Technical Appendix II

Hydrological Analyses

Phoenix Lake Preservation & Restoration Plan

TECHNICAL MEMORANDUM

Date:	February 13, 2012
To:	Ted Allen, P.E. (Tuolumne Utilities District), Kevin Fisher (Horizon Water and Environment)
From:	Sridhar Ponangi, P.E. , Chris Hammersmark, Ph.D., P.E.
Project:	10-1019 – Phoenix Lake Preservation and Restoration Plan
Subject:	Task 1 - Hydrologic Data Collection and Analysis

cbec has completed the hydrologic data collection and analysis for the Phoenix Lake Preservation and Restoration Plan (PLPRP). The goal of the study was to help quantify the flow rates into and out of Phoenix Lake (lake), as well as from each of the lake's contributing sub-watersheds in order to support the preliminary planning and design of potential sediment removal facilities. Hydrologic and bathymetric data were collected and analyzed to provide a general functional description of the hydrologic system of the contributing watershed and lake. The analysis was conducted using the data collected during the 2011 water year leading to the development of a hypsometric curve relating lake level to usable lake storage, a rating curve relating lake level to spillway discharge, water balance accounting, and a flood frequency analysis. The hypsometric curve provides a tool to quantify usable storage and how it relates to demand. The water balance accounting provides a baseline understanding of the lake inflows, outflows, lake water surface elevation and stored usable volume. The flow frequency analysis provides a relationship between the magnitude and frequency of streamflow discharges and an improved understanding of the partitioning of flow inputs from the various sub-watersheds. This technical memorandum (TM) describes the procedures and the results of the analyses. The raw data, summary hydrographs and water balance calculations are provided in the attached MS Excel spreadsheets. Appendix A provides a list of spreadsheets attached and a brief description of the data/calculations included. All elevations described in this TM are referenced to the North American Vertical Datum of 1988 (NAVD88).

Phoenix Lake is a drinking water reservoir operated and maintained by Tuolumne Utilities District (TUD). The lake is located approximately 3 miles east of Sonora at the confluence of Sullivan, Chicken and Power Creeks. The components of the lake conveyance system include:

- Spillway with an operable radial gate and a flashboard system,
- Shaws Flat Pipeline to TUD's water treatment plant,
- Regulated fish release to lower Sullivan Creek, downstream of the lake.

The lake is operated in two seasonal modes. From the beginning of November through the end of April (winter mode), the lake is operated to maintain the water level at a spillway crest elevation of 2379.1 ft with the radial gate open. From the beginning of May through the end October (summer mode), the flashboards are installed on the spillway to maintain the lake water level at the top of flashboard elevation of 2385.1 ft with the radial gate closed. The spillway and fish release discharge to the lower Sullivan Creek. The fish release is used to maintain discharge in lower Sullivan Creek during periods when the lake level is below the spill elevation, as well as to temporarily lower the lake level to allow for installation or removal of the flashboards.

DATA COLLECTION

TUD has established two streamflow gages on Sullivan Creek located upstream and downstream of Phoenix Lake. Figure 1 shows the locations of the two gages in relation to the lake. The gages record the pressure head (in pounds per square inch or psi) in the creek that is converted to the equivalent water depth, or creek stage. The temporally varying creek stage values are used to estimate flows based on the existing stage-discharge rating curves previously developed by TUD.

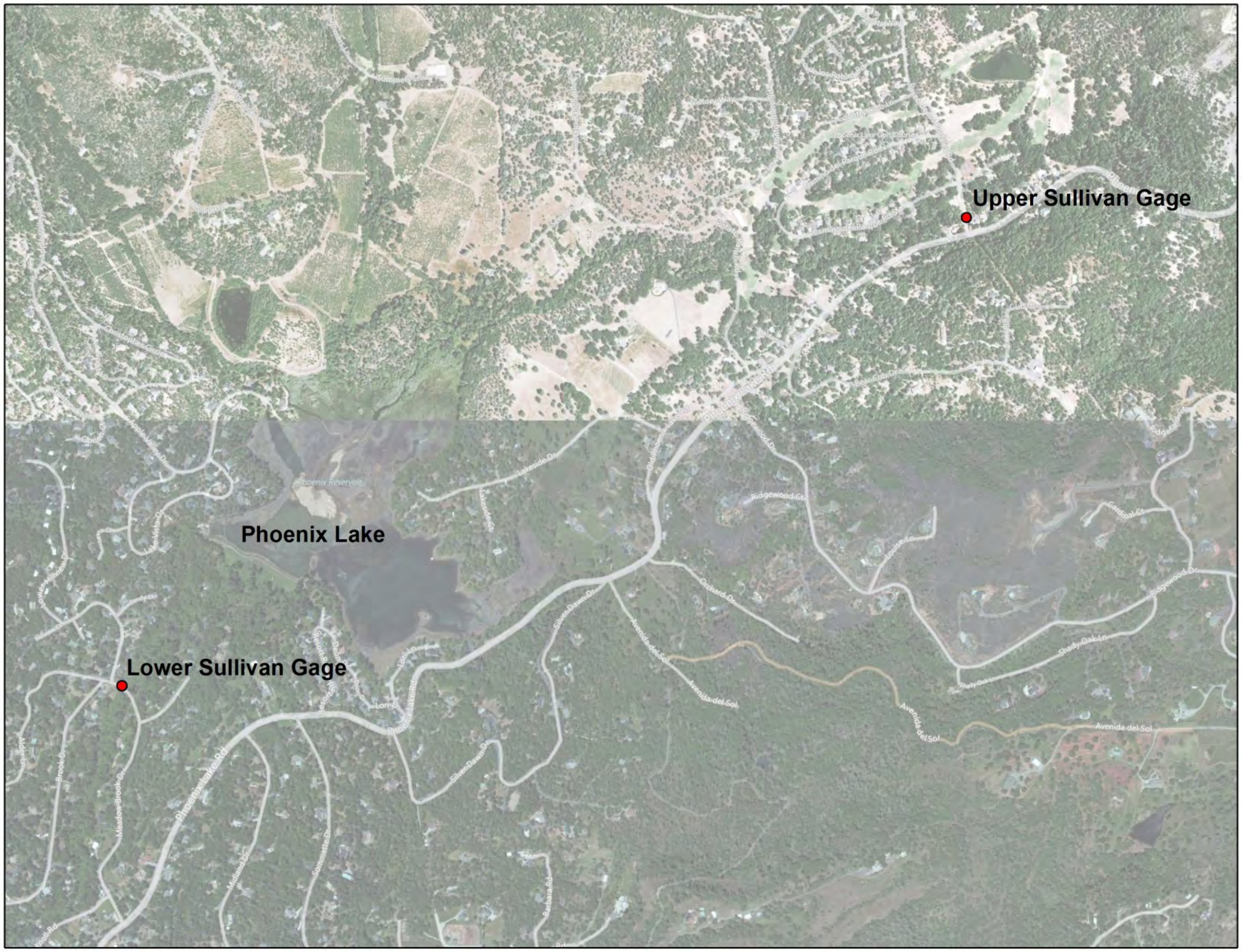
To assist with the analysis of the watershed/lake hydrologic system, two pressure transducers were installed within the lake to record semi-continuous stage at hourly intervals. In addition, two flow measurements were taken at each of the upper and lower Sullivan Creek gages in an attempt to provide additional data to refine the existing stage-discharge rating curves.

Lake Level Monitoring

Two pressure transducers are deployed at the lake. The first is submerged and non-vented, such that it records both barometric (atmospheric) pressure and water pressure. The second is not submerged and therefore only collects barometric pressure. Figure 2 provides a photographic illustration of the transducer deployment. Using a combination of the data collected by the instruments, the amount of water pressure, and therefore stage (water height) is determined. This stage data is then translated to the NAV88 datum. Data from these instruments are available for a period of almost ten months from the time of deployment on November 11, 2010 through the last instrument download on August 30, 2011. The units are still deployed and collecting data, but have not been downloaded since the end of August 2011. Figure 3 is a plot of the lake water surface elevation during the monitoring period. Also included on Figure 3 is a time series of the volume of usable storage, calculated with the hypsometric curve provided in Figure 4, and discussed under “Phoenix Lake Hypsometric Curve” subsection of this TM.

Stage-Discharge Relationships for Upper and Lower Sullivan Creek

Two flow measurements were taken at each of the two gage locations using acoustic Doppler technology. The first set were taken by foot using a FlowTracker handheld ADV® on a top set wading rod, and the second set of measurements were taken with an acoustic Doppler current profiler (ADCP) mounted to a raft. The purpose of these measurements was to collect additional discharge data to refine the existing stage-discharge rating curves developed by TUD. The first set of flow measurements were collected on February 2, 2011, representing a low flow condition; the second set of flow measurements were collected on March 25, 2011, representing a high flow condition. Table 1 provides the flows measured at each location. The flow measurements collected on February 2 agree well with



Notes: Map Not to Scale

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Upper and Lower Sullivan Creek Gage Locations

Project No. 10-1019	Created By: SP	**Figure 1**

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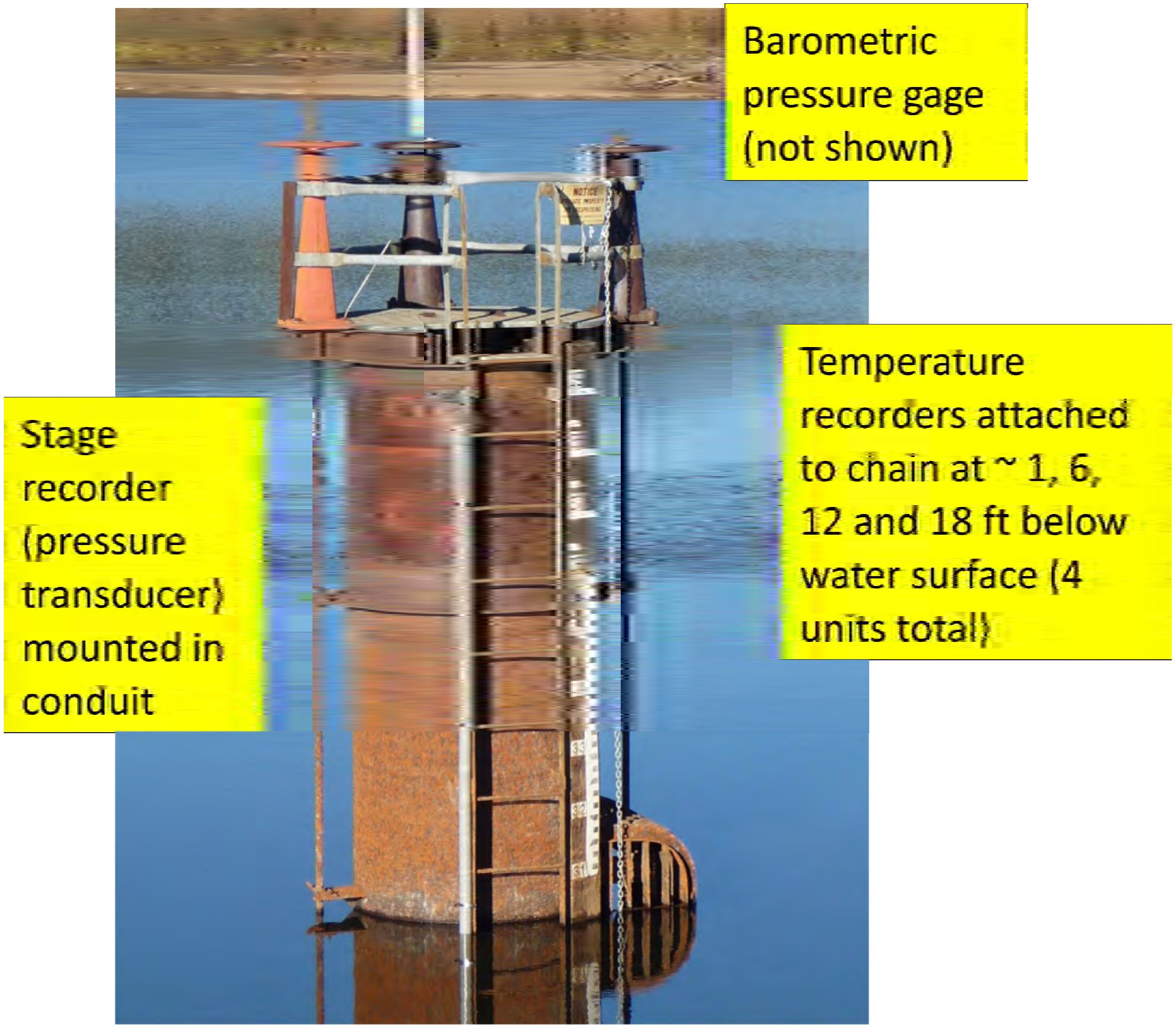

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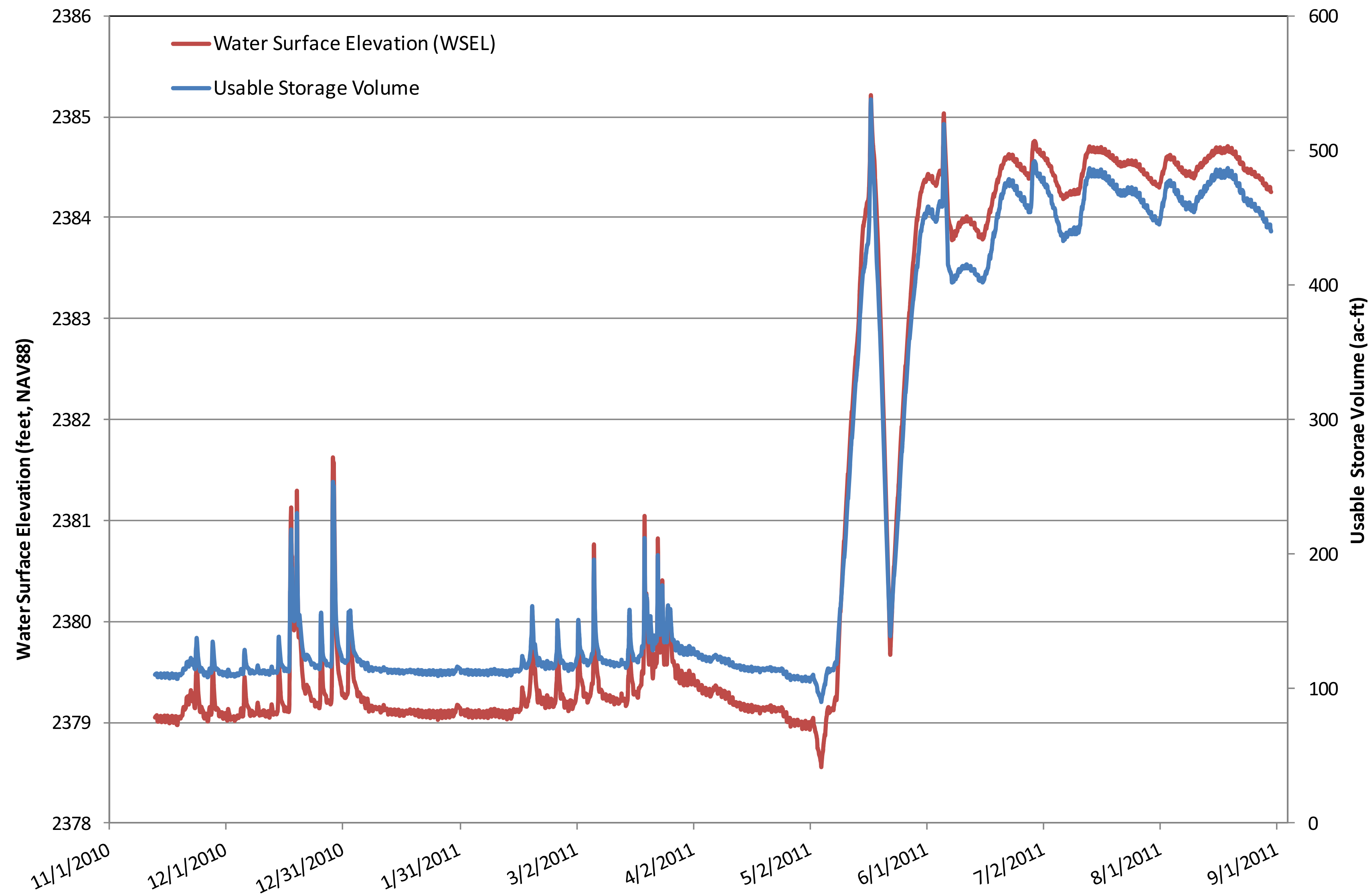
Pressure Transducers at Phoenix Lake

Project No. 10-1019	Created By: KF/SP	**Figure 2**



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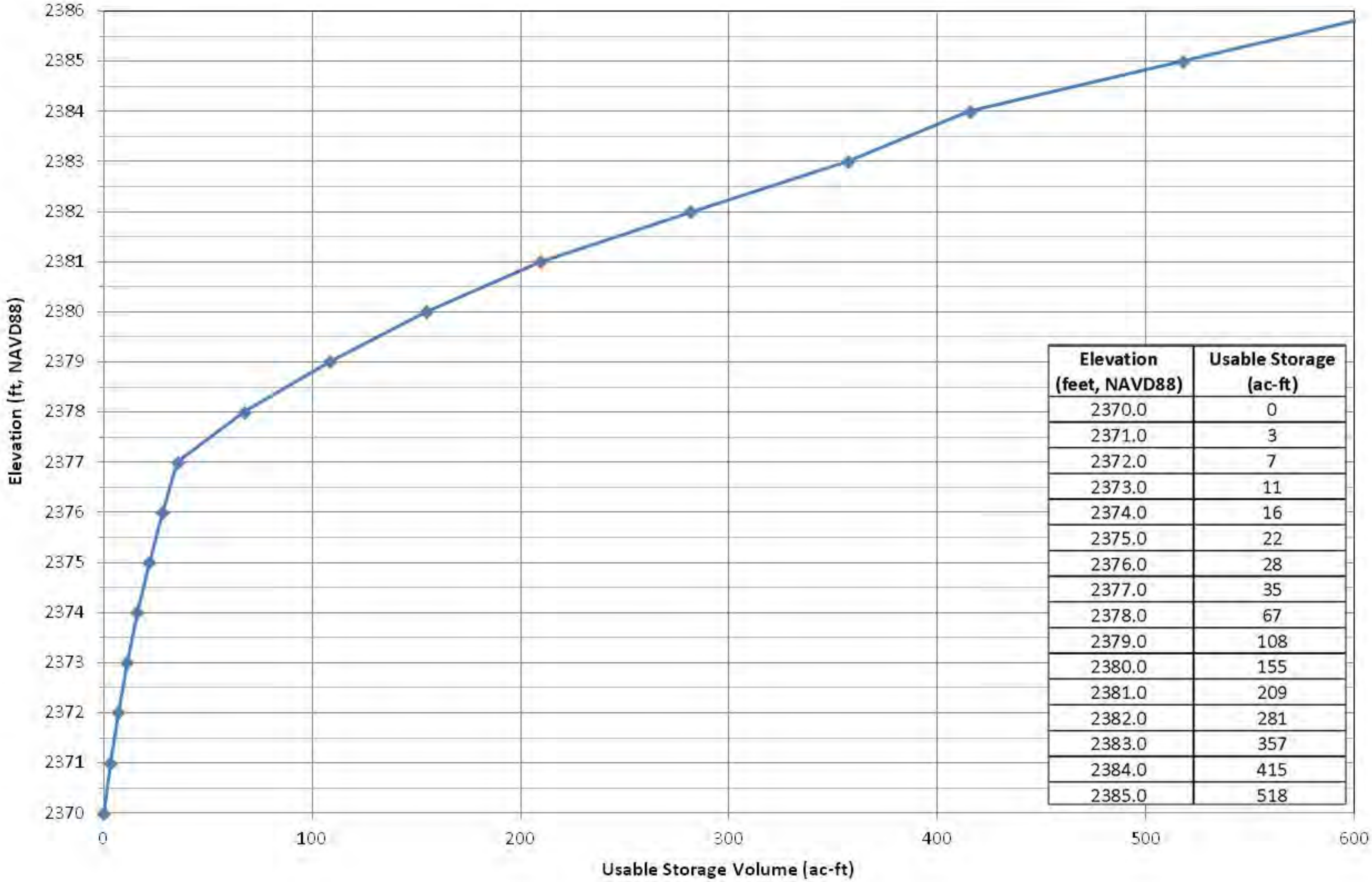
Phoenix Lake Water Surface Elevation and Usable Storage Volume

Project No. 10-1019	Created By: SP/CH	**Figure 3**



Elevation (feet, NAVD88)	Usable Storage (ac-ft)
2370.0	0
2371.0	3
2372.0	7
2373.0	11
2374.0	16
2375.0	22
2376.0	28
2377.0	35
2378.0	67
2379.0	108
2380.0	155
2381.0	209
2382.0	281
2383.0	357
2384.0	415
2385.0	518

Notes:
Usable storage is provided, not total storage.

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Phoenix Lake Hypsometric Curve

Project No. 10-1019 | Created By: SP | **Figure 4** the existing TUD stage-discharge curves. Unfortunately, on March 25, the gages failed to record the stage in the creek due to a malfunction, which prevents this high flow measurement from being utilized to refine the existing TUD rating curves. Therefore, the existing TUD rating curves for the upper and lower Sullivan Creek gages were retained for the current analysis without any modification.

Table 1. Measured Discharge at Upper and Lower Sullivan Creek Gages

Date and Time	Measured Discharge (cfs)
Upper Sullivan Creek Gage	
February 2, 2011 at 4:31 pm	7.3
March 25, 2011 at 1:28 pm	145.3
Lower Sullivan Creek Gage	
February 2, 2011 at 7:48 am	23.9
March 25, 2011 at 11:42 am	208.5

DEVELOPMENT OF RATING CURVES

Phoenix Lake Hypsometric Curve

The hypsometric relationship between lake level and usable storage capacity was developed as a part of the lake volumetric analysis, Figure 4. Due the presence of ridges in the lake, usable storage is less than the total lake capacity. The usable storage capacity at the spillway crest is approximately 113 acre-feet while the capacity when the flashboards are installed is approximately 528 acre-feet.

Spillway Discharge Rating

The discharge rating curve for the spillway was developed using the equation for discharge over a weir:

$$Q = CLH^{\exp}$$

where Q = flow rate in cfs

C = coefficient of discharge

L = length of spillway crest in feet

H = head over the spillway crest in feet

exp = exponent applied to the head, usually around 1.50

The length of the spillway differs between winter and summer operating modes. Based on the Dam and Spillway plans provided by TUD, the length of the spillway was determined to be 140.9 ft during winter operation and 103.5 ft during summer operation. Under winter mode, the spillway acts as a broad crested weir and hence a coefficient of discharge of 2.6 (HEC, 2010) was used. Under summer mode, the installed flashboards act as a sharp crested weir and hence a discharge coefficient of 3.0 (HEC, 2010) was used. Figure 5 shows two images, one of the downstream side lake spillway and another looking

Downstream of the Lake Spillway

Upstream of the Lake Spillway

Notes: Photos: Kevin Fisher	cbec eco engineering / Horizon WATER and ENVIRONMENT	*Phoenix Lake Preservation and Restoration Plan* **Phoenix Lake Spillway**		
		Project No. 10-1019	Created By: SP/KF	**Figure 5**

upstream of the spillway. The spillway discharge rating curves for winter and summer operating modes are presented in Figure 6.

WATER BALANCE

A basic water balance accounting was conducted for the lake that computes lake inflow from the known quantities of lake outflow and change in storage. Additional components such as evapotranspiration (loss), seepage (loss), groundwater inflow (gain), change in lake surrounding moisture (gain or loss), direct precipitation (gain) were not individually included in the water balance. The water balance accounting was performed at one-hour time increments. The inflows from and outflows to Sullivan Creek were estimated based on the lake water balance computations and compared with the flows derived from the upper and lower Sullivan Creek gages.

Lake Inflows

The lake inflows were derived from lake outflows and change in storage in accordance with the following relationship.

Inflow – Outflow = Change in Lake Storage

Outflow from the lake is comprised of: 1) discharge over the spillway, 2) flow to the water treatment plant via Shaws Flat Pipeline and 3) fish releases. Discharge over the spillway was estimated using the spillway rating curve discussed under "Spillway Discharge Rating" subsection of this TM. Figure 7 presents the lake water surface elevation and the corresponding calculated discharge over the spillway. The daily average flows through Shaws Flat Pipeline were provided by TUD and were evenly distributed over the 24-hour period on each day. Fish releases in summer mode were based upon readings at the lower Sullivan Creek gage, while the fish releases were assumed to be zero during winter operations. Change in lake storage was calculated from the lake storage timeseries, derived from the hypsometric curve and lake level monitoring data (Figures 3 and 4).

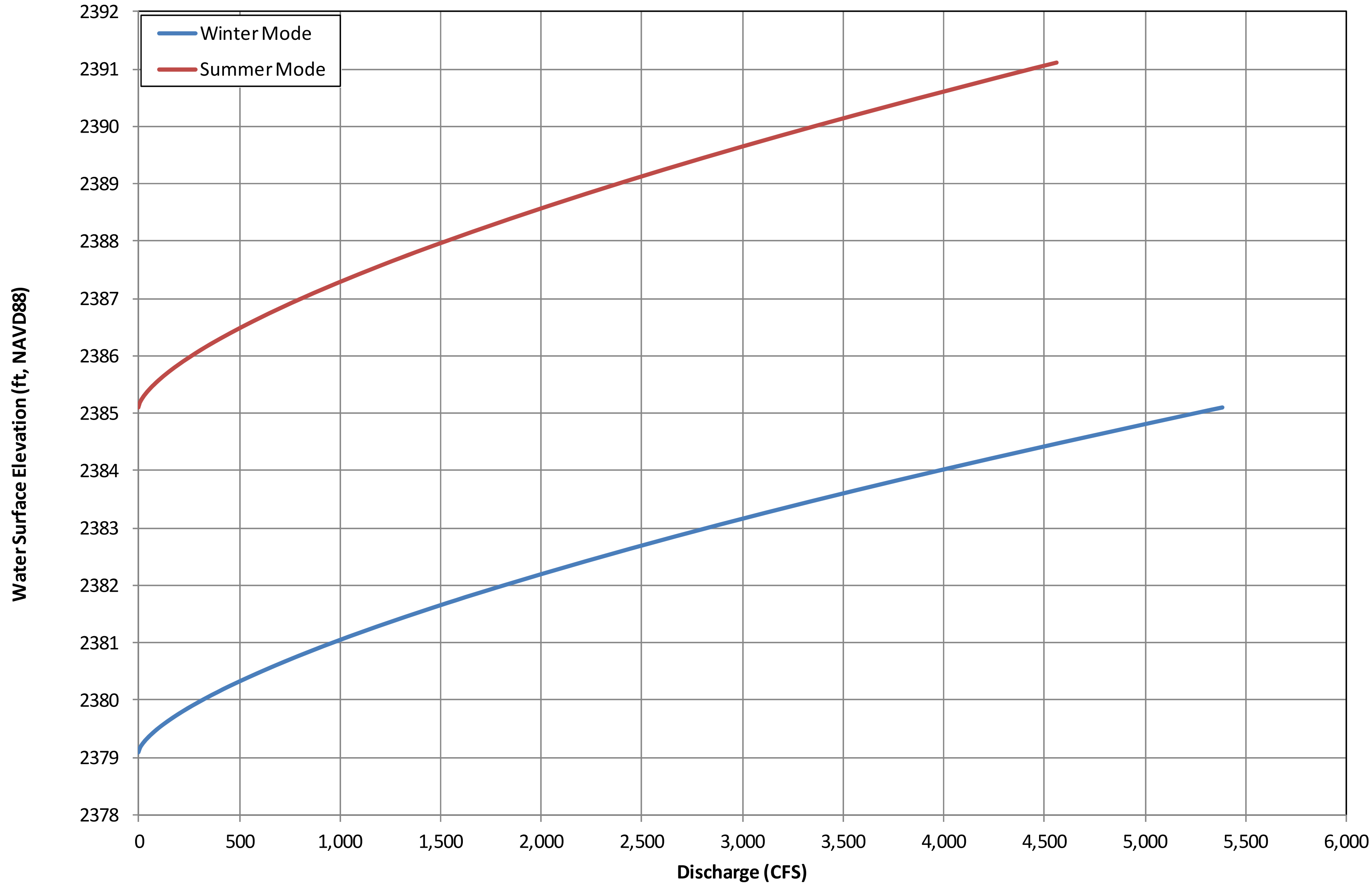
Sub-Watershed Flows

The individual flow hydrographs for Sullivan, Chicken and Power Creek sub-watersheds were generated by scaling the computed lake inflows in proportion to the 2-year sub-watershed flows based on USGS regression equations (USGS, 1993). The 2-year flow estimates are discussed in the following section "Flood Frequency Analysis" of this TM. Flows provided for Power Creek do not include PG&E Main Canal Inputs. The flow data and the hydrographs are included in the attached spreadsheets.

Upper and Lower Sullivan Creek Flows

The raw data and existing rating curves from the Sullivan Creek gages were provided by TUD. Stage data were available for the following time periods:

- Upper Sullivan Creek: Mid-September, 2010 - end of February 2011; daily averages March 25-27 and October 2011;



Notes:	cbec eco engineering / Horizon WATER and ENVIRONMENT	*Phoenix Lake Preservation and Restoration Plan* **Spillway Discharge Rating Curves**		
		Project No. 10-1019	Created By: SP	**Figure 6**

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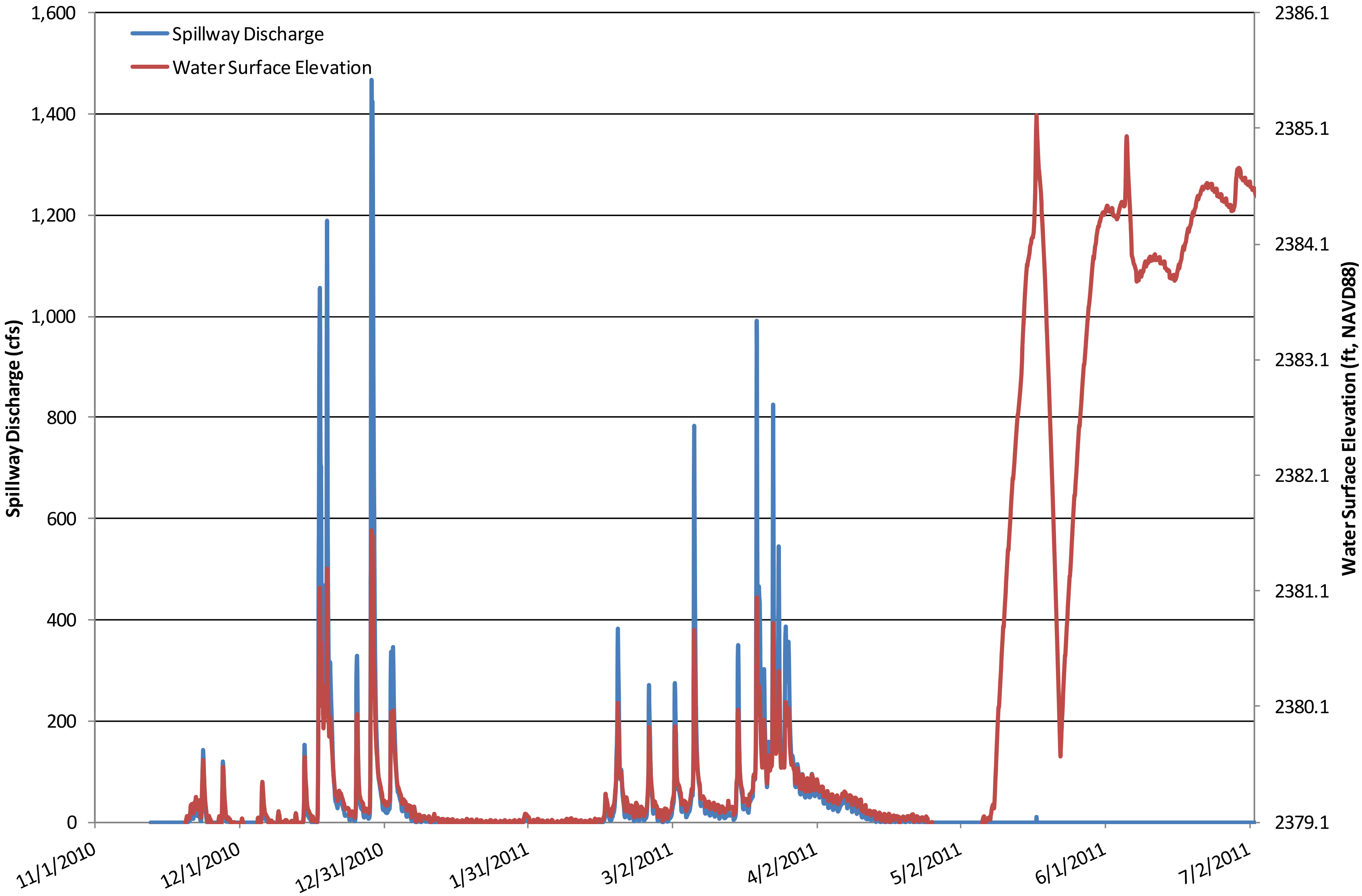


Notes:		*Phoenix Lake Preservation and Restoration Plan* **Lake Water Surface Elevation and Spillway Discharge**		
	cbec eco engineering / Horizon WATER and ENVIRONMENT	Project No. 10-1019	Created By: SP	**Figure 7**

- Lower Sullivan Creek: January - end of February 2011; March 19-23, 2011; October 2011 and daily averages March through October 2011.

The creek stages were computed from the raw data and the flow hydrographs were developed using the existing TUD stage-discharge curves.

Comparison of Lower Sullivan Creek Flow with Computed Lake Discharge

To validate the flows estimated using lake water balance accounting, the inflows from and outflows to Sullivan Creek based on water balance were compared with the flows derived from the upper and lower Sullivan Creek gages. The Appendix B figures B.1 through B.4 depict these comparisons.

Figures B.1 and B.2 compare the flow hydrographs for lower Sullivan Creek based on the computed lake discharge with the flow hydrographs generated from the gage data from the lower Sullivan Creek station. Figure B.1 presents the flows from January 9 to March 1, 2011; Figure B.2 presents the flows from March 19 to March 23, 2011. The computed discharge from the lake to lower Sullivan Creek includes discharge over the lake spillway and the fish release flows. The flow hydrograph at the lower Sullivan gage is based on pressure head data converted to stage and the existing TUD stage-discharge curve for the gage. Gage data points recorded on Feb 18 at 11:41 pm and on March 20 at 6:47 pm appeared erroneous and were not included in the hydrograph plots.

The figures indicate that the flows estimates from both the water balance and the preliminary rating curves agree for most part. However, the established TUD rating curve may underestimate peak flows, or conversely the equation used to calculate spillway discharge may overestimate peak flows. Refining the rating curve with additional higher flow measurements can be expected to provide a better estimate of peak flows.

Comparison of Upper Sullivan Creek Flow with Estimated Lake Inflow

Figures B.3 and B.4 compare the flow hydrographs for Sullivan Creek watershed based on a portion of total calculated lake inflows with the flow hydrographs from the gage at the upper Sullivan Creek location. Figure B.3 presents the flows from November 11 to December 31, 2010; Figure B.4 presents the flows from January 9 to February 18, 2011. The flow hydrographs for the Sullivan Creek watershed were generated by scaling the computed lake inflows as described under the subsection “Sub-Watershed Flows”. The flow hydrograph at the upper Sullivan Creek gage is based on pressure head data converted to stage and the existing TUD stage-discharge curve established for the gage.

The figures indicate that the flow estimates from both the water balance and the preliminary rating curves agree for most part. However, the existing TUD rating curve may underestimate peak flows, or conversely the equation used to calculate spillway discharge may overestimate peak flows, resulting in inflated estimates of total inflow to the lake. Refining the existing rating curve with additional higher flow measurements can be expected to provide better estimate of peak flows.

FLOW FREQUENCY ANALYSIS

A flow frequency analysis was performed using the USGS regional regression equations (USGS, 1993). The basin variables used in the equations are drainage area, mean annual precipitation (MAP) and an altitude index defined as the average of altitudes in thousands of feet at points along the main channel at 10 percent and 85 percent of the stream length. Phoenix Lake and its sub-watersheds lie within the Sierra hydrologic region. The mean annual precipitation (MAP) values for the sub-watersheds were derived from the isohyetal curves developed by California Department of Transportation (Caltrans, 2000). The altitudes were extracted from the 30m USGS Digital Elevation Model for Tuolumne County and surrounding areas (USGS, 2009). The regression equations were used to estimate the 2-, 5-, 10-, 25-, 50- and 100-year flows. Table 2 summarizes the input parameters and calculated flows.

Table 2. Flood Frequency Analysis for the sub-watersheds of Phoenix Lake

Subbasin Name	Chicken Creek	Power Creek[1]	Sullivan Creek	Ridgewood
Area (sq.mi.)	2.15	4.52	15.96	1.13
MAP (inches)	40	42	44	40
10% Altitude (ft)	2388	2396	2391	2397
85% Altitude (ft)	2715	3444	3855	2987
Average Altitude (1000 x ft)	2.552	2.920	3.123	2.692
2-year Flow (cfs)	76	141	436	41
5-year Flow (cfs)	193	349	1002	110
10-year Flow (cfs)	283	505	1412	164
25-year Flow (cfs)	458	812	2239	268
50-year Flow (cfs)	601	1060	2885	354
100-year Flow (cfs)	814	1432	3854	484

Notes:

1. The flood frequency analysis of Power Creek is based on a rainfall-runoff analysis and does not include a detailed analysis of flows into or out of the creek such as the PG&E Main Canal.

SUMMARY AND CONCLUSIONS

As a part of the PLPRP, this memo provides a general functional description of the hydrologic system of Phoenix Lake and its contributing watershed. The hydrologic assessment included the development of a hypsometric curve relating lake level to usable lake storage, a rating curve relating lake level to spillway discharge, water balance accounting, and a flood frequency analysis. The hypsometric curve provides a tool to quantify usable storage and how it relates to demand. The water balance accounting provides a baseline understanding of the lake inflows, outflows, lake water surface elevation and stored usable volume. The flow frequency analysis can be used to support the planning of the sedimentation basins in the lower creek/lake transition zones, as well as providing an improved understanding of the partitioning of flow inputs from the various sub-watersheds. The water balance accounting provides a baseline understanding of the lake inflows, outflows, lake water surface elevation and stored usable volume.

In an attempt to provide additional data to refine TUD's existing stage-discharge rating curves, two flow measurements were taken at each of the upper and lower Sullivan Creek gages. Unfortunately, the gages failed to record the stage in the creek at the time of the flow measurements, which prevented high flow measurement from being utilized to potentially refine the existing TUD rating curves.

A comparison of flow estimates from water balance computations with estimates developed with stage data collected at the two gages combined with the existing TUD rating curves indicates that the two flow estimates agree for most part. However, the existing TUD rating curves may underestimate peak flows, or the weir equations used to calculate spillway outflow may be overestimating flow at that location. Refining the existing rating curve with higher flow measurements can be expected to potentially provide better estimates of peak flows. Therefore, it is recommended that TUD take additional high flow discharge measurements to further refine the gage rating curves.

REFERENCES

HEC, 2010. HEC-RAS River Analysis System: Hydraulic Reference Manual, Version 4.1, January 2010

USGS, 1993. Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites: U.S. Geological Survey Water-Resources Investigations Report 94-4002

Caltrans, 2000. California Department of Transportation's Intensity Duration Frequency (IDF2000) Curves

USGS, 2009. National Elevation Dataset maintained by USGS (http://ned.usgs.gov/Ned)

Construction Drawings of the Phoenix Lake Dam and Spillway provided by Tuolumne Utilities District

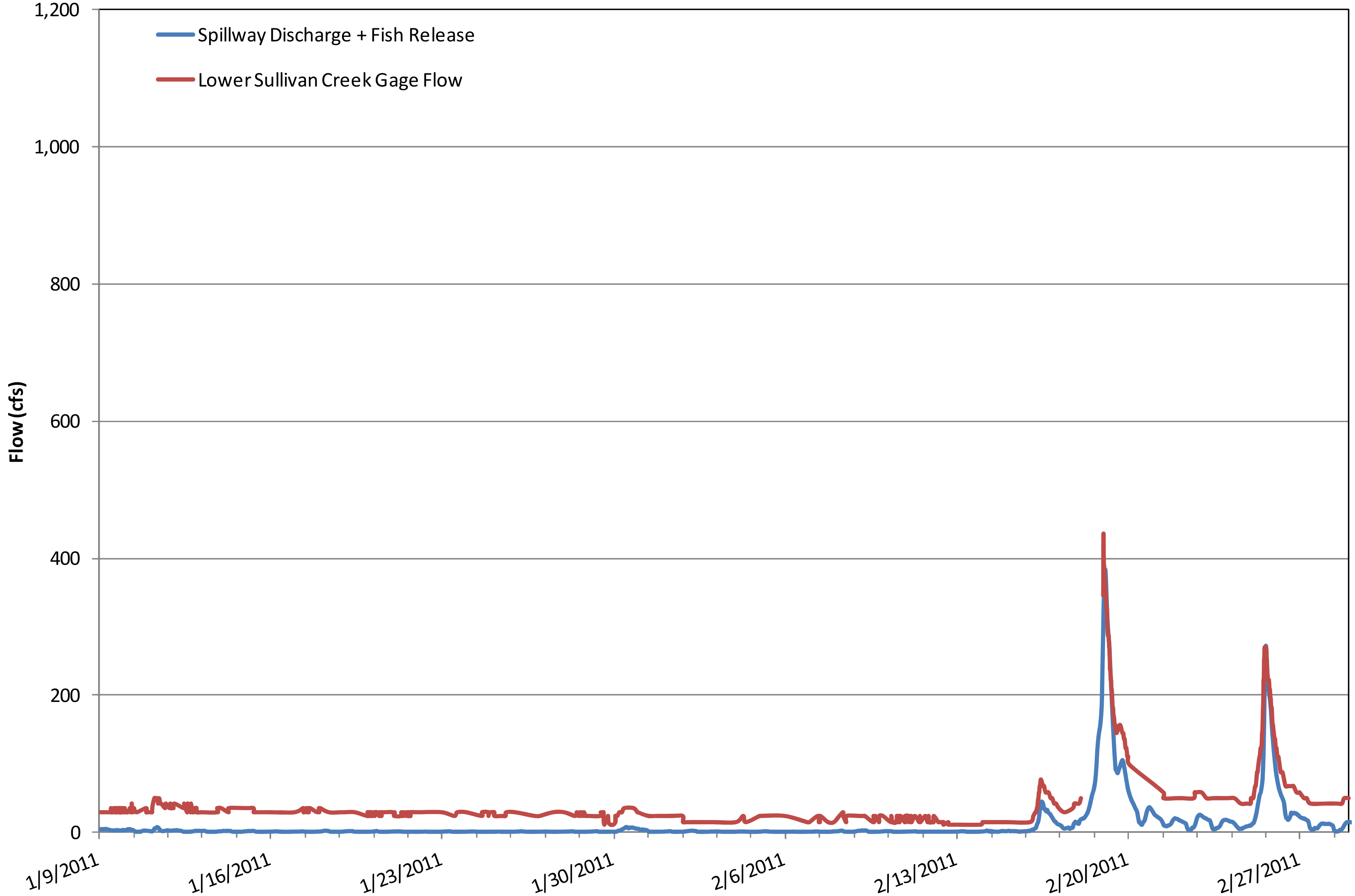
APPENDIX A

List of Spreadsheets and a Brief Description of the Data/Calculations

MS Excel Spreadsheet File Name	Description of Data/Calculations
PhoenixLake_HourlyWSEL_Data.xslx	Raw data of the lake stage, computations and plot of hourly WSELs recorded at the pressure transducer installed at Phoenix Lake
Usable_Storage_Curve.xslx	Data and plot of the relationship between lake level and usable storage capacity
Spillway Discharge Rating Curves.xlsx	Data and plot of the relationship between lake level and spillway discharge
ShawsandPHflow_ComputedAvgHourlyQ	Shaws Flat Pipeline average daily flows and computations of average hourly flow
PhoenixLake_WaterBalance & Sub-watershed Hydrographs.xslx	Lake inflow computations based on water balance; computations and plots of sub-watershed flow hydrographs
RawSCADA & ComputedQs_LowerSullivan.xslx	Raw data from lower Sullivan Creek gage and computations of the corresponding flows based on TUD's existing stage-discharge curves
RawSCADA & ComputedQs_UpperSullivan.xslx	Raw data from upper Sullivan Creek gage and computations of the corresponding flows based on TUD's existing stage-discharge curves
HourlyQ_LakeDischarge_vs_LowerSullivan.xslx	Comparison of computed lake discharges with the flows based on lower Sullivan Creek gage
HourlyQ_UpperSullivan_vs_WatershedInflow.xslx	Comparison of computed Sullivan watershed inflow with the flows based on upper Sullivan Creek gage

APPENDIX B

Estimated Flows Comparison - Water Balance Accounting vs. Gage Data



Notes: January 9 to March 1, 2011

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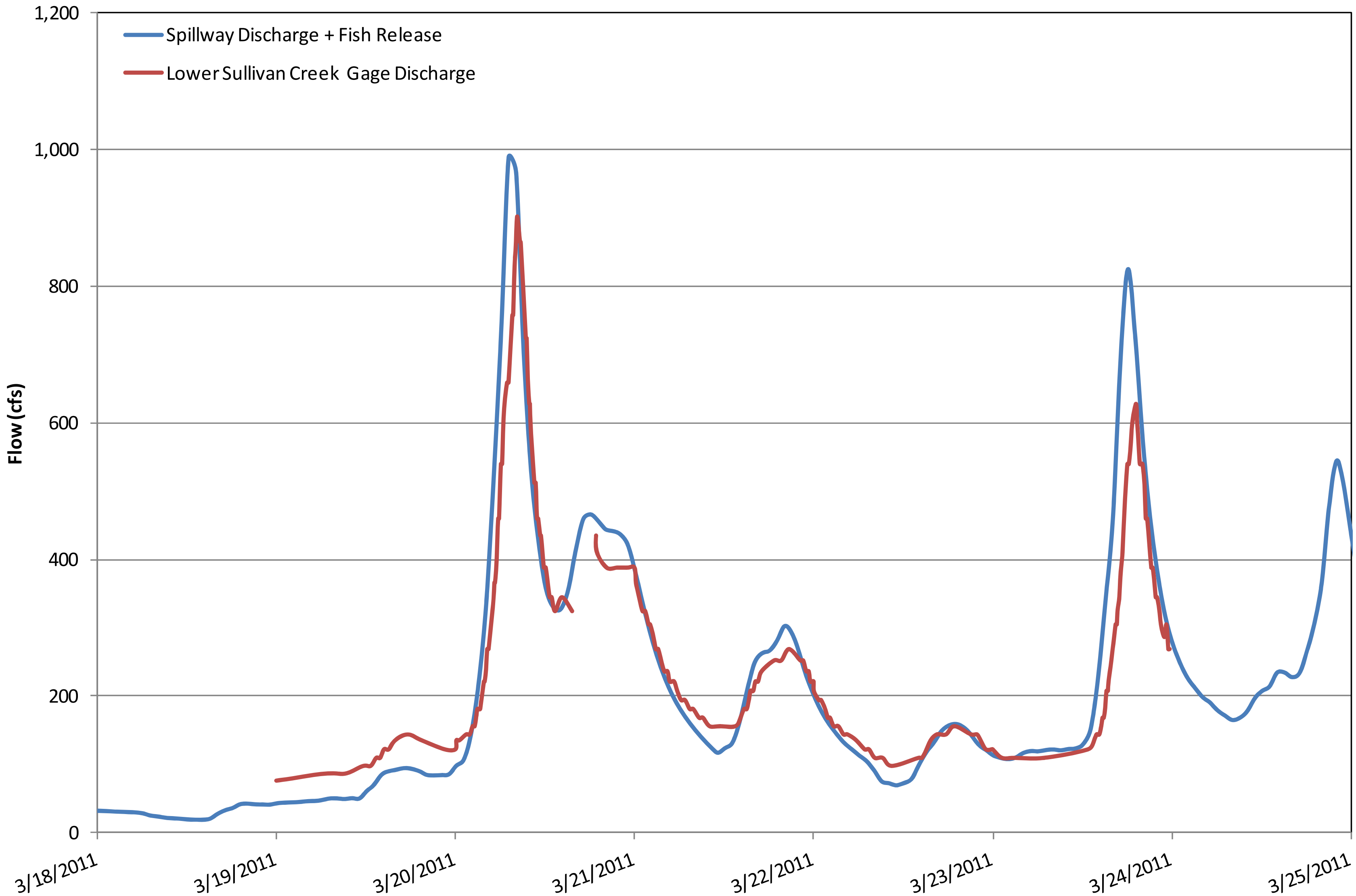
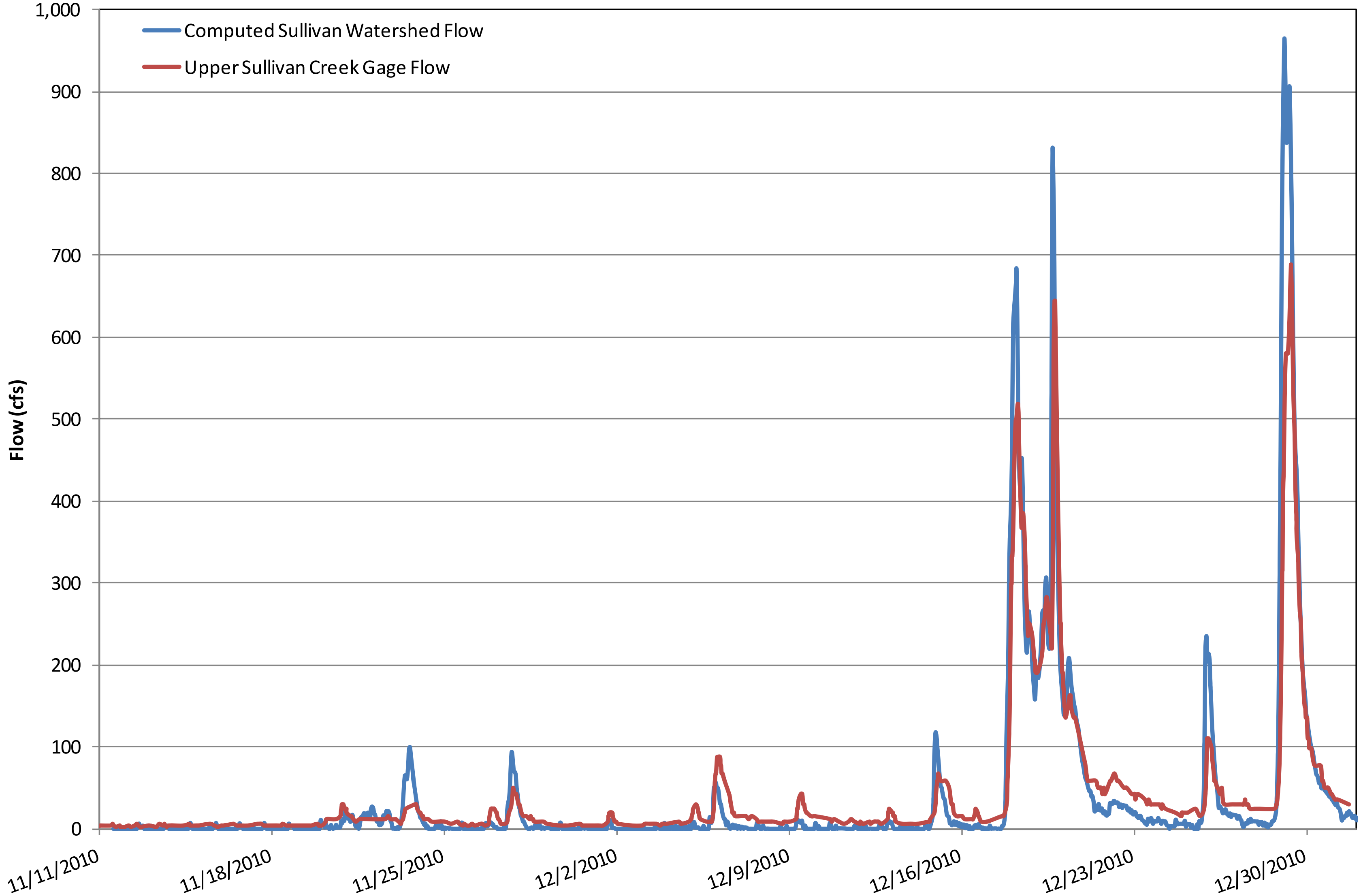
Lower Sullivan Creek Gage Flow vs. Lake Discharge

Project No. 10-1019	Created By: SP	**Figure B.1**



Notes: March 19 to March 23, 2011	cbec eco engineering / Horizon WATER and ENVIRONMENT	*Phoenix Lake Preservation and Restoration Plan* **Lower Sullivan Creek Gage Flow vs. Lake Discharge**
		Project No. 10-1019 — Created By: SP — **Figure B.2**



Notes: November 11 to December 31, 2010	cbec eco engineering / Horizon WATER and ENVIRONMENT	*Phoenix Lake Preservation and Restoration Plan* **Upper Sullivan Creek Gage Flow vs. Sullivan Watershed Flow**		
		Project No. 10-1019	Created By: SP	**Figure B.3**

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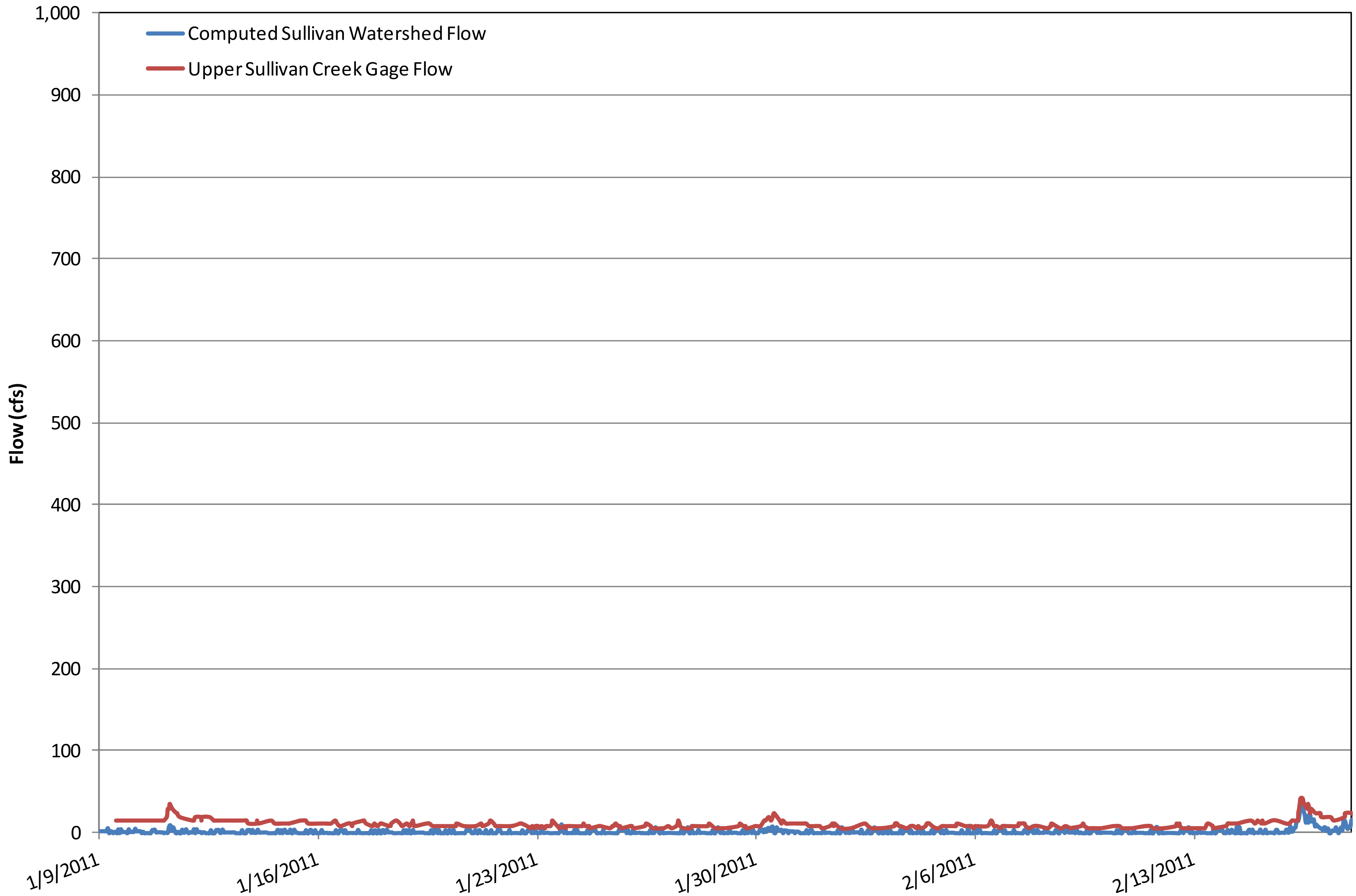

Notes: January 9 to February 18, 2011	cbec eco engineering / Horizon WATER and ENVIRONMENT	*Phoenix Lake Preservation and Restoration Plan* **Upper Sullivan Creek Gage Flow vs. Sullivan Watershed Flow**		
		Project No. 10-1019	Created By: SP	**Figure B.4**

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