Susitna-Watana Hydroelectric Project
(FERC No. 14241)

2012 Susitna River Water Temperature and Meteorological Field Study

Appendix B

Prepared for

Alaska Energy Authority

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APPENDIX B: WATER QUALITY MODELING STUDY: MODEL SELECTION

SUSITNA-WATANA
HYDROELECTRIC PROJECT

Water Quality Modeling Study:
Model Selection

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1.0 BACKGROUND

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). The application will use the Integrated Licensing Process (ILP). The proposed Project is located in the Southcentral region of Alaska, approximately 120 miles (mi) north-northeast of Anchorage and 110 mi south-southwest of Fairbanks. As proposed, the Project would include construction of a dam, reservoir and power plant on the Susitna River starting at river mile (RM) 184, approximately 32 mi upstream of Devils Canyon.

As currently envisioned and described in the Revised Study Plan (RSP, AEA 2012 at Section 1.3), the Project would include a large dam with a 23,546-acre reservoir at El 2050 ft mean sea level (msl). The dam has a nominal crest elevation (El.) 2,075 ft (msl) corresponding with a maximum height of about 750 ft above the prepared rock foundation. The Watana Reservoir normal top water level (TWL) is proposed as El. 2,050 ft msl, which will impound a reservoir approximately 42.5 mi long (measured along the centerline of the reservoir at El. 2050) with an average width of approximately 1 to 2 mi. The total water surface area at normal maximum operating level is approximately 23,546 acres. The reservoir will have a total capacity of 5.2 million ac-ft, of which 3.4 million ac-ft will be active storage. The installed capacity of the power plant would be approximately 600 MW.

Construction and operation of the Susitna-Watana Project (Project) will change the Susitna River reach inundated by the Project reservoir, as well as portions of the drainage down-gradient. Changes will include flow, water depth, surface water elevation, water chemistry, channel characteristics, and sediment deposition. The potential effects of the Project need to be carefully evaluated as part of the licensing process because changes to these parameters may adversely affect aquatic and riparian habitat quality, which can in turn affect fish populations, riparian dependent species, and recreation opportunities along the river corridor. This can be done by collecting information from the area and using modeling to project the impacts of the Dam on various physical parameters.

There are a large number of different water quality models available for use. Selection of the appropriate model is based on a variety of factors, including applicability of the model, necessary data inputs, model availability, time, stakeholder familiarity, cost, level of expertise required, ease of use, and available documentation.

This memo provides an overview of select non-proprietary hydrodynamic, temperature, and water quality models that could be used to simulate the effects of a dam and reservoir on the Susitna River. The applicability of each model will be evaluated and key considerations will be identified. The desired model will be able to predictively represent vertical mixing in reservoirs and predict future conditions. The model should internally couple water quality with the hydrodynamic and temperature modeling processes in both the reservoir and downstream to allow develop a holistic framework to address the major concerns in the river.

Under the current study, a multi-dimensional model capable of representing reservoir flow circulation, temperature stratification, and dam operations among other parameters is necessary. The proposed reservoir model must account for water quality conditions in the proposed Watana Reservoir, including temperature, dissolved oxygen (DO), suspended sediment and turbidity, chlorophyll a, nutrients, metals, and potentially ice formation and breakup. The proposed river model must be able to account for water quality conditions in the Susitna River downstream of the proposed dam. The river model must also simulate current Susitna River conditions (in the absence of the dam) for comparison to conditions in the presence of the dam and reservoir.

A coupled reservoir and downstream river model is required to facilitate data transfer and associated inconsistency in prototype representations across multiple models and to increase the efficiency of the model. The models must also be dynamic to account for within and between day changes in the reservoir or river as a result of Project operations.

The following section discuss the previous modeling done at the site, as well as other models that might be utilized and better suited to the needs of the project.

2.0 PREVIOUS MODELING APPROACH

In the 1980s, hydrologic and temperature modeling was conducted in the Susitna Basin to predict the effects of one or more dams on downstream temperatures and flows. The modeling suite used was called H2OBAL/SNTEMP/DYRESM. The modeling suite addressed temperature and had some limited hydrodynamic representation, but it lacked the ability to predict vertical stratification or local effects (e.g., local discharge elevation). In addition, the modeling suite lacked a water quality modeling component.

2.1 H2OBAL, SNTEMP AND DYRESM MODEL REVIEW

The existing H2OBAL/SNTEMP/DYRESM model of the Susitna River basin is perhaps the most obvious candidate model to implement when assessing the effects of the proposed Susitna-Watana Hydroelectric Project. The existing model was expressly configured to represent the unique conditions in the Susitna River basin. However, the modeling suite is limited to flow and temperature predictions and is based on the modeling technology available in the early 1980s. Hydrodynamics are simplified, and water quality is not addressed.

The Arctic Environmental Information and Data Center (AEIDC) previously completed a study that examined the temperature and discharge effects if the proposed Susitna Hydroelectric Project was completed and compared the effects to the natural stream conditions, without a dam and reservoir system (1983a). The study also assessed the downstream point at which post-project flows would be statistically the same as natural flows. The functions of the multiple models used in the assessment were: SNTEMP, a riverine temperature model, H2OBAL, a water balance program and DYRESM, a reservoir hydrodynamic model.

The simulation period covered the years 1968 through 1982. Only the summer period was simulated. Historical meteorological and hydrological were data to represent normal, maximum and minimum stream temperature conditions, represented by the years 1980, 1977, and 1970, respectively (AEIDC 1983a). Post-project conditions were modeled for these summer periods to compare natural conditions to post-project stream temperatures. Due to a lack of data, a monthly time-step was used in these summer condition simulations.

2.2 H2OBAL

Mainstem discharges from the Watana dam site were estimated from statistically based streamflow data and a water balance program – H2OBAL, which computed tributary inflow on a watershed area-weighted basis. Post-project flows were predicted for both a one-dam scenario and a two dam scenario using release discharge estimates from a reservoir operation schedule scenario in the FERC licensing application. Flows derived from H2OBAL were input into SNTEMP.

2.3 SNTEMP

SNTEMP is a riverine temperature simulation model that can predict temperature on a daily basis but can also predict for longer periods, allowing analysis of both critical river reaches at a fine scale and the full river system over a longer averaging period (AEIDC 1983b). SNTEMP was selected because it contained a regression model that could fill in data gaps in temperature records. This was useful in the Susitna River because data records were sparse. SNTEMP can also be calibrated to adjust for low-confidence input parameters. SNTEMP outputs include average daily water temperatures and daily maximum and minimum temperatures.

SNTEMP contains several sub-models, including a solar radiation model that predicts solar radiation based on stream latitude, time of year, topography, and meteorological conditions (AEIDC 1983b). SNTEMP was modified to include the extreme shading conditions that occur by developing a monthly topographic shading parameter. Modifications were made to represent the winter air temperature inversions that occur in the basin. Sub-models were also included for heat flux, heat transport, and flow mixing.

SNTEMP validation indicated that upper tributary temperatures were under predicted (AEIDC 1983b). Most of the data for the tributaries was assumed or estimated, leading to uncertainty. Five key poorly defined variables were identified as possible contributors to the under-prediction of temperatures: stream flow, initial stream temperature, stream length, stream width and distributed flow temperatures. Distributed flow temperatures were highlighted as the most important of the five variables. During calibration, groundwater temperature parameters were adjusted to modify distributed flow and improve tributary temperature prediction.

Water temperatures were derived from USGS gages, but when data was lacking, SNTEMP computed equilibrium temperatures and then estimated initial temperatures from a regression model. AEIDC noted that the reliability of the regression models “restricts the accuracy of the physical process temperature simulations” (1983a). The level of confidence in the regression model varied by the amount of gage data available. Continuous data yielded higher confidence, while years with only grab sample data notably decreased the confidence in the predicted temperatures.

2.4 DYRESM

The DYRESM model is a one-dimensional, hydrodynamic model designed specifically for medium size reservoirs (Patterson, et al. 1977). The size limitation ensures that the assumptions of the model algorithm remain valid. DYRESM predicts daily temperature and salinity variations with depth and the temperature and salinity of off-take supply. The reservoir is modeled as horizontal layers with variable vertical location, volume, temperature and salinity. Mixing between layers is through amalgamation. Inflow and withdrawal are modeled by changes in the horizontal layer thickness, and insertion or removal of layers as appropriate. The model incorporates up to two submerged off-takes and one overflow outlet. Model output is on a daily time-step.

The DYRESM model was run to simulate the two reservoir scenario for 1981 conditions. Other reservoir release temperature estimates were not available (AEIDC 1983a). The AEIDC report cautions that the results from 1981 may not be representative of other years due to annual variations in meteorology, hydrology, reservoir storage, and power requirements (1983a). The lack of reservoir release temperature data limited the simulation of downstream temperatures under operational conditions to one year.

AEIDC noted that the “effort to delineate river reaches where post-project flows differ significantly from natural flows has been unsuccessful” (1983a). This was attributed in large part to the lack of estimates for the reservoir release temperatures. Additional data was needed to increase the predictive ability of SNTEMP.

Perhaps the biggest limitations of the existing H2OBAL/SNTEMP/DYRESM modeling suite as implemented historically are the lack of suitable data, simplified hydrology and the lack of a water quality component. Modeling was limited to discharge and temperature. Other issues that limit the suitability of the modeling suite for the Susitna River basin project were the chronic under-prediction of upper tributary temperatures, and the inability to predict vertical stratification within the reservoir.

3.0 OTHER MODELING APPROACHES

Three general approaches have been considered for applicability to the Susitna River basin project. The first is implementation of the existing H20BAL/SNTEMP/DYRESM modeling suite that was used to model the Susitna River basin in the early 1980s. The second is implementation of a two-dimensional hydrodynamic and water quality modeling framework (i.e., CE-QUAL-W2). The third is implementation of a three-dimensional hydrodynamic and water quality modeling framework (i.e., Environmental Fluid Dynamics Code [EFDC]). All approaches have their merits and limitations.

3.1 Two-Dimensional Approach (CE-QUAL-W2)

The U.S. Army Corps of Engineers' CE-QUAL-W2 is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole et al 2000). The model allows for application to streams, rivers, lakes, reservoirs, and estuaries with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation.

The two major components of the model include hydrodynamics and water quality kinetics. Both of these components are coupled, i.e. the hydrodynamic output is used to drive the water quality at every time-step. The hydrodynamic portion of the model predicts water surface elevations, velocities, and temperature. The water quality portion can simulate 21 constituents including DO, nutrients, phytoplankton interactions, and pH. A dynamic shading algorithm is incorporated to represent topographic and vegetative cover effects on solar radiation. This model has model has been extensively tested, documented, and applied to environmental studies world-wide by universities, governmental agencies, and environmental consulting firms.

3.2 Three-Dimensional Approach (EFDC)

The EFDC model was originally developed at the Virginia Institute of Marine Science and is considered public domain software (Hamrick 1992). This model is now being supported by US Environmental Protection Agency (EPA). EFDC is a dynamic, three-dimensional, coupled water quality and hydrodynamic model. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. The EFDC model has been extensively tested, documented, and applied to environmental studies world-wide by universities, governmental agencies, and environmental consulting firms.

The structure of the EFDC model includes four major modules: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model. The water quality portion of the model simulates the spatial and temporal distributions of 22 water quality parameters including DO, suspended algae (3 groups), periphyton, various components of carbon, nitrogen, phosphorus and silica cycles, and fecal coliform bacteria. Salinity, water temperature, and total suspended solids are needed for computation of the 22 state variables, and they are provided by the hydrodynamic model. EFDC incorporates solar radiation using the algorithms from the CE-QUAL-W2 model.

3.3 Qualitative Comparison of Models

Table 1 presents an evaluation of the models applicability to a range of important technical, regulatory, and management considerations. Technical criteria refer to the ability to simulate the physical system in question, including physical characteristics/processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. Management criteria comprise the operational or economic constraints imposed by the end-user and include factors such as financial and technical resources. Although the evaluation is qualitative, it is useful in supporting a model determination based on the factors that are most critical to this project, in particular. The relative importance of each consideration, as it pertains to the project, are presented alongside the models' applicability ratings.

Table 1: Evaluation of Models Based on Technical, Regulatory, and Management Criteria

● High Suitability ◐ Medium Suitability ◌ Low Suitability

Considerations	Relative Importance	H2OBAL/SNTEMP/ DYRESM	CE QUAL W2	EFDC
Technical Criteria				
Physical Processes:				
• advection, dispersion	High	◐	●	●
• momentum	High	◌	●	●
• compatible with external ice simulation models	High	◌	●	●
• reservoir operations	High	◐	●	●
• predictive temperature simulation (high latitude shading)	High	◐	●	●
Water Quality:				
• total nutrient concentrations	High	◌	●	●
• dissolved/particulate partitioning	Medium	◌	●	●
• predictive sediment diagenesis	Medium	◌	◌	●
• sediment transport	High	◌	◐	●
• algae	High	◌	●	●
• dissolved oxygen	High	◌	●	●
Temporal Scale and Representation:				
• long term trends and averages	Medium	◐	◐	●
• continuous – ability to predict small time-step variability	High	◌	●	●

● High Suitability ◐ Medium Suitability ◌ Low Suitability				
Considerations	**Relative Importance**	**H2OBAL/SNTEMP/ DYRESM**	**CE QUAL W2**	**EFDC**
Spatial Scale and Representation:				
• multi-dimensional representation	High	◌	◐	●
• grid complexity - allows predictions at numerous locations throughout model domain	High	◌	◐	●
• suitability for local scale analyses, including local discharge evaluation	Medium	◌	◐	●
Regulatory Criteria				
Enables comparison to AK criteria	High	◌	●	●
Flexibility for analysis of scenarios, including climate change	High	◐	●	●
Technically defensible (previous use/validation, thoroughly tested, results in peer-reviewed literature, TMDL studies)	High	◐	●	●
Management Criteria				
Existing model availability	High	●	●	●
Data needs	High	●	●	●
Public domain (non-proprietary)	High	●	●	●
Cost	Medium	●	◐	◐
Time needed for application	Medium	N/A	◐	◐
Stakeholder community familiarity	Low	●	◐	◐
Level of expertise required	Low	●	●	●
User interface	Low	◐	◐	◐
Model documentation	Medium	◐	●	●

Based on the evaluation summarized in the table above, the existing H2OBAL/SNTEMP/DYRESM suite of models is not suitable for conducting the current analysis because it lacks the capability to address the major water quality concerns, and lacks the predictive capability needed to address the response of the reservoir to future conditions. Therefore, the modeling approach should be selected from the two multi-dimensional models and based on key technical considerations.

4.0 TECHNICAL CONSIDERATIONS

The following discussion highlights some of the key technical considerations for modeling associated with the Susitna River basin project and compares the ability of CE-QUAL- W2 and EFDC to address these considerations. For informational purposes, the SYNTEMP/DYRESM modeling suite is also discussed in the technical considerations. Based on a review of the literature and the objectives of the study plan (RSP Section 5.6), the key factors that are important in the modeling effort include:

1. Predicting vertical stratification in the reservoir when the dam is present;
2. Nutrient and algae representation;
3. Sediment transport;
4. Ability to represent metals concentrations;
5. Integration between temperature and ice dynamics models; and
6. Capability of representing local effects.

4.1 Predicting Vertical Stratification

Both EFDC and CE-QUAL-W2 are equipped with turbulence closure schemes which allow prediction of temporally/spatially-variable vertical mixing strength based on time, weather condition, and reservoir operations. Therefore, both are capable of evaluating the impact of dam/reservoir operations/climate change on reservoir stratification. In contrast, the existing SYNTEMP/DYRESM model does not have the necessary predictive capability because vertical stratification is represented based on parameterization through calibration. Therefore, it cannot represent the response of vertical mixing features to the changes in external forces.

4.2 Nutrient and Algae Representation

Both EFDC and CE-QUAL-W2 are capable of simulating dynamic interactions between nutrients and algae in reservoirs and interactions between nutrients and periphyton in riverine sections. This is very important for addressing the potential impact of the proposed project on water quality and ecology in the river. EFDC has additional nutrient predictive capabilities due to its sediment diagenesis (sediment change) module, which simulates interactions between external nutrient loading and bed-water fluxes. EFDC is thus capable of predicting long-term effects of the proposed project. CE-QUAL-W2 does not have the sediment diagenesis predictive capability. The existing SNTEMP/DYRESM modeling suite is not capable of representing nutrient and algae interactions.

4.3 Sediment Transport

EFDC is fully capable of predicting sediment erosion, transport, and settling/deposition processes. CE-QUAL-W2 has limited sediment transport simulation capabilities. It handles water column transport and settling; however, it is not capable of fully predicting sediment bed resuspension and deposition processes. SNTEMP/DYRESM is not capable of simulating sediment transport.

4.4 Ability to Represent Metals Concentrations

EFDC is fully capable of simulating fate and transport of metals in association with sediments in both rivers and reservoirs. CE-QUAL-W2 does not have a module to simulate metals; however, a simplified representation can be implemented using the phosphorus slot in the model and simple partitioning (to couple with its basic sediment transport representation). The SNTEMP/DYRESM is not capable of addressing metals issues.

4.5 Integration between Temperature and Ice Dynamics Models

The CE-QUAL-W2 model has a coupled temperature-ice simulation module, which is of moderate complexity and predictive capability. EFDC has a slightly simpler ice representation which was previously applied to a number of Canadian rivers. Both models, however, can be coupled to external ice models with a properly designed interface to communicate temperature results. Fully predictive simulation within either model would require code modification to handle the interaction between temperature simulation, ice formation and transport, and hydrodynamics simulation, and water quality simulation.

4.6 Capability of Representing Local Effects

CE-QUAL-W2 is a longitudinal-vertical two-dimensional model; therefore, it is capable of resolving spatial variability in the longitudinal and vertical directions. It is not capable of representing high resolution local effects such as lateral discharge, areas impacted by secondary circulation, or certain habitat characteristic changes. EFDC is a three-dimensional model which can be configured at nearly any spatial resolution to represent local effects. SNTEMP/DYRESM is a one dimensional modeling suite and therefore has limited capability representing local effects.

5.0 RECOMMENDATIONS

Based on the review of select models described above, the EFDC model is recommended for the Susitna-Watana Hydroelectric Project.

6.0 REFERENCES

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