K3.16 SURFACE WATER HYDROLOGY

This appendix contains supplemental technical information on the following topics related to baseline surface water hydrology discussed in Section 3.16, Surface Water Hydrology:

- Meteorological inputs to water balance models (operations and closure)
- Water balance calibration
- Long-term climate change

K3.16.1 Meteorological Inputs to Water Balance Models

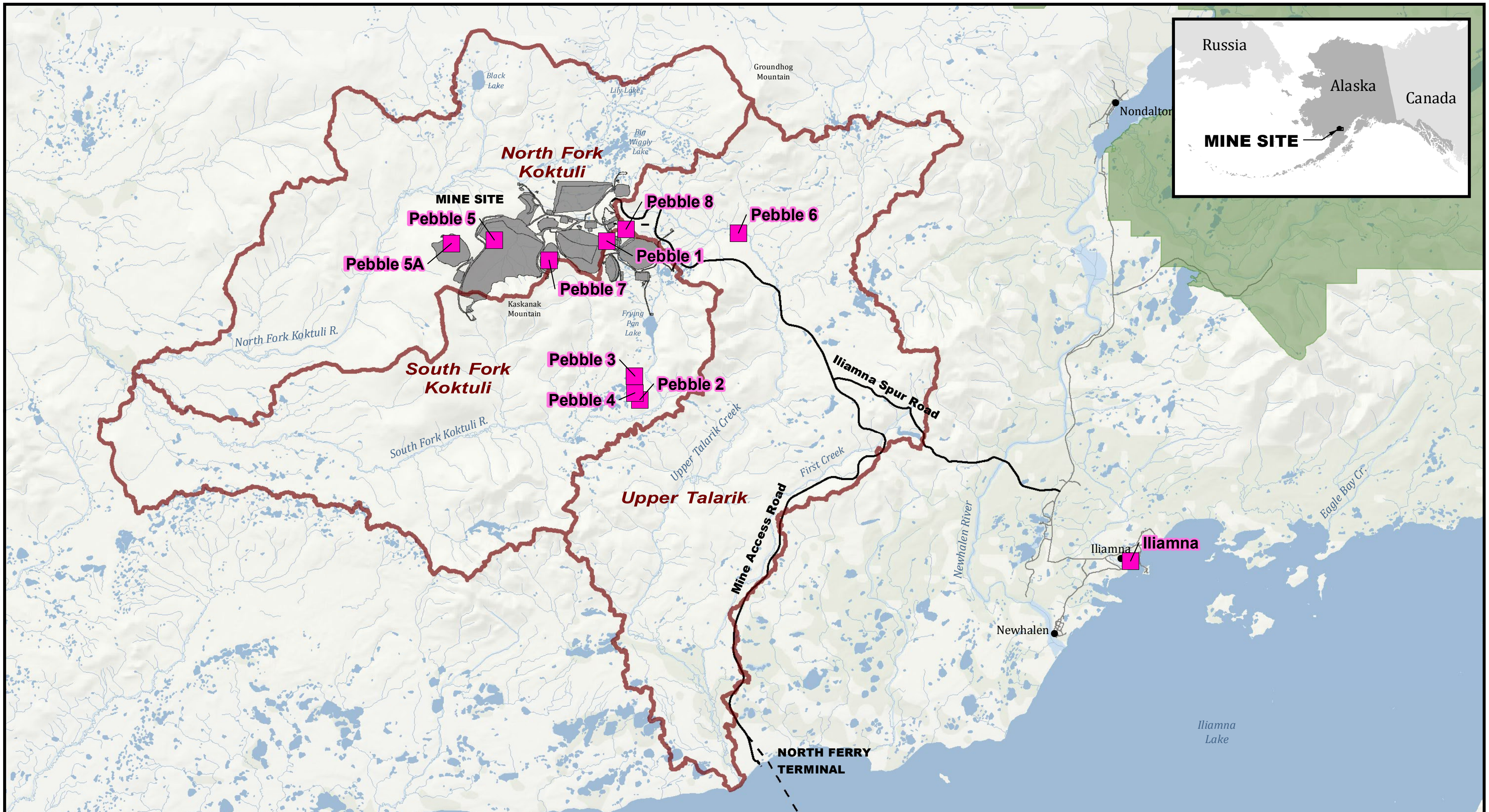
The surface water (watershed) balance model was initially calibrated using continuous streamflow records collected from 2004 to 2008 at 15 streamflow gaging stations (Schlumberger 2011a). The model was also used to validate site meteoric data and precipitation variability across the site. A meteorological data collection program was designed and implemented to provide data representative of the mine site analysis area. Meteorological data have been collected from eight monitoring stations (Figure K3.16-1) (SLR 2015a). The stations are labeled Pebble 1, Pebble 3, Pebble 4, Pebble 5, Pebble 5A, Pebble 6, Pebble 8 in the general mine site analysis area, and the Iliamna Air Quality station in Iliamna, Alaska (Iliamna Airport). The closest long-term meteorological records are from Iliamna Airport.

To evaluate surface water and groundwater interaction, a month-to-month water balance approach was selected, which included a semi-distributed spreadsheet method (Schlumberger 2011a). The selected method allowed for adjacent sub-catchments (smaller watersheds or basis) to be chained together, including the interaction of surface water and groundwater components.

The development of the mine site water balance model included the following components (Schlumberger 2011a):

- The watersheds of the North Fork Koktuli (NFK) and South Fork Koktuli (SFK) rivers and the Upper Talarik Creek (UTC) were divided into sub-catchments; each sub-catchment is numbered and associated with a gaging station (Figure K3.16-2).
- Inputs to each sub-catchment included precipitation and inflow from up-gradient catchments.
- Precipitation distribution was accounted for in runoff, recharge, evapotranspiration, and sublimation.
- Groundwater recharge (combination of precipitation recharge and stream leakage) was accumulated in groundwater storage.
- Groundwater was discharged in and from each sub-catchment in proportion to the amount of groundwater in storage. A portion of this groundwater was transmitted down-gradient to the next sub-catchment according to Darcy's Law. The remainder of the groundwater was discharged in the sub-catchment as surface water.
- Snowmelt was accounted for when temperatures rose enough to melt accumulated snow and generate runoff.

The input parameters to the water balance model were adjusted until modeled streamflows closely resembled measured streamflows. The following inputs were used to develop the water balance model (Schlumberger 2011a).



Sources: PLP 2018d; ADNR

Meteorological Stations

Alternative 1

Natural Gas Pipeline

Transportation Corridor

Mine Site

Other Features

Local Roads

Major Drainage Boundary

National Park

US Army Corps of Engineers®

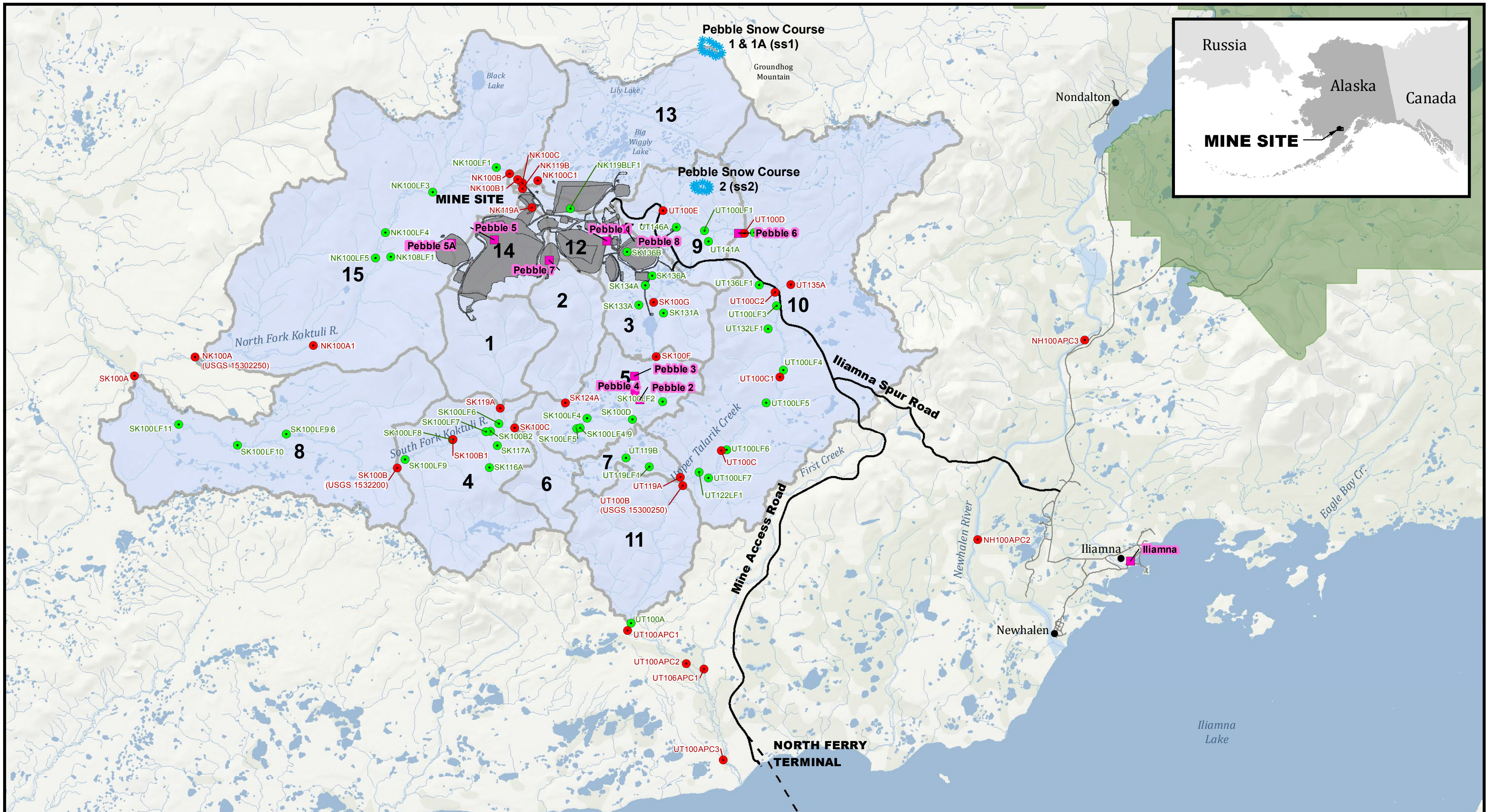
2 0 2 4

Miles

METEOROLOGICAL MONITORING STATIONS IN THE MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE K3.16-1



Sources: PLP 2018d; ADNR

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2 0 2 4
Miles

- Snow Course Station
- Continuous Monitoring Gage Stations
- Early Spring Low-Flow Measurement Sites
- Meteorological Stations
- Sub-catchment

Alternative 1

- Transportation Corridor
- Natural Gas Pipeline
- Mine Site

Other Features

- Local Roads
- National Park

STREAM GAGING STATIONS AND WATERSHED BOUNDARIES

PEBBLE PROJECT EIS

FIGURE K3.16-2

K3.16.1.1 Temperature

Monthly mean temperature data from the Iliamna Airport were used for developing a long-term dataset for the mine site water balance model. Temperature data selected for this purpose was from the period of record from 1942 to 2017. Data gaps in the temperature data were addressed using regional regression analysis to estimate missing data from the long-term dataset (Knight Piésold 2018m).

Scaling factors were then applied to transform the temperature record from Iliamna Airport into synthetic (estimated) series at the Pebble 1 station location. Scaling factors represent fundamental physical relationships and processes, which have been quantified by empirical calibration methods (Knight Piésold 2018a). The adiabatic[1] relationship between topographic elevation and air temperature is an example of a scaling factor considered for temperature. The standard adiabatic lapse rate relationship between elevation and temperature is -3.6 degrees Fahrenheit (°F) per 1,000 feet of elevation. The observed temperature difference between Iliamna Airport and Pebble 1 station is -4.7°F, which equates to a lapse rate of -3.4°F per 1,000 feet of elevation. Therefore, the observed temperature difference of -4.7°F was adopted and applied to each month of the Iliamna Airport data to create the synthetic temperature dataset for the mine site at Pebble 1 station.

K3.16.1.2 Precipitation

Monthly precipitation data from Iliamna Airport for the same period of record (1942 to 2017) were used for developing a long-term precipitation dataset for the mine site water balance model. Data gaps in the precipitation data set were addressed using regional regression analysis to estimate missing data from the long-term dataset (Knight Piésold 2018m).

Scaling factors were then applied to transform the precipitation record from Iliamna Airport into synthetic (estimated) series at the Pebble 1 station location. Scaling factors were applied to the Iliamna Airport precipitation dataset to account for location and elevation. The calibrated scaling factors are shown in Table K3.16-1, and were based on the following:

- Group A: Factors that represent differences in measured precipitation between the Iliamna Airport and Pebble 1 meteorology stations; values for these factors were calibrated by comparison of concurrent measured records at the two stations for the period from 2005 to 2009.
- Group B: Factors that represent differences between measured and estimated actual precipitation at the Pebble 1 station; values for these factors were calibrated by comparison of measured meteorology parameters at Pebble 1 station and measured streamflow at downstream gaging stations for the period from 2005 to 2009.
- A combination of Group A and Group B factors were applied to the Iliamna precipitation data that were used as input to the Pebble watershed module, in order to achieve a good match between the flows measured in the field at numerous locations and the flows predicted by the watershed module for those same locations.

The combined scaling factors presented in Table K3.16-1 applied to each applicable monthly total precipitation value in the Iliamna Airport precipitation record to generate the synthetic monthly precipitation series for the Pebble 1 station location (Knight Piésold 2018m).

[1] The adiabatic relationship is the process of heat being reduced in the air with change in air pressure that occurs at increased elevations. Air expands and cools as it rises – thus resulting in cooler air at higher elevation.

Table K3.16-1 Monthly Precipitation Scaling Factors between Iliamna Airport (Measured) and Pebble 1 (Estimated)

Factor[1]	Monthly Scaling Factors											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Orographic Factor (per 328 ft)	1.100	1.100	1.100	1.058	1.058	1.058	1.058	1.058	1.058	1.058	1.100	1.100
Orographic Factor (Iliama Airport to Pebble 1)	1.489	1.489	1.489	1.266	1.266	1.266	1.266	1.266	1.266	1.266	1.489	1.489
Group A: Measured Iliama → Measured Pebble 1												
A1) Specific Orographic Effect (based on station elevations):	1.489	1.489	1.489	1.266	1.266	1.266	1.266	1.266	1.266	1.266	1.489	1.489
A2) Geographic Location Factor:	1.477	1.477	1.477	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.477	1.477
Group B: Measured Pebble 1 → Estimated Actual Pebble 1												
B1) Pebble 1 Undercatch:	1.600	1.600	1.600	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.600	1.600
Group A and B Factors Combined:	3.519	3.519	3.519	1.582	1.582	1.582	1.582	1.582	1.582	1.582	3.519	3.519

Notes:
Elevations: Iliamna Airport elevation 190 feet amsl
Pebble 1 elevation: 1,560 feet above mean sea level (amsl)
Source: Knight Piésold 2018m, Table 1; PLP 2018-RFI 028a

K3.16.1.3 Snowmelt

Annual maximum snow water-equivalent (SWE) values surveyed at the project snow courses and regional snow courses during the period of 2004 through 2008 are presented in Table K3.16-2 (Knight Piésold 2018g). Snow course locations are depicted on Figure K3.16-2.

K3.16.1.4 Other Meteorological Data

Other meteorological data collected include temperature, radiation, wind speed, relative humidity, evaporation, and sublimation.

Table K3.16-2: Annual Maximum Snow Water Equivalent – Project and Regional Snow Courses

Snow Course	Elevation (feet)	Annual Maximum Snow Water Equivalent (inches)						
		2004	2005	2006	2007	2008	Average	Long-Term Average
Project Snow Courses								
Pebble Snow Course 1	2,000	10.5	15.5	9.7	5.8	19.4	12.2	12.5
Pebble Snow Course 1A	2,000	8.2	13.8	7.5	5.3	16.7	10.3	10.6
Pebble Snow Course 2	1,200	9.8	12.0	8.1	6.3	15.6	10.4	10.6
Regional Snow Courses								
Brooks Camp	150	1.8	-	1.5	-	0.8	1.4	2.4
Fishtrap Lake	1,800	8.6	11.7	-	4.9	9.5	8.7	9.4
Port Alsworth	270	5.1	2.5	2.2	1.9	-	2.9	3.4
Telaquana Lake	1,550	4.4	6.4	4.5	1.4	5.8	4.5	4.1
Three Forks	900	8.2	-	2.5	-	3.0	4.6	3.0
Upper Twin Lakes	2,000	6.5	6.8	4.0	4.0	7.2	6.1	6.1

Source: Knight Piésold 2018g, Table 5.1.

The annual maximum SWE was similar at both Snow Course 1A and Snow Course 2. The annual maximum SWE averaged around 10 inches at these two snow courses, and ranged from around 6 inches in 2007 (lowest snowpack were Fishtrap Lake, Telaquana Lake, and Upper Twin Lakes. These sites had mean annual maximum SWE values of around 5 to 9 inches during the 2004 to 2008 period, with the lowest values in 2007 and highest values in 2005 and 2008, indicating a general coherence in snowpack patterns throughout the region in this elevation range. The estimated long-term mean for each of the three project snow courses is an average of three estimates generated by the relationships between that project snow course and each of the three regional snow courses (Knight Piésold 2018g).

K3.16.2 Water Balance Calibration and Validation

K3.16.2.1 Calibration

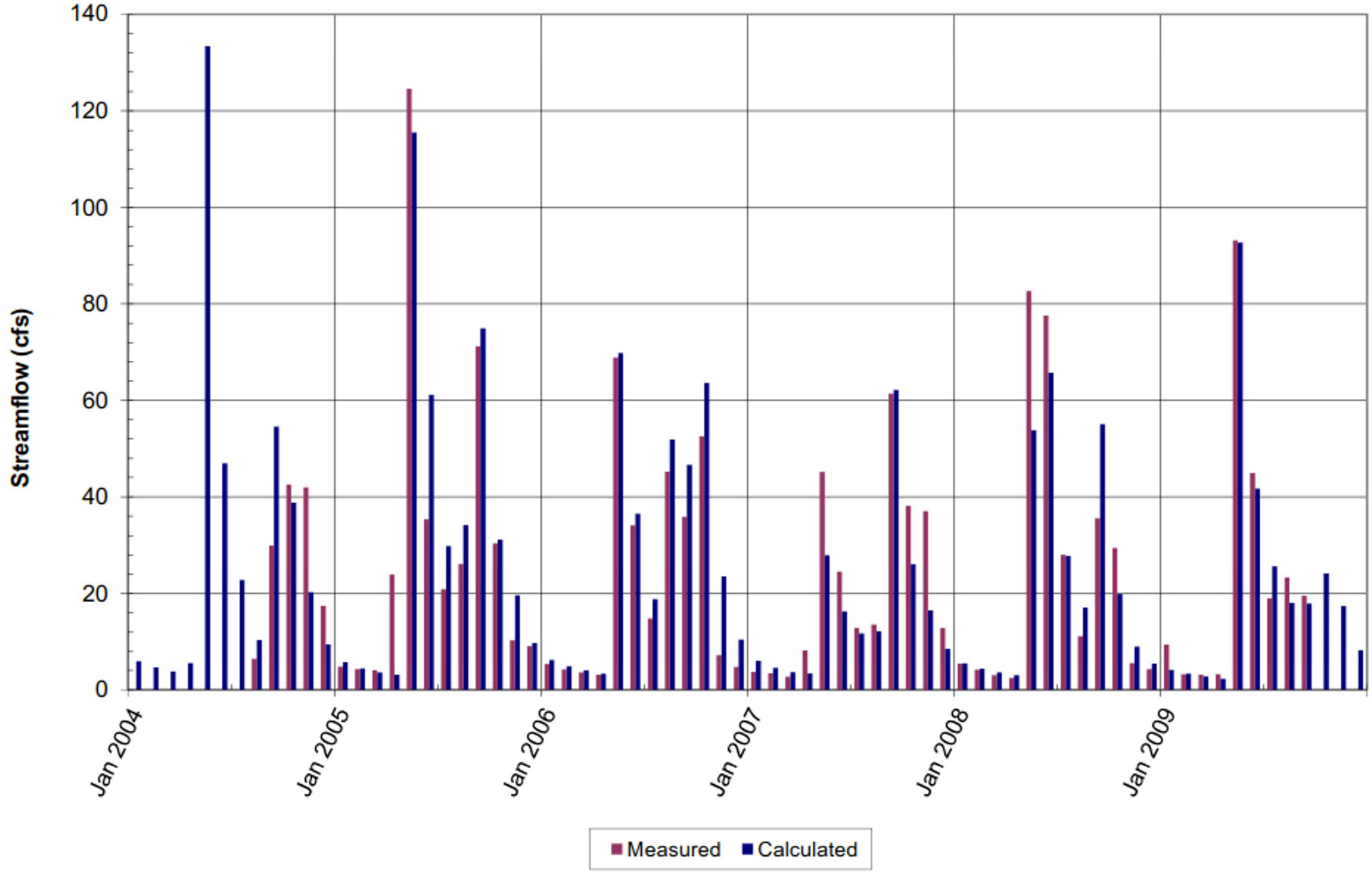
The watershed module was calibrated to stream flows over the period of September 2004 through September 2009. Four calibration plots were generated per gaging station to provide results for the present model for measured and calculated monthly streamflow. The following four plot types were developed for each gaged site considered for the period of calibration (PLP 2019-RFI 104):

- A histogram illustrating the monthly flows.
- A cumulative plot covering the calibration period showing the total volume of water passing the gage.
- A comparison of the distribution of flow rates that provides a measure of the ability of the water balance to provide the full range of measured values.
- A scatter plot of measured versus calculated flows that provides a visual comparison of the monthly modeled versus measured flows.

Calibration plots are presented in Figure K3.16-3 through Figure K3.16-22. Gaging stations in close proximity to the mine footprint were selected to show calibration results (Section 3.16, Surface Water Hydrology, Figure 3.16-2). From the NFK watershed, gaging stations NK119A and NK100C were selected, with NK119A representing a tributary and NK100C representing the main stem. From the SFK watershed, gaging stations SK119A and SK100F were selected, with SK119A representing a tributary and SK100F representing the main stem. From the UTC watershed, gaging station UT100D was selected to represent the main stem close to the mine foot print.

The calibration procedure focused primarily on obtaining a good match to cumulative flows and the distribution of flows (plots b and c). The calibration plots provide a visual indication of the results of the model and show the variability between the measured and modeled flows. In general, modeled flows replicate the winter low flows and the peaks created by freshet and fall rains. The cumulative plots show that the total water passing the gage over the calibration period matches well; however, the model over predicts the cumulative volume of water over the first two years of the calibration period and under predicts the cumulative flow for the remaining 3 years for most gage sites. The maximum discrepancy between calculated and measured cumulative flows is up to about 20 percent across the sites. The flow distribution plots (c plots) show that the full range of flow is adequately characterized at all stations during the calibration period (PLP 2019-RFI 104).

Modeled flows are predicted using the long-term precipitation record from Iliamna. The precipitation at Iliamna is not expected to be representative of precipitation at all on-site catchments on a month-to-month basis due to local variability. Rather, the climate at the Iliamna climate station and on-site catchments are under the same climatic influences and are expected to display similar variability. For that reason, the model calibration focused on matching cumulative flows and the distribution of flow rates. The measured versus calculated plots (d plots) illustrate the month-to-month variability (PLP 2019-RFI 104).



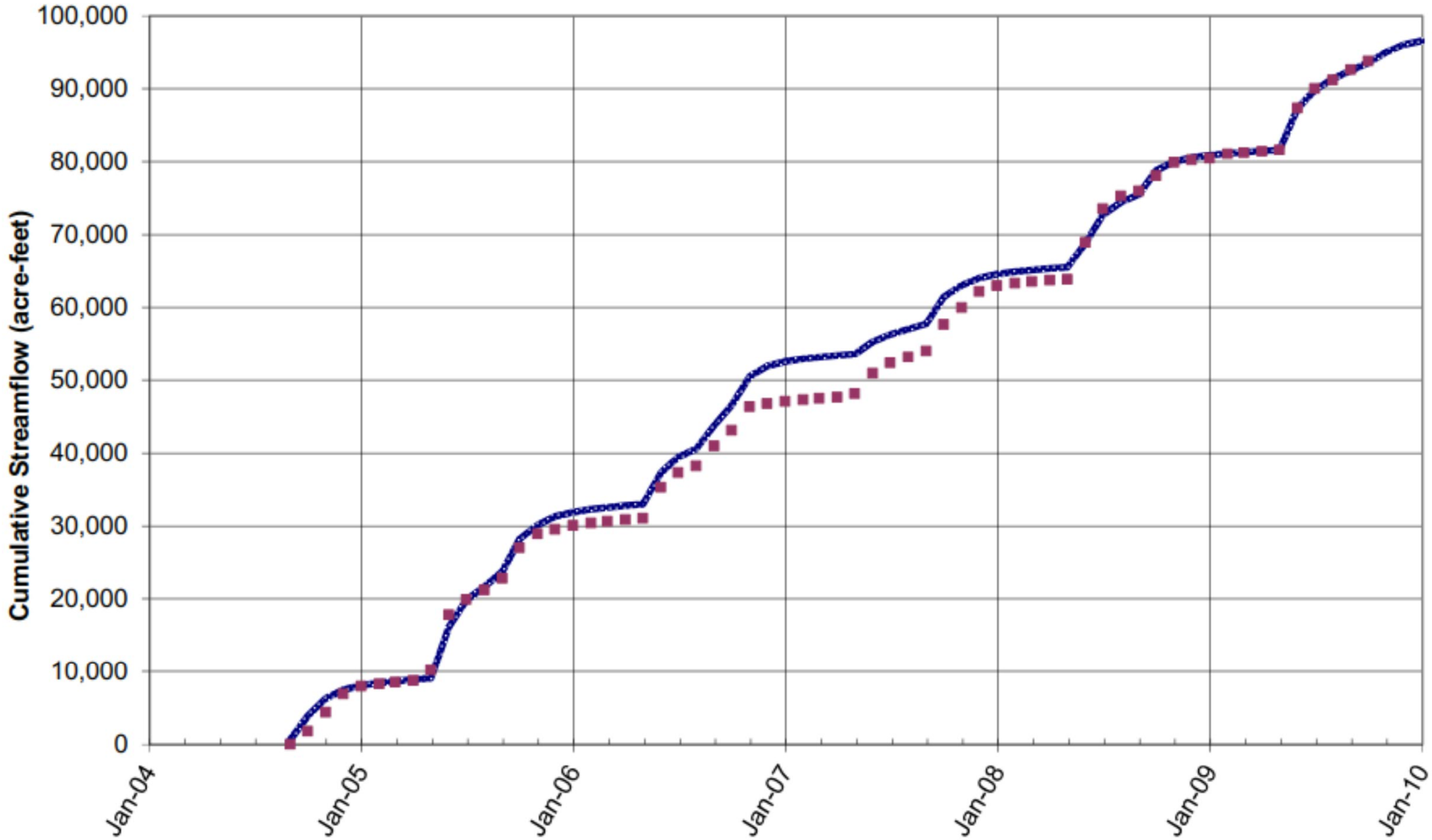
Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED STREAMFLOW NK119A

PEBBLE PROJECT EIS

FIGURE K3.16-3



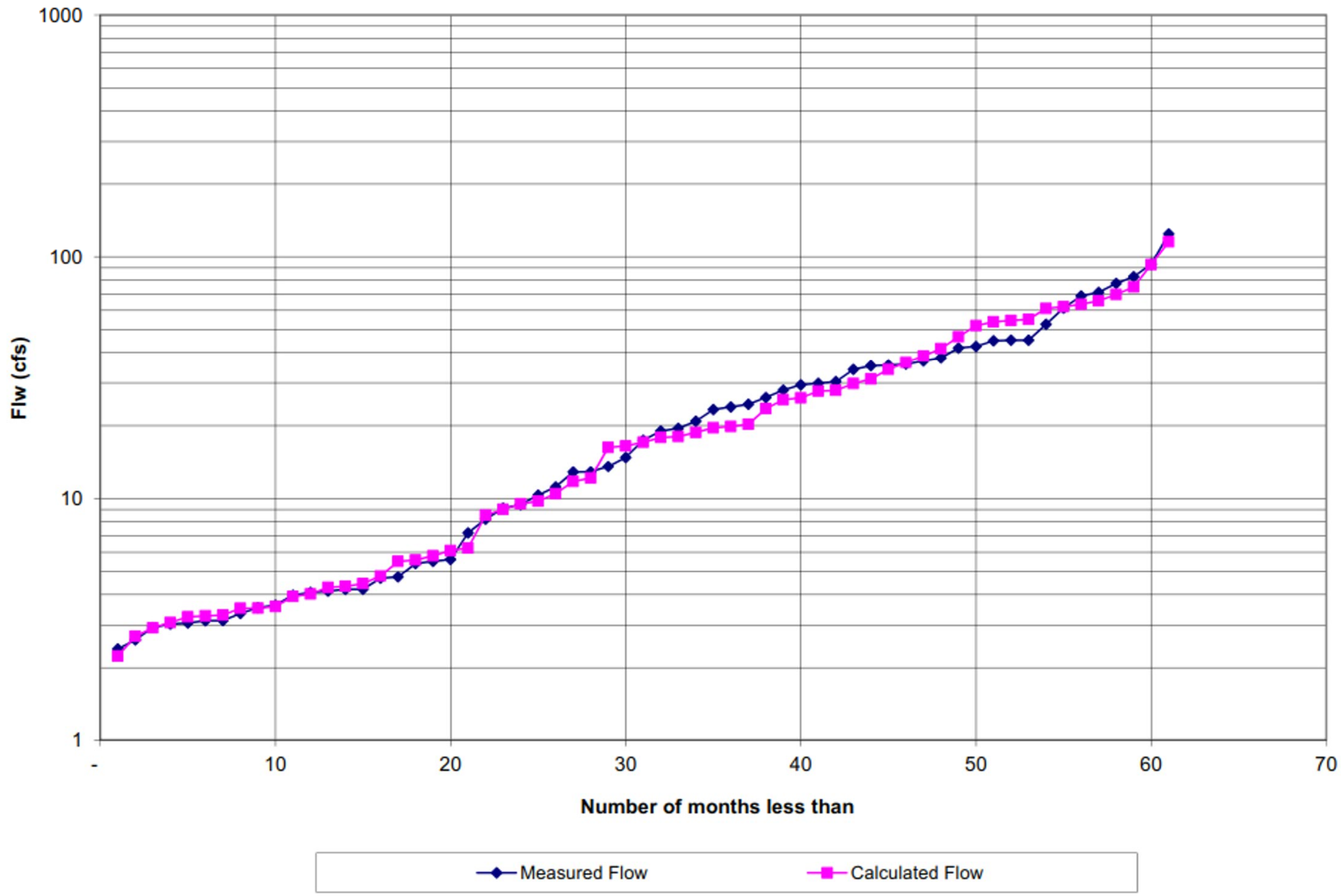
Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW NK119A

PEBBLE PROJECT EIS

FIGURE K3.16-4



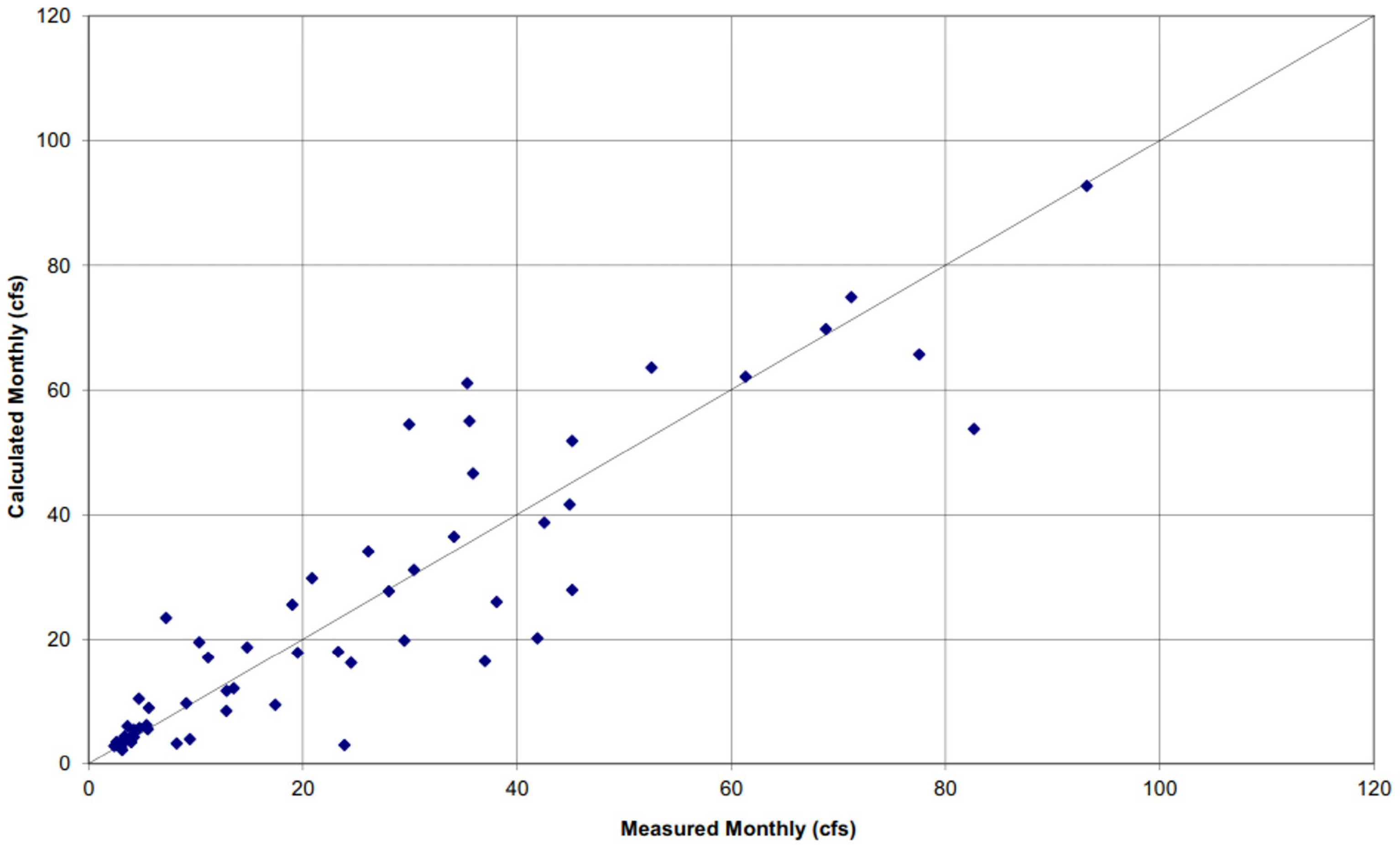
Sources: PLP RFI 104a

US Army Corps of Engineers®

NK119A FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-5



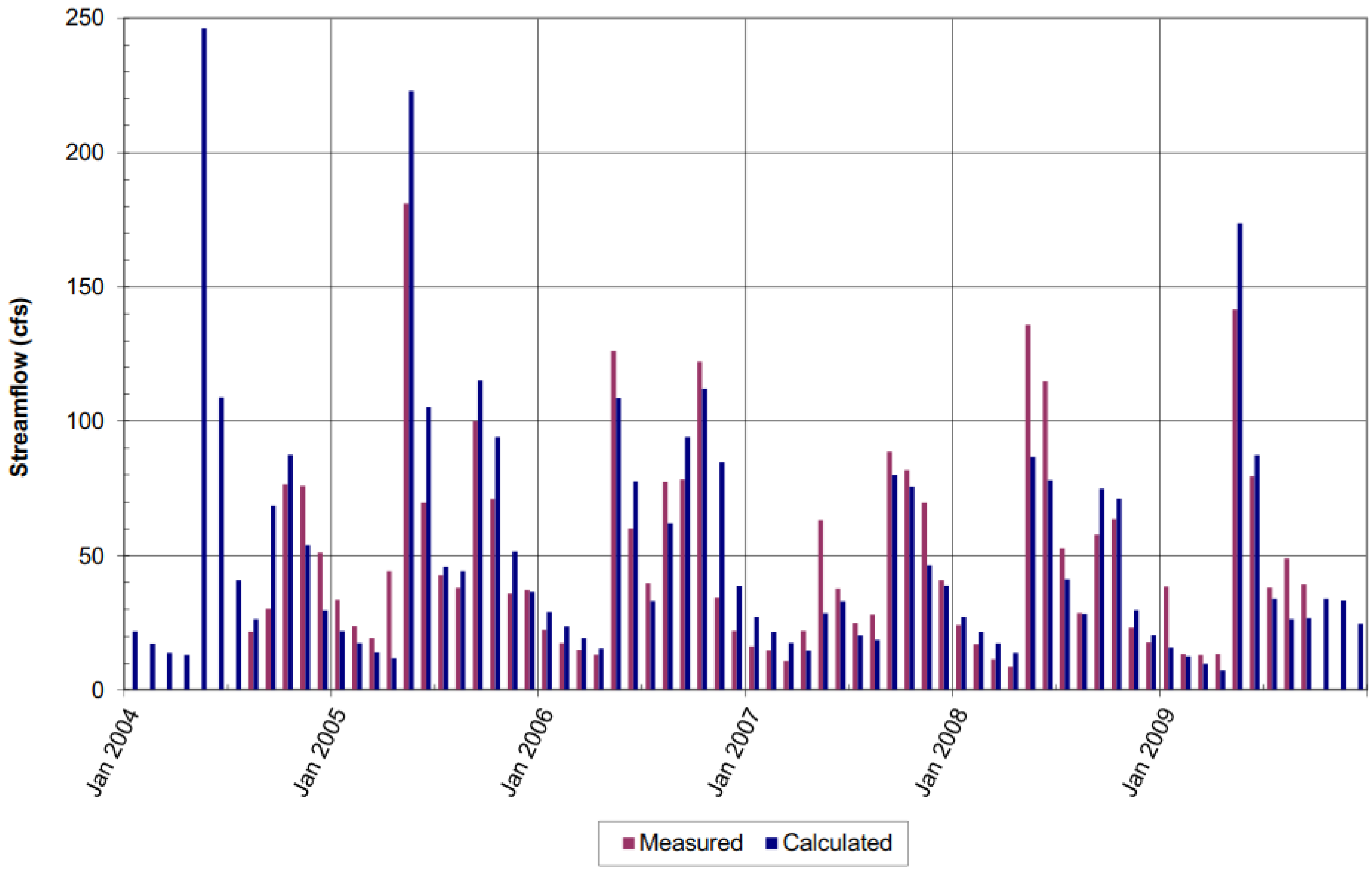
Sources: PLP RFI 104a

US Army Corps of Engineers

NK119A MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-6



Sources: PLP RFI 104a

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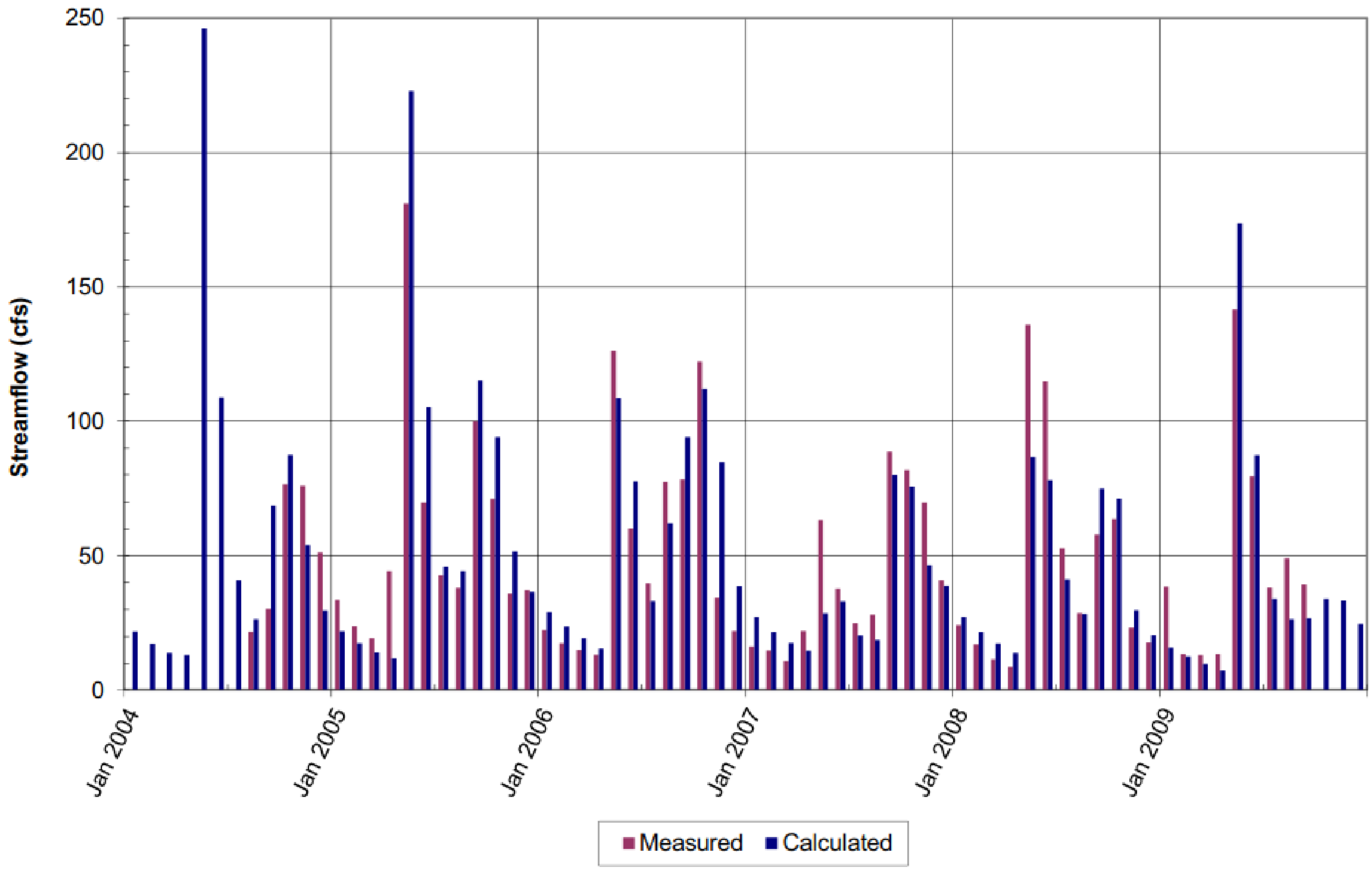
MEASURED AND CALCULATED STREAMFLOW NK100C



Sources: PLP RFI 104a

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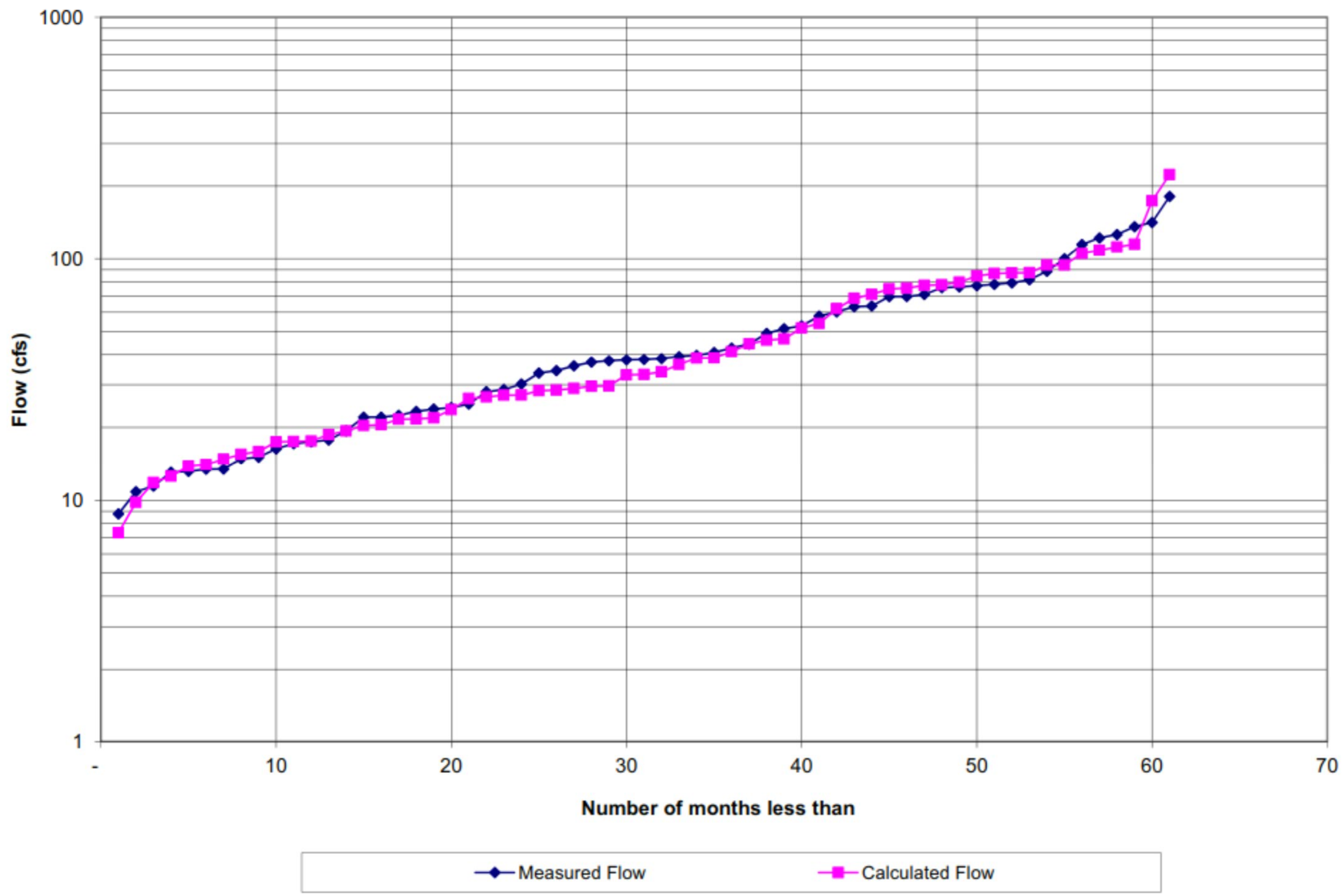
MEASURED AND CALCULATED STREAMFLOW NK100C

PEBBLE PROJECT EIS

FIGURE K3.16-8



Sources: PLP RFI 104a

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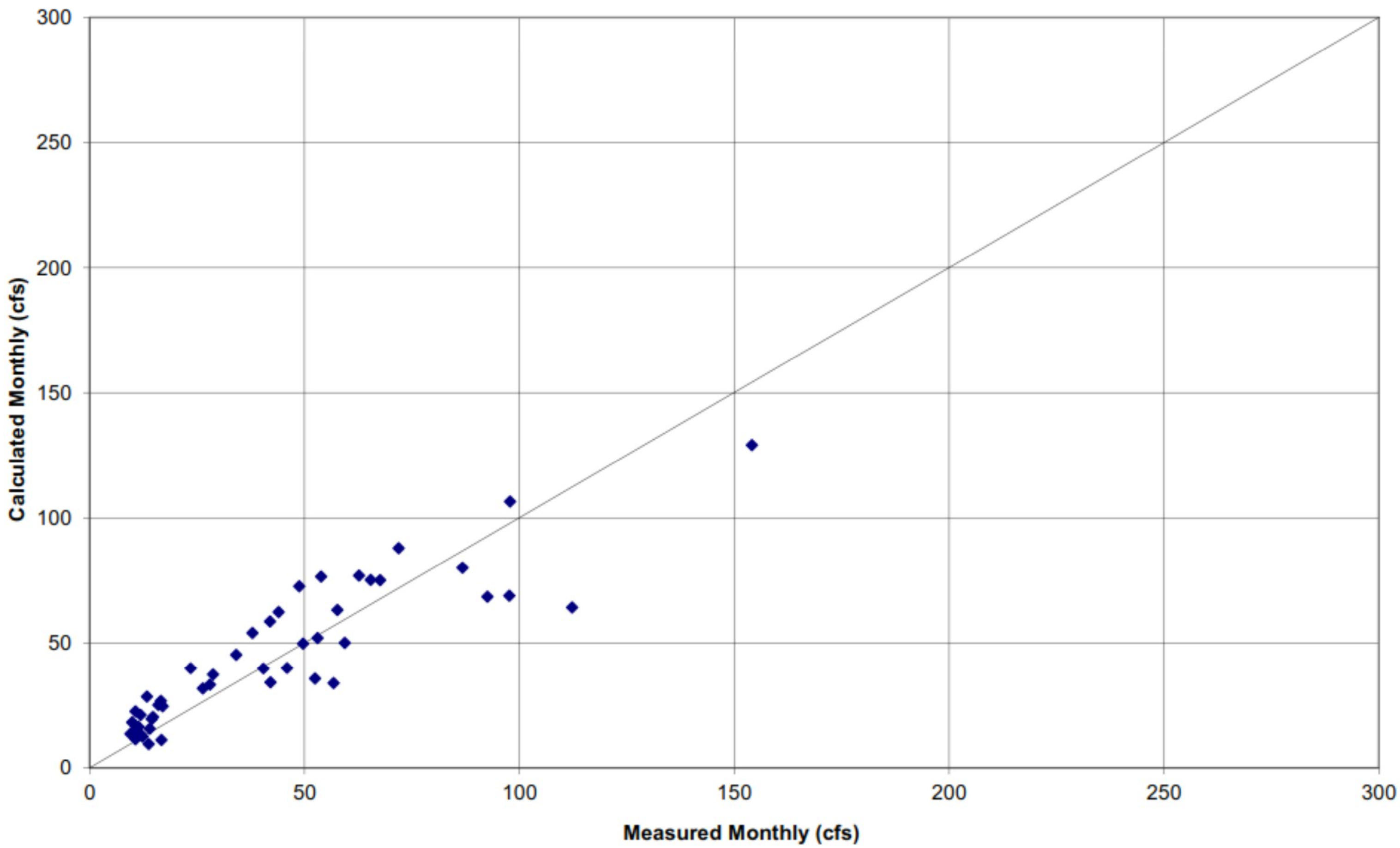
NK100C FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-9



Sources: PLP RFI 104a

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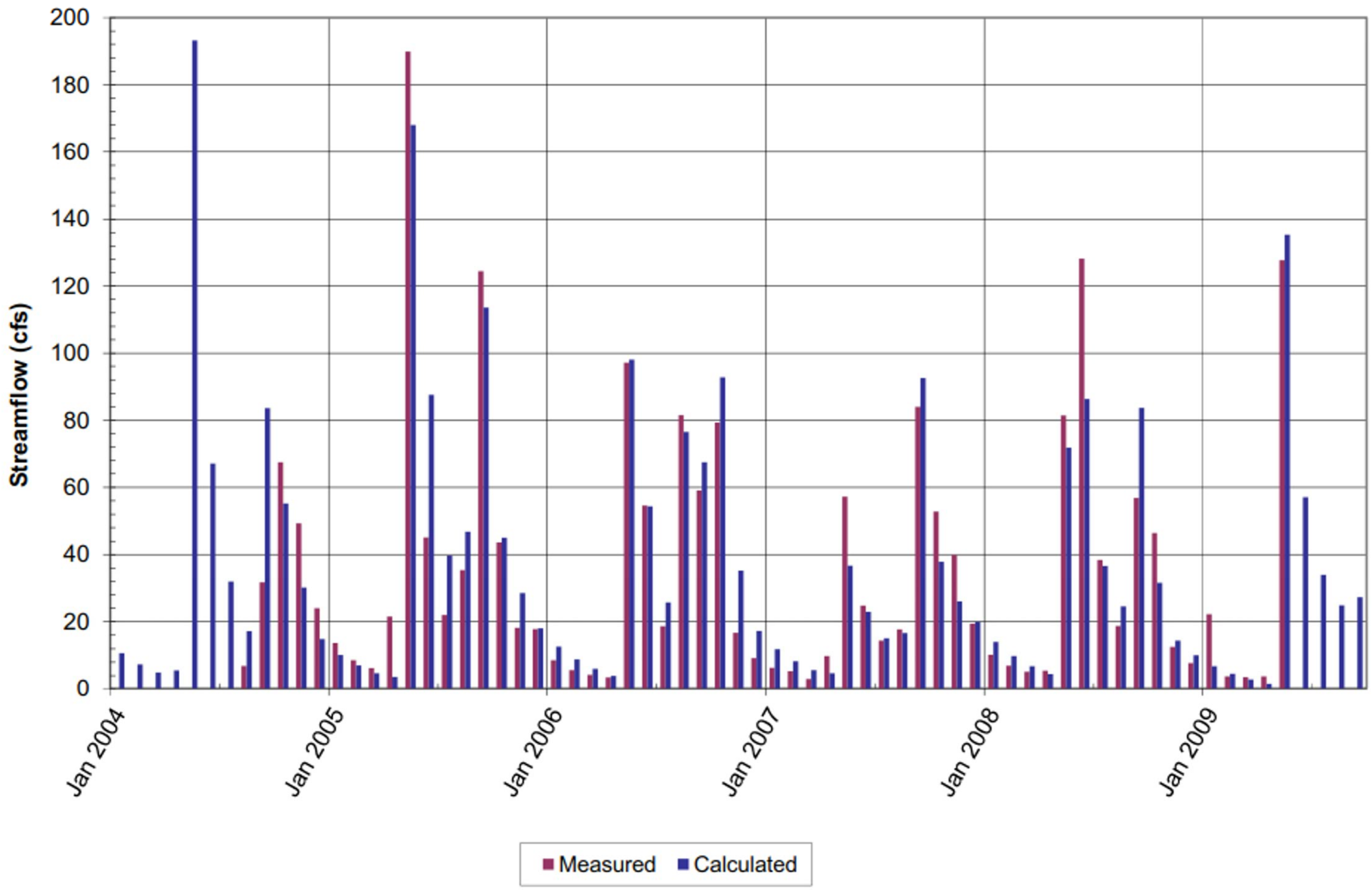
NK100C MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-10



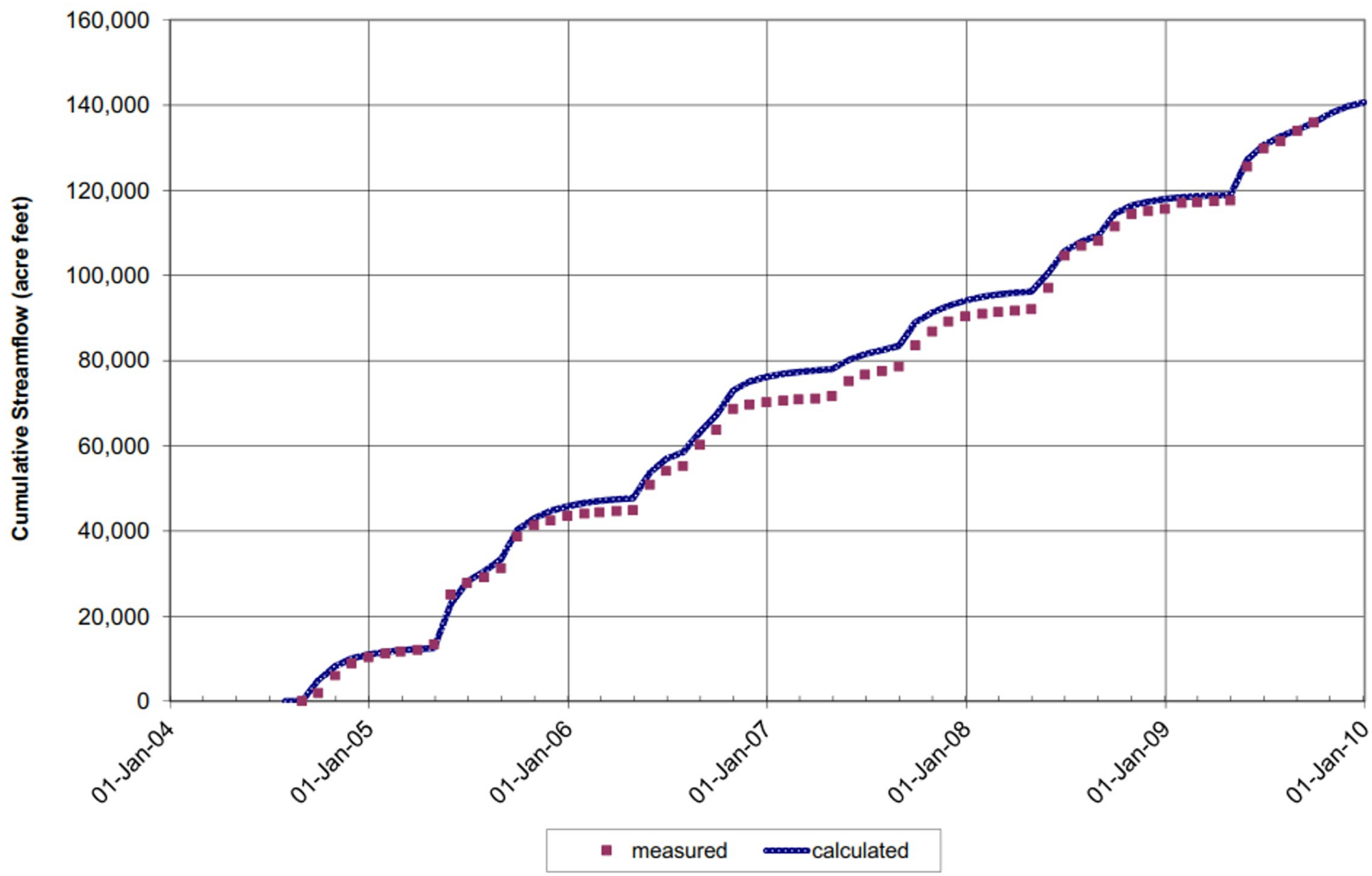
Sources: PLP RFI 104a

US Army Corps
of Engineers®

MEASURED AND CALCULATED STREAMFLOW SK119A

PEBBLE PROJECT EIS

FIGURE K3.16-11



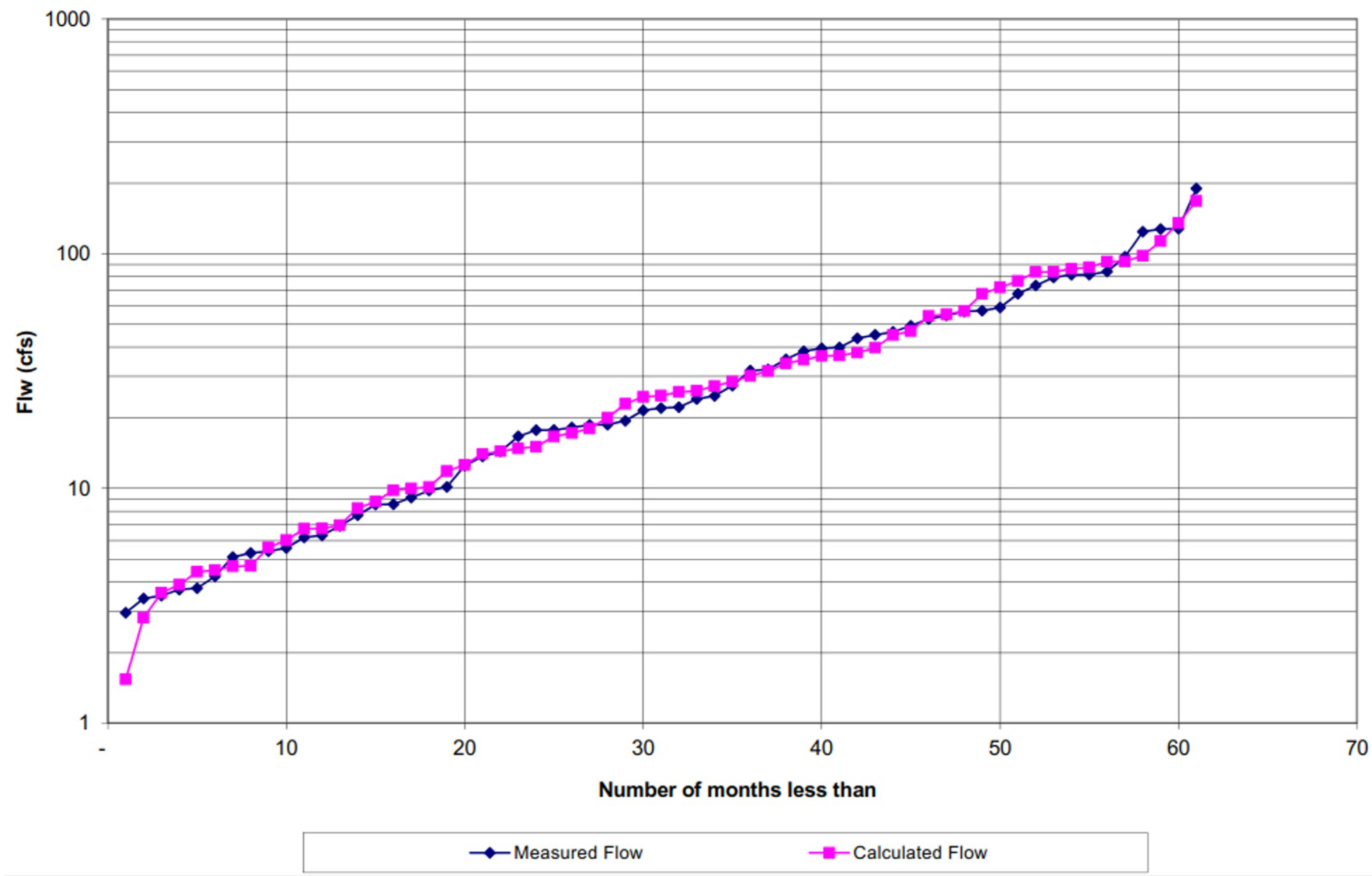
Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW SK119A

PEBBLE PROJECT EIS

FIGURE K3.16-12



Sources: PLP RFI 104a

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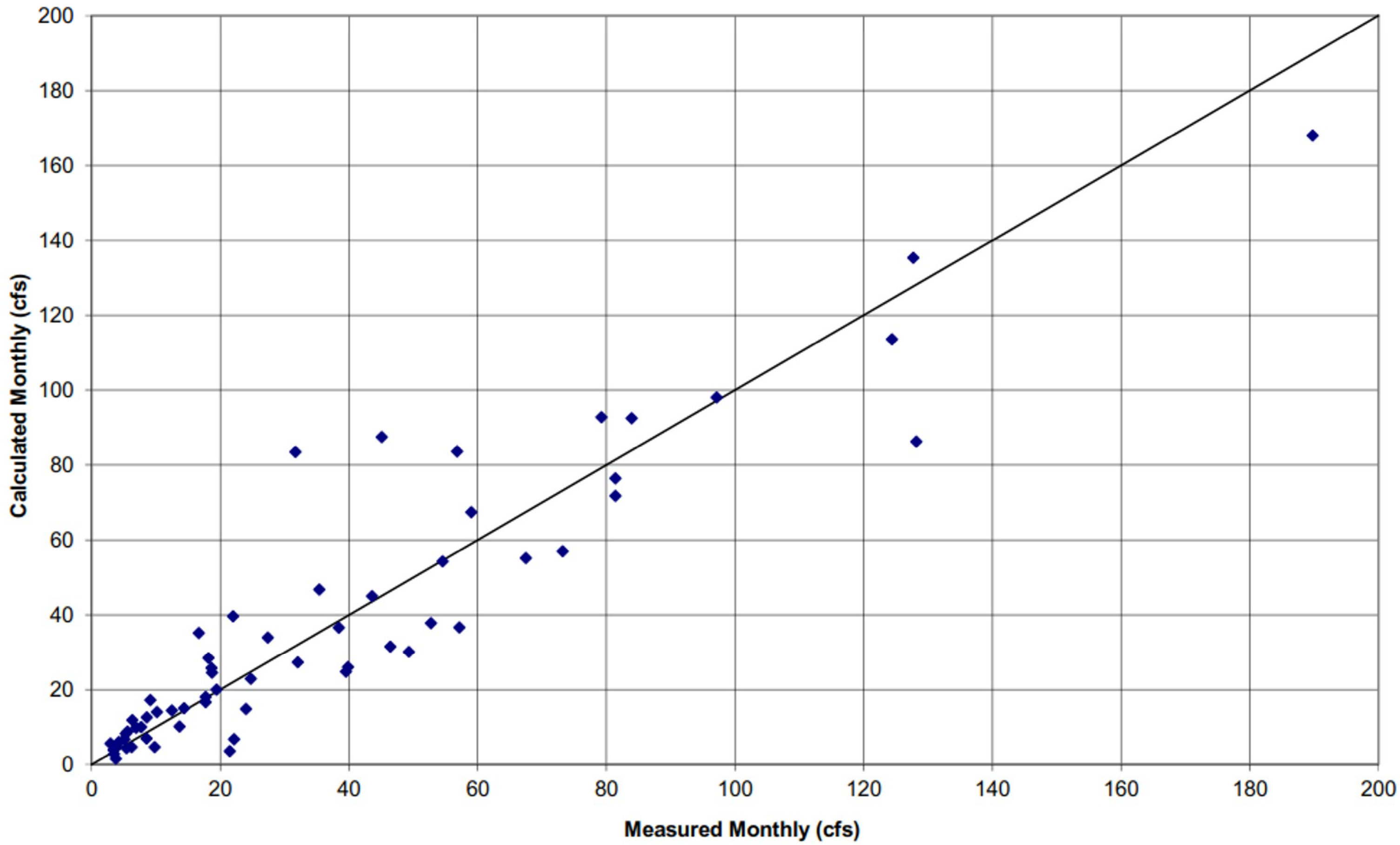
SK119A FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-13



Sources: PLP RFI 104a

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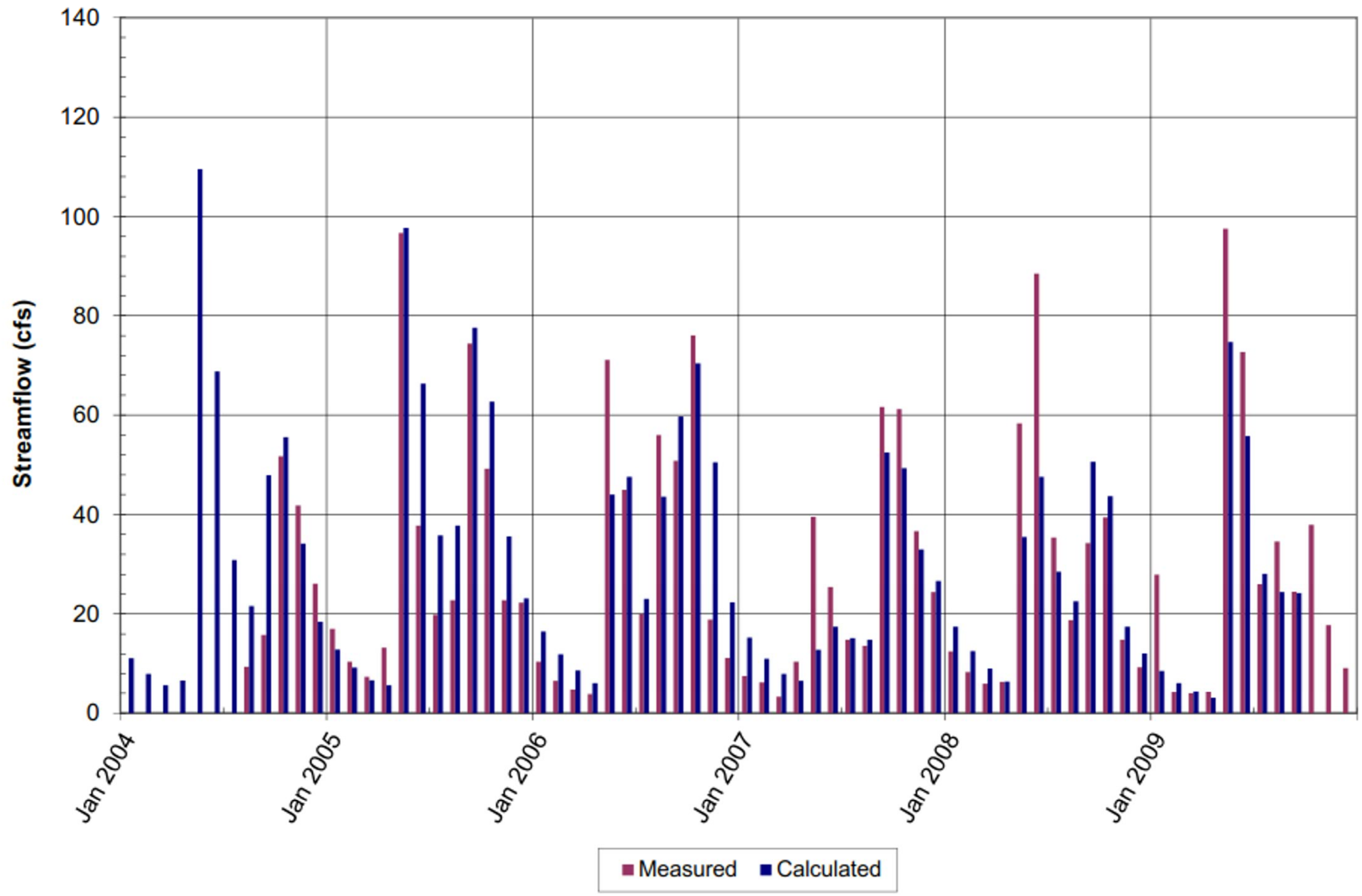
SK119A MEASURED VERSUS CALCULATED



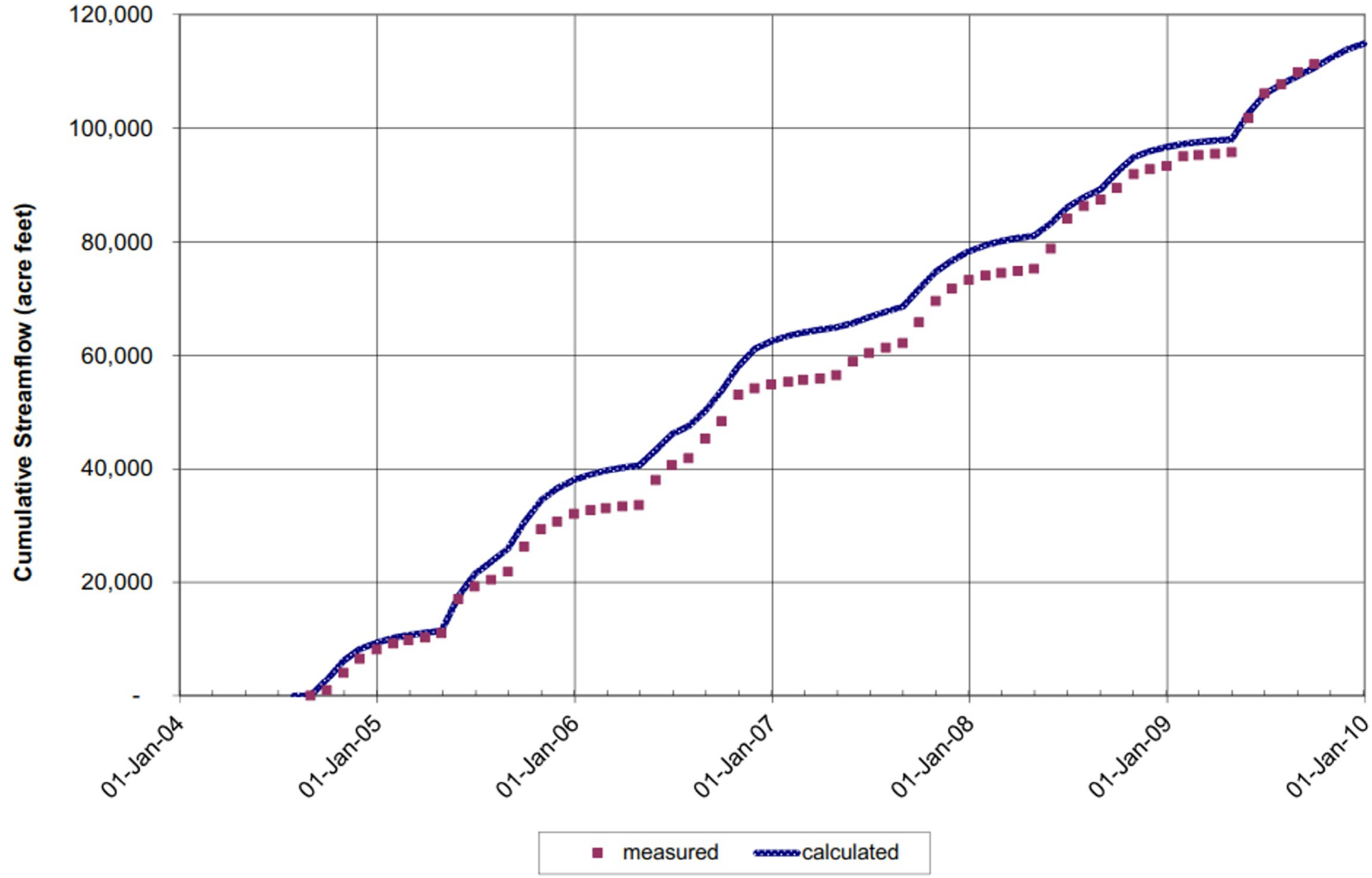
Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED STREAMFLOW SK100F

PEBBLE PROJECT EIS

FIGURE K3.16-15



Sources: PLP RFI 104a

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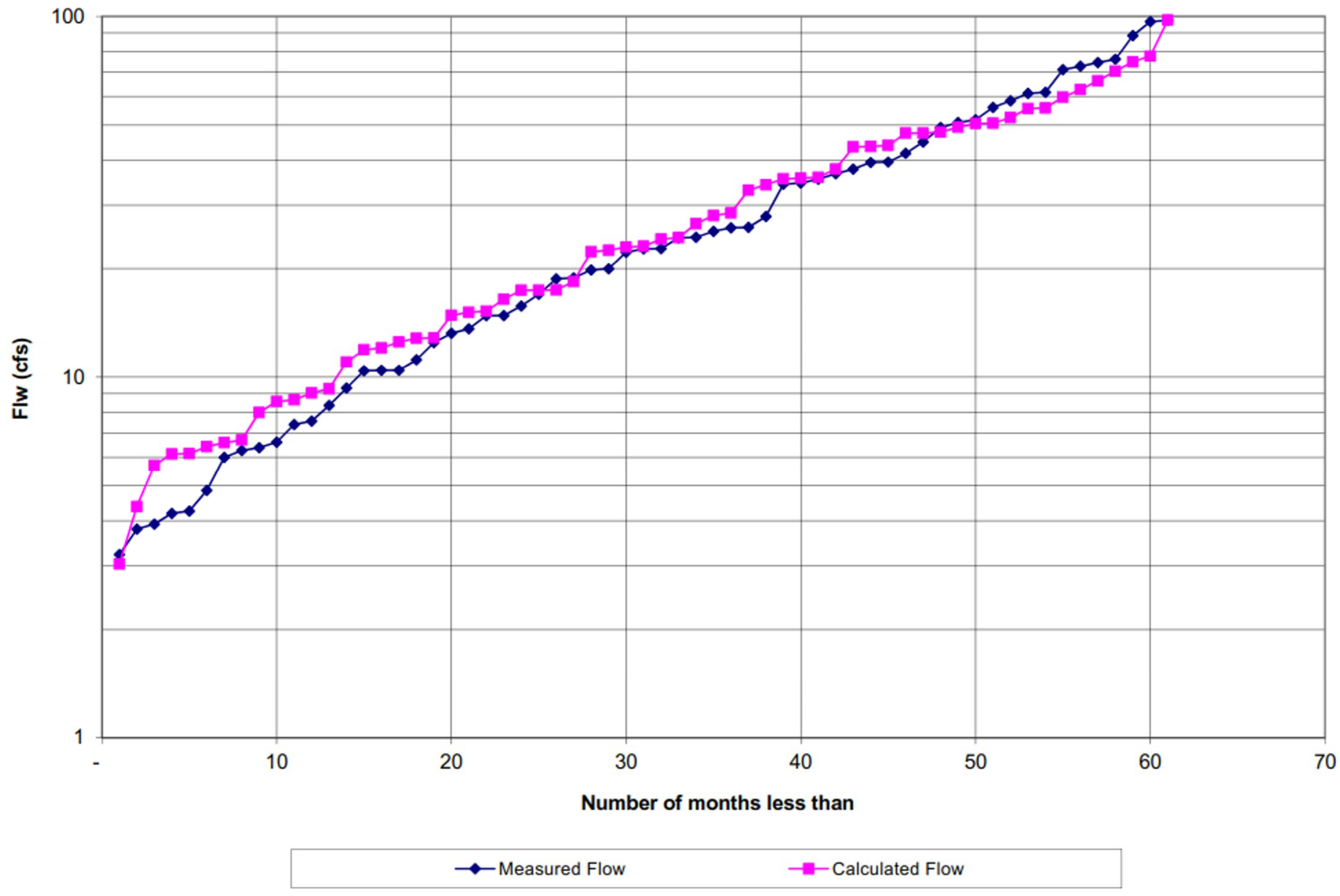
MEASURED AND CALCULATED CUMULATIVE STREAMFLOW SK100F



Sources: PLP RFI 104a

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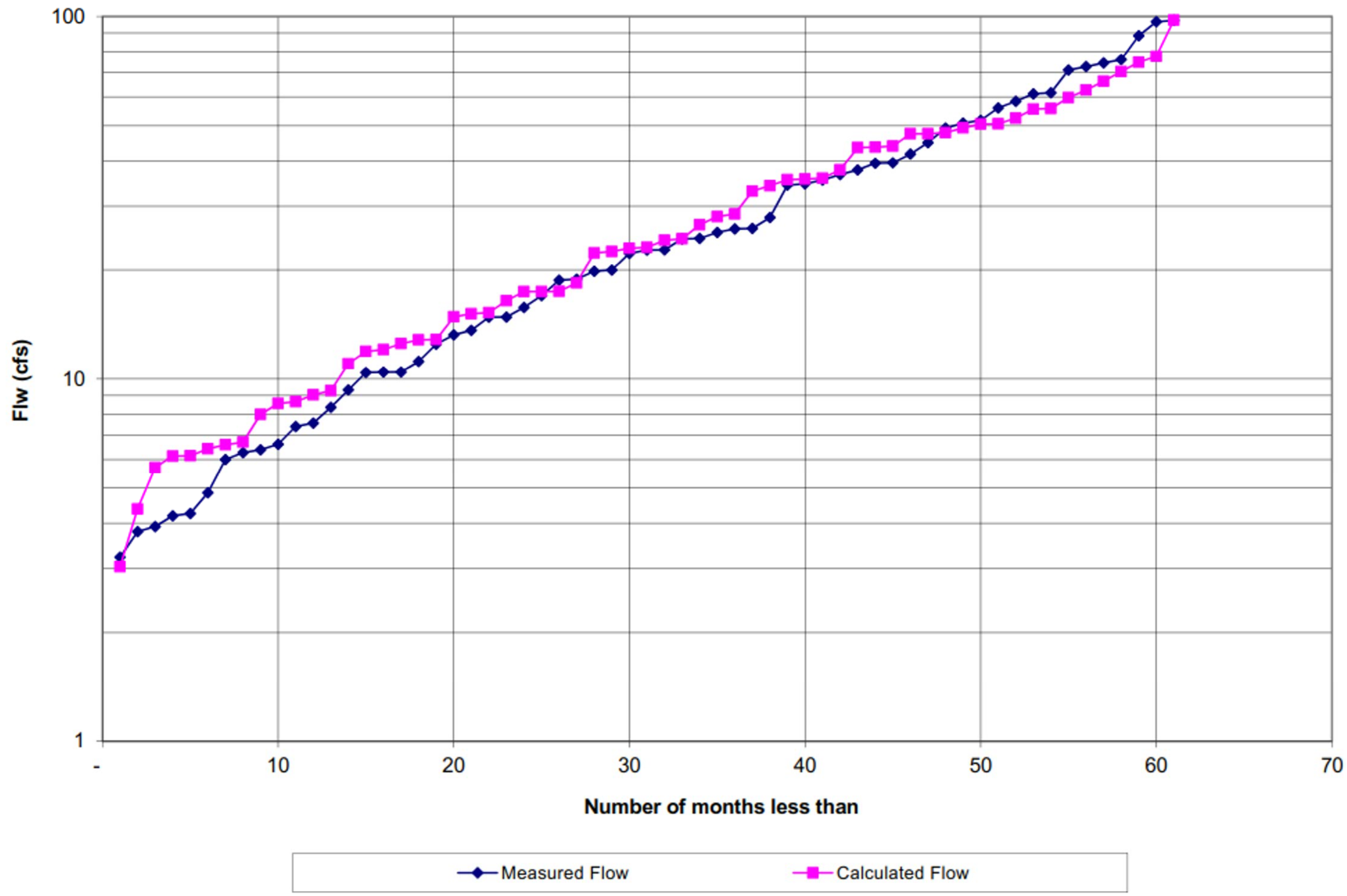
SK100F FLOW DISTRIBUTION



Sources: PLP RFI 104a

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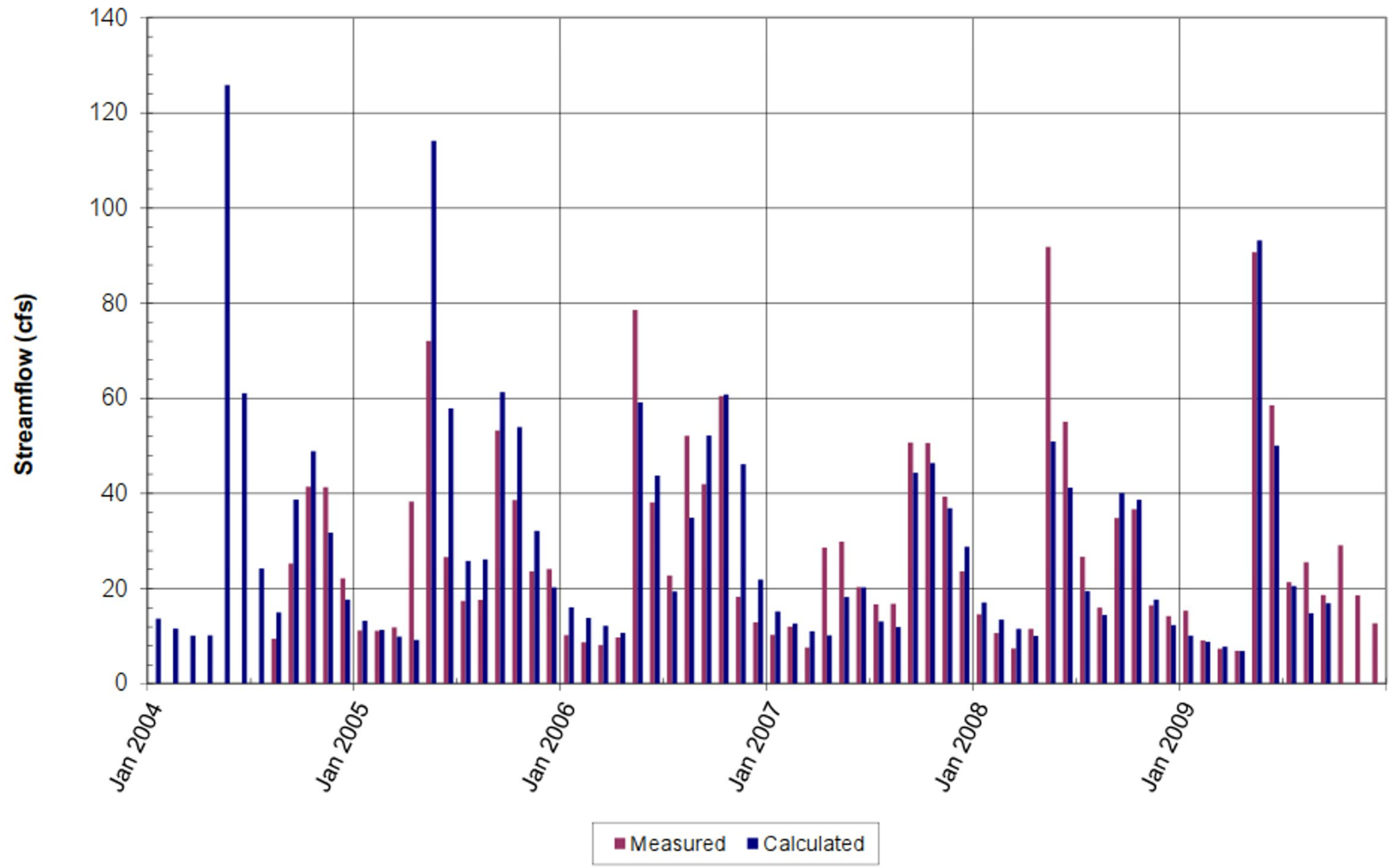
SK100F MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-18



Sources: PLP RFI 104a

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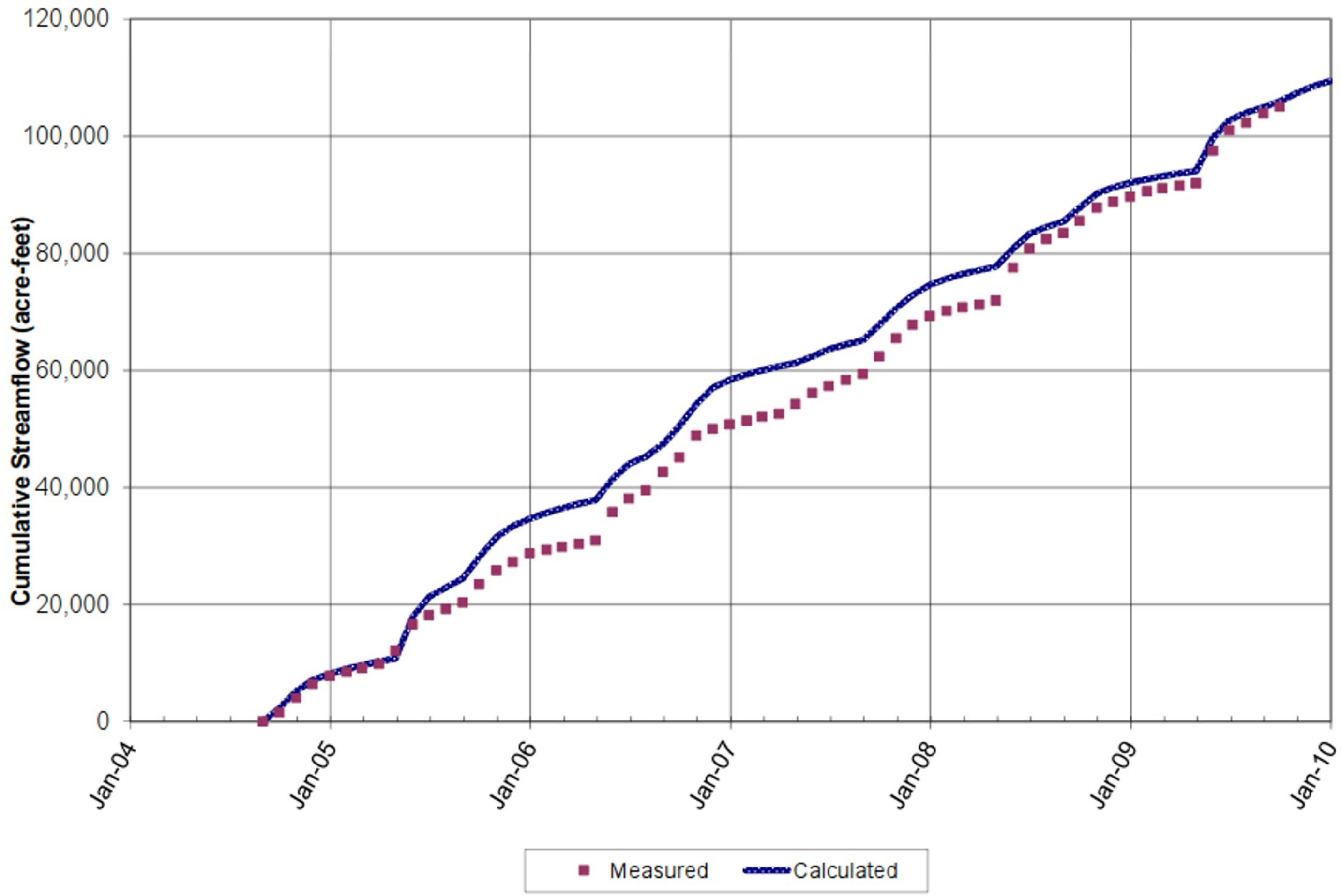
MEASURED AND CALCULATED STREAMFLOW UT100D

PEBBLE PROJECT EIS

FIGURE K3.16-19



Sources: PLP RFI 104a

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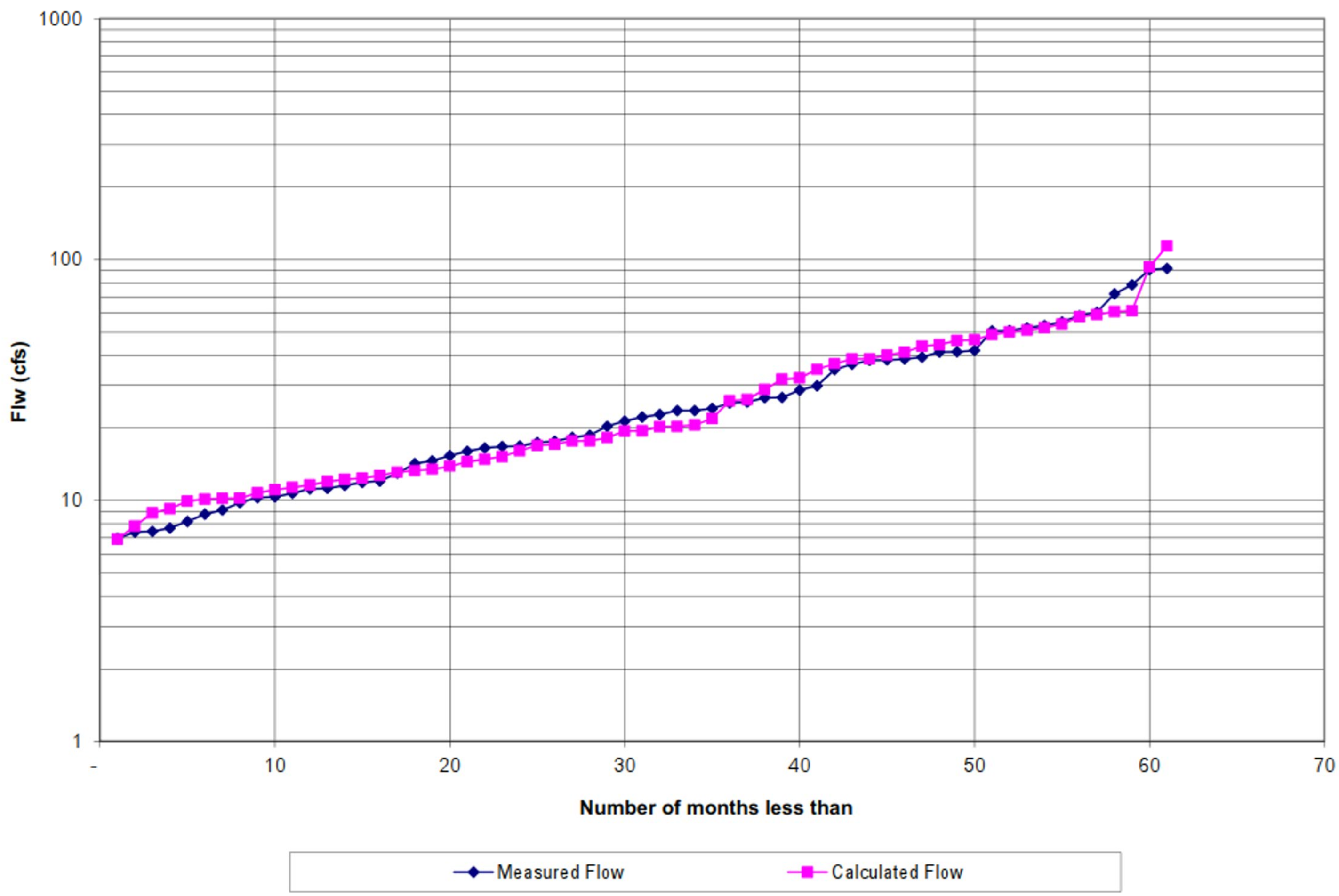
MEASURED AND CALCULATED CUMULATIVE STREAMFLOW UT100D

PEBBLE PROJECT EIS

FIGURE K3.16-20



Sources: PLP RFI 104a

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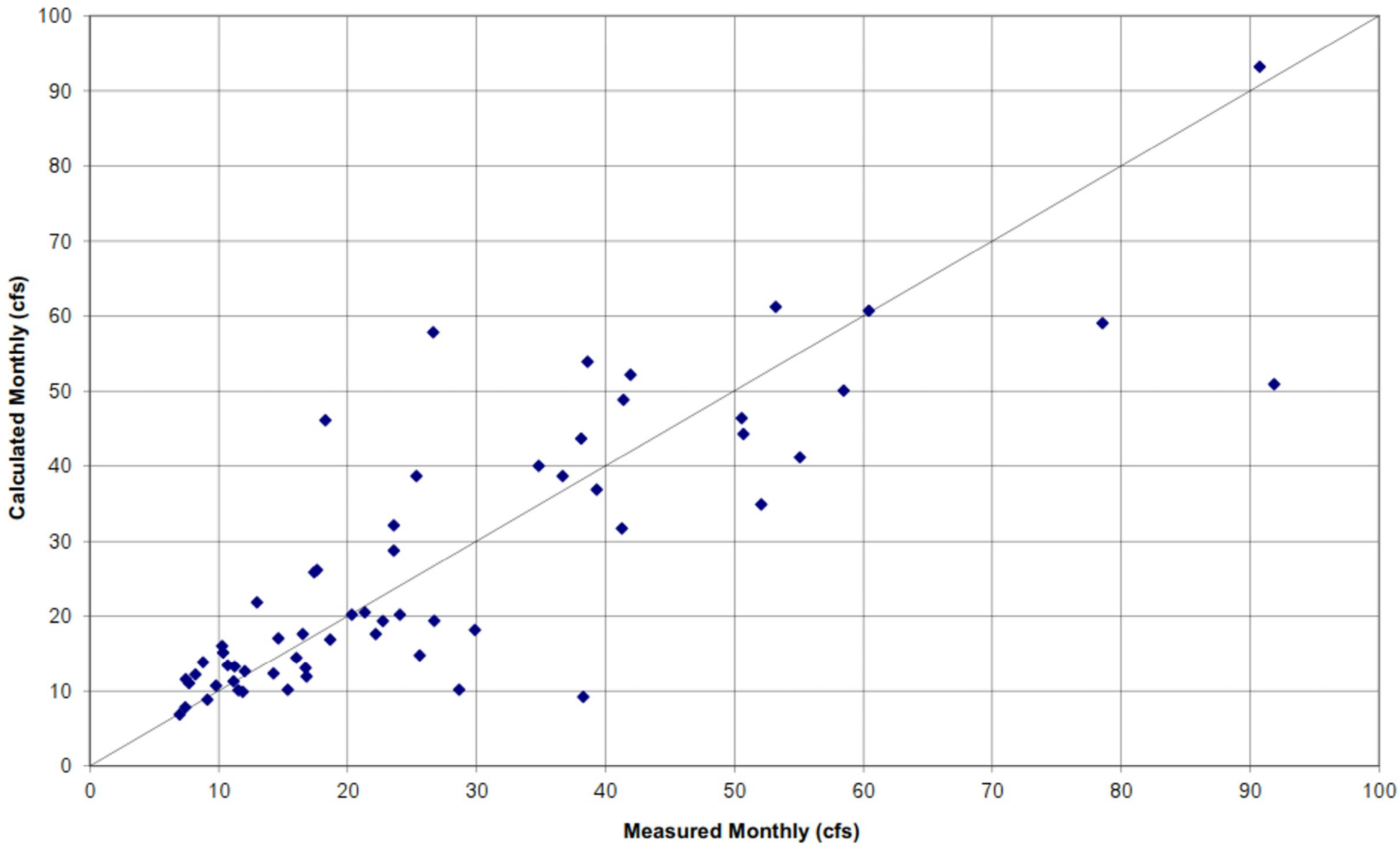
UT100D FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-21



Sources: PLP RFI 104a

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UT100D MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-22

K3.16.2.2 Validation

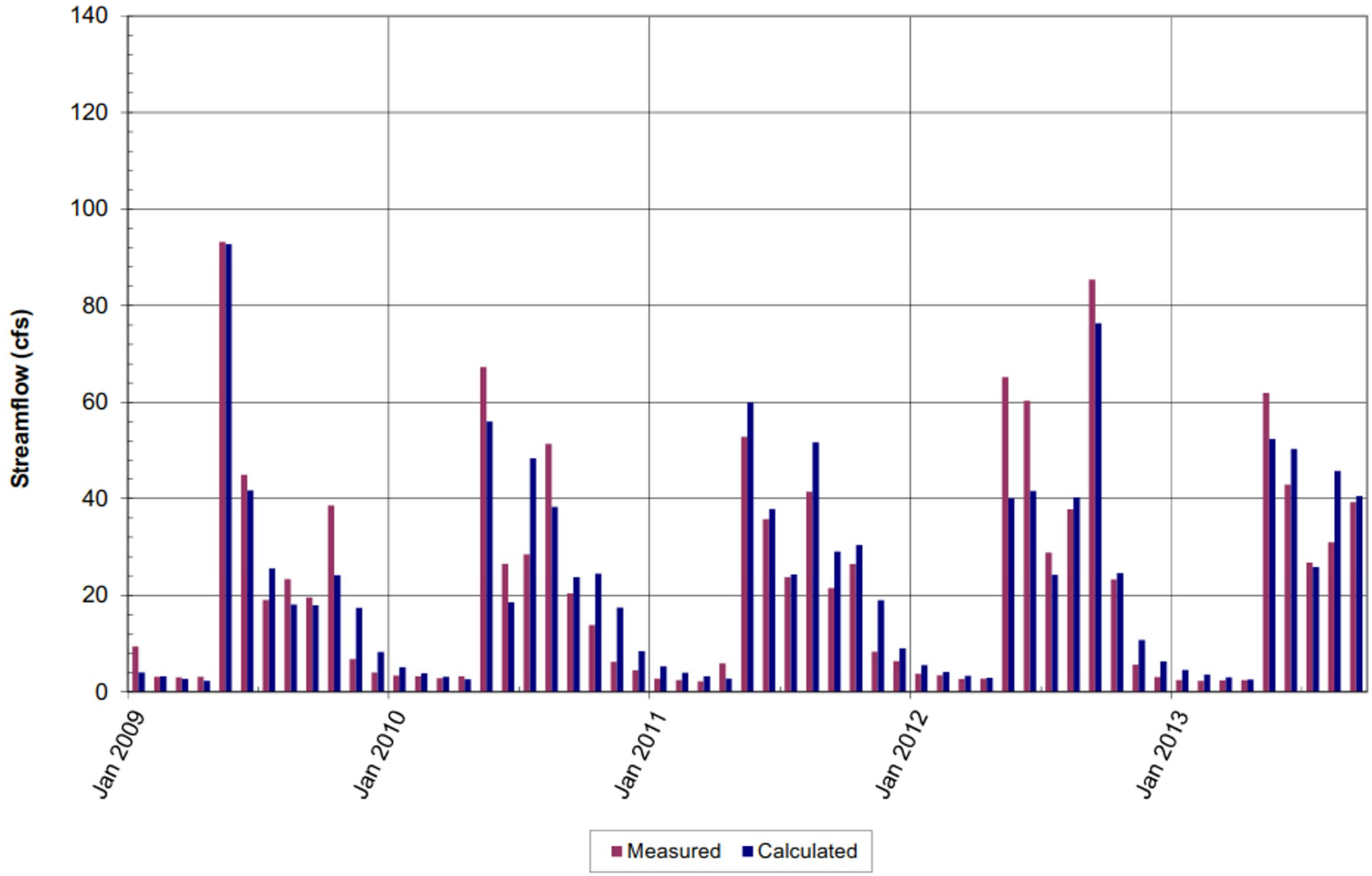
The watershed module was validated over the period from October 2009 through September 2013. This validation period spans from the end of the calibration period to the time when on-site gaging stations became inactive. The validation was conducted by extending the monthly precipitation and temperature strings input to the model. No changes were made to any calibration parameters (PLP 2019-RFI 104).

Results of the model validation are shown using the same four plot types (a through d) as the model calibration. The validation plots include flows during the validation period only. Validation plots are presented in Figure K3.16-23 through Figure K3.16-42, and represent the same gaging stations selected for calibration. As shown in the plots, flows are as well predicted for the validation period as for the calibration period. The cumulative flow plots (b plots), which show the total modelled and measured flow leaving a catchment, visually show a comparable or better match between measured and simulated cumulative flows during the validation period than the calibration period. The streamflow distribution plots (c plots) show that the model represents the occurrence of higher flows in the simulated records well; however, the lower frequency flows are over-predicted by the model at most stations. Winter low flows at each gaging station are estimated by correlation with flows measured at the three US Geological Survey (USGS) gages (at NK 100A, SK 100B, and UT 100B). Winter low flows at the three USGS gages were lower in years following 2009 than years prior. As a result of the correlation to USGS data, winter low flows in the “measured” record of the on-site gaging stations were similarly estimated to have lower winter flows after 2009. The model over-predicts these lowest flows, which suggests the model may not predict the lowest flows during drier periods (PLP 2019-RFI 104).

K3.16.3 Long-Term Climate Change

K3.16.3.1 Temperature

The Knight Piésold studies (2009, 2018g) noted that the 1943 through 2016 temperature records for Iliamna airport appear to indicate that temperatures near the mine site are increasing over time. Mean temperatures appear to be increasing an average of 0.06°F per year and annual minimum daily temperatures appear to be increasing an average of 0.13°F per year. Assuming this trend would continue, over the next three decades, this equates to an increase of 1.8°F in the mean annual temperature and an increase of 3.9°F in the average annual minimum daily temperature. These changes are generally consistent with the climate change projections of the US Global Change Research Program (USGCRP 2017) which states: “…over the next few decades (2021-2050), annual average temperatures are expected to rise by about 2.5°F for the United States relative to the recent past (average from 1976-2005), under all plausible future climate scenarios.”



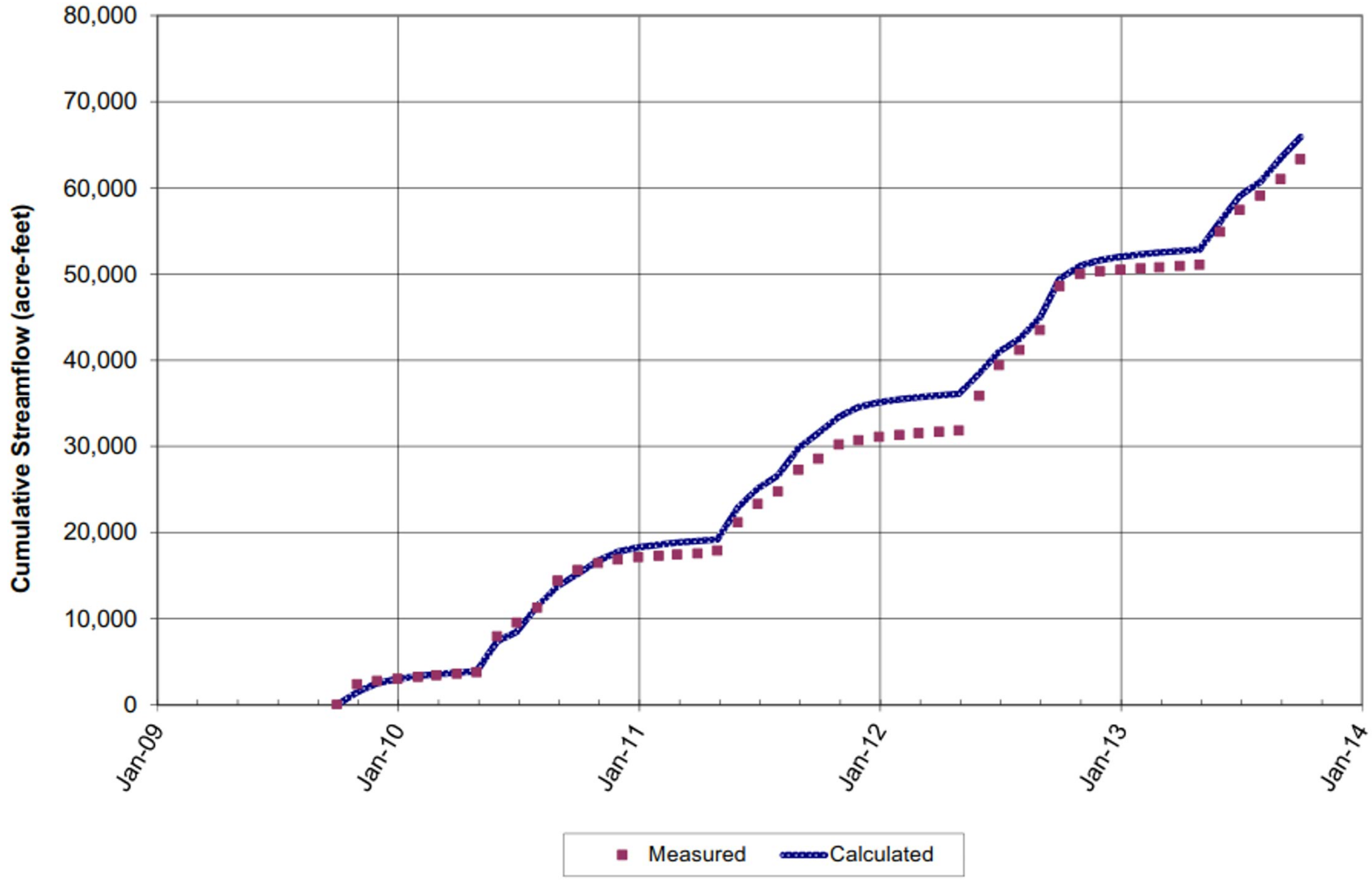
Sources: PLP RFI 104a

US Army Corps of Engineers

MEASURED AND CALCULATED STREAMFLOW NK119A

PEBBLE PROJECT EIS

FIGURE K3.16-23



Sources: PLP RFI 104a

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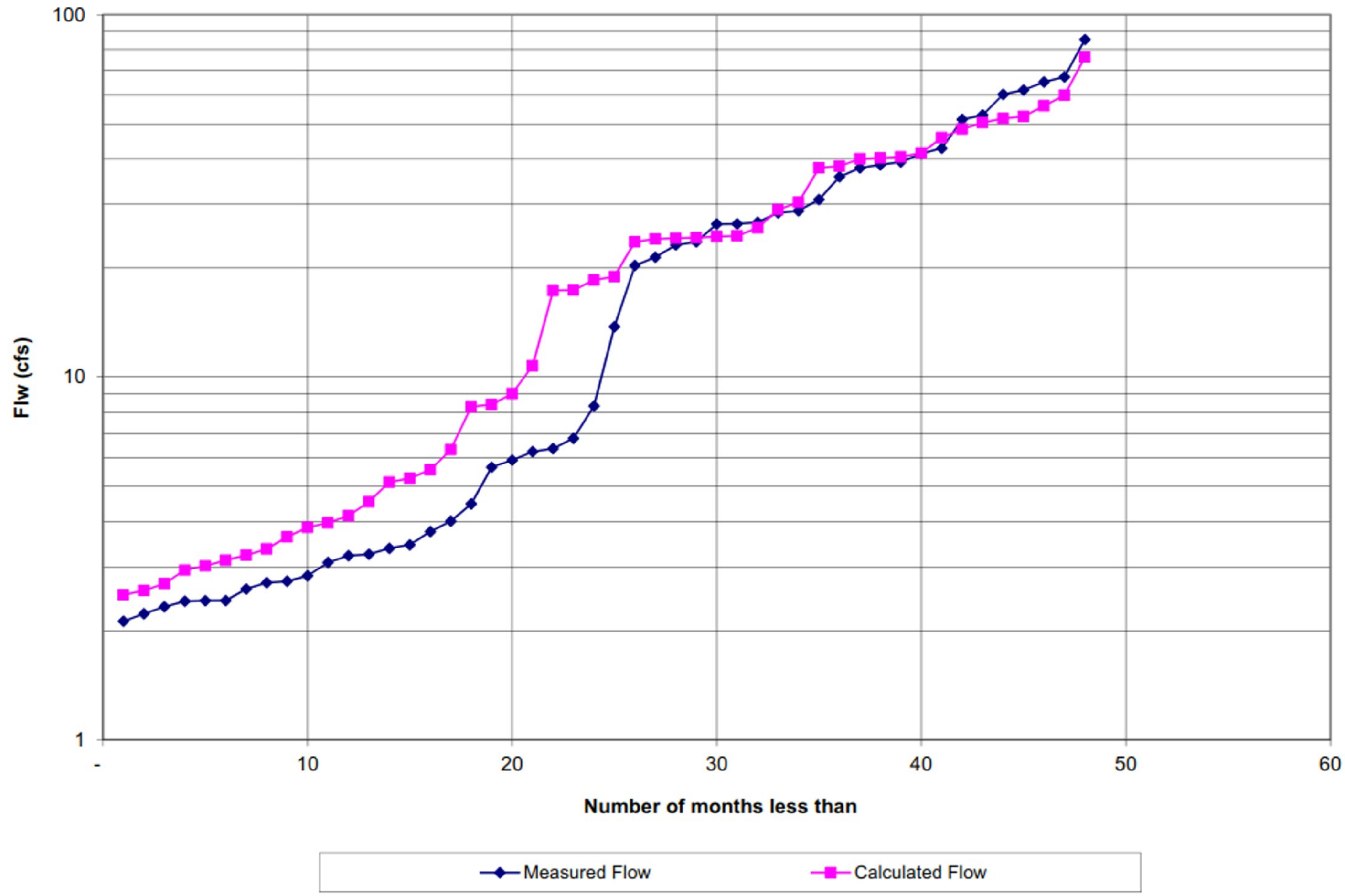
MEASURED AND CALCULATED CUMULATIVE STREAMFLOW NK119A

PEBBLE PROJECT EIS

FIGURE K3.16-24



Sources: PLP RFI 104a

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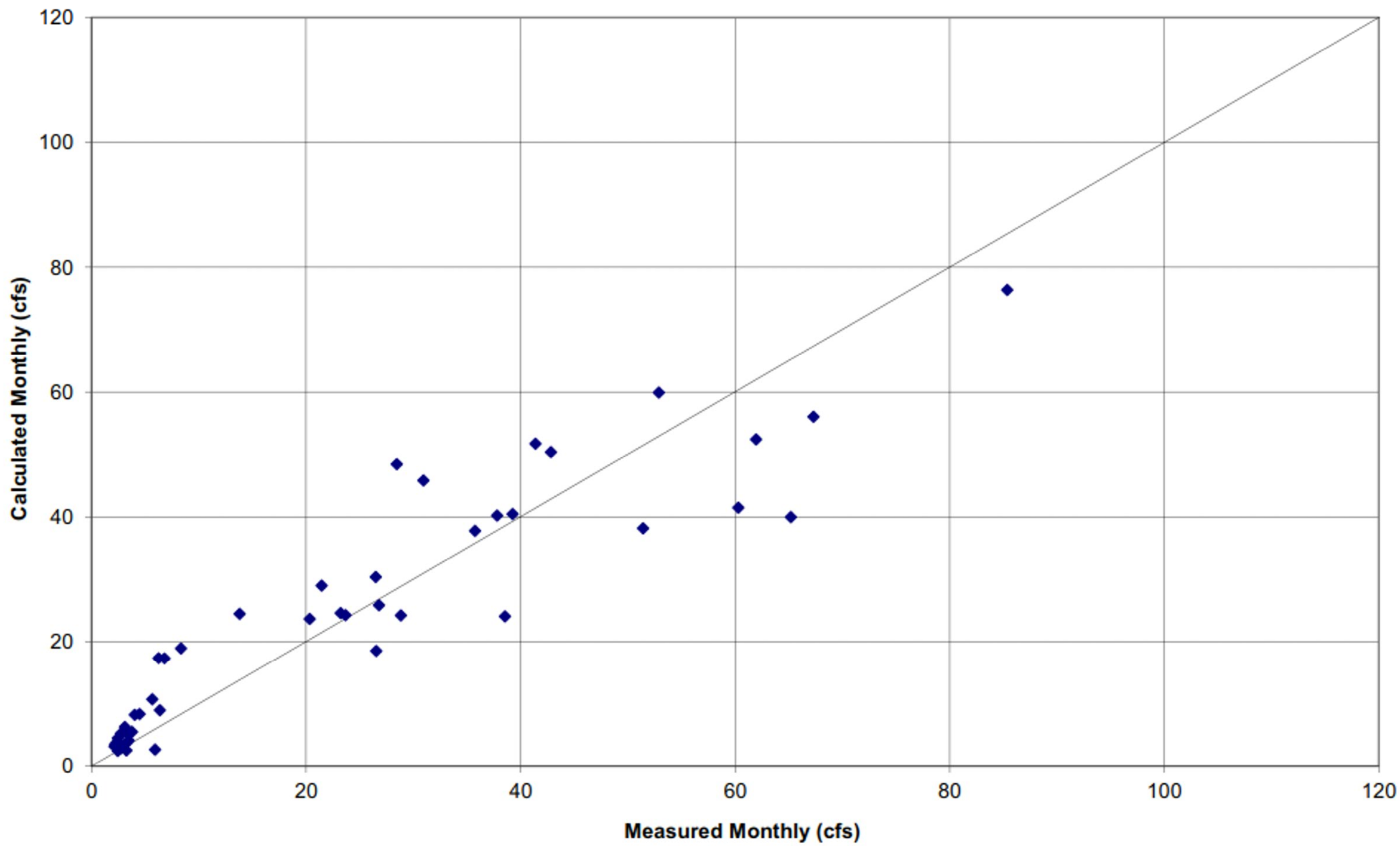
NK119A FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-25



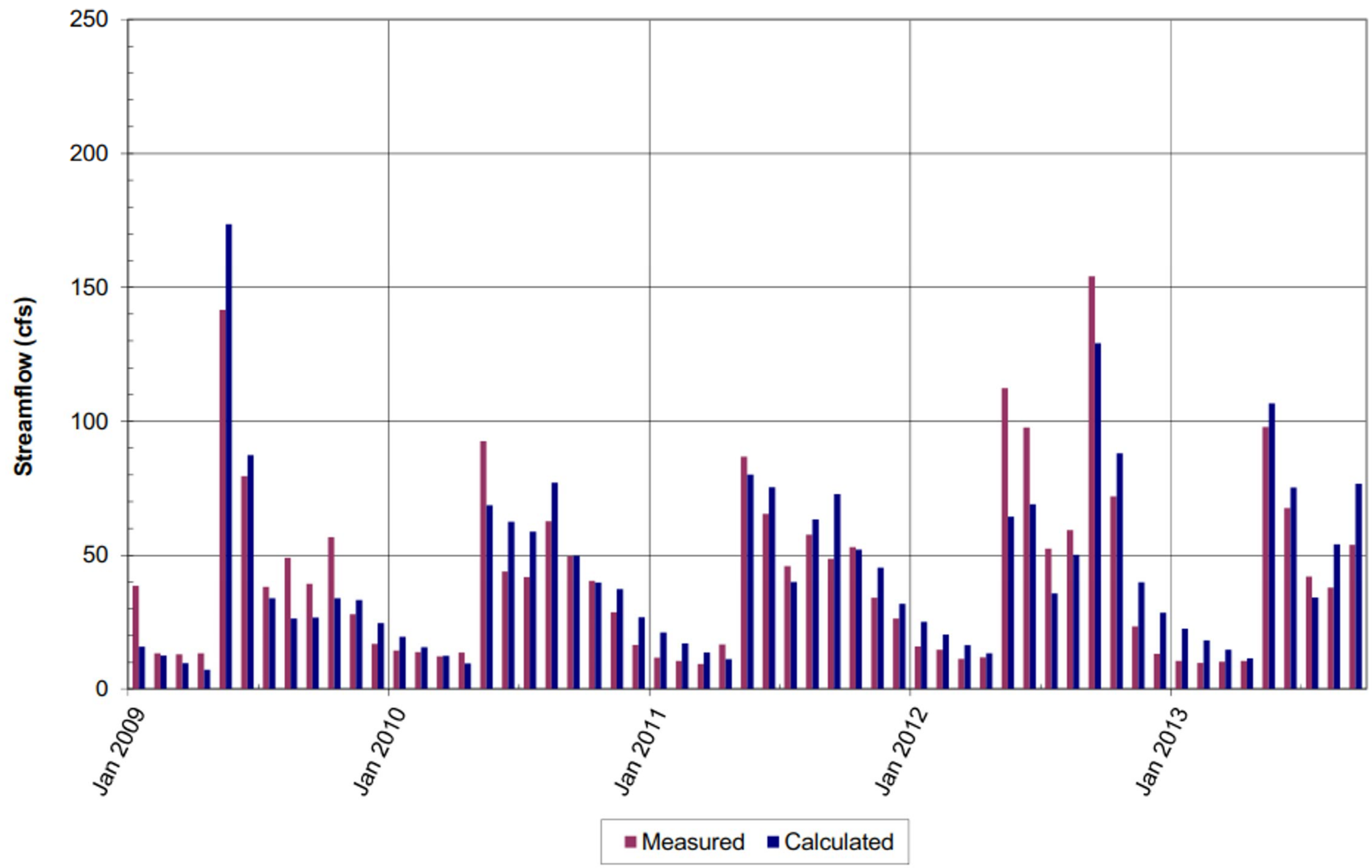
Sources: PLP RFI 104a

US Army Corps of Engineers®

NK119A MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-26



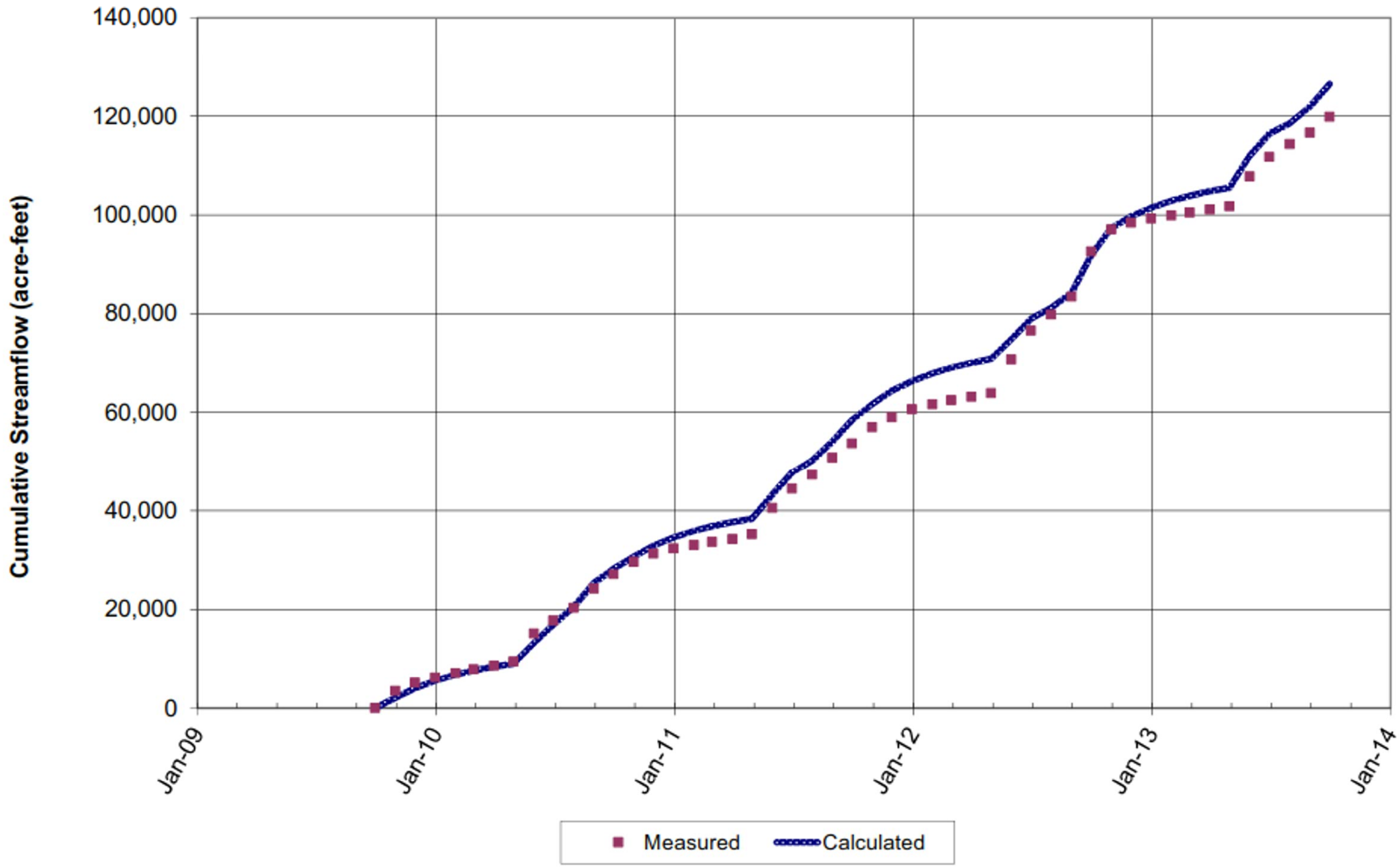
Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED STREAMFLOW NK100C

PEBBLE PROJECT EIS

FIGURE K3.16-27



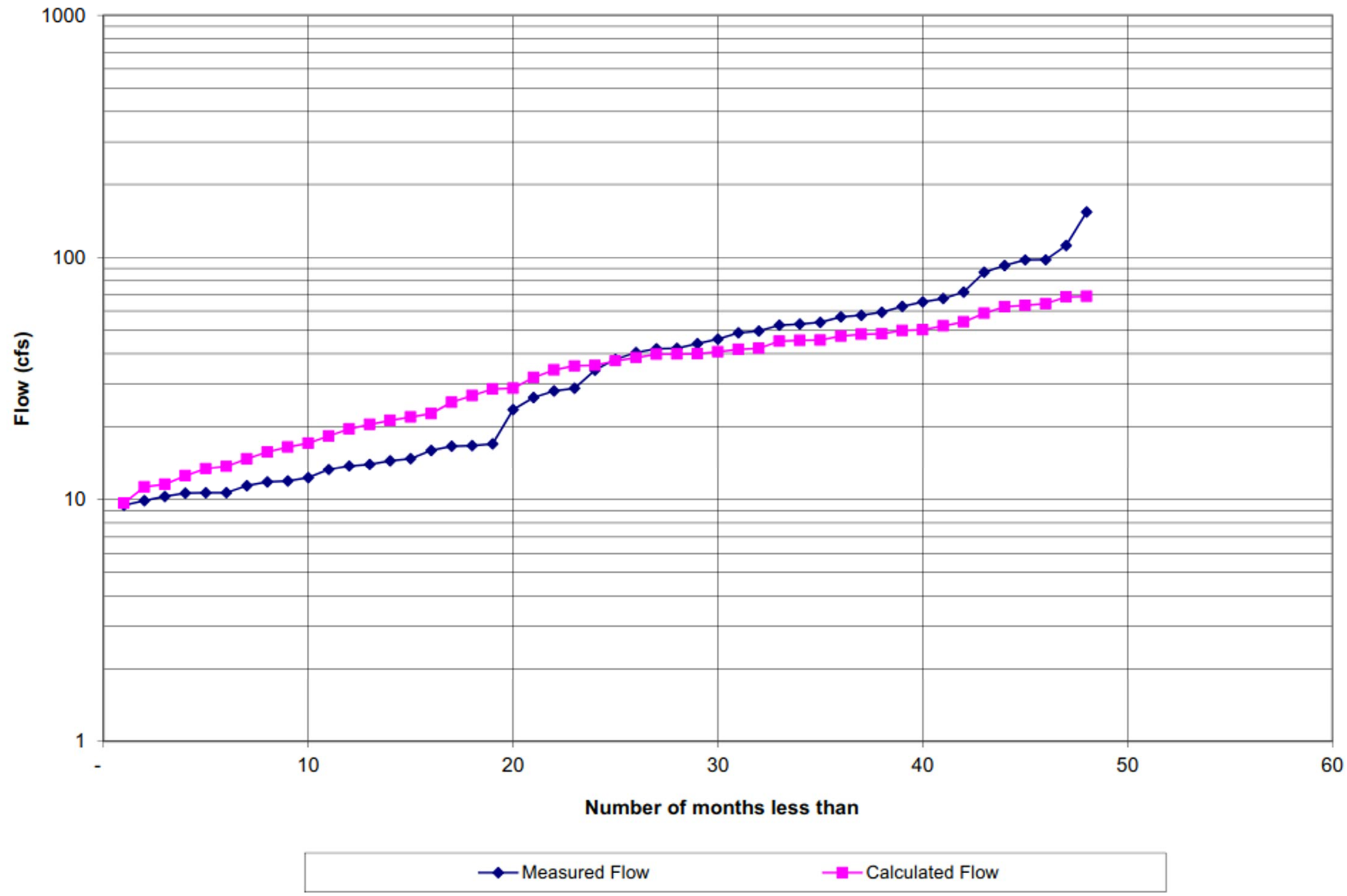
Sources: PLP RFI 104a

US Army Corps of Engineers

PEBBLE PROJECT EIS

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW NK100C

FIGURE K3.16-28

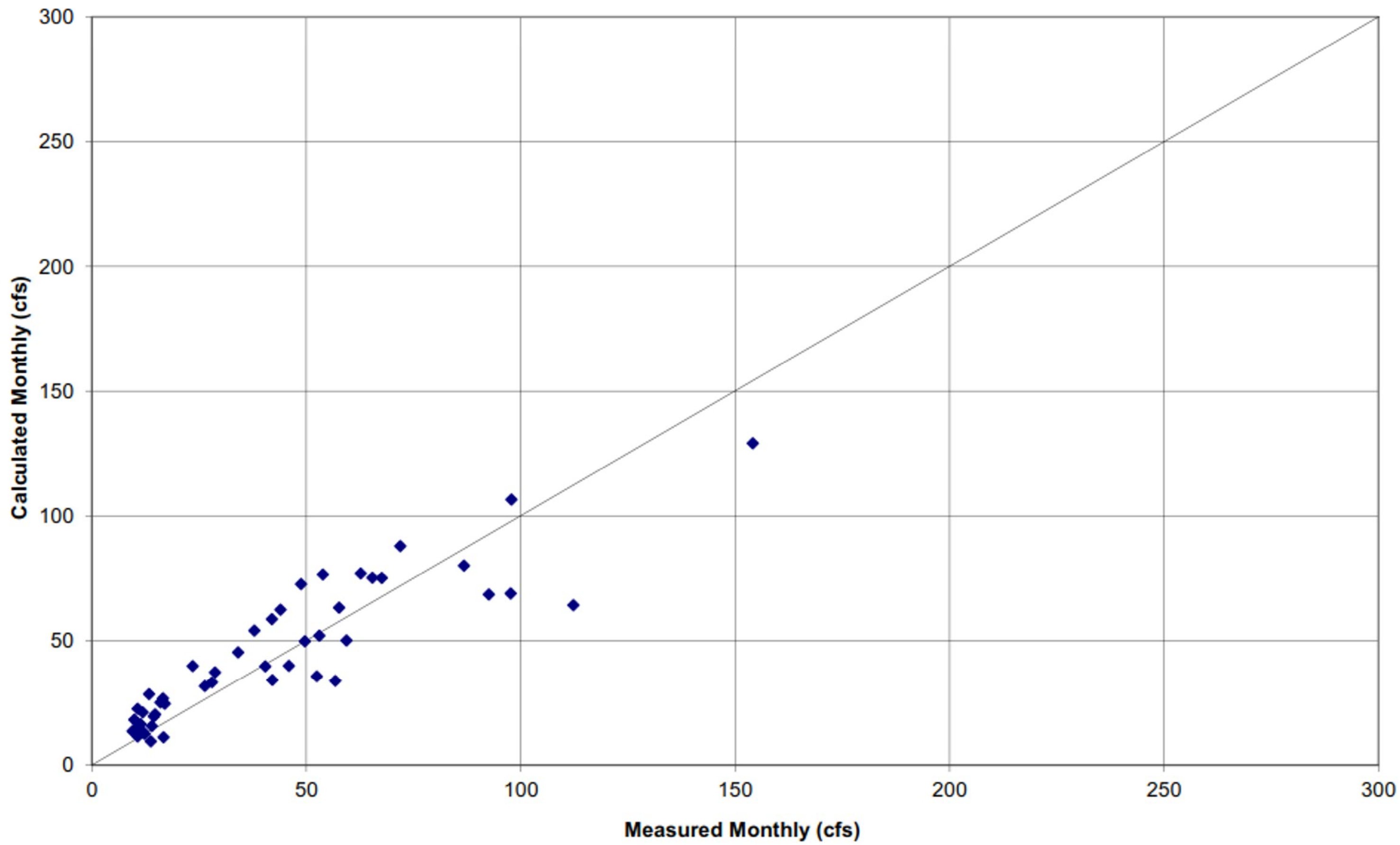


Sources: PLP RFI 104a

US Army Corps of Engineers

NK100C FLOW DISTRIBUTION

FIGURE K3.16-29



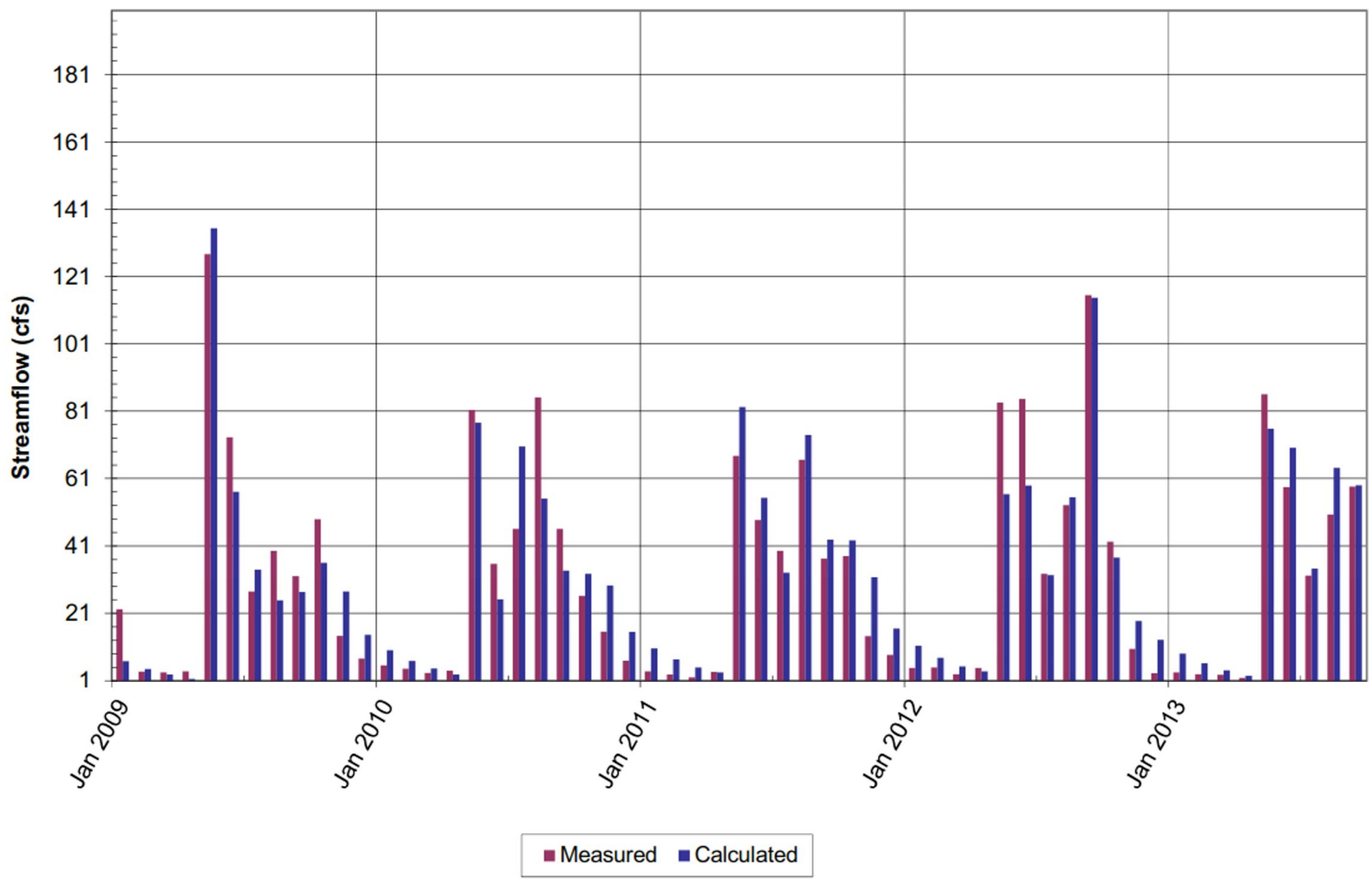
Sources: PLP RFI 104a

US Army Corps of Engineers®

NK100C MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

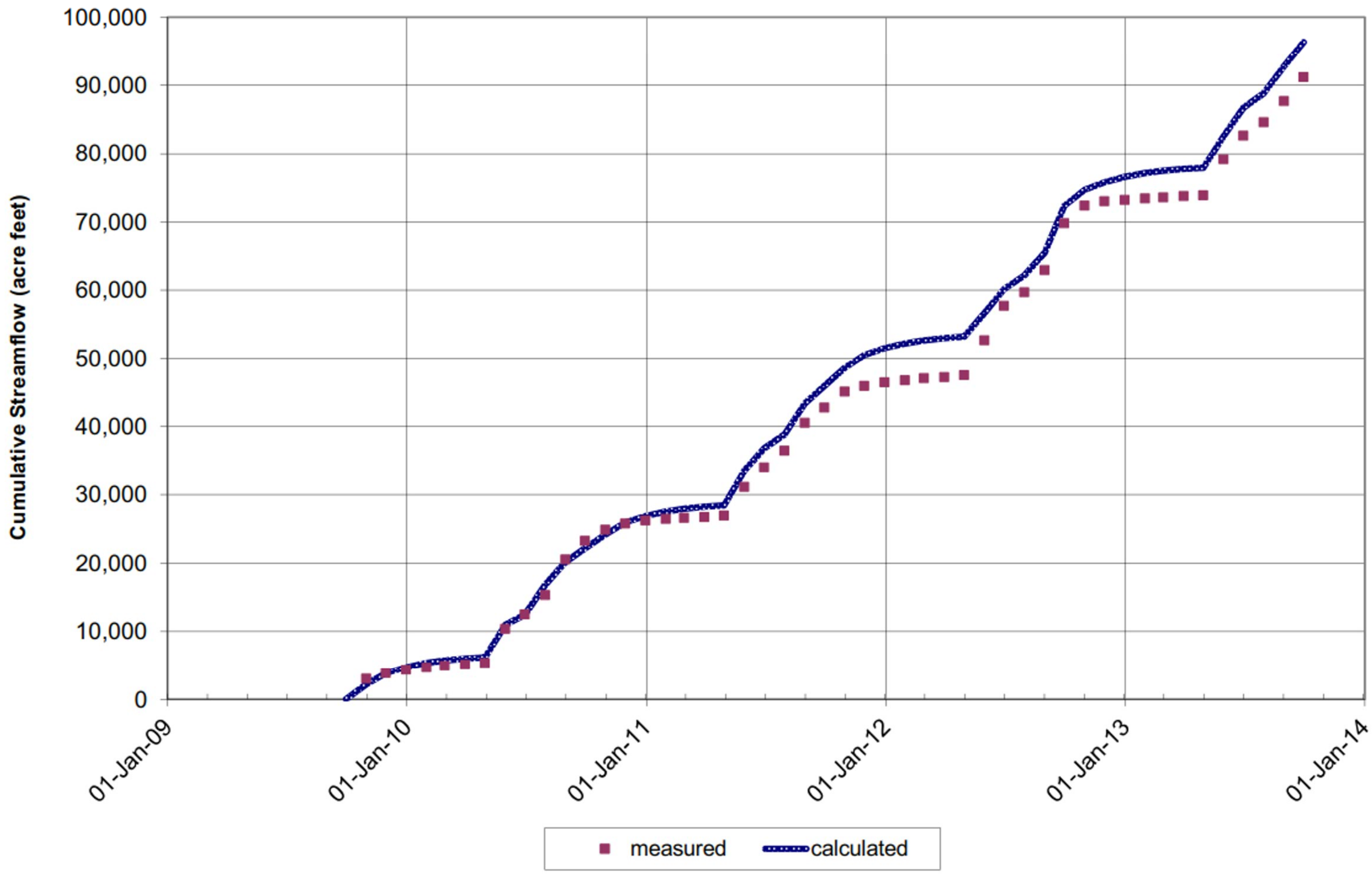
FIGURE K3.16-30



Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED STREAMFLOW SK119A



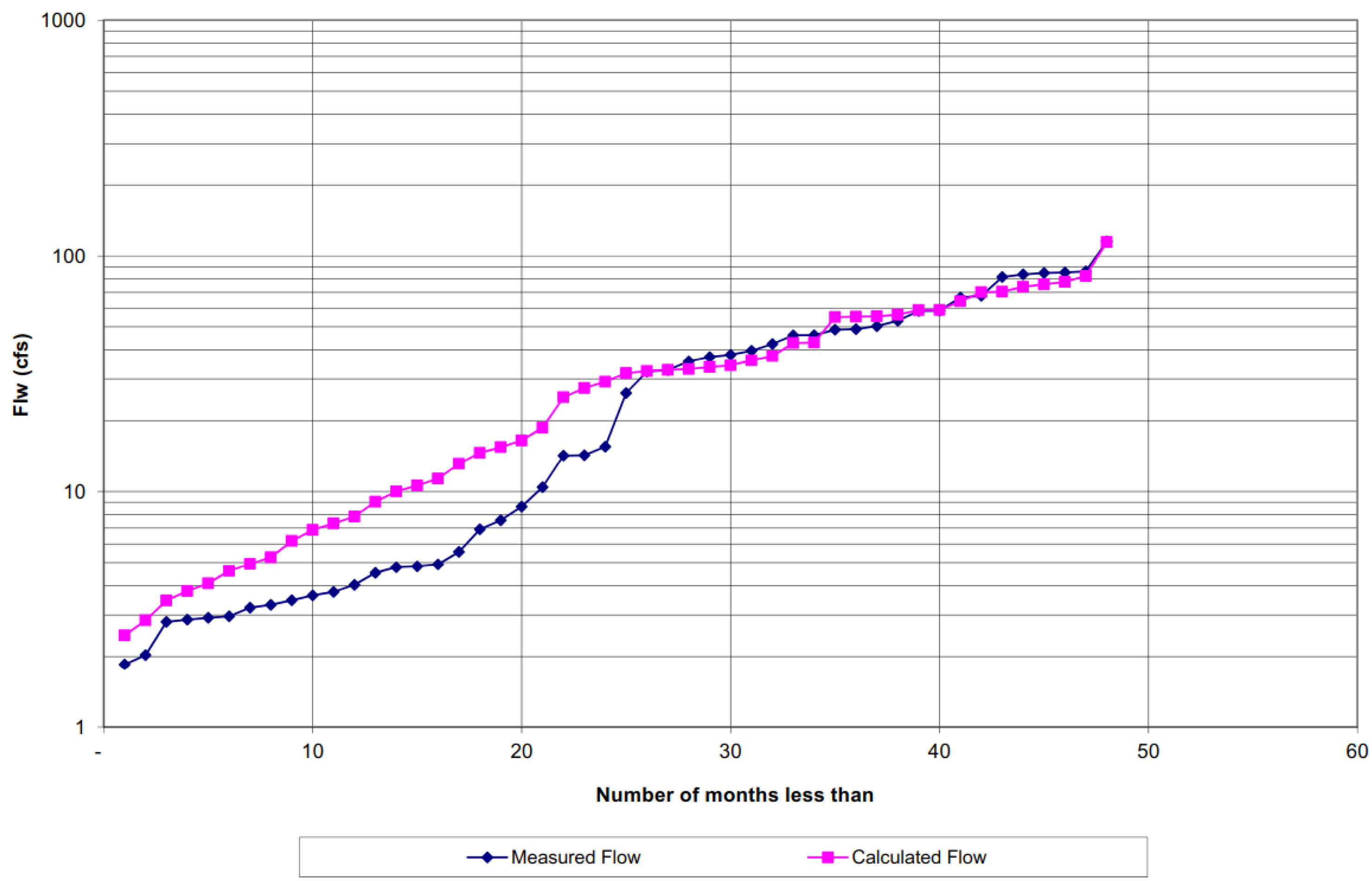
Sources: PLP RFI 104a

US Army Corps of Engineers

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW SK119A

PEBBLE PROJECT EIS

FIGURE K3.16-32



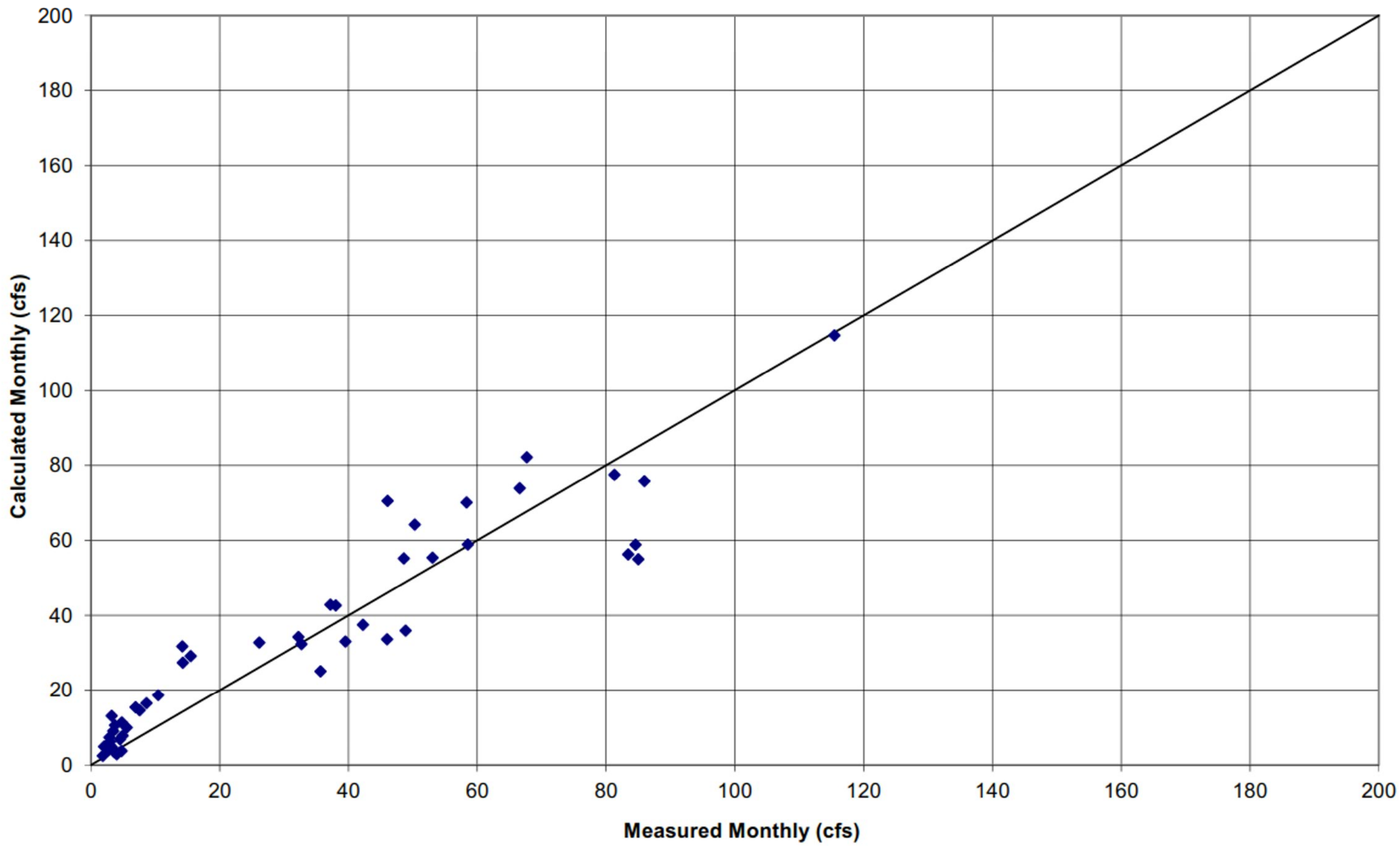
Sources: PLP RFI 104a

US Army Corps of Engineers®

SK119A FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-33



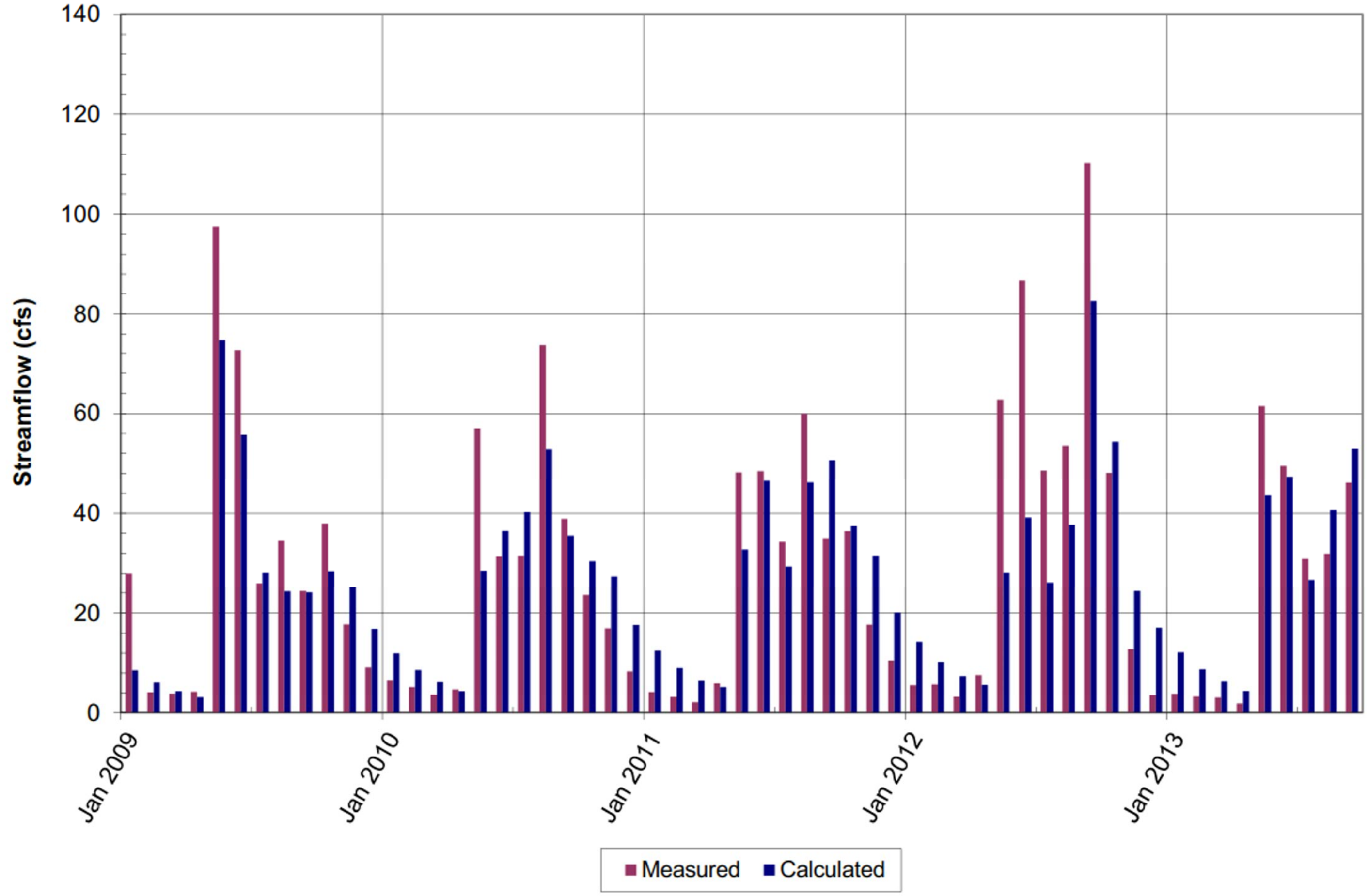
Sources: PLP RFI 104a

US Army Corps of Engineers®

SK119A MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

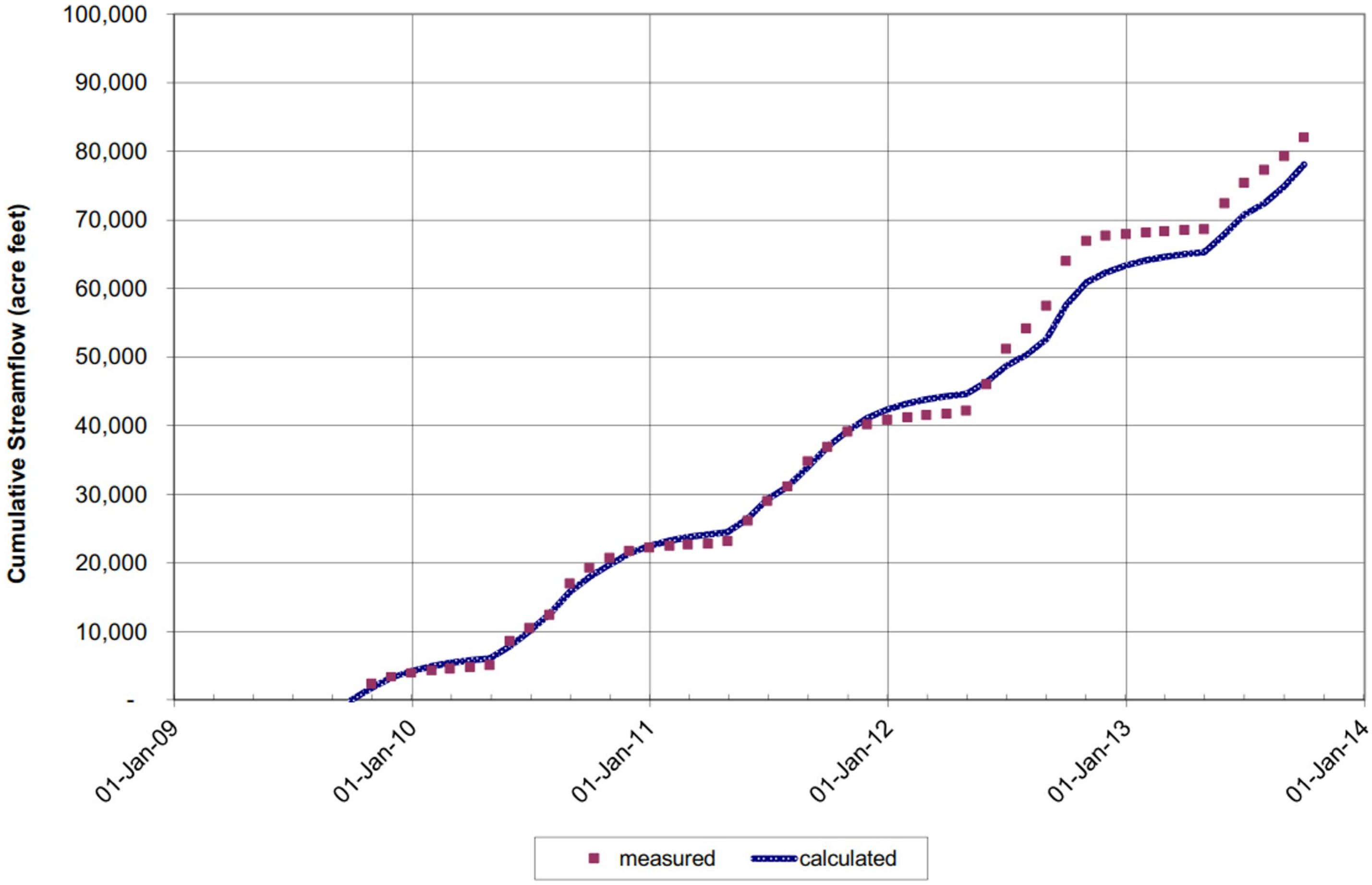
FIGURE K3.16-34



Sources: PLP RFI 104a

US Army Corps of Engineers®

MEASURED AND CALCULATED STREAMFLOW SK100F



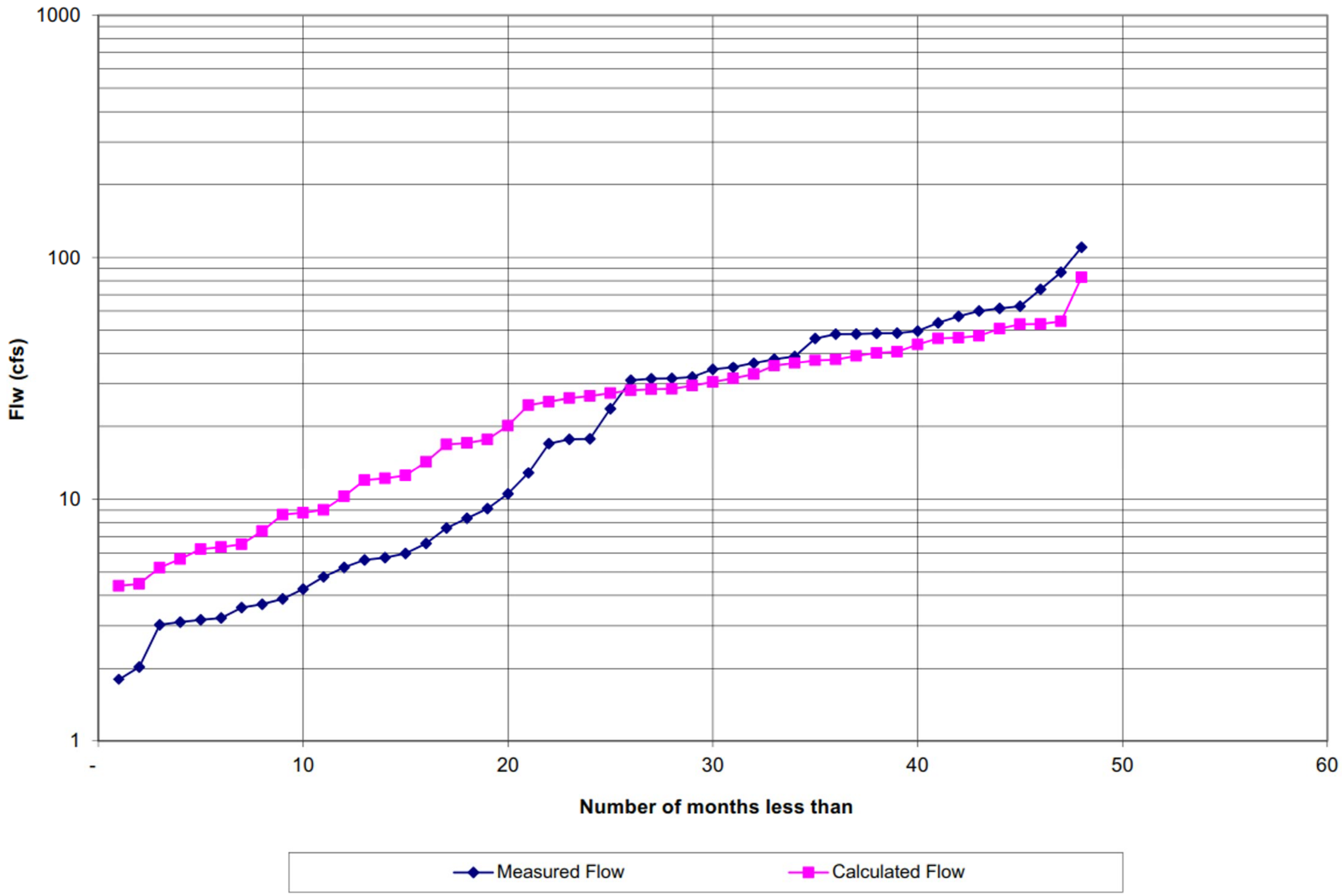
Sources: PLP RFI 104a

US Army Corps of Engineers

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW SK100F

PEBBLE PROJECT EIS

FIGURE K3.16-36



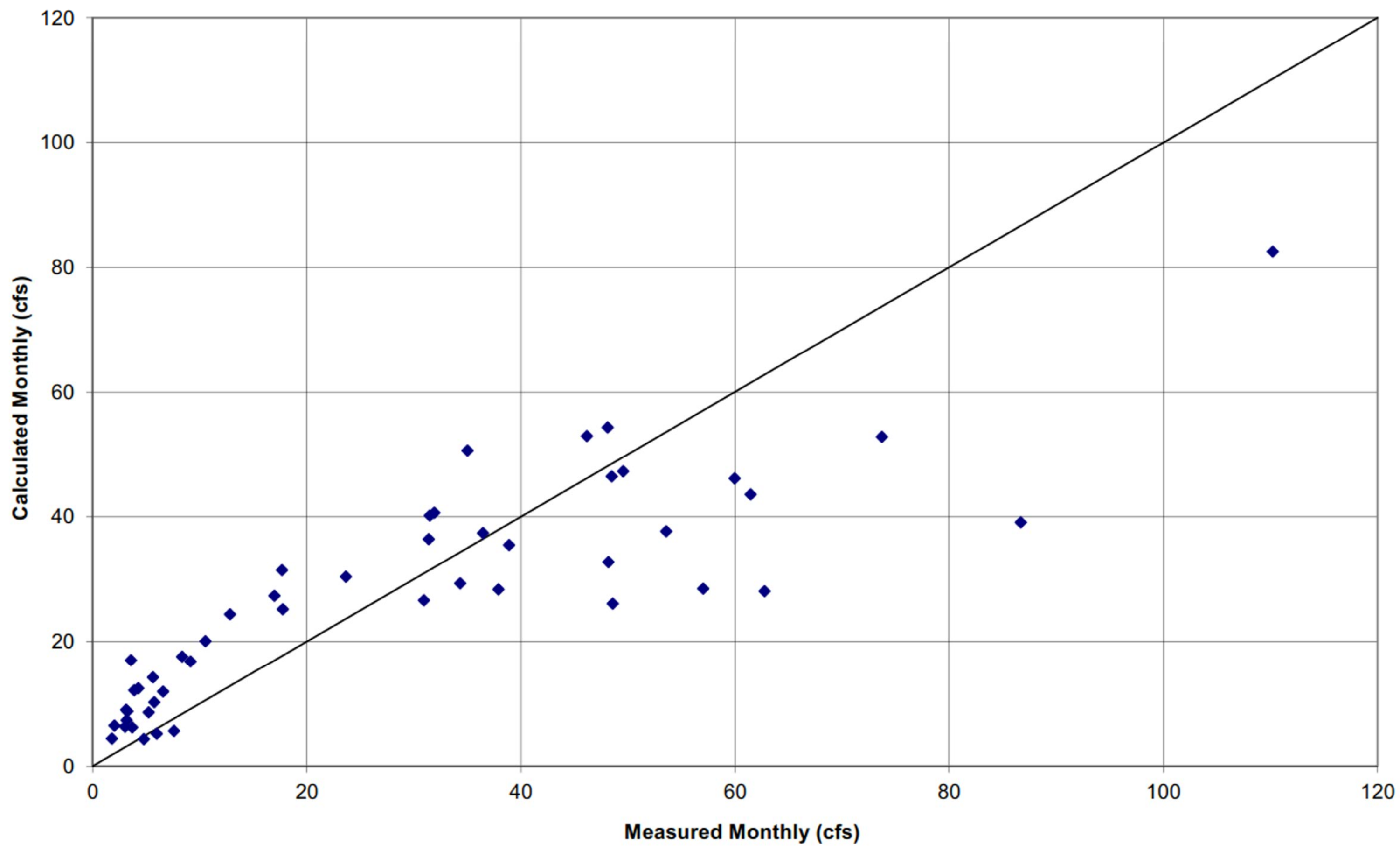
Sources: PLP RFI 104a

US Army Corps of Engineers

SK100F FLOW DISTRIBUTION

PEBBLE PROJECT EIS

FIGURE K3.16-37



Sources: PLP RFI 104a

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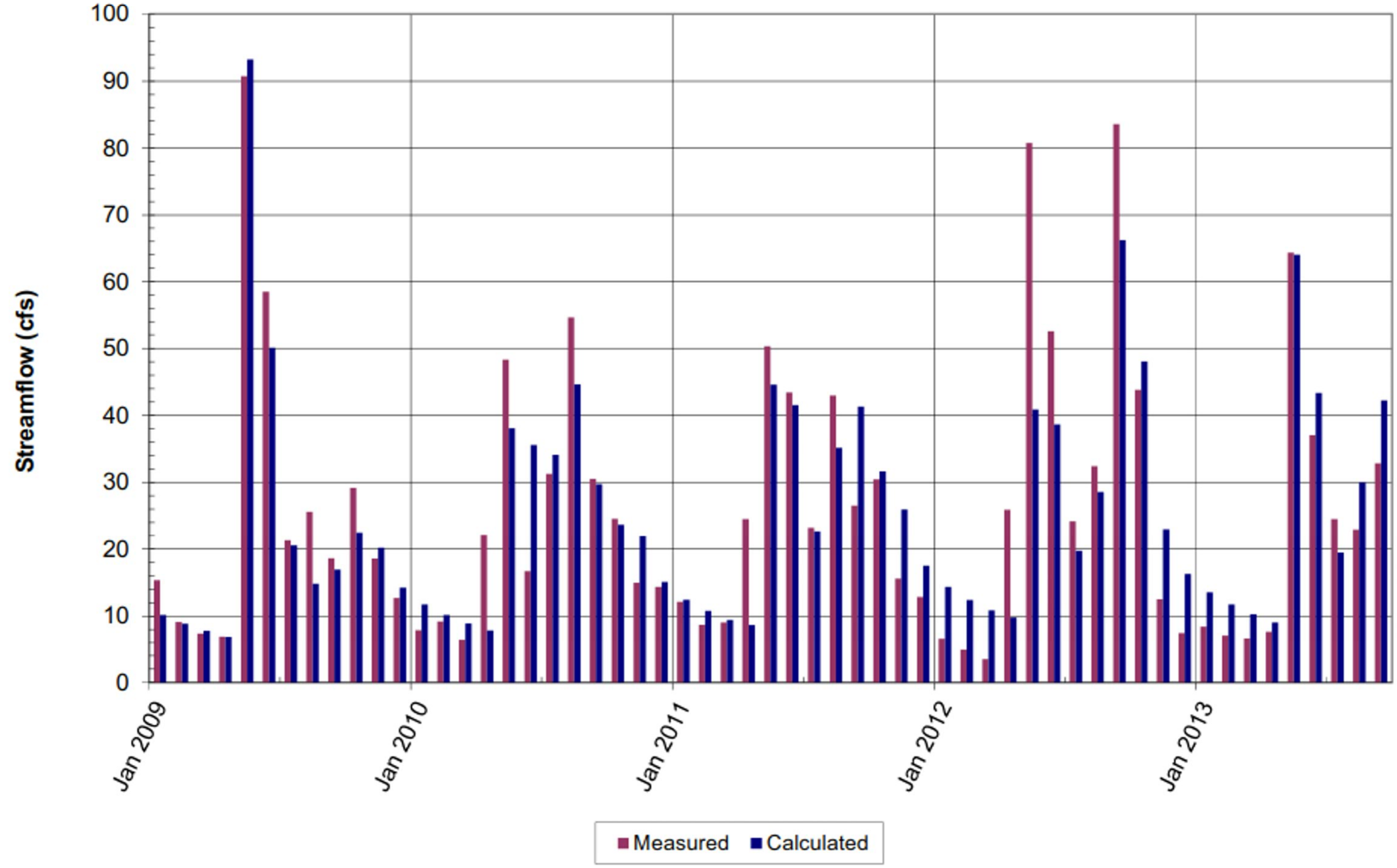
SK100F MEASURED VERSUS CALCULATED



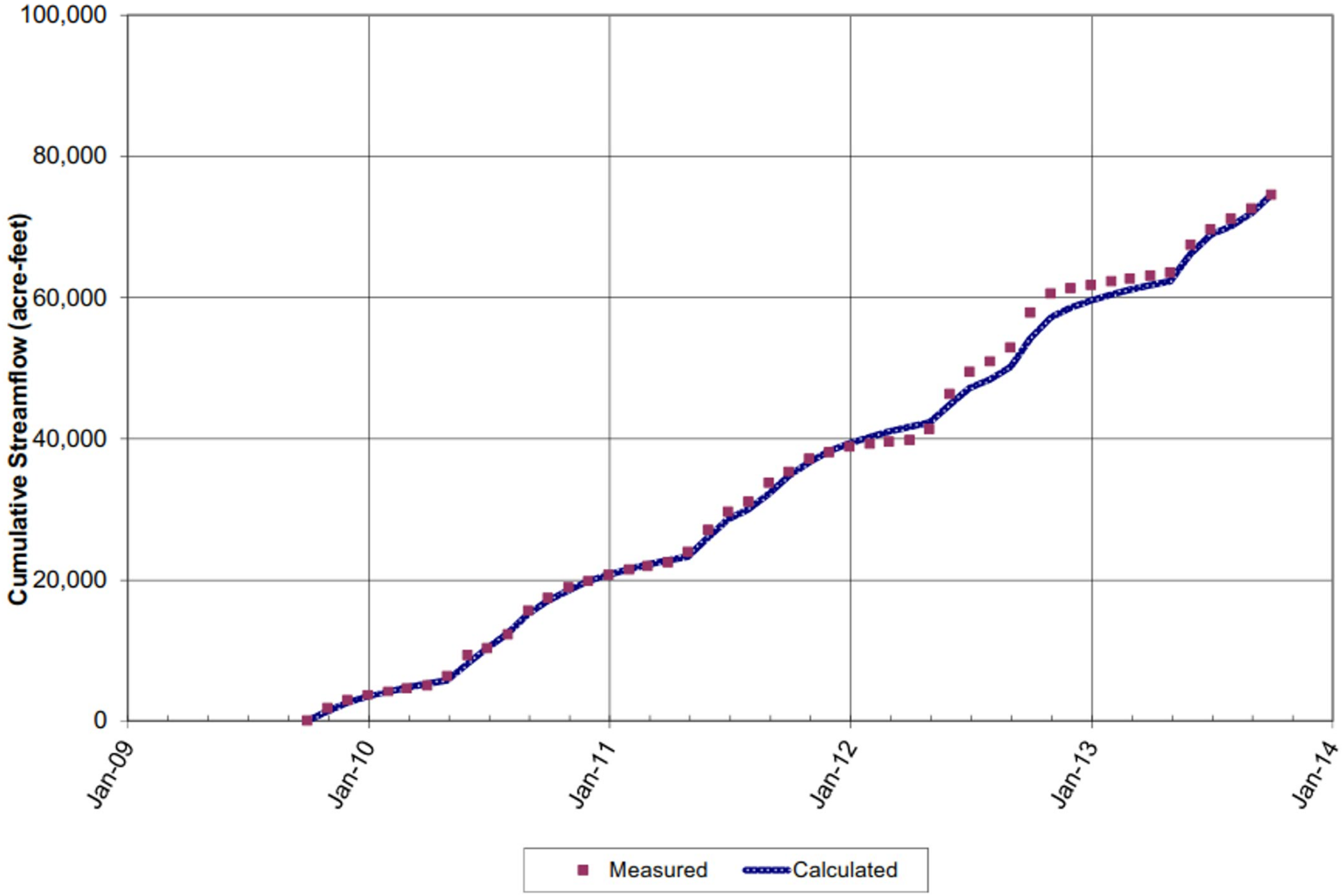
Sources: PLP RFI 104a

US Army Corps of Engineers

MEASURED AND CALCULATED STREAMFLOW UT100D

PEBBLE PROJECT EIS

FIGURE K3.16-39



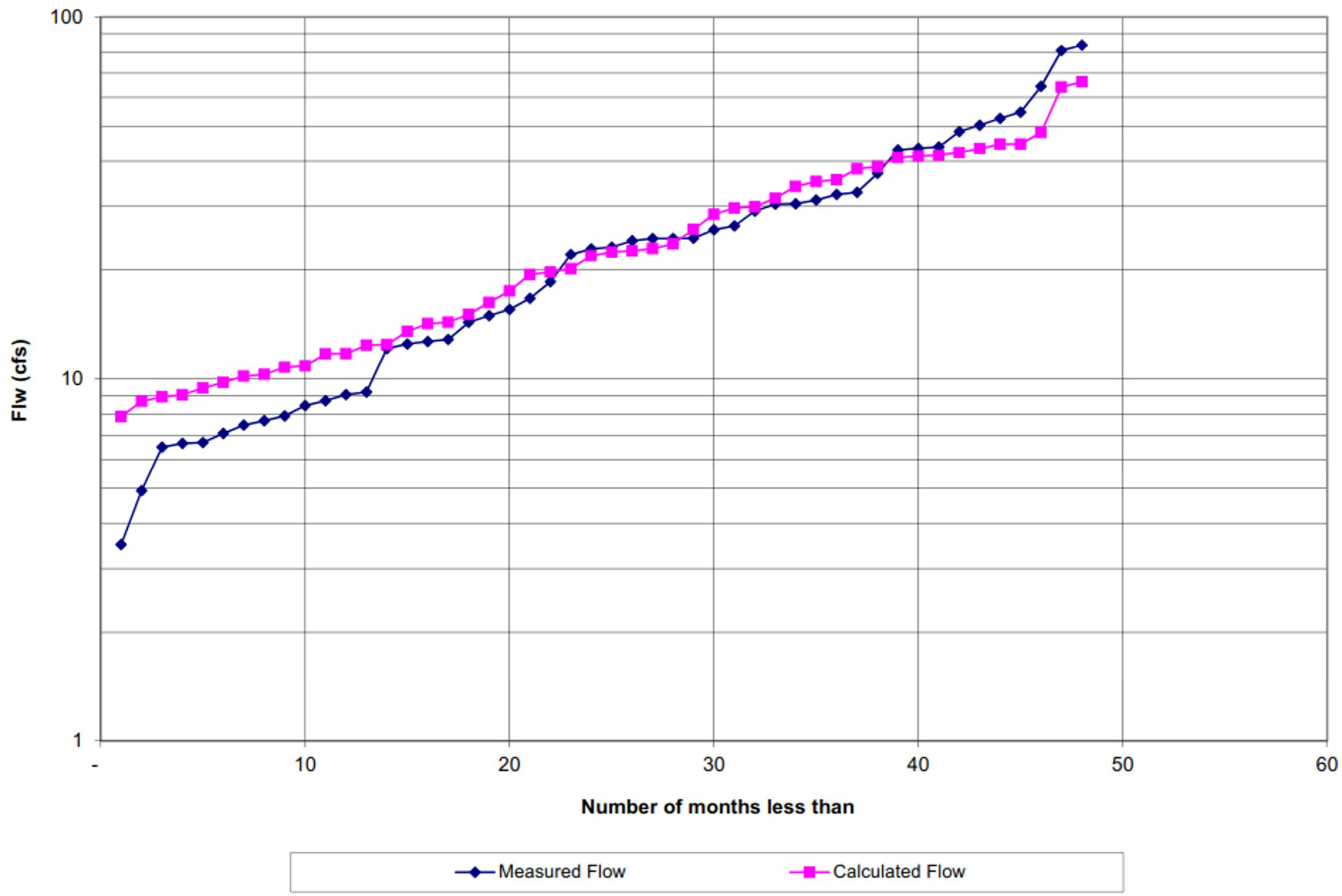
Sources: PLP RFI 104a

US Army Corps of Engineers

MEASURED AND CALCULATED CUMULATIVE STREAMFLOW UT100D

PEBBLE PROJECT EIS

FIGURE K3.16-40



Sources: PLP RFI 104a

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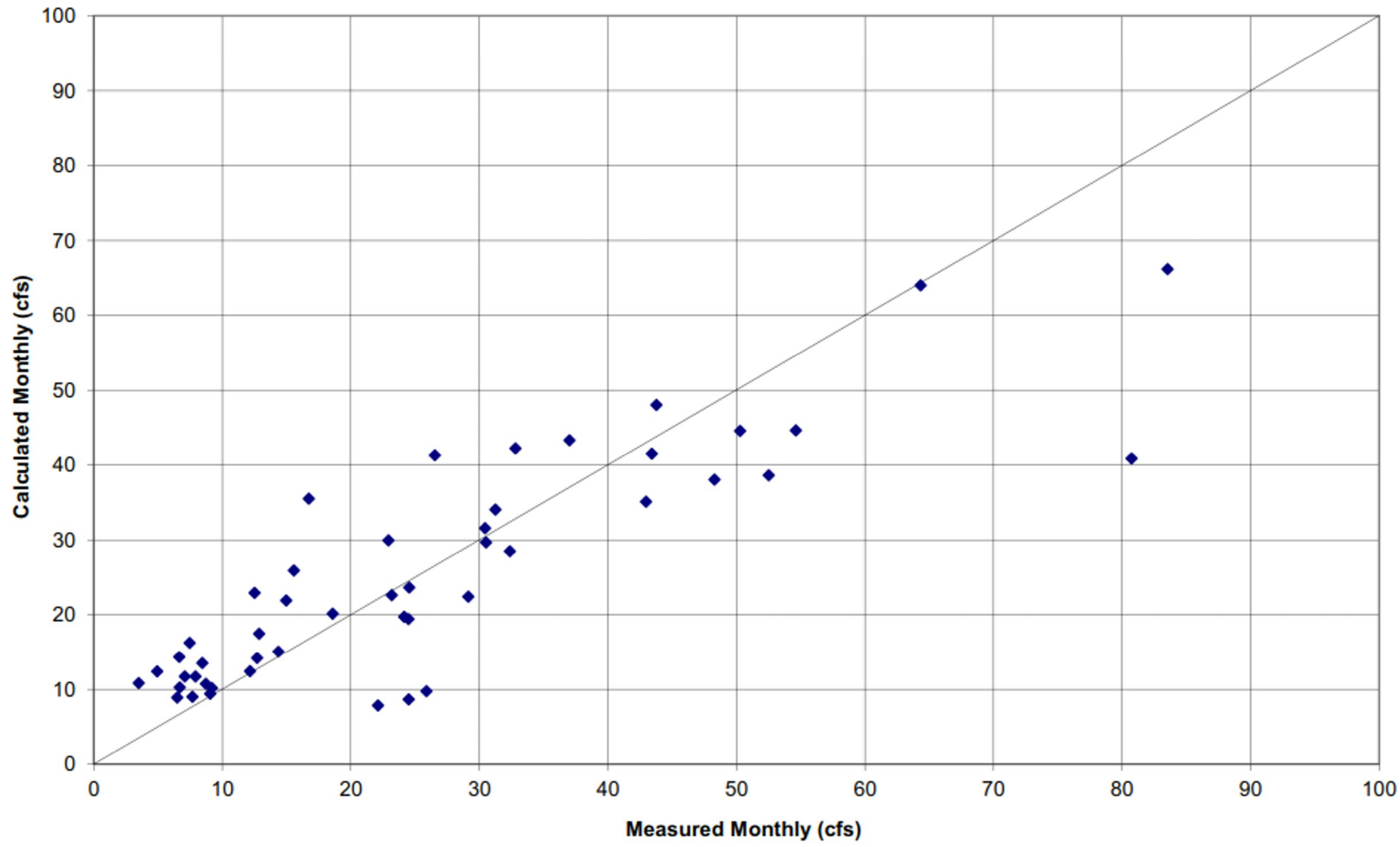
UT100D FLOW DISTRIBUTION



Sources: PLP RFI 104a

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UT100D MEASURED VERSUS CALCULATED

PEBBLE PROJECT EIS

FIGURE K3.16-42

However, Knight Piésold studies (2009, 2018g) went on to evaluate the possible impact of the Pacific Decadal Oscillation (PDO). Based on long-term temperature data for Port Alsworth, Intricate Bay, Iliamna, and Nome, it appears that there was a marked change in the mean annual temperature starting in 1977; the year a shift occurred in the PDO (Knight Piésold 2009, Figures 9, 10, 11). When the cold and warm phases of the PDO are considered, the temperatures show no significant trend (Knight Piésold 2018g). Temperatures in each period appear reasonably consistent (1943 to 1976 versus 1977 to 2016), but the mean annual temperature for the pre-shift period is 1.9°F lower than for the post-shift period, and the mean annual minimum daily temperature is 5.6°F lower (Knight Piésold 2018g). The PDO has been in a warm phase for the last 40 years, and based on past patterns, can be expected to shift into a cold phase in the future. This shift may or may not be accompanied by a general drop in temperatures.

When comparing temperatures from the pre- and post-PDO, cold temperatures appear to have increased more than warm temperatures (Knight Piésold 2018g). Temperatures for winter months have increased more than temperatures for any other season. Annual minimum daily temperatures have increased more than maximum daily temperatures. However, during the cold and warm periods of the PDO, none of the temperature series show any significant trends (Knight Piésold 2018g).

Average monthly temperature predictions were obtained from Scenarios Network for Alaska and Arctic Planning (SNAP 2018) based on Scenario A1B[2] (see also Section 3.20, Air Quality). The predictions suggest that the average monthly Iliamna Airport temperature in 2040 through 2049 will be 1.6 to 7.0ºF higher than the average monthly temperatures between 1981 and 2010 (see Section 3.20, Air Quality, Table 3.20-6 and Table 3.20-7). The annual average temperature is estimated to increase by about 3.8ºF. The SNAP predictions are about twice the Knight Piésold (2009 and 2018g) predicted increase and about 50 percent more than the USGCRP (2017) estimated increase “under all plausible future climate scenarios.”

K3.16.3.2 Precipitation

The Knight Piésold (2009) study also evaluated historical precipitation data looking for possible trends in precipitation magnitude and frequency. Plots of historical annual precipitation at Iliamna, Port Alsworth, and Intricate Bay show no common trend, suggesting that the precipitation regime near the mine site is not undergoing a consistent change (Knight Piésold 2009, Figure 14). A statistical analysis of trends indicated that, where trends are statistically significant, they vary in trend direction from location to location. For instance, Port Alsworth recorded statistically significant negative changes in precipitation volume in the spring, summer, and on an annual basis, with no statistically significant change in winter or fall. Records for Intricate Bay and Iliamna show statistically significantly positive volume increases during the fall but no statistically significant changes at other times of the year, or on an annual basis (Knight Piésold 2009, Table 1). Similarly, evaluating the Iliamna data according to the timing of the cold and warm phases of the PDO did not reveal any significant trends (Knight Piésold 2018g). The mean annual precipitation values for the cold and warm phases of the PDO are 26.3 and 26.2 inches, respectively.

Although the USGCRP report (2017) indicates that winter/spring precipitation in Alaska is projected to increase, the Iliamna precipitation record indicates that winter/spring precipitation has been essentially constant for the past 70 years (Knight Piésold 2018g). Knight Piésold (2018g) found no statistically significant trend in the 1943 to 2016 Iliamna winter/spring

[2] The predictions are the average of five models, represent the mid-range emissions, and have a resolution of 771 meters.

precipitation record. Furthermore, splitting the winter/spring precipitation record according to the timing of the cold and warm phases of the PDO revealed that there was no significant trend during the cold phase, but that there is a significant decreasing trend during the warm phase (Knight Piésold 2018g). The mean winter/spring precipitation for the two periods is 10.2 and 10.3 inches, respectively.

Average monthly precipitation predictions from SNAP (2018) based on Scenario A1B indicate that the average monthly Iliamna airport precipitation in 2040 through 2049 will be 0 to 0.7 inches higher than the average monthly precipitation between 1981 and 2010 (Section 3.20, Air Quality, Table 3.20-6 and Table 3.20-7). The annual average precipitation is estimated to increase by about 1.7 inches.

With regard to the possibility that climate change will lead to an increase in extreme precipitation events, Knight Piésold (2018g) evaluated the 1943 to 2016 annual maximum daily precipitation record for Iliamna. Based on their analysis, there are no trends in the record as a whole.

The National Weather Service (NWS) also evaluated whether there is a trend in the extreme precipitation dataset for Alaska. During the process of developing new precipitation-duration-frequency statistics for the State of Alaska, the NWS tested the assumption that there was no statistically significant trend in the 1-day and 1-hour annual maximum daily precipitation record. The NWS precipitation-duration-frequency statistics are prepared with the understanding that they will be use to predict the magnitude and frequency of future rainfall-runoff flood events, in addition to other uses. Statistical tests were conducted to determine the likelihood of trends (both a parametric t-test and a non-parametric Mann-Kendal test) in the data at the 5 percent significant level. Only stations with 40 or more years of record were used.

With regard to the 1-hour annual maximum precipitation data, there were only 12 stations with a 40-plus year record length. Neither of the statistical tests detected a trend in the data for a single station.

With regard to the 1-day annual maximum precipitation data, there were 154 stations with 40 or more years of record. At 85 percent of the stations, no statistically significant trends were detected. At 8 percent of the stations, a positive trend was detected, and at 7 percent of the stations, a negative trend was detected. Spatial maps did not reveal any spatial cohesiveness in positive and negative trends. Based on review of Figure A.2.1 (NWS 2012), the three closest stations to the mine site indicated no significant trend at the 5 percent significance level.

Knight Piésold (2018g) also evaluated the possibility of trends in extreme precipitation corresponding to the cold and warm phases of the PDO and concluded that there were no trends. The mean precipitation value for the cold phase of the PDO is 1.64 inches and the mean precipitation value of the warm phase of the PDO is 1.73 inches (Knight Piésold 2018g). However, the coefficient of variation (i.e., standard deviation divided by the mean) is 0.23 for the cold phase, and 0.33 for the warm phase (Knight Piésold 2018g). The difference indicates that there is greater year-to-year variation during the recent warm phase than there was during the past cold phase. This has significant implications for design. For instance, using data from the warm phase of the PDO to calculate the Probable Maximum Precipitation results in a value that is approximately 40 percent greater than would be computed based on the cold phase data (Knight Piésold 2018g).

K3.16.3.3 Streamflow

With regard to streamflow, Knight Piésold (2009) evaluated the discharge records for three regional USGS streamflow gaging stations in an attempt to detect changes attributable to climate change. The three stations were: Nuyakuk River Station (15302000), Little Susitna River

Station (15290000), and Kuskokwim River Station (15304000). These three stations were selected because of their length and completeness of record, proximity to the mine site, circumferential spacing around the mine site, varied range in watershed size, and varied exposure to coastal and continental climate regimes.

Annual mean discharge-time plots (Knight Piésold 2009, Figures 18, 19, and 20) for the three stations indicate a statistically significant trend of increasing streamflow for the Nuyakuk River, but no significant trend for either the Little Susitna River or Kuskokwim River. Because the Kuskokwim River basin has a very small percentage of glacier cover and the other two basins contain no glaciers, substantial glacier melt is not likely confounding the results. The increase in the Nuyakuk River discharge occurs in every month (Knight Piésold 2009, Figure 21). This is unexpected because increasing temperatures and associated increases in evapotranspiration would be expected to result in a lowering of flows during the warmest period of the year (Knight Piésold 2009). In this instance, it appears that the possible increase in precipitation exceeds any increase in evapotranspiration (Knight Piésold 2009). The Little Susitna and Kuskokwim rivers generally exhibit increases in streamflow during the coolest months of the year and decreases in streamflow in the warmest months of the year (Knight Piésold 2009, Figures 22 and 23). These changes are generally consistent with those expected for watersheds that are warming, but have little or no increase in precipitation.

Knight Piésold (2009) also evaluated annual instantaneous peak discharge trends. The apparent trends are not particularly strong (Knight Piésold 2009. Figures 24, 25, and 26), and only the trend for the Kuskokwim River data is statistically significant, which indicated a decreasing trend in the magnitude of the annual instantaneous peak discharge.

Knight Piésold (2009) concludes that overall, both the mean annual discharge and the annual peak instantaneous discharge appear to be relatively stable. However, the annual hydrograph shape appears to be getting “flatter,” with greater winter flows and lower summer flows.

The USGS evaluated and used the flood-peak data set to develop regression equations to predict flood-peak discharge for use in designing infrastructure throughout Alaska (Curran et al. 2016). Statistically significant trends were detected at 43 of the 387 stream gages evaluated. Of the 43 stream gages with significant trends, 22 stream gages show increasing trends and 21 stream gages showed decreasing trends. The report (Curran et al. 2016) goes on to state that:

> *No underlying cause of any trend was obvious when considering spatial distribution, regulation, land-use changes, and urbanization. Although a cursory consideration of climate as a variable in peak-flow trends suggested no obvious patterns, a thorough assessment of any correlation of significant peak-flow trends at individual sites to temporal changes in climate was beyond the scope of this report.*

In an effort to further assess the potential effects that higher temperatures might have on streamflow patterns at the mine site, Knight Piésold (2009) ran a water balance model that assumed that the increasing temperature trend experienced over the past 66 years mine site area would continue at the same rate over the next 66 years. Based on this assumption, the model generally predicted higher base flows in the winter, lower flows in the spring, lower summer baseflows, and similar but slightly lower fall rainfall flows (Knight Piésold 2009). Knight Piésold (2009) also concluded that the model predicted lower mean annual discharge values (which is consistent with higher evapotranspiration losses), but that these changes may be exaggerated due to the influence of the PDO, which was not considered in this analysis.