a weekly extrapolation was developed that accounts for uncertainty in sample density and the expected change in pump operations over a week. The following estimate employs a quantile-based extrapolation, where densities are extrapolated at the 10th, 50th and 90th percentile. This method estimates both the average expected entrainment and places bounds on our estimate by extrapolating worst and best case scenarios. For example, the worst-case scenario includes the 90th percentile sample density and 90th percentile expanded operations, while the best base scenario extrapolates on the 10th percentile sample density and the 10th percentile expanded operations. This method differs from the original 2016 estimate, which described the seasonal densities with a parametric distribution (negative binomial). A quantile based extrapolation was preferred because it was able to account for uncertainty within a week.

The first step calculates individual sample densities with equation 2, which simply divides the sample count by the sample volume:

$$\rho_{wij} = \frac{x_{wij}}{v_{wi}} \qquad 2$$

Where ρ_{wij} is the density of the j^{th} species/lifestage in sample i during week w, x_{wij} was the count of species/lifestage j in sample i within week w, and v_{wi} is the volume of the i^{th} sample in week w. Following the computation of each ρ_{wij}, FirstLight calculated weekly sample density quantiles at the 10th, 50th and 90th percentile (ρ_{wj}^{10}, ρ_{wj}^{50}, ρ_{wj}^{90}).

Next FirstLight extrapolated the number of entrained organisms under baseline and expanded operations. The first estimate is the weekly baseline extrapolation (Equation 3– 5) and is imply the product of the weekly pumped volume and weekly sample density:

$$x'^{10}_{wj} = Q_w * \rho^{10}_{wj} \qquad 3$$

$$x'^{50}_{wj} = Q_w * \rho^{50}_{wj} \qquad 4$$

$$x'^{90}_{wj} = Q_w * \rho^{90}_{wj} \qquad 5$$

Where Q_w is the weekly summed flow for 2016 (baseline) and ρ^{10}_{wj} is the 10^{th} percentile organism density and x'^{10}_{wj} is the weekly 10% baseline extrapolation. The superscripts indicate the percentile. These equations are simple volumetric flow expansions where the density quantiles (organism per m^3) are multiplied by the weekly volume of water pumped (m^3).

The expanded extrapolation is given with equations 6- 8:

$$z'^{10}_{wj} = (Q_w + (Q_w * \lambda^{10}_w)) * \rho^{10}_{wj} \qquad 6$$

$$z'^{50}_{wj} = (Q_w + (Q_w * \lambda^{50}_w)) * \rho^{50}_{wj} \qquad 7$$

$$z'^{90}_{wj} = (Q_w + (Q_w * \lambda^{90}_w)) * \rho^{90}_{wj} \qquad 8$$

Where λ^{10}_w is the 10^{th} percentile of the expanded operations volume change. These equations are still simple volumetric flow expansions calculated for the expanded 2016 weekly flow. Density quantiles (organism per m^3) are multiplied by the weekly volume of water pumped (m^3).

4 RESULTS AND DISCUSSION

4.1 Operations Data

While expanded operations will allow for more water to be pumped to the Northfield Mountain Upper Reservoir, the model results show that greater volumes are pumped over a shorter time period during the American shad spawning period- calendar weeks 20-31 (sample dates 5/18/2016 – 7/29/2016). The peaks and valleys of the expanded operations (dashed line) (Figure 4.1-1) exhibit much larger fluctuations than baseline conditions (solid line), but these fluctuations occur less frequently.

Figure 4.1-2 depicts the percent change in water pumped per day during the spawning period (defined as calendar weeks 20 through 31). It is evident from the figure that the daily percent change between baseline and expanded operations varies. The data does not appear to be temporally autocorrelated.

The daily percent change (λ) statistics were aggregated by calendar week and described with the 10th, 50th and 90th percentile (Table 4.4-1). Note that in some weeks, the median percent change in water pumped is negative, meaning that the expanded operations results in less water pumped that calendar week. Figure 4.1-3 depicts the weekly percent change (λ) with a histogram.

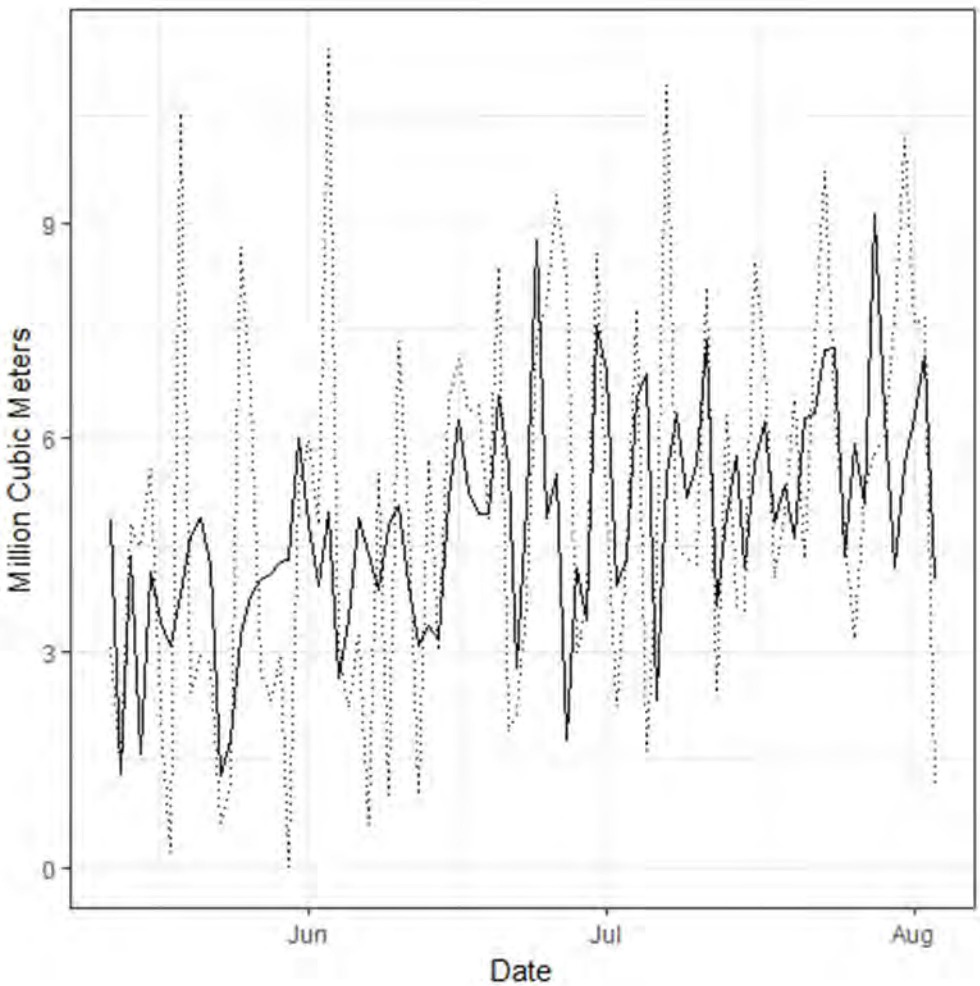

Figure 4.1-1: The baseline and expanded volume of water pumped during the spawning season (defined as calendar weeks 20-31). The baseline is the solid line, while the expanded operation is the dashed line.

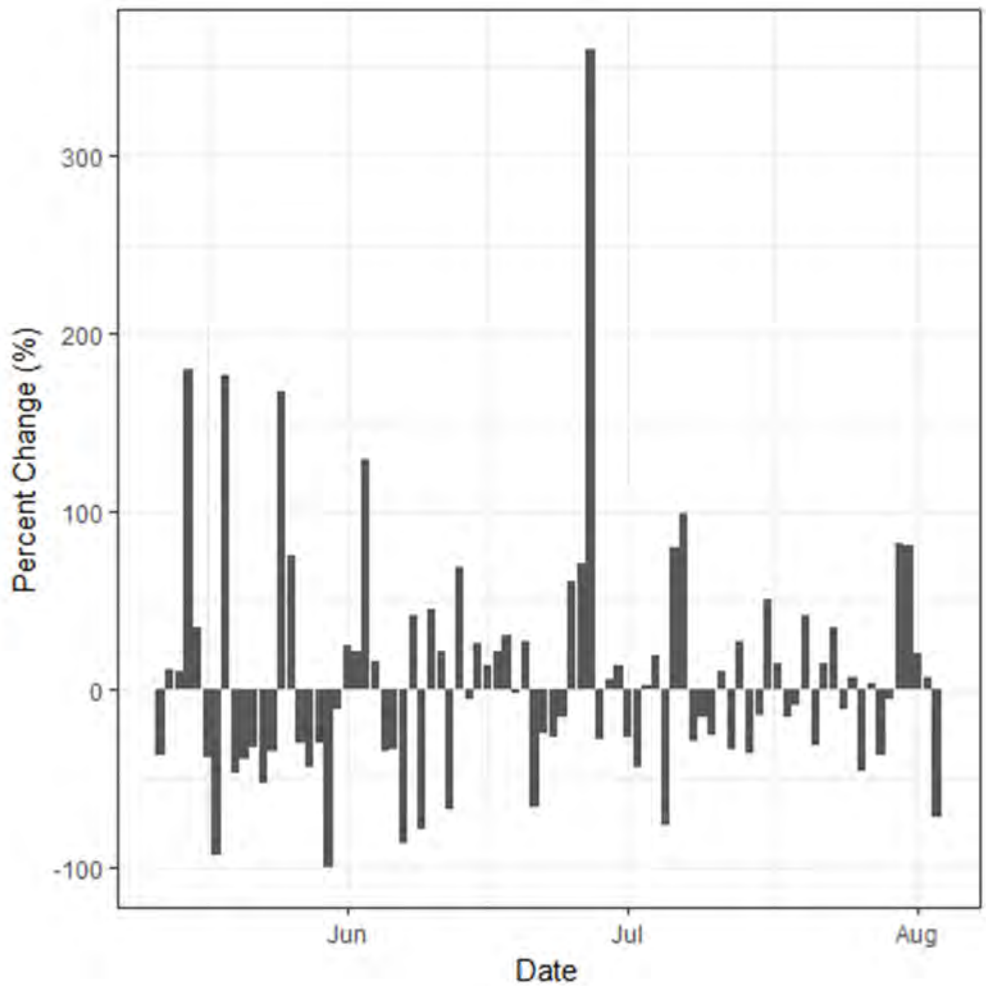

Figure 4.1-2: The daily percent change in pump volume under expanded operations compared to baseline conditions throughout the spawning season.

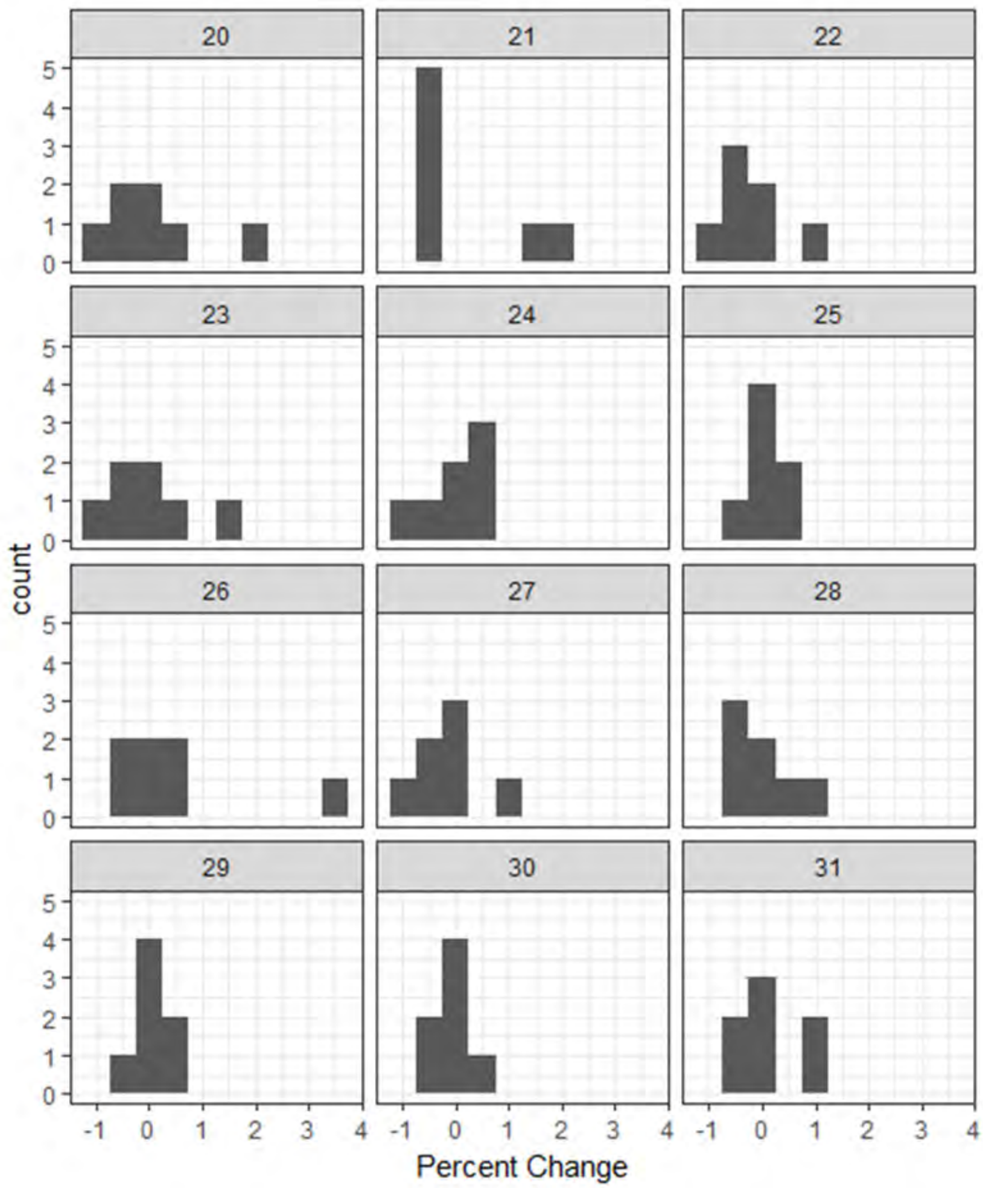

Figure 4.1-3: The weekly percent change histogram. Note there are 7 observations in each histogram. It is evident that there is wide fluctuations in the amount of water needed under expanded operations per week.

Table 4.1-1. The weekly percent change (λ) at the 10th, 50th and 90th percentiles.

Week	10%	50%	90%
20	-0.60	0.11	0.93
21	-0.50	-0.35	1.71
22	-0.66	-0.31	0.45
23	-0.56	-0.16	0.77
24	-0.72	0.21	0.55
25	-0.41	0.13	0.29
26	-0.27	0.05	1.86
27	-0.57	0.02	0.43
28	-0.31	-0.16	0.56
29	-0.24	-0.09	0.45
30	-0.38	0.03	0.22
31	-0.51	0.07	0.81

4.2 Organism Density

The weekly extrapolation estimate used the observed data organism density (ρ) at the 10th, 50th (the median) and 90th percentiles. Table 4.2-1 contains the organism densities by week and percentile.

Table 4.2-1: The weekly organism densities (org/m^3) at the 10th, 50th and 90th percentiles and the number of samples (n) per week with which we calculating these percentiles.

Week	Eggs			n	Larvae			n
	10%	50%	90%		10%	50%	90%	
20	0	0	0	3	0	0	0	3
21	0	0	0	4	0	0	0	4
22	0	0	0	5	0	0	0.024	5
23	0.088	0.120	0.184	3	0.064	0.080	0.176	3
24	0.081	0.135	0.238	4	0.006	0.025	0.037	4
25	0.004	0.020	0.020	3	0.004	0.020	0.020	3
26	0	0	0.016	3	0	0	0	3
27	0	0	0.012	5	0	0	0	5
28	0	0	0.014	4	0	0.01	0.02	4
29	0	0	0	5	0	0	0	5
30	0	0	0	4	0	0	0	4
31	0	0	0	4	0	0	0	4

4.3 Extrapolation

Figures 4.3-1 and 4.3-2 contain the weekly extrapolated counts for eggs and larvae respectively. Note that the combination of 90th percentile sample density and 90th percentile expanded operations in week 23 more than doubles the median estimate.

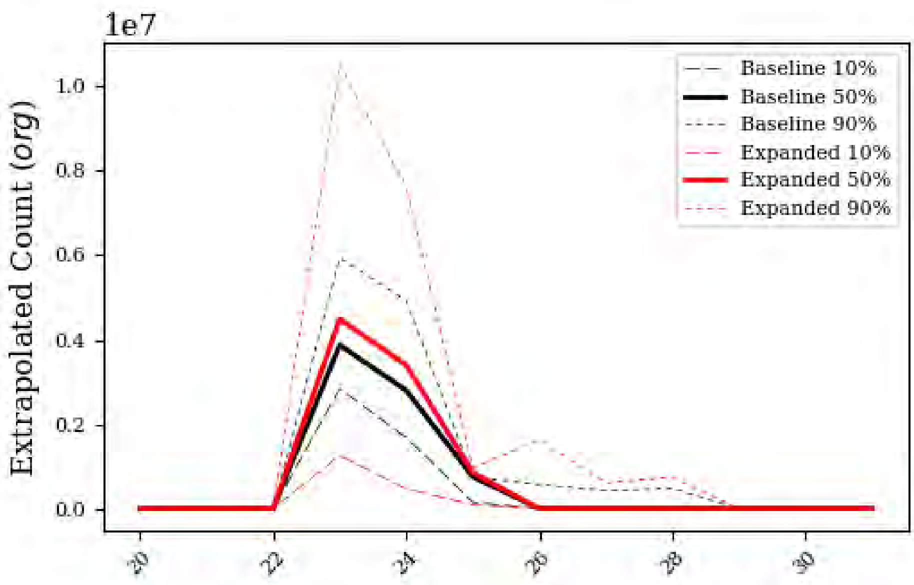

Figure 4.3-1: Weekly extrapolation of entrained American Shad Eggs at Northfield Mountain using 2016 observed data adjusted based on week percent change in pump volumes under expanded operations versus baseline conditions..

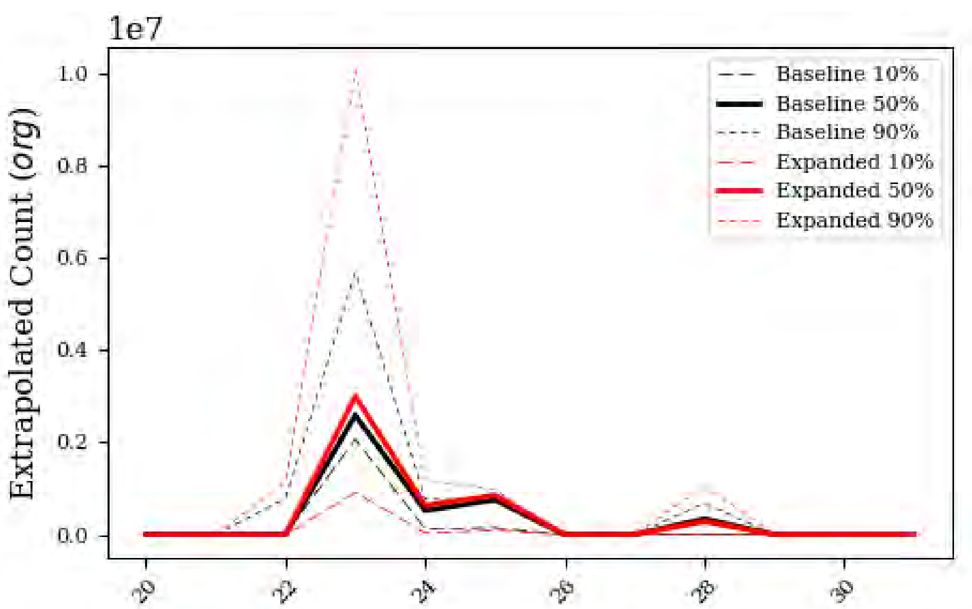

Figure 4.3-2: Weekly extrapolation of entrained American Shad Larvae at Northfield Mountain using 2016 observed data adjusted based on week percent change in pump volumes under expanded operations versus baseline conditions..

4.4 Equivalent Adults

Table 4.4-1 contains the number of equivalent adults impacted under baseline and expanded operations using the weekly quantile extrapolation method. Note that the expanded operations resulted in an increase in the number of equivalent adults lost to entrainment. This method results in a larger amount of adult equivalents lost because of the density value used to extrapolate the estimate. This application did not attempt to model density with a parametric distribution, rather it described the weekly estimates at specific quantiles. In the original method, we did not find differences in density between weeks (because sample sizes were too small), which prompted an extrapolation using a single seasonal density. The over-abundance of samples with zero counts meant the original estimate was biased low. The new method resulted in a larger extrapolation over a shorter amount of time.

Table 4.4-1: Equivalent adult estimates of all entrained eggs at the 10th, 50th, and 90th percentile using the weekly extrapolation method.

Equivalent Age	Baseline Conditions			Expanded Operations		
	10%	50%	90%	10%	50%	90%
J	2,321	3,960	7,713	974	4,560	12,895
3	80	136	266	34	157	444
4	177	303	590	75	349	986
5	53	90	175	22	103	293
6	3	4	8	1	5	14
7	0	0	0	0	0	0

5 CONCLUSION

Expanded operations will result in more hours of pumping and more volume of water pumped, which will lead to an increase in the number of equivalent American shad adults lost. Throughout the spawning season, both operating conditions and organism density will change. To capture some of this variability, FirstLight used a quantile based extrapolation method. The 10th and 90th percentiles were chosen because they bound 80% of the known variability in both sample densities and potential expanded operations. The 50th percentile extrapolates on the median sample density, and should be considered the expected entrainment. The 0% quantile sample density was not used to extrapolate because it would have resulted in 0 individuals entrained. This was because there were samples every week that had a count of 0 organisms. Overall, it is predicted that 600 additional juveniles and 81 adults may be affected by ichthyoplankton entrainment under expanded operations.