Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Water Quality Modeling Study
Study Plan Section 5.6

2014 Study Implementation Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

URS Corporation/Tetra Tech, Inc.

November 2015

TABLE OF CONTENTS

LIST OF TABLES

APPENDICES

ATTACHMENTS

LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
CFR	Code of Federal Regulations
Commission	Federal Energy Regulatory Commission
DO	dissolved oxygen
EFDC	Environmental Fluid Dynamics Code
FA	Focus Area
FERC	Federal Energy Regulatory Commission
ILP	Integrated Licensing Process
ISR	Initial Study Report
POC	proof of concept
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project
RSP	Revised Study Plan
SPD	study plan determination
TSS	total suspended solids

1. INTRODUCTION

This Water Quality Modeling Study, Section 5.6 of the Revised Study Plan (RSP) approved by the Federal Energy Regulatory Commission (FERC or Commission) for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241, focuses on predicting the potential impacts of the dam and its proposed operations on water quality through the development of a water quality model. The goal of the Water Quality Modeling Study will be to utilize the extensive information collected from the Baseline Water Quality Study (Section 5.5 of the RSP) to develop a model(s) to evaluate the potential impacts of the proposed Project and operations on various physical parameters within the Susitna River watershed.

A summary of the development of this study, together with the Alaska Energy Authority's (AEA) implementation of it through the 2013 study season, appears in Part A, Section 1 of the Initial Study Report (ISR) filed with FERC in June 2014. As required under FERC's regulations for the Integrated Licensing Process (ILP), the ISR describes AEA's "overall progress in implementing the study plan and schedule and the data collected, including an explanation of any variance from the study plan and schedule." (18 CFR 5.15(c)(1)).

Since filing the ISR in June 2014, AEA has continued to implement the FERC-approved plan for the Water Quality Modeling Study. These efforts have included the following:

- On September 30, 2014, AEA filed with FERC the *Water Quality and Lower River Modeling Technical Memorandum* (AEA 2014a), which provided results of the analysis and recommendation of extending the Water Quality Model below Project River Mile (PRM 29.9) and an evaluation of the adequacy of the water temperature and meteorological data collected through 2014. Based on the findings, AEA did not propose extending the model downstream beyond PRM 29.9.
- On October 16, 2014, AEA held an ISR meeting about the Baseline Water Quality Monitoring Study (Study 5.5), Water Quality Modeling Study (Study 5.6), and Mercury Assessment and Potential for Bioaccumulation Study (Study 5.7).
- Since the 2014 ISR, the riverine model was calibrated for temperature using observed temperature data from 2012 and 2013.
- Although turbidity is not a direct output from the water quality models, it is a parameter that will be included when evaluating potential Project effects. Because turbidity and the concentration of suspended sediment, which is a modeled constituent, are correlated, relationships between these two variables are required to interpret model results. These relationships were developed for the Susitna River from data collected by Study 5.5, and the results are presented in Attachment 1 of this report.

In furtherance of the next round of ISR meetings and FERC's SPD, this report describes AEA's overall progress in implementing the Water Quality Modeling Study during calendar year 2014. Rather than a comprehensive reporting of all field work, data collection, and data analysis since the beginning of AEA's study program, this report is intended to supplement and update the information presented in Part A of the ISR for Water Quality Modeling through the end of calendar year 2014. It describes the methods and results of the 2014 effort, and includes a discussion of the results achieved.

2. STUDY OBJECTIVES

The collective goal of the water quality studies (Baseline Water Quality Study, Water Quality Modeling Study, and the Mercury Assessment and Potential for Bioaccumulation Study) is to assess the impacts of the proposed Project operations on water quality in the Susitna River basin with particular reference to state water quality standards. Predicting the potential impacts of the dam and its proposed operations on water quality requires the development of a water quality model. The goal of the Water Quality Modeling Study is to utilize the extensive information collected from the Baseline Water Quality Study to develop a model(s) to evaluate the potential impacts of the proposed Project and operations on various physical parameters within the Susitna River watershed.

The objectives of the Water Quality Modeling Study are as follows:

- Implement (with input from licensing participants) an appropriate reservoir and river water temperature model for use with past and current monitoring data.
- Using the data developed as part of the Baseline Water Quality Study, model water quality conditions in the proposed Watana Reservoir, including (but not necessarily limited to) temperature, dissolved oxygen (DO), fine suspended sediment and turbidity, chlorophyll-a, nutrients, ice, and metals.
- Model water quality conditions in the Susitna River from the proposed site of the Watana Dam downstream, including (but not necessarily limited to) temperature, DO, fine suspended sediment and turbidity, chlorophyll-a, and nutrients. Ice processes effects are accounted for using output from the River 1D Ice Processes Model (in coordination with the Ice Processes Study).

3. STUDY AREA

As established in RSP Section 5.6.3, the study area begins at PRM 19.9 and extends past the proposed dam site to PRM 235.2; data collection sites are described in Table 3-1. The distribution of data collection sites for the Susitna Basin also is shown in Figure 3-1. These data were used in the calibration of the EFDC water quality model.

As described in Study 5.6 ISR, Part C, Section 7.1.1.1, a decision point was considered in 2014 regarding extension of the water quality modeling downstream of PRM 29.9 (AEA 2014e). On September 30, 2014, AEA filed with FERC the *Water Quality and Lower River Modeling Technical Memorandum* (AEA 2014a), which provided results of the analysis. Based on the small difference between pre and post-Project temperatures at PRM 29.9 and similar small changes in DO based on observed saturation, extension of the water quality model downstream of PRM 29.9 was not recommended.

4. METHODS AND VARIANCES

4.1. Methods

4.1.1. Model Selection

During 2013, AEA selected a 3-dimensional Reservoir Water Quality Model, a 2-dimensional River Water Quality Model, and a (2-D) River Water Quality Model with Enhanced Resolution Focus Areas for this Project. The rationale for selection of the Reservoir and River Water Quality models is set forth in Section 5.6.4.6 of the RSP (AEA 2012).

Section 5.6.4 in the RSP provides a detailed discussion of the model selection factors and evaluation based on technical, regulatory, and management criteria (AEA 2012). The three modeling systems evaluated were H2OBAL/SNTEMP/DYRESM, CE-QUAL-W2, and the Environmental Fluid Dynamics Code (EFDC) model. The EFDC model was selected to implement the study. It is capable of simulating both reservoir and river environments; includes hydrodynamics, water temperature, water quality, and sediment transport modules; and considers ice formation and breakup.

4.1.2. Reservoir and Downstream River Modeling Approaches

The reservoir and riverine modeling approaches are described in ISR Part A, Section 4.2. In 2014, AEA continued with the modeling approaches as described in the ISR. The downstream riverine model boundary was determined to be PRM 29.9 in the *Water Quality and Lower River Modeling Technical Memorandum* (AEA 2014a).

4.1.3. Focus Area Modeling

Focus area (FA) modeling was described in ISR Part A, Sections 4.3 and 5.4 (AEA 2014c).

4.1.4. Scales for Modeling and Resolution of the Output

The scales for modeling and output resolution are discussed in ISR Part A, Section 4.4 (AEA 2014c). Model domain and spatial resolution can differ at points along the river depending on channel width and complexity. The cell sizes for the reservoir model, river model, and FA-128 (Slough 8A) model are presented below.

- Reservoir model
    - Cell width: 357–2,953 feet
    - Average width: 1,690 feet
    - Cell length: 8–560 feet
    - Average length: 230 feet
- River model
    - Cell width: 87–567 feet

    - Average width: 244 feet
    - Cell length: 1,066–2,206 feet
    - Average length: 1,599 feet
- FA-128 (Slough 8A) model
    - Cell width: 50–111.5 feet
    - Average width: 70 feet
    - Cell length: 103–229 feet
    - Average length: 145 feet

4.1.5. Selection of Model State Variables and Options

The selection of model state variables and outputs is summarized in ISR Part A, Section 5.1 and ISR Part B (AEA 2014c; AEA 2014d).

4.2. Variances from Study Plan

No variances from the established methods occurred during the implementation of this study in 2014.

5. RESULTS

5.1. Reservoir Model

The reservoir modeling is complicated because of pool level fluctuations of up to approximately 200 feet, in addition to complete drying of shallow areas of the reservoir. The outflow elevation in the reservoir is based on movable vertical shutters to allow water withdrawals at multiple water depths, allowing cooler water to be drawn from lower depths in the summer and warmer water to be drawn from lower depths in the winter. The most extreme water withdrawal strategy scenario is water being discharged from only the warmer reservoir surface where solar radiation is absorbed during summer and early fall. Actual operation will likely differ from this scenario. The April 2014 Proof of Concept (POC) simulations of the reservoir model assumed that water withdrawn from the entire intake elevation range resulted in discharge temperatures being lower than pre-Project conditions during the summer months (Tetra Tech 2014a). This is not representative of planned operations of the dam.

The POC model runs simulated reservoir discharge and temperature to show how model results would be transferred to other study components. The results from the POC were discussed at the April 2014 Technical Work Group meetings (Tetra Tech 2014a). The model runs simulated the 1974–1976 period (a dry period with a large pool drawdown) and the 1979–1981 period (a wet period with a small pool drawdown). Pre-Project river flow and temperature were used as upstream boundary conditions for the reservoir model.

As discussed in Section 1.1 of Study 8.5 ISR, Part C Appendix N (AEA 2014b), the POC reservoir model was robust and demonstrated that vertical resolution captures thermal stratification and mixing processes in the reservoir model. Plots from the POC model runs are provided in Appendix A.

5.2. River Model

The POC model runs were discussed at the April 2014 Technical Work Group meetings (Tetra Tech 2014b). For the model runs, the pre-Project conditions upstream river temperature boundary was based on a 3-year synthesized temperature record that correlated observed temperatures with time of year and river flow. The upstream boundary post-Project conditions were taken from the reservoir model. As discussed in Section 1.2 of Study 8.5 ISR, Part C Appendix N (AEA 2014b), although the results should not be considered as representative of future conditions in the river, the POC indicated that the river model was stable and had an acceptable run-time performance for decadal time scale simulations. Plots from the POC model runs are provided in Appendix A. The Baseline Water Quality Study (Study 5.5) and Water Quality Modeling Study (Study 5.6): Water Quality and Lower River Modeling Technical Memorandum (AEA 2014a) include additional modeling results for the river model at the dam site, PRM 125, PRM 60, and PRM 29.9.

After the POC modeling, the river model was calibrated against high-frequency temperature monitoring data at seven stations (PRM 152.7, PRM 152.2, PRM 142.3, PRM 140, PRM 88.3, PRM 87.8, and PRM 59.9). The locations of the monitoring sites are shown in Figure 3-1. The monitoring data are available for different periods between July 2012 and September 2013. The results of the model calibration versus the observed temperature data are presented in Figures 5.2-1 and 5.2-2. The plots present the modeled and observed temperature data as a function of the days since the model run began on December 31, 2009, with the plots starting with July 18, 2012 (Day 930) and running through October 2013.

Figures 5.2-1 and 5.2-2 indicate the model predicts the temperature well. The model is able to represent the general magnitude and trend of observed temperature data and will be able to be used to predict potential impacts of the proposed Project and operations. On an annual basis, the data show that 2013 had higher water temperatures at all stations, and the model was able to predict that pattern. The model reproduces short-term magnitude and variability of water temperature as well.

The model determined that the simulated water temperatures in the Susitna River are sensitive to the magnitude and timing of temperature in the boundary conditions, indicating that the uncertainty in the boundary condition can influence the simulated temperature. Since the data available to accurately represent the boundary conditions are limited, considerable uncertainties are present in the simulated temperature, particularly the details in short-term behavior. In this case, the best way to evaluate model performance is through visual comparison, which looks at identifying the pattern and trend rather than point-to-point comparison. This process is used with hydrodynamic and water quality models across the country.

Slight differences in model results from observed data can be attributed to uncertainty from the model boundary conditions, as well as in the observed data. In addition, the observed data might have specific local conditions that deviate from the general pattern. For example, the observed temperature at PRM 88.3 is low and below 12 degrees Celsius (°C), but at PRM 87.8 (0.5 miles downstream), the observed temperature becomes significantly higher (almost 15 °C). While the model is able to reproduce the temperature at PRM 88.3 well, it cannot reproduce the higher temperatures at PRM 87.8 during the same period. PRM 87.8 is likely under the influence of local conditions or is not representative (e.g., the location of the Talkeetna Wastewater Treatment Facility outfall). Similarly, the high temperature at PRM 59.9 might be partly explained by local conditions given that with the flow rate and water volume during the period, the solar radiation would not have the ability to increase water temperature to that degree from the previous upstream observations.

In general, the model is adequately calibrated for temperature. Future refinement in calibration might be possible during the water quality model calibration process.

5.3. FA-128 (Slough 8A) Model

The Focus Area models will have higher-resolution than the full river model. The FA-128 (Slough 8A) mode, located from PRM 129.7 to PRM 128.1, was configured separately from the full river model. The full river model was used to determine the upstream and downstream boundary conditions for FA-128.

The POC model runs were discussed at the April 2014 Technical Work Group meetings (Tetra Tech 2014c). Section 1.3 of Study 8.5 ISR, Part C Appendix N contains a discussion of the POC FA-128 (Slough 8A) results (AEA 2014b). Plots from the POC model runs are provided in Appendix A of this report. No additional modeling has occurred.

6. DISCUSSION

Although the POC results should not be considered as representative of future conditions in the reservoir and river, they indicated that the models are robust and provide physically realistic simulation of water surface elevation, velocity, and temperature (Tetra Tech 2014a, 2014b, 2014c; AEA 2014b). In addition, the reservoir POC model demonstrated that vertical resolution captures thermal stratification and mixing processes in the reservoir model.

The models have been tested with potential Project flow scenarios to demonstrate stability and acceptable run-time performance. Test data sets for water temperature generated in 2012 have been used in both the reservoir and riverine models, which are capable of decade time scale simulations. The same data sets were extended into 2013 to verify and further refine model calibration. Temperature data from 2014 was not available during POC modeling.

As described in Study 5.6 ISR, Part C, Section 7.1.1.1, a decision point was considered in 2014 regarding the extension of the water quality modeling downstream of PRM 29.9 (AEA 2014e). Based on the minor difference between pre and post-Project temperatures at PRM 29.9 and similar minor changes in DO based on observed saturation, extension of the water quality model downstream of PRM 29.9 was not recommended.

The Baseline Water Quality Study (Study 5.5) and Water Quality Modeling Study (Study 5.6): Water Quality and Lower River Modeling Technical Memorandum included additional modeling results for the river model at the dam site, PRM 125, PRM 60, and PRM 29.9 (AEA 2014a).

After the POC modeling, the river model was calibrated using temperature data from 2012 and 2013, as the 2014 temperature data was not available. The 2014 data will be used for future model validation. The model reproduces short-term magnitude and variability of water temperature, as shown in Figures 5.2-1 and 5.2-2. The model is considered acceptably calibrated for temperature.

Though not part of the water quality model development, the interpretation of model results of suspended sediment concentrations in relation to turbidity will be required to evaluate potential Project effects. The initial evaluation of correlations between total suspended solids (TSS) and turbidity is included as Attachment 1 of this report.

7. CONCLUSION

AEA has made extensive progress in implementing the water quality modeling study, which provides the groundwork for completing the development of the reservoir and riverine models. The reservoir, riverine, and FA-128 (Slough 8A) models have been configured and tested, as shown in the POC modeling (Tetra Tech 2014a, 2014b, 2014c). The POC included spatial configuration of each model to run a multiyear hydrodynamic and temperature simulation. Based upon the work already completed, AEA expects to achieve the objectives for the Water Quality Monitoring Study (Section 2), in addition to work identified in Study 5.6 ISR Part D Section 8 (AEA 2014f). No additional field work is planned or deemed necessary at this time, as the data is sufficient to complete the modeling.

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9. TABLES

Table 3-1. Susitna River Basin Temperature and Water Quality Monitoring Sites.

PRM	Description	Latitude (WGS84)	Longitude (WGS84)	Water Temperature							Water Quality Monitoring				
				Historic		Current					Historic		Current		
				W	S	S 2012	W 2012 - 2013	S 2013	W 2013 - 2014	S 2014	W	S	S 2013	W 2013 - 2014	S 2014
19.9	Susitna above Alexander Creek	61.43903	-150.48456			X	X	X		X					
29.9	Susitna Station	61.54428	-150.51556	X	X			X		X	X	X	X	X	X
32.5[1]	Yentna River	61.587604	-150.48301	X	X	X	X	X	X	X	X	X	X		X
33.6	Susitna above Yentna	61.57595	-150.42741			X	X	X	X	X			X		X
45.1[1]	Deshka River	61.710142	-150.32470			X	X	X		X			X		X
59.9	Susitna	61.86220	-150.18463			X	X	X	X	X			X		X
87.8	Susitna at Parks Highway East	62.174531	-150.173677			X	X	X	X	X			X	X	X
88.3	Susitna at Parks Highway West	62.181096	-150.16787	X	X	X	X	X	X	X	X	X			
99.2	LRX 1	62.306018	-150.108764			X	X	X	X	X					
102.8[1]	Talkeetna River	62.34243	-150.11266			X	X	X		X			X		X
118.6[1]	Chulitna River	62.567703	-150.23782	X	X	X	X	X	X	X	X	X	X		X
107	**Talkeetna**	62.39724	-150.13728		**X**	**X**		**X**		**X**			**X**		**X**
116.7	**LRX 18**	62.526527	-150.114671			**X**		**X**	**X**	**X**					
124.2	**Curry Fishwheel Camp**	62.61783	-150.01373		**X**	**X**		**X**		**X**			**X**		**X**
129.6	Slough 8A	62.670479	-149.903241			X		X	X	X					
129.9	**LRX 29**	62.673914	-149.899025			**X**		**X**		**X**					
132.7	Slough 9	62.702358	-149.841895			X		X	X	X					
134.1	LRX 35	62.713854	-149.808926			X		X	X	X					
140	Susitna near Gold Creek	62.767054	-149.693532			X		X	X	X				X	
140.1[1]	Gold Creek	62.767892	-149.68978	X	X	X		X	X	X	X	X	X		X
141.0	Slough 16B	62.780204	-149.68536			X		X	X	X					
142.2[1]	Indian River	62.78635	-149.65878					X	X	X			X		X
142.3	**Susitna above Indian River**	62.785776	-149.64890			**X**	**X**	**X**		**X**			**X**		**X**
143.6	Slough 19	62.793819	-149.614255			X		X	X	X					
143.6	**LRX 53**	62.79427	-149.61327		**X**	**X**		**X**	**X**	**X**					
145.6	Slough 21	62.814667	-149.575329			X		X		X					
152.2	Susitna below Portage Creek	62.830397	-149.382743			X	X			X			X		X
152.3[1]	Portage Creek	62.830379	-149.380289			X	X			X					
152.7	**Susitna above Portage Creek**	62.827002	-149. 827002			**X**	**X**			**X**		**X**	**X**		**X**
168.1	Susitna	62.791696	-148.993825				X			X					
183.1	Susitna below Tsusena Creek	62.81348	-148.656868			X				X					
184.8[1]	Tsusena Creek	62.821783	-148.606809				X			X				X	
187.2	Susitna at Watana Dam site	62.82260	-148.55300		X		X			X			X		X
196.8	Watana Creek	62.82960	-148.25900							X					
209.2	Kosina Creek	62.78220	-147.94000			X	X	X	X	X					
225.5	Susitna near Cantwell	62.70520	-147.53800											X	
235.2[2]	Oshetna River	62.63961	-147.383109			X	X	X	X	X			X		X

Notes:

PRM = Susitna River Project River Mile

W = Winter

S = Summer

* Indicates sampling location was a tributary to the Susitna River

[1] indicates the Susitna River PRM at the confluence of the tributary (samples collected from the tributary)

[2] indicates an alternate monitoring location from PRM 225.5 due to river inaccessibility by helicopter during summer sample collection

10. FIGURES

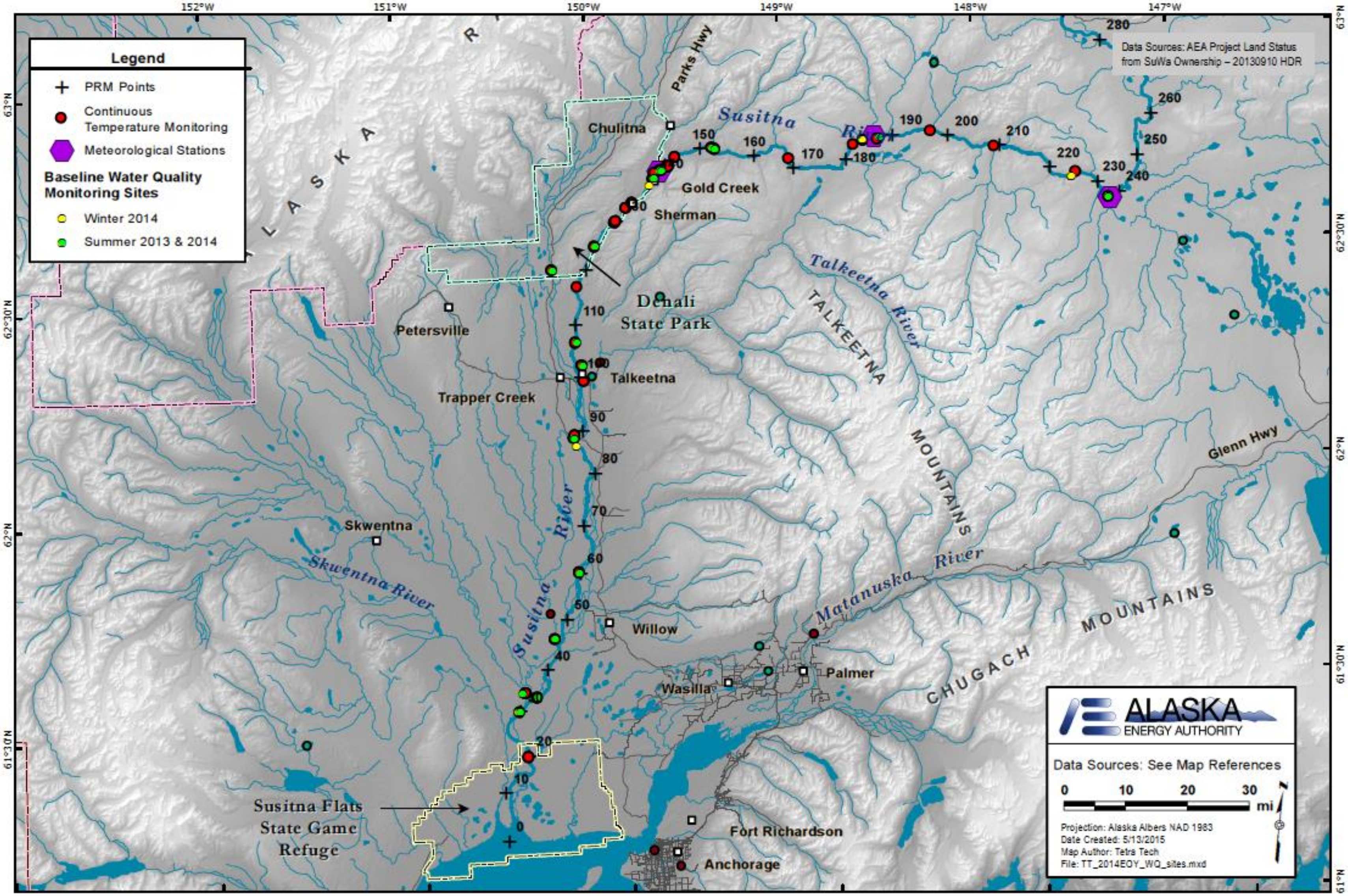


Figure 3-1. Stream Water Quality and Temperature Data Collection Sites for the Susitna-Watana Hydroelectric Project.

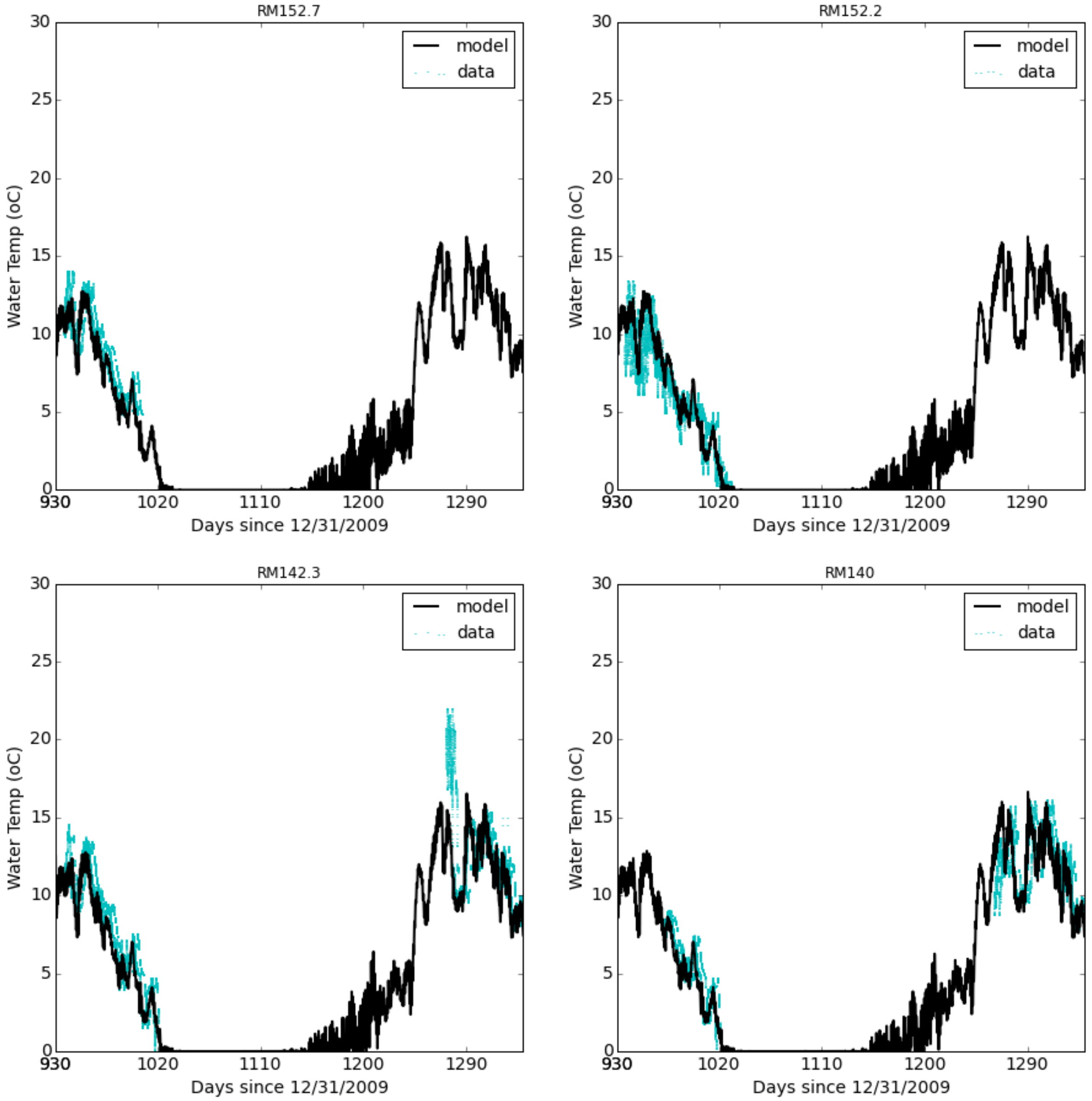


Figure 5.2-1. River Model Temperature Calibration Plots (PRM 152.7, 152.2, 142.3, 140).

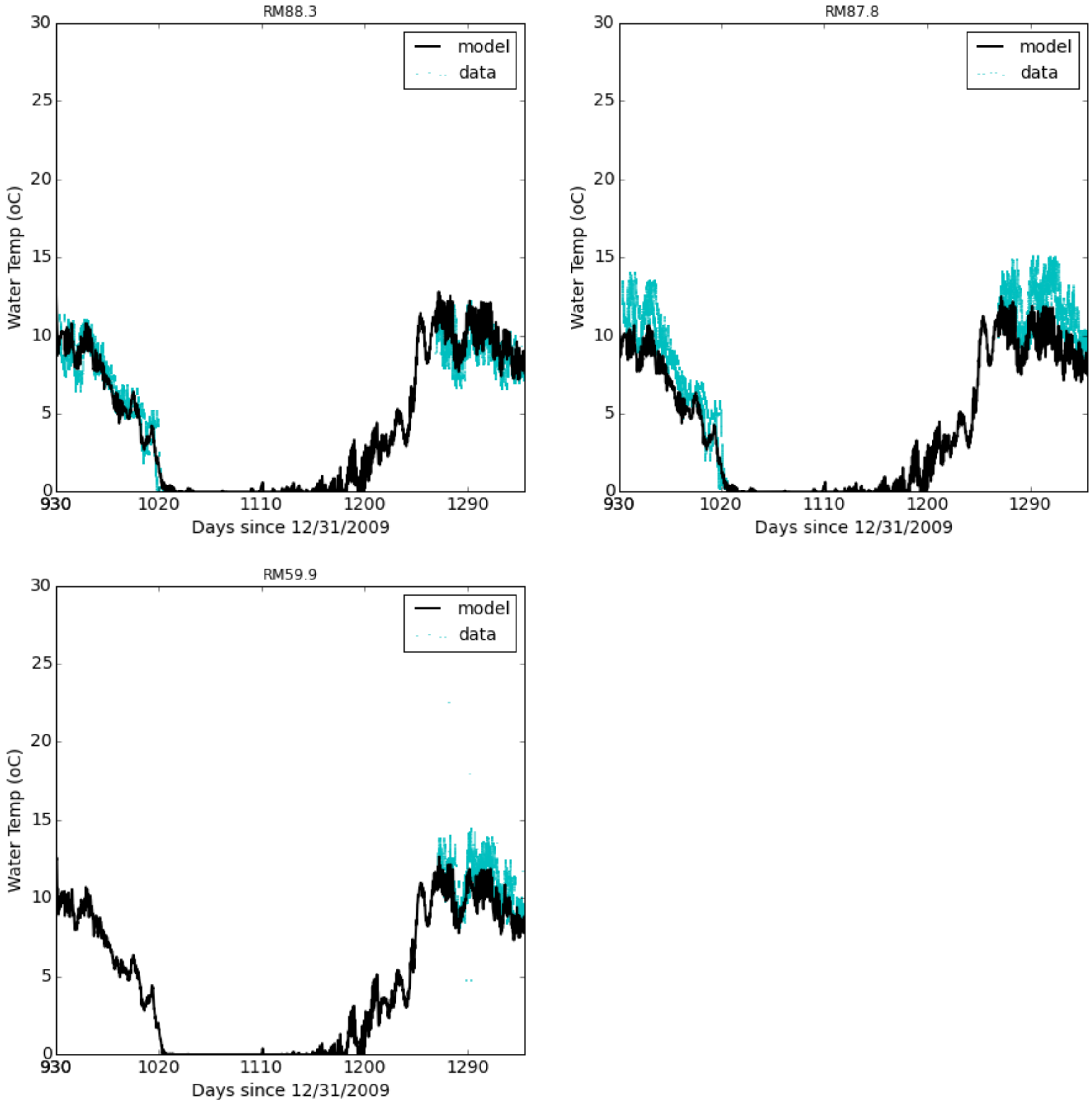
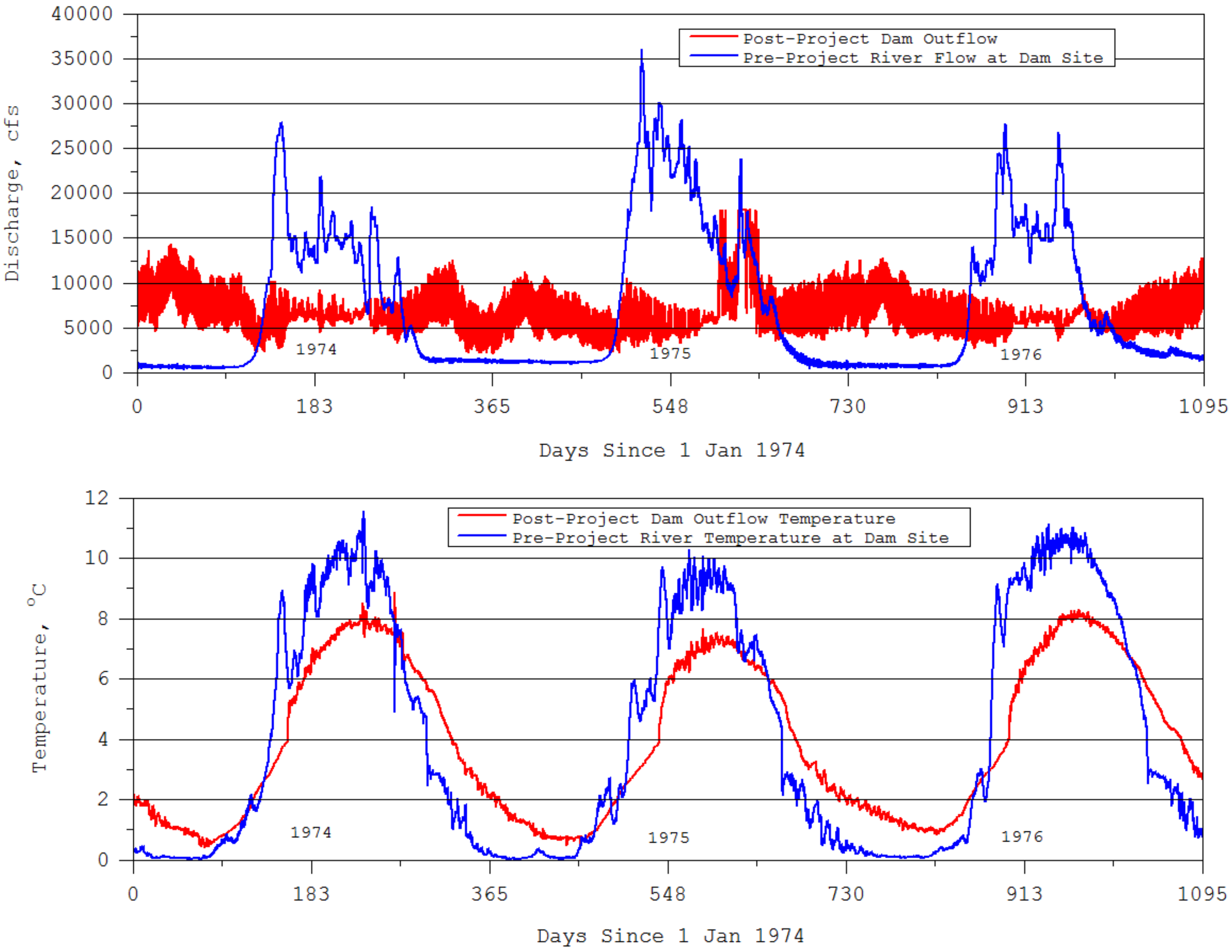


Figure 5.2-2. River Model Temperature Calibration Plots (PRM 88.3, 87.8, 59.9).

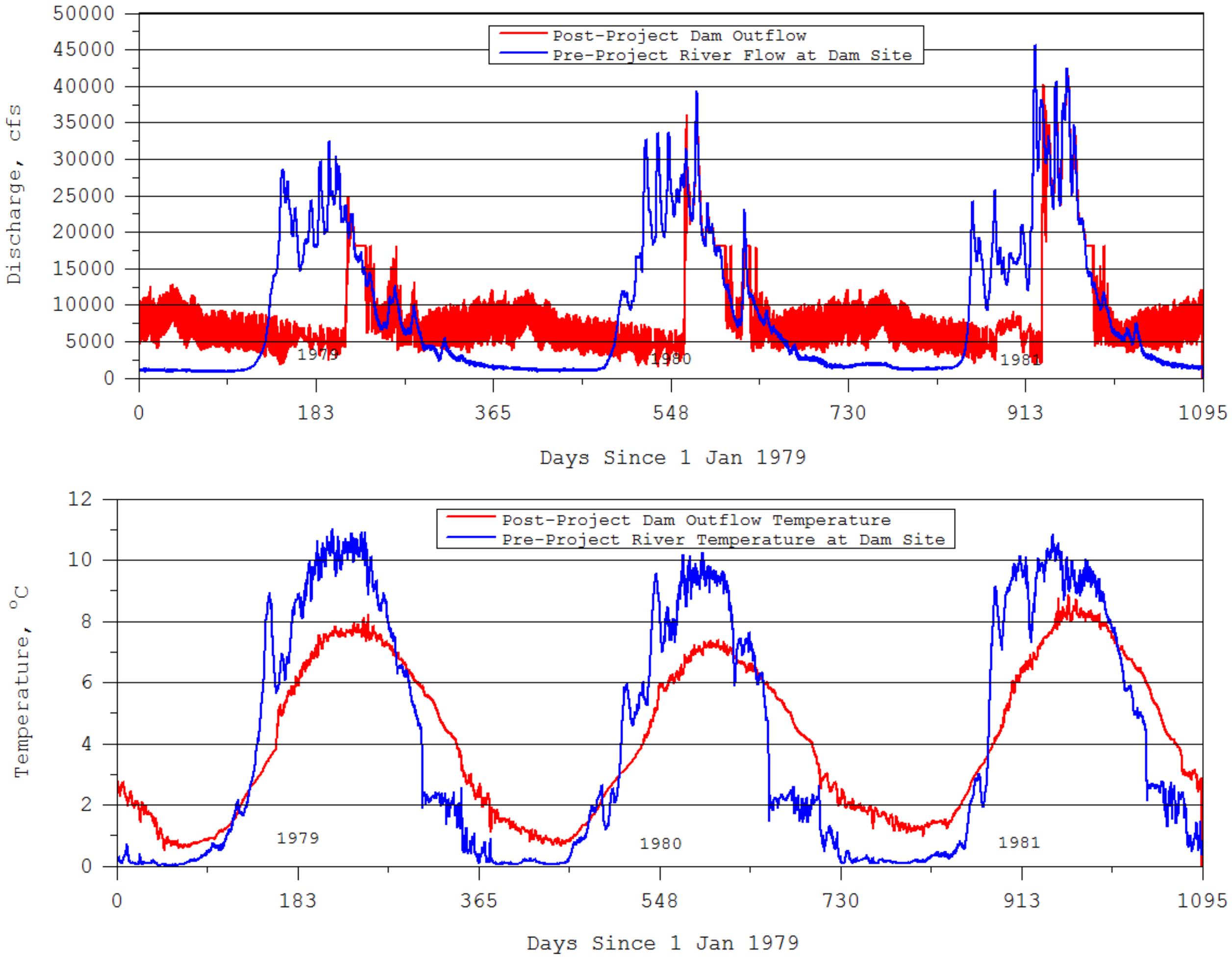
APPENDIX A: APRIL 2014 PROOF OF CONCEPT RESULT PLOTS

LIST OF FIGURES



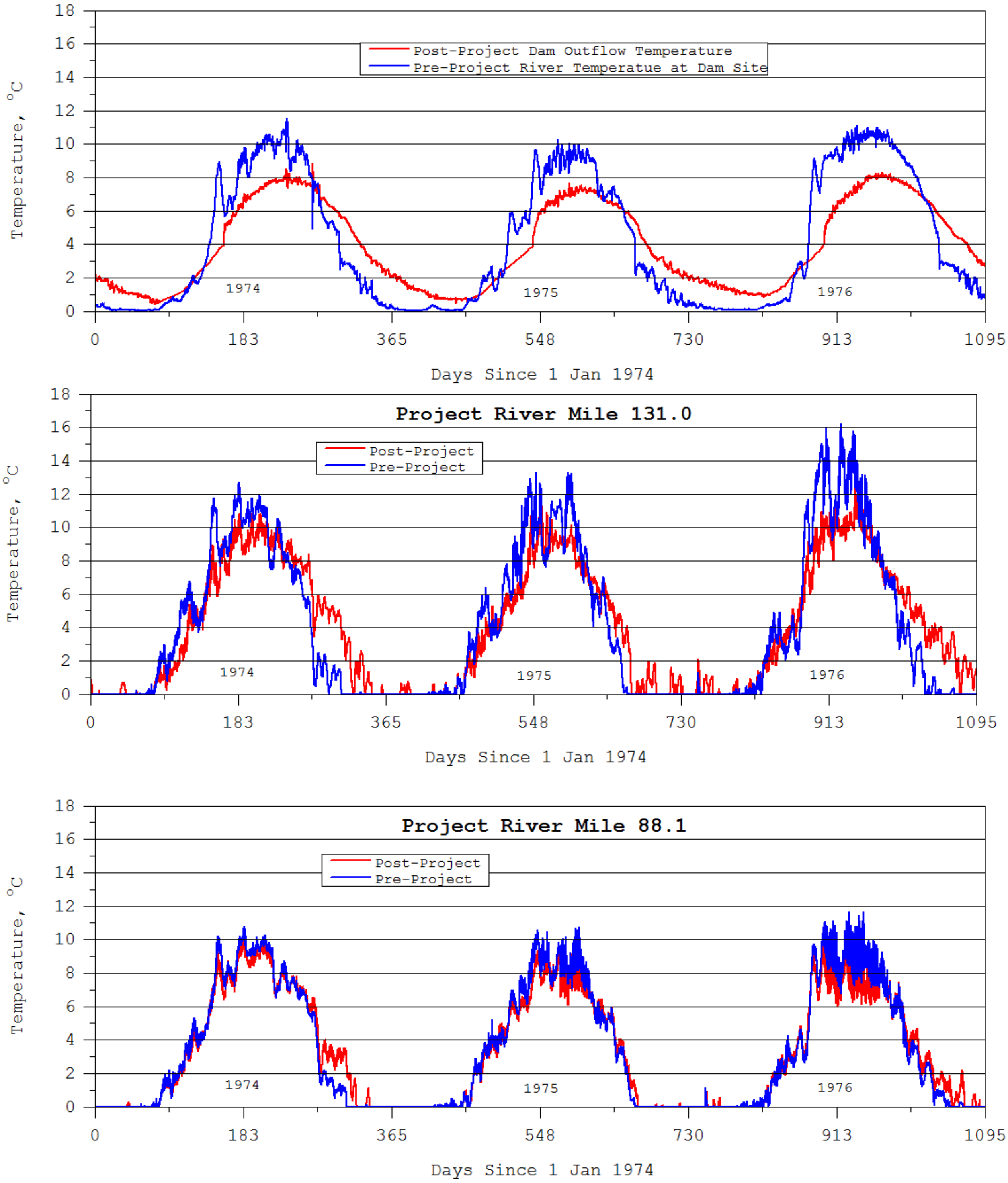
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-1. Proof of Concept 1974–1976 Simulation Boundary Conditions River Model Discharge and Temperature Results at Dam Site.



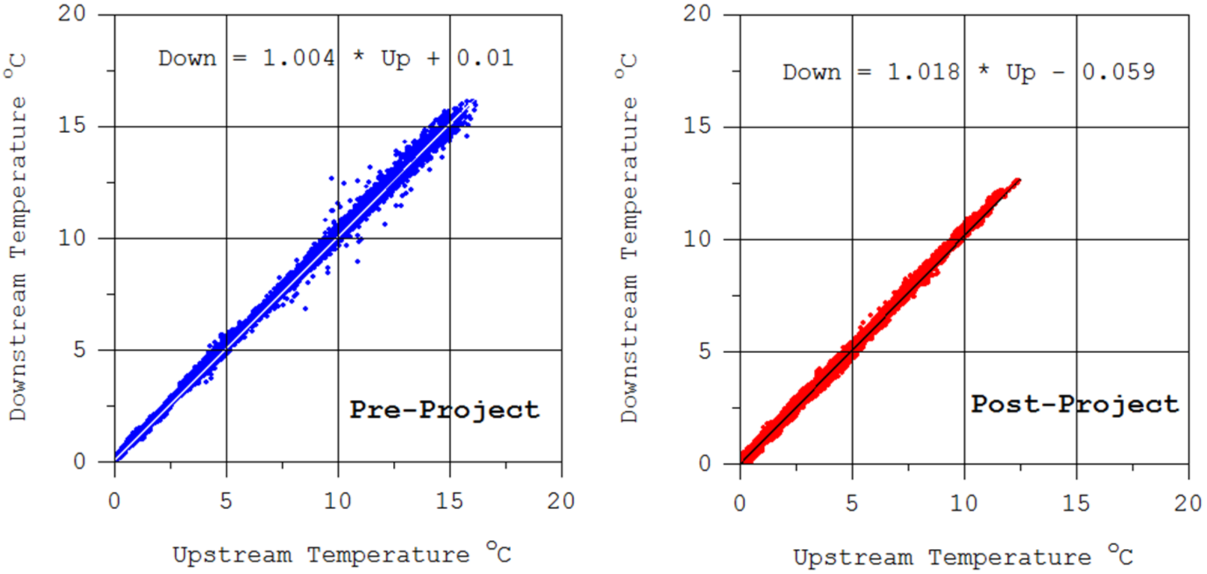
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-2. Proof of Concept 1979–1981 Simulation Boundary Conditions River Model Discharge and Temperature Results at Dam Site.



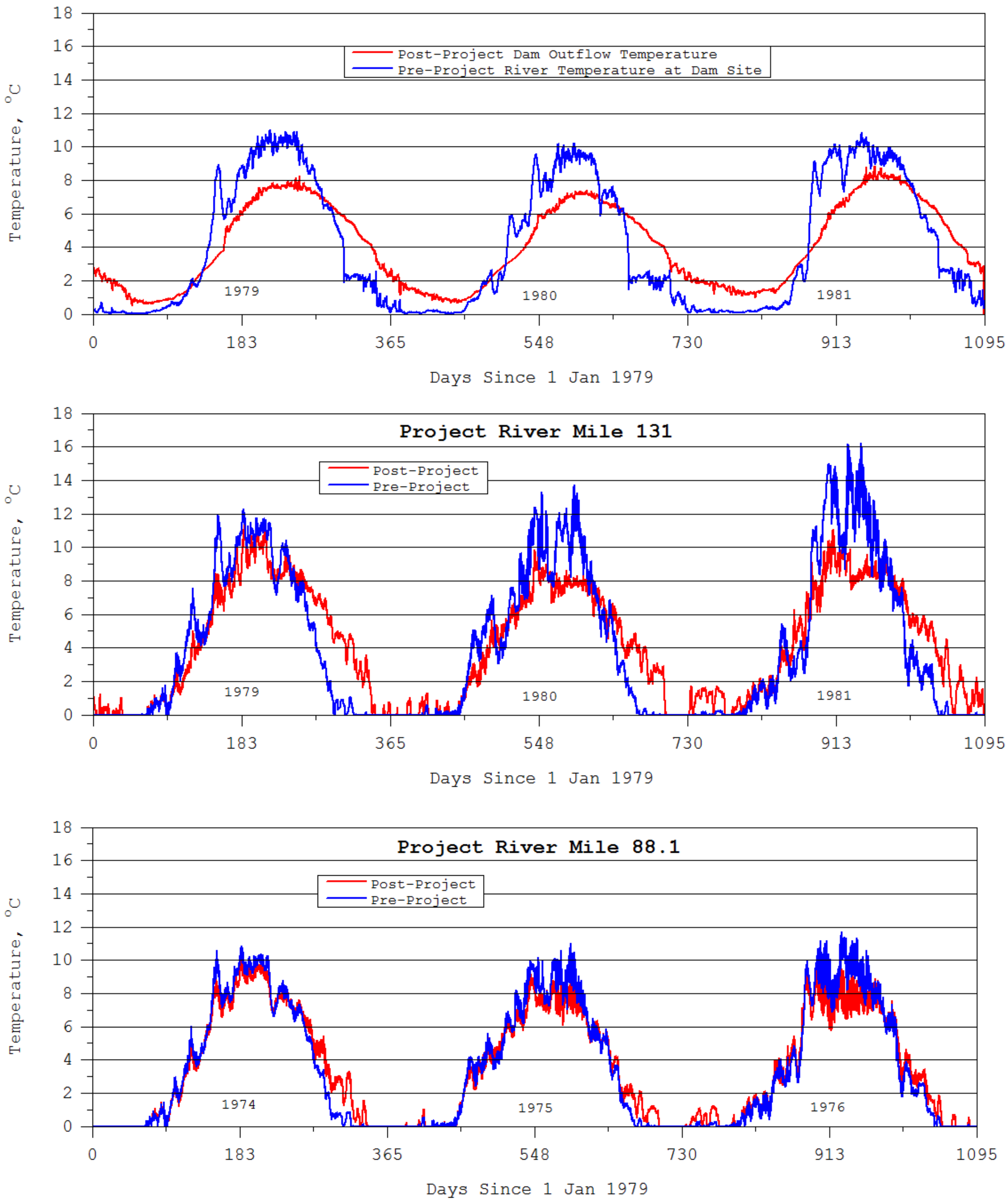
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-3. Proof of Concept 1974–1976 Simulation Boundary Conditions River Model Temperature Results.



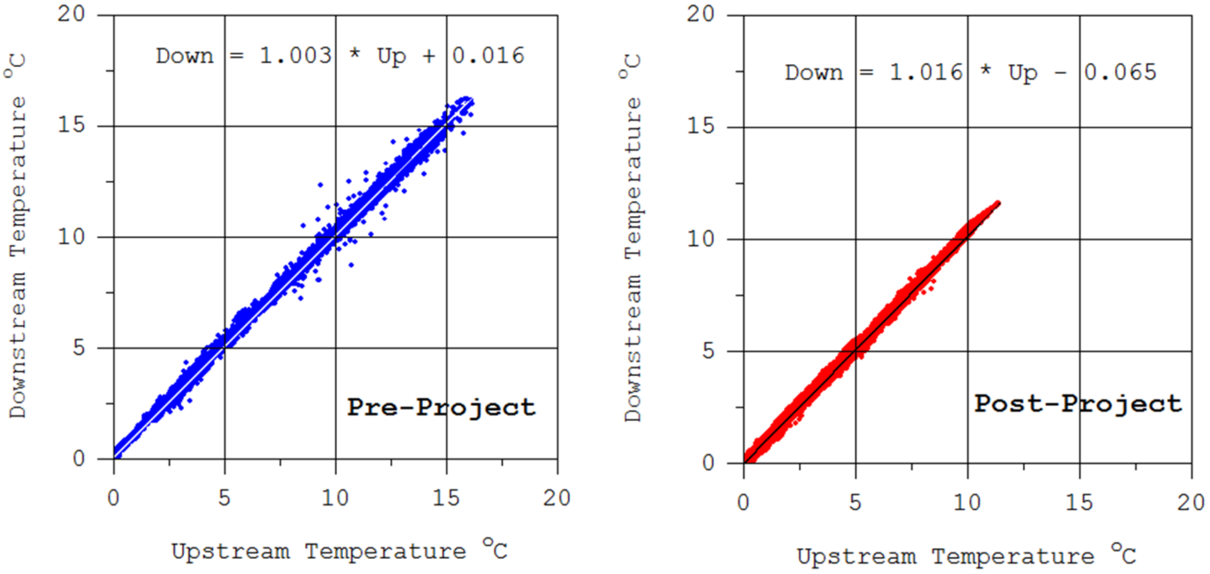
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-4. Proof of Concept 1974–1976 Comparison of Pre- and Post-Project Temperature at FA-128 (Slough 8A) (RM131/RM127.8).



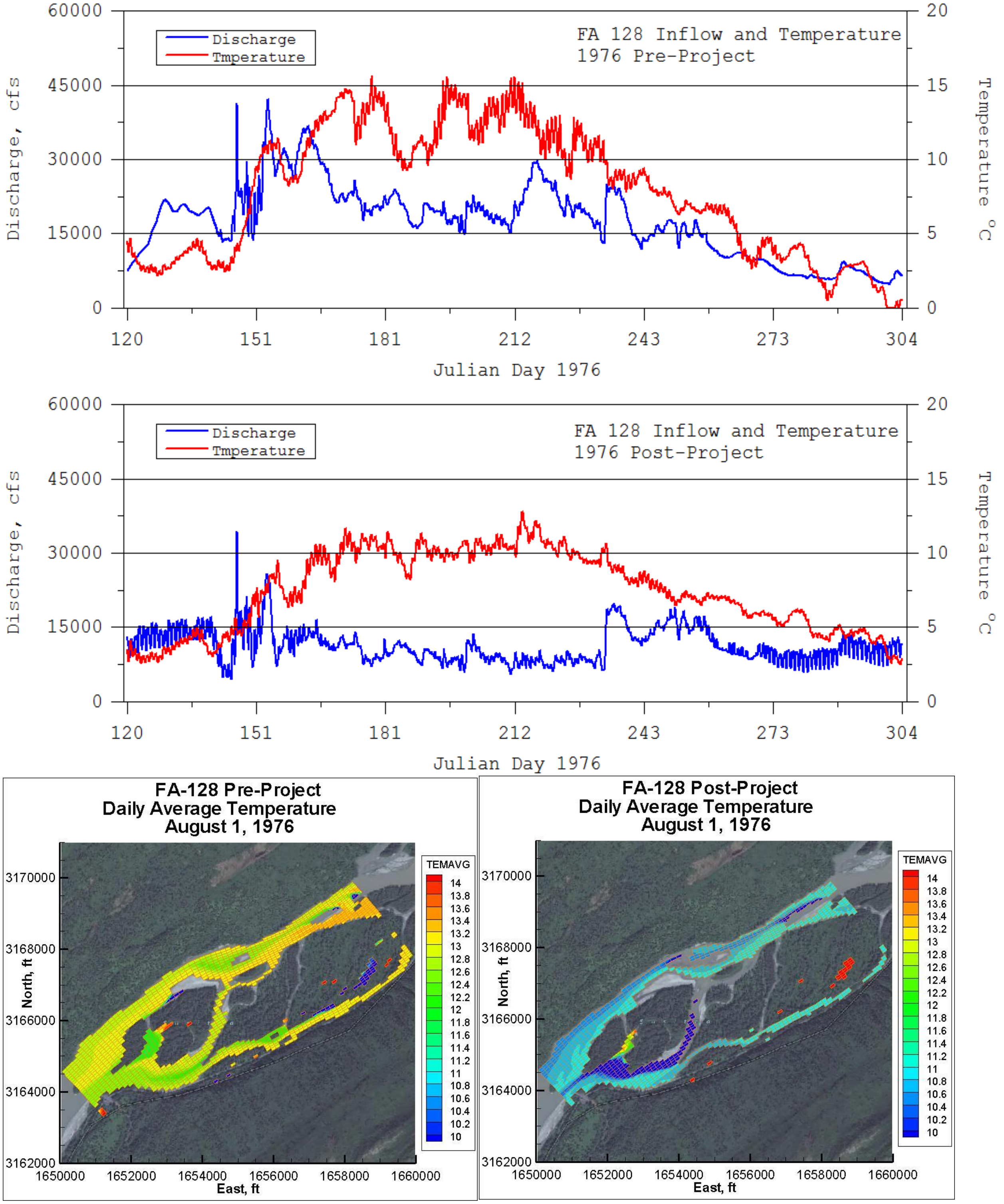
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-5. Proof of Concept 1976–1981 Simulation Boundary Conditions River Model Temperature Results.



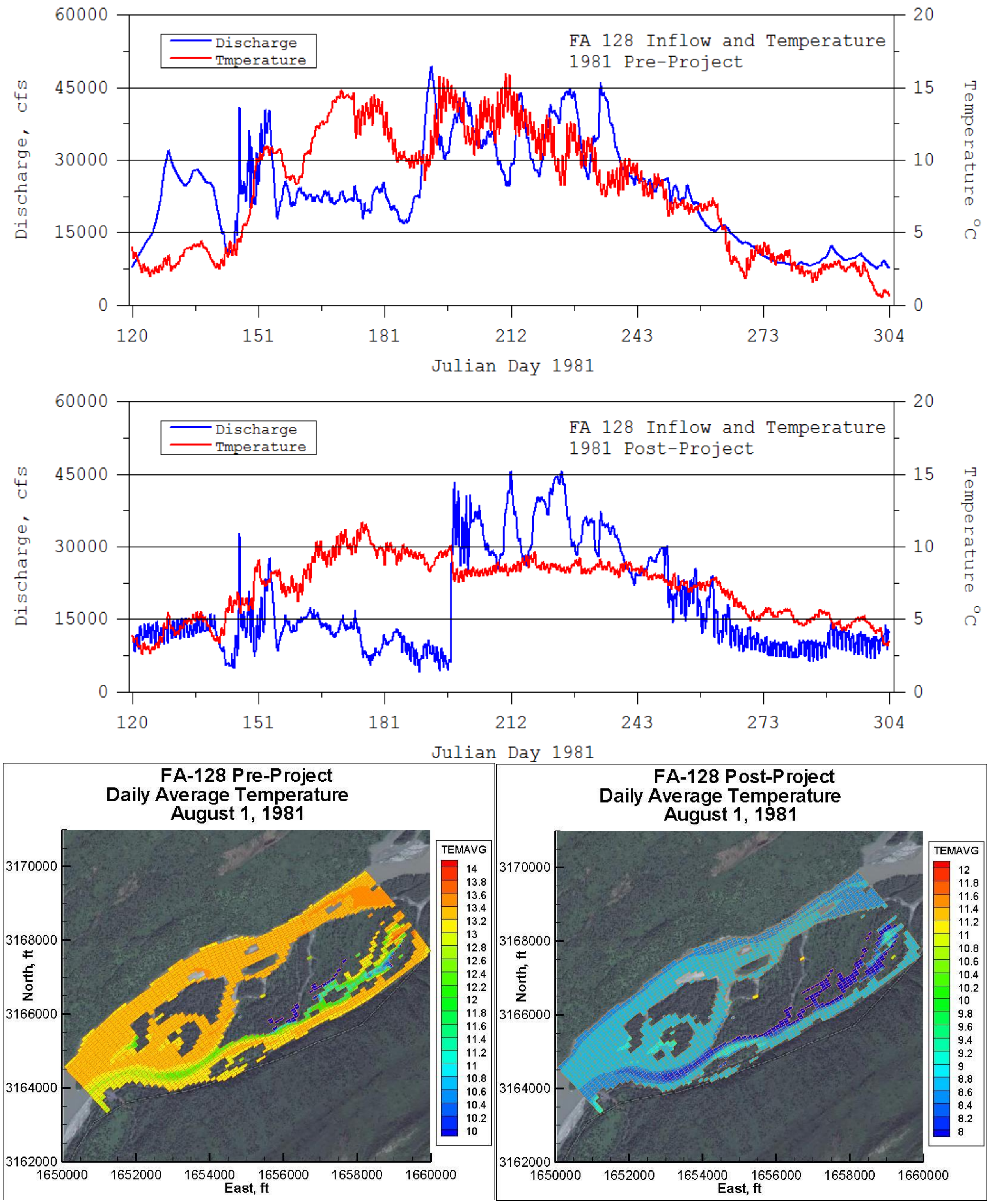
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-6. Proof of Concept 1979–1981 Comparison of Pre- and Post-Project Temperature at FA-128 (Slough 8A) (RM131/RM127.8).



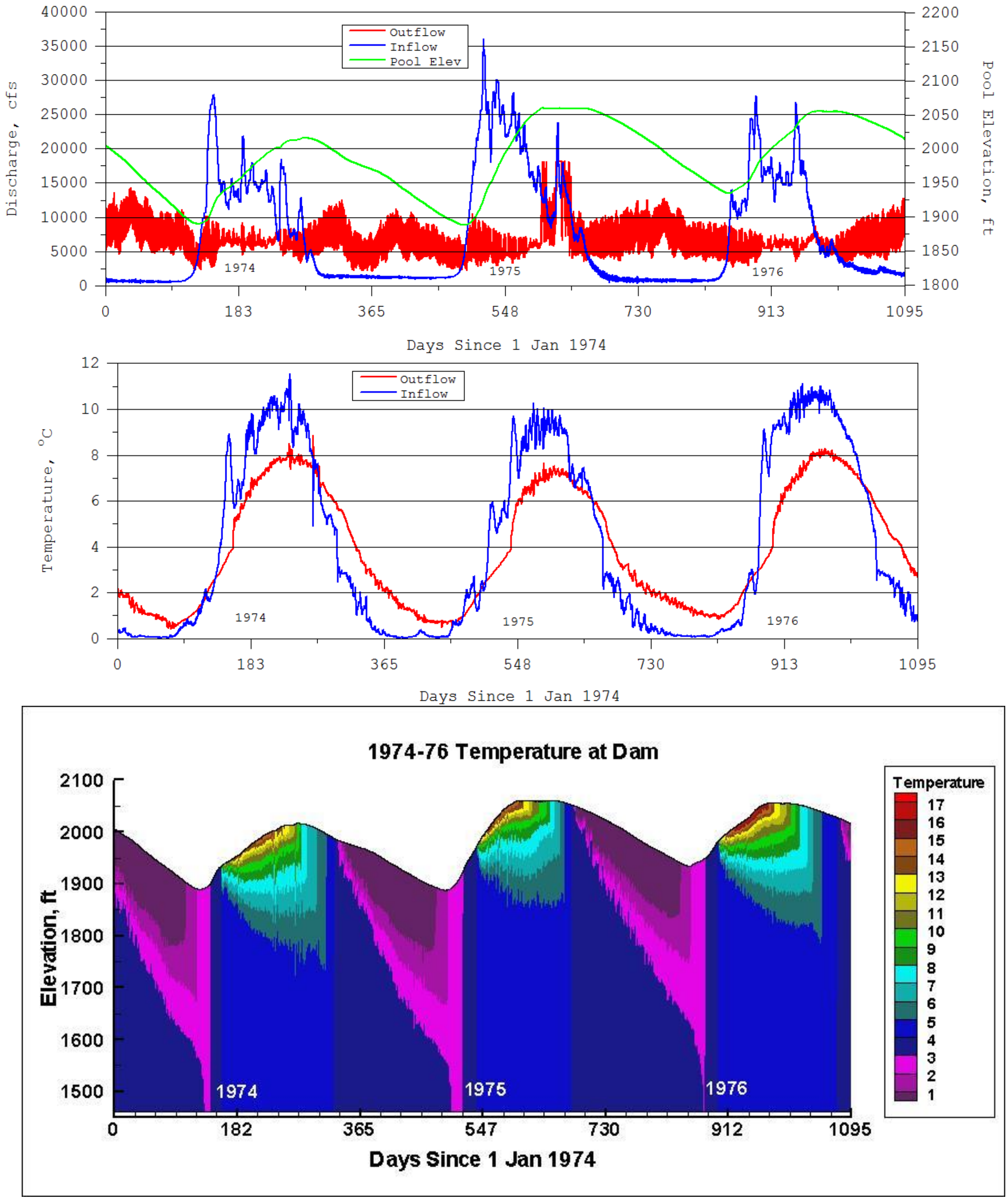
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-7. Proof of Concept May–October 1976 Comparison of Pre- and Post-Project Discharge and Temperature at FA-128 (Slough 8A).



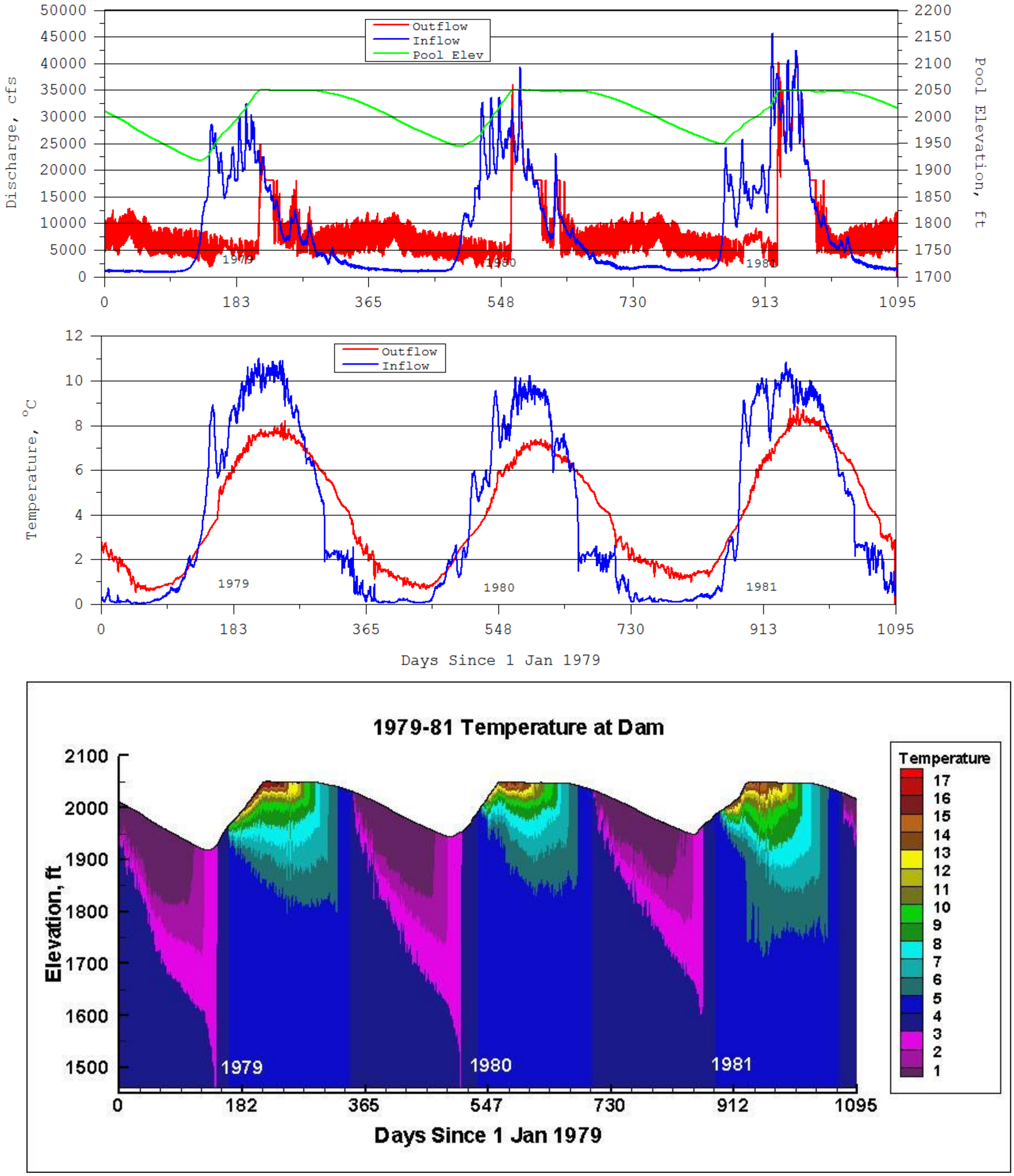
Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-8. Proof of Concept May–October 1981 Comparison of Pre- and Post-Project Discharge and Temperature at FA-128 (Slough 8A).



Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-9. Proof of Concept 1974–1976 Simulation Boundary Conditions Reservoir Model Discharge and Temperature Results at Dam Site.



Note: Proof of Concept model runs assumed reservoir water withdraw from the entire intake elevation range, which is not representative of planned operation of the dam.

Figure A-10. Proof of Concept 1979–1981 Simulation Boundary Conditions Reservoir Model Discharge and Temperature Results at Dam Site.

Attachment 1: Relationship between Turbidity and Total Suspended Solids: A Correlation Model Plots

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Water Quality Modeling Study
Study Plan Section 5.6

2014 Study Implementation Report

Attachment 1
Relationship between Turbidity and Total Suspended Solids: A Correlation Model

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech, Inc.

November 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
EFDC	Environmental Fluid Dynamics Code
FERC	Federal Energy Regulatory Commission
ILP	Integrated Licensing Process
mg/L	Milligrams per Liter
NTU	Nephelometric Turbidity Unit
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project
RSP	Revised Study Plan
SPD	Study Plan Determination
SSC	SSC Suspended Sediment Concentration
TSS	Total Suspended Solids

1. INTRODUCTION

The Alaska Energy Authority (AEA) is preparing a License Application that will be submitted to the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project (Project) using the Integrated Licensing Process (ILP). The Project is located on the Susitna River, an approximately 300-mile-long river in Southcentral Alaska. The Project's dam site would be located at Project River Mile (PRM) 187.1.

On December 14, 2012, AEA filed its Revised Study Plan (RSP) with the FERC for the Susitna-Watana Hydroelectric Project (FERC Project No. 14241), which included 58 individual study plans (AEA 2012). Included with the RSP are the Baseline Water Quality Study (RSP Study 5.5) and the Water Quality Modeling Study (RSP Study 5.6). The collective goal of the water quality studies is to assess the effects of the proposed Project and its operations on water quality in the Susitna River basin, which will inform development of any appropriate conditions for inclusion in the Project license. Study 5.5 focuses on data collection and documenting physical water quality along the Susitna River. Predicting the potential impacts of the dam and its proposed operations on water quality requires the development of a water quality model. The goal of Study 5.6 is to utilize the extensive information collected from the Baseline Water Quality Study to develop a model(s) to evaluate the potential impacts of the proposed Project and operations on various physical parameters within the Susitna River watershed.

On April 1, 2013 FERC issued its study determination (April 1 SPD) for the Revised Study Plan (RSP) Section 5.6 with modifications.

This technical memorandum describes the development of the relationships between total suspended solids (TSS) concentrations and turbidity in the Susitna River that will be applied to TSS model results to estimate turbidity.

2. STUDY OBJECTIVES

The objective of this technical memorandum is to describe the development of a relationship(s) that estimates turbidity from total suspended solids (TSS) concentrations. This relationship will be used to convert TSS results from the EFDC (Tetra Tech 2007a, b and c) model to turbidity as part of the Water Quality Modeling Study (Study 5.6).

3. STUDY AREA

As established by RSP Section 5.5.3, the study area for water quality monitoring includes the Susitna River from PRM 29.9 to PRM 235.2 (Oshetna River), and selected tributaries within the proposed transmission lines and access corridors. The study area is shown in Figure 3-1.

4. METHODS

4.1. Background Information

Total suspended solids (TSS) are particles in the water column larger than 2 µm (smaller particles are considered dissolved). TSS therefore, refers to that portion of the total sediment load of rivers that is carried in suspension in the water column. This portion can include a wide variety of particles – such as, sand, silt, clay, and algae – that settle at varying rates depending on the water velocity as well as the size and weight of the particles. Turbidity is an optical measurement of the quantity of light absorbed or scattered by particles in a sample of water, and is measured in nephelometric turbidity units (NTUs, Duchrow and Everhart 1971; McCluney 1975). Turbidity and TSS are typically generated by the re-suspension of bottom sediments and the erosion and transport of inorganic particles from the surrounding watershed to rivers and streams (Wetzel 2001). However, in the Susitna River turbidity is also due in large part to the presence of glacial rock flour (Peratrovich et al. 1982). Even small quantities of suspended sediment can substantially affect turbidity in water (Duchrow and Everhart 1971). Because of the numerous factors that affect turbidity there is no universal relationship between TSS and turbidity (Davies-Colley and Smith 2001). As a result, river-specific relationships have to be developed (e.g., Lloyd et al. 1987).

4.2. Existing Models of Turbidity and TSS Relationships

Although turbidity and TSS are strongly related, and turbidity is often used to indicate changes in TSS concentration in water, the two parameters are not typically related by a 1:1 ratio. This may be due to variation in sediment types (Duchrow and Everhart 1971) and size fractions, and the fact that turbidity does not include settled solids, and, conversely, TSS does not include colored dissolved organic matter (Davies-Colley and Smith 2001; Chen et al. 2006; Wood 2014).

Lloyd et al. (1987) described relationships between suspended sediment concentration (total non-filterable residue) and resulting turbidity from Alaskan streams. The authors developed three relationships to determine if turbidity criteria could provide reasonable approximations of water quality criteria based on suspended sediment concentrations. Using data from 34 Alaskan rivers (including the Susitna River) that was compiled by the U.S. Geological Survey during the period 1976-1983 (May-October), they found a significant correlation between suspended sediment concentration (SSC) and turbidity ($r^2 = 0.83$) as shown by Equation (1). The data were log/log transformed. A similar relationship was developed specifically for the Susitna River (Peratrovich et al. 1982) as shown by Equation (2). Another example of a river-specific relationship was developed by Barrett et al. (1992), as shown by Equation (3) ($r^2 = 0.94$; $P<0.001$) using experimental sample data. This third relationship was used in a study investigating reactive distance and pursuit speed of fish during foraging.

$$T = 0.44(SSC)^{0.858} \qquad (1)$$

$$T = 0.185(SSC)^{0.998} \qquad (2)$$

$$SSC = 3.399(T) - 5.603 \qquad (3)$$

Where, T = turbidity (NTU) and SSC = suspended sediment concentration (mg/L)

4.3. Method for Relationship Development

Geologic formations with distinct ages and structures have a major effect on water quality conditions along all three of the defined river segments. The morphologic characteristics of the Upper Susitna River (above PRM 187.1) are dominated by the products of Quaternary-age glaciation. The Middle Susitna River segment (from PRM 187.1 to PRM 102.4) is heavily influenced by bedrock outcrops as well as Quaternary-age glaciations. The Lower Susitna River segment (below PRM 102.4) is dominated by sediment loading from the major tributaries (Chulitna and Talkeetna Rivers) and variable resistance to erosion of the Pleistocene-age, glacially-derived materials including tills (moraines), glacio-fluvial sediments in various elevation outwash-surfaces and glacio-lacustrine sediments that control the width of the valley. Therefore, this analysis considers the three Susitna River segments separately.

Another consideration for developing the relationships is whether to segregate the data by open-water flow periods versus winter conditions. There is a significant difference in both TSS and turbidity between winter and summer because the supply of glacially-derived sediments is drastically reduced during the winter. Because the relationships will be used to evaluate potential Project effects, it was decided that ice-covered and open-water data would be combined. This is because the reservoir would retain, mix, and release water year-round and the release flows would include upstream flow from each flow period.

The procedure for developing the relationships is a simple correlation of the paired TSS and turbidity samples collected in the three Susitna River segments. As illustrated by Equations 1, 2, and 3, linear and power relationships will be considered.

5. RESULTS

As part of the Baseline Water Quality Study (Study 5.5), turbidity (NTU) and total suspended solids (TSS) concentrations were measured monthly at 17 sampling locations within the study area in 2013 and 2014, resulting in 281 observations of each parameter. Using these data, significant relationships were determined with data from the Upper (n=57), Middle (n=119) and Lower (n=105) River segments. This section details the correlation models relating turbidity (NTU) and total suspended solids (mg/L), as measured in water samples collected throughout the Susitna Basin during field sampling in 2013 and during winter 2014.

The range in turbidity and TSS values in the main Susitna River in 2013 and 2014 was large. Observed turbidity levels ranged from 1.5-4 NTU (in the very clear waters of the Deshka River) to more than 1,000 NTU in the mainstem (Figure 5-1a), and the observed range in TSS concentrations was similar and also exceeded 1,000 mg/L (Figure 5-1b).

The Susitna data for summer 2013 and winter 2014 were separated among the Lower River (data collected between PRM 29.1 to 101.8), Middle River (data collected between PRM 103.9 to 187.1) and the Upper River segments (data collected above PRM 187.1). All data for both summer and winter periods are included because the winter data provide the lower end of the TSS/Turbidity range and the open water flows provide the high end and because the relationships will be used for with-Project conditions that will consist of water sourced throughout the year.

The linear relationships between TSS and turbidity were stronger ($r^2 > 0.9$) in the Middle and Upper River segments than in the Lower River ($r^2<0.8$) (Figure 5-2a, b, c). The estimate of turbidity NTUs from TSS was nearly 1:1 for all three Susitna River segments. For Upper and Middle River data (Figures 5-2c and 5-2b) the relationships tend to be slightly, though consistently higher than the observed turbidity when the observations are less than 200 NTU. This trend was even more exaggerated in the Lower River (Figure 5-2a).

The strength of the relationship between TSS and turbidity for all three river sections increased if data were log transformed (Figure 5-3a, b, c). With the log transformation, the coefficients of determination (r^2) were about 0.97 for Upper and Middle River data and 0.95 for the Lower River data. These figures illustrate that turbidity and TSS approach zero together and that there is an approximate 1:1 relationship between TSS and turbidity in the three segments with coefficients ranging from 0.62 to 1.04 and exponents ranging from 0.97 to 1.07. The relationship for the Lower Susitna River (Figure 5-3a) segment still shows general under-prediction of turbidity in the 100 to 200 NTU range but this is not readily evident for the other segments.

Previous models (Equations 1 and 2) that were developed with data from Alaskan rivers (Equation 1 data from several Alaska rivers; Equation 2 data from the Susitna River basin) appear to substantially underestimate turbidities predicted from observed TSS values when compared to the present models for the 3 river segments (Figure 5-3a, b, c).

Relationships were also developed for data only in the 0 to 200 NTU range because of the tendency of the relationships to over-predict in that range, especially for the Lower River. The linear equations of Lower and Middle river data with 0 – 200 NTU had relatively high r^2s of 0.88 and 0.95, respectively (Figure 5-4a and 5-4b). A couple of outlying data points produced a weaker fit for the Upper River model, which had an r^2 of 0.67 (Figure 5-4c). Log-log transformations improved the relationship between turbidity and TSS for turbidities between 0 and 200 NTU for both the Upper and Lower river data, but not for the Middle River data (Figures 5-5a, 5-5b, 5-5c).

6. DISCUSSION

The correlations developed from the 2013 and 2014 data collected by the Baseline Water Quality Study (5.5) between TSS and turbidity are quite strong and will allow accurate predictions of turbidity over a large range of suspended solid concentrations. Separate regression models were constructed for turbidity versus TSS for each of the river segments: Lower River, Middle River, and Upper River. The Lower River linear regression model showed greater variation in the TSS-turbidity relationship in the mid-range (400 – 1,000) of the set of observations (Figure 5-2a). This was in contrast to the Middle River and Upper River models (Figure 5-2b and Figure 5-2c, respectively) both of which had higher r^2 values (amount of variation explained by the regression model).

For all segments, observed variability in turbidity levels increased above TSS concentrations of 100 mg/L, with the greatest variability between predicted and observed turbidity values occurring in the Lower River. This is expected based on there being three distinct sources (Middle Susitna, Chulitna, and Talkeetna Rivers) of suspended sediment in the Lower River.

There is actually very little difference in the resulting equations. As illustrated in Figure 6-1, the six power relationships (the three river segments using the complete data sets and the three river segments using only <200 NTU data), only the Lower River equation for lower NTUs differs. The selection of the final equation or equations will consider combining data from the Middle and Upper Susitna River segments and whether a greater emphasis should be placed on the lower turbidity data because this will likely be the range most frequently encountered under with-Project conditions and because this range is likely to be important for habitat analysis. Therefore, final selection will be made in coordination with the Study 8.5 (Fish and Aquatics Instream Flow Study).

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8. FIGURES

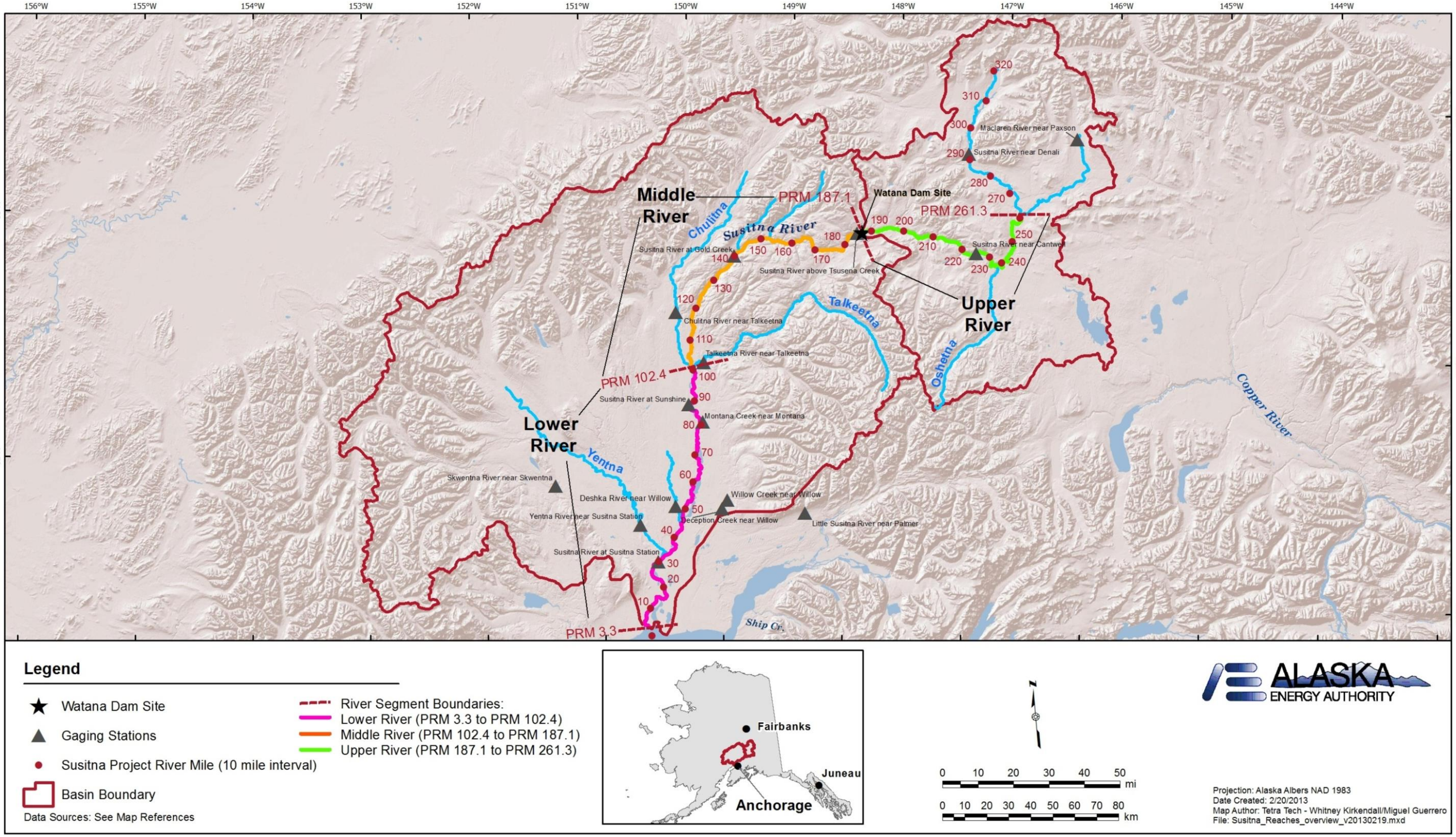

Figure 3-1. Susitna River Study Area and Large-scale River Segments.

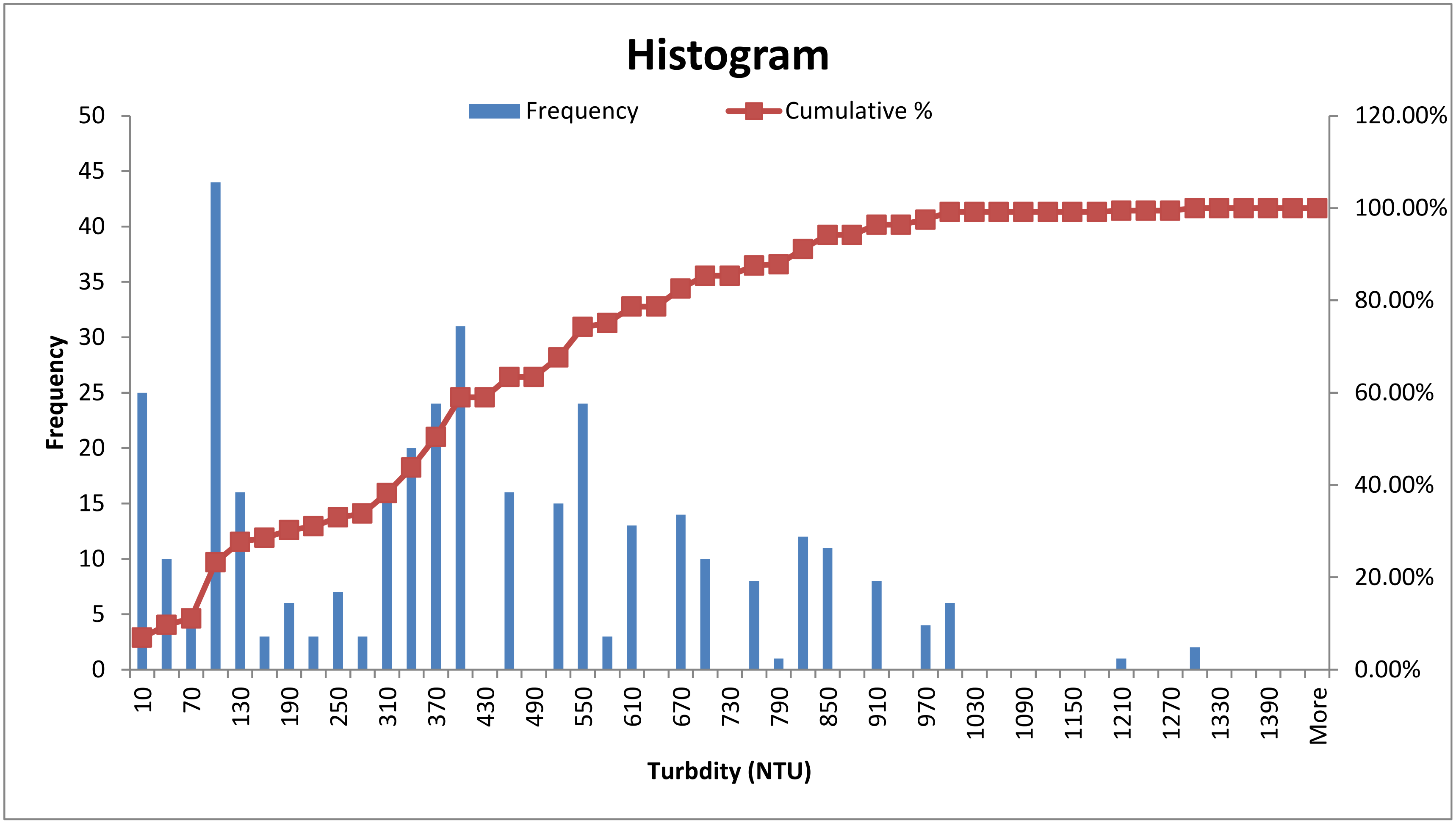

Figure 5-1a. Distribution of turbidity at cross-sectional sampling sites throughout the Susitna River.

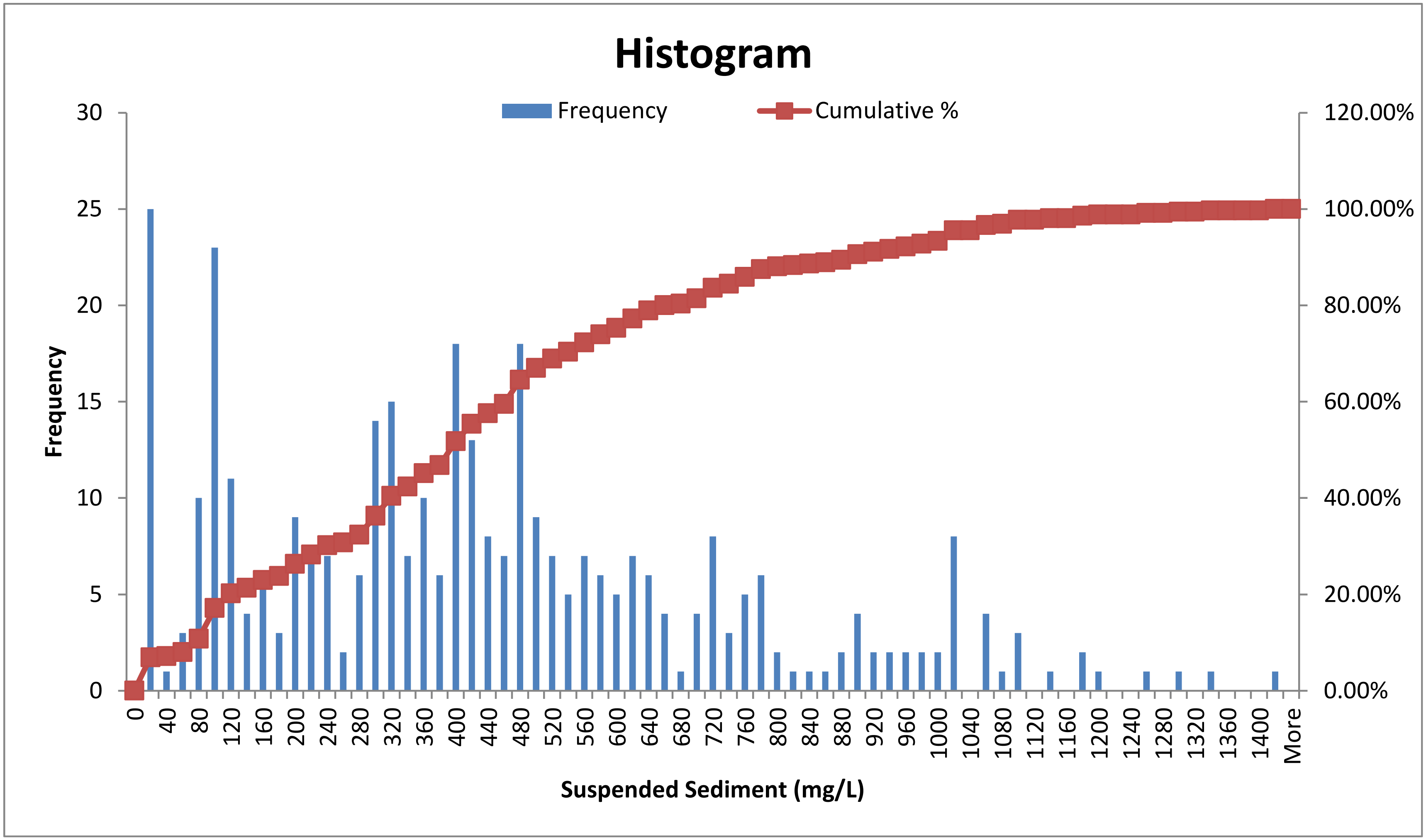

Figure 5-1b. Distribution of TSS at cross-sectional sites throughout the Susitna River.

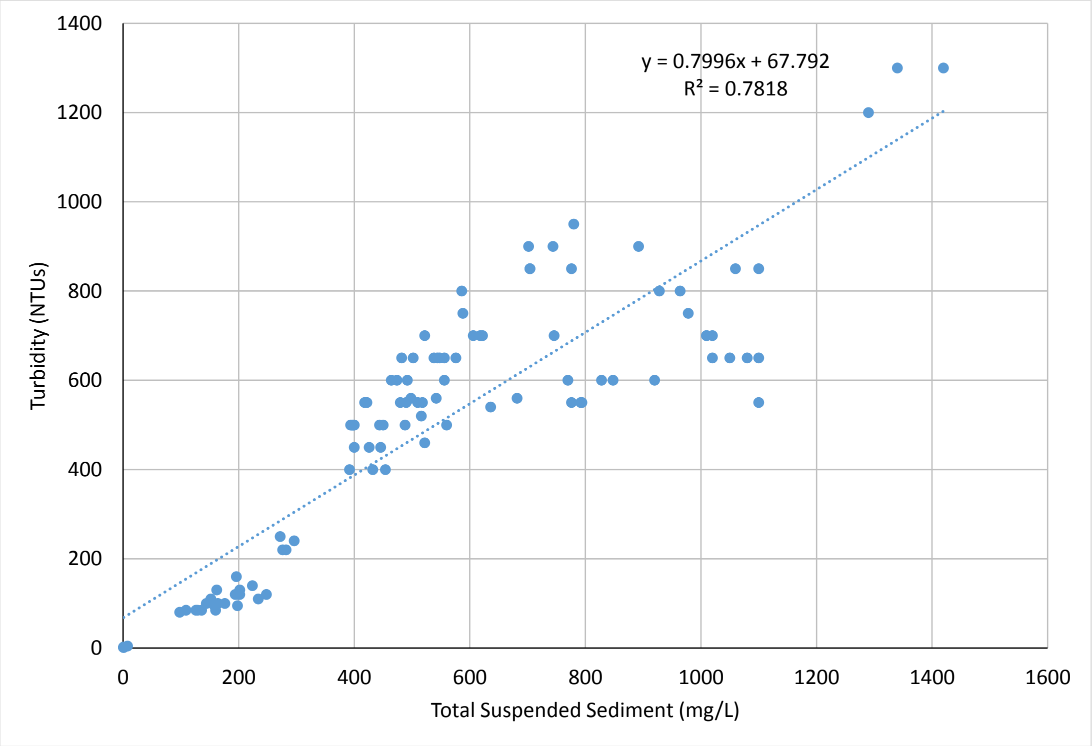

Figure 5-2a. Relationship between TSS and Turbidity (NTUs) in the Lower Susitna River, Summer 2013 – Winter 2014 (using full turbidity range).

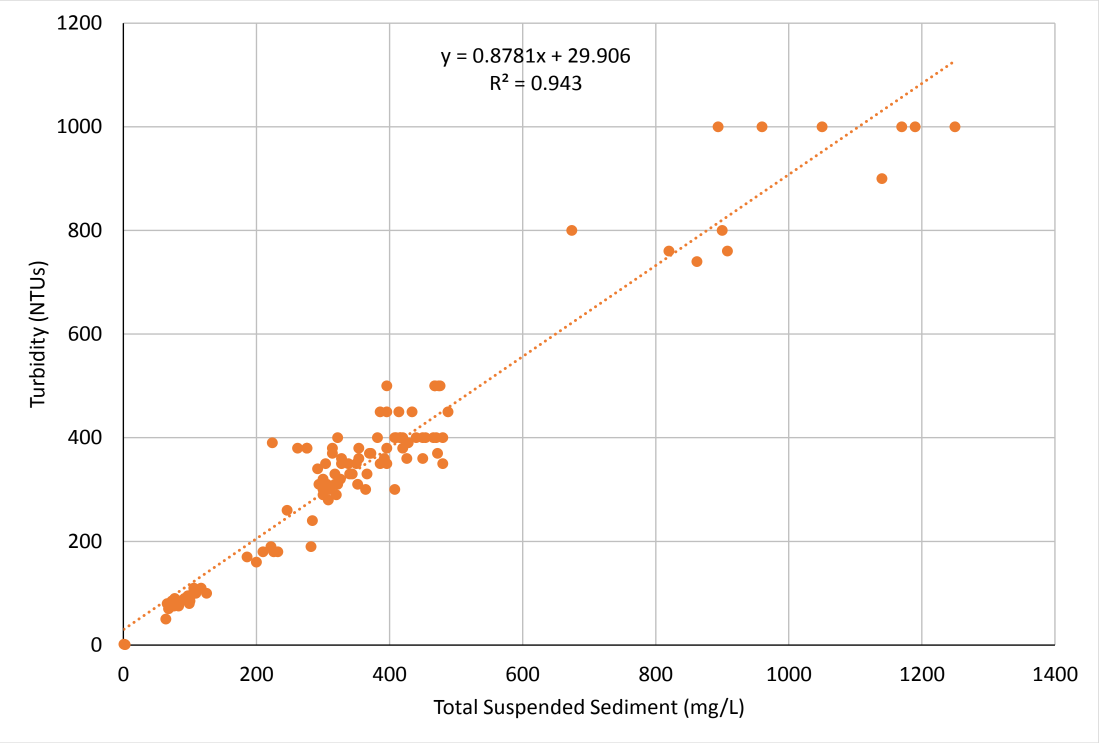

Figure 5-2b. Relationship between TSS and Turbidity (NTUs) in the Middle Susitna River, Summer 2013 – Winter 2014 (using full turbidity range).

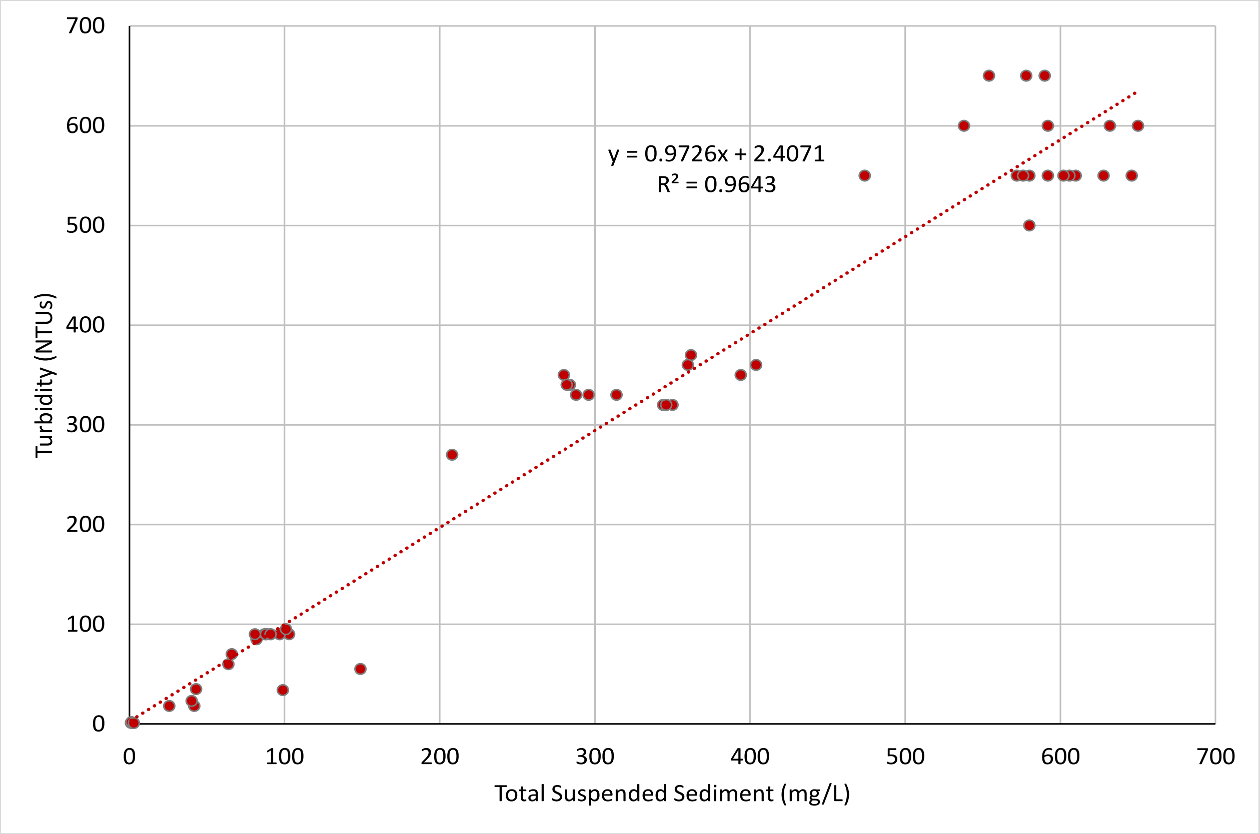

Figure 5-2c. Relationship between TSS and Turbidity (NTUs) in the Upper Susitna River, Summer 2013 – Winter 2014 (using full turbidity range)

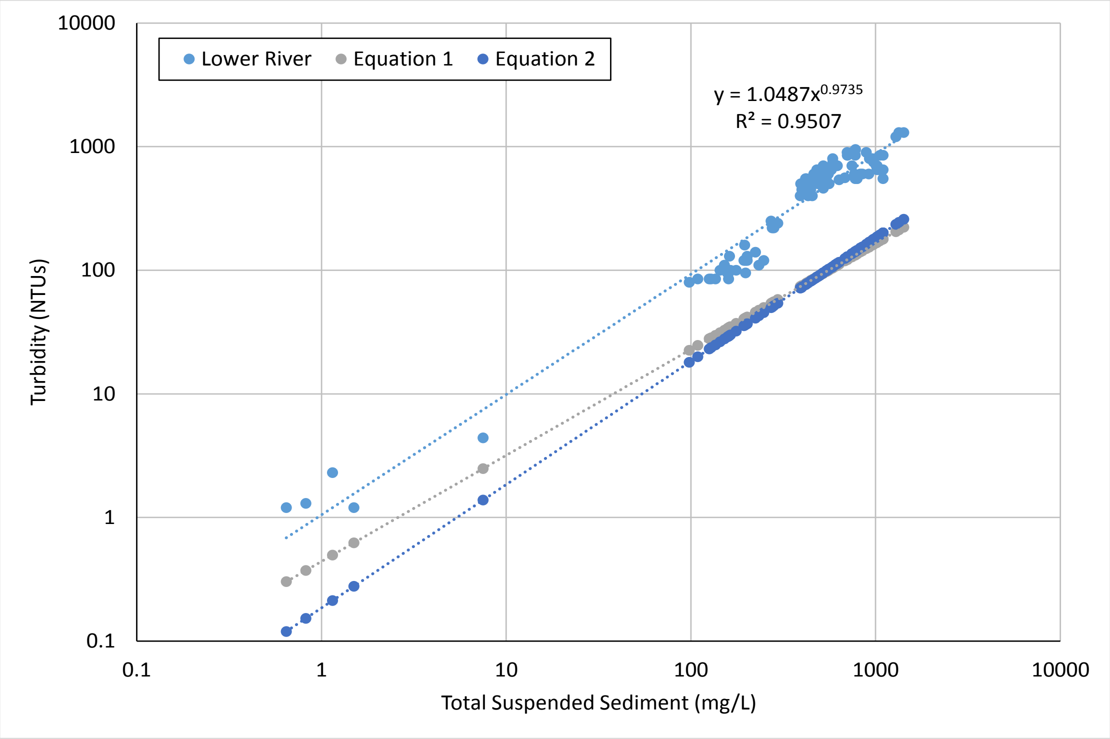

Figure 5-3a. Relationship between TSS and Turbidity (NTUs) in the Lower Susitna River, on a log-log scale, compared to turbidity predicted from Equation 1 and Equation 2 (Section 4.2).

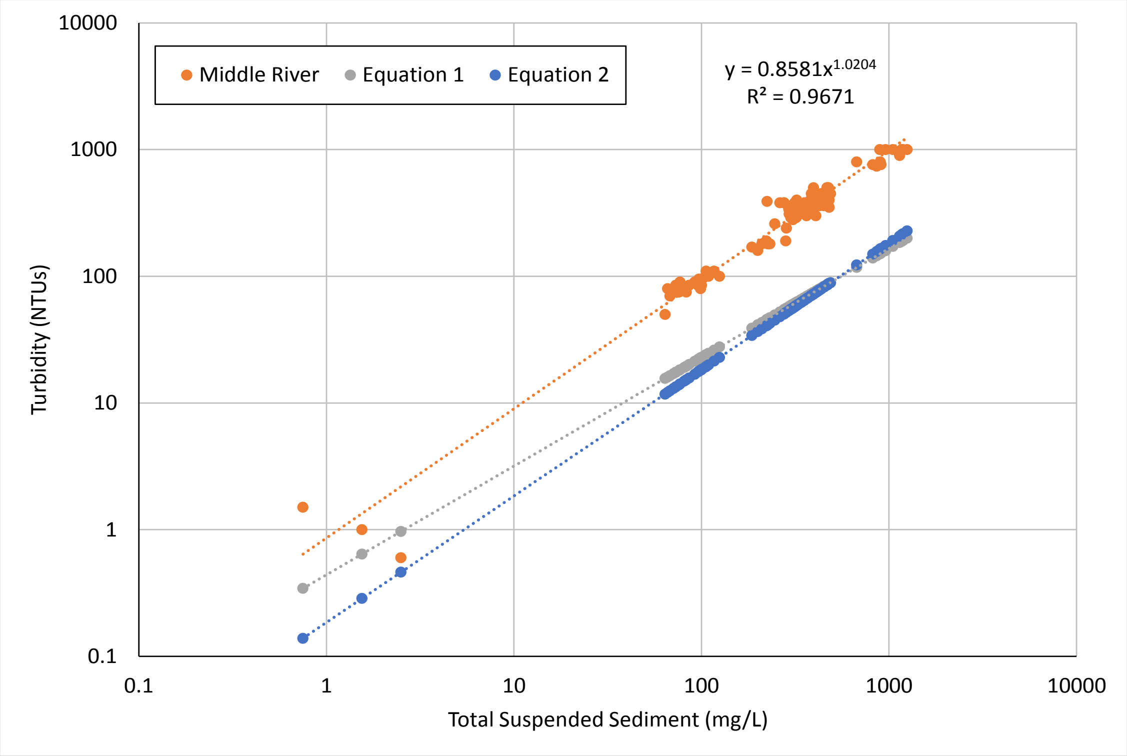

Figure 5-3b. Relationship between TSS and Turbidity (NTUs) in the Middle Susitna River, on a log-log scale, compared to turbidity predicted from Equation 1 and Equation 2 (Section 4.2).

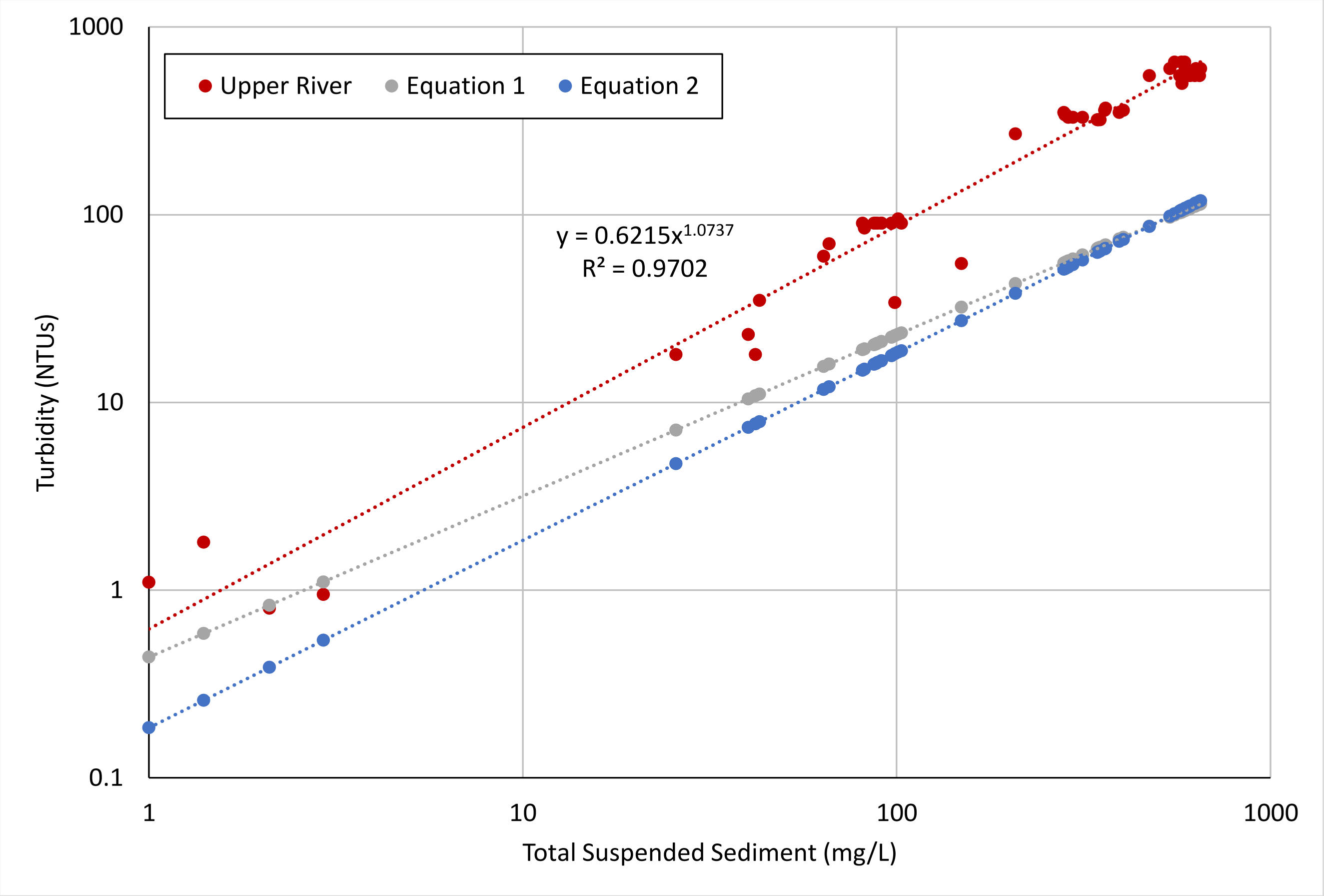

Figure 5-3c. Relationship between TSS and Turbidity (NTUs) in the Upper Susitna River, on a log-log scale, compared to turbidity predicted from Equation 1 and Equation 2 (Section 4.2).

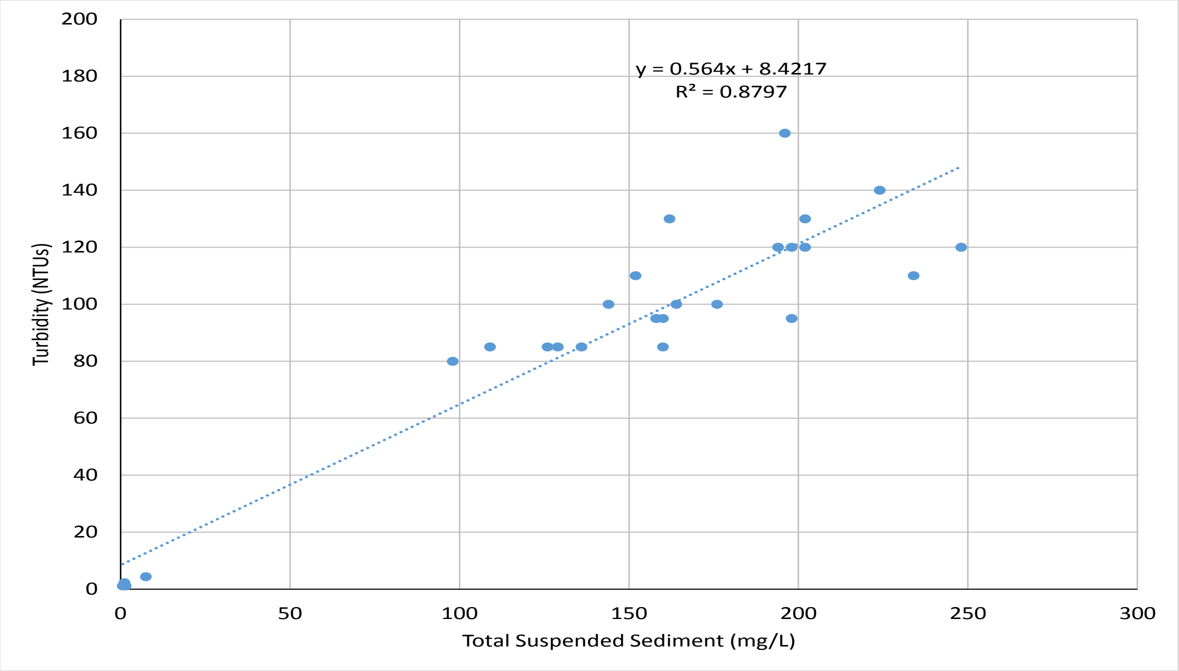

Figure 5-4a. Relationship between TSS and Turbidity (NTUs) in the Lower Susitna River, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

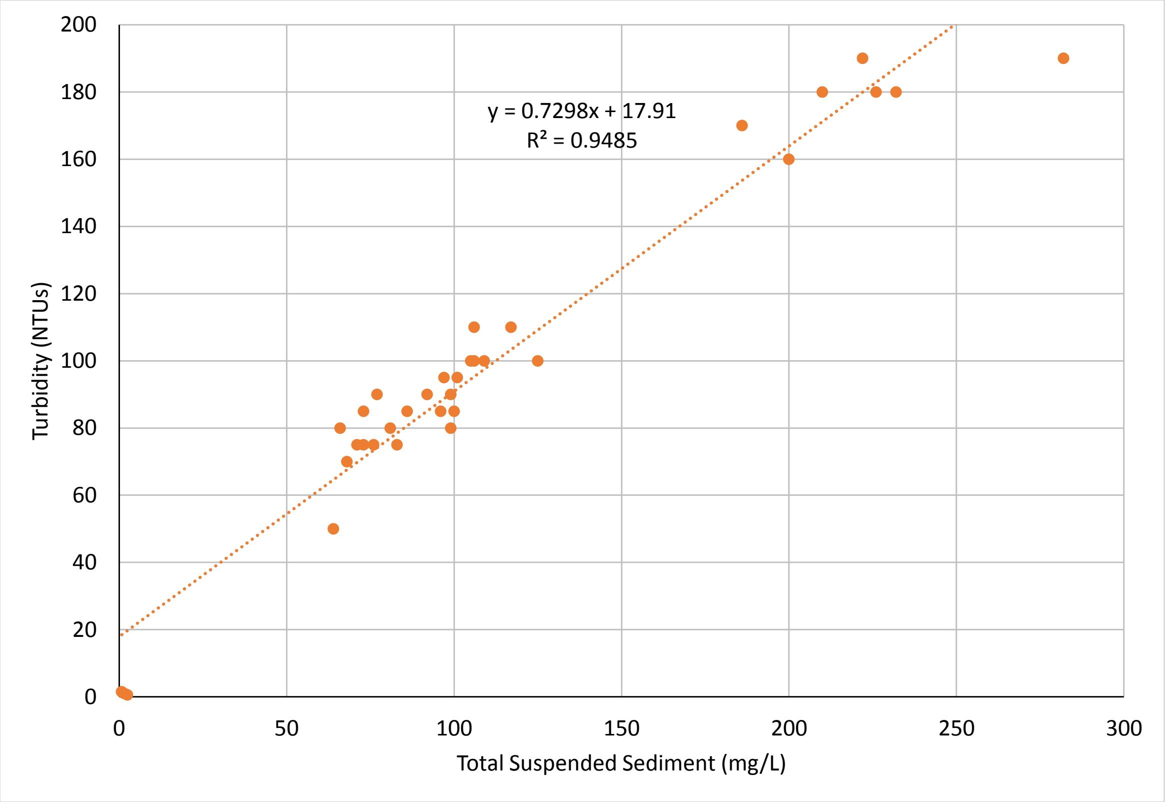

Figure 5-4b. Relationship between TSS and Turbidity (NTUs) in the Middle Susitna River, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

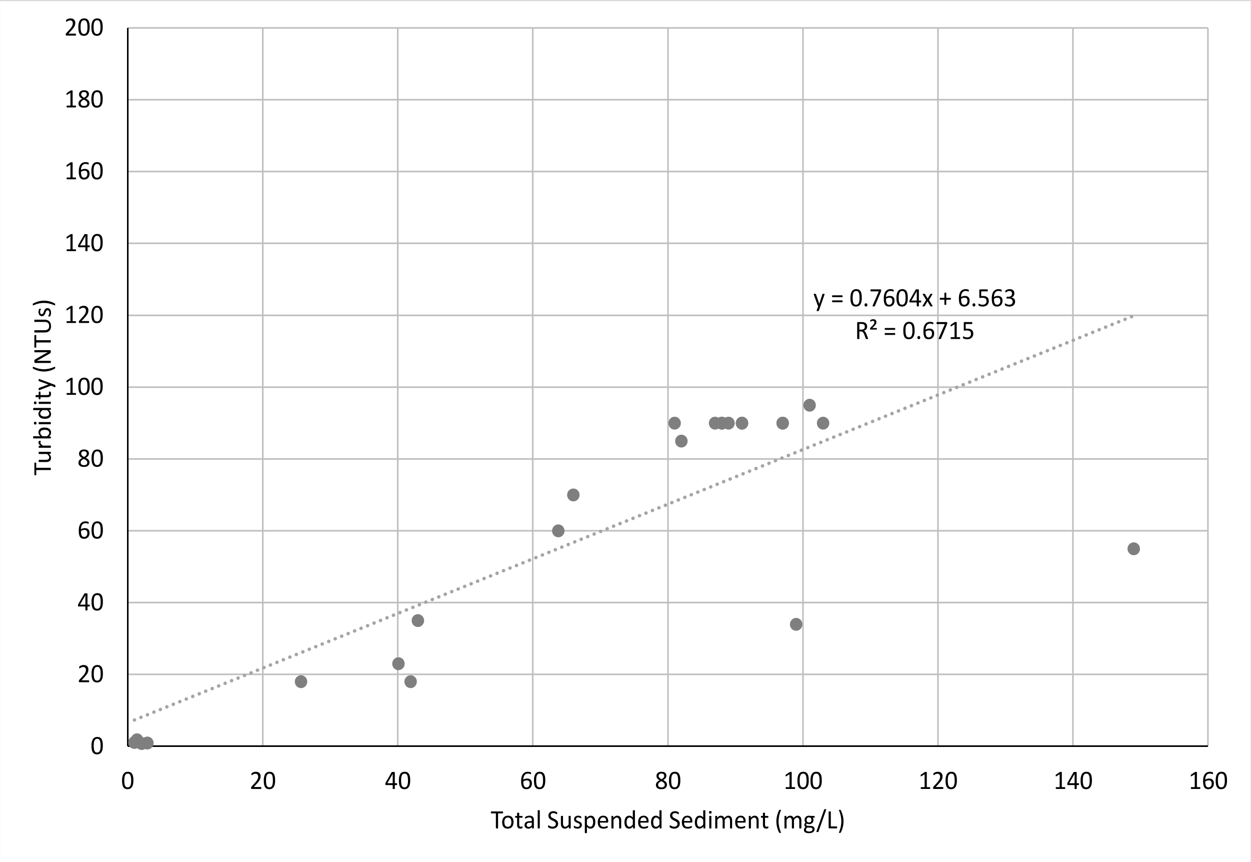

Figure 5-4c. Relationship between TSS and Turbidity (NTUs) in the Upper Susitna River, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

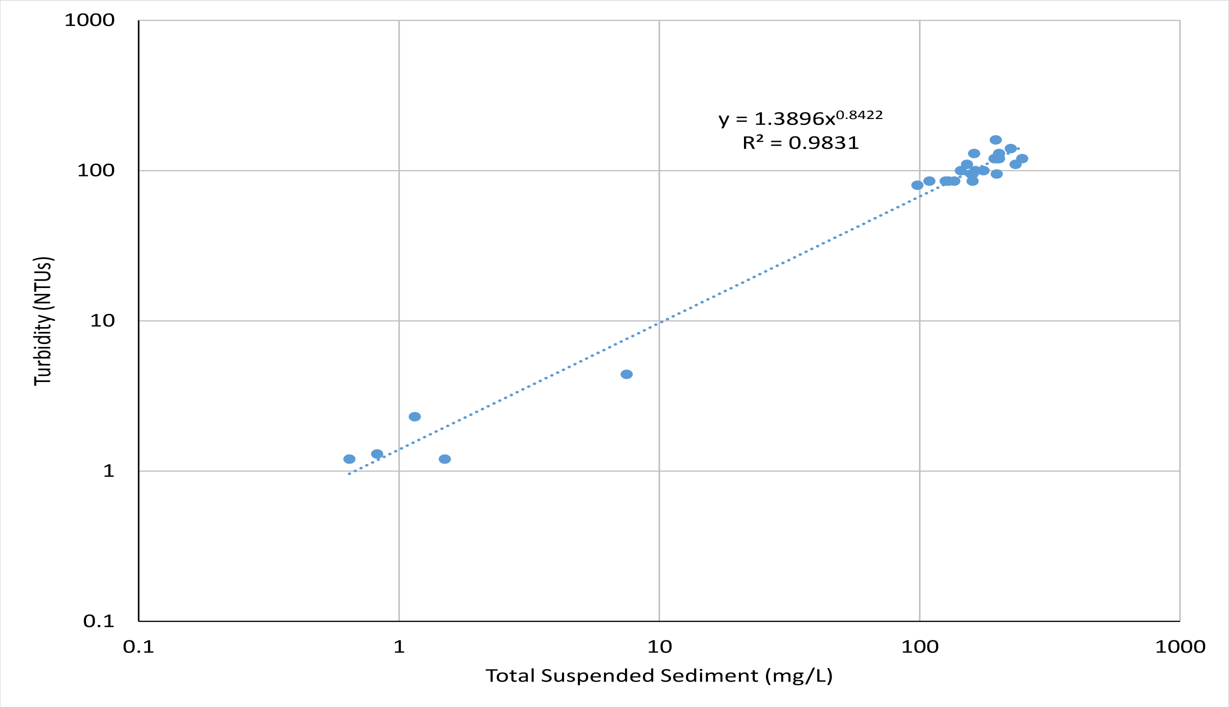

Figure 5-5a. Relationship between TSS and Turbidity (NTUs) in the Lower Susitna River, on a log-log scale, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

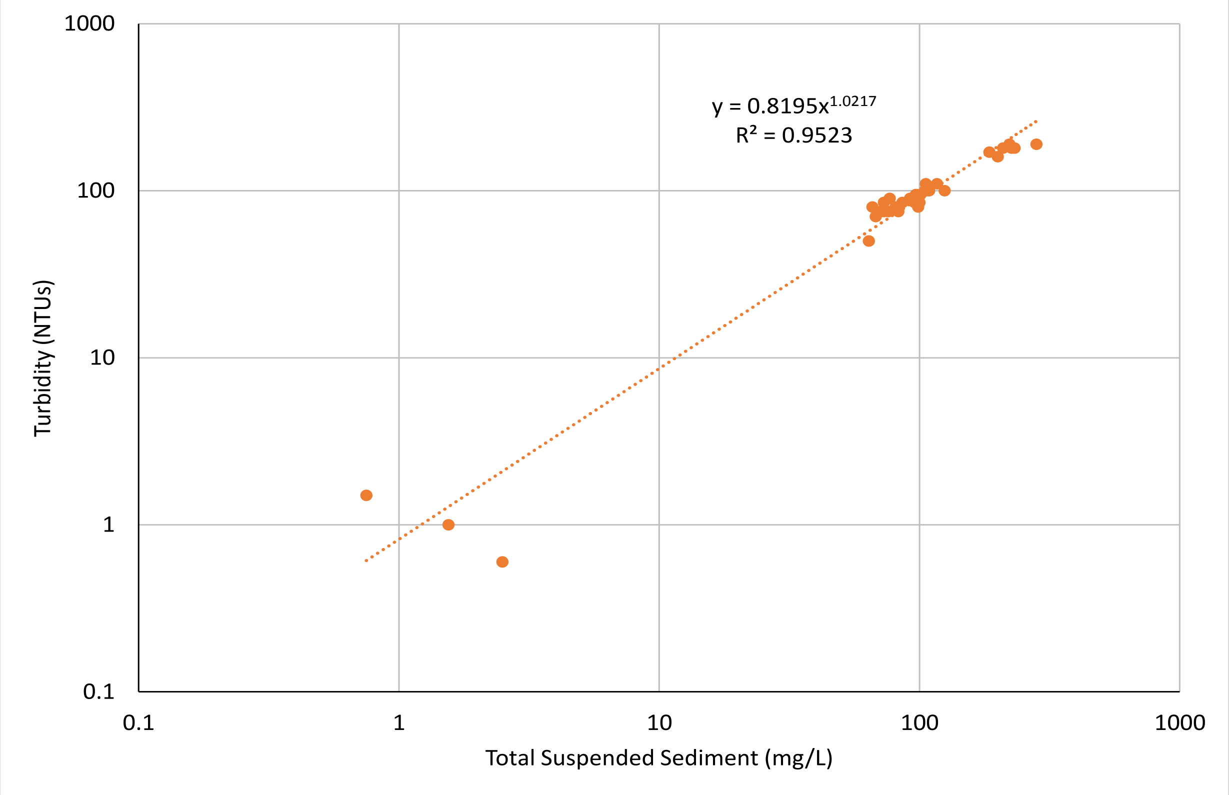

Figure 5-5b. Relationship between TSS and Turbidity (NTUs) in the Middle Susitna River, on a log-log scale, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

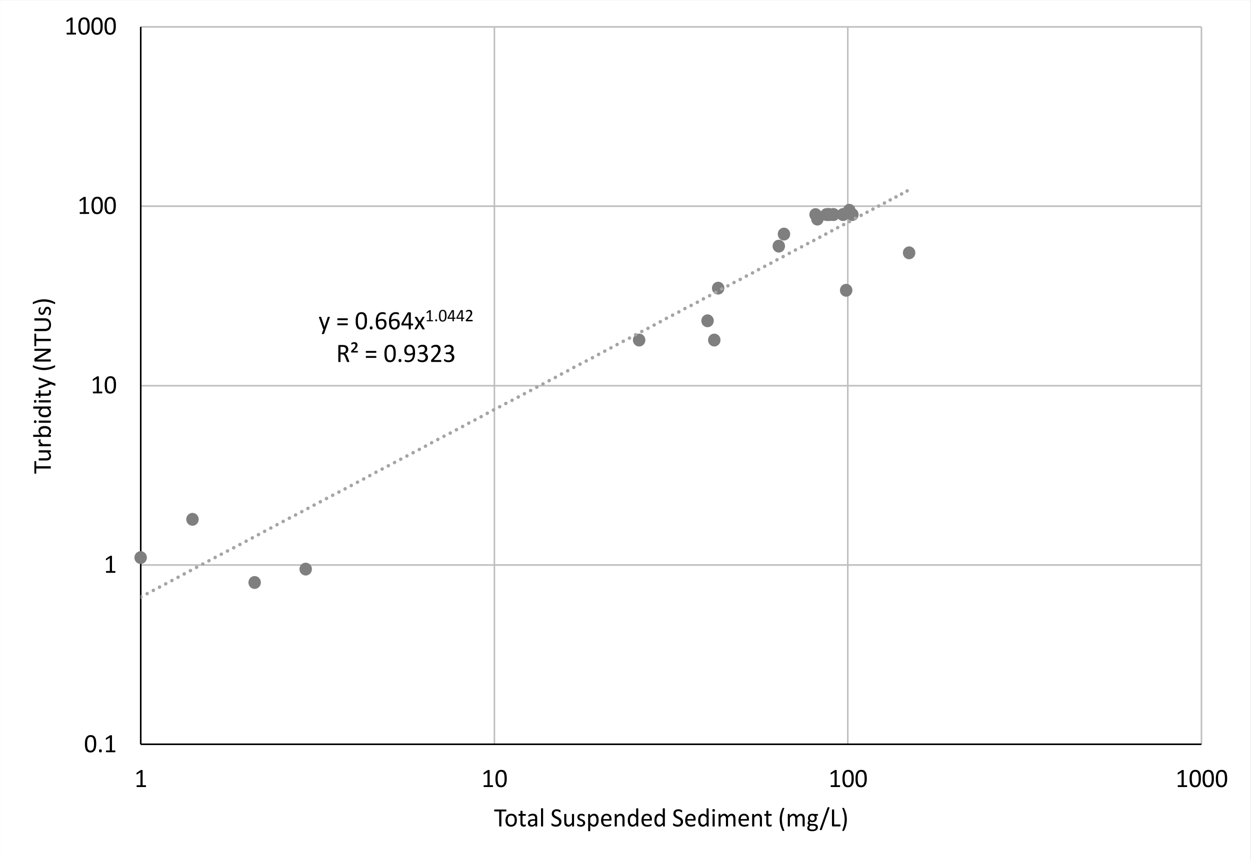

Figure 5-5c. Relationship between TSS and Turbidity (NTUs) in the Upper Susitna River, on a log-log scale, Summer 2013 – Winter 2014 (using turbidity between 0 and 200 NTUs).

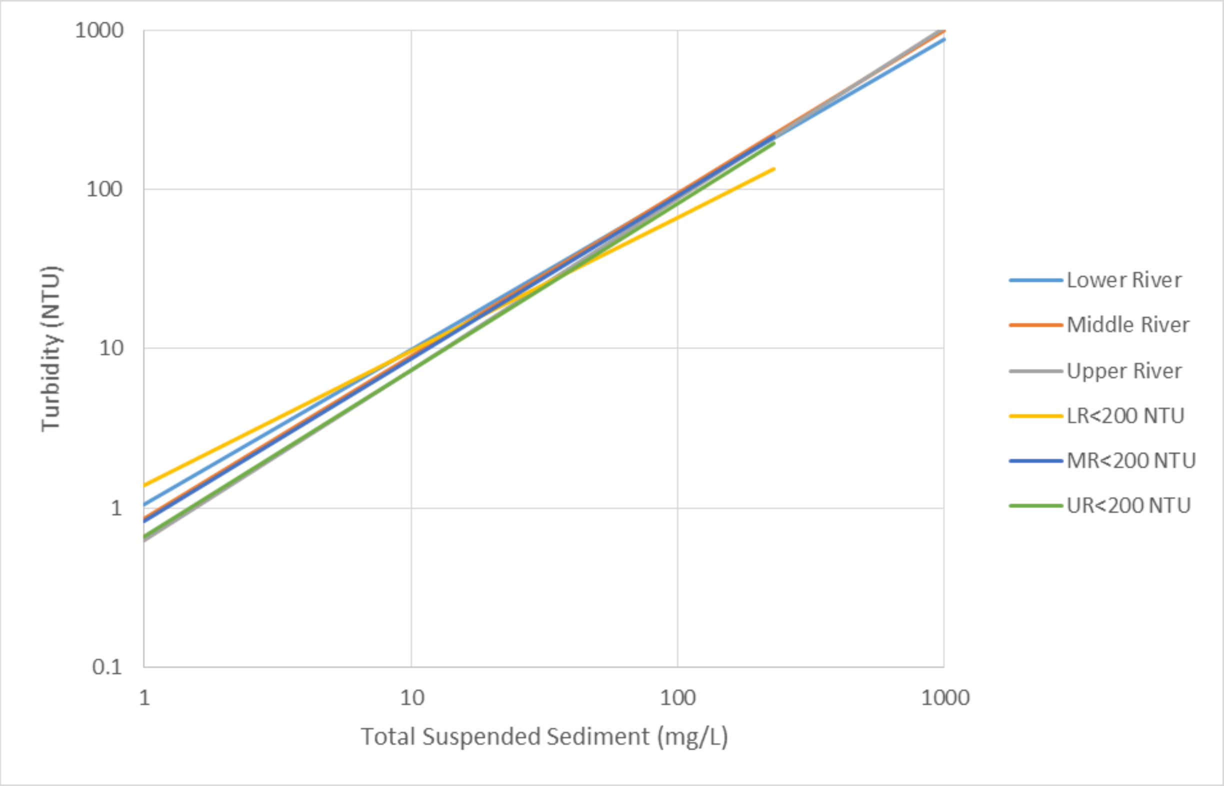

Figure 6-1. Power relationships (log-log) developed for the three Susitna River Segments.