FISH PASSAGE CENTER

847 N.E. 19th Avenue, #250, Portland, Oregon 97232
Phone: (503) 833-3900 Fax: (503) 232-1259
www.fpc.org
e-mail us at fpcstaff@fpc.org

MEMORANDUM

TO: Michele DeHart

Bobby Hsu

FROM: Bobby Hsu, Fish Passage Center

DATE: February 5, 2018

SUBJECT: Relationship between Project Operations and Spring Chinook Adult Passage at Little Goose Dam

Operations decisions at Little Goose Dam that affect adult salmon passage can result in increased juvenile salmon and steelhead passage through the powerhouse. The analysis presented is the result of and continuation of past Fish Passage Center reviews and analyses of adult fish passage at Little Goose Dam.

- The pattern of adult spring Chinook counts at Little Goose Dam followed closely to the adult counts at Lower Monumental Dam, and dam operations at Little Goose partly contributed to the variability in that pattern.
- Spill volume through spill bay one had a negative relationship with the adult spring Chinook counts at Little Goose Dam. Effects of spill bay one dominated other dam operation variables in our model.
- Spill volume through spill bays two through eight did not seem to be important in affecting the adult spring Chinook counts at Little Goose Dam.
- Powerhouse discharge had a positive relationship with the adult spring Chinook counts at Little Goose Dam, but the magnitude of their effects was not as strong as spill bay one.

Background

A temporary spillway weir was installed in 2009 at the spill bay one of Little Goose (LGS) Dam to improve smolt passage during spring migration. Because of the spillway weir operation, spill volume through bay one was restricted and had a different pattern than the rest of the spill bays (two through eight). In general, when the total flow volume exceeded 85 Kcfs, spill volume at bay one was increased from seven to eleven Kcfs. Individually, bays two through eight were spilled at a lower volume compared to bay one. During most circumstances, the spillway weir operation created an uneven discharge pattern (ie. bulk pattern), which resulted in formation of eddies in the LGS tailrace. An uniform spill pattern, which was characterized by spilling similar volumes of water through most spill bays, was thought to minimize the production of these eddies. Jepson et al. (2009) observed that radio-tagged adult salmon that entered the LGS tailrace during a bulk spill pattern spent more time approaching a fishway entry, compared to an uniform spill pattern. However, contrary to the findings by Jepson et al, there was a misconception suggesting adult salmon passage was affected by overall spill percent instead of spill patterns.

In 2017, observation indicated a disparity in adult spring Chinook cumulative counts between Lower Monumental (LMN) and LGS Dams, and a modified spill operation was implemented at LGS in order to mitigate a slow down of adult passage. The operational manipulations resulted in decreased spill during the morning hours for a period of 11 days. The Fish Passage Center (FPC) was asked to evaluate the effects of LGS powerhouse and spill operations on adult salmon passage, and we concluded that a number of factors could affect adult and juvenile salmon passage at LGS, including actual physical configuration of the project, the specific combination of turbine units operating, the flow through operating turbines, specific combination of spill bay opening, amount of spill through each spill bay operation of the temporary spillway weir, conditions at fishway entrances, conditions at fishway exits, fishway water temperatures, temperature differentials in fishways and route of passage during the juvenile downstream migration (FPC, 2017a). Moreover, these factors affecting adult and juvenile passage at LGS were complex and interrelated, and further studies were needed in order to thoroughly evaluate their relationship. In order to begin examining the operations complexities affecting adult passage at LGS Dam, the FPC filed an request under Freedom of Information Act and received hourly spill bay and turbine unit operations from the US Army Corps of Engineers (FPC, 2017b). The objective of this analysis was to examine the principal components of operations that affect rate of adult passage at the project.

Methods

Lower Monumental and Little Goose Chinook Counts

Fish Passage Center staff summarized adult count data for Chinook adults and jacks that were seen at LMN and LGS Dams during April, May, and June in return years 1991 to 2017. We observed that, in general, fish counts at LGS follow the patterns of fish counts at LMN, given a lag time for fish to travel between the two dams (Figure 1). That is, LMN counts could potentially be used to predict LGS counts, after accounting for some travel time.

In order to find a best match for LGS counts amongst LMN counts with different time lags, we compared linear regression models with LGS counts on LMN counts with no lag, a one-day lag, a two-day lag, and a three-day lag. Each model we fitted had LGS counts as the response variable and LMN counts (with a different lag time for each model), migration year, and LMN counts and migration year interaction term as the explanatory variables. We compared and selected the best fitting model based on AIC (Akaike 1973).

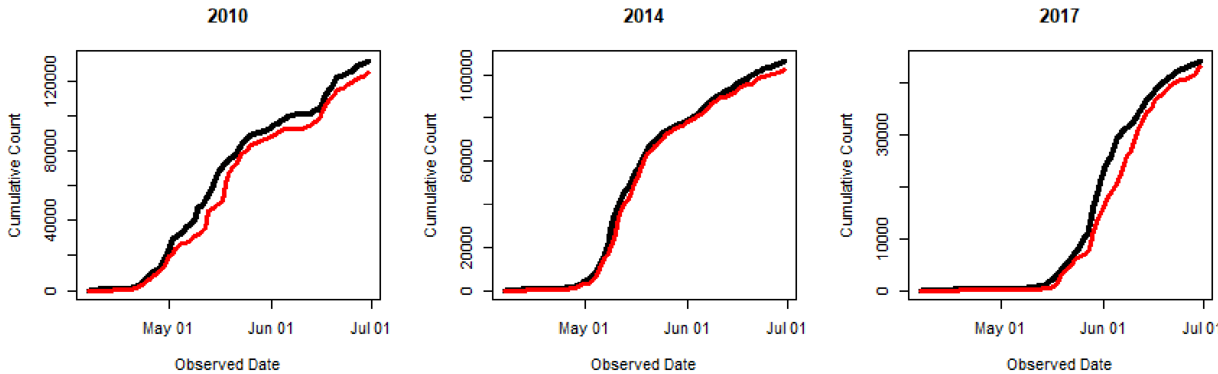

Figure 1: Comparisons of observed cumulative counts of adult Chinook at LMN (black lines) and LGS (red lines) for selected return years.

LGS Project Operations

In order to assess the relationship between adult salmon passage and flow/spill patterns at the LGS Dam, we obtained LGS powerhouse operation data from the U.S. Army Corps of Engineers, Walla Walla District. The LGS hourly powerhouse operation data consisted of discharge volume for individual powerhouse units (in Kcfs, unit one to six), discharge volume for individual spill bays (in Kcfs, for spill bays one to eight), and total flow volume (in Kcfs). The operation data ranged from December 2007 to October 2017.

To match the LGS dam operation data with the daily fish counts, we calculated the daily averages for all variables in the hourly operation data. Because adult passage was most active during the morning hours [1], daily average operations were based on data from 5 AM to 1 PM.

Principal Component Analysis

Many of the operation variables were highly correlated with each other, especially among individual spill bays (Figure 2). Prior to constructing a model to assess the relationship between LGS fish counts and operations, we conducted a principal components analysis (PCA) in order to reduce the dimensionality of our data and multicollinearity between variables. We performed the PCA on a correlation matrix of the operations variables using `prcomp()` function in R.

Linear Regression for LGS Counts and LGS Operations

Based on results from the PCA, we fitted a linear regression model using the daily LGS fish counts as the response variable, and lagged LMN fish counts, discharge volume from powerhouse units one through three, discharge volume from powerhouse units four through six, spill volume from spill bay one, and spill volume from spill bays two to eight as the explanatory variables. In addition, the linear model was adjusted for time series correlations using an auto-regressive of order one, or AR-1. To focus our analysis on days with adequate counts, we limited the data to records where the lagged LMN count was greater than 100 fish. We transformed the LGS and LMN counts using a natural logarithmic function to improve model fit. The logarithmic transformation helped normalizing the model variances, and the log-log form of LGS and LMN

[1] Approximately 71% of PIT-tagged spring Chinook adults passed LGS PIT detection during 5 AM to 1 PM, based on records from 2014 to 2017.

counts measured the percentage changes in their relationship instead of absolute changes. We fitted the linear model using `gls()` function from the *nlme* package (Pinheiro et al., 2017).

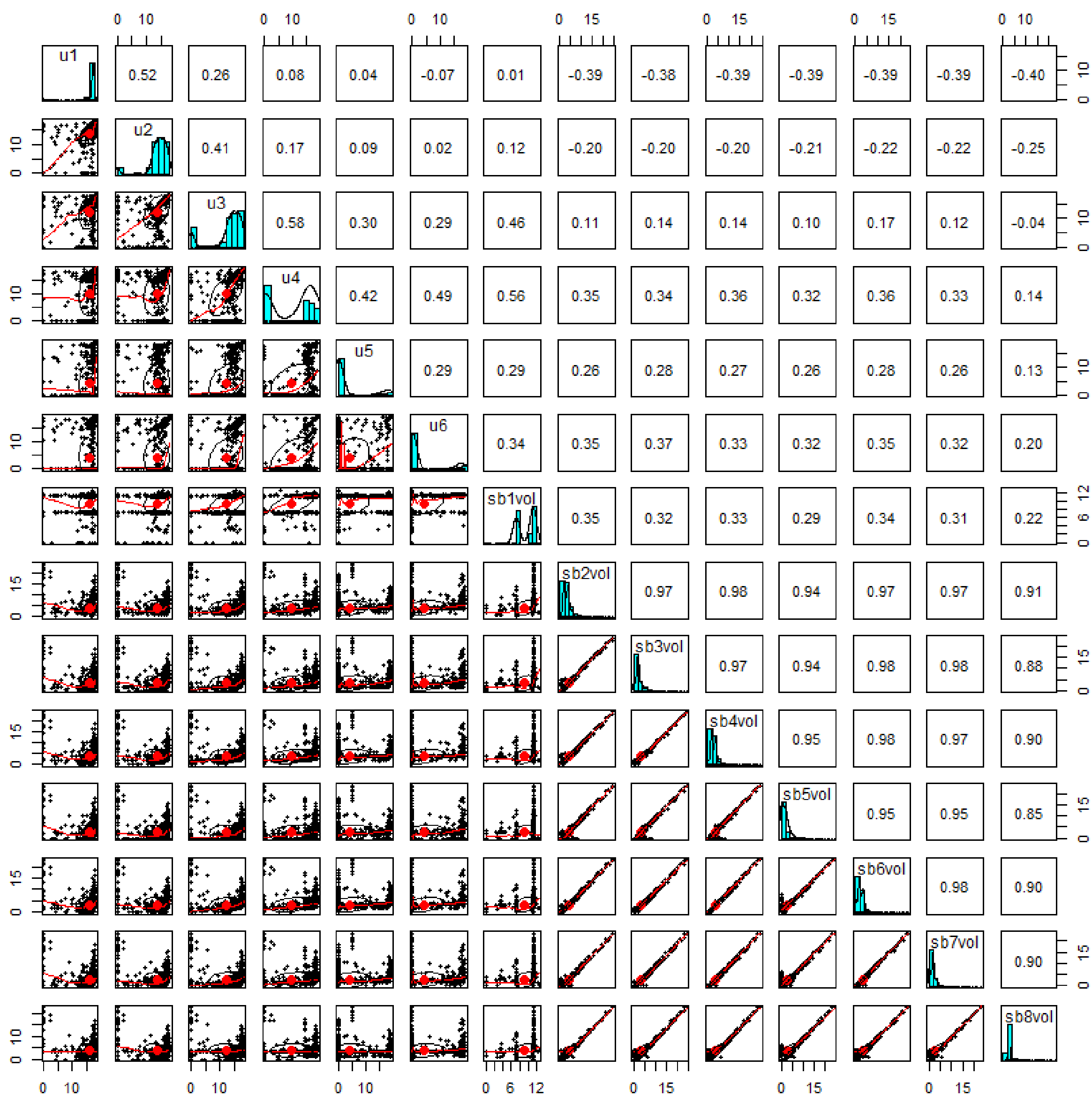

Figure 2: Scatterplot matrix with correlation estimates between the variables in the Little Goose Dam powerhouse operation data.

Results

Lower Monumental and Little Goose Chinook Counts

The linear regression models of LGS counts on LMN counts indicated that LGS counts had the best linear fit with the counts at LMN with a one-day lag (Table 1). According to the records from 2014 to 2017, 56% of PIT-tagged spring Chinook adults spent one day traveling from LMN to LGS (Table 5).

Table 1: Comparison between linear models with different lags in LMN counts. "Other variables" includes migration year and LMN counts:year interaction.

	Variables	DF	AIC	Resid SE	R^2
0 lag	LMN counts with no lag + other variables	55	35713	638.7	0.67
1-day lag	LMN counts with a one-day lag + other variables	55	35058	552.7	0.76
2-day lag	LMN counts with a two-day lag + other variables	55	35544	615.3	0.7
3-day lag	LMN counts with a three-day lag + other variables	55	35786	649.1	0.66

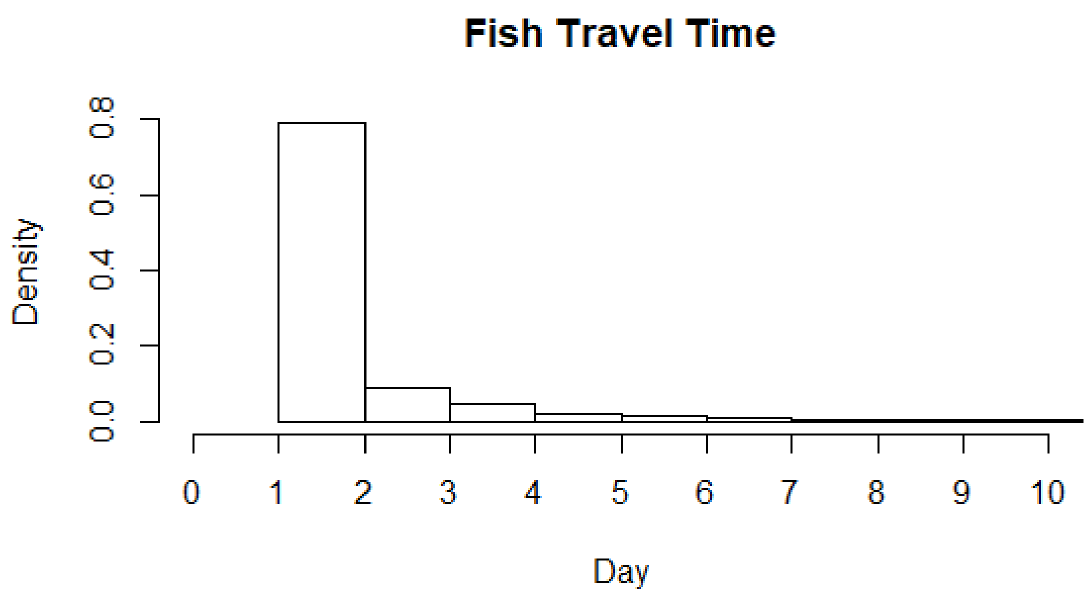

Figure 3: Histogram shows the distribution of travel time between LMN and LGS (in days) for PIT-tagged spring Chinook, based on records from 2014 to 2017. The X-axis is limited to ten days.

Over the nine years where operations data were available (2009-2017), there were a total of 569 records where the lagged daily count at LMN fit our criteria of greater than 100 (Table 2).

Table 2: Summary of dataset by return year.

	Number of records	LMN counts> 100
2009	85	61
2010	85	71
2011	85	57
2012	85	60
2013	85	64
2014	85	69
2015	82	70
2016	85	67
2017	84	50

Principal Component Analysis

Results of the PCA indicated that the first two principal components (PCs) explained 71.5% of the variation in the data (Table 3). Based on the loading values, PC1 was dominated by spill bays two to eight, and biplot showed these variables were strongly correlated (Figure 4). Therefore, it would be reasonable to group spill bays two through eight together as a single variable. Principal component two was dominated by all powerhouse units and spill bay one. After examining the biplot, it appears that powerhouse units one through three and powerhouse units four through six should be grouped separately into two variables. Powerhouse units one through three were located closer to the south shore (Oregon side), and Powerhouse units four through six were further away from the south shore and closer to the spill bays. Lastly, spill bay one stayed as its own variable due to its unique spill pattern.

Table 3: Summary of the PCA shows the linear combinations, eigenvalues (standard errors), and cumulative percentage of variation explained for the first two principal components.

	PC1	PC2
Powerhouse Unit 1	-0.154	0.325
Powerhouse Unit 2	-0.082	0.381
Powerhouse Unit 3	0.068	0.491
Powerhouse Unit 4	0.158	0.44
Powerhouse Unit 5	0.122	0.286
Powerhouse Unit 6	0.154	0.262
Spill Bay 1	0.15	0.355
Spill Bay 2	0.36	-0.044
Spill Bay 3	0.359	-0.037
Spill Bay 4	0.361	-0.04
Spill Bay 5	0.35	-0.06
Spill Bay 6	0.362	-0.035

Spill Bay 7	0.359	-0.057
Spill Bay 8	0.328	-0.16
—	—	—
Eigenvalue	7.403	2.611
Cumulative var	0.529	0.715

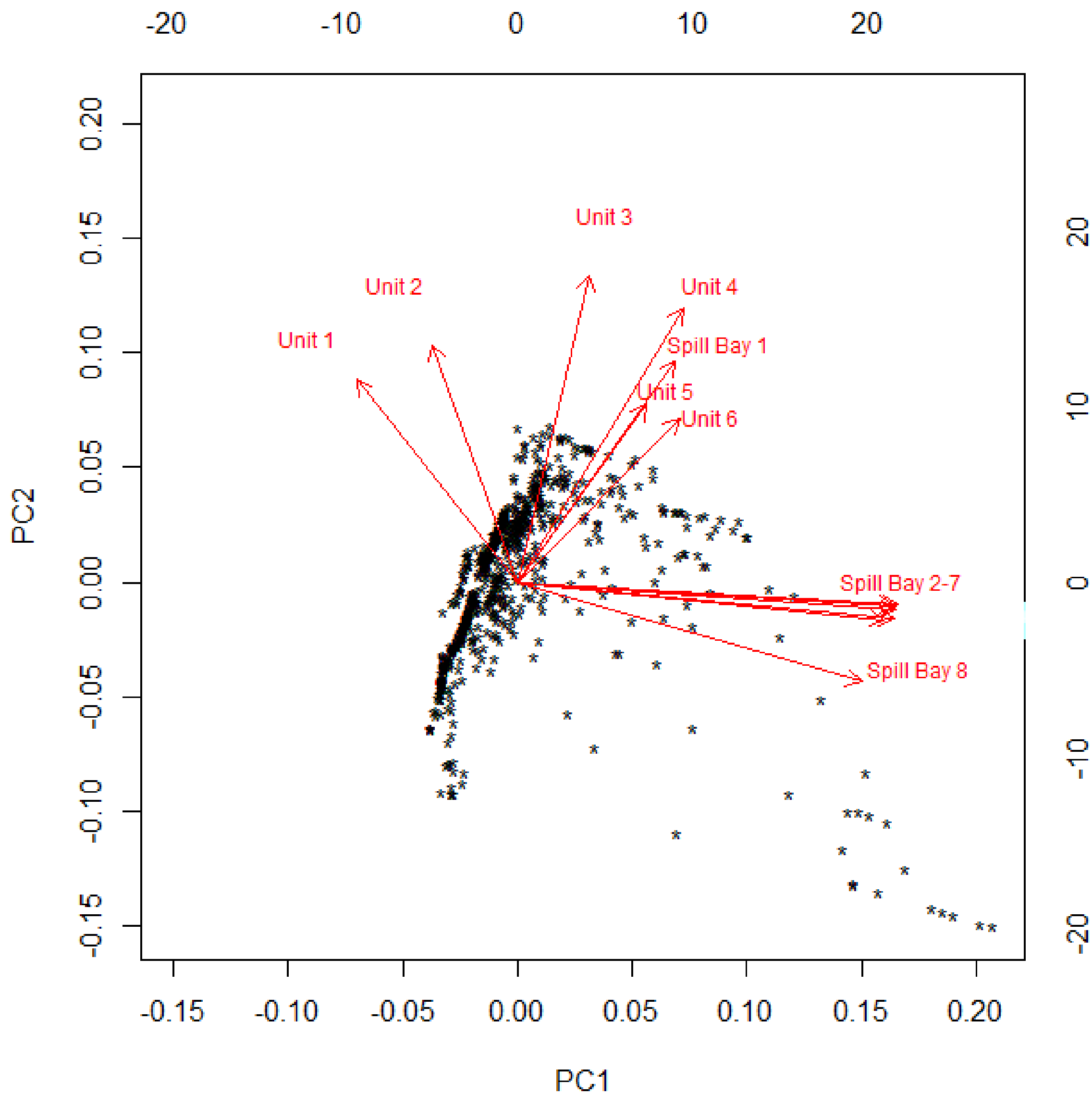

Figure 4: Biplot shows the first two princial components of the LGS spill and powerhouse operation data.

Linear Regression for LGS Counts and LGS Operations

As mentioned above, the linear regression analysis we used to evaluate LGS counts and LGS project operations included an explanatory variable for lagged LMN counts. The linear regression models for LGS counts on LMN counts indicated that a one-day lag was the most appropriate time lag to use for this lagged LMN count variable (Table 1).

Results from our LGS counts versus project operations model indicated that the log of LMN counts were the strongest predictors for the log of LGS counts compared to other variables (0.825, SE= 0.037, p< 0.001). The results supported the assumption that fish counts at LGS follow the patterns of fish counts at LMN. Spill volume through bay one had the strongest negative relationship with the log of adult counts at LGS amongst operation variables (-0.039, SE= 0.014, p= 0.004). Spill volume through bay two to eight also had a negative relationship with the log of LGS counts, but the evidence was inconclusive (-0.002, SE= 0.002, p= 0.109). Discharge volume through powerhouse units one to three had a positive relationship with the log of LGS counts (0.009, SE= 0.003, p= 0.002). Discharge volume through powerhouse units four to six also had a positive relationship with the log of LGS counts, but slightly weaker compared to powerhouse units one to three (0.006, SE= 0.002, p= 0.006; Table 4).

It is worth noting that this analysis was based on years when priority was typically given in the order of one to six for powerhouse unit operation, and it was not surprising to see a stronger effect of units one through three compared to units four through six. However, modeling at the U.S. Army Engineer Research and Development Center in 2017 indicated that prioritizing the operation in the opposite order (ie. from unit six to one) may help breaking up the eddy that is thought to be slowing the adult passage.

Table 4: Coefficient estimates for the linear model.

	Value	Std.Error	t-value	p-value
(Intercept)	1.033	0.286	3.614	< 0.001
ln(LMN count)	0.825	0.037	22.25	< 0.001
Powerhouse Units 1-3	0.009	0.003	3.178	0.002
Powerhouse Units 4-6	0.006	0.002	2.759	0.006
Spill Bay 1	-0.039	0.014	-2.862	0.004
Spill Bays 2-8	-0.002	0.002	-1.607	0.109

Residual versus fitted plot showed a constant spread of the residuals (Figure 5). Autocorrelation function (ACF) plots showed that temporal correlations were adequately accounted for in our linear model. Normal q-q plot and histogram indicated short tails for the distribution of residuals, but otherwise showed no major concerns for model fit (Figure 6).

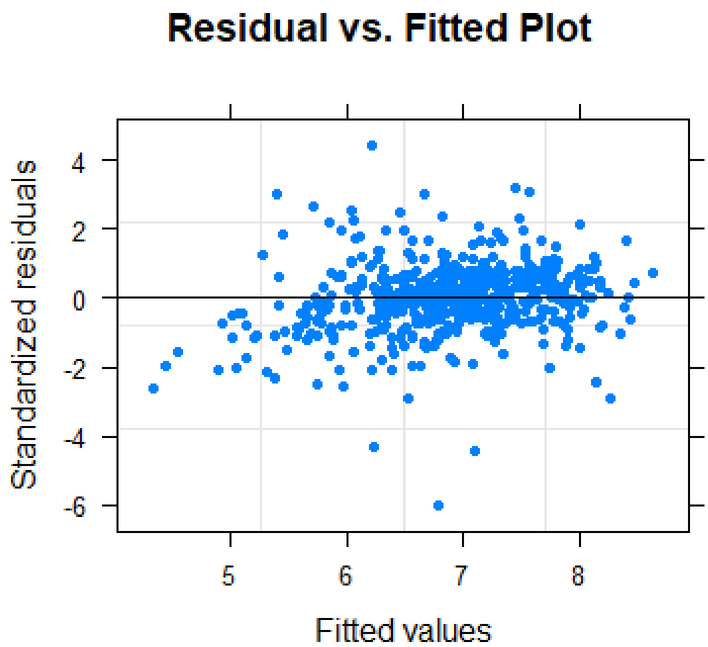

Figure 5: Residual vs. fitted plot for the linear model.

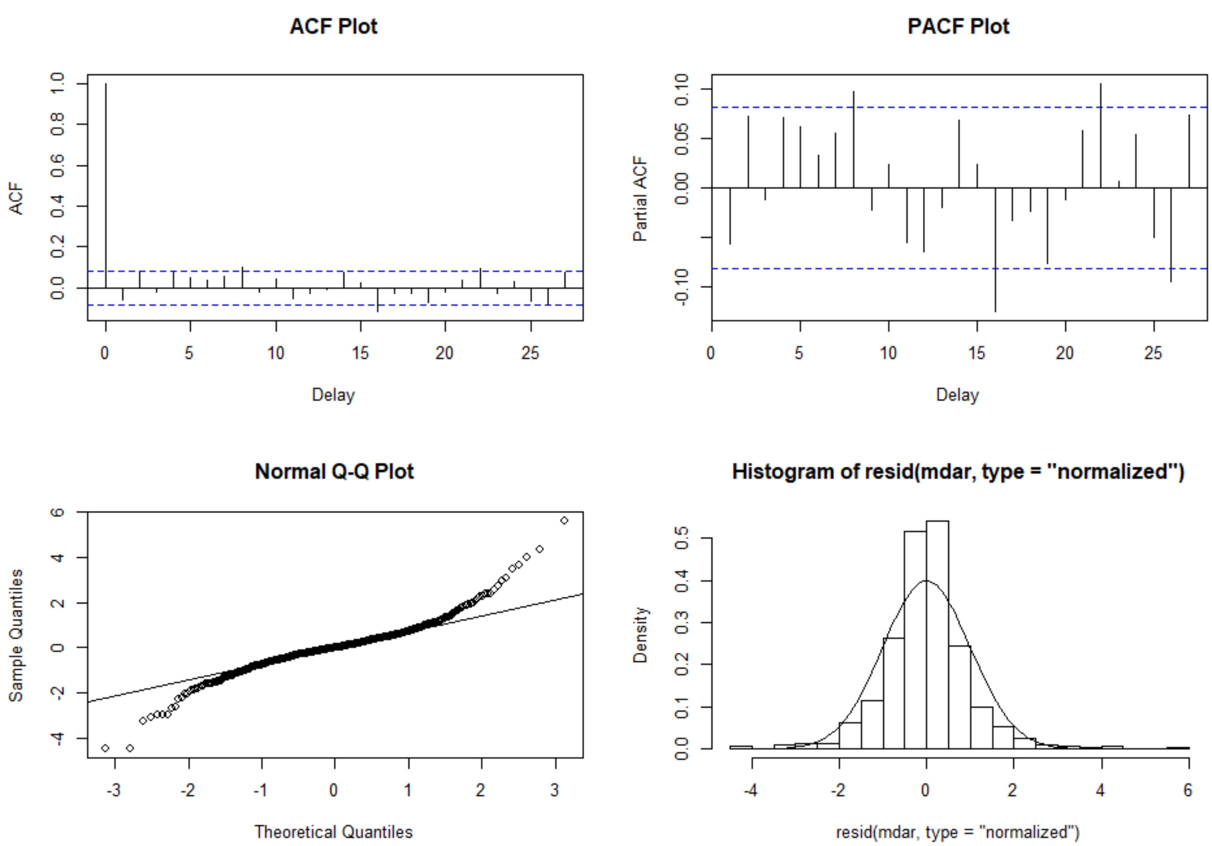

Figure 6: ACF plots, Normal q-q plot, and histogram of residuals of the linear model.

References

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267-281 in BN Petrov, Csaki F, editors. Second International Symposium on Information Theory. Akadémiai Kiadó, Budapest, Hungary

Fish Passage Center. 2017a. Review of NOAA evaluation of 2017 Little Goose spill for fish passage manipulations (August 16, 2017). http://www.fpc.org/documents/memos/40-17.pdf.

Fish Passage Center. 2017b. Little Goose Adult Passage Questions (October 13, 2017). http://www.fpc.org/documents/memos/48-17.pdf.

Jepson, M.A., C.C. Caudill, T.S. Clabough, C.A. Peery, J.W. Beeman, S. Fielding. 2009. Adult Chinook salmon passage at Little Goose Dam in relation to spill operations – 2008. Technical Report for the U.S. Army Corps of Engineers, Walla Walla. (Technical Report 2009-6).

Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team. 2017. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-131, https://CRAN.R-project.org/package=nlme.