Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Probable Maximum Flood (PMF) Study
Study Plan Section 16.5

Final Study Plan

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

July 2013

16.5. Probable Maximum Flood (PMF) Study

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Section 16.5 of the RSP described the Probable Maximum Flood (PMF) Study. This study focuses on developing a site-specific Probable Maximum Precipitation (PMP) and modeling the PMF. RSP 16.5 provided goals, objectives, and proposed methods for data collection regarding PMF.

On February 1, 2013, FERC staff issued its study plan determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. RSP Section 16.5 was one of the 31 studies approved with no modifications. As such, in finalizing and issuing Final Study Plan Section 16.5, AEA has made no modifications to this study from its Revised Study Plan.

16.5.1. General Description of the Proposed Study

16.5.1.1. Study Goals and Objectives

The general goals and objectives of the PMF study are as follows:

- develop a site-specific Probable Maximum Precipitation (PMP) to be used for the derivation of the PMF including both a temporal and spatial distribution of rainfall;
- model the runoff through the project drainage basin to produce the PMF inflow, including snowmelt considerations for the Project reservoir;
- route the PMF inflow through the Project to obtain the PMF outflow and maximum flood elevation at the dam; and
- use the Board of Consultants (BOC) for technical review during development and performance of the site-specific studies.

The FERC PMF study request (FERC 2012) contains references to assessing the stability of Project facilities during flood loading conditions, which will be addressed in detailed design documents, and requirements for several geologic and geotechnical assessments that relate to dam safety, which will be addressed in the Geology and Soils study plan. Geology and soils considerations would only be included in the PMF study to the extent that they affect flood runoff. Structural aspects of Project facilities will not be included in the PMF study.

16.5.1.2. Selection of the Inflow Design Flood

The Inflow Design Flood (IDF) is used in the design of the spillways and other structures that are affected by maximum flood levels. The adequacy of a spillway is evaluated by considering the hazard potential that would result from failure of the Project works during passage of flood flows. For dams of different sizes and hazard potentials, the IDF may range anywhere from the 100-year flood up to the PMF. Because of its size and downstream hazard potential, the selected IDF for Watana Dam will be the PMF.

The PMF is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study. The PMF is normally generated by the PMP, which is defined as theoretically the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographic location at a certain time of year. The PMP development process will follow the storm-based approach and adhere to the guidance of being a "physically possible" scenario.

16.5.2. Existing Information and Need for Additional Information

A PMF study was developed about 30 years ago for the Watana Dam site (Acres 1982) at the time that feasibility reports were being prepared for the then proposed APA Susitna Hydroelectric Project. Although the PMF study report from the previous study is available, few calculations and little model input data, and no model output are available. This means that preparation of an updated PMF study is required. In addition to the availability of more years of meteorological and streamflow data since the time of the previous PMF study, new PMF guidelines have been developed (FERC 2001) and additional data and more advanced methods are available for development of site-specific PMP.

Development of the PMP and PMF are based on a variety of historical data, including streamflow data, meteorological data, watershed data, and far-field information such as sea surface temperatures and storm patterns. Data availability is anticipated to be adequate for development of the PMP and PMF for Watana Dam.

16.5.3. Study Area

The study area will be the entire watershed tributary to the Watana Dam site, plus the additional drainage area between Watana Dam and the USGS gaging station at Gold Creek. The watershed drainage area is 5,180 square miles at the Watana Dam site and 6,160 square miles at the Gold Creek USGS gage. Extension of the study area to the Gold Creek USGS gage is necessary because this is where a long-term streamflow record is available for calibration and verification of hydrographs for the entire watershed tributary to the Watana Dam site.

16.5.4. Study Methods

The following sections describe the study methods and major tasks necessary to develop the PMP and PMF for Watana Dam.

16.5.4.1. Board of Consultants Review

A BOC has been established for technical review of many aspects of the dam design. The BOC review of the subject studies will be primarily focused on the development of the site-specific PMP but may include other aspects of the PMF study. The BOC will meet and review design progress at appropriate intervals and, if appropriate, will co-opt specialists for particular topic review. The study methods and tasks described herein may be subject to suggested alteration by the BOC.

16.5.4.2. Data Acquisition

A variety of historical recorded meteorological and hydrologic data are necessary to develop the PMP and PMF. Data acquisition should begin at the earliest possible time as some data (e.g., streamflow data on a time increment less than daily) could take months to retrieve. Additionally, the availability and area extent of next-generation radar (NEXRAD) data has been investigated for use in a site-specific PMP and will be extensively applied where appropriate. The types of data to be collected for storm periods at stations in the vicinity of the study area include, but are not limited to streamflow, precipitation, dry-bulb and wet-bulb temperature, snowpack and snow water equivalent, wind direction and speed, and humidity. Relevant watershed data will also be collected including the drainage area of sub-basins, the area within elevation bands for snowpack and snowmelt estimation, channel slopes, vegetation cover, lake area, and soil types. For the site-specific PMP, information far from the study area may be collected including sea-surface temperatures and synoptic storm information.

16.5.4.3. Historical Data Analysis

Historical data analysis will contribute to the PMP and PMF analysis in several ways, including being used to perform the following tasks:

- determine the major historic storms by analysis of total storm precipitation, intensity, duration, and areal extent;
- summarize historic peak flows for selection of major flood events for model calibration and verification;
- estimate flood frequency up to at least the 100-year flood from historical peak flow data;
- determine the 100-year snowpack and snow water equivalent for various elevation bands;
- develop a basis for antecedent watershed conditions prior to the PMP;
- summarize maximum seasonal temperature conditions associated with PMP-type storm; and
- summarize coincident data availability for major storm events.

16.5.4.4. Review of Previous PMF Study Report

In support of the previous design and licensing effort for the APA Susitna Hydroelectric Project, a PMF study was performed (Acres 1982). The 1982 PMF study included developing a site-specific PMP and used generally accepted methods at the time. It is notable that although many new data have become available in the 30-year interim since the previous PMF study, all of the five largest floods of record at the Gold Creek USGS gaging station were available for calibration and verification studies in 1982. Although few calculations and model input data, and no output are available, the 1982 study does contain useful information regarding final results and conclusions of the analysis, including numerous tables and figures. The 1982 PMF study report will be thoroughly reviewed to gain applicable insights to be used in the current PMF study.

16.5.4.5. Field Visit

A field visit is a recommended part of the PMF study (FERC 2001). Observations made during the field visit would include

- Manning's "n" and general hydrologic and hydraulic characteristics of river channels;
- special features within the drainage basin such as marshes, lakes, and closed basins that may delay or reduce runoff;
- constrictions such as bridge abutments that may influence flood routing characteristics;

- large natural constrictions that could act as hydraulic control structures; and
- areas that could result in locally different infiltration rates, including rock exposures, dense forest, or high altitude meadows.

16.5.4.6. Flood Hydrology Model Selection

At least three flood hydrology models are available, and a key task will be to select which to use to develop the PMF. These models include:

- Streamflow Synthesis and Reservoir Routing (SSARR). This model was developed by the U.S. Army Corps of Engineers (USACE), North Pacific Division. The SSARR model was used for the 1982 Susitna PMF study. In addition to its use by the USACE, the SSARR model was used occasionally by consultants for flood simulation on major watersheds, particularly in the Pacific Northwest. The SSARR model is no longer in general use. The latest version of SSARR was modified in 1991 to run on IBM-compatible personal computers. The USACE has noted that there will be no further program updates or modifications to the SSARR files by the USACE, and no user support is available.
- Flood Hydrograph Package (HEC-1). This model was developed by the Hydrologic Engineering Center (HEC) of the USACE and was (possibly still is) the most widely used model in PMF studies. HEC-1 is one of the two rainfall-runoff models recommended for PMF studies (FERC 2001). Compared to other models, HEC-1 has the advantage of including the recommended energy budget snowmelt method as well as fully documented equations for calculating snowmelt in the model.
- Hydrologic Modeling System (HEC-HMS). This model was also developed by the HEC and is the Windows-based successor to HEC-1. HEC-HMS contains many of the same methods as HEC-1 and is the other model recommended for PMF studies (FERC 2001). Snowmelt in the HEC-HMS model is based on a method that uses temperature data only.

Flood hydrology model selection was reviewed with the BOC during the initial BOC meeting on November 2, 2012. With BOC input from that review, AEA proposes to use the HEC-1 Flood Hydrograph Package.

16.5.4.7. Flood Hydrology Model Initial Setup

The flood hydrology computer model initial setup will include sub-basin delineation, areas in elevation bands for use in snowmelt calculations, lake areas, areas in various soil groups, coincident base flow, and initial estimates of infiltration rates. Sub-basin delineation will be aligned with USGS stream-gaging station locations whenever possible to facilitate model calibration and verification. River channel geometry will be checked for areas that may warrant special consideration for storage-outflow routing. Topographic mapping will be developed using ArcGIS software.

16.5.4.8. Flood Hydrology Model Calibration and Verification

This task would include calibration and verification of the sub-basin unit hydrographs to the extent that available recorded streamflow and meteorological data allow. Calibration provides the important adjustments to hydrograph parameters that are initially estimated from standard equations or based on experience in similar watersheds. Two of the largest floods on record will be selected for calibration, with a third large historical flood used for verification. More storms will potentially be available if further calibration/validation is required. The calibration points at the outlets of the sub-basins will coincide with USGS stream-gaging stations to the extent possible. The selection of storm periods to use in model calibration and verification will include the availability of data at multiple stream-gaging stations. Activities under this task will also include estimating ungaged local runoff as necessary, base flow separation, and a final estimate of infiltration loss rates.

16.5.4.9. Development of the Site-Specific PMP

The applicable available National Weather Service (formerly the U.S. Weather Bureau) PMP guidance document is *Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska,* Technical Paper No. 47 (Miller 1963). Technical Paper No. 47 is applicable to areas up to 400 square miles and durations up to 24 hours. Because the drainage area at the Watana Dam site is 5,180 square miles and current standards call for the PMP to have a duration of at least 72 hours, development of a site-specific PMP is necessary. The existing PMP studies can be used to make comparisons to the 1982 Susitna site-specific PMP and the Technical Paper No. 47 PMP at the highest-intensity central 400-square-mile area and 24-hour duration of the new site-specific PMP. Development of the site-specific PMP for the watershed tributary to the proposed Watana Dam site will require a substantially greater effort than is necessary for most other dams in the USA because of new storm analyses, sparse data availability and cool season considerations.

The site-specific PMP study will follow many of the methods (e.g., a storm-based approach) used to develop the current National Weather Service PMP hydrometeorological reports (HMR). The basic techniques for storm maximization and transposition are well-established. An additional 30 years of data and more advanced models and recent adjustments to methods are now available for development of site-specific PMP (e.g. radar aided storm analyses, quantification of orographic affects). Results will include both a temporal and spatial distribution of the PMP for durations appropriate to most accurately model the PMF. No predetermined maximum storm sequence length will be set so that the critical PMP sequence could be 96 hours or more. Long duration, high volume events will be among the candidate PMF cases evaluated to determine if they constitute the critical storm event for the determination of the PMF maximum reservoir elevation. In addition, guidance for alternative centerings of the PMP design storm will be determined based on the patterns of the actual storm events used to derive the PMP values. NEXRAD data will be used when available (generally after 1995) in all storm analyses.

AEA’s storm search will include all twelve months of the year, so the months that are potentially PMP drivers will naturally result from this process. Based on an analysis of historic flow frequency, peak annual flood data, and anticipated seasonal reservoir levels, the PMP development is expected to be focused on the months of May through October. The site-specific PMP task will also include development of the 100-year precipitation temporal and spatial distribution during a season coincident with the probable maximum snowpack. Applied Weather Associates, a consultant with extensive experience in developing site-specific PMP will be retained to perform this task.

16.5.4.10. Coincident Conditions for the PMF

Developing coincident conditions would include the 100-year snowpack, the probable maximum snowpack, necessary temperature, dew point, and wind speed sequences, and other data for energy budget method as necessary. The 100-year precipitation will also be developed, because one of the potential combinations of coincident conditions that can result in the PMF is the probable maximum snowpack combined with the seasonally appropriate 100-year precipitation. A determination of the maximum reservoir level during the 50-year flood may also be required, as this may become the starting reservoir elevation for spillway operation.

16.5.4.11. Development of the PMF Inflow Hydrograph

The PMF will be developed at the proposed Watana Dam site by combining sub-area runoff and performing channel and reservoir routings for various cases and months. The energy budget snowmelt method will be used. Routing of the PMF through the reservoir may account for use of the fixed-cone outlet valves for discharges up to the 50-year flood and use of the spillway only after the expected maximum level of the 50-year flood has been exceeded, but final flood operating procedures are not yet finalized. This task also includes a sensitivity analysis to test the effects of variation in parameters with relatively high uncertainty that could potentially have more significant effects on the results. The PMF channel routing would be performed using the selected flood hydrology model.

16.5.4.12. Reservoir Routing of the PMF

Spillway capacity should be determined as part of the economical combination of spillway capacity and surcharge storage. Surcharge storage is defined as the storage between the maximum normal pool level (still water) and the maximum design flood water storage level. Determining the economical combination of surcharge storage/spillway capacity requires evaluation of the cost of increasing spillway capacity versus the cost of raising the dam height to provide the required freeboard (routed maximum flood level plus any required allowance for wind setup and wave run-up). Reservoir flood routing is used to determine the temporal and water level variation of the hydrograph as the flood passes through the reservoir. Increasing the spillway capacity will reduce the necessary surcharge storage (determined by flood routing), thereby lowering the required height of the dam. Alternatives analysis will be performed to optimize spillway capacity and flood surcharge. The PMF reservoir routing would be performed using the selected flood hydrology model.

It is expected that the volume and distribution of potential future sedimentation in the reservoir will form a PMF routing sensitivity case. AEA will evaluate the potential for glacial lake outburst floods (GLOF). If any are identified, AEA will compare the GLOF to the critical PMF inflow hydrograph and will route the GLOF to determine the peak reservoir level if the GLOF potentially forms the critical condition for spillway design.

16.5.4.13. Freeboard Analysis

Freeboard provides a margin of safety against the potential for overtopping of dams. Freeboard and flood control storage are required to provide the capacity to store and/or route the design storm through the reservoir considering inflows, precipitation on the reservoir basin, and wind generated waves without hazardous overtopping of the dam. Although freeboard selection involves more than simply the PMF water level, the freeboard selection will be made as part of the subject study, based on wind setup, wave action, uncertainties in analytical procedures, and uncertainties in Project function in combination with the most critical pool elevation (USACE 1991). The freeboard determination will be based on site-specific conditions that can be reasonably expected to occur simultaneously. Design criteria will be developed for logical combinations of reservoir levels/precipitation and wind conditions for freeboard determination. Wind setup and wave run-up would be determined with standard methods (USACE 1984 and USACE 2003).

Normal freeboard is defined as the difference in elevation between the top of the dam and the normal maximum pool elevation. Minimum freeboard is defined as the difference in pool elevation between the top of the dam and the maximum reservoir water surface that would result from routing the PMF through the reservoir. It is generally not necessary to prevent splashing or occasional overtopping of a dam by waves under extreme conditions particularly for a concrete dam. If studies demonstrate that the RCC dam can withstand wave overtopping without erosion of foundation or abutment material, then minimum (or no) freeboard will be selected for the PMF condition. In that case, only normal freeboard would be required. The study of freeboard will take into account unusual circumstances.

16.5.4.14. Reporting

Two reports will be prepared, one covering the development of the site-specific PMP, the other an overall PMF report for all aspects of the PMF study, including a summary of the site-specific PMP. The sections of the PMF report would generally follow the outline suggested by FERC for PMF studies (FERC 2001). AEA proposes to submit all reports and supporting information for this study only to the Commission and the Alaska Department of Geological and Geophysical Surveys pursuant to FERC's Critical Energy Infrastructure Information (CEII) regulations, which are designed to ensure that critical energy infrastructure is protected from security threats. Licensing participants who wish to review this information can request it from FERC pursuant to FERC's CEII regulations.

16.5.5. Consistency with Generally Accepted Scientific Practice

Accepted standard practices for PMF studies are available in the FERC *Engineering Guidelines*, Chapter 7, "Determination of the Probable Maximum Flood" (FERC 2001). Exceptions taken from these guidelines, if any, will be noted and justified. Hydrologists performing the studies will have prior experience using the FERC guidelines in preparation of other recent previous PMF studies.

Hydrometeorological reports are available and applicable for determining the PMP for most PMF studies in the USA. Because of this, the FERC *Engineering Guidelines*, Chapter 7 do not provide methods for preparation of the site-specific PMP that is necessary for the Watana Dam PMF. Applied Weather Associates, a consultant that is experienced in preparation of site-specific PMP under FERC jurisdiction, will perform the necessary study. Methods used in preparation of the site-specific PMP are very similar to those used in preparation of the most recent NOAA PMP hydrometeorological reports. The BOC will review the PMF Study with an emphasis on the site-specific PMP.

16.5.6. Schedule

A PMF study is typically a part of the Feasibility Report for a new dam. It is anticipated that the site-specific PMP and PMF study would begin during early 2013 and be completed in December 2013 (Table 16.5-1).

16.5.7. Relationship with Other Studies

As depicted in Figure 16.5-1, the PMF study will not require information inputs from other Project studies other than related engineering studies. The outputs of this study will also feed back into the engineering studies to assist in sizing the spillways at the dam and other related Project features.

16.5.8. Level of Effort and Cost

The estimated level of effort for the study is as follows:

Activity	Effort
Site-Specific Probable Maximum Precipitation	16 full-time person months
Probable Maximum Flood	11 full-time person months
Total	27 full-time person months

This study is estimated to cost up to $750,000.

16.5.9. Literature Cited

Acres, 1982. *Susitna Hydroelectric Project, Feasibility Report*, Volume 4, Appendix A, Hydrological Studies, Final Draft, prepared for the Alaska Power Authority.

Federal Energy Regulatory Commission (FERC), October 1993. *Engineering Guidelines*, Chapter II, Selecting and Accommodating Inflow Design Floods for Dams.

Federal Energy Regulatory Commission (FERC), September 2001. *Engineering Guidelines*, Chapter VIII, Determination of the Probable Maximum Flood.

Federal Energy Regulatory Commission (FERC), May 31, 2012. Letter from Jennifer Hill, Chief, Northwest Branch, Division of Hydropower Licensing, FERC, to Wayne Dyok, Susitna-Watana Project Manager, Alaska Energy Authority.

Miller, John F., 1963. *Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska, Technical Paper No. 47*, U.S. Weather Bureau, Department of Commerce, Washington D.C.

U.S. Army Corps of Engineers (USACE), March 1, 1991. *Inflow Design Floods for Dams and Reservoirs*, ER 1110-8-2(FR).

U.S. Army Corps of Engineers (USACE), 1984. *Shore Protection Manual*, Coastal Engineering Research Center, Waterways Experiment Station, Second Printing.

U.S. Army Corps of Engineers (USACE), July 31, 2003. Coastal Engineering Manual, EM-1110-2-1100, Part II Coastal Hydrodynamics.

16.5.10. Tables

Table 16.5-1. Schedule for Implementation of the PMF Study.

Activity	2012				2013				2014				2015
	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1Q
Data Acquisition and Analysis				—	—								
Develop Probable Maximum Precipitation				—	—	—	—	—					
Model Setup, Calibration, and Verification					—	—	—						
Route PMF through Reservoir and Size Spillway							—						
Initial Study Report							—	—	Δ				
Updated Study Report											—	—	▲

Legend: —— Planned Activity
Δ Initial Study Report
▲ Updated Study Report

16.5.11. Figures

Figure 16.5-1. Interdependencies for Probable Maximum Flood Study.