HYDRODYNAMIC MODELING OF THE SAN GABRIEL RIVER ESTUARY

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INTRODUCTION

More than 20 miles of the San Gabriel River, including the San Gabriel River Estuary (SGRE), are identified as impaired for water quality with respect to their designated beneficial uses and, consequently, have been added to the US Environmental Protection Agency's (USEPA) 303(d) list. Specifically, more than 45 of USEPA's 303(d) listings exist on different reaches in the watershed, including the entire estuarine portion of the San Gabriel River. The numerous USEPA's 303(d) listings include algae, nutrients, bacteria, metals, organic constituents and abnormal fish histology. The upper area of the watershed, which is comprised of National Forest lands, is impacted by trash and debris as well as being affected by habitat destruction due to recreational activities. The middle and lower areas of the watershed, which are heavily urbanized, are also impacted due to non-point sources of pollution. In addition, there are 5 publicly owned treatment works (POTWs) that discharge more than 150 million gallons per day (mgd) of highly treated effluent to the river, 2 power generating stations that discharge up to 2.2 billion gallons per day to the Estuary, and other discharges covered by National Pollutant Discharge Elimination System (NPDES) permits within the watershed. All of these upstream sources commingle and eventually find their way to the Estuary before the San Gabriel River discharges to the Pacific Ocean.

Two options to characterize the SGRE are to extensively monitor it over a variety of conditions or collect data to support the development of a model of the system. To accurately characterize the system, empirical data should be collected over a wide range of conditions over a long period. The modeling approach allows for a smaller sampling program and the development of a computer model to characterize those sampling periods.

One way to characterize the interaction between the watershed and the SGRE is to model each system. Hydrodynamic and water quality models have become important tools in aiding decisions about water quality management. Models provide the ability to evaluate water quality under a range of expected conditions, to evaluate potential management scenarios, and to identify key knowledge gaps that should be the focus of future research. To date, models have been developed for several of the watersheds draining into Santa Monica and San Pedro Bays (Tetra Tech 2004), including the San Gabriel River Watershed.

Watershed models provide information about pollutant discharge and loading at the downstream end of the watersheds studied. However, to link watershed-based sources with receiving water effects, managers need to understand the fate of pollutants after they exit the watershed and enter coastal estuaries and embayments. Estuary modeling is the next logical step in the development of an integrated set of management tools to support water quality management decisions in coastal regions, such as the greater Los Angeles Basin.

Development of estuary models provides several challenges that are different from watershed models. Unlike streams, estuaries are subject to bidirectional flow associated with tidal action. Second, estuaries experience spatially complex and temporally variable salinity patterns. Third, vertical stratification and mixing can lead to deposition and scour that vary along the length of the estuary.

Like watershed modeling, development of estuary models is multi-step process. The first, and foundational step is the development, calibration, and validation of a hydrodynamic model. Once movement of water through the estuary can be simulated with confidence, then models for water quality (i.e., fate of pollutants) can be developed. Finally, biological models (i.e., bioaccumulation) can be developed to predict the ultimate effects of pollutants.

This study is the first of a series of steps in model development of the SGRE. The goal of this effort is to capture the physics (hydrodynamics) of the system under dry weather conditions. Data was collected in support of the development of a hydrodynamic model to characterize the current conditions within the estuary. The calibrated and validated model was then used to look at the residence time of a conservative tracer in the estuary under three scenarios. Additional sampling and hydrodynamic modeling will be needed to characterize the SGRE under storm flows. The model can then be further expanded to incorporate pollutants to better understand water quality, to assist in planning activities, and to aid in the design and implementation of a watershed monitoring and management programs.

Watershed Background

The San Gabriel River Watershed is located in the eastern portion of Los Angeles County. It is bounded by the San Gabriel Mountains to the north, the San Bernardino Mountains to the east, the watershed divide with the Los Angeles River to the west, and the Pacific Ocean to the south. The watershed is composed of approximately 640 square miles of land with 26% of its total area developed. Its estuary is 4 miles long with concrete and riprap sides, extending from the upstream tidal prism to the end of the southern jetty. The San Gabriel River Estuary (SGRE; Figure 1) has upstream inputs from the San Gabriel River and Coyote Creek. The San Gabriel River, together with the Los Angeles River, forms the twin-river delta of San Pedro Bay, which is semi-enclosed by a 7.5 mile breakwater.

The flow characteristics and habitat condition in the San Gabriel River are affected by a complex series of dams, diversions, discharges, and channels. Discharge and flow of natural, imported, and reclaimed water can be directed throughout the river system to a series of recharge areas, where most of dry season flow is captured and infiltrated. Much of the channels are concrete-lined in an effort to reduce flooding and protect property, which have resulted in loss of habitat and degraded water quality throughout much of the river system (Cross *et al.* 1992).

Flows into the estuary are from upstream inputs, once-through cooling water from two power-generating stations (PGSs) and oceanic tidal exchange. Dry weather flows from the San Gabriel River and Coyote Creeks consist of flows from two water reclamation plants (WRPs), Los Coyote and Long Beach, and nonpoint source urban runoff. The two PGS draw oceanic water from channels on either side of the estuary and discharge into the estuary as once-through cooling water. Wet weather flows are from direct runoff in the Coyote Creek and lower San Gabriel River watersheds. During large storms, additional water from the upper watershed is allowed to flow through the dams to the estuary.

METHODS

The purpose of the study was to develop a computer model that describes the movement of water throughout tidal cycles in the SGRE as a foundation for future modeling efforts. As such, the model employed must be able to represent the characteristics of the SGRE channel, inputs of water to the estuary (e.g., creek and power plant discharges), and the water movement and stratification within the SGRE. Data collection reflected the needs to develop that model. Once the model was developed, it was calibrated and validated against measured conditions. The calibration data was used to adjust model parameters to improve the model's ability to reflect conditions in the SGRE. The independent validation data set was used to test the model's performance and to assess confidence in model output.

Model Selection

The hydrodynamic model Environmental Fluid Dynamics Code (EFDC), which can be used to simulate water movement and associated water quality, was selected to model the SGRE. Its governing hydrodynamic equations are three-dimensional (i.e., it addresses water movement up and down stream, vertically in the water column, and horizontally across the channel) . The model balances water pressure while allowing water density and water surface elevation (WSE) to change with turbulence-averaged equations. It is a three-dimensional sigma-coordinate model, meaning that there are a constant number of layers throughout the model domain each with a specified percentage of total depth and thus, the thickness of those layers changes with WSE (Tetra Tech 2002). The EFDC has been used extensively throughout the United States with applications including the Los Angeles Harbor/San Pedro Bay and Dominguez Channel.

Data Sources

Data were collected to characterize the model domain, inputs and the conditions within the estuary. Data sources included as-built drawings, discharge measurements, atmospheric measurements, WSE, and in situ salinity and temperature measurements. Data detailing velocities throughout the water column at two locations were also taken (Rosenberger *et al*. 2007).

Physical setting

Channel configuration was derived from a combination of aerial photography and as-built drawings. Offshore bathymetry data was obtained from a NOAA mapping survey in 1988 (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html). Initial bottom elevation and channel cross sections were obtained from the Los Angeles Department of Public Works (LADPW) 1951 as-built drawings. It is important to note that bathymetry reflecting the current bottom elevation of the estuary was not available and thus the as built elevation was modified to reflect the observed average depths at the three in situ monitoring locations (Resenberger *et al*., 2007).

Atmospheric conditions

Meteorology data was used in the simulation of WSE (barometric pressure) and temperature (atmospheric temperature). Throughout the study period, data were collected from two sources.

Barometric pressure and atmospheric data were collected from a NOAA site at the Port of Los Angeles (tidesandcurrents.noaa.gov). Other meteorological data unavailable at that site (dry bulb temperature, relative humidity, evaporation and solar radiation) were collected or derived from data collected at the Long Beach Airport (ncdc.noaa.gov).

Oceanic conditions

The oceanic WSE was needed to drive the simulation of tidal circulation within the SGRE. No data was available at the seaward boundary of the study area, so the predicted tidal conditions from the JTides program (www.arachnoid.com/JTides) were used (Figure 2).

Like the oceanic WSE boundary, no temperature or salinity data was available for the nearshore area adjacent to the mouth of the SGRE. Temperature and salinity data are necessary to define conditions at the boundary of the region being modeled. Therefore, data from the Newport Pier (Figure 3), which is the closest monitoring station to the SGRE (27 km south) was used (www.sccoos.org).

Inputs

There are two major streams and three major point sources that discharge to the SGRE. Data from the San Gabriel River, Coyote Creek, and the Long Beach WRP, were obtained to quantify the daily average flow into the SGRE (LADPW 2005; Los Angeles County Sanitation District (LACSD) 2005). Temperatures from the creeks and the Long Beach WRP were characterized by the monthly sampling conducted by the Los Angeles County Sanitation Districts (LACSD Beth Bax, personal communication). No conductivity/salinity measurements were available at those sites.

The largest source of water discharged into the estuary was from the two PGSs: the AES plant on the western side of the channel and the Haynes Generating station on the eastern side (Figure 1). Each plant discharges its once-through cooling water into the estuary through three discharge locations (six in total). Hourly flow and temperature data from July 1, 2005 to May 31, 2006 were obtained from each plant (Steven Maghy and Sid Walkman, personal communication; Figures 4 through 7). Salinity from the PGSs was not measured but was assumed to be equal to that measured at the Newport pier because their intake is from Alamitos Bay.

Water column stratification

In situ instruments were used to quantify the WSE and stratification at three locations in the SGRE (Figure 1). Pressure changes, conductivity and temperature were measured at three locations in the SGRE using Seabird Microcats that were deployed by the US Geological Survey (USGS) from July 5 to September 15, 2005 (Figure 1). At each station, temperature and conductivity were collected at one minute intervals within 15 cm of the bottom and 1 meter from the surface (Rosenberger *et al*. 2007).

The USGS also conducted two water column surveys of the estuary on July 6, 2005 and September 1, 2005. The July survey sampled vertical salinity and temperature profiles across the SGRE at 14 locations. The September survey measured the same parameters at 16 locations, with duplicate sampling at two locations (Figure 8). These data were used as a second layer of validation to investigate the model's predictive ability at points throughout the estuary.

Velocity

The USGS deployed two acoustic Doppler current profilers (ADCPs), one near the upstream boundary of the SGRE at USGSc and a second just downstream of the PGS discharges at USGSb. Two different ADCPs were used; the downstream ADCP was an RDI Workhorse 1200 kHz SDCP, the upstream ADCP was a 2 MHz Nortek Aquadopp profiler. Much of the data at the most downstream site was compromised and precluded its use in the model calibration/validation; however, this data was usable to provide a rough estimate of the discharge from the SGRE. Details of the data quality evaluation and interpretation are described in the USGS report (Rosenberger *et al*. 2007). Velocity data from the upstream ADCP was used in the model calibration/validation and the velocity within each vertical model cells was averaged for comparison with model estimates.

Model development

The first step in developing a model of the SGRE was to define the spatial extent to be modeled. The estuarine portion of the model extended from the end of the concrete apron below the confluence of San Gabriel River and Coyote Creek to the mouth of the SGRE (Figure 1). The model extended offshore to provide a seaward boundary that would not have significant influence on the dynamics within the SGRE. In the offshore area, a grid spaced 125 by 125 m was made of 19 cells parallel with the shoreline and 14 cells perpendicular with the shoreline (vertical structure was the same as that of the SGRE). The area between the constructed SGRE banks was modeled with one cell cross channel and four cells vertically. The vertical cells were equally spaced at 25% of the total depth.

Flows were input into the model from the upstream freshwater sources and the six discharge ports of the PGSs. Upstream flows were input into the uppermost vertical layer to mimic water flowing off the concrete apron into the SGRE. Flows from the PGSs were evenly distributed throughout the water column grid. Hourly temperatures from the PGSs were applied to their discharges and the weekly temperature data applied to the freshwater inputs. Salinity data was only available from the Newport Pier and that data was used for the PGS discharges. No salinity or conductivity measurements were available for the freshwater discharges; therefore, a constant salinity of 1.5 psu was assumed to represent those discharges.

Using the input data described above, the SGRE was modeled for a two-month period beginning in July to simulate summer dry-season conditions. The minimum model time step was set at 1 minute but the model was allowed to expand that time step to minimize run time while maintaining model integrity. The available bathymetry of the SGRE consisted of the 1951 as-built drawings from the LADPW. However, significant scour and sediment transport has occurred in the SGRE since construction. For example, the as-built drawings indicate that the concrete apron was flush with the SGRE bottom but there is now approximately a 6-foot drop off at that location. Thus, the bathymetry of the estuary was modified to best fit the measured WSE measured at the three pressure sensors (Figure 1).

Model Calibration and Validation

Model calibration and validation compared model output to measurements made in the SGRE. The first comparison was between measured and modeled water surface elevation at the three USGS monitoring locations. Next, the temperature and salinity near the surface and bottom at those same sites were compared. Velocities in each model segment were compared with average velocities throughout that portion of the water column at the upstream ADCP. Finally, a broad comparison was also made of total discharge from the SGRE at USGSa gauge

The model was calibrated against the data collected at the *in situ* USGS sampling locations throughout July 2005 and validated against the data collected in August 2005. Model output was compared against measured temperature and salinity near the surface and bottom as well as bottom pressure. Because EFDC is a sigma coordinate model and the thickness of each cell was variable as the tide floods and ebbs, field instruments could be in different vertical cells throughout the simulation period, depending on water depth. The cell that the measured data was in throughout the simulation was adjusted accordingly.

Model performance was evaluated by comparing measured and modeled values and calculating the mean error, absolute mean error, correlation coefficients, and root mean squared errors (RMSE) using the following equations:

Mean error

$$\frac{\sum (O-P)}{n}$$

Absolute mean error

$$\frac{\sum |(O-P)|}{n}$$

Root Mean Square Error

$$\sqrt{\frac{\sum (O-P)^2}{n}}$$

Correlation Coefficient

$$\frac{\sum (O-\overline{O})(P-\overline{P})}{\sqrt{\sum (O-\overline{O})^2 (P-\overline{P})^2}}$$

$O = Observed$

$P = Predicted$

$\overline{O} = Observed\ mean$

$\overline{P} = Predicted\ mean$

Comparisons were also made of the water column structure during two surveys on July 6, 2005 and September 1, 2005 to assess the models ability to simulate changes in water column stratification. Measured temperature and salinity profiles were compared to model output at each cast location to ensure that water column structure throughout the estuary was reflected by the model.

Sensitivity Analysis

Model performance is influenced by confidence in the input data used for model development and calibration. Sensitivity analysis is an important step of the model development process in order to determine how variability the specific data sets used affects confidence in model output. The results of the sensitivity analysis can also be used to identify priorities for future data collection.

Sensitivity of the SGRE model was evaluated by altering key model parameters and assessing the relative effect on model predictions. The vertical distribution of model layers and roughness height were modified to examine their significance to model prediction. The model was run for one week with vertical layers defined at (from bottom to surface) 40%, 30%, 20%, 10% and 30%, 30%, 20%, 20% depth and +/- one order of magnitude for the log roughness height, and the resultant output was compared to the USGS data to assess model sensitivity.

Model Application

Application of the SGRE model was demonstrated by simulating the effect of changes in water input on residence time in the estuary. Residence time was estimated by modeling the time necessary for 90% of a conservative tracer (i.e., dye) to leave the SGRE under different tidal conditions. In all cases, the dye was simulated at the most upstream end of the SGRE and every 600 m downstream at the high spring and high ebb high tides of July 2005 (Table 1). For one set of simulations, flow from the PGSs and upstream freshwater sources were set to the maximum potential flow from each discharge point, using the average monthly temperature (Table 1). A second set of simulations was run with all the PGS inputs removed and maximum potential upstream freshwater flow. Differences between the two scenarios were used to assess the role of the PGS discharges on residence time, as a demonstration of the application of the hydrodynamic model.

RESULTS AND DISCUSSION

The hydrodynamic model accurately simulated patterns of water movement in the SGRE. However, model performance at a given location varied based on the availability and quality of input data for calibration. In general, more comprehensive temperature, salinity, and flow data was available for the lower estuary (associated with the PGS discharges) than for the upper estuary (associated with watershed discharge). Consequently, the model predictions more closely simulated measured values in the lower portion of the estuary.

Summary of Empirical Results

Results of the two USGS surveys conducted during the summer of 2005 showed pronounced stratification within the SGRE, as shown in Figures 9 through 11. The effects of the PGSs are evident in that they greatly mix the water column and completely mix the freshwater. Figures 12 and 13 show the measured velocities at sites USGSb and USGSc, respectively. The data shows that for the majority of the period, water flows seaward. Velocities at USGSc, the most upstream site, can flow landward but at the most downstream site, water rarely flows landward. A more detailed discussion of the results of the summer 2005 field survey can be found in Rosenberger *et al*. (2007).

Model Calibration and Validation

Water surface elevation

Modeled WSE generally calibrated and validated well with measured values. The WSE simulated at the gages downstream of the PGSs agreed with the observed values more closely than at the gage upstream of the PGSs (Figures 14 through 19). The statistics describing the model's performance showed good comparison between measured and modeled values at all three locations with high correlation and low error (Tables 2 and 3).

Visual comparison of the modeled and observed WSE plots show that the model had difficulty reproducing the low tides at the upstream location (Figure 16). Because bathymetry data was unavailable for the SGRE, the bathymetry from the as-built drawings was modified to fit the observed depths at the three gages. A better representation of the bathymetry would have greatly improved the modeled WSE at the upstream location.

Temperature

The modeled temperature simulated the daily fluctuations and monthly trends at the two downstream stations (USGSa and USGSb) throughout July and August 2005 (Figures 20 through 25). Comparison of surface and bottom temperatures at the two sites showed good correlations ($r \geq 0.9$; Tables 2 and 3). The hourly temperature data from the PGSs enabled the model to simulate measured values well. In contrast, temperature data for the creek discharge locations were only available at weekly time intervals. This hindered the models ability to simulate observed values in the upper estuary. The model was able to predict overall changes in water temperature in the upper estuary throughout the two simulation periods with a slight underprediction during July and overprediction in August. However, the lack of high resolution temperature data for calibration translated to the model not being able to replicate small temporal scale fluctuations in the upper estuary (Figures 22 and 25).

Salinity

Like temperature, the model was able to simulate salinity patterns best downstream of the PGSs. The model reproduced the observed surface salinity better than the bottom salinity at USGSa and USGSb (Tables 2 and 3). It was able to capture some of the small-scale surface variability but little of the bottom variability (Figures 26 and 29). The results were similar at USGSb during the calibration and validation simulations (Figures 27 and 30). While the PGSs had hourly temperature records for the discharge points, no data existed for salinity from those discharges. The salinity measured at the Newport Pier, 27 km south of the system, was used instead. The AES plant takes its cooling water from a storm channel that is connected to the northern portion of Alamitos Bay. The Haynes plant draws water from the northeast corner of the bay, through a siphon under the SGRE, and into a channel east of the SGRE. Alamitos Bay has numerous flowing storm drains that discharge during the summer months which would likely result in a lower salinity than observed at the Newport Pier. A better representation of the cooling water salinity would have greatly enhanced model performance.

The salinity simulations generally reproduced the patterns seen in the upstream gage (Figures 28 and 31) but, again, had difficulty in capturing small-scale variability. The source of this error is the assumptions that the model was constructed on, based on available input data. There was no conductivity/salinity data available for the upstream sources, so a constant value of 1.5 psu was assumed. The salinity from the upstream sources will naturally vary and those variations cannot be captured without sufficient measured data to populate the model.

Flow and velocity

The ADCP data collected by the USGS showed that water consistently flowed seaward downstream of the PGSs throughout the tidal cycle at USGSb (Figure 32). While that data wasn't sufficient for calibration/validation comparisons, the USGS estimate of an average seaward flow of 22 m^3s^{-1} Rosenberger *et al*. (2007) compared well to the 25 m^3s^{-1} (Figure 35) during the calibration and validation periods. Flow at the upstream gage was a net 2 m^3s^{-1} seaward.

Velocity data was taken at two locations (USGSb and USGSc) but only USGSc had data sufficient for comparison with model output. During the calibration period (Figure 34), the model predicted a seaward flow in the upper cell and a landward flow in the lower layer. The upper layer velocity compared well with the measured in terms of both magnitude and direction. Flow in the lower layer compared well in magnitude but not direction. The reason for the disagreement is most probably twofold. First the model was unable to reproduce the low tides at the upstream site because the bathymetry was derived and not measured. Thus, a mass of water stayed upstream of USGSc longer than measured and did not ebb to the sea. Secondly, the components of stratification, temperature and salinity, were not captured well by the model. Again, this is because of the limitations of the calibration data, and the associated assumptions that were made in the model development (i.e., weekly temperature values and constant salinity).

Sensitivity Analysis

The sensitivity of the model was tested to determine the relative influence of key model parameters on model output. Ranges of WSE, salinity, temperature and velocity at the three USGS in situ locations were analyzed by calculating mean differences in model output. The bottom roughness was modified by +/- an order of magnitude and the WSE changed by 10-17 cm and –5.5 to –3.4 cm, respectively (Table 2). Since the mass of water moving into and out of the system changed, so did the velocities. The velocities at USGSb were more sensitive to the changes in roughness than at USGSc, which was station upstream of the PGSs. Increased roughness caused lower average velocities in the surface layer and higher velocities in the other layers at USGSb. The response at USGSc was similar, but less pronounced with slightly lower velocities resulting from increased roughness in the lower layer. The differences are likely due to the higher velocities seen at the downstream station, and the PGS discharges having such a large impact on the lower estuary. Temperature and salinity at the three stations were relatively insensitive to changes in roughness.

The vertical distribution of the layers had little impact on the water column structure at the two downstream gages but significant impact on the upstream gage (USGSc). Both layer changes resulted in a lower salinities profile at the upstream gage and a higher temperatures profile. There was a lower average velocity in the bottom layer and higher in the other layers for both sensitivity scenarios. These results should not indicate that either of the two sensitivity scenarios is significantly different than the calibrated and validated model. The vertical model layers are a reflection of the average condition seen in that section of water. The results simply show that the water column is stratified and that assumptions about different vertical averaging can produce quite different results.

Model Application to Estimate Residence Times

The presence of the PGSs greatly affected the residence time of a conservative tracer in the SGRE. During both the spring and neap tide simulations, the residence time for 90% removal of the tracer was less than 20 hours when the tracer was input at the upstream boundary (Figure 36). When the system was simulated without any PGS discharge, the residence time increased to between 50 and 70 hours.

The results from the residence time simulations show that a parcel of water that enters from the watershed remains in the SGRE for about 10 to 20 hours. Once the water mass reaches the location of the PGS discharges, it is advected out of the SGRE more quickly. The implication is that dissolved pollutants that enter the estuary from the watershed generally would be flushed to sea within a day.

Particulate pollutants are more likely to be deposited upstream of the PGSs because of the lower, bi-directional velocities, and thus, longer residence time over an equal distance. For example, at neap high tide, it takes about 10 hours for a tracer to reach the PGS discharges. The measured average depth at USGSc was 2.7 m. Particles with a settling velocity of $7.5\text{x}10^{-3}$ cm s^{-1} would be deposited upstream of the PGSs. Using Stokes' law, and assuming that particles only settled, particles larger than 10 μm would deposit upstream of the PGSs. This was confirmed by the video survey done by the USGS that showed that the sediment near the head of the SGRE was mucky and became sandier near the PGSs and completely sand downstream of the PGSs. In the absence of PGS discharges, additional settling would occur and more particle mass would be retained in the estuary. This likely results due to 1) less mixing associated with the PGS discharges, and 2) longer residence times.

CONCLUSIONS

The hydrodynamic model developed for SGRE accurately simulates stratification and water movement patterns. As such, it provides a good foundation for future development of water quality and bioaccumulation models. The model performs well in simulating overall patterns of water movement, but would be improved by a better understanding of the SGRE bathymetry, salinity of the PGS discharges, and salinity and temperature of the upstream sources. These areas could be the focus of future data collection efforts

Terrestrial pollutant discharges have been characterized both by routine monitoring as well as snapshot surveys in the San Gabriel River/Coyote Creek systems. Because those discharges enter saline, tidal waters, the pollutant dynamics (settling, flocculation, etc.) become increasingly more significant to their distribution in the SGRE and ultimate discharge to the bay. Two surveys have been conducted of water quality in the SGRE by SCCWRP where samples have been taken near the surface and near the bottom at seven locations. Those surveys characterize the pollutants during a defined temporal window. Additional sampling information about pollutant dynamics at points throughout multiple tidal cycles would enhance our knowledge of the system and provide an excellent data set to calibrate a future water quality model.

Development of the hydrodynamic model provides the foundation for future development of a sediment and water quality model for the SGRE. Ultimately, these models will provide tools for evaluating the effects of watershed-based management on estuary and receiving water quality. Finally, knowledge gained by this study can be applied to other urban estuaries in the Los Angeles area (e.g., Los Angeles River and Ballona Creek) to facilitate modeling of those systems.

LITERATURE CITED

Cross, J., K. Schiff and H. Schafer. 1990. Surface runoff to the Southern California Bight. Southern California Coastal Water Research Project Annual Report 1990-1992. Southern California Coastal Water Research Project. Westminster, CA.

Rosenberger, K.J., J. Xu, E.D. Stein, M.A. Noble and A.L. Gartner. 2007. Circulation and physical processes within the San Gabriel River estuary during summer 2005. USGS Open file Report 2007-1011. US Geological Survey. Reston, VA.

Tetra Tech. 2004. Model Development for Simulation of Wet-Weather Metals Loading from the Los Angeles River Watershed. Tetra Tech, Inc. San Diego, CA.

Tetra Tech. 2002. User’s manual for Environmental Fluid Dynamics Code Hydro Version (EFDC-Hydro). Tetra Tech, Inc. Fairfax, VA.

Table 1. Residence time dye injection conditions.

Tidal Condition	Time	Tidal Height (m)
Neap High	July 27,2005 02:53	1.17
Neap Low	July 27,2005 08:53	0.45
Spring High	July 20,2005 20:15	2.26
Spring Low	July 21,2005 04:05	-0.52

Power Generating Stations	Flow (m^3/s)	Temperature (ºC)
Haynes #1	10.09	26.4
Haynes #2	12.11	26.4
Haynes #3	20.19	22.4
AES #1	9.08	25.2
AES #2	17.04	25.9
AES #3	29.53	22.4
Upstream Flows		
Coyote Creek	2.22	27.2
San Gabriel River	1.87	27.2
Long Beach WRP	0.48	27.2

Table 2. Long term model performance for water surface elevation, salinity, and temperature at the three USGS monitoring sites during the calibration period.

		Observed Mean	Modeled Mean	Observed Std Dev	Std Dev Modeled	Mean Error	Abs Mean Error	RMSE	Correlation Coefficient
USGSc									
Depth (m)		2.73	2.76	0.50	0.50	0.03	0.15	0.93	0.87
Salinity (psu)	Surface	31.40	31.83	1.25	0.94	0.43	1.10	0.22	0.05
	Bottom	31.47	32.17	1.20	0.65	0.70	0.92	0.60	0.36
Temperature (ºC)	Surface	26.48	25.92	3.27	3.46	-0.49	0.85	0.96	0.93
	Bottom	26.43	25.87	3.26	3.55	-0.49	0.85	0.97	0.94
USGSb									
Depth (m)		2.73	2.83	0.50	0.47	0.11	0.16	0.93	0.87
Salinity (psu)	Surface	31.40	32.41	1.25	1.30	1.01	1.57	0.00	0.00
	Bottom	31.47	33.12	1.20	0.20	1.65	1.65	0.52	0.27
Temperature (ºC)	Surface	26.48	25.88	3.27	3.50	-0.53	0.98	0.95	0.90
	Bottom	26.43	25.87	3.26	3.68	-0.48	1.01	0.95	0.90
USGSc									
Depth (m)		2.73	2.72	0.50	0.47	0.00	0.14	0.93	0.87
Salinity (psu)	Surface	31.40	26.13	1.25	2.01	-5.27	5.27	0.00	0.00
	Bottom	31.47	31.47	1.20	1.29	0.00	1.06	0.40	0.16
Temperature (ºC)	Surface	26.48	26.25	3.27	2.60	-0.18	1.61	0.79	0.62
	Bottom	26.43	25.88	3.26	3.15	-0.49	1.67	0.78	0.61

Table 3. Long term model performance for water surface elevation, salinity, and temperature at the three USGS monitoring sites during the validation period.

		Observed Mean	Modeled Mean	Observed Std Dev	Std Dev Modeled	Mean Error	Abs Mean Error	RMSE	Correlation Coefficient
USGSa									
Depth (m)		2.73	2.78	0.49	0.48	0.05	0.15	0.94	0.94
Salinity (psu)	Surface	31.34	31.43	1.07	0.93	0.09	1.10	0.00	0.00
	Bottom	31.51	31.77	1.04	0.76	0.25	0.72	0.57	0.57
Temperature (ºC)	Surface	24.81	24.97	1.75	1.60	0.16	0.57	0.91	0.91
	Bottom	24.82	24.99	1.76	1.62	0.17	0.48	0.94	0.94
USGSb									
Depth (m)		2.95	2.86	0.50	0.46	-0.09	0.13	0.96	0.96
Salinity (psu)	Surface	31.74	32.18	0.83	1.14	0.45	0.98	0.00	0.00
	Bottom	31.65	32.92	1.01	0.20	1.26	1.26	0.61	0.61
Temperature (ºC)	Surface	24.91	25.03	1.80	1.74	0.11	0.53	0.92	0.92
	Bottom	24.79	25.10	1.69	1.76	0.31	0.51	0.94	0.94
USGSc									
Depth (m)		2.62	2.75	0.49	0.45	0.12	0.15	0.96	0.96
Salinity (psu)	Surface	27.20	24.51	2.05	1.92	-2.69	3.34	0.30	0.30
	Bottom	30.35	30.75	1.11	1.42	0.40	1.45	0.00	0.00
Temperature (ºC)	Surface	23.40	24.21	1.41	1.29	0.82	1.23	0.55	0.55
	Bottom	22.78	23.67	1.09	1.69	0.88	1.30	0.51	0.51

Table 4. Sensitivity of the model to changes in roughness height.

		Increased Roughness				Decreased Roughness			
		Bottom Layer 1	Layer 2	Layer 3	Surface Layer 4	Bottom Layer 1	Layer 2	Layer 3	Surface Layer 4
USGSc	WSE (cm)				17.77				-5.50
	Temperature (°C)	-0.08	-0.08	-0.07	0.00	0.04	0.03	0.00	-0.01
	Salinity (psu)	-0.09	0.64	0.75	0.05	0.06	-0.28	-0.17	0.16
	Velocity (cm/s)	-1.27	-0.23	2.03	0.35	1.61	-0.48	-0.85	-0.03
USGSb	WSE (cm)				17.25				-5.24
	Temperature (°C)	-0.05	-0.05	0.10	0.02	0.02	-0.02	-0.05	0.01
	Salinity (psu)	-0.24	-0.21	0.50	0.25	0.04	-0.09	-0.32	-0.04
	Velocity (cm/s)	6.00	2.58	4.91	-5.01	-3.27	-3.59	-0.16	3.54
USGSa	WSE (cm)				10.82				-3.38
	Temperature (°C)	0.03	0.02	0.02	-0.01	-0.03	-0.03	-0.01	0.02
	Salinity (psu)	-0.22	-0.21	-0.13	0.16	0.36	0.34	0.18	-0.45

Table 5. Sensitivity of the model to different vertical layer definitions.

		40% Bottom Layer 1	**30%** Layer 2	**20 %** Layer 3	**10 %** Surface Layer 4	**30 %** Bottom Layer 1	**30 %** Layer 2	**20 %** Layer 3	**20 %** Surface Layer 4
USGSc	WSE (cm)				0.41				1.20
	Temperature (°C)	0.03	0.12	0.20	0.10	0.22	0.36	0.59	0.33
	Salinity (psu)	-0.50	-1.59	-2.51	-0.84	-1.89	-5.00	-6.91	-2.44
	Velocity (cm/s)	0.24	-1.50	-4.88	-1.40	1.22	-5.54	-12.43	-3.02
USGSb	WSE (cm)				0.39				0.98
	Temperature (°C)	-0.08	-0.14	-0.03	0.12	-0.14	-0.23	0.09	0.22
	Salinity (psu)	-0.41	-0.62	-0.58	0.37	-0.97	-1.48	-0.63	1.55
	Velocity (cm/s)	-1.82	-5.15	-1.52	2.09	-4.63	-11.20	-1.20	7.51
USGSa	WSE (cm)				0.12				0.36
	Temperature (°C)	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
	Salinity (psu)	-0.07	-0.07	-0.08	0.05	-0.15	-0.14	-0.09	0.20

Figure 1. Site map of the San Gabriel River estuary and model segmentation.

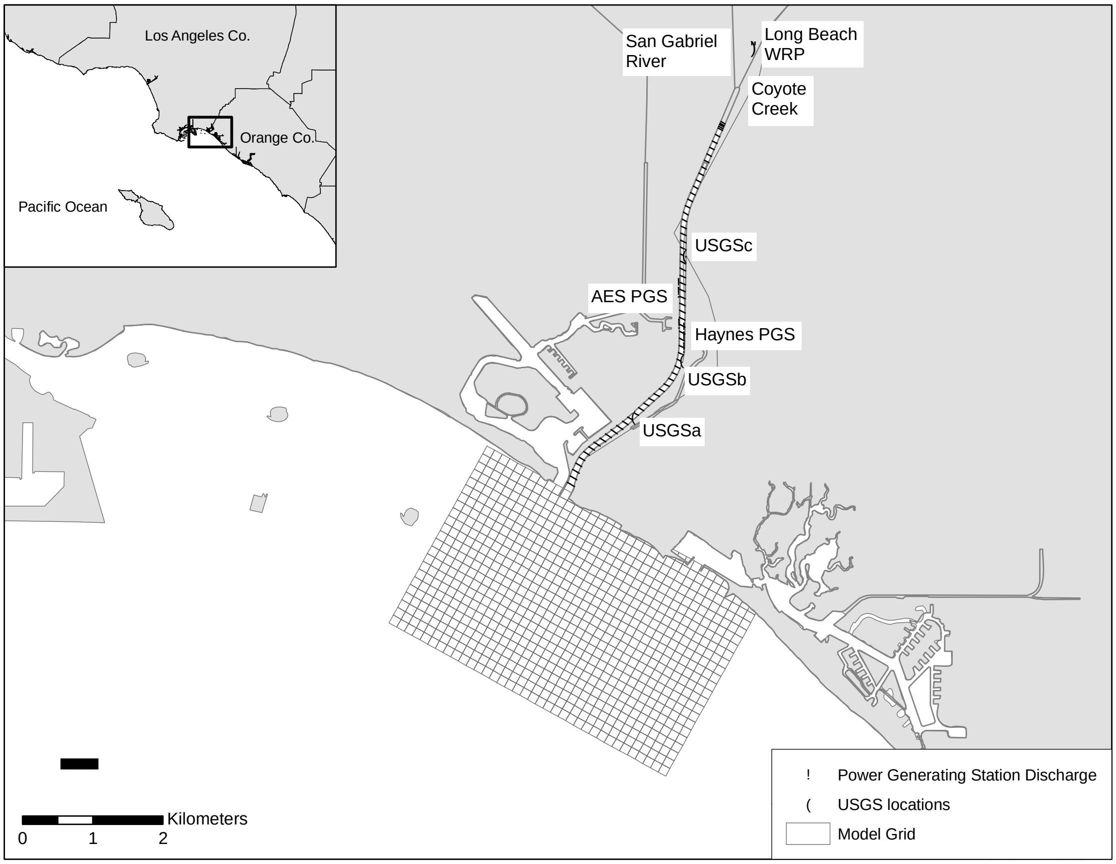


Figure 2. Predicted tides at the seaward boundary of the model domain.

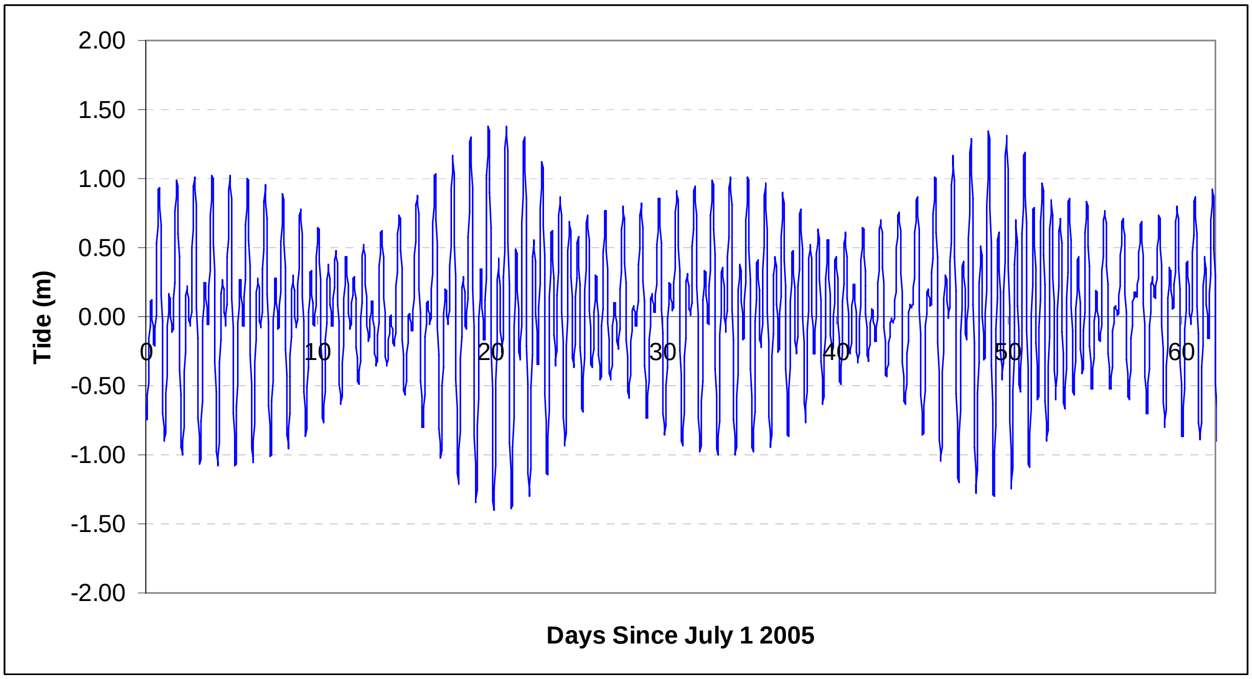


Figure 3. Measured temperature and salinity at the Newport Pier.

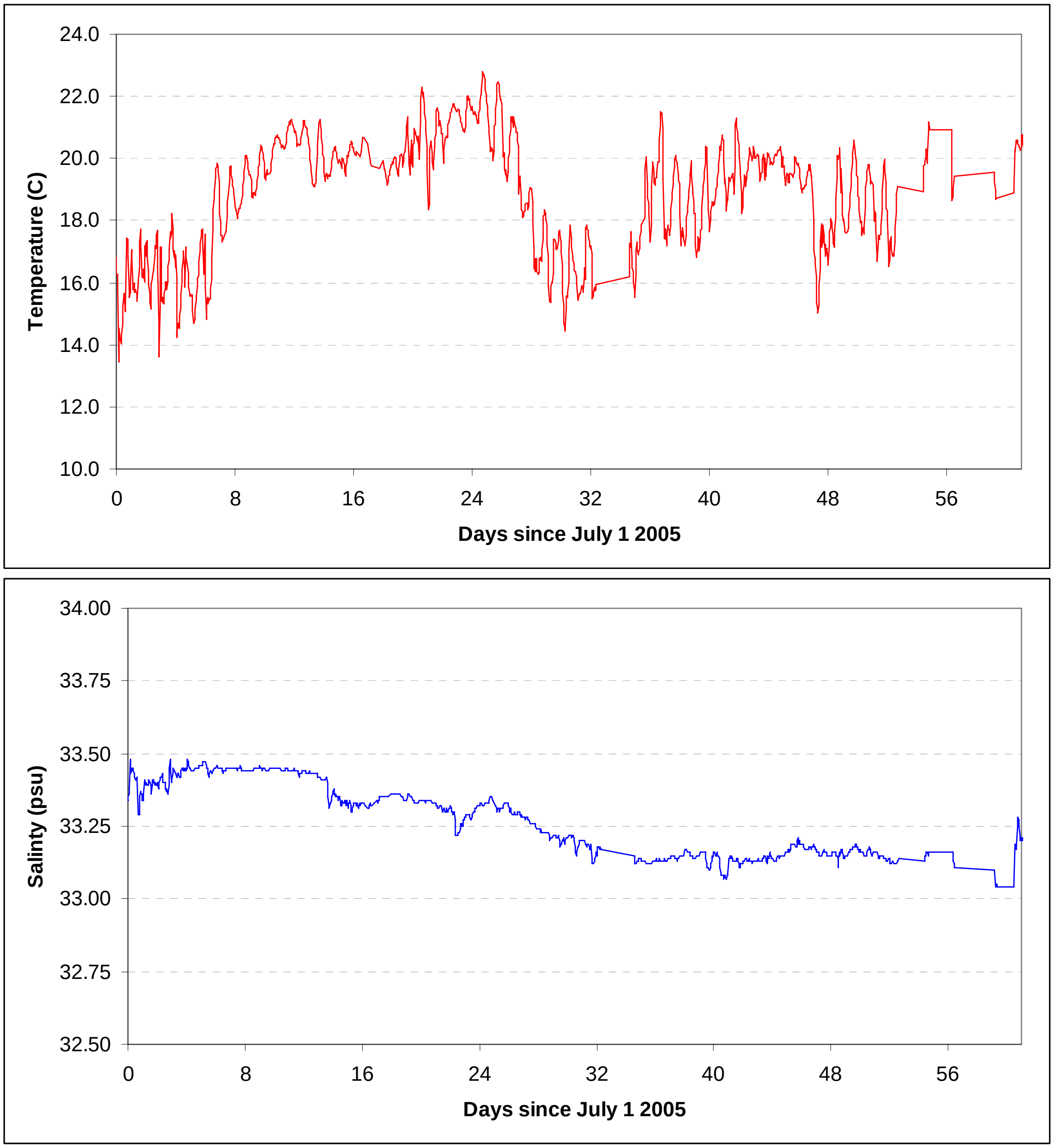


Figure 4. Measured temperature of Haynes PGS outfalls.

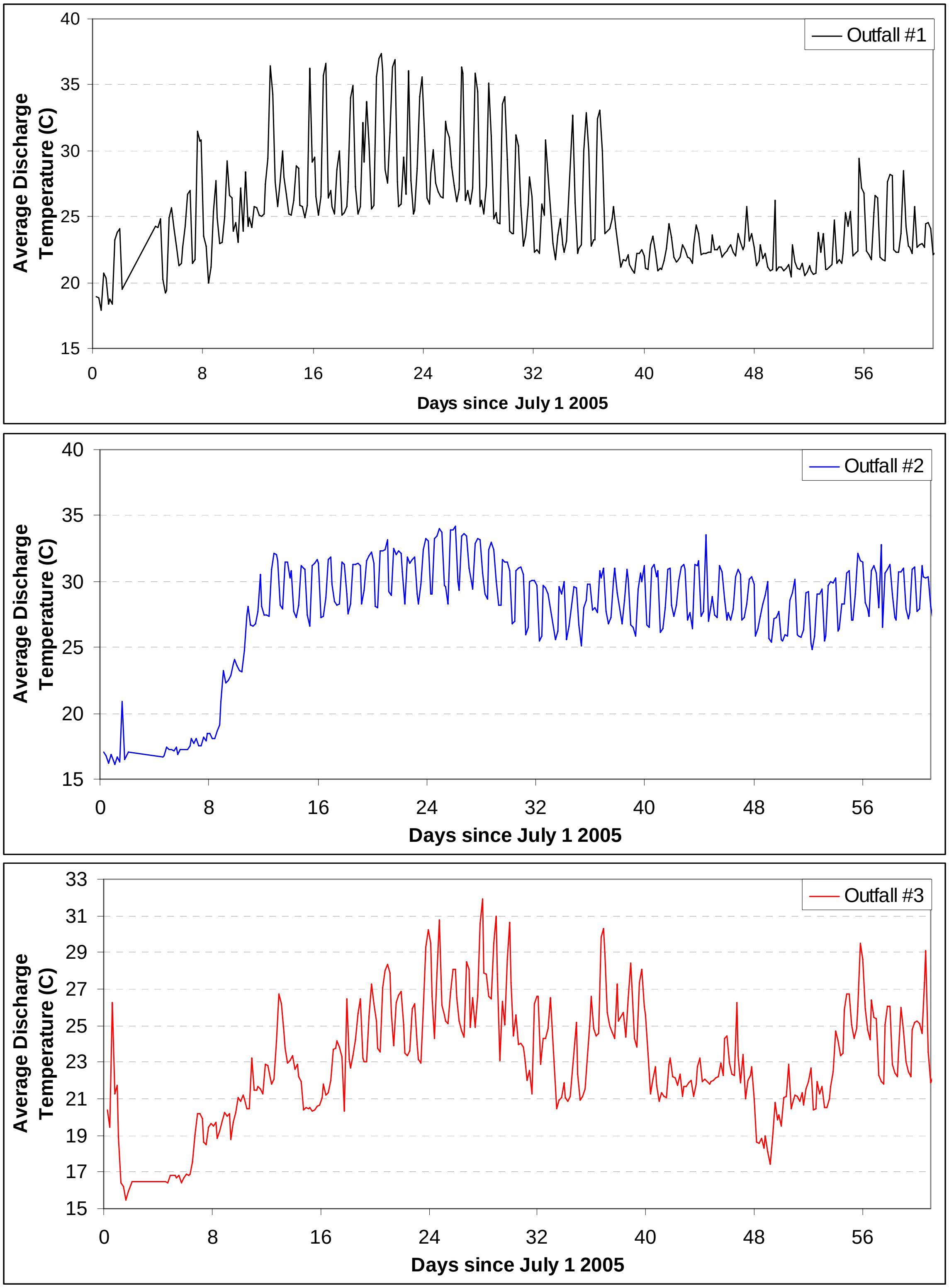


Figure 5. Measured flow of Haynes PGS outfalls.

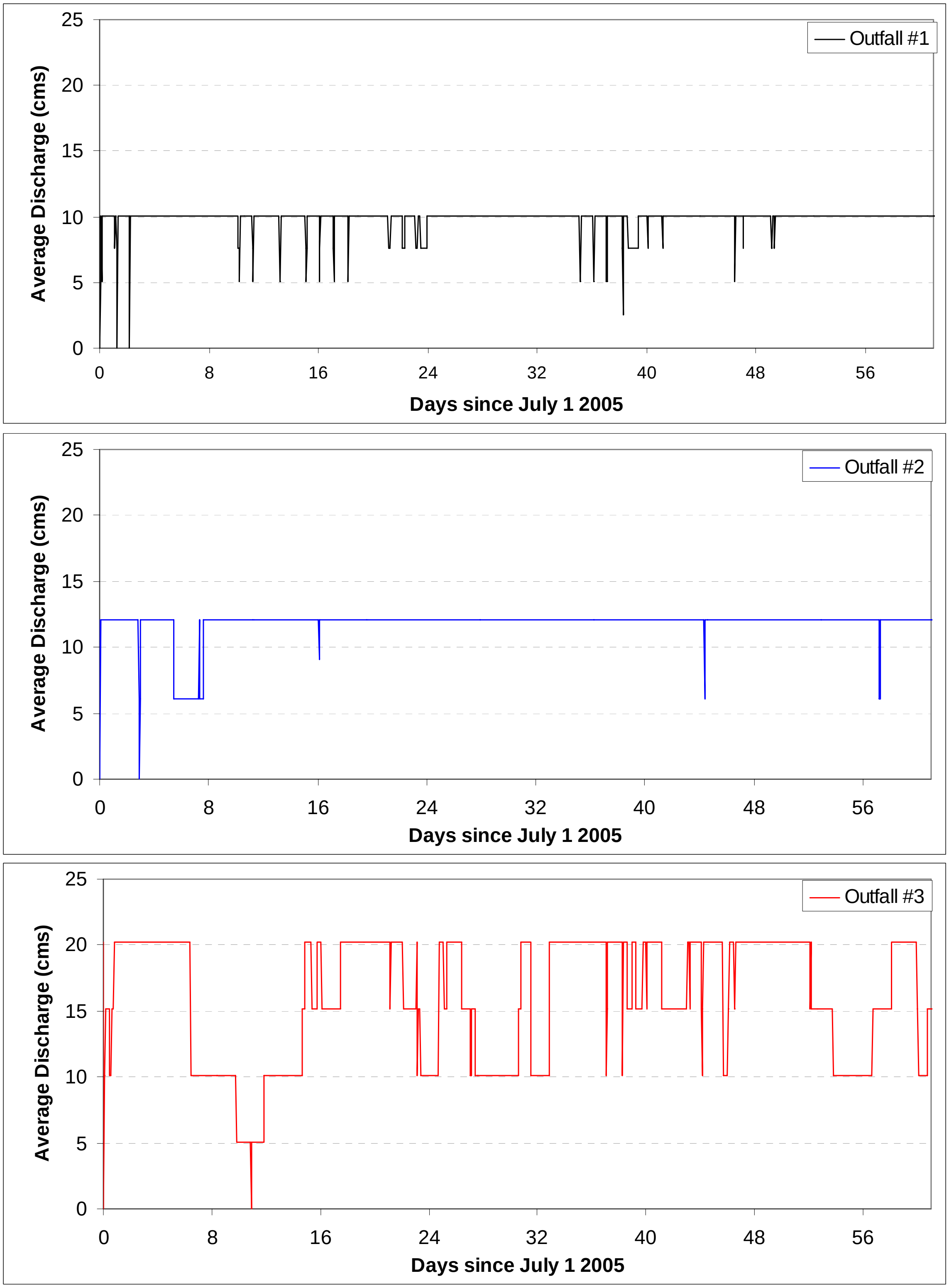


Figure 6. Measured temperature of AES PGS outfalls.

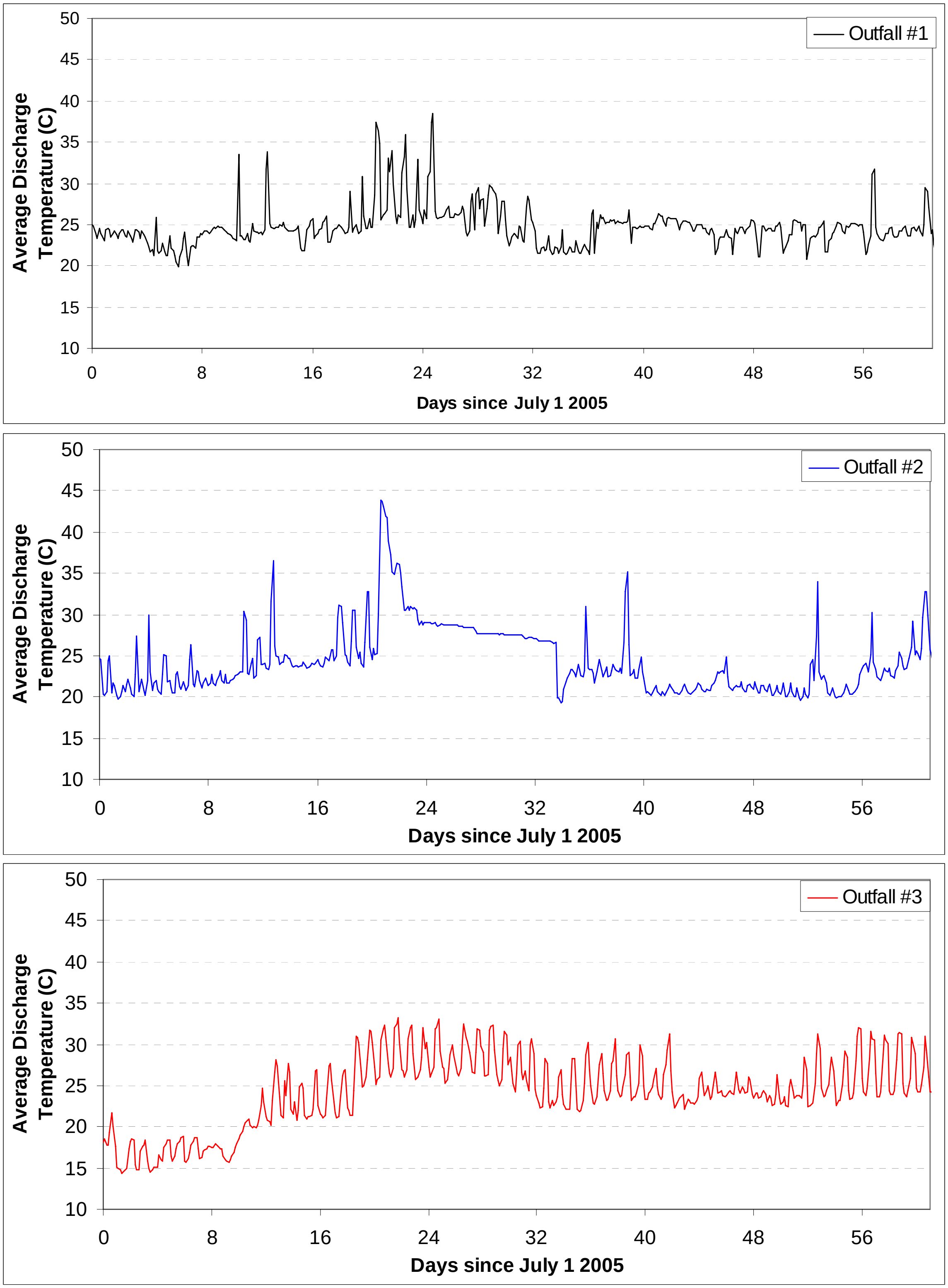


Figure 7. Measured flow of AES PGS discharges.

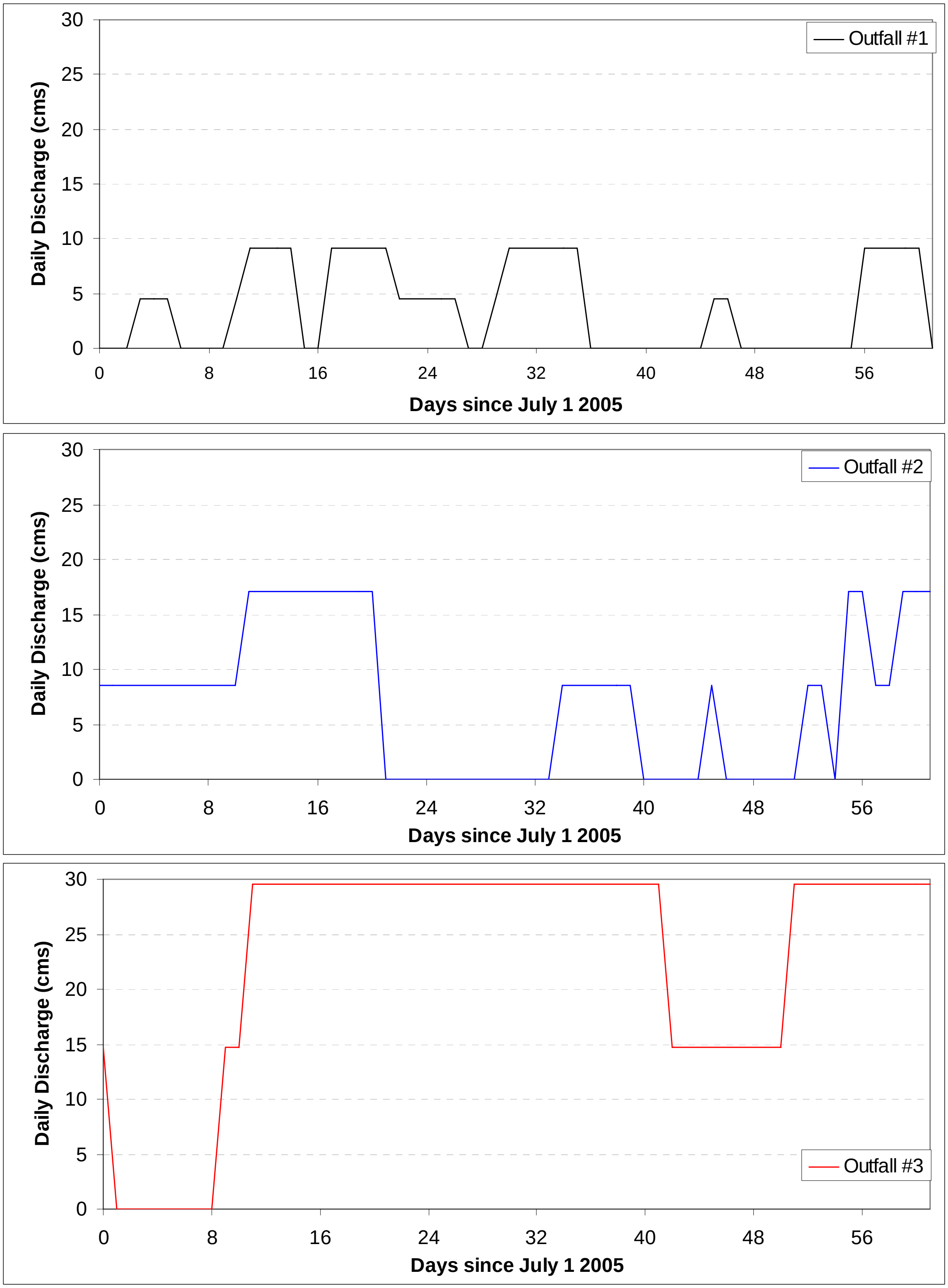


Figure 8. Site map with the USGS in situ monitoring and cast locations.

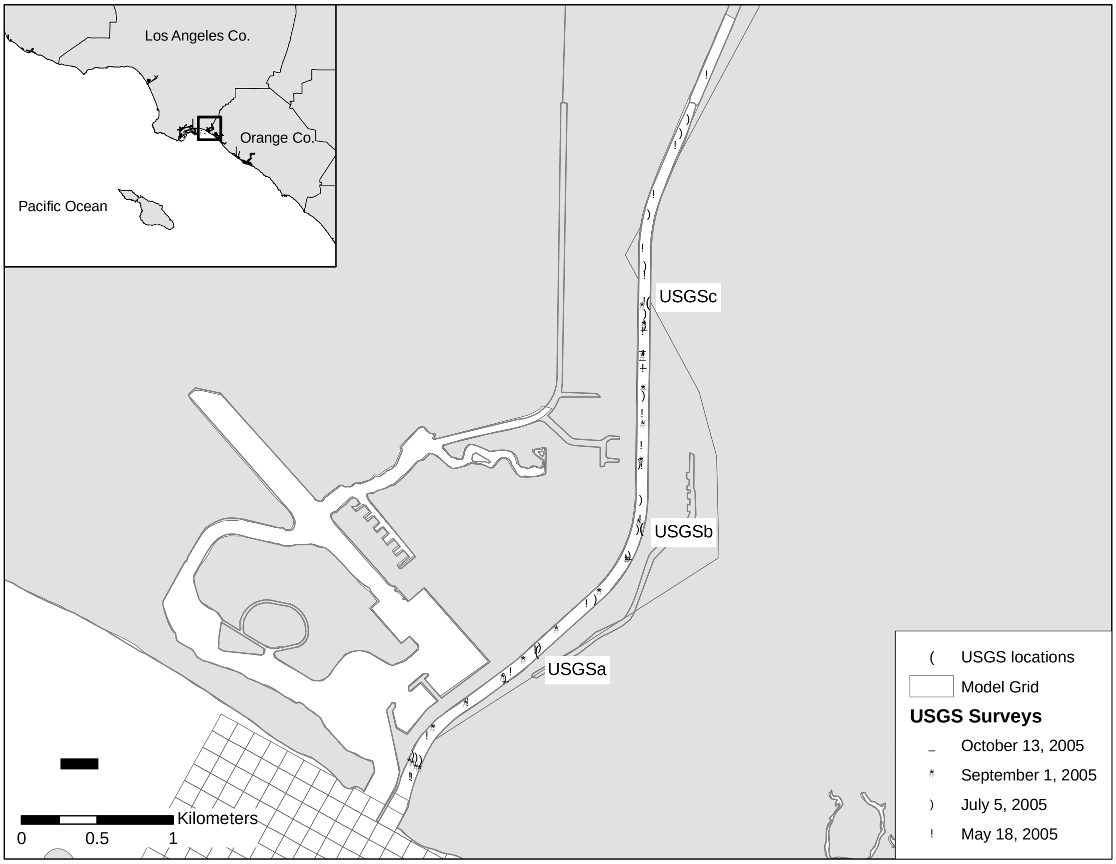


Figure 9. Temperature and salinity during the 17 May 2005 survey.

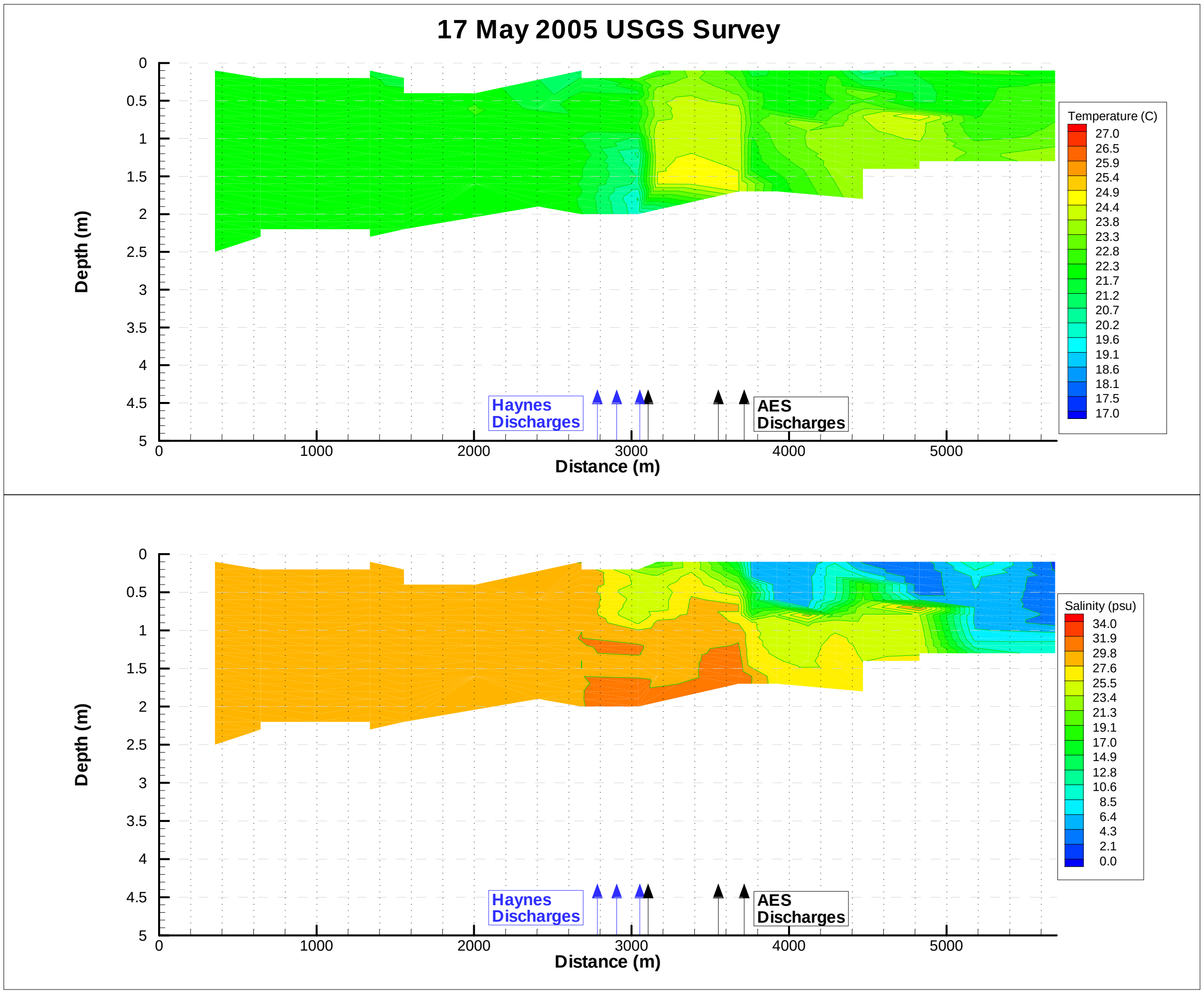


Figure 10. Temperature and salinity during the 6 July 2005 survey.

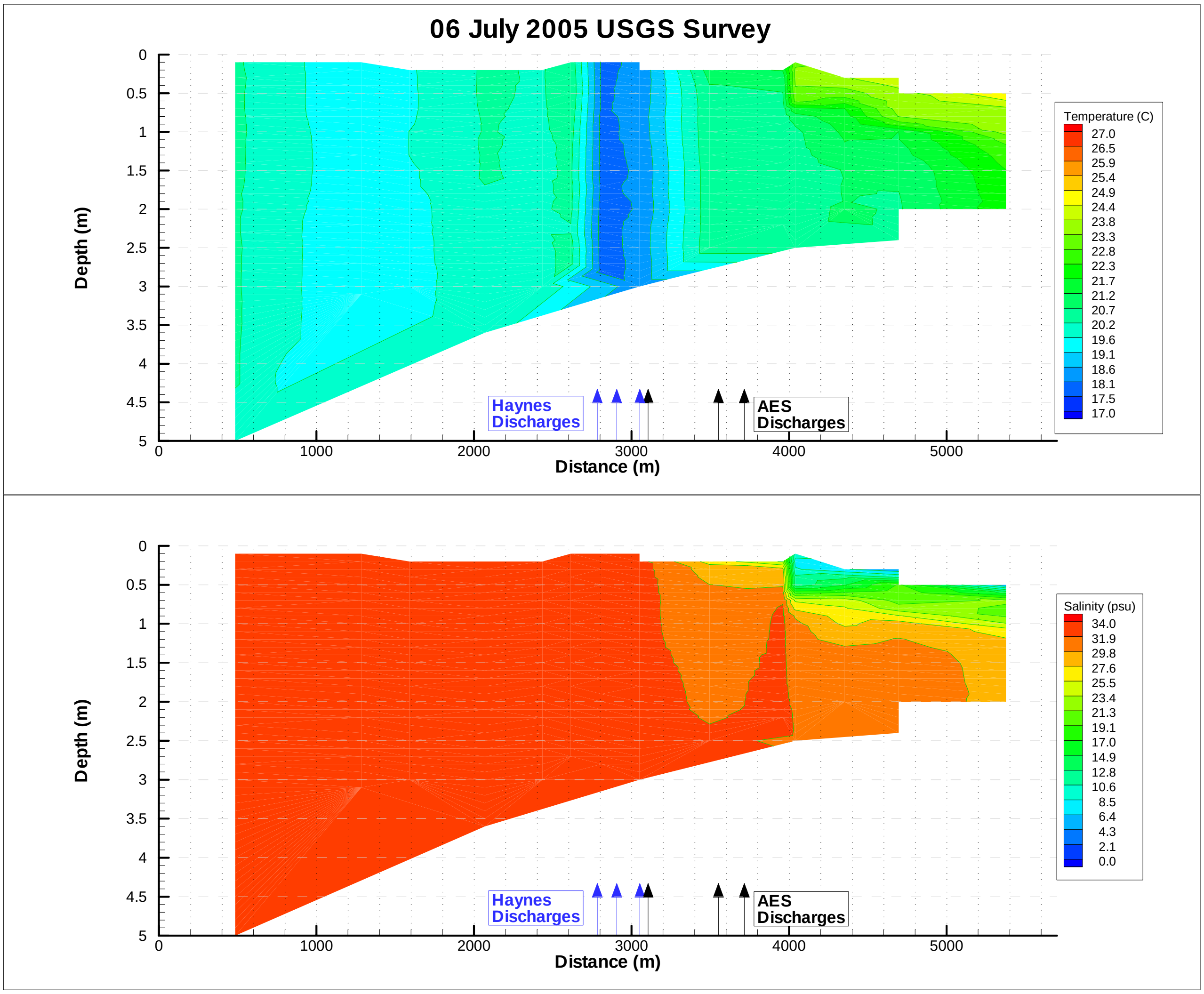


Figure 11. Temperature and salinity during the 1 September 2005 survey.

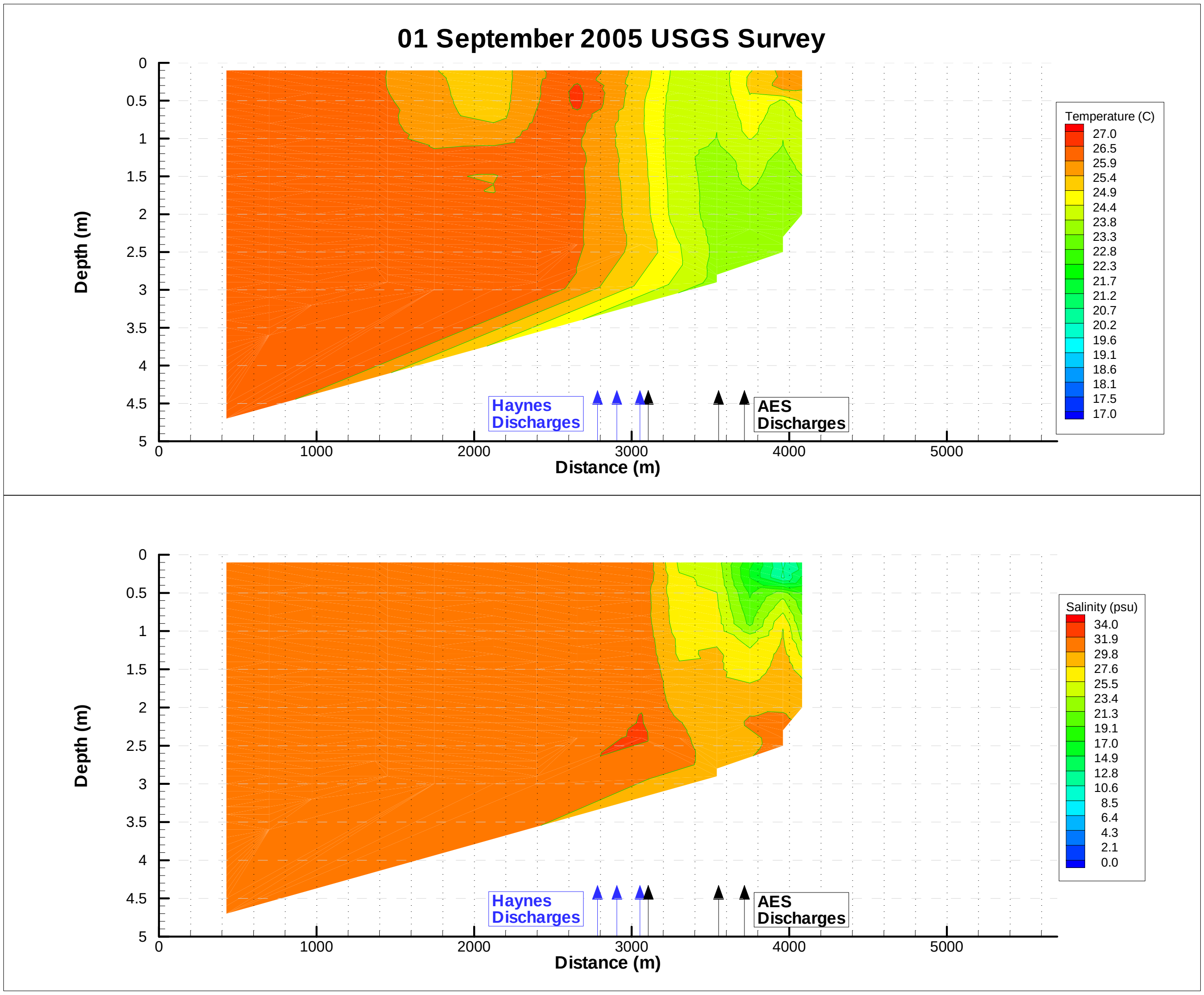


Figure 12. Measured water column velocity at site SG-3 from July 14 – 26, 2005 (positive is upstream).

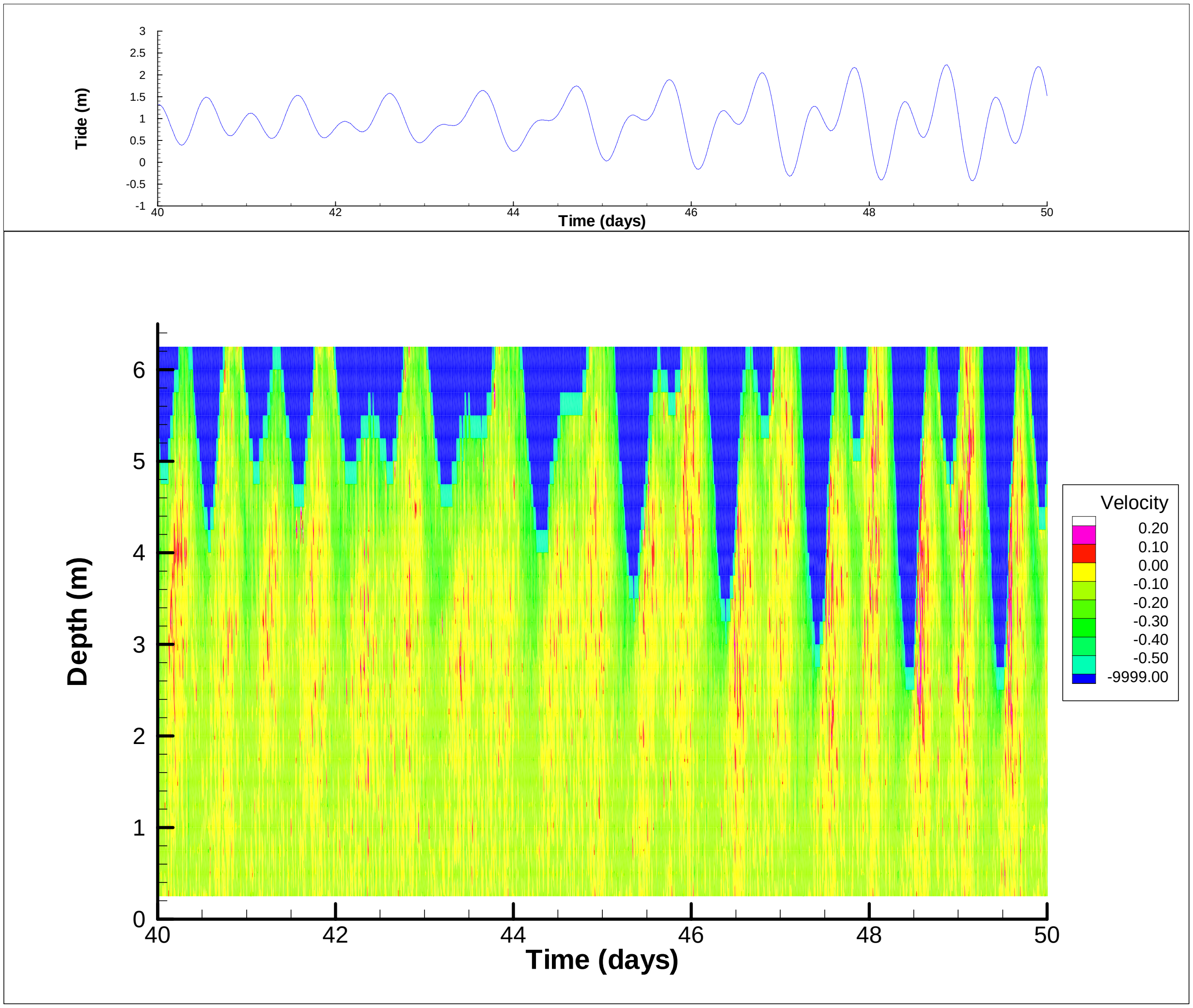


Figure 13. Measured water column velocity at site SG-5 from August 10 – 20, 2005 (positive is upstream).

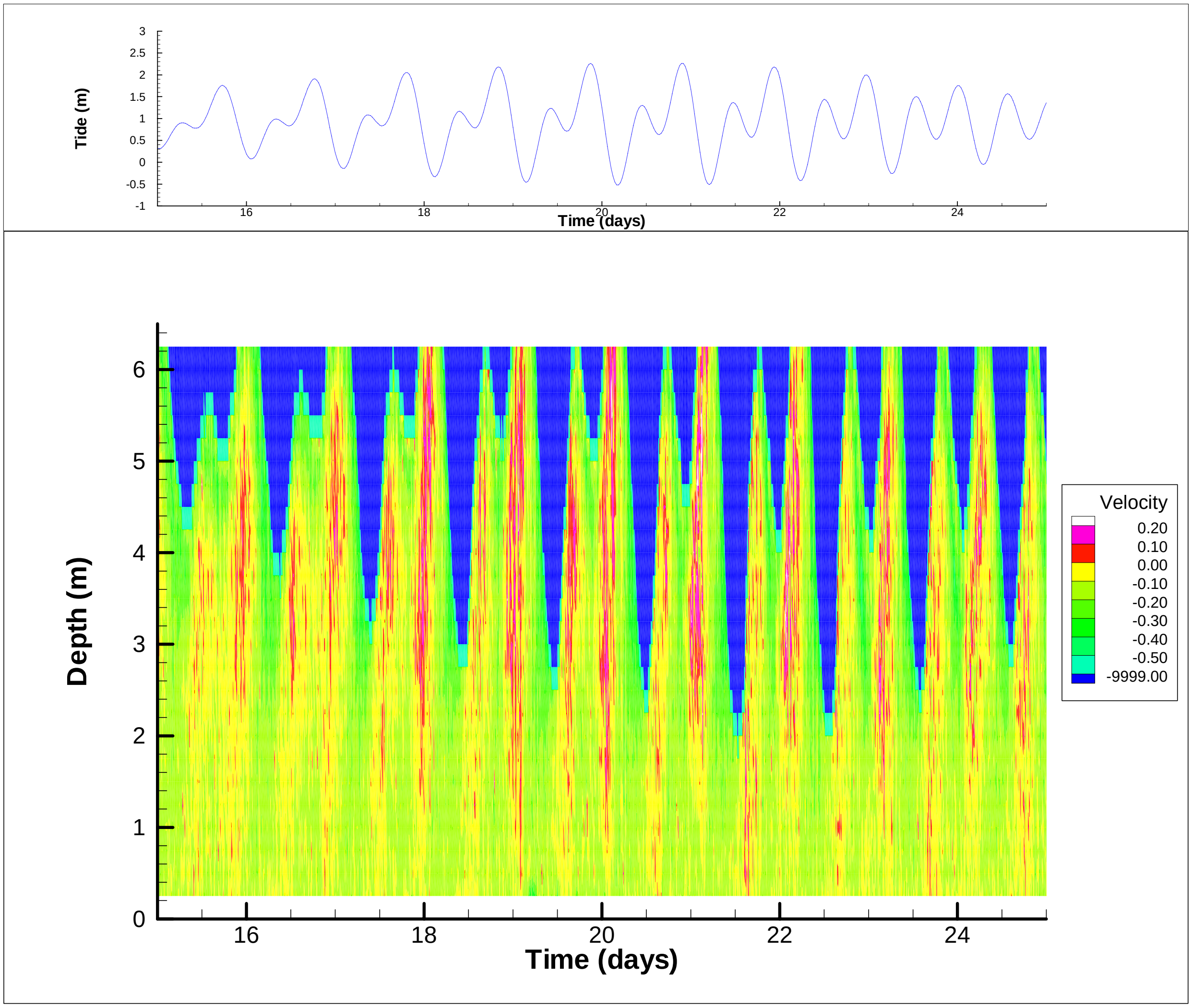
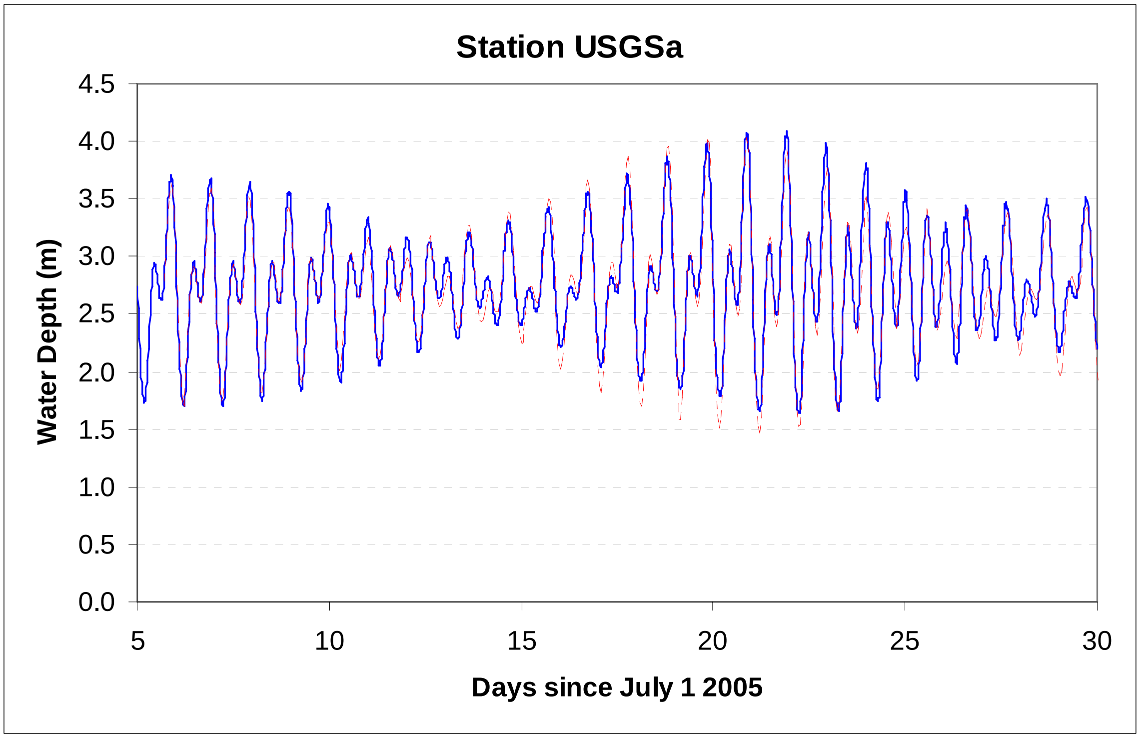


Figure 14. Calibration water depth comparison at the downstream (USGSa) station (measured is in red and modeled in blue).



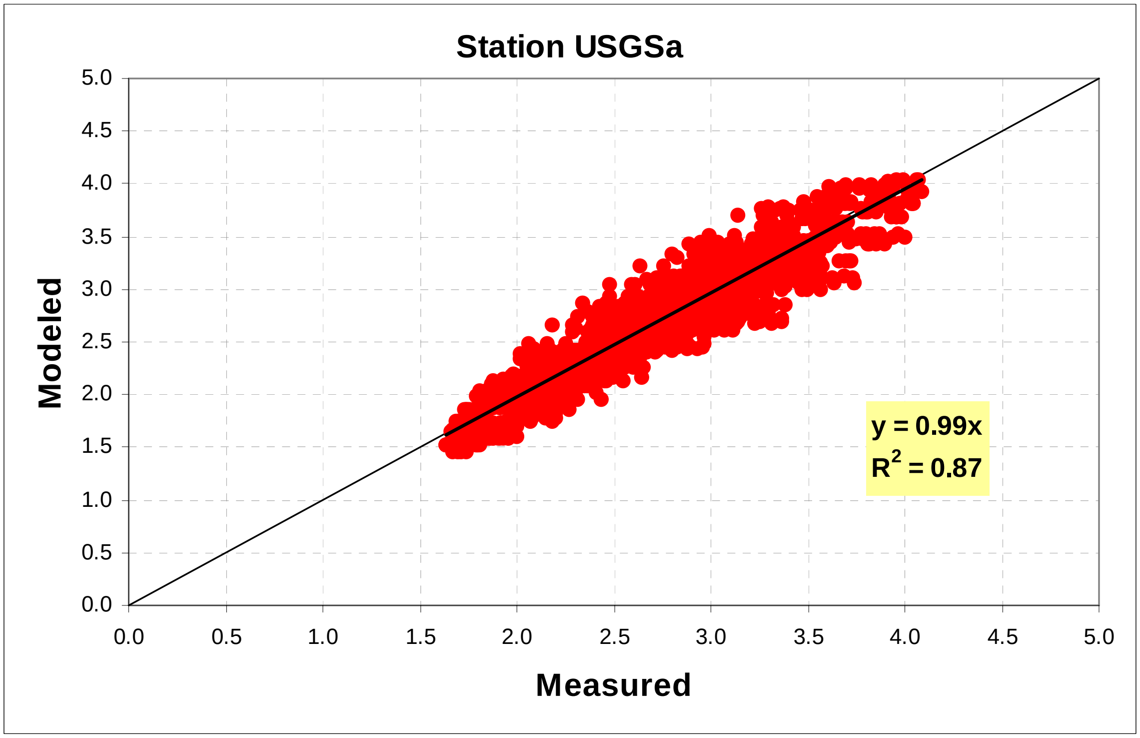
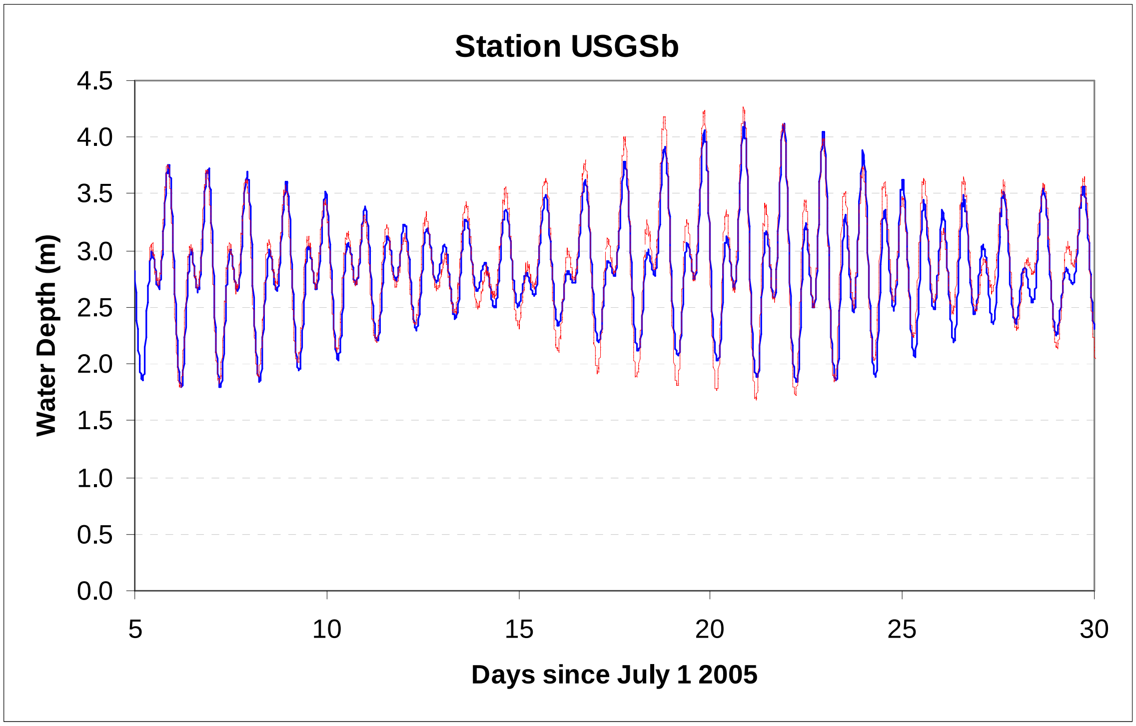


Figure 15. Calibration water depth comparison at the USGSb station (measured is in red and modeled in blue).



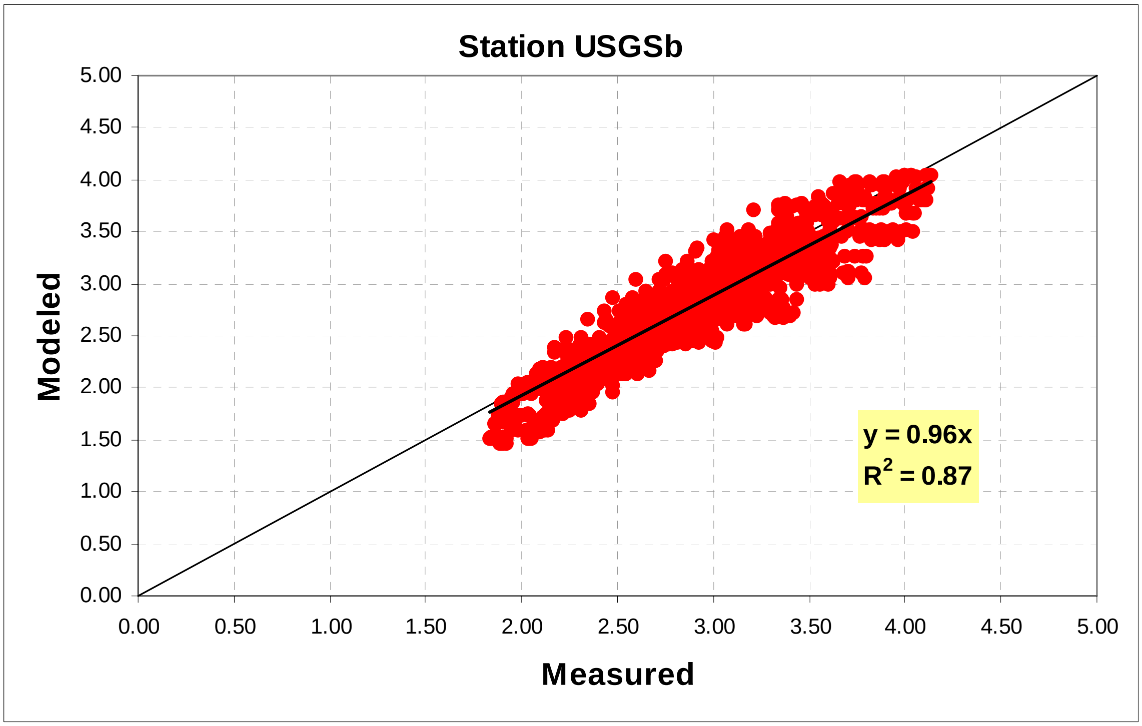
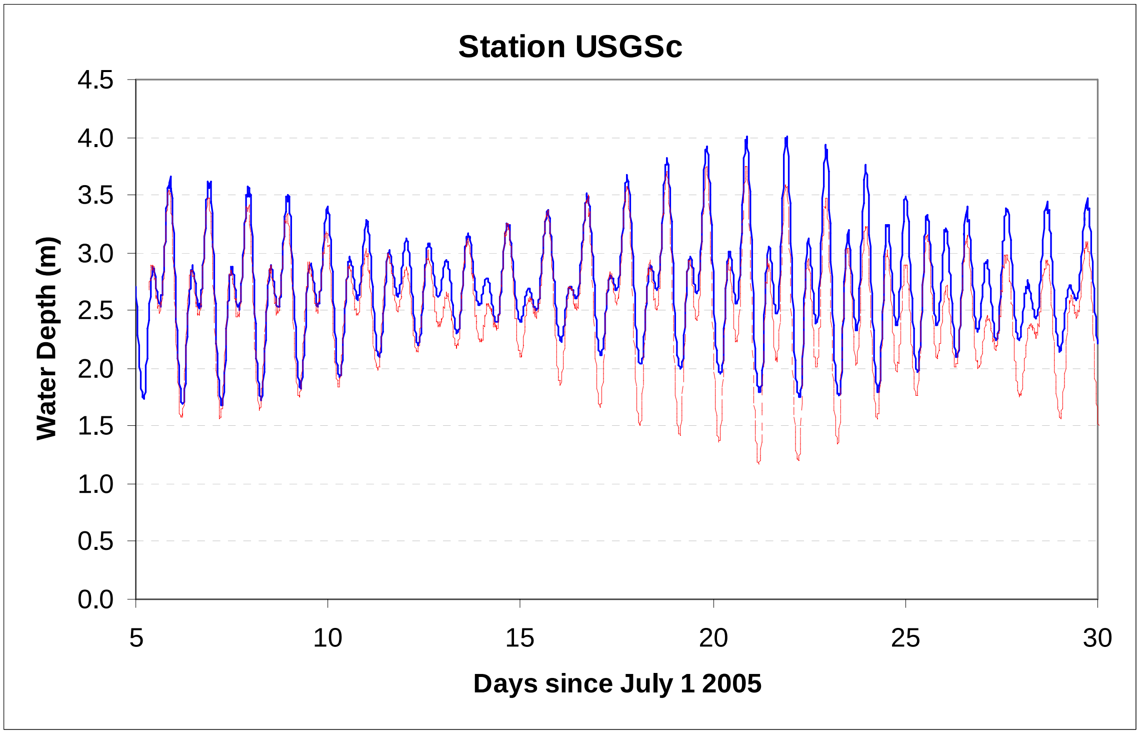


Figure 16. Calibration water depth comparison at the upstream (USGSc) station (measured is in red and modeled in blue).



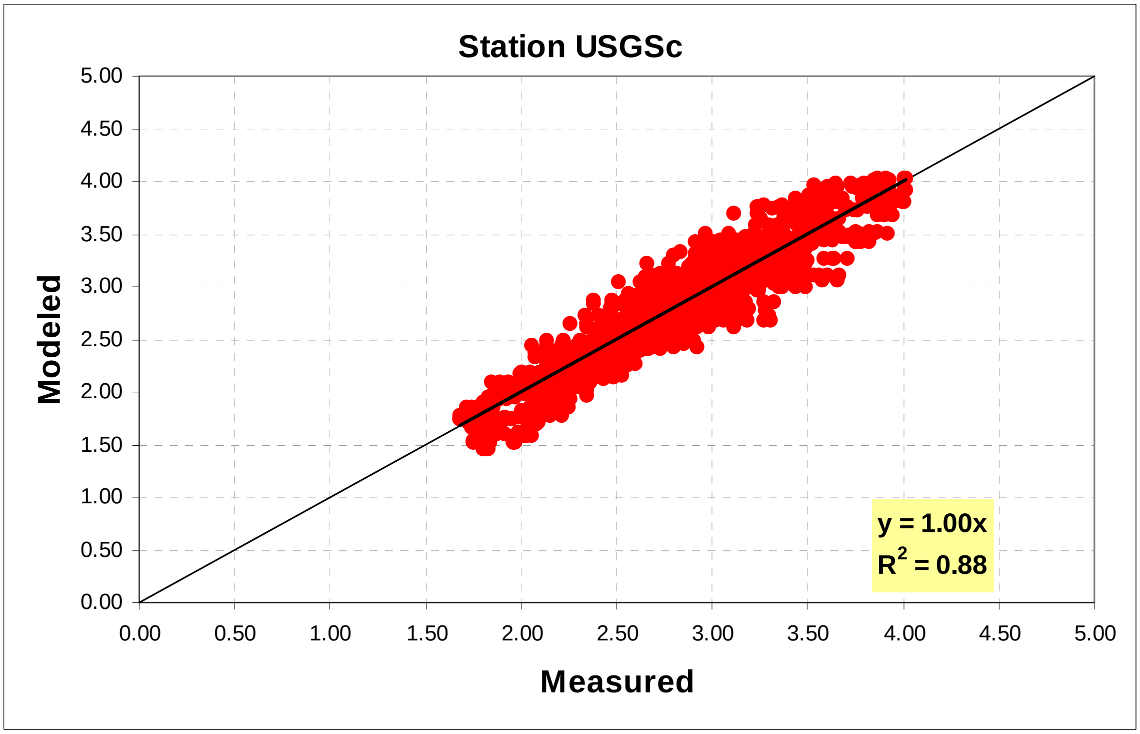


Figure 17. Validation water depth comparison at the downstream (USGSa) station (measured is in red and modeled in blue).

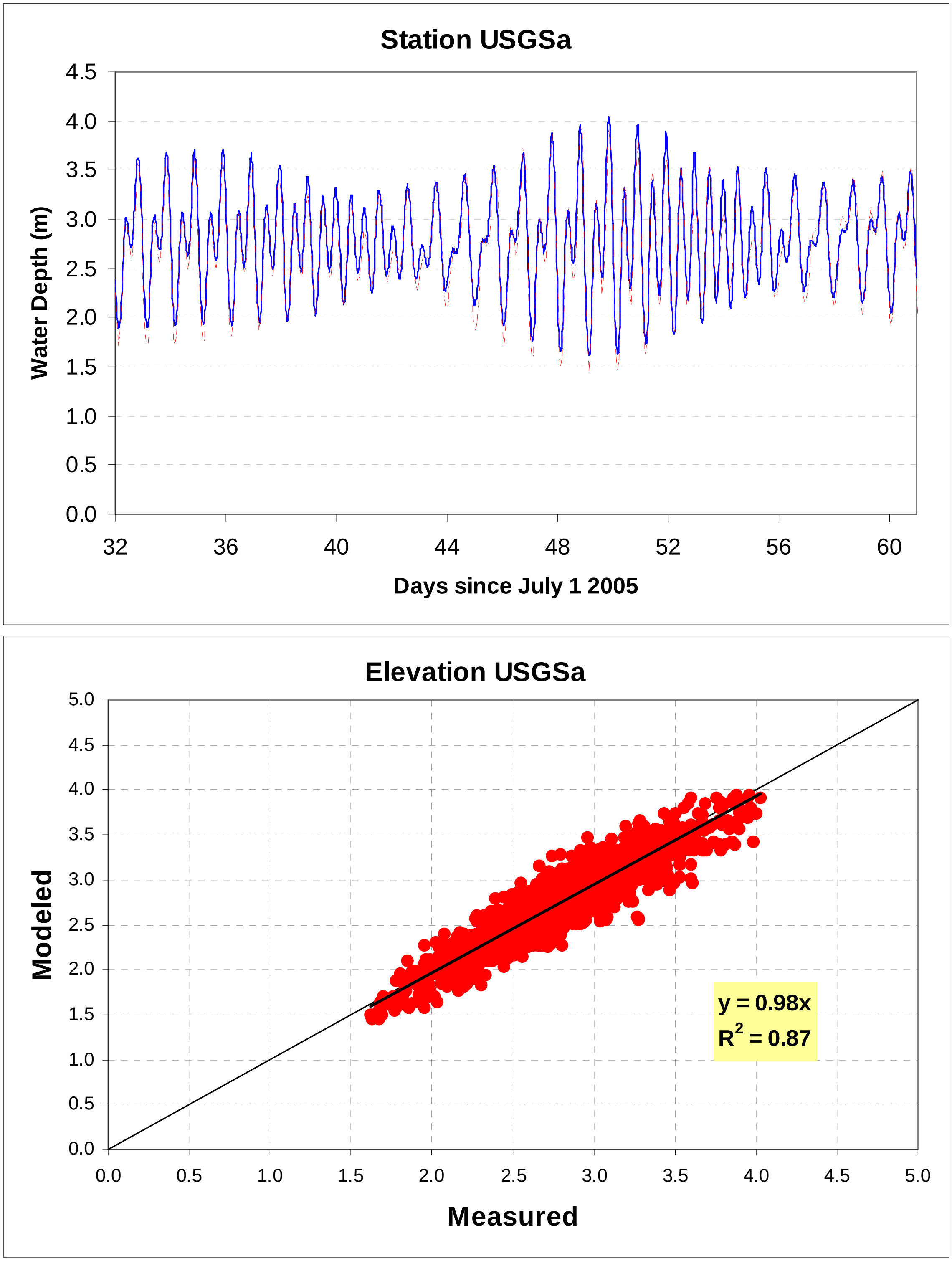
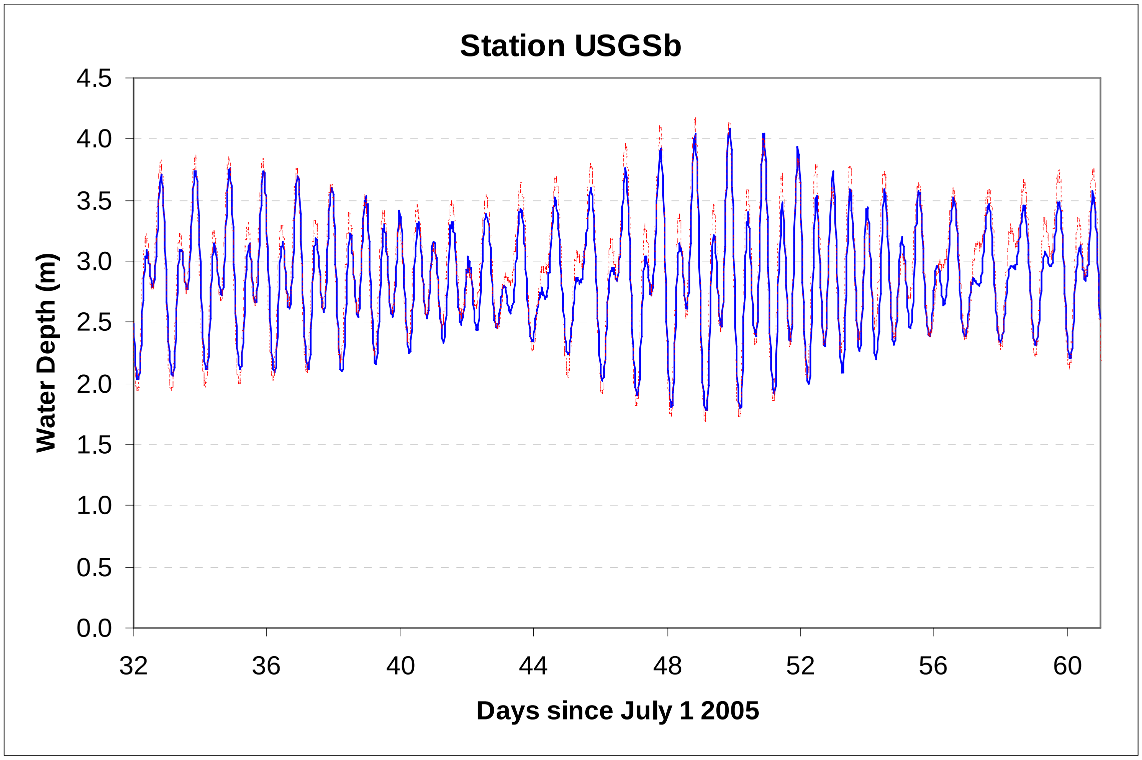


Figure 18. Validation water depth comparison at the USGSb station (measured is in red and modeled in blue).



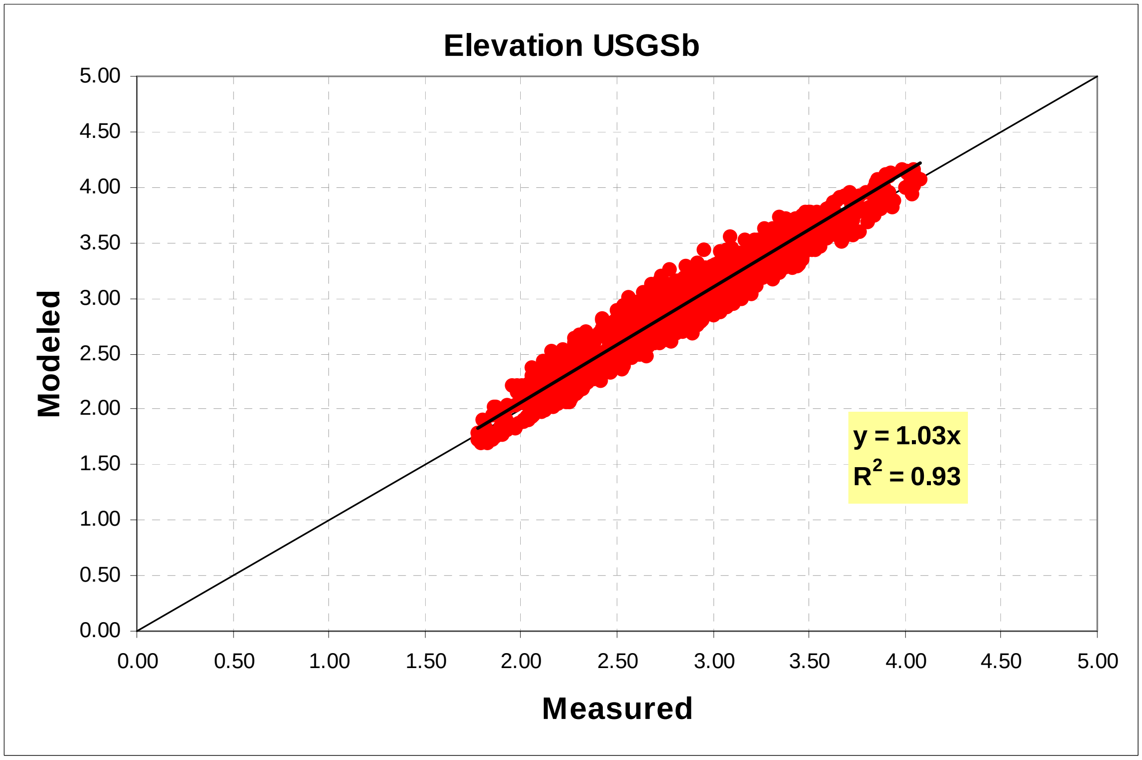
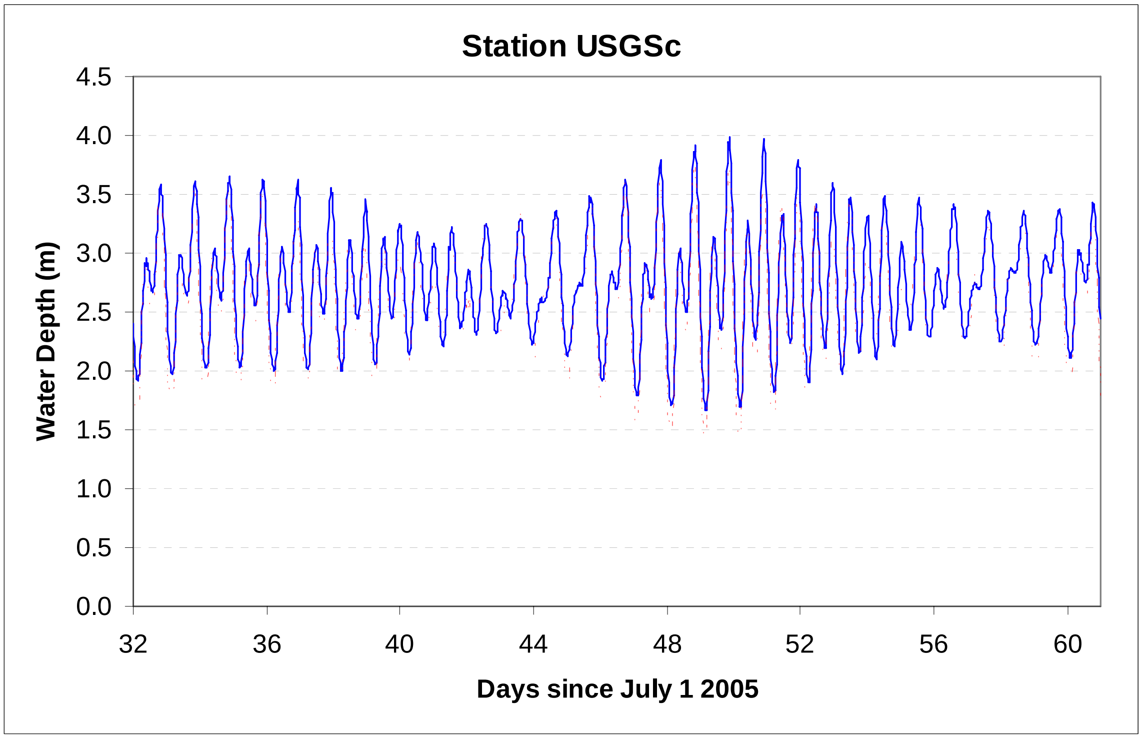


Figure 19. Validation water depth comparison at the upstream (USGSc) station (measured is in red and modeled in blue).



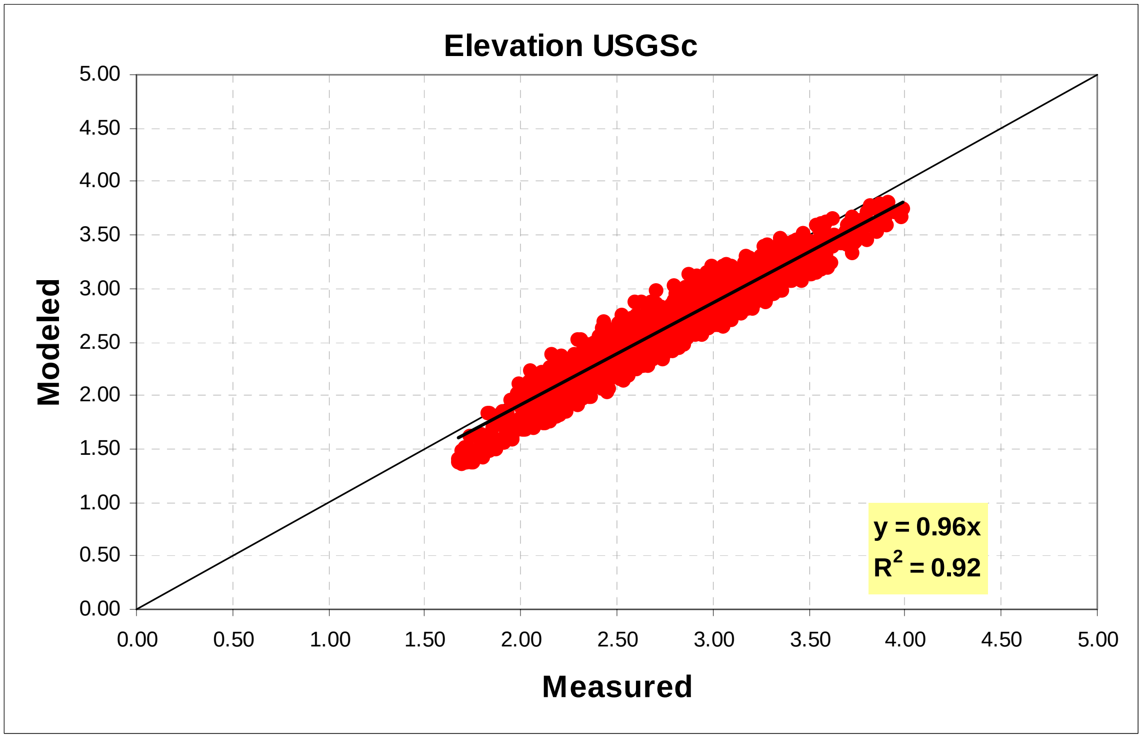


Figure 20. Temperature calibration at the downstream (USGSa) station.

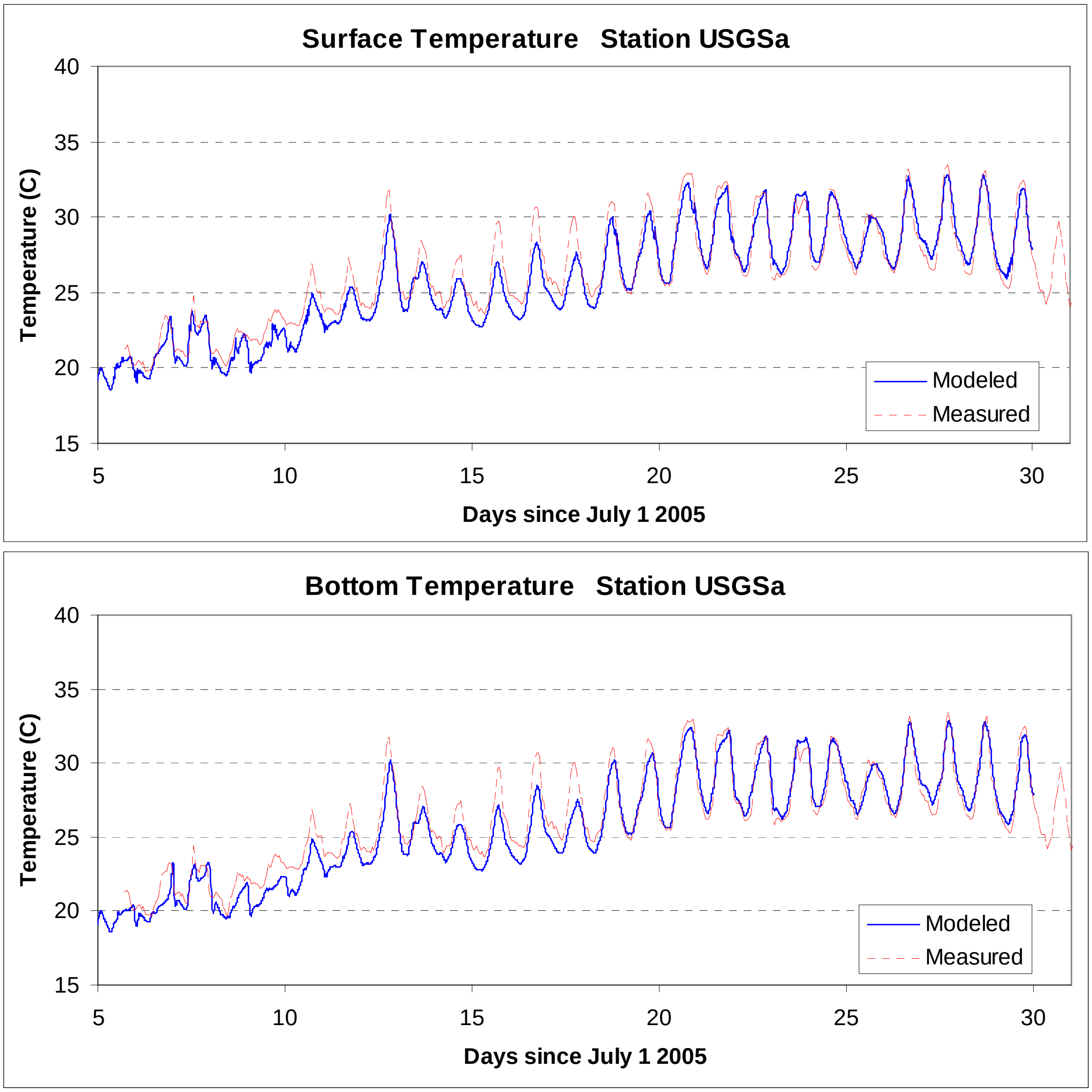


Figure 21. Temperature calibration at the USGSb station.

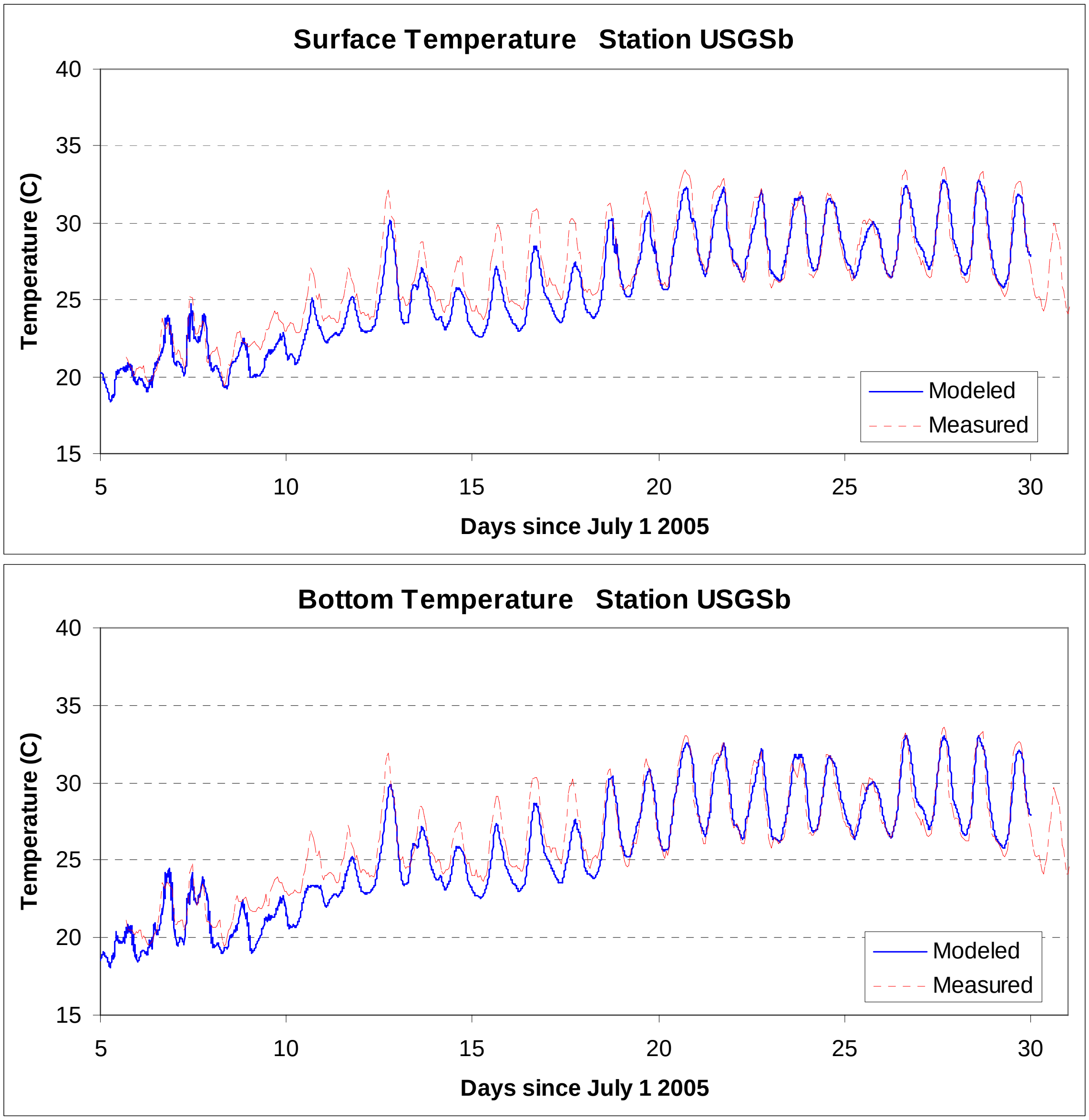


Figure 22. Temperature calibration at the upstream (USGSc) station.

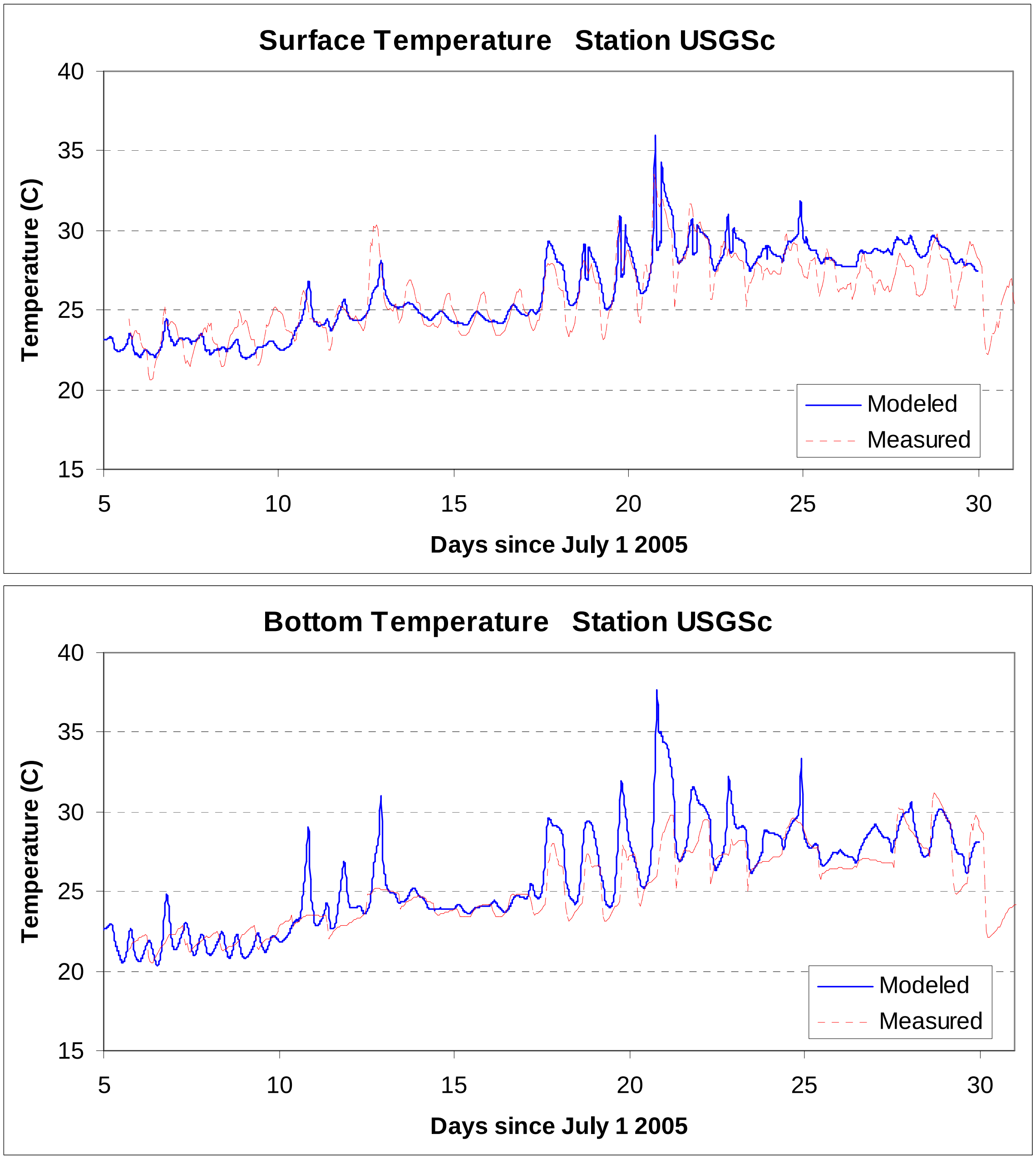


Figure 23. Validation temperature comparison at the downstream (USGSa) station.

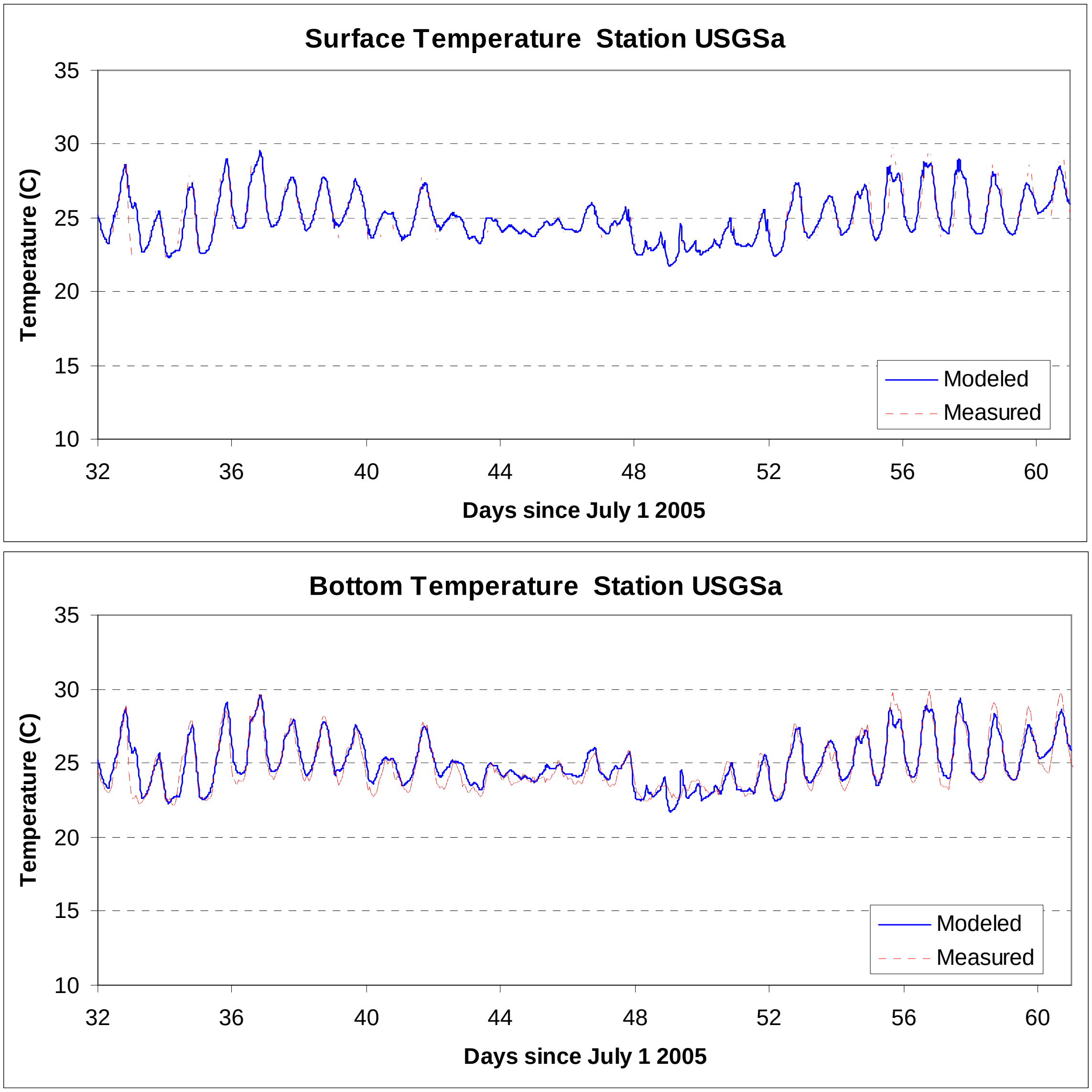
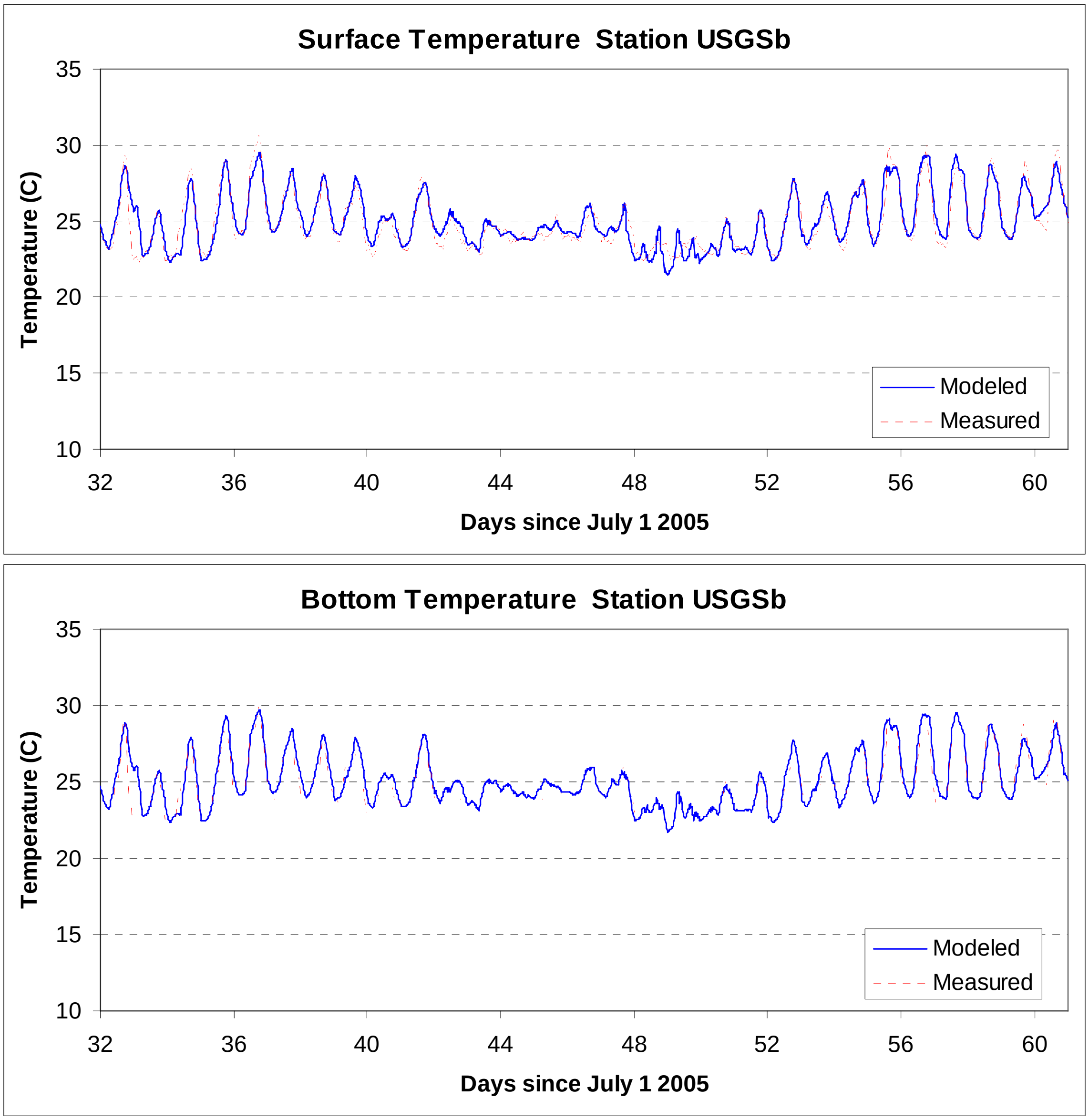


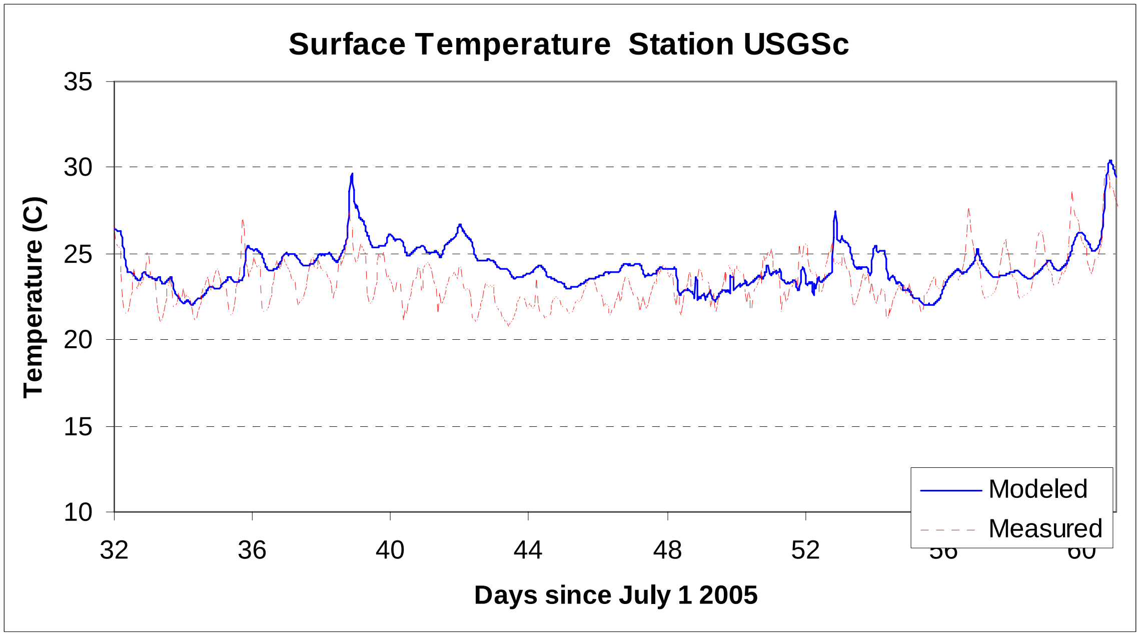
Figure 24. Validation temperature comparison at the USGSb station.



Surface Temperature Station USGSb

Bottom Temperature Station USGSb

Figure 25. Validation temperature comparison at the upstream (USGSc) station.



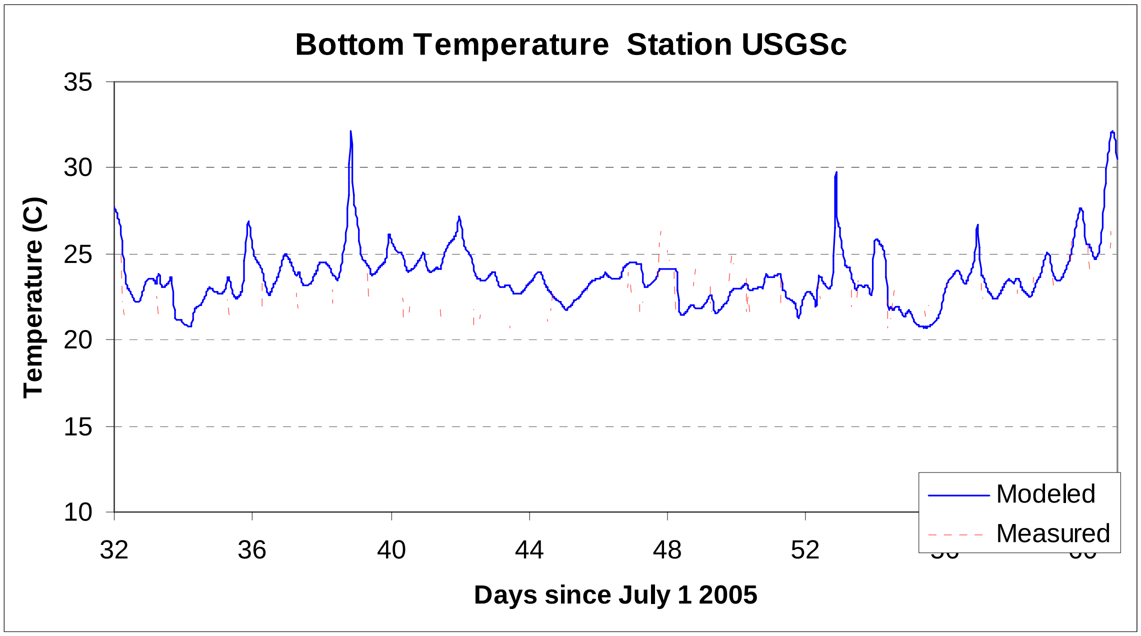


Figure 26. Salinity calibration at the downstream (USGSa) station.

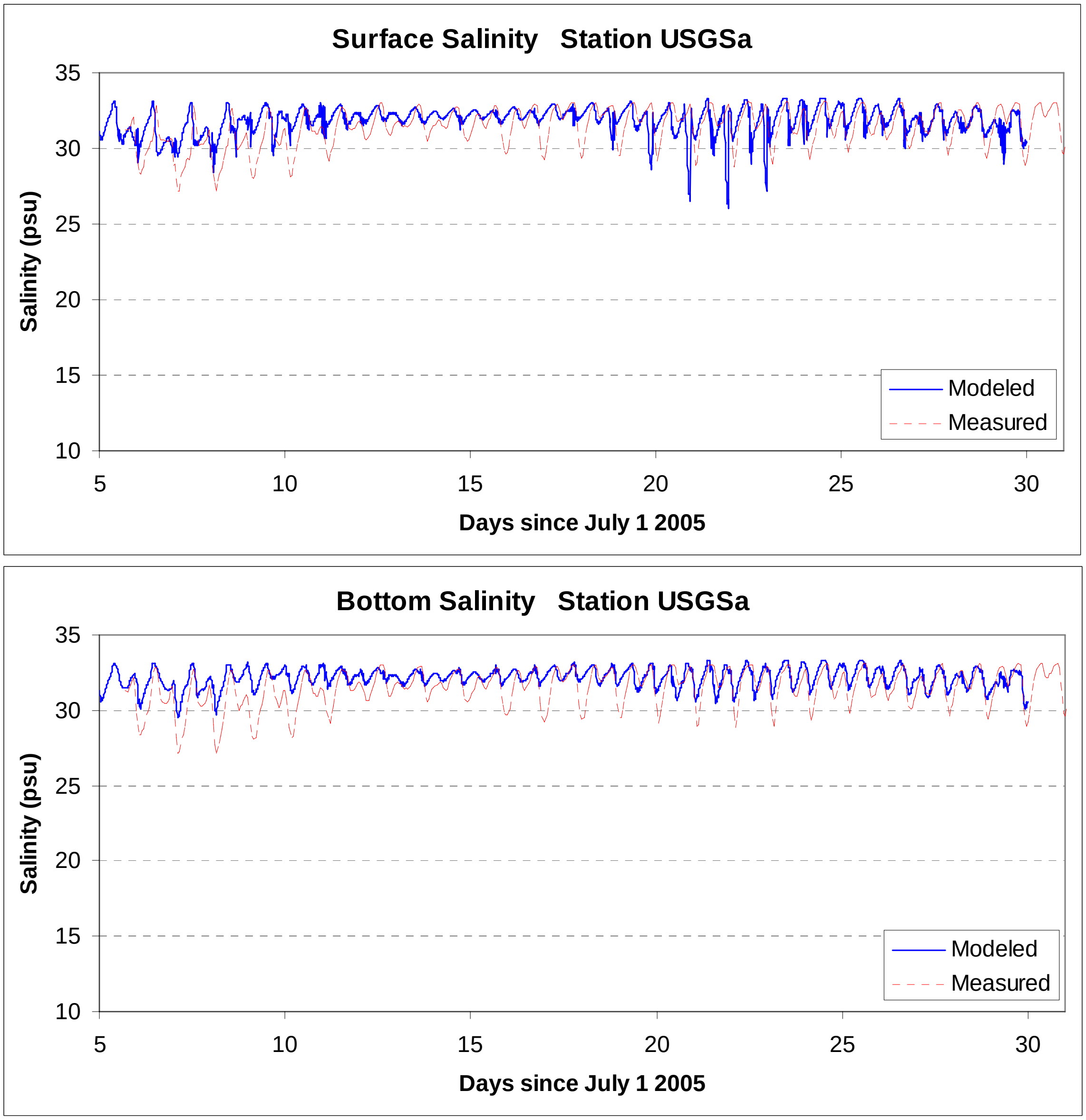
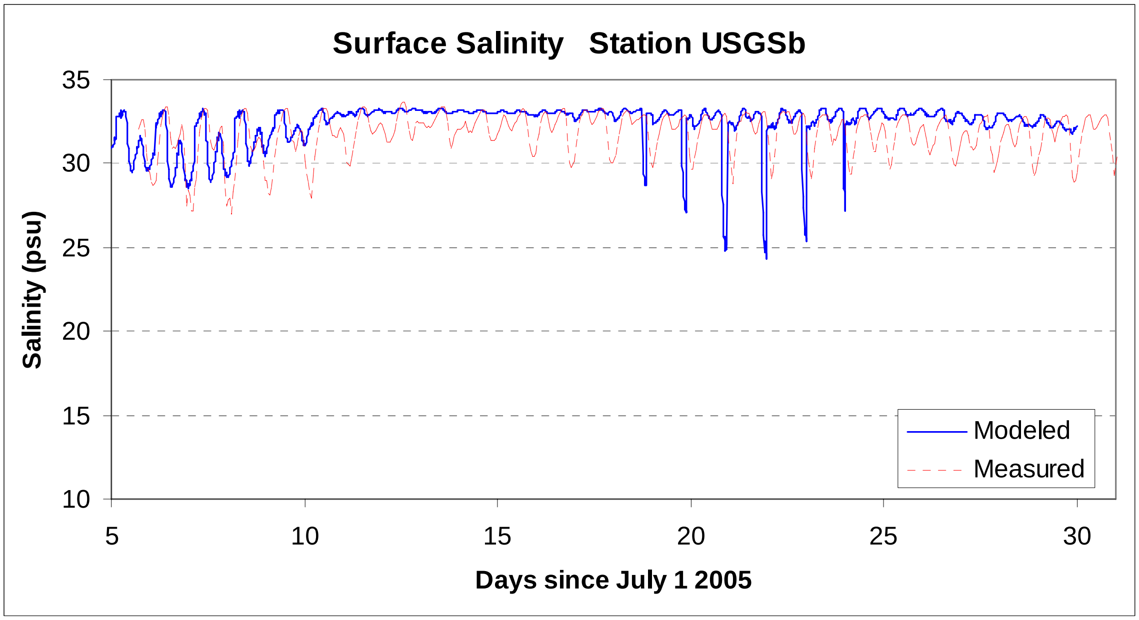


Figure 27. Salinity calibration at the USGSb station.



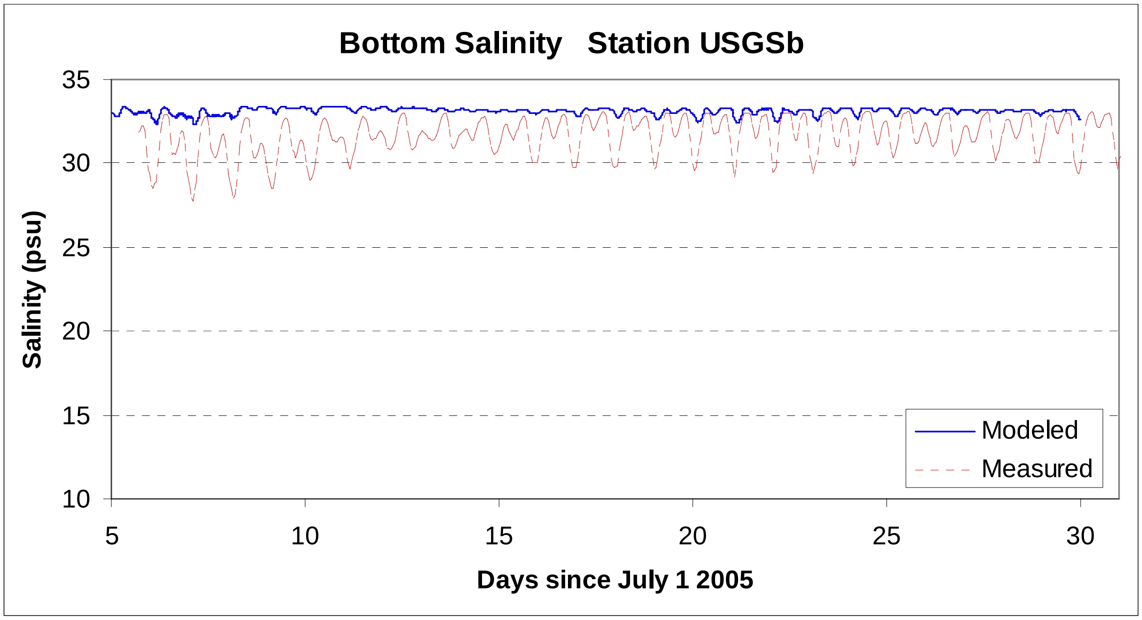
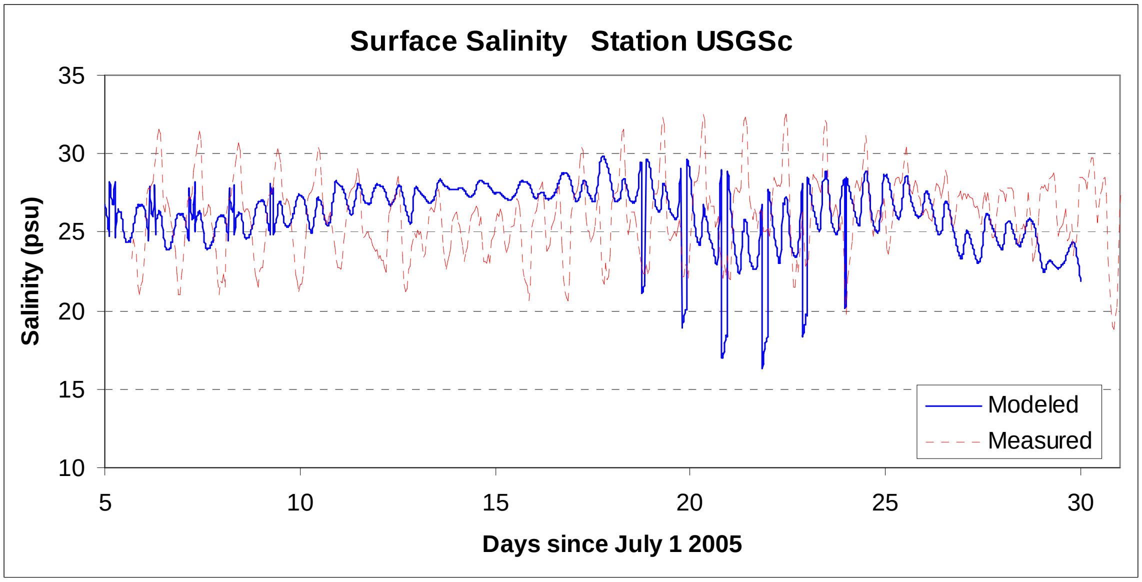


Figure 28. Salinity calibration at the upstream (USGSc) station.



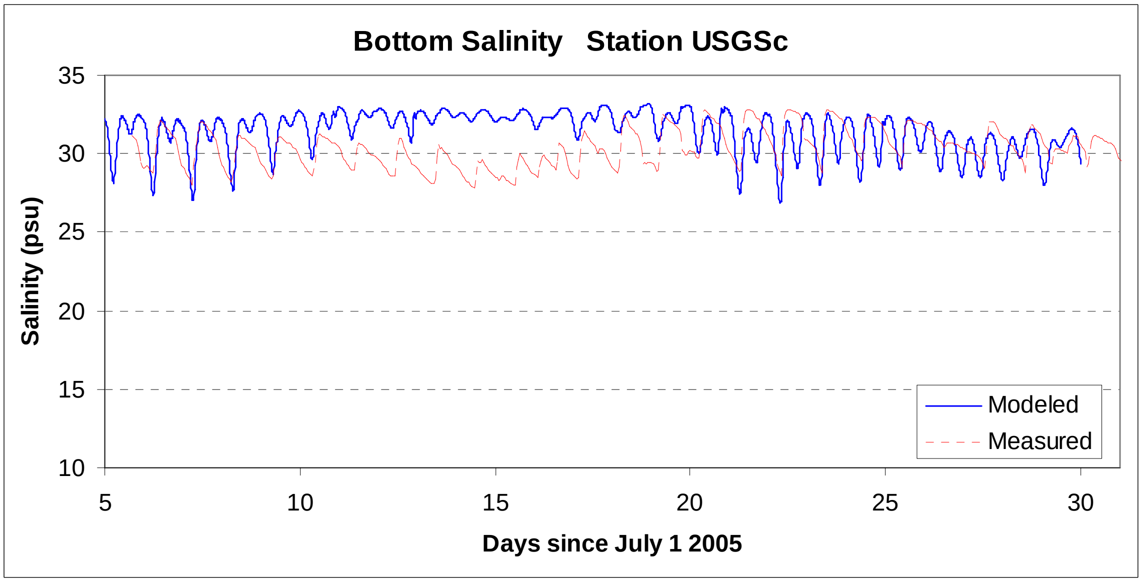


Figure 29. Validation salinity comparison at the downstream (USGSa) station.

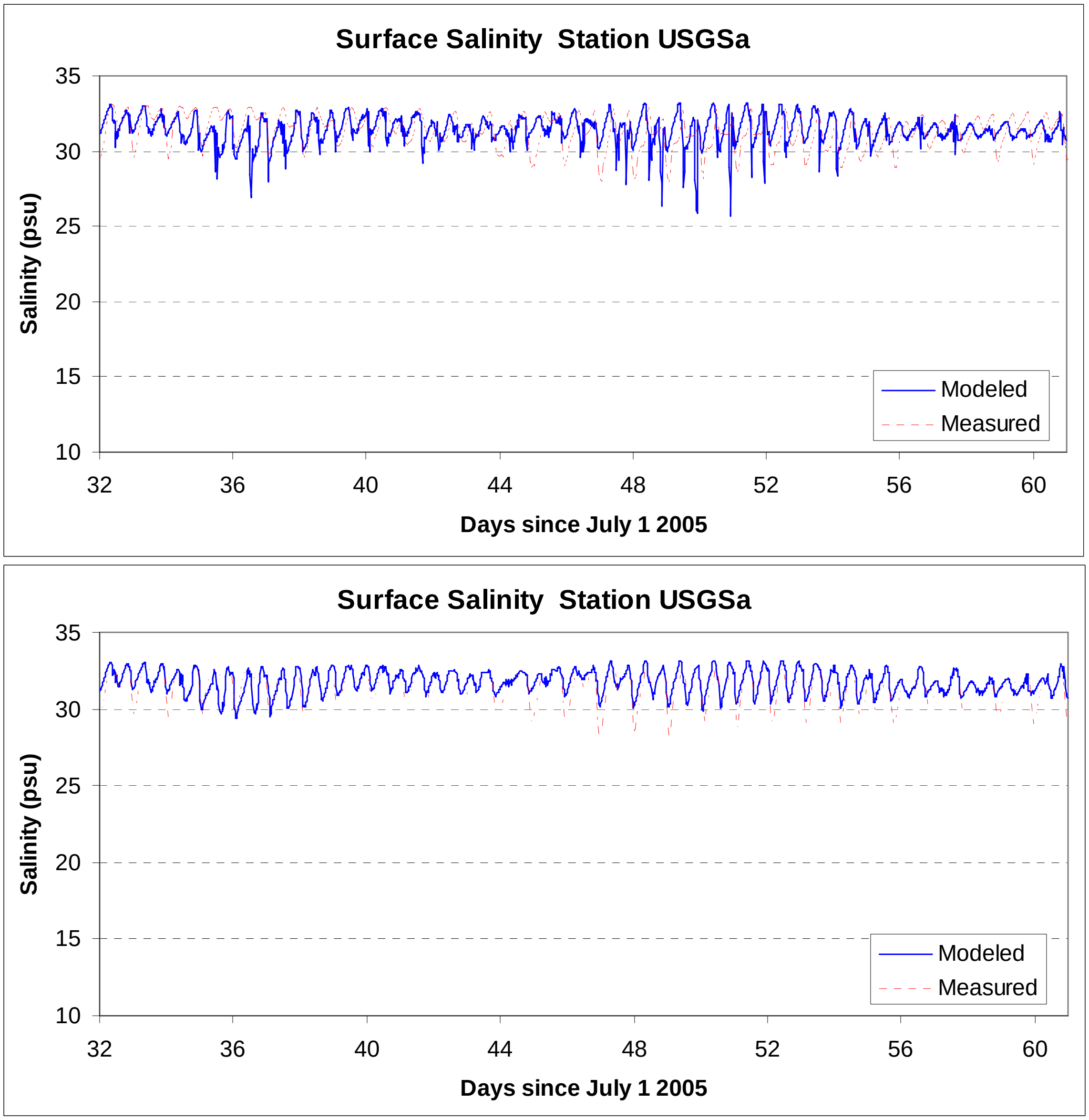
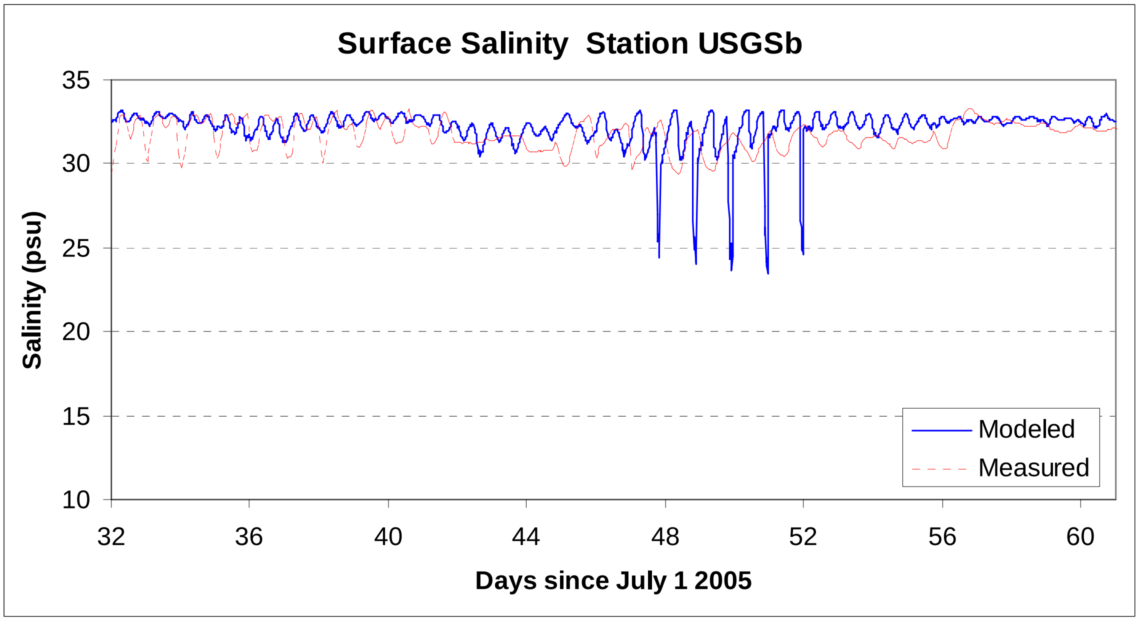


Figure 30. Validation salinity comparison at the USGSb station.



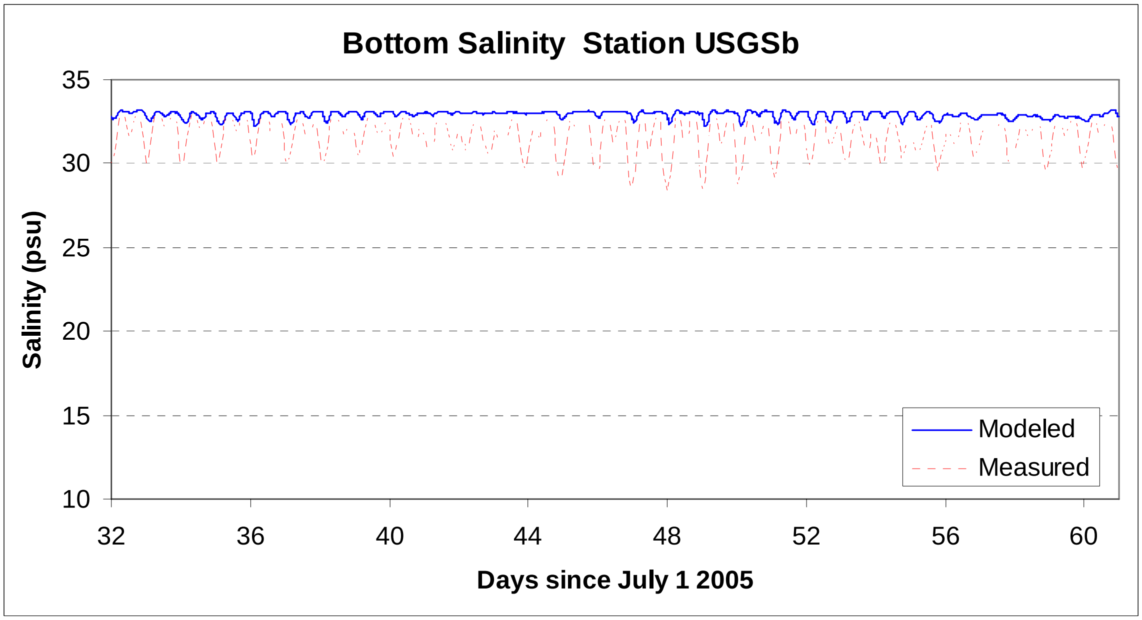


Figure 31. Validation salinity comparison at the upstream (USGSc) station.

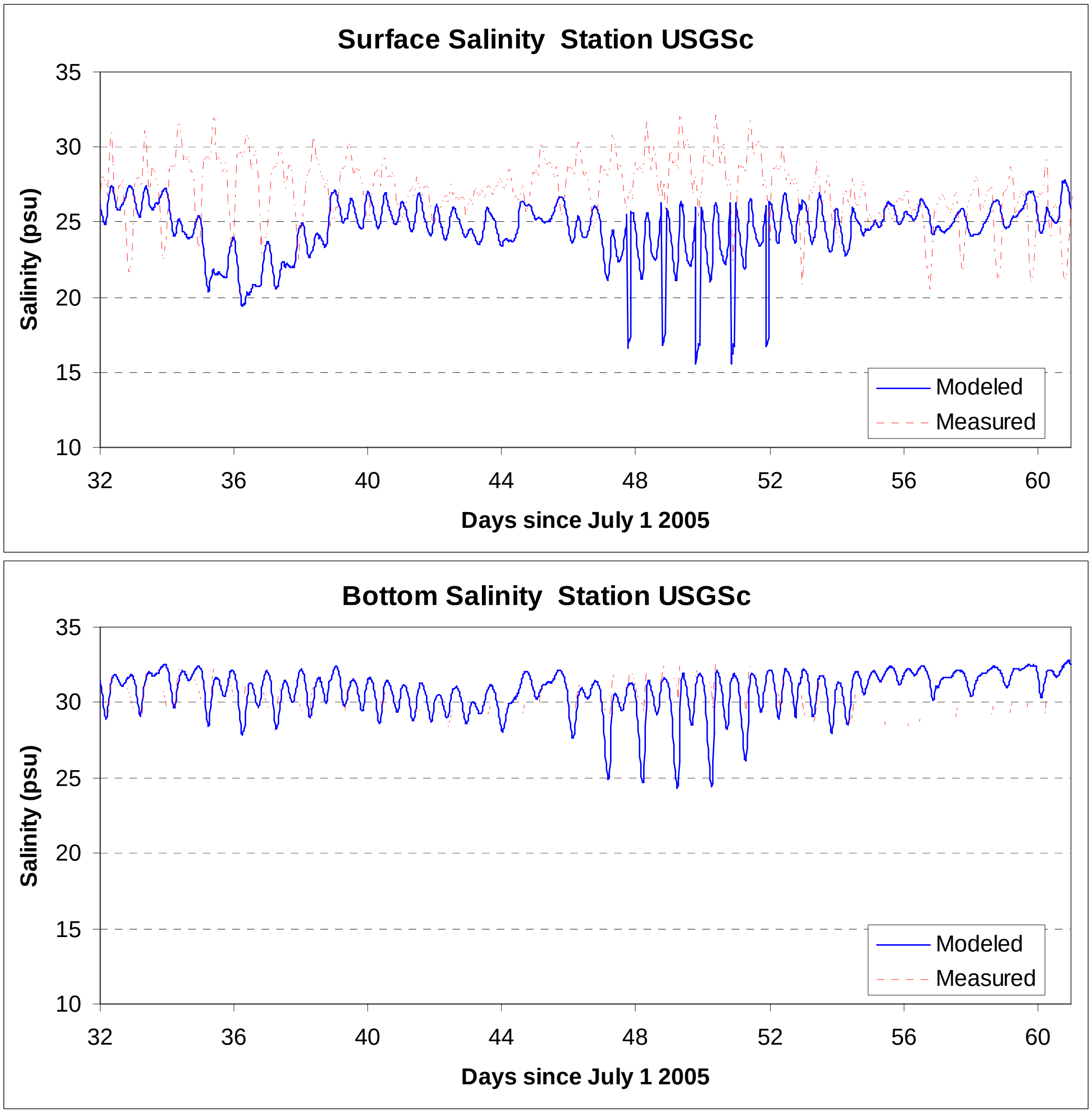


Figure 32. Modeled velocity at USGSbduring the calibration period.

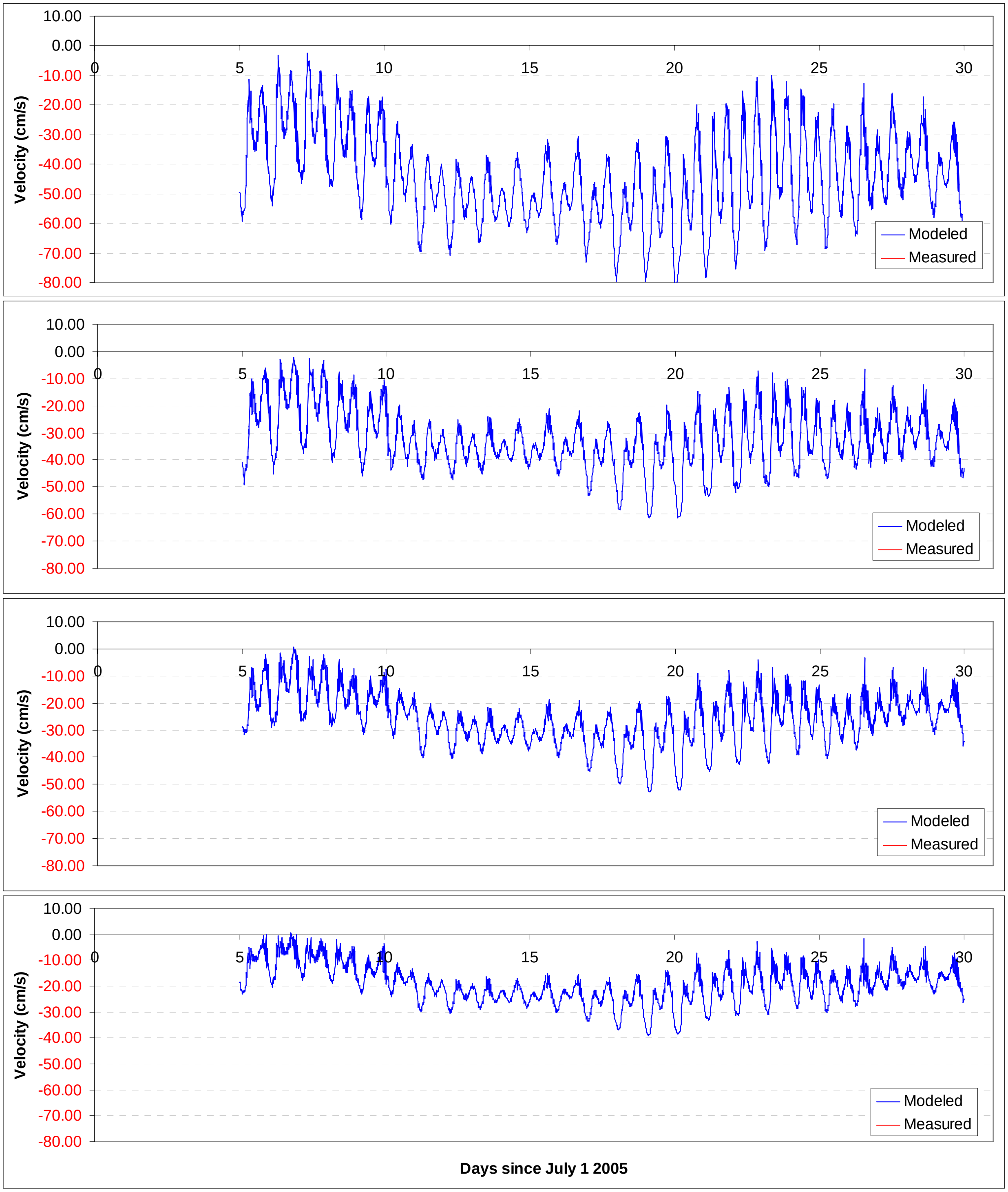


Figure 33. Modeled flow at the downstream station USGSb during the calibration period.

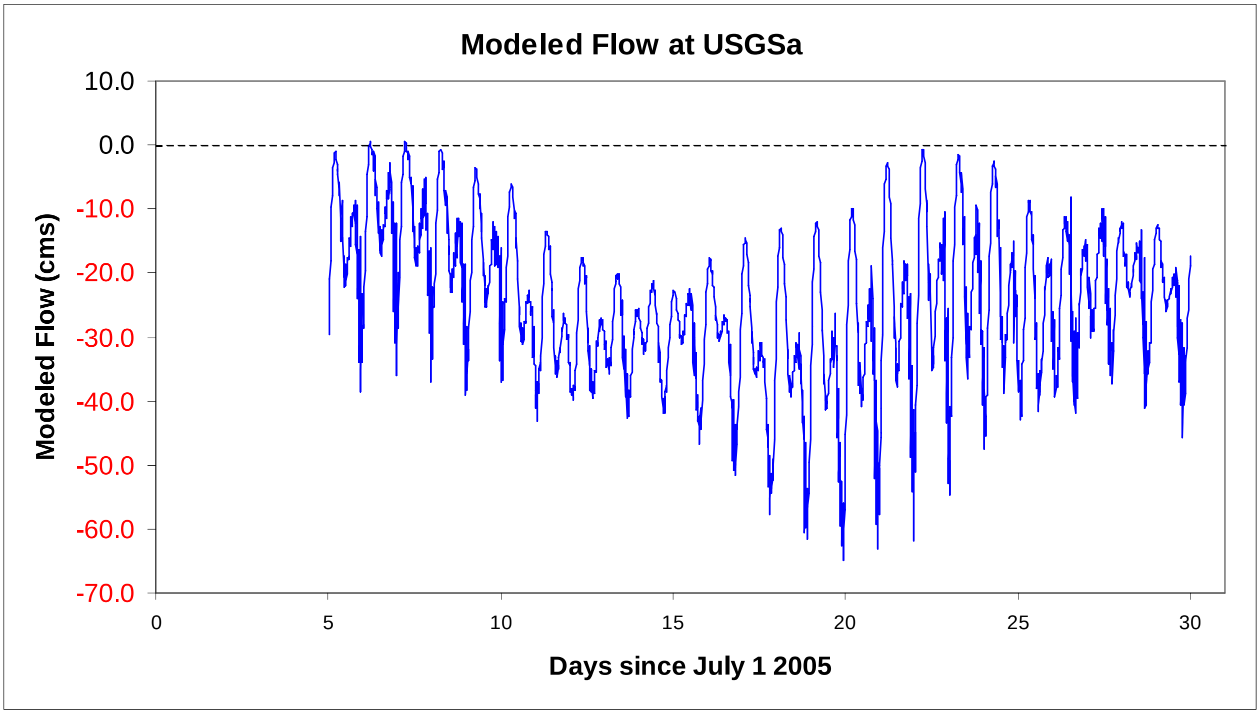


Figure 34. Modeled velocity at the upstream station (USGSc) during the validation period.

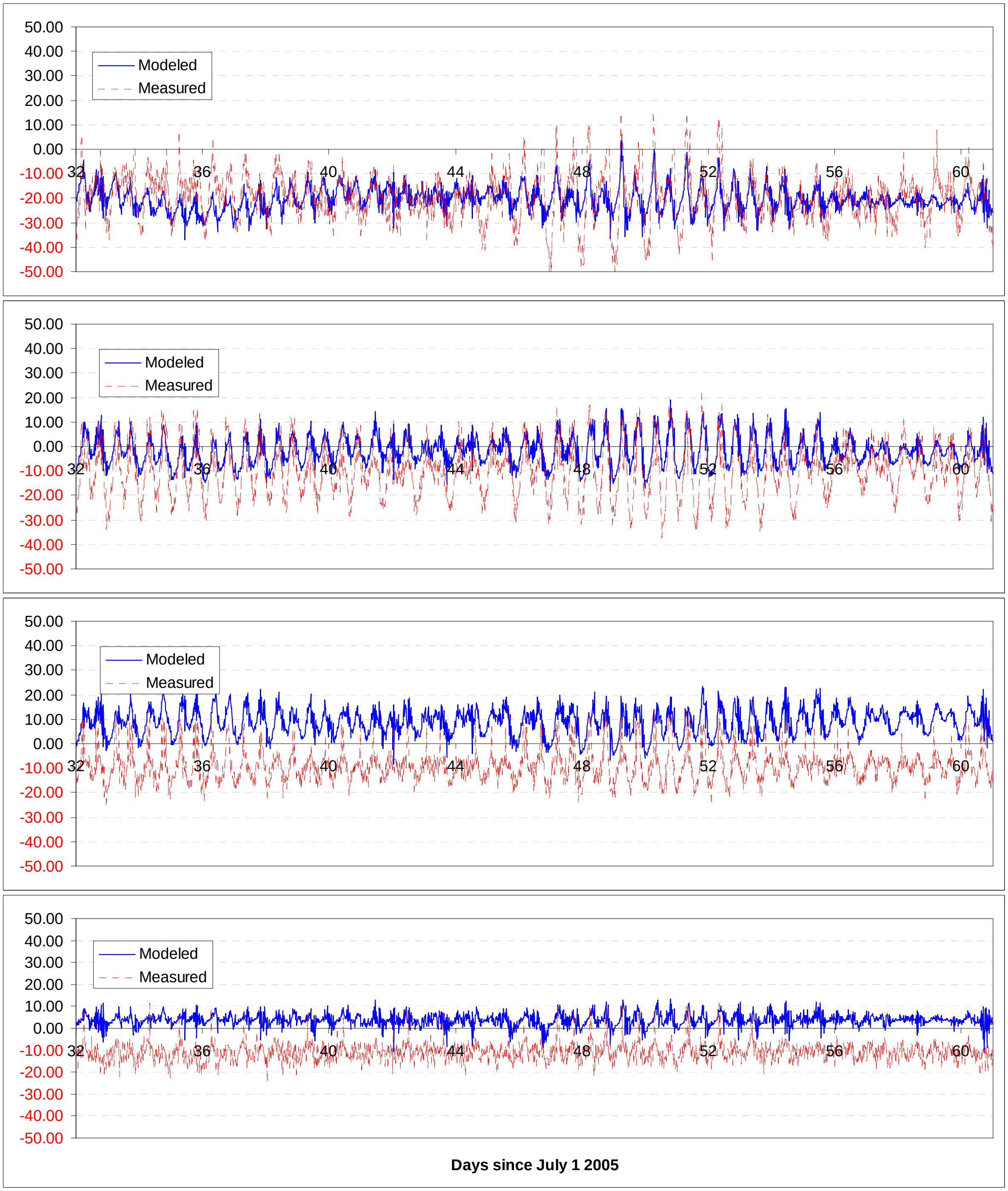


Figure 35. Modeled flow at the downstream station (USGSc) during the validation period.

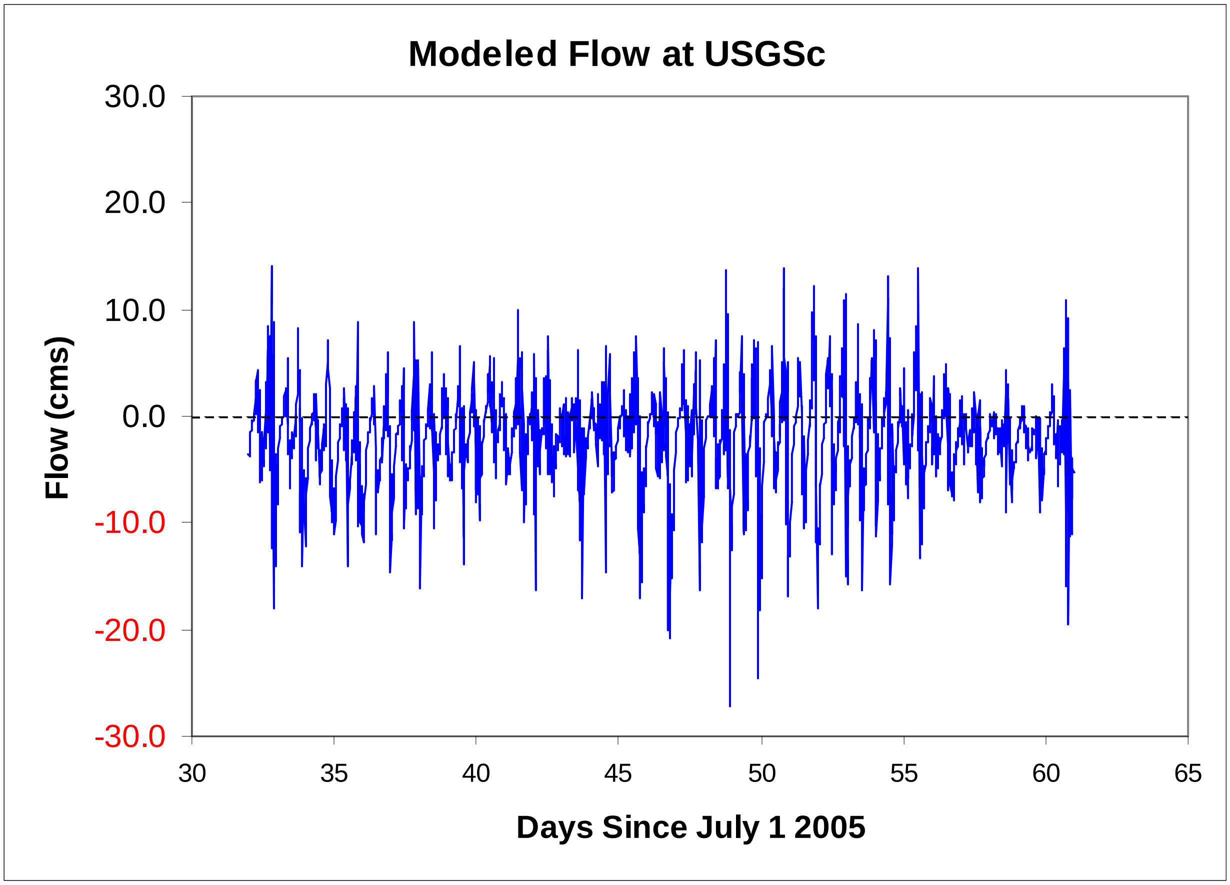


Figure 36. Residence times with and without PGSs.