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TECHNICAL MEMORANDUM

Date:	February 12, 2016
To:	Brett Ewart, City of Sacramento; Tom Gohring, Sacramento Water Forum
From:	Chris Hammersmark, Chris Campbell and Poyom Riles
Project:	14-1004 – Lower American River - Drought Year Analytical Support
Subject:	Sacramento River Low Flow Modeling at SRWTP Intake

1 Purpose

The drought in 2014 and the subsequent low water levels in the Sacramento River near I Street have prompted the City of Sacramento to consider a retrofit to the Sacramento River Water Treatment Plant (SRWTP) intake structure on the Sacramento River, upstream of I Street. The SRWTP is designed to operate at a water surface elevation (WSE) no lower than 1.5 ft (NGVD29) inside the structure. This corresponds to a slightly higher WSE outside the fish screen to offset any head loss across the screens. The intent of the current analysis is to assess the potential for WSEs at the SRWTP intake to drop below the minimum operable value at flow regimes in the range of 3500 cfs to 7500 cfs (combination of Sacramento River and American River). To this end, a one dimensional HEC-RAS (RAS) model was developed to assess the river stages at the SRWTP in this flow range.

2 Methods

2.1 Model Domain

The river stage in the proximity of the SRWTP intake is heavily influenced by the tidal stages in the Delta as well as flow in the Sacramento River and San Joaquin River. It was necessary to model the lower Sacramento River (see Figure 1) to accurately simulate the tidal influence within the area of interest. An existing RAS model of the lower Sacramento River system, which was developed for the Department of Water Resources (DWR) Central Valley Floodplain Evaluation and Delineation (CVFED) Program, was modified for use in the current analysis. The CVFED RAS model was developed as a model for flood flows, and as such, required modifications to function as a low flow model for tidal simulations. As shown in Figure 1, the CVFED model of the lower Sacramento River System was truncated to include: 1) the Sacramento River from Verona to Collinsville; 2) the American River below Watt Ave; 3) the Sacramento River Deep Water Ship Channel; 4) Liberty Island at the southern extent of the Yolo Bypass;

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5) Cache, Lindsey, Haas, Elk, Sutter, Miner, and Steamboat Sloughs; 6) Georgiana Slough; and 7) Threemile Slough and Horseshoe Bend.

2.2 Topographic Data

The lower Sacramento River CVFED model geometry is based on several sets of topographic data to include LiDAR, single beam bathymetry, and multi-beam bathymetry. All model geometry is in the vertical datum of NAVD88; however, all results reported for the SRWTP location have been converted to the NGVD29 vertical datum using an adjustment factor of +2.54 ft.

2.3 Boundary Conditions

All 12 model boundary conditions are listed in Table 1. Observed data from DWR and USGS gages were used for 4 of the model boundary conditions. All of the other boundary conditions were assigned a nominal flow of 1 cfs for model stability, with the exception of the American River, which was assigned a flow of 500 cfs to approximate low flow conditions in the lower American River. 500 cfs is the lowest flow experienced on the American River in recent history, and it is the observed flow on the American River during the model calibration period.

Table 1. RAS Model Boundary Conditions

Boundary Location	Boundary Type	Data (Source)
American River @ Watt Ave	Flow hydrograph	500 cfs
Cache Slough	Dummy Flow	1 cfs
Elk Slough	Dummy Flow	1 cfs
Georgiana Slough @ Mokelumne River	15-minute Stage	Observed Stage (USGS, 11336930)
Hass Slough	Dummy Flow	1 cfs
Lindsey Slough	Dummy Flow	1 cfs
Sacramento River @ Verona	Daily Flow	Observed Flow (USGS, 11425500)
Sacramento River @ Collinsville	15-minute Stage	Observed Stage (CA DWR, CSE)
Deep Water Ship Channel	Dummy Flow	1 cfs
Threemile Slough @ San Joaquin River	15-minute Stage	Observed Stage (USGS, 11337080)
Yolo Bypass/Toe Drain	Flow hydrograph	1 cfs

2.4 Calibration and Validation

The purpose of this modeling effort is to assess the Sacramento River stage at the SRWTP intake structure near I Street Bridge at extreme low flows. As stated earlier, the tidal influence in this area is significant when flows are low. To calibrate the model, the lowest flow period on record for the lower Sacramento River, a two week period from January 12 to January 26, 2014, was used. During this period, the daily average flow at Verona ranged from 5600 cfs to 6400 cfs and stages at I Street ranged from 1.24 to 3.88 ft NGVD29. Model calibration was conducted by reach wide adjustments to Manning's n values, modifications to hydraulic structures, and adjustments to the Mokelumne River gage stage datum used for the downstream boundary of Georgiana Slough:

- Manning's n values in the CVFED RAS model were based on calibrated values for flood conditions. To simulate low flows, Manning's n values were globally adjusted on a reach by reach basis in an effort to reduce the root mean square error (RMSE) between modeled and observed stage values.
- The hydraulic conveyance through several bridge structures, while adequate for a flood model, was not accurate in simulating the tidal flux at low flows. For this reason, the following structures were removed during calibration: the SRWTP intake structure, I Street Bridge, Hwy 275/Capitol Mall Bridge, I-80/US50 Bridge, and Freeport Bridge.
- The Mokelumne river gage, used as the boundary condition where Georgiana Slough meets the Mokelumne River, has an arbitrary datum. During calibration, the datum was adjusted to calibrate to the tidal signal at the gage on Georgiana slough near Sacramento River, as well as to match the stage at other gages within its vicinity.

Figure 2 shows the location of all stage gages that were used as boundary conditions as well as to calibrate and validate the model.

The model was validated using an earlier, slightly higher flow period from December 16 to December 29, 2013, when daily average flow at Verona ranged from 6000 cfs to 8000 cfs and stages at I Street ranged from 1.84 to 4.49 ft NGVD29.

2.5 Low Flow Analysis

A low flow analysis of the stage at the SRWTP Intake was conducted by modeling a set of 5 constant inflows on the Sacramento River at Verona ranging from 3000 cfs to 7000 cfs at Verona for a two week period, when combined with an assumed low flow value for the lower American River, this resulted in combined flows of 3500 cfs to 7500 cfs at the SRWTP Intake. All of the other model boundaries were identical to the calibration run, including the tidal stage boundaries. It should be noted that the low low tide in the San Francisco Bay (see Figure 3) varies throughout the course of the year, and is generally lowest in winter and summer. Low low tides occurring in spring or fall tend to be higher in elevation. The low flow tidal boundary used in the analysis is a conservative estimate of the stage because it is a winter tidal signal (January 12 to January 26).

3 Results

3.1 Calibration and Validation Results

The results of the calibration and the validation are provided in Figure 4 through Figure 11. For the calibration period, the modeled daily minimum stage is within 0.06 ft on average of the observed values at I Street and within 0.11 feet on average of the observed values at Freeport. Final calibrated roughness values are shown in Table 2.

Table 2. Calibrated Roughness Values

River	Reach	Channel Roughness
American River	Watt Ave to Sacramento River	0.035
Cache Slough	To Sacramento River	0.028
Elk Slough	Sacramento River to Sutter Slough	0.035
Georgiana Slough	Sacramento River to Mokelumne River	0.03
Hass Slough	To Cache Slough	0.04
Horseshoe Slough		0.03
Lindsey Slough	To Cache Slough	0.04
Lower Egbert Tract		0.044
Miner Slough	Sutter Slough to Cache Slough	0.045
Sacramento River	Verona to Cache Slough	0.025
Sacramento River	Cache Slough to Collinsville	0.022
Deep Water Ship Channel	Washington Lake to Cache Slough	0.035
Steamboat Slough	Sacramento River to Cache Slough	0.035
Sutter Slough	Sacramento River to Steamboat Slough	0.035
Threemile Slough	Sacramento River to San Joaquin River	0.1
Yolo Bypass	Putah Creek to Lindsay Slough	0.035
Yolo Bypass	Lindsey Slough to Lower Egbert	0.044

3.2 Low Flow Modeling Results

The results for the low flow analysis are provided in Figure 12 and Table 3. The model indicates that the stage may be as low as 1.65 ft when the combined flow of the Sacramento River and the American River is 7500 cfs. The results show that as the flow decreases, the minimum stage decreases and the daily range in stage increases as the tidal influence becomes more dominant. All of the flows below 7500 cfs have a minimum water surface that is below the current required operable water surface for the SRWTP intake structure of 1.5 ft NGVD29.

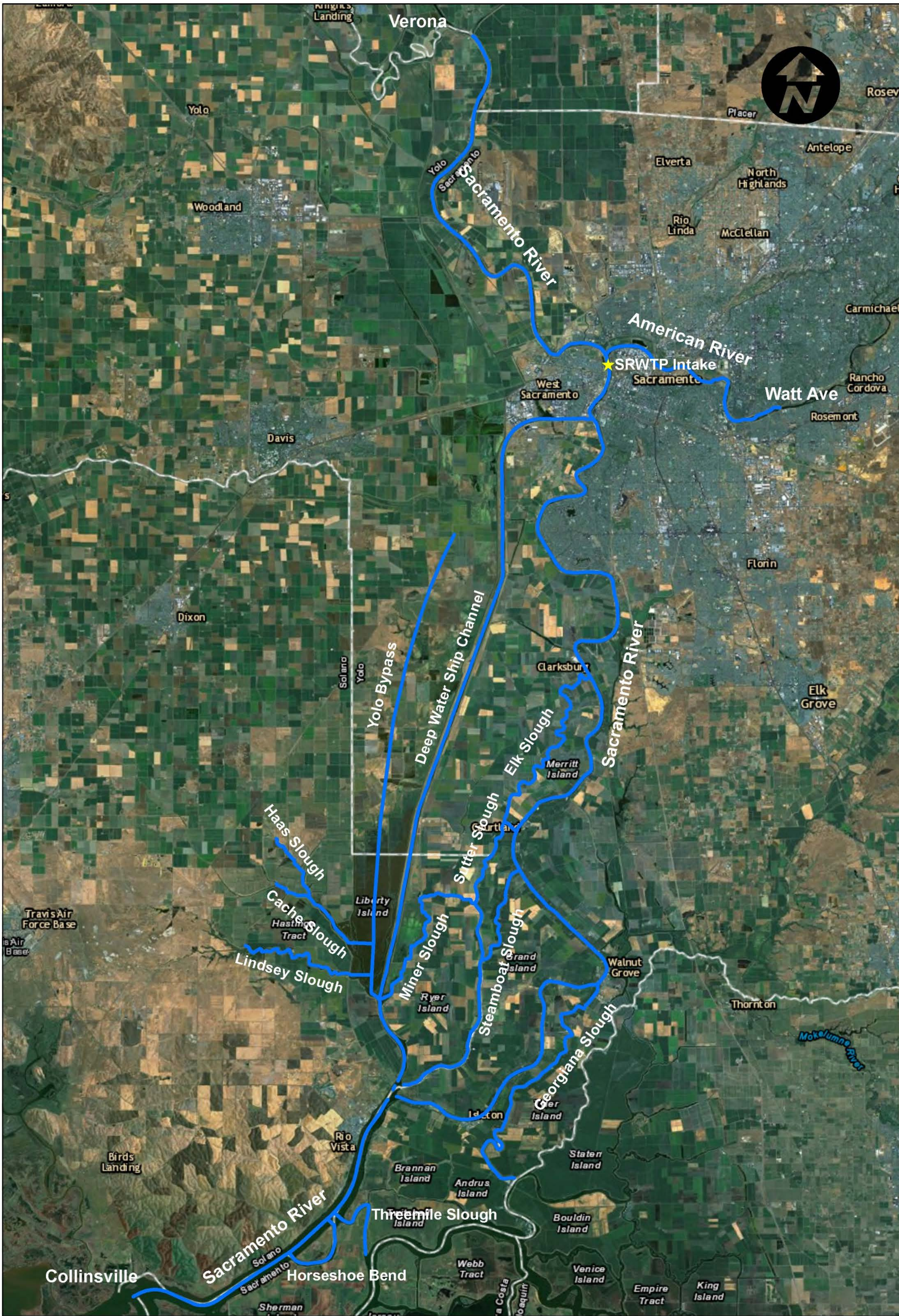
Table 3 can be used to predict river stage at the SRWTP intake based on the combined flow of Sacramento River and American River. American River flow at Watt Avenue is not readily available and can be substituted with American River flow at Fair Oaks for periods of constant low flow. However, approximating the flow at Watt Avenue with flow at Fair Oaks will ignore the effect of travel time as well as other attenuation and losses that occurs due to evaporation, evapotranspiration, groundwater recharge or surface storage. When using Table 3 to predict a minimum stage based on the combined flow, it should be assumed that the predicted minimum stage values can vary by as much as ± 0.25 ft .

Table 3. Low Flow Modeling Results

Combined Sacramento River Flow and American River Flow (cfs)	Stage at SRWTP Intake (ft NGVD29)		
	Minimum	Daily Average	Max Daily Range[1]
3500	0.69	1.82	2.25
4500	0.91	1.99	2.16
5500	1.14	2.17	2.07
6500	1.39	2.35	1.96
7500	1.65	2.55	1.84

Notes:

1) Actual range is likely larger, due to the fact that the calibration effort did not emphasize matching high tides, as the emphasis of the effort was on simulating the extreme low WSE conditions.



Notes: Background courtesy of ESRI	cbec	*Sacramento River Low Flow Modeling at SRWTP Intake* **Model Domain**		
		Project No. 14-1004	Created By: PFR	**Figure 1**

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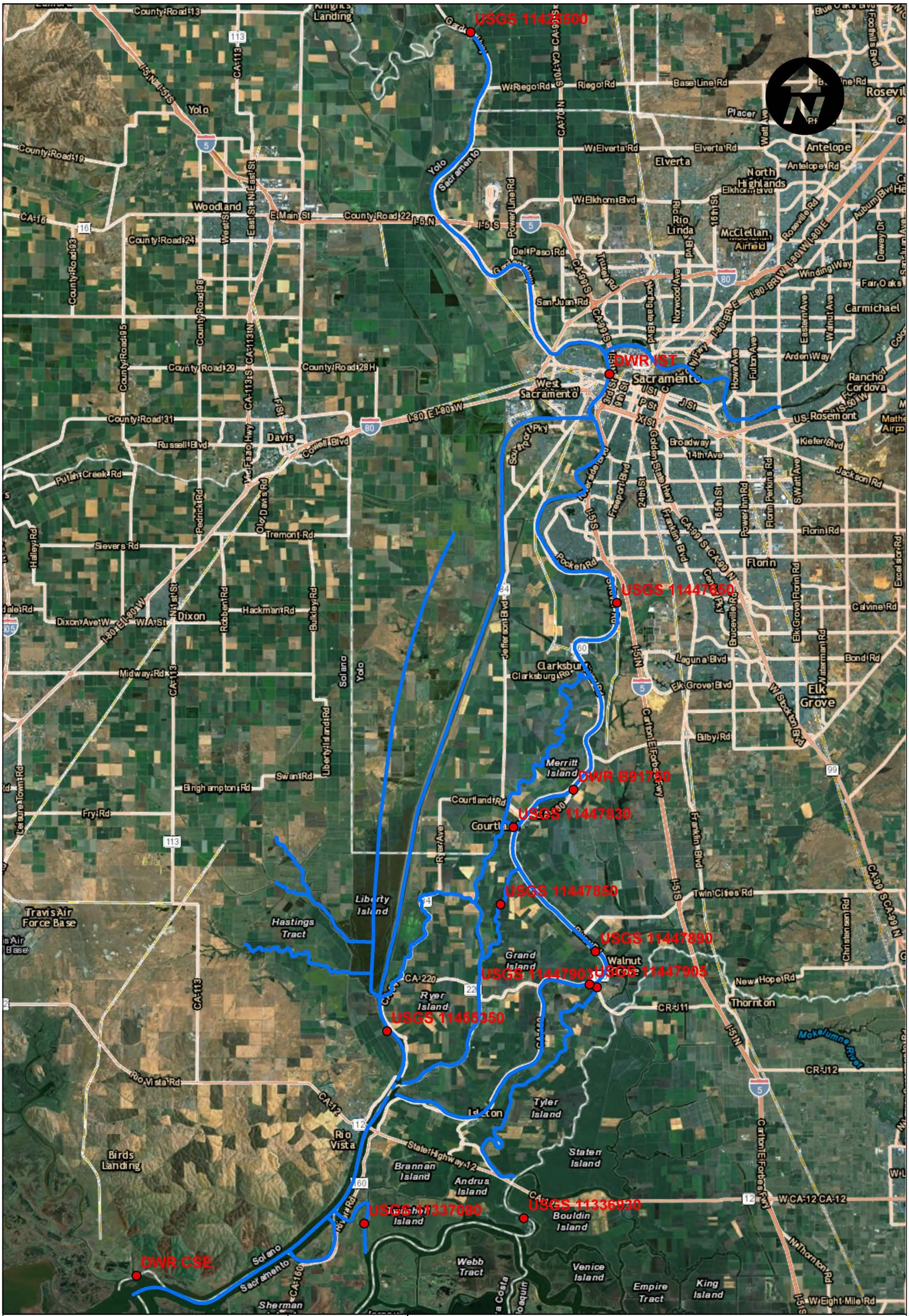

Notes: Background courtesy of ESRI	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake*	
		Gage Locations	
		Project No. 14-1004	Created By: PFR
			Figure 2

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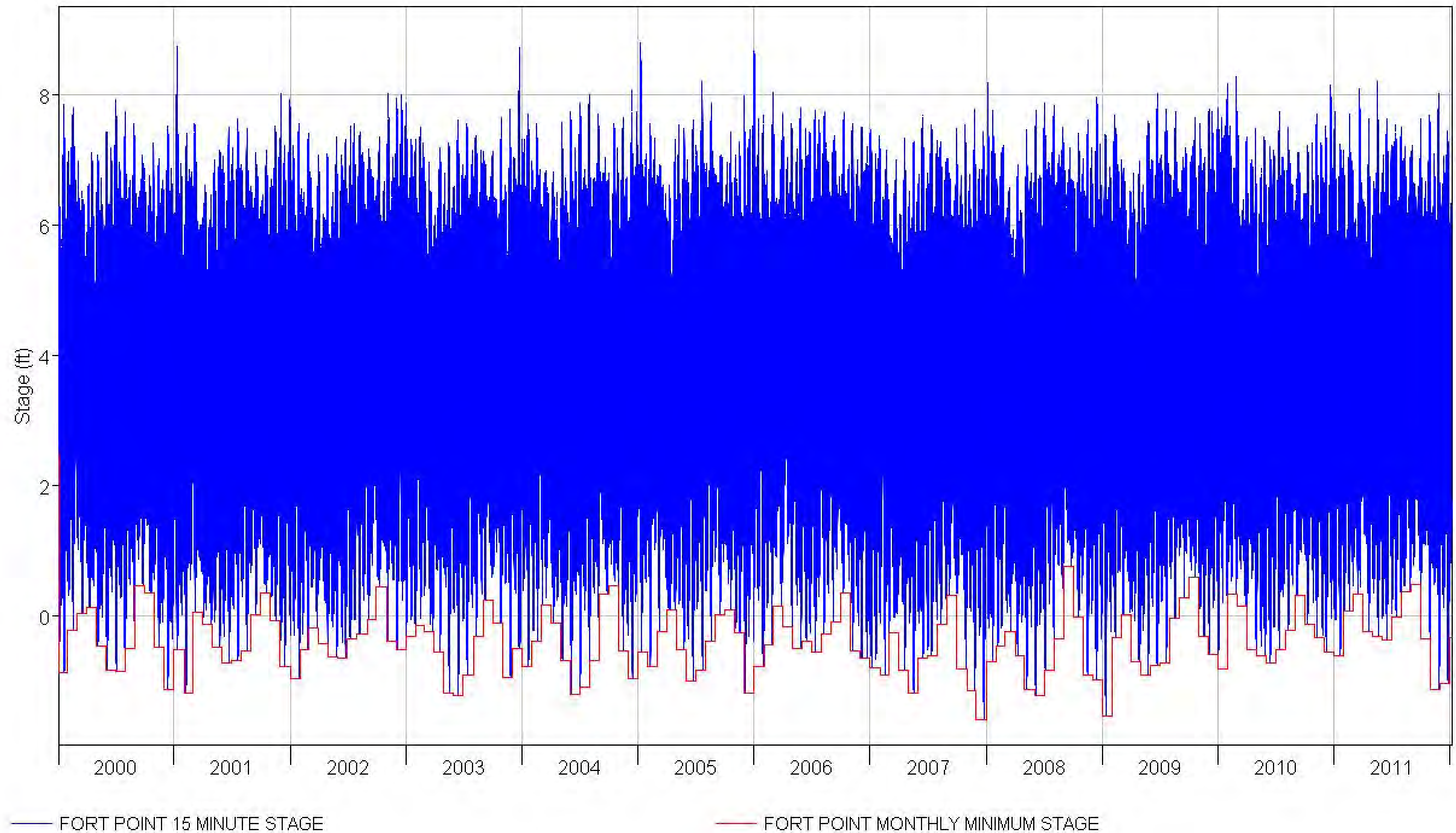

Notes:	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **San Francisco Bay Tidal Signal**		
		Project No. 14-1004	Created By: PFR	**Figure 3**

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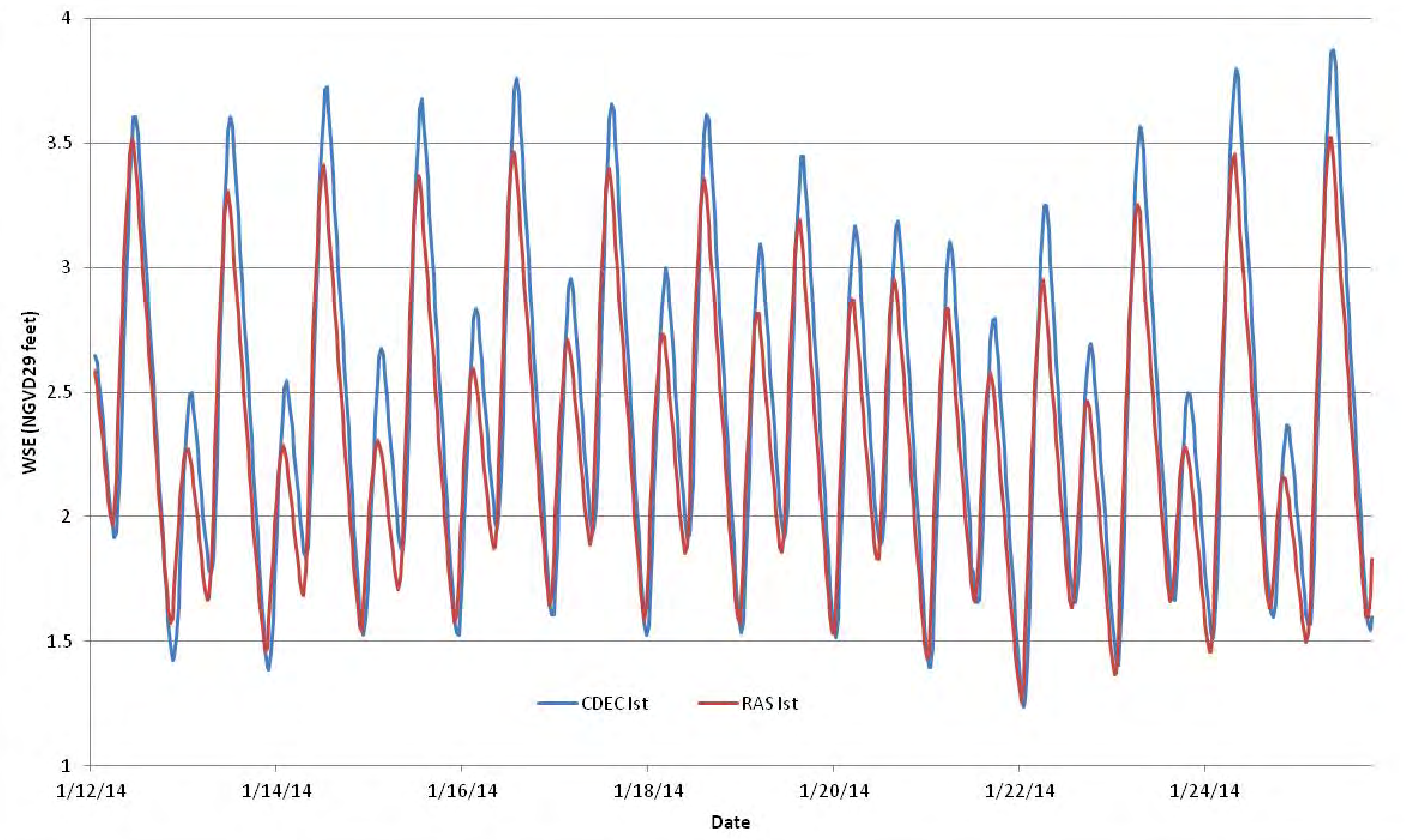

Notes: DWR gage Sacramento River at I Street Bridge

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Sacramento River Low Flow Modeling at SRWTP Intake

Calibration Results at Sacramento River at I Street

Project No. 14-1004	Created By: PFR	**Figure 4**

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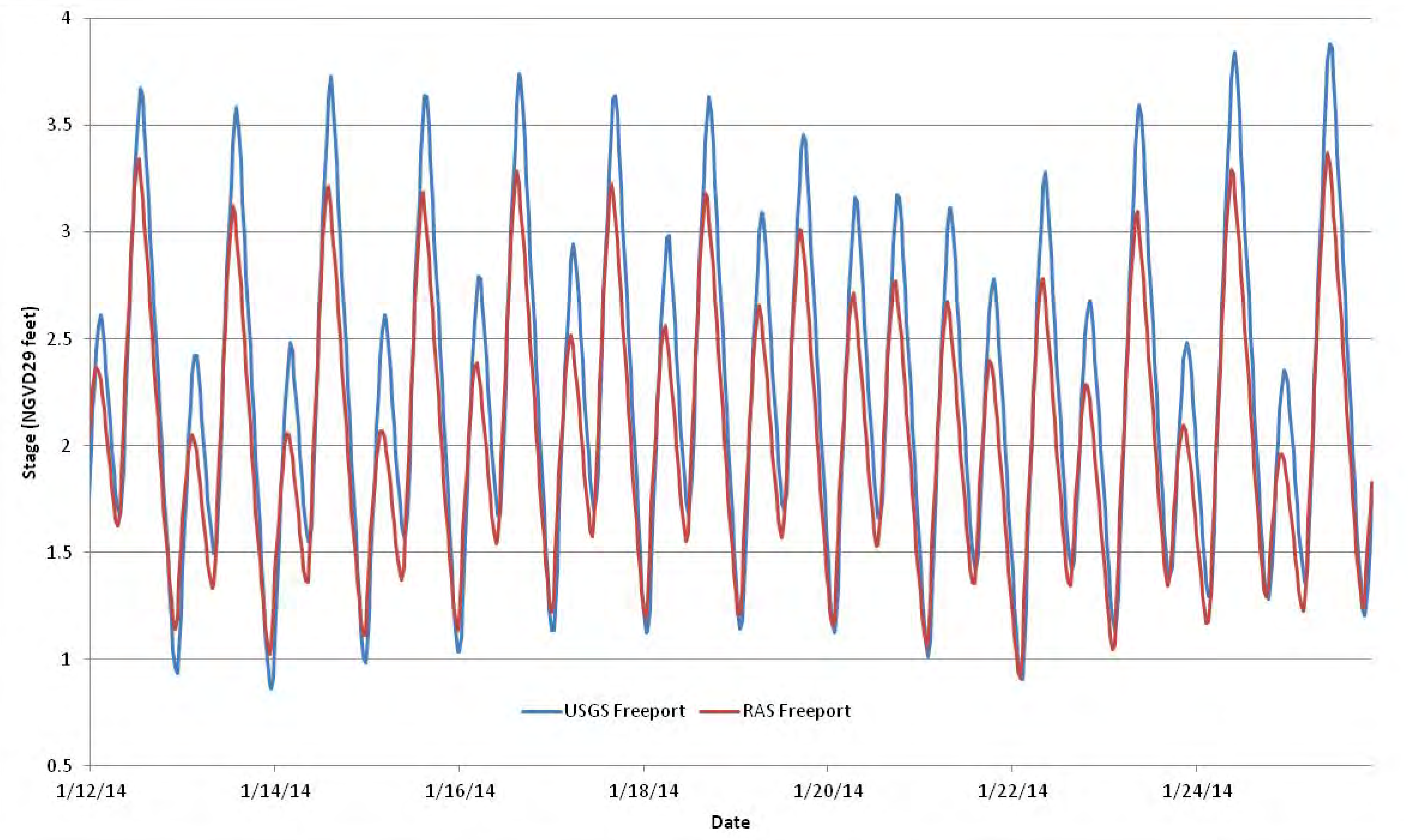

Notes: USGS gage 11447650	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Calibration Results at Sacramento River at Freeport**		
		Project No. 14-1004	Created By: PFR	**Figure 5**

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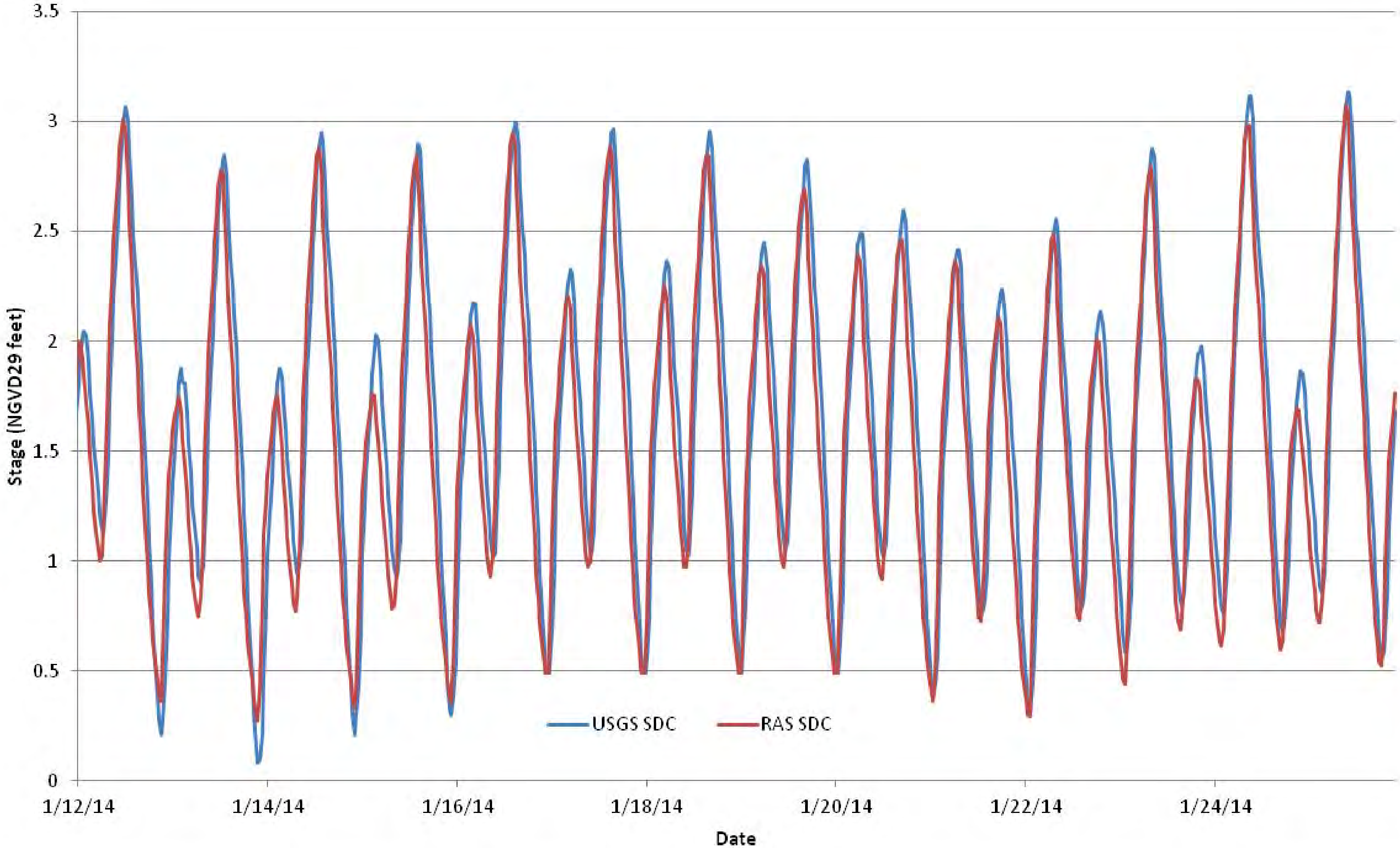

Notes: USGS gage 11447890	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Calibration Results at Delta Cross Channel**		
		Project No. 14-1004	Created By: PFR	**Figure 6**

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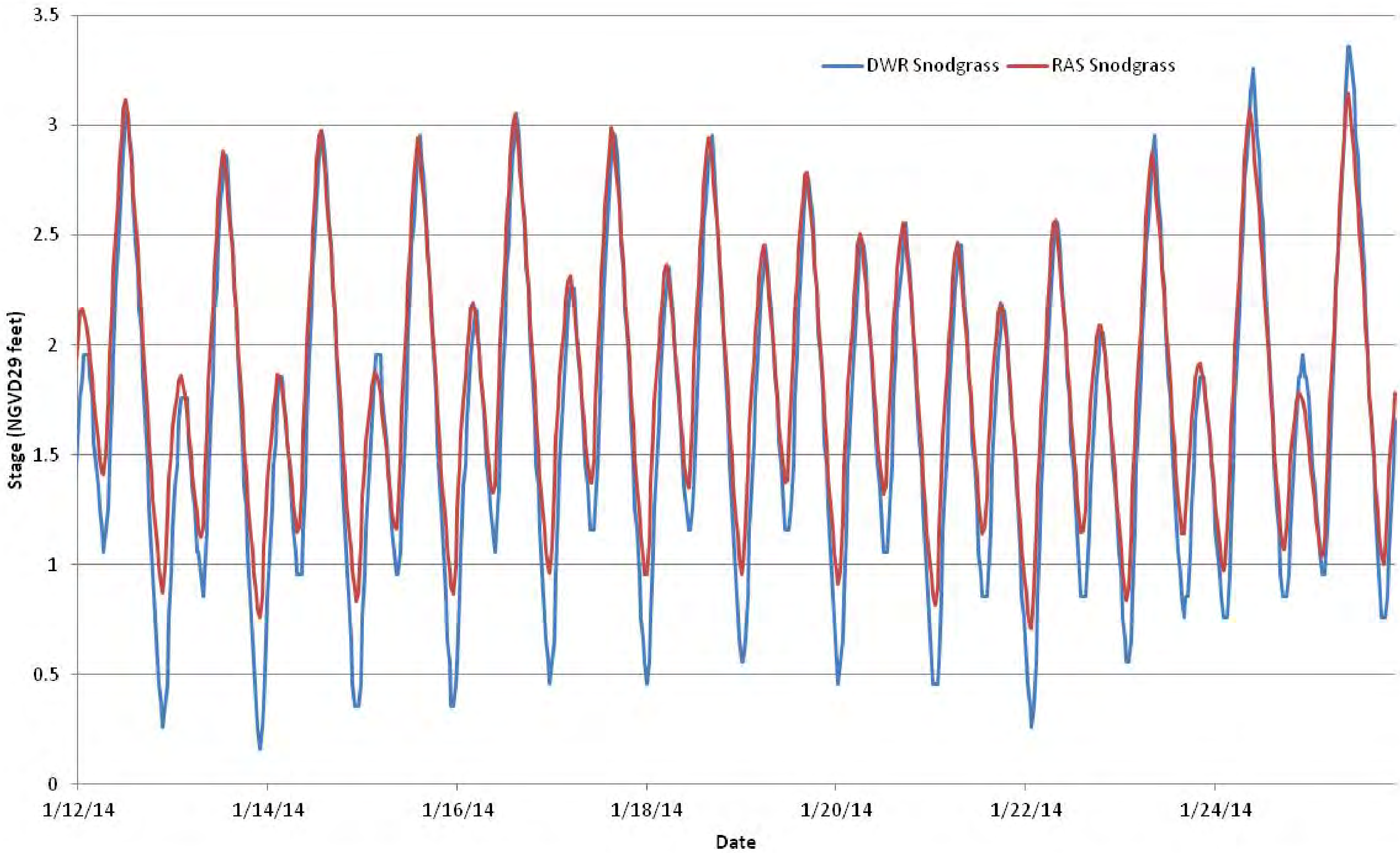

Notes: DWR gage B91750	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Calibration Results at Sacramento River at Snodgrass**		
		Project No. 14-1004	Created By: PFR	**Figure 7**

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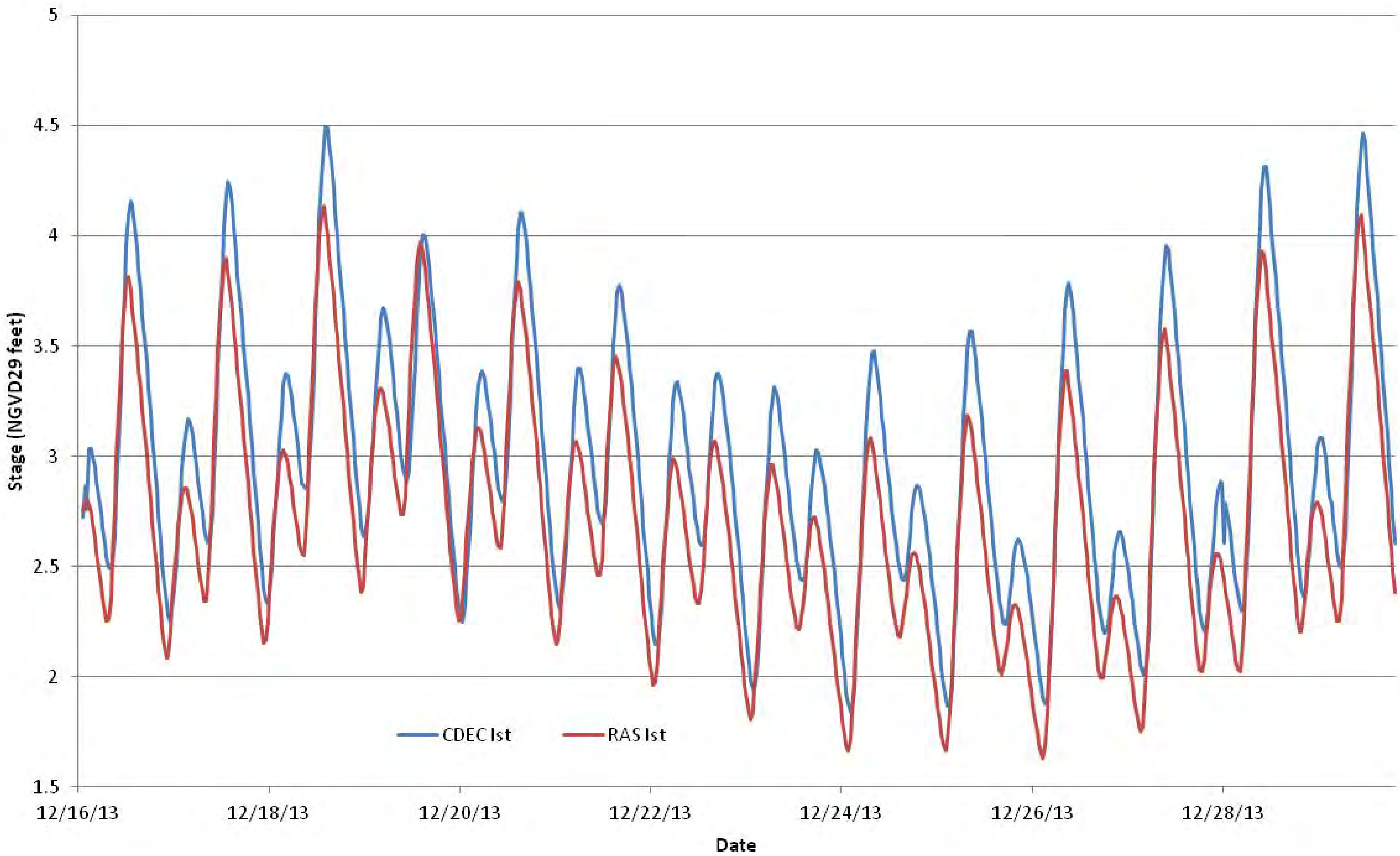

Notes: DWR gage Sacramento River at I Street Bridge	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Validation Results at Sacramento River at I Street**		
		Project No. 14-1004	Created By: PFR	**Figure 8**

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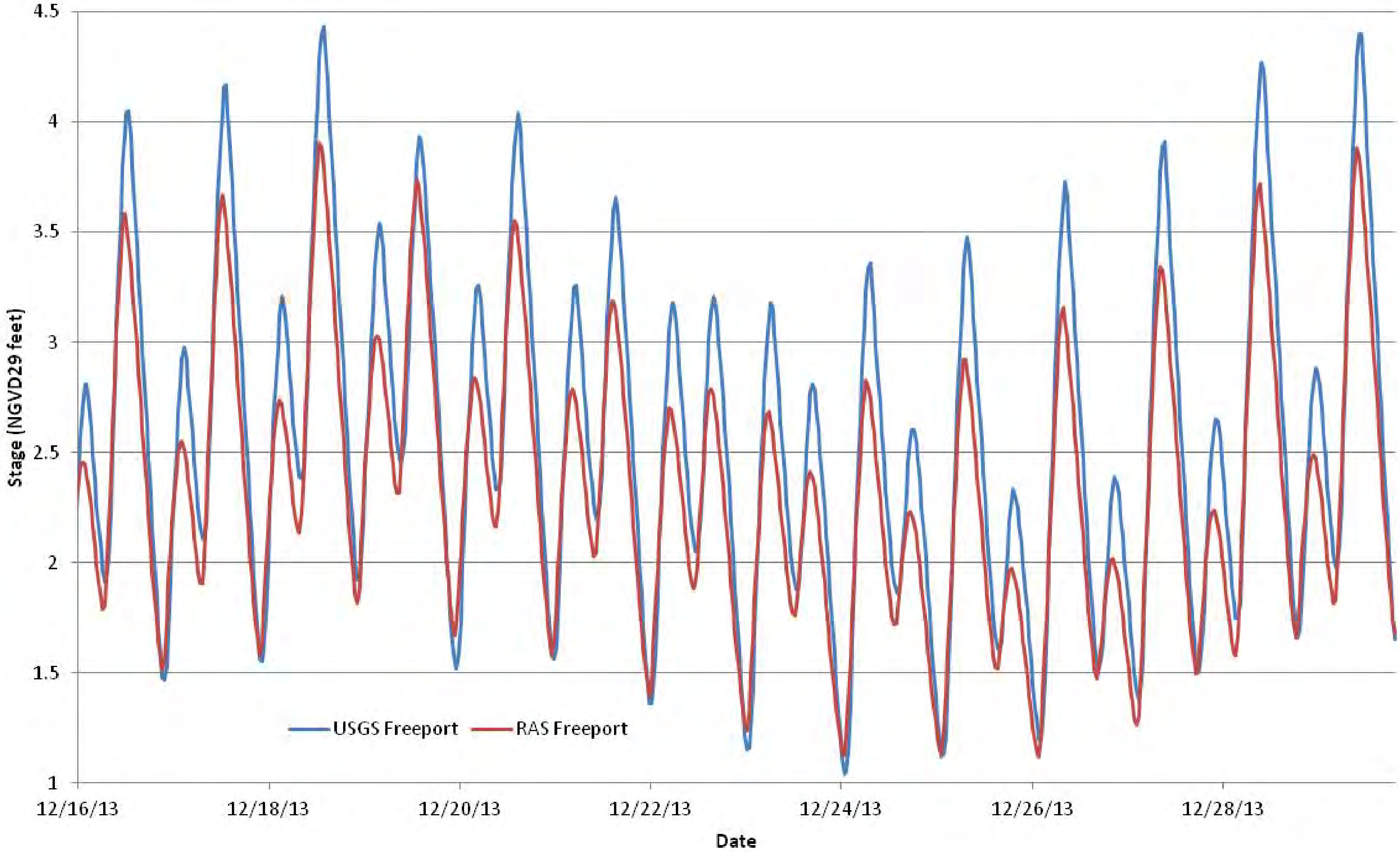

Notes: USGS gage 11447650	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Validation Results at Sacramento River at Freeport**		
		Project No. 14-1004	Created By: PFR	**Figure 9**

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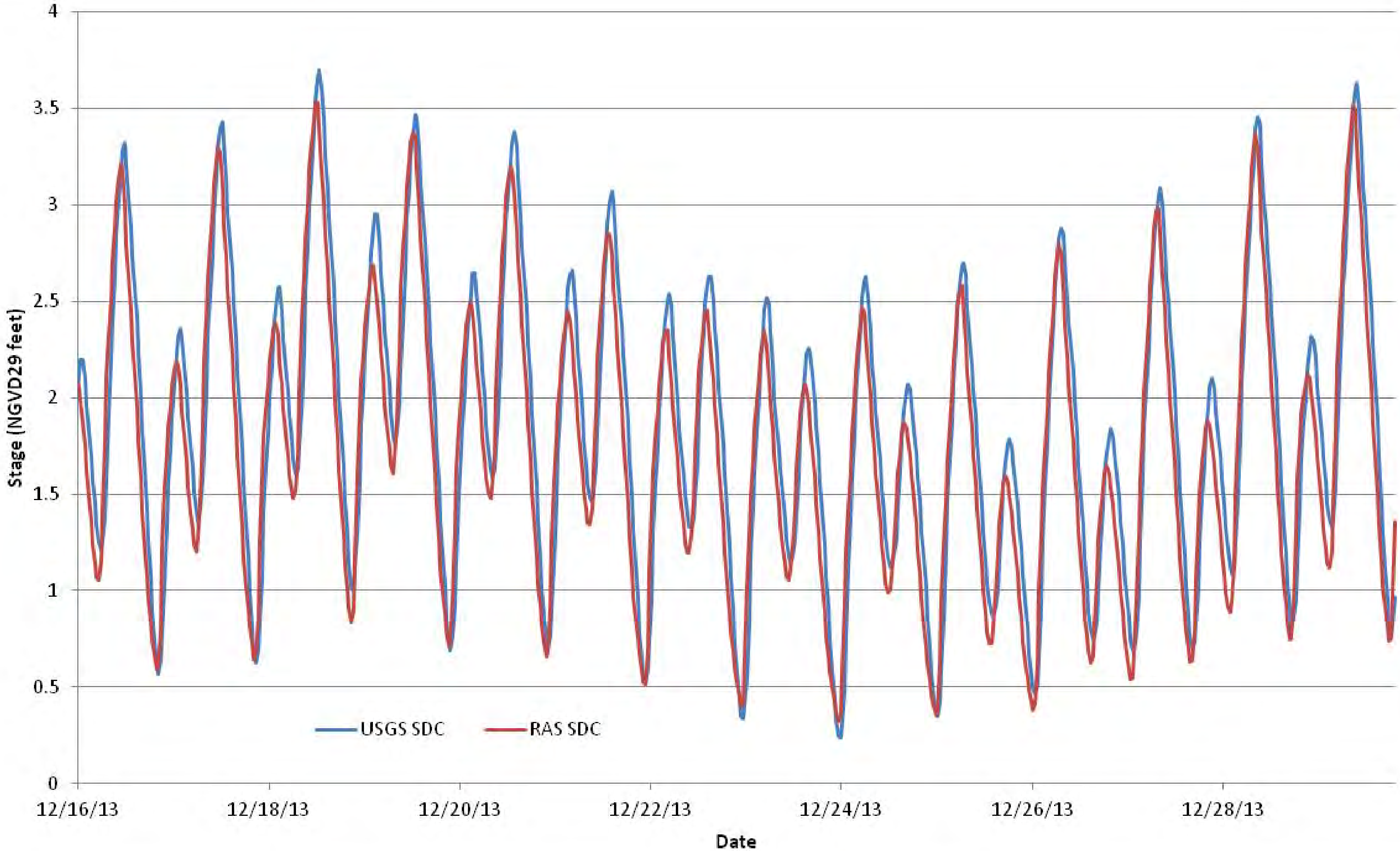

Notes: USGS gage 11447890	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Validation Results at Delta Cross Channel**		
		Project No. 14-1004	Created By: PFR	**Figure 10**

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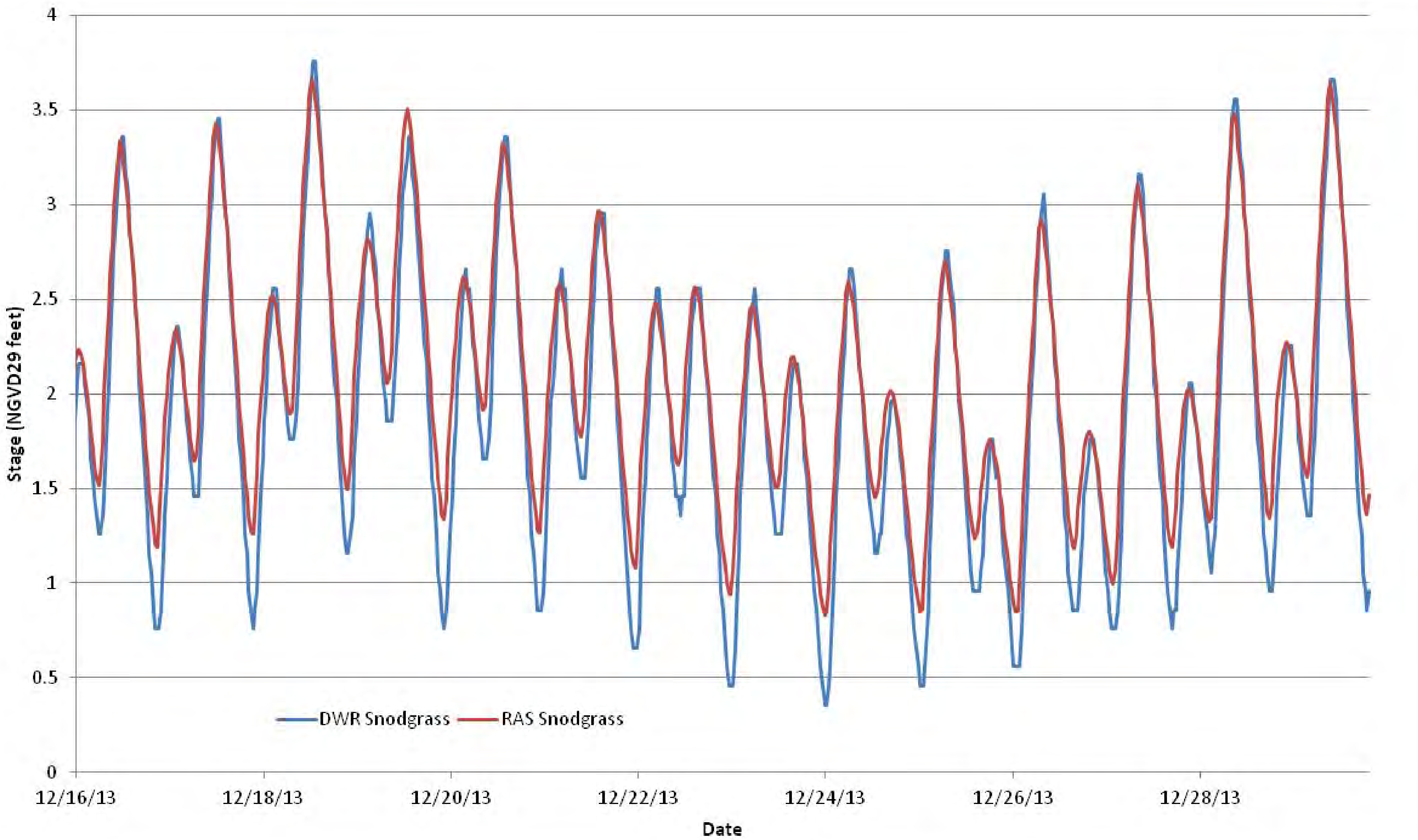

Notes: DWR gage B91750	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **Validation Results Sacramento River at Snodgrass**		
		Project No. 14-1004	Created By: PFR	**Figure 11**

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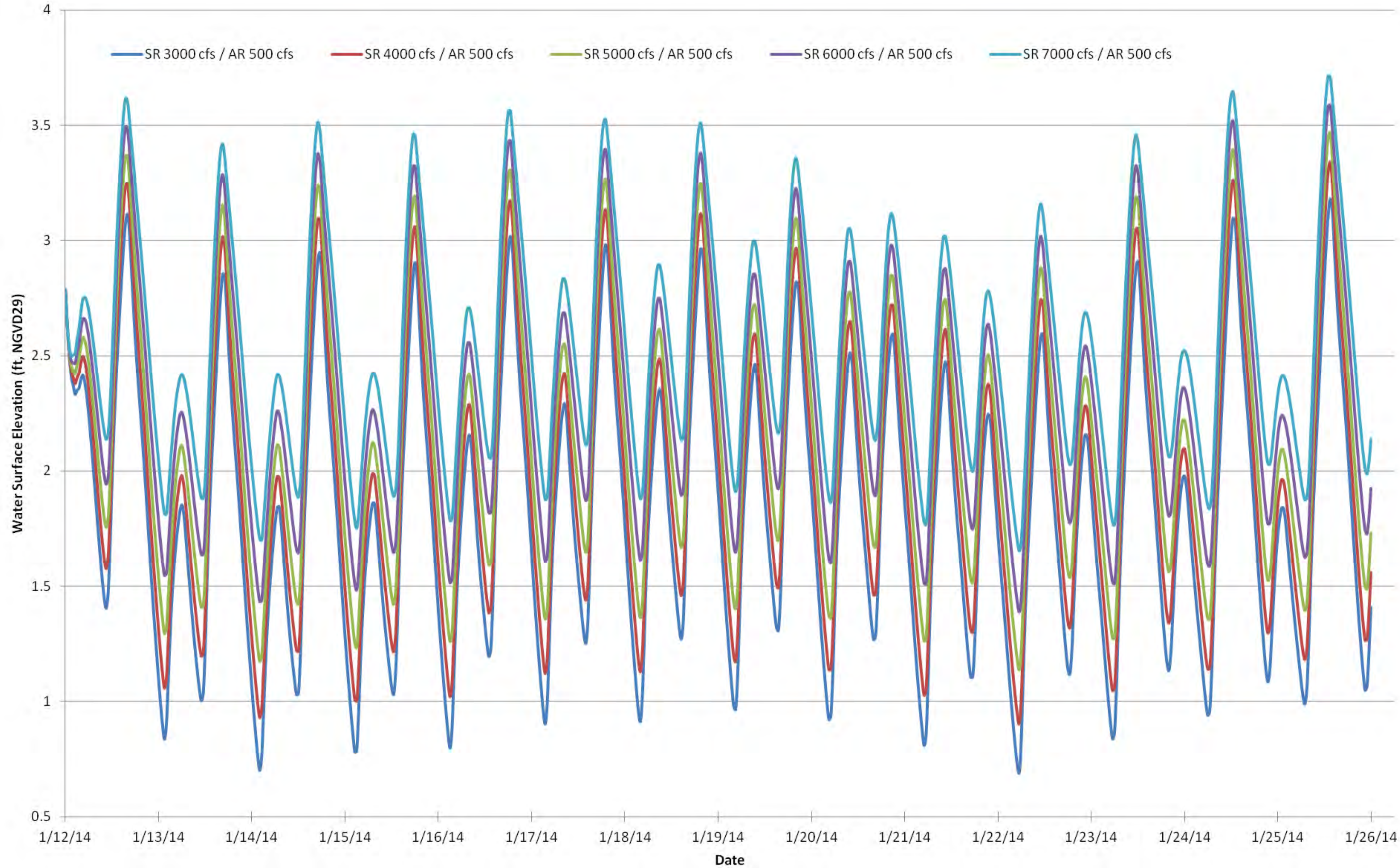

Notes:	cbec eco engineering	*Sacramento River Low Flow Modeling at SRWTP Intake* **SRWTP Stage for Various Combined Low Flow Rates**		
		Project No. 14-1004	Created By: PFR	**Figure 12**

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