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Spatial Heterogeneity of Zooplankton in the Stockton Deep Water Ship Channel

REPORT 4.4.1

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List of Acronyms

BDT	San Joaquin River at Brandt Bridge
CDFW	California Department of Fish and Wildlife
chl	Chlorophyll pigment measurement
CP	Channel Point sampling site
DO	Dissolved oxygen
DO-TMDL	Dissolved oxygen Total Maximum Daily Load
DWSC	Deep Water Ship Channel
LT 48	Navigation Light 48 sampling site
PAR	Photosynthetically active radiation
pha	Pheophytin pigment
rm	river mile
RRI	Rough and Ready Island
SJG	San Joaquin River at Garwood Bridge
SJR	San Joaquin River
SJR Burns	San Joaquin River at Burns Cut sampling site
SJR Navy	San Joaquin River at Navy Drive Bridge sampling site
TB	Turning Basin sampling site
TBD	Turning Basin Downstream sampling site
TBU	Turning Basin Upstream sampling site
YSI	Yellow Springs Instruments Co. Inc.
WS	Wine Slip sampling site

Introduction

The distribution of zooplankton is a key component of the San Joaquin River (SJR) ecosystem dissolved oxygen (DO) model because their abundance and habitat location are potentially important parameters for determining the density of phytoplankton. Prior to this study, spatial and temporal variations in zooplankton biomass have been quantified in the SJR (2005 – 2008), however no studies have been conducted in the Deep Water Ship Channel near Stockton (DWSC).

Physical features in rivers and estuaries, including oxbows, islands, and vegetation as well as physical conditions, such as river and/or tidal flow, temperature, salinity, and sunlight, can influence zooplankton concentrations in rivers (Gagnon and Lacroix 1981; Lair 2005; Vadstein, Olsen et al. 2012). Other research showed that variability between samples is caused by spatial heterogeneity, species composition of the organisms, diurnal/nocturnal migration behavior, and tidal influences (Sameoto 1975). Gagnon and Lacroix (1981) further observed that zooplankton biomass in the St. Lawrence Estuary was strongly influenced by tidal advection, however tidal action did not account for all the variability observed. In addition, they found that measurements of biomass variability suggest that differences in zooplankton biomass between sampling stations are not significant until measurements differ by at least a factor of four.

The objective of this subtask was to evaluate whether zooplankton distributions can be predicted by channel depth, tidal stage, geometry, or other physical characteristics. In addition, statistical sampling was performed to determine if zooplankton concentration could be represented by a single mid-channel, mid-depth sample. Preliminary monitoring conducted during past studies has shown that the Turning Basin serves as breeding waters for algae and zooplankton and could represent a significant source of these organisms to the DWSC of the SJR (Brunell, Borglin et al. 2006; Litton, Brunell et al. 2007; Stringfellow, Borglin et al. 2008).

To address these questions the following studies were conducted in 2011 and 2012 to understand zooplankton distribution and variability in the SJR, the DWSC and the Turning Basin. In a longitudinal study, mid-channel, mid-depth zooplankton samples were collected weekly between June through September 2009, May through September of 2011 and April through December of 2012 to address the question of zooplankton variability over long time periods and between sites with differing physical characteristics. To address the representativeness of mid channel mid-depth sampling, zooplankton samples were collected at the top, bottom, sides and mid-depth mid-channel at 6 locations including the Turning Basin, the DWSC and the upstream SJR on 8/27/11, 7/11/12, 8/19/12 and 11/26/12. Additionally, on 7/11/12, ten consecutive samples in the same location, but with varying depths were taken at 3 sampling sites to determine sample variability at one location over a short time period. Previous studies have identified the Turning Basin as harboring high concentrations of zooplankton and chlorophyll. To investigate the interaction and movement of zooplankton between the Turning Basin and the rest of the DWSC an in depth survey of the Turning Basin and nearby DWSC was conducted on 10/23/11. Stationary sampling was conducted at Channel Point, the intersection between the DWSC and the Turning Basin, between 11 pm 11/22/11 and 9 am 11/23/11 covering a full tidal cycle with the objective of observing the exchange of water and zooplankton between the DWSC and the Turning Basin.

Methods

Site Description

All sampling sites are shown in Figure 1. The sites are broken into four general regions; the upstream SJR, the Turning Basin, the DWSC and urban tributaries. Stockton's deepwater ship channel (DWSC), located on the San Joaquin River upstream in the San Francisco-Bay Delta, is a slow, tidally influenced body of water dredged to approximately 9-13 m deep and 150-350 m wide (Smith et al. 2004). The SJR, upstream of the DWSC (south of Channel Point), is not dredged and is typically 2 - 3 m deep and 55 – 80 m wide (Smith et al. 2004). Water velocities drop significantly at Channel Point where the shallow SJR enters the DWSC. The Turning Basin is a portion of the Port of Stockton which is approximately 100 m wide and dredged to a depth of 12m. Entrance to the Turning Basin is from the DWSC, and the Turning Basin reach is approximately 150 m long, with shallow overflow areas toward the east end (Figure 2). The tributaries are located north of the DWSC and generally have low flows fed mostly by urban runoff from the city of Stockton and surrounding area during the summer months. The details of the sites including depth, width and land use are listed in Appendix table A-1.

Zooplankton collection and analysis

Zooplankton were collected with a 30 L Schindler-Patalas Trap fitted with a 63 µm net (Wildlife Supply Company, Buffalo, NY). Using a power winch, the trap was lowered into the water column to approximately one-half depth or specific depths depending on the site and date. The 30 L sample was taken at the point in the water column where the trap was pulled upward. The samples were preserved in buffered formalin sucrose (5% final concentration). Samples were thoroughly mixed by inversion and a 5-20 mL subsample was taken from each using a Stempel pipette (Wildlife Supply Company, Buffalo, NY) (volume adjusted for sediment amount in sample). The subsamples were added to a settling apparatus, and settled for 5-20 hrs depending on volume. Prior to settling, 100 µL of 1% rose Bengal dye (Sigma Aldrich, St. Louis, MO) was added to facilitate counting of zooplankton.

Zooplankton were examined with a Leica DM-IL inverted microscope (Buffalo Grove, IL) using 100x magnification. All sampling, processing and identification of species follow standard methods and texts (Chengalath 1971; Pontin 1978; Balcer 1984; Pennak 1989; Wallace 1991; APHA 2005) During zooplankton counts the entire chamber floor was examined. For biomass estimates, body measurements were taken from a maximum of twenty individuals of each species using a calibrated ocular Whipple Grid. Conversion of body measurements into biomass follows guidelines from the EPA publication LG403 (Environmental Protection Agency 2006) which specifies that a minimum of 200 individual organisms are counted for each sample.

Zooplankton data collected from 2009-2012 were averaged for each site in the study area (Appendix Table A-2). The study area was defined as covering a portion of the upstream SJR to just north of Disappointment Slough in the DWSC (see Figure 1, Appendix Table A-2). Physical features at the sample sites were investigated by visualization from Google Earth and Nautical Charts (NOAA 2006; Google 2013).

High flows in the San Joaquin River (SJR) delayed most of the zooplankton monitoring in the Deep Water Ship Channel (DWSC) throughout the summer of 2011. The flow at Vernalis exceeded 10,000 cfs in June 2011 and remained at or above 4,000 cfs until November 2011. Details of net flows to the DWSC during monitoring in 2011 and 2012 are presented in Figure 3. Because the goals of this project include correlation of zooplankton and algal biomass to dissolved oxygen deficits, and because significant dissolved oxygen deficits are typically not observed in the DWSC when SJR flows exceed 2000 to 3000 cfs at Vernalis, resources were conserved in 2011; most of the proposed zooplankton studies were conducted in summer 2012.

Spatial distributions were monitored on August 27, 2011; July 11, 2012; August 19, 2012; and November 26, 2012 to provide an assessment of the validity of the sample collection procedures. Sampling occurred at six stations: four in the DWSC (sites 402, 428, 406, 427), one in the SJR upstream of the DWSC (SJR at Brandt Bridge, site 127), and one in the Turning Basin (TB) (Figure 1, Appendix Table A-3). At each station, samples were taken at five locations: mid-channel surface, mid-channel mid-depth, mid-channel bottom, north bank mid-depth, and south bank mid-depth.

In addition, a sample repeatability test was conducted on September 7, 2012 to assist interpretation of the spatial variability study, where stations 402, 406, and TB were each sampled mid-channel, mid-depth 10 consecutive times. Station 402 was sampled between 19:40 – 20:25, 406 between 18:35 – 19:25, and TB between 17:15 – 17:55.

Turning Basin Sampling

Zooplankton and water quality monitoring were performed to gain a better understanding of the influence of the Turning Basin on the DWSC. Longitudinal and vertical sampling was performed on October 23, 2011 and November 23, 2011 to assess the contribution of high zooplankton concentrations in the Turning Basin to the DWSC. On October 23, 2011 sampling occurred in and near the Turning Basin, with two SJR sites, one DWSC site, three Turning Basin sites, and two transitional site between the TB and DWSC (CP and WS) (Appendix Table A-3). On November 22-23, 2011, sampling took place at the CP site, hourly for 11 hours, starting at 23:00 and ending 9:00 (Appendix Table A-4). These monitoring stations are shown in Figure 1.

Lateral and vertical water quality profiles were measured for temperature, conductivity, pH, dissolved oxygen (DO), turbidity, chlorophyll fluorescence, and photosynthetically active radiation (PAR) in the TB and in the waters of the SJR. Temperature and conductivity measurements served as indicators of flow exchange behavior of the TB with the DWSC.

Additional monitoring was performed on November 22 and 23 to independently verify the October 23 tidal circulation observation. The November survey boat was anchored at the entrance of the TB (CP) during a 12-hr continuous flood and ebb tide period. Zooplankton samples and vertical water quality profiles were measured every hour to evaluate the exchange of water at the entrance (Appendix Table A-4).

Tidal conditions during zooplankton monitoring

Tidal conditions and flows are important to zooplankton and water quality parameter distributions in the Stockton DWSC and its tributaries. Tidal stage in the DWSC varies approximately 3 - 4 feet at Stockton with two high and two low tides generally observed per day. Tidal excursion varies in the DWSC, but in Stockton, dye investigations have shown tidal action to move water approximately 1 to 1.5 miles per flood or ebb tide period when net flows are below 1000 cfs. Appendix Figures A-1 - A-7 show tidal stage and instantaneous flow data in the study reach for each of the sample dates.

In-situ water quality measurements

The day before sample collection YSI 6600 Sonde was calibrated following procedures in the YSI 6-Series Environmental Monitoring Systems Handbook (Yellow Springs Instrument Co. Inc. 2002). A SeaBird SBE-25 profiler (SeaBird Electronics, Inc, Everest, WA) was also used for vertical water column measurements. Measured parameters include depth, temperature, conductivity, pH, DO, Photosynthetically Active Radiation (PAR), chlorophyll fluorescence (chl). Vertical profiles using the SBE-25 were performed by lowering the instrument at 1-2 ft/s until it reached the sediment surface.

Extracted Chlorophyll a

Chlorophyll a (chl) and pheophytin a (pha) are extracted and analyzed using UV absorption as described in SM 10200 H (APHA 2005). Both the trichromatic chl and the pha methods were used for quantification. Algae fluorescence measured in-situ was calibrated with the extracted chl results.

Additional Data

In Appendix Figures A-9 – A-25 detailed measurements of chl, specific conductance, and temperature in the river at low and high tides for mid, south, and north banks of the river for 8/27/11 sampling are shown.

Results and Discussion

Zooplankton distribution and variability between sites with varying physical characteristics

Longitudinal sampling included sites from the Turning Basin and DWSC, urban tributaries in and near the city of Stockton, and upstream SJR sites in the un-dredged portion of the river (Figure 1). Data from the additional targeted studies are included in this analysis. When multiple samples were taken from one site on one date, a mean value is used in this analysis. Average regional zooplankton data is plotted in Figures 4 and 5. The sites with the highest mean concentration (> 30 µg/L) of total zooplankton were located in the Turning Basin and the tributary sites 413 and 421 (Table 1). Maximum zooplankton concentrations (>200 µg/L) were also observed in tributary sites 413, 421 and in the Turning Basin (Table 1). The upstream SJR sites harbor significantly lower concentrations of zooplankton than the Turning Basin and the tributaries (pairwise t-test, alpha = 0.05). In the upstream SJR, maximum concentrations are below 30 µg/L and mean concentrations are below 15 µg/L, except site 127 which had a maximum concentration of 105 µg/L and a mean of 16.1 µg/L (Table 1).

Zooplankton concentrations found in the DWSC are significantly lower than the Turning Basin sites, but not significantly different from either the upstream SJR or the tributaries. The DWSC in general has a stable population of zooplankton with a lower coefficient of variation than the Turning Basin, the tributaries, or the upstream SJR (Table 2). Sites with occasionally high concentrations (maximum above 75 µg/L) were spread throughout the DWSC and included sites 427, 402, 428, and 406 (Table 1). The Turning Basin sites had the highest mean and median zooplankton biomass overall, but this difference was not statistically significantly higher than the tributaries (Table 2). The highest observed concentration was found at site 413, Smith Canal at Yosemite Lake with a value of 835.5 µg/L on April 26, 2012. For the entire data set, which includes 419 observations, 90% of the values were below 40 µg/L, and the overall mean of 20 µg/L and median of 7 µg/L total zooplankton.

Further description of the physical conditions of sites which had the greatest concentrations of zooplankton observed is presented in Appendix Table A-5. Sites 413, 421, 433, 127, 427, 406, 428, 402, 405 and TB are listed along with nautical map and Google Earth image, as well as channel depth and width. This survey shows that many of the sites with high zooplankton biomass observations corresponded to sites with mid-channel islands, had nearby river bending, or were shallow in locations with little or no flow. All DWSC and tributary sites downstream from site 406 had mid-channel islands nearby the sampling site, possibly due to the increased tidal action or dredging operations. The only site upstream from 406 with mid-channel islands was site 405 on the Calaveras River. Maximum zooplankton concentrations had no correlation to river depth or width, or width/depth ratio. DWSC sites were similar in geometry, with site 427 probably seeing the highest maximum zooplankton concentration due to the proximity of the Turning Basin directly upstream.

SJR upstream site 127 at Brandt Bridge is on a section of the river with a series of curves not present in upstream sites 2 and 4, which causes a shallower area mid-river. The tributaries have no consistent distinguishing characteristic but all have features that could be conducive to producing zooplankton habitat. Sites 405 and 433 have islands and vegetation, site 413 is shallow and quiescent, and site 421 is covered by heavy vegetation. However, other tributary sites had similar characteristics and did not have high biomass numbers which may be due to low sampling frequency for some sites, the spatial heterogeneity of zooplankton population, or some other factor (e.g. water quality). For the tributary sampling points located a significant distance from the confluence with the DWSC and/or very low flow, more sampling would be needed to determine if those organisms influence conditions in the DWSC.

Variation in Zooplankton with respect to Tidal Cycle

Overall, higher mean and maximum concentrations of zooplankton were observed during outgoing or ebb tides for the sites in the Turning Basin, the DWSC and Tributary sites, however the reverse was true for the upstream SJR sites (Table 3). This difference in zooplankton concentration between ebb and flood tides was not statistically significant for any of the study reaches when looking at all sampling data together.

Total zooplankton biomass for sampling date 8/27/11 is shown in Table 4, when all 6 sites were sampled at both high and low tide at mid-channel surface, mid-channel mid-depth, mid-channel bottom, north bank mid-depth, and south bank mid-depth. Samples taken at low tide for these sites had significantly lower biomass (11.9 ± 14.1 µg/L) compared to samples taken at high tide (15.8 ± 20.4 µg/L) (t-test, alpha = 0.05).

During the in-depth Turning Basin study on 10/23/11, no consistent change in biomass was observed within the Turning Basin sites with respect to tidal conditions. Both site CP and WS, which are transitional between the DWSC, and the Turning Basin, had lower levels of zooplankton during the ebb tides compared to flood tides, possibly indicating that zooplankton are being transported into the TB toward the DWSC. Detailed tide conditions for this sampling date can be seen in appendix Table A-3.

For the 11/22/11-11/23/11 study conducted at site CP over a full tidal cycle, there was no statistically significant difference between samples collected during flood, ebb or slack tides (pairwise t-test, alpha = 0.05). Unlike the data collected at CP and WS on 10/23/11, the mean concentrations of zooplankton in this study are almost the same during flood and ebb tide with flood tide concentrations of 4.5 ± 2.2 µg/L and ebb tide concentrations 4.4 ± 3.1 µg/L zooplankton. Detailed tide conditions for this sampling date can be seen in appendix Table A-4.

From these studies there does not appear to be a predictable association between zooplankton concentration and tidal conditions.

Lateral and Vertical Distribution of Zooplankton

On 8/27/11, 7/11/12, 8/19-20/12, and 11/26/12, six sites were sampled at mid-channel surface, mid-channel mid-depth, mid-channel bottom, north bank mid-depth, and south bank mid-depth to determine zooplankton variation within the channel at a given site and to determine if the mid-channel mid-depth samples are representative of zooplankton concentrations throughout the channel at a given site. On 8/27/11 these samples were taken at both flood and ebb tide. Table 5 and Figure 6 show results from these sampling dates.

Within-site variability is generally high and follows no consistent pattern (Figure 6). The coefficient of variation (CV) for each sample site was over 50% ranging from a minimum of 56% at site 406 to a maximum of 143% at site 127. Despite the high variability within sites, there is no statistically significant difference between the mid-depth mid-channel (Mm) samples and samples taken at any other location within the channel (pairwise t-test, alpha = 0.05). Another way to assess the accuracy of the Mm location compared to samples at other locations in the channel is to look at the relative error (%) which was calculated with the mean of five measurements per location:

$$\frac{|Mean - Mm|}{Mean} \; x \; 100.$$

The histogram shown in Figure 7 indicates that 84% of the time, the Mm sample with be within 50% of the site mean. Over all sampling dates during the spatial variability study, the mean zooplankton concentration ranged from 19 – 29 µg/L in upstream and DWSC sites, which is consistent with findings from the longitudinal study where an overall mean zooplankton concentration of 20 µg/L was observed. As with the longitudinal studies, the mean zooplankton concentration in the Turning Basin was generally higher than the DWSC or the upstream SJR with site TB having a mean of 102 µg/L zooplankton in this study, more than 3 times larger than the mean of any other site. The results of this study indicate that the mid-channel mid-depth sample is a reasonable location within the channel to represent a site's total zooplankton concentration.

Repeatability Study

This study was conducted to assess the variability in zooplankton biomass at three fixed locations and at mid-depth. For site TB, the range of 10 consecutive samples was 36.6 – 64.6 µg/L with a coefficient of variation (CV) of 17%. For site 406, the range was 56.3 – 145 with a CV of 28%. For site 402, the range was 15.4 – 113 with a CV of 54%. Depending on which fixed-point CV is used, approximately 20% - 80% of the spatial CVs exceeded the fixed-point CV, suggesting that part of the variation is spatially-influenced. The fixed-point CVs increased with longitudinal distance from site TB.

Observed variability complicates simple characterization of zooplankton population densities in this reach of the SJR; the influence of this variability on dissolved oxygen in the DWSC can now be accessed with modeling sensitivity analysis.

Exchange of zooplankton between the Turning Basin and the DWSC

The Turning Basin is a portion of the Port of Stockton which is approximately 100 m (340 ft) wide and dredged to a depth of 12m (40 ft). Entrance to the Turning Basin is from the DWSC, and the TB reach is approximately 150 m (500 ft) long, with shallow overflow areas toward the east end (Figure 2, Table A-1). The increased width and depth of the Turning Basin causes decreased flow velocities resulting in increased residence in which algae and zooplankton can proliferate. Past studies have shown that the Turning Basin serves as a breeding ground for algae and zooplankton and could represent a significant source of these organisms to the DWSC.

To better understand the abundance and distribution of zooplankton within the Turning Basin an in depth survey of the turning basin and nearby DWSC was conducted on 10/23/11. To investigate the exchange of zooplankton between the Turning Basin and the rest of the DWSC stationary sampling was conducted at site CP, the intersection between the DWSC, the SJR and the Turning Basin. CP sampling occurred between 11 pm 11/22/11 and 9 am 11/23/11 covering a full tidal cycle. In addition to zooplankton measurements taken during these studies, temperature and specific conductivity were taken at the surface, mid-depth and channel bottom at each site on 10/23/11 and vertical profiles of temperature, specific conductivity and chlorophyll fluorescence were taken on 11/22/11 and 11/23/11 to help determine the exchange of water between the SJR, the Turning Basin, and the DWSC.

Zooplankton distribution within the Turning Basin

Samples were taken throughout the Turning Basin and in nearby sites in the DWSC and SJR on 10/23/11. Three samples were taken at most sites sampled in this study over different tidal conditions. Over the three sample time periods on 10/23/11, and in differing tidal conditions, zooplankton concentrations in the TB were markedly higher than in the SJR and DWSC (Table 6, Figure 2 and 8). Zooplankton in the Turning Basin sites, including TBU, TB, and TBD, had significantly higher concentrations than zooplankton in the DWSC or the upstream SJR (paired t-test, alpha = 0.05). Site WS between the Turning Basin and confluence of the SJR and the DWSC was statistically similar to both the Turning Basin sites and the rest of the DWSC and SJR sites (paired t-test, alpha = 0.05).

Exchange of zooplankton between the Turning Basin, the DWSC and the SJR

On 11/22/11 and 11/23/11, zooplankton samples were taken at the surface, mid-depth and the channel bottom of site CP, the confluence between the upstream SJR, the DWSC and the Turning Basin. Samples were collected every hour between 11 pm 11/22/11 and 9 am 11/23/11 covering a full tidal cycle (Table 7, Figures 9 & 10). At the CP site, zooplankton biomass varies spatially and temporally, but the variations do not appear to be related to depth or tidal cycle (Table 7, Figure 9 & 10). Similar to the lateral and vertical distribution study, no statistically significant difference was found between samples collected at different depths (matched pairs t-test, alpha = 0.05). The single largest biomass value was seen in the 2:00 am bottom collection under a flood tide condition; mid-depth samples also showed high levels of zooplankton at this time. This pattern possibly indicates movement of zooplankton into the TB from the SJR/DWSC along the bottom and at mid-depths. During this sample period, overall levels of zooplankton at the CP site were low with a mean concentration of 3.8 µg/L zooplankton in this study compared to 14.6 µg/L observed at this site during the longitudinal studies, possibly the result of the time of year.

Exchange of water between the Turning Basin, the DWSC and the SJR

Water quality profiles collected on Oct 23, 2011 during the in-depth investigation of the Turning Basin and nearby sites, suggest that cold waters from the SJR enter the Turning Basin during flood tides along the channel bottom, and exits on the surface during ebb tides as shown in Figures 11 and 12. Inspection of the surface and bottom temperatures in Figure 11 for the high-high tide monitoring (end of a flood tide flowing up into TB) shows colder SJR and DWSC water entering the Turning Basin channel at the bottom, but not at the surface. Conversely, the surface temperature measurements near the end of an ebb flow period (low-low tide) remained elevated at the entrance to the TB, but not at mid-depth or along the channel bottom. This pattern is also visible in the conductivity plotted in Figure 12. This circulation of cool water entering the TB along the channel bottom during flood tides and the corresponding outflow of warm surface water during ebb tides may be an important advective mass transfer mechanism for the TB and the SJR. Nutrients from the SJR are conveyed into the TB, where algae and zooplankton flourish, and twice a day during flood tides, while ebb tides twice a day may be flushing high concentrations of algae and zooplankton from the surface waters back to the DWSC. This “convection” current may also help to explain the low chl concentration observed at the bottom of the Turning Basin on August 27 if low chl waters from the DWSC enter the TB along the channel bottom.

Water temperature vertical profiles from 11/22/11 and 11/23/11 at site CP, the entrance to the TB, are presented in Figures 13 and 14. The flood tide measurements show the coldest water from the SJR entering at the bottom. Surface waters also exhibited cooling which may be associated with more vertical mixing, since the profile in not well stratified at this time (November). The ebb tide temperature measurements show less temperature variation, which is probably due to enhanced vertical mixing allowed by weak stratification and the relatively weak ebb tide during this period. Inspection of the associated conductivity profiles for this period exhibit a similar response (Figures 15 and 16). During the flood tide excursion, lower conductivity water of the SJR entered at the bottom while higher conductivity water in the Turning Basin exited at the surface. During the ebb tide flows out of the Turning Basin, conductivity differences were relatively small and do not show clear water movement pathways, again due to the weak temperature stratification yielding a relatively well mixed water quality profile. This vertical mixing may also be responsible for the erratic distribution of zooplankton measured during this time. These conclusions are based on relatively few observations and warrant further investigation.

Conclusions

Comparison of physical features with zooplankton biomass concentrations was investigated using total zooplankton concentrations observed from 2009-2012 in the DWSC, SJR upstream of the DWSC, and surrounding tributaries. Maximum zooplankton concentrations were found at sites with physical characteristics that could potentially increase habitat or produce conditions that were conducive to zooplankton growth. While the biomass concentrations are highly variable, mean concentrations at each site are similar to the overall average of 20 µg/L total zooplankton biomass, with the exception of the Turning Basin.

During this study, the Turning Basin typically has higher levels of both algae and zooplankton than the adjacent DWSC and SJR near the Port of Stockton. These observations are also consistent with results of the spatial distribution study especially during low-flow summer months. Whether the Turning Basin contributes a significant load of algae and zooplankton to the DWSC remains unresolved. Focused investigation of circulation between the Turning Basin and the DWSC is needed. Other dead-end tributaries may also warrant further investigation to assess their load contributions to the DWSC.

As observed with other studies, zooplankton variability at a given location was significant in the SJR. However, the spatial monitoring showed that the mid-depth, mid-channel sample could fairly represent zooplankton populations at a given longitudinal river location. No significant difference was found between the Mm sample and any other samples within the channel. Approximately 84% of the time, the Mm sample was within 50% of the location mean, with some inherent non-spatial variability as shown with the repeatability trial. These observations suggest that data generated in the longitudinal zooplankton sampling may be used with reasonable confidence during zooplankton model calibration and verification tasks.

References

APHA (2005). Standard Methods for the Examination of Water and Wastewater, 20th Edition. Washington, D.C., American Public Health Association.

Balcer, M. D., N. L. Korda, and S. I. Dodson. (1984). "Zooplankton of the Great Lakes: a guide to the identification and ecology of the common crustacean species." University of Wisconsin Press, Madison.

Basu, B. K., J. Kalff, et al. (2000). "The influence of macrophyte beds on plankton communities and their export from fluvial lakes in the St Lawrence River." Freshwater Biology 45(4): 373-382.

Brunell, M., S. Borglin, et al. (2006). Interim Task Report #1, Task 9: Grazing Study.

Chengalath, R., C. H. Fernando, and M. G. George. (1971). "Planktonic Rotifera of Ontario." University of Waterloo Biology Series Number Two.

Environmental Protection Agency (2006). Application of Elements of a State Water Monitoring and Assessment Program For Wetlands, Wetlands Division Office of Wetlands, Oceans and Watersheds.

Gagnon, M. and G. Lacroix (1981). "Zooplankton sample variability in a tidal estuary: An interpretative model." Limnology and Oceanography 26(3): 401-413.

Google, I. (2013). Google Earth.

Lair, N. (2005). Abiotic vs. biotic factors: lessons drawn from rotiers in the Middle Loire, a meandering river monitored from 1995 to 2002, during low flow periods. Rotifer X: Rotifer Research: Trends, New Tools, and Recent Advances. A. Herzig, R. D. Gulati, C. D. Jersabek and L. May, Springer.

Litton, G. M., M. Brunell, et al. (2007). San Joaquin River Up-Stream DO TMDL Project (ERP-02D-P63) Task 8: Linking the San Joaquin River to the Stockton Deep Water Ship Channel Interim Task Report #3. Stockton, CA, Civil Engineering Department, University of the Pacific.

NOAA (2006). NOAA Chart 18663.

Pennak, R. W. (1989). "Fresh-water invertebrates of the United States: Protozoa to Mollusca." John Wiley and Sons, Inc.(3rd Ed).

Pontin, R. M. (1978). "A key to the freshwater planktonic and semiplanktonic rotifera of the British Isles." Freshwater Biological Association Sci. Pub. No. 38.

Sameoto, D. D. (1975). "Tidal and diurnal effects on zooplankton sample variability in a nearshore marine environment." J. Fish. Res.Bd. Can 32: 347-366.

Stringfellow, W., S. Borglin, et al. (2008). "Scientific studies supporting the development of a dissolved oxygen TMDL." Water Practice 2(1): 1-10.

Vadstein, O., L. M. Olsen, et al. (2012). "Prey–predator dynamics in rotifers: density-dependent consequences of spatial heterogeneity due to surface attachment." Ecology 93(8): 1795-1801.

Wallace, R. L., and T. W. Snell. (1991). " Rotifera." Academic Press, Inc. (In: Thorp, J. H., and A. P. Covich (Eds), Ecology and Classification of North American Freshwater Invertebrates): 187 – 248.

Yellow Springs Instrument Co. Inc. (2002). YSI 6-Series Environmental Monitoring Systems Manual. Revision B. Yellow Springs, OH, Yellow Springs Instruments Co., Inc.

Figure 1. Summary of zooplankton concentrations (µg/L) for each site and region of the study area. Includes data from 2009, 2011, and 2012.

	Site Type	Site	n	Min	Max	Mean	Median	CV	(max-min)
East	Upstream SJR	SJR Burns	3	1	13	5	1	138	12.5
↓	Upstream SJR	SJR Navy	1	3	3	3	3		0.0
↓	Upstream SJR	1	3	9	24	14	9	63	15.7
↓	Upstream SJR	127	20	0	105	16	3	161	105.2
	Upstream SJR	11	17	0	17	5	4	106	17.1
West	Upstream SJR	2	20	0	13	3	1	141	13.5
	Upstream SJR	4	18	0	26	4	2	166	25.9
East	Turning Basin	CP	14	2	14	5	4	71	11.8
	Turning Basin	WS	2	13	30	21	21	54	16.5
↓	Turning Basin	TBD	3	34	77	49	36	49	42.7
↓	Turning Basin	TB	7	7	257	83	42	113	250.5
↓	Turning Basin	TBU	3	23	38	31	32	24	15.1
	Turning Basin	409	3	19	41	32	37	36	21.9
West	Turning Basin	426	21	1	285	37	6	217	284.3
	Turning Basin	414	1	7	7	7	7		0.0
	Tributaries	401	3	4	8	7	8	32	3.7
East	Tributaries	423	1	3	3	3	3		0.0
	Tributaries	433	18	3	69	19	15	88	65.8
↓	Tributaries	424	18	2	57	16	9	102	55.3
↓	Tributaries	410	23	2	48	11	9	95	46.5
	Tributaries	420	22	0	36	5	2	146	35.9
↓	Tributaries	421	18	2	372	61	12	181	370.1
	Tributaries	412	1	55	55	55	55		0.0
West	Tributaries	411	1	6	6	6	6		0.0
	Tributaries	405	26	0	149	23	8	157	148.7
	Tributaries	413	21	0	836	58	5	322	835.4
	DWSC	430	1	8	8	8	8		0.0
East	DWSC	402	25	0	103	17	9	131	103.0
	DWSC	425	18	1	26	8	7	73	24.8
↓	DWSC	404	3	3	5	4	4	27	2.0
	DWSC	428	24	1	100	22	14	103	98.1
↓	DWSC	403	3	8	20	12	8	56	11.6
↓	DWSC	406	25	2	80	17	10	102	77.8
	DWSC	407	3	2	14	9	11	72	12.6
West	DWSC	427	23	0	159	21	13	156	158.2
	DWSC	408	3	2	15	7	5	94	12.9
	DWSC	LT 48	3	4	9	6	4	45	4.4

Figure 2. Summary of zooplankton concentrations (µg/L) for each region of the study area. Includes data from 2009, 2011, and 2012. Includes both longitudinal data and special study data. For special study data where more than one sample was collected at a site, the mean value was used for the concentration at that time/site.

Site Type	n	Min	Max	Mean	Median	CV	Range (max-min)
Upstream SJR	82	0	105	7	2	198	105
Turning Basin	38	1	285	45	21	164	284
Tributaries	152	0	836	26	8	312	835
DWSC	147	0	159	15	8	134	158

Figure 3. Summary of zooplankton concentrations (µg/L) for each region of the study area during flood or ebb tides. Includes both longitudinal data and special study data. For special study data where more than one sample was collected at a site, the mean value was used for the concentration at that time/site.

Site Type	Tide Cycle	n	Min	Max	Mean	Median	CV	Range (max-min)
Upstream SJR	Flood	37	0	105	9	3	209	105
	Ebb	44	0	40	6	1	164	40
Turning Basin	Flood	15	1	257	34	6	196	256
	Ebb	23	3	285	52	24	150	282
Tributaries	Flood	32	0	93	15	8	130	93
	Ebb	118	0	836	30	8	311	835
DWSC	Flood	47	0	103	14	7	124	103
	Ebb	99	0	159	16	8	138	158
Overall	Flood	132	0	257	15	6	190	257
	Ebb	284	0	836	23	8	286	836

Table 4. Total zooplankton biomass (µg/L) for August 27, 2011. Sample were collected at mid-channel surface (mid-surface), mid-channel mid-depth (mid-mid), mid-channel bottom (mid-bottom), north bank mid-depth (North-mid), and south bank mid-depth (South-mid). Site 402: River mile (RM) 30.2; Site 428: RM 33.3; Site 406: RM35.6; Site 427: RM 39.0; Site 127: RM 47.7 (Brandt Bridge); TB: Turning Basin, RM 39.70.

Site	Mid-surface	Mid-mid	Mid-bottom	North-mid	South-mid	Flow (approx) cfs
High Tide Sampling						
402	11.5	12.7	23.8	15.2	17.6	1000
428	41.6	23.8	13.6	57.0	27.2	1500
406	18.1	9.6	15.0	20.0	23.8	2000
427	13.6	5.5	17.6	5.6	11.5	2000
127	4.3	3.7	5.5	0.8	1.5	6000
TB	19.8	34.1	57.1	57.7	42.2	2250
LowTide Sampling						
402	18.0	16.8	15.7	12.9	13.1	5000
428	16.6	12.5	21.7	10.8	32.1	5000
406	10.3	6.6	8.2	11.9	10.2	4800
427	5.0	6.0	5.9	6.0	5.0	4500
127	4.5	1.5	3.0	1.4	1.5	5000
TB	17.1	54.2	22.1	29.4	42.9	4000
Difference (Low-High)						
402	6.5	4.1	-8.1	-2.3	-4.5	
428	-25.1	-11.3	8.1	-46.2	4.9	
406	-7.8	-3.0	-6.8	-8.1	-13.6	
427	-8.6	0.5	-11.7	0.4	-6.5	
127	0.3	-2.2	-2.5	0.6	0.0	
TB	-2.7	20.1	-35.0	-28.3	0.7	

	Low Tide Mean	High Tide Mean	Difference (Low- High)	Overall Mean
402	15.3 ± 2.3	16.2 ± 4.9	-0.9	15.7 ± 3.6
428	18.7 ± 8.6	32.7 ± 16.9	-13.9	25.7 ± 14.6
406	9.4 ± 2.1	17.3 ± 5.3	-7.9	13.4 ± 5.6
427	5.6 ± 1.4	10.8 ± 5.2	-5.2	8.2 ± 4.4
127	2.4 ± 1.4	3.2 ± 2.0	-0.8	2.8 ± 1.6
TB	33.1 ± 15.3	42.2 ± 16.1	-9.0	37.7 ± 15.5

Table 5. Total zooplankton biomass (µg/L) for 2012 spatial distribution study. Sample were collected at mid-channel surface (mid-surface), mid-channel mid-depth (mid-mid), mid-channel bottom (mid-bottom), north bank mid-depth (North-mid), and south bank mid-depth (South-mid). Site 402: River mile (RM) 30.2; Site 428: RM 33.3; Site 406: RM35.6; Site 427: RM 39.0; Site 127: RM 47.7 (Brandt Bridge); TB: Turning Basin, RM 39.70.

	Site	Mid-surface	Mid-mid	Mid-bottom	North-mid	South-mid	Tidal Condition
August 27, 2011							
	402	11.5	12.7	23.8	15.2	17.6	High Tide
	428	41.6	23.8	13.6	57.0	27.2	High Tide
	406	18.1	9.6	15.0	20.0	23.8	High Tide
	427	13.6	5.5	17.6	5.6	11.5	High Tide
	127	4.3	3.7	5.5	0.8	1.5	High Tide
	TB	19.8	34.1	57.1	57.7	42.2	High Tide
August 27, 2011							
	402	18.0	16.8	15.7	12.9	13.1	Low Tide
	428	16.6	12.5	21.7	10.8	32.1	Low Tide
	406	10.3	6.6	8.2	11.9	10.2	Low Tide
	427	5.0	6.0	5.9	6.0	5.0	Low Tide
	127	4.5	1.5	3.0	1.4	1.5	Low Tide
	TB	17.1	54.2	22.1	29.4	42.9	Low Tide
July 11, 2012							
	402	11.7	106.0	22.6	43.8	54.5	Ebb near low tide
	428	3.0	11.7	21.8	11.1	22.7	Low slack tide
	406	15.2	33.1	45.8	17.9	24.3	Flood just after low tide
	427	19.8	44.6	23.5	40.4	46.3	Flood tide
	127	110.1	123.3	112.4	96.4	83.6	Flood tide
	TB	124.3	398.6	163.8	319.5	279.0	Flood tide
August 19-20, 2012							
	402	33.0	32.2	19.7	50.2	18.0	Slack high tide
	428	12.2	45.5	43.8	66.9	21.0	Ebb tide just after high tide
	406	34.4	33.8	32.9	26.0	28.4	Ebb tide
	427	76.6	46.2	21.6	51.6	36.1	Ebb tide
	127	28.4	46.4	27.6	18.9	50.0	Ebb tide
	TB	107.1	204.0	219.2	171.1	149.8	Ebb tide just before low tide
November 26, 2012							
	402	1.4	3.9	5.6	10.2	0.0	Flood before high tide
	428	16.6	12.3	2.4	21.3	6.5	Slack high tide
	406	31.9	7.6	11.7	6.9	10.0	Slack high tide
	427	4.8	14.3	44.8	5.6	19.9	Ebb tide just after high tide
	127	0.0	0.2	0.0	0.0	3.7	Slack high tide
	TB	7.0	10.5	2.7	6.7	5.9	Ebb tide

Averages		***August 27, 2011***	***July 11, 2012***	***Nov 26, 2012***	***Aug 19-20, 2012***		***Overall***
	402	15.7 ± 3.3	47.7 ± 36.7	4.2 ± 4.0	30.6 ± 12.9		22.8 ± 21.4
	428	25.7 ± 13.6	14.1 ± 8.2	11.8 ± 7.6	37.9 ± 21.7		23.0 ± 15.6
	406	13.4 ± 5.4	27.2 ± 12.5	13.6 ± 10.4	31.1 ± 3.7		19.7 ± 10.6
	427	8.2 ± 4.2	34.9 ± 12.4	17.9 ± 16.3	46.4 ± 20.4		23.1 ± 19.0
	127	2.7 ± 1.5	105.2 ± 15.4	0.8 ± 1.6	34.3 ± 13.3		29.1 ± 41.4
	TB	37.7 ± 14.2	257 ± 112.6	6.6 ± 2.8	170.2 ± 44.6		101.8 ± 107.9

Table 6. Total zooplankton biomass (µg/L) for October 23, 2011.

Sample Location	North (latitude)	West (longitude)	3:35-5:45	8:20-10:50	11:10-14:55	Mean	s.d.
LT 48	37.95226	-121.33845	8.5	4.1	4.2	5.6	2.5
CP	37.95207	-121.32770	6.1	12.9	13.7	10.9	4.2
WS	37.95207	-121.32770		13.2	29.7	21.5	11.7
TBD	37.95251	-121.32122	36.3	34.0	76.7	49.0	24.0
TB	37.95255	-121.31751		26.3	43.4	34.9	12.1
TBU	37.95319	-121.31183	31.9	38.4	23.3	31.2	7.6
SJR_Navy	37.94644	-121.34018			2.9	2.9	
SJR_Burns	37.94283	-121.34487	0.8	1.3	13.3	5.1	7.1
		Mean	16.7	18.6	25.9		
		s.d.	16.2	14.5	24.5		

*SJR Burns: San Joaquin River at Burns Cut entrance; SJR Navy: San Joaquin River at Navy Bridge; L**T** 48: Navigation light 48 (in DWSC outside entrance to TBT); CP: Channel Point Sta. (at entrance to TBT); WS: Wine Slip Sta. (in TBT adjacent to the Wine Slip); TBD: Turning Basin Downstream (immediately downstream of the Turning Basin); TB: Turning Basin middle; TBU: Turning Basin Upstream (immediately upstream of the Turning Basin).

Table 7. Total zooplankton biomass (µg/L) for samples collected at the entrance to the Turning Basin Tributary (Station CP) on 22/November 23, 2011. Mid-depth samples taken at 20 feet.

Time	Surface	Mid-depth	Bottom	Mean	s.d.
23:00	1.7	3.0	1.1	1.9	**0.9**
0:00	3.6	6.4	4.3	4.7	**1.1**
1:00	4.1	2.0	1.3	2.5	**0.6**
2:00	2.5	8.3	10.9	7.2	**1.9**
3:00	1.9	7.9	2.0	3.9	**3.0**
4:00	1.1	2.3	3.2	2.2	**0.6**
5:00	8.2	5.4	5.8	6.5	**0.5**
6:00	2.7	2.3	5.4	3.5	**1.6**
7:00	1.4	2.9	5.5	3.3	**1.5**
8:00	4.5	7.0	1.6	4.4	**2.7**
9:00	1.5	3.1	1.3	2.0	**0.9**
Mean	**3.0**	**4.6**	**3.8**		
s.d.	**2.0**	**2.3**	**2.8**		

Figure 1. Zooplankton monitoring study area.

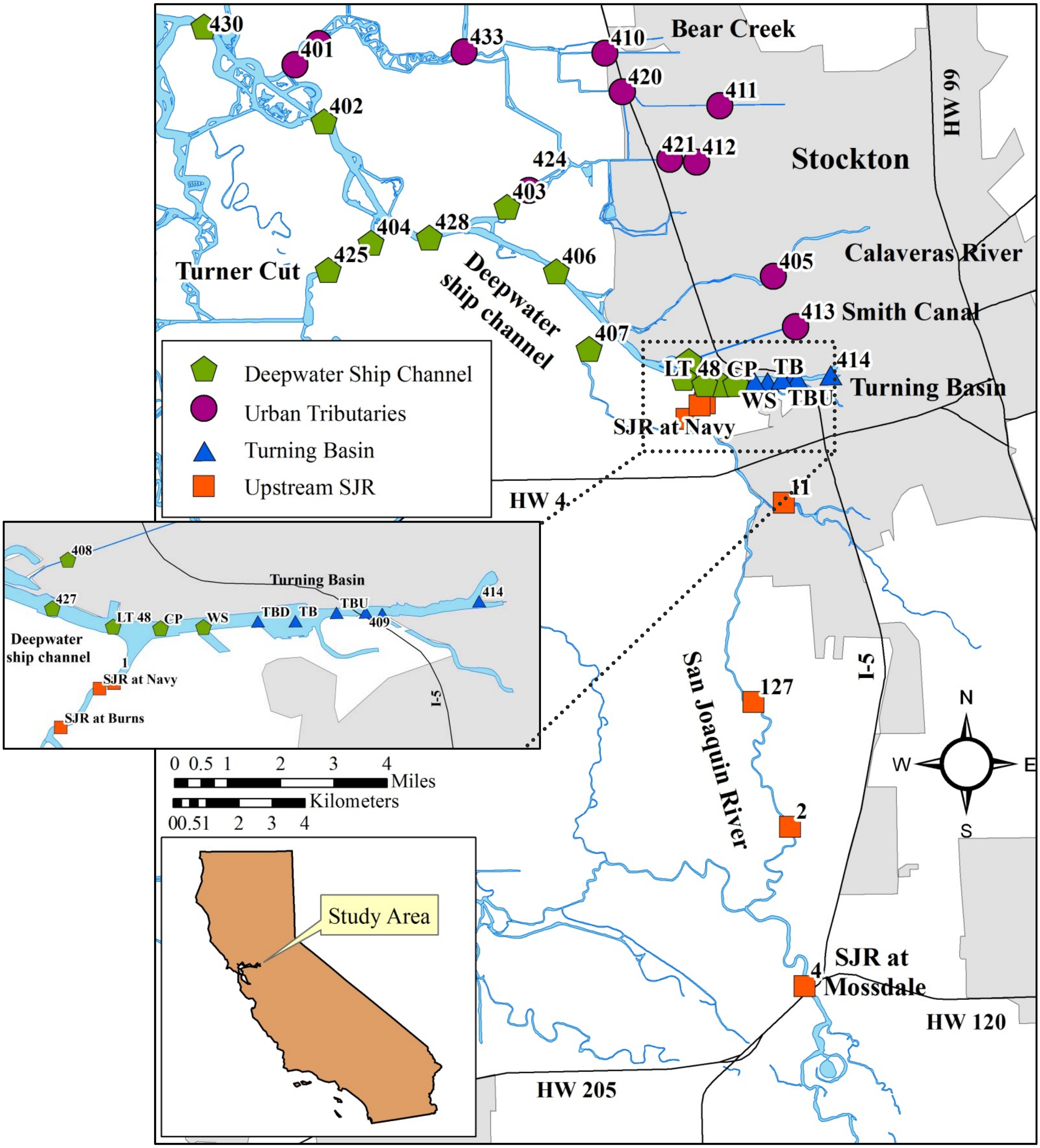


Figure 2. Details of the Turning Basin study area. Insets show the typical zooplankton and phytoplankton pigment concentrations on Oct 23, 2011. The highest zooplankton concentrations measured at each location on this date are shown in parentheses.

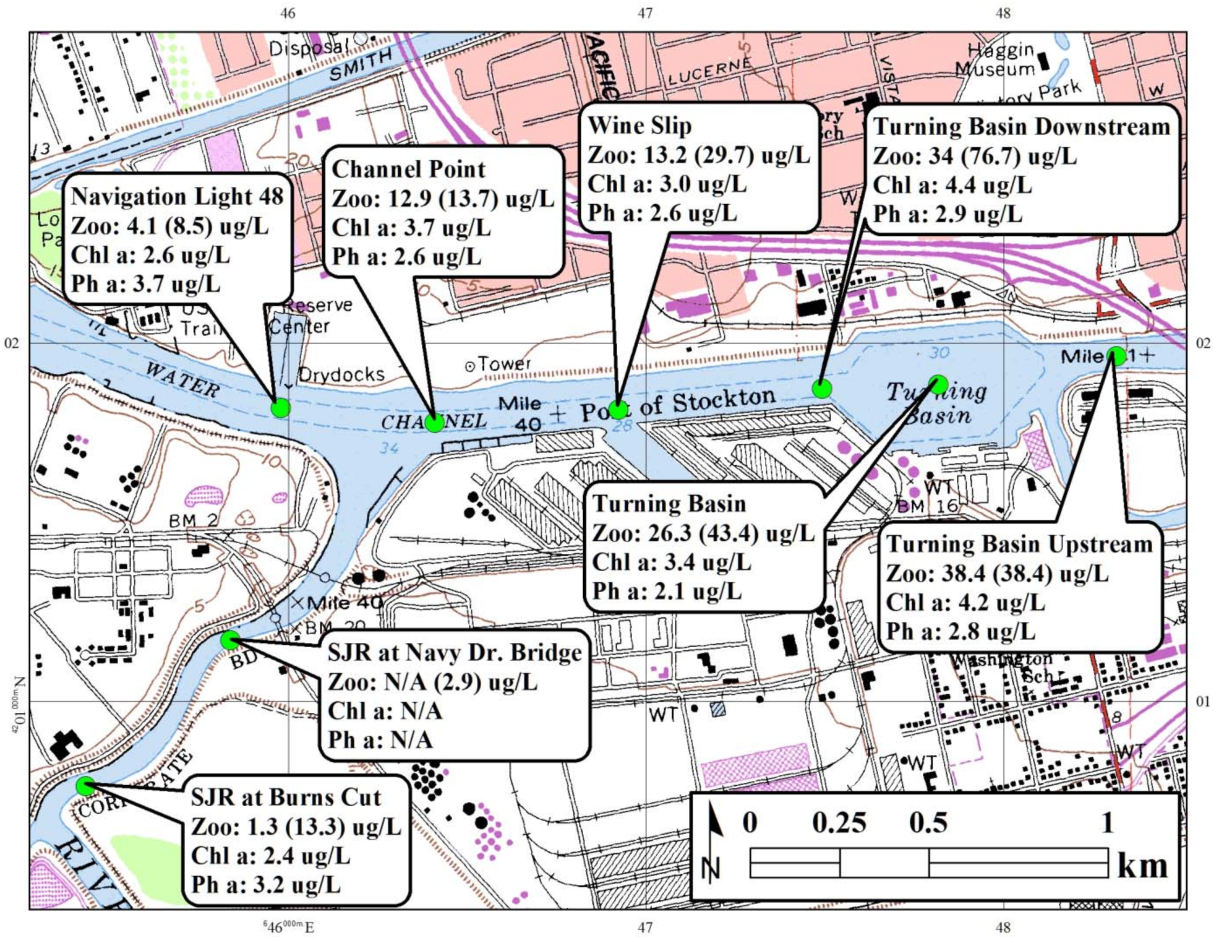


Figure 3: Net San Joaquin River Flows (cfs) during 2011 and 2012 reported for SJR at Brandt Bridge Station (site 127, BDT), 7 miles upstream of the Stockton DWSC

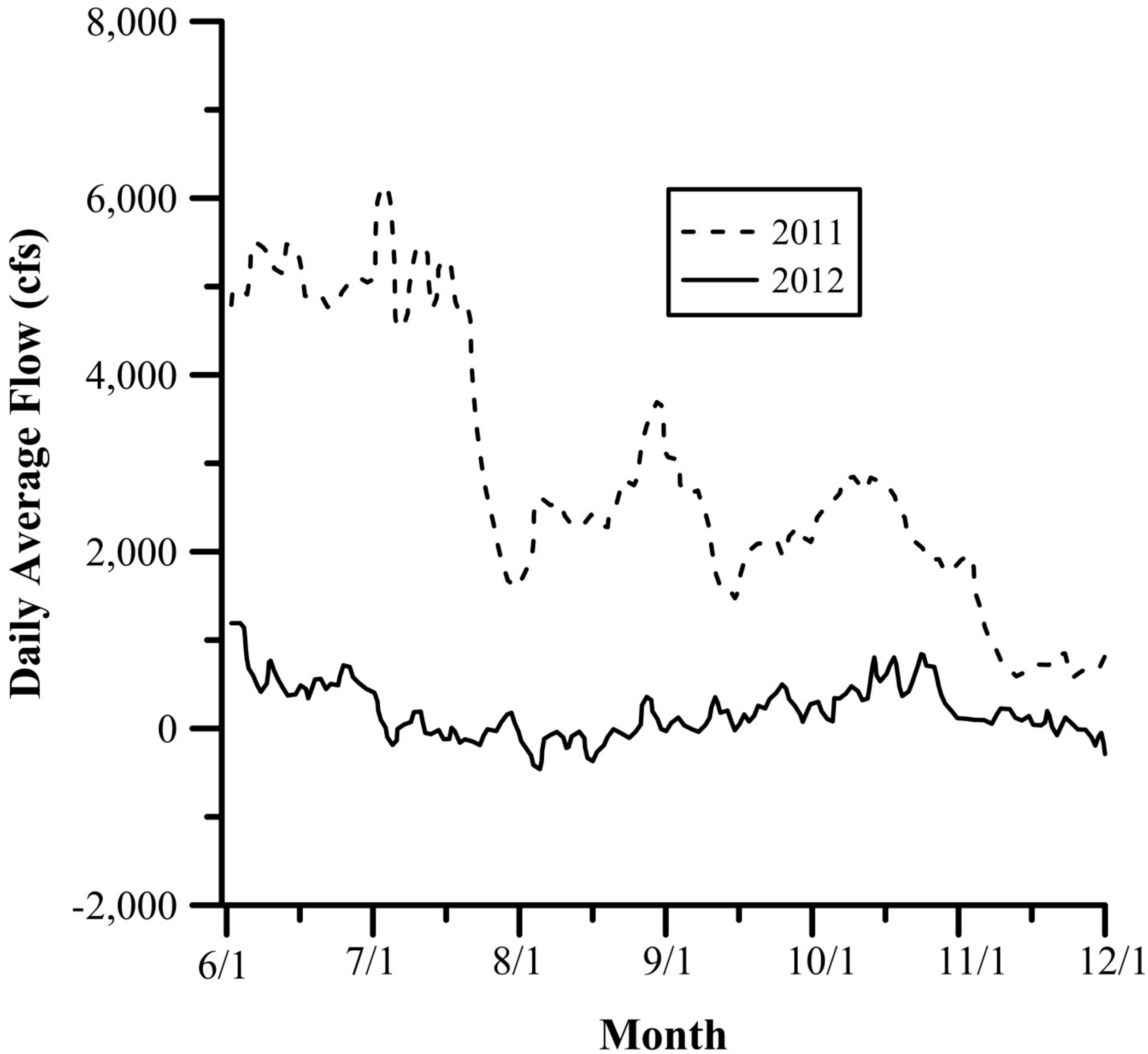


Figure 4. Zooplankton concentrations throughout the region. Size of symbol represents average zooplankton mass measured during 2009-2012.

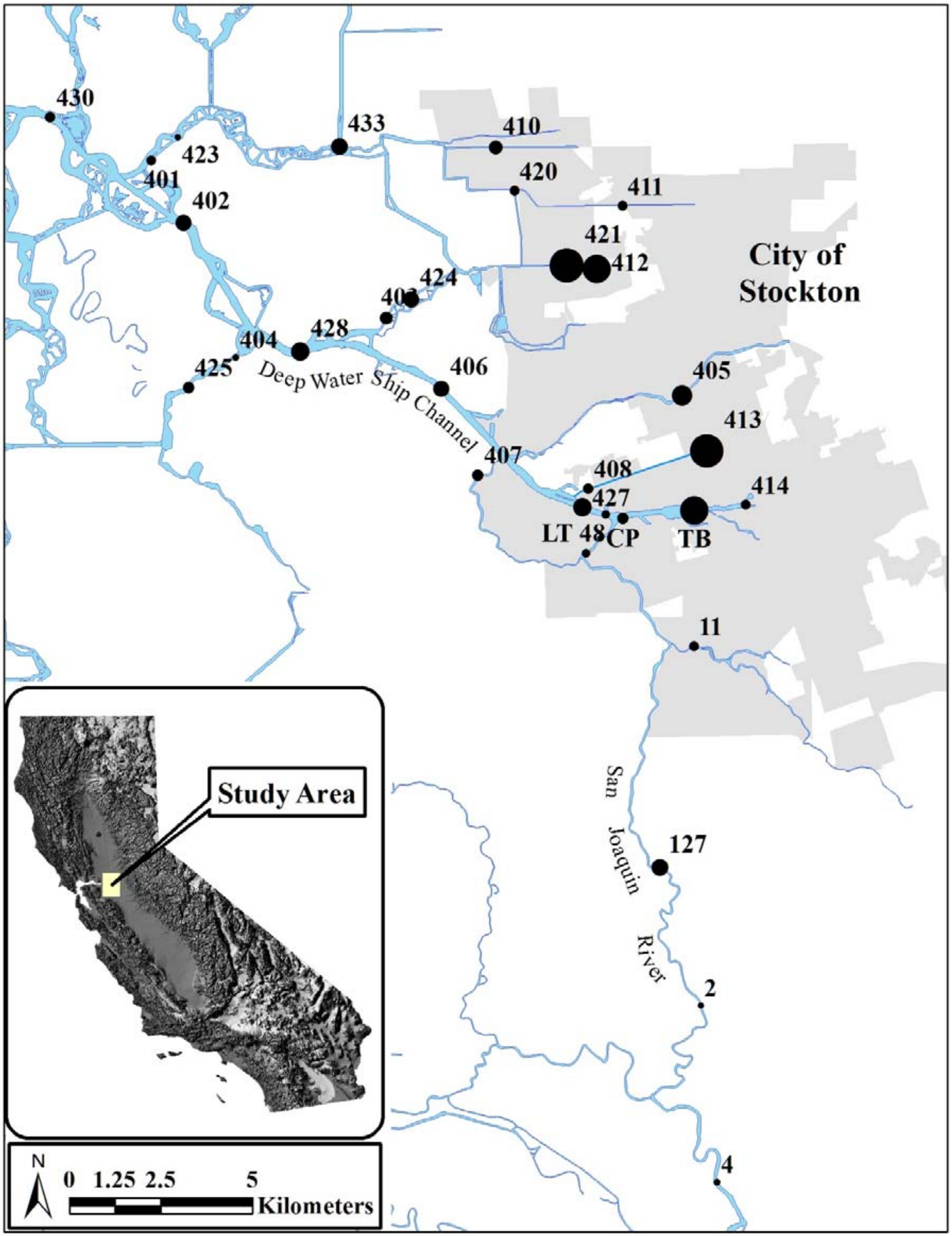


Figure 5. Range of Zooplankton biomass at all the tributary, upstream SJR, and DWSC locations in the study region from 2009-2012. Note that site 413, Smith Canal at Yosemite Lake, had the highest zooplankton biomass concentration of 836 µg/L on 4/26/12, but this point is not shown to better scale the data.

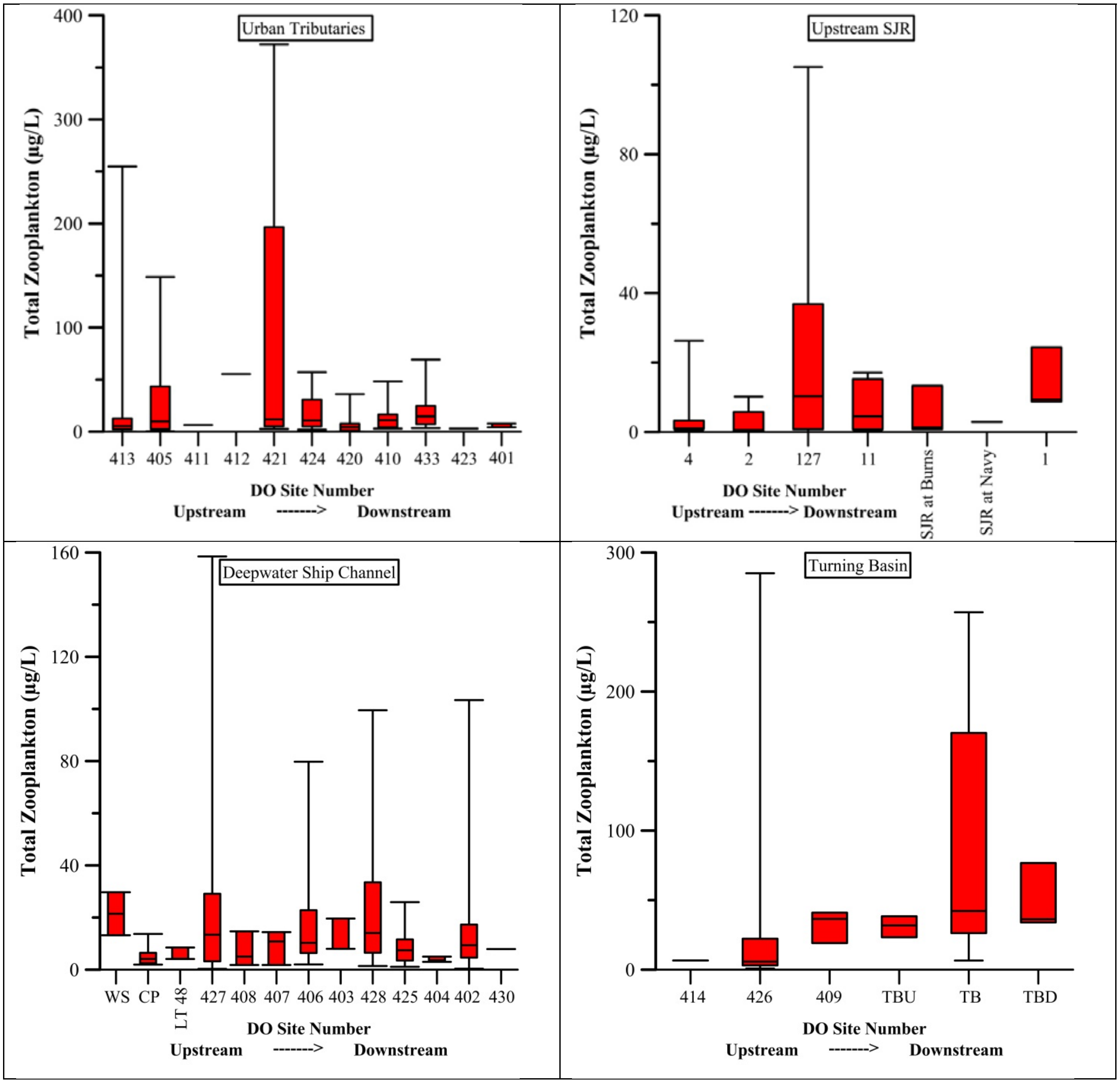


Figure 6. Spatial distribution analysis of 2011 and 2012 zooplankton data. Circle area is proportional to total zooplankton biomass. Circles represent mid-channel surface, mid-depth, and bottom samples and S (right) and N (left) lateral samples

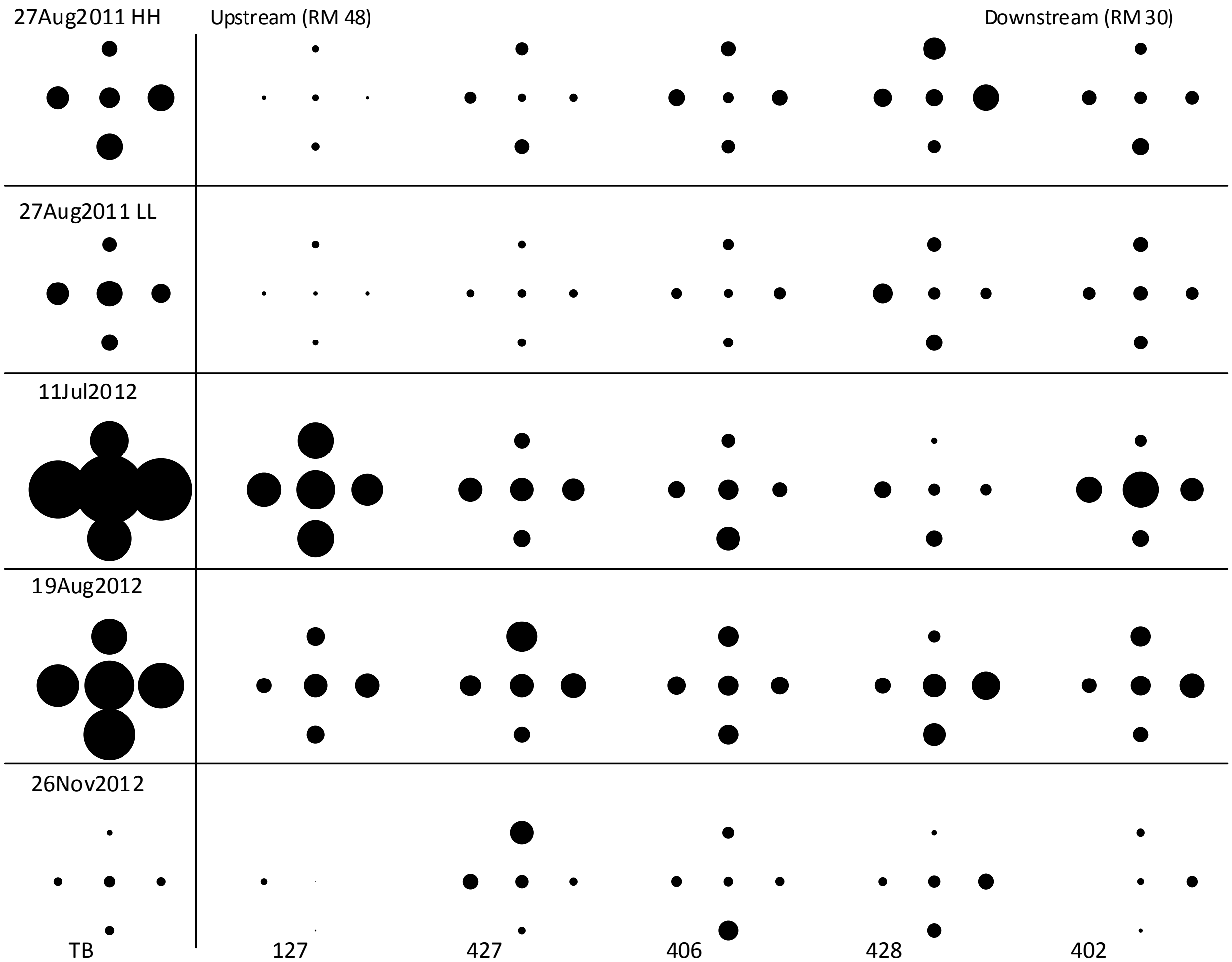


Figure 7: Histogram of relative error values for spatial monitoring of 2011 and 2012.

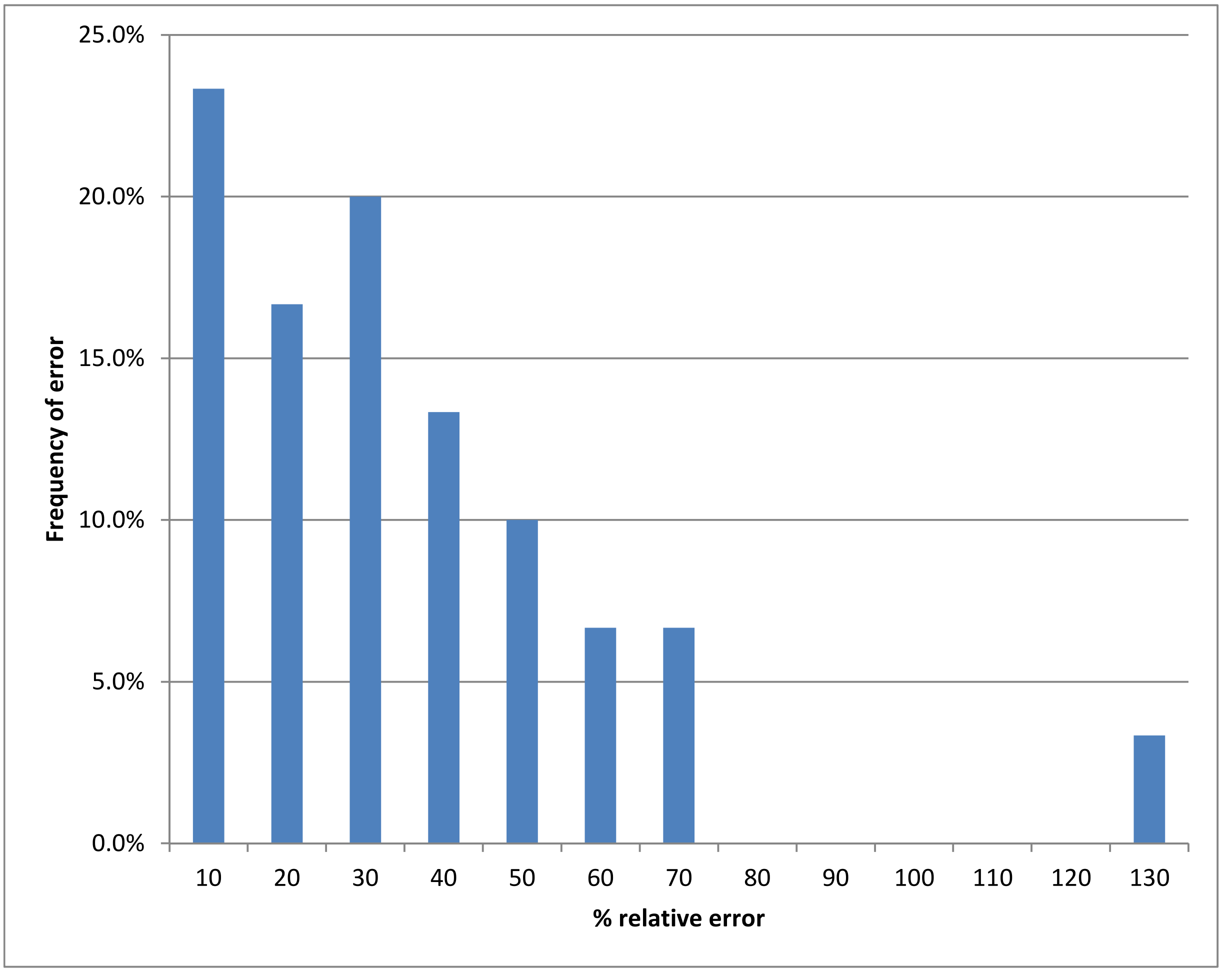


Figure 8. Longitudinal distribution of total zooplankton biomass on October 23, 2012; circle diameter is proportional to biomass. Lt48: Navigation light 48 (in DWSC outside entrance to TBT); CP: Channel Point Sta. (at entrance to TBT); TBD: Turning Basin Downstream (immediately downstream of the Turning Basin); TBU: Turning Basin Upstream (immediately upstream of the Turning Basin). (a) High High tide; 03:35 – 05:45 (b) Near Low Low tide; 09:00 – 11:10 (c) Flood tide near high slack tide; 13:05 – 14:55

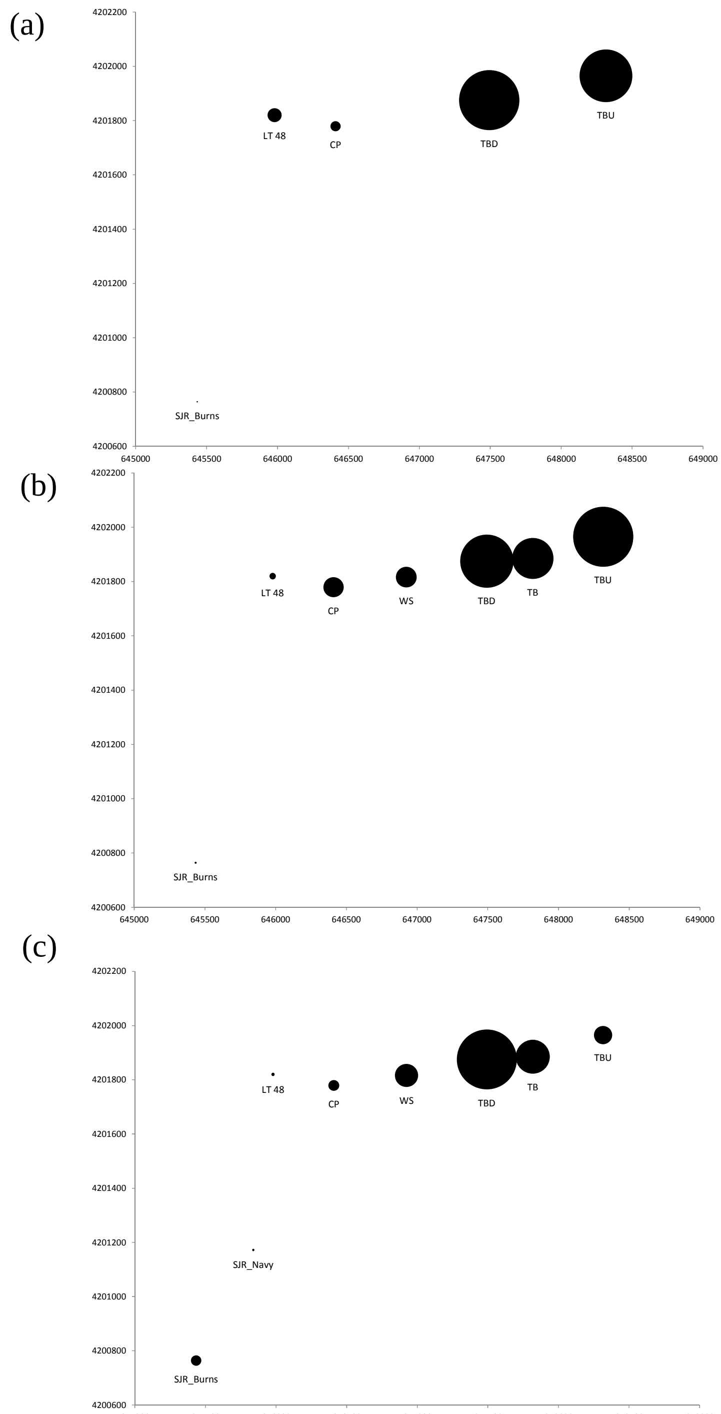


Figure 9. Zooplankton total biomass at Channel Point, based on samples from three depths, sampled over 11 time periods, November 22 & 23, 2011.

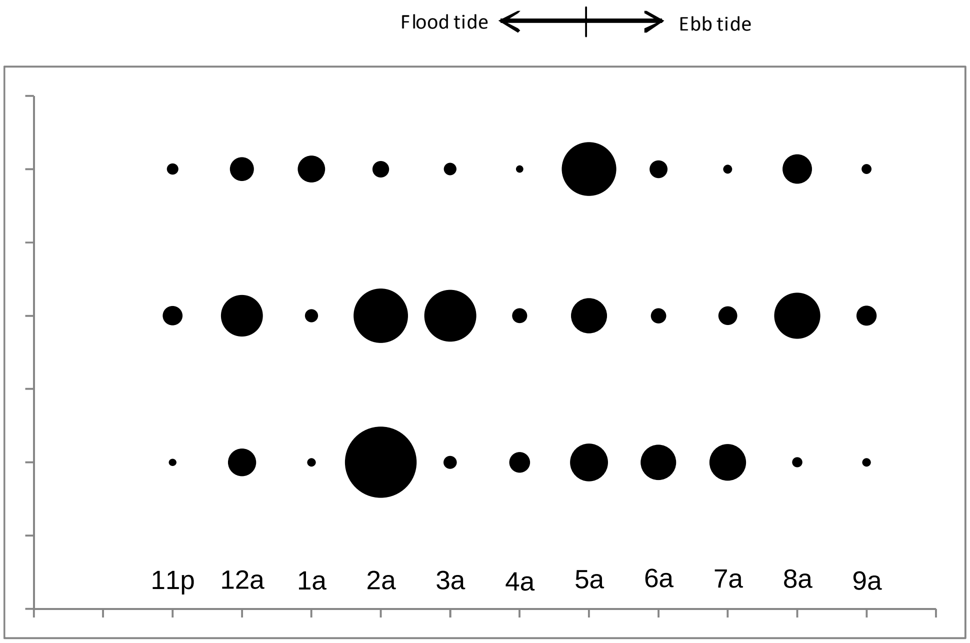


Figure 10. Mean zooplankton total biomass based on samples from three depths, sampled over 11 time periods, November 22 & 23, 2011.

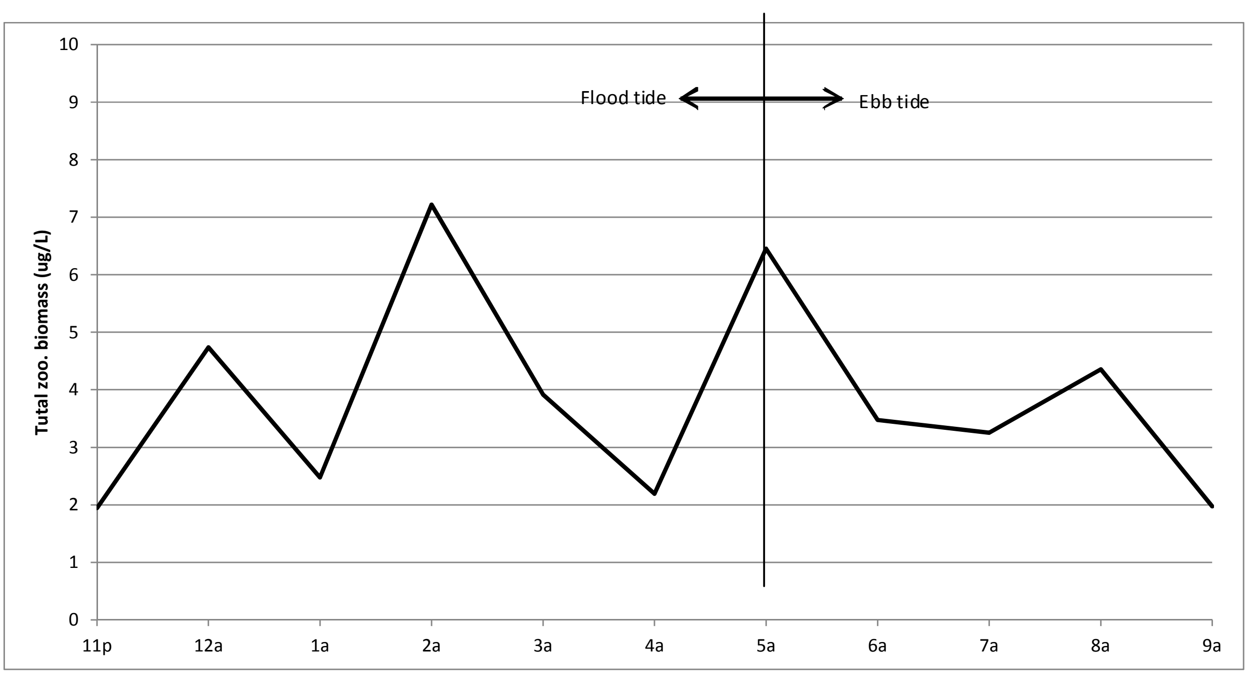


Figure 11. Longitudinal water temperatures at mid-depth and mid-channel compiled from vertical profiles measured on October 23, 2011.

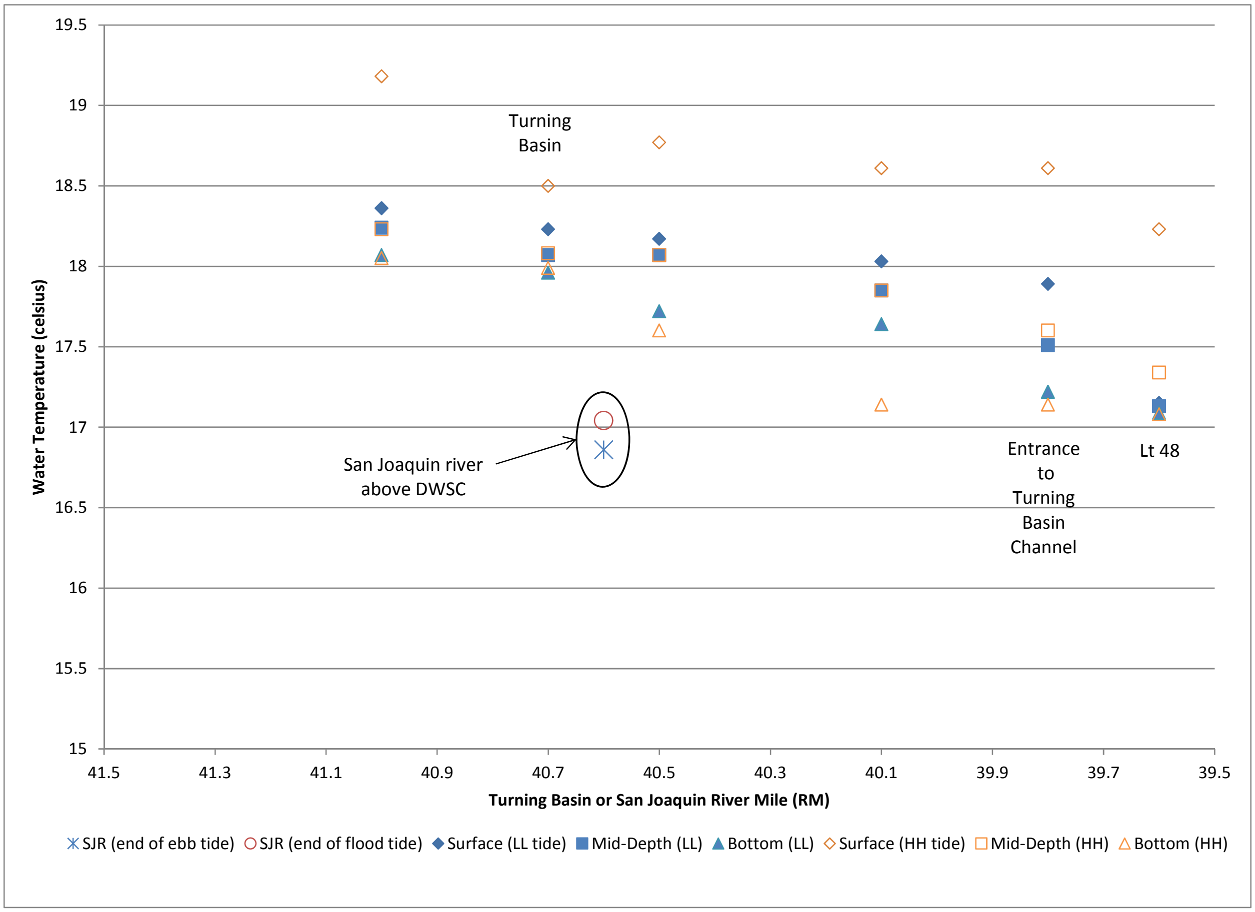


Figure 12. Longitudinal conductivity levels at mid-depth and mid-channel compiled from vertical profiles measured on October 23, 2011.

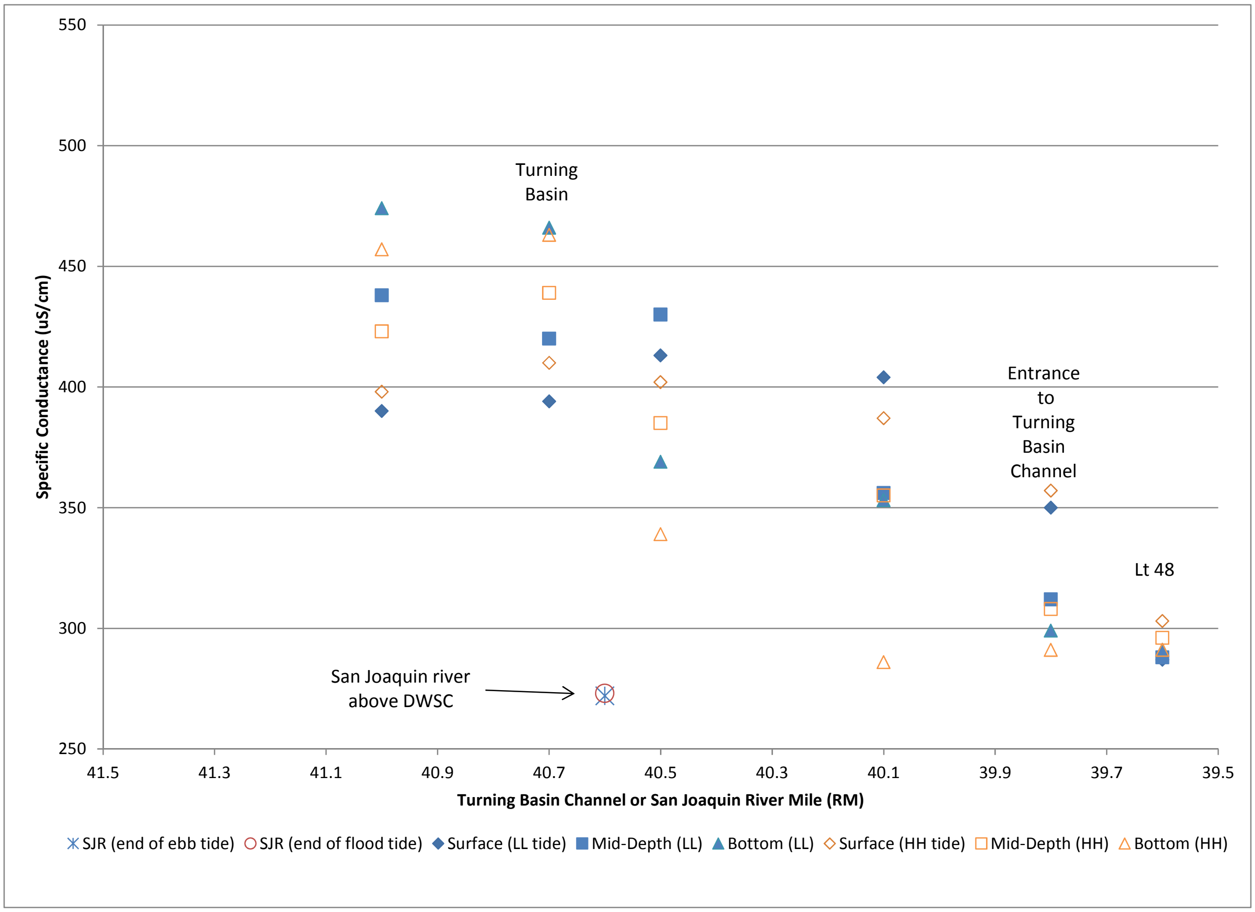


Figure 13. Vertical temperature profiles measured during a flood tide on November 22-23, 2011 at the entrance to the Turning Basin Tributary (Channel Point).

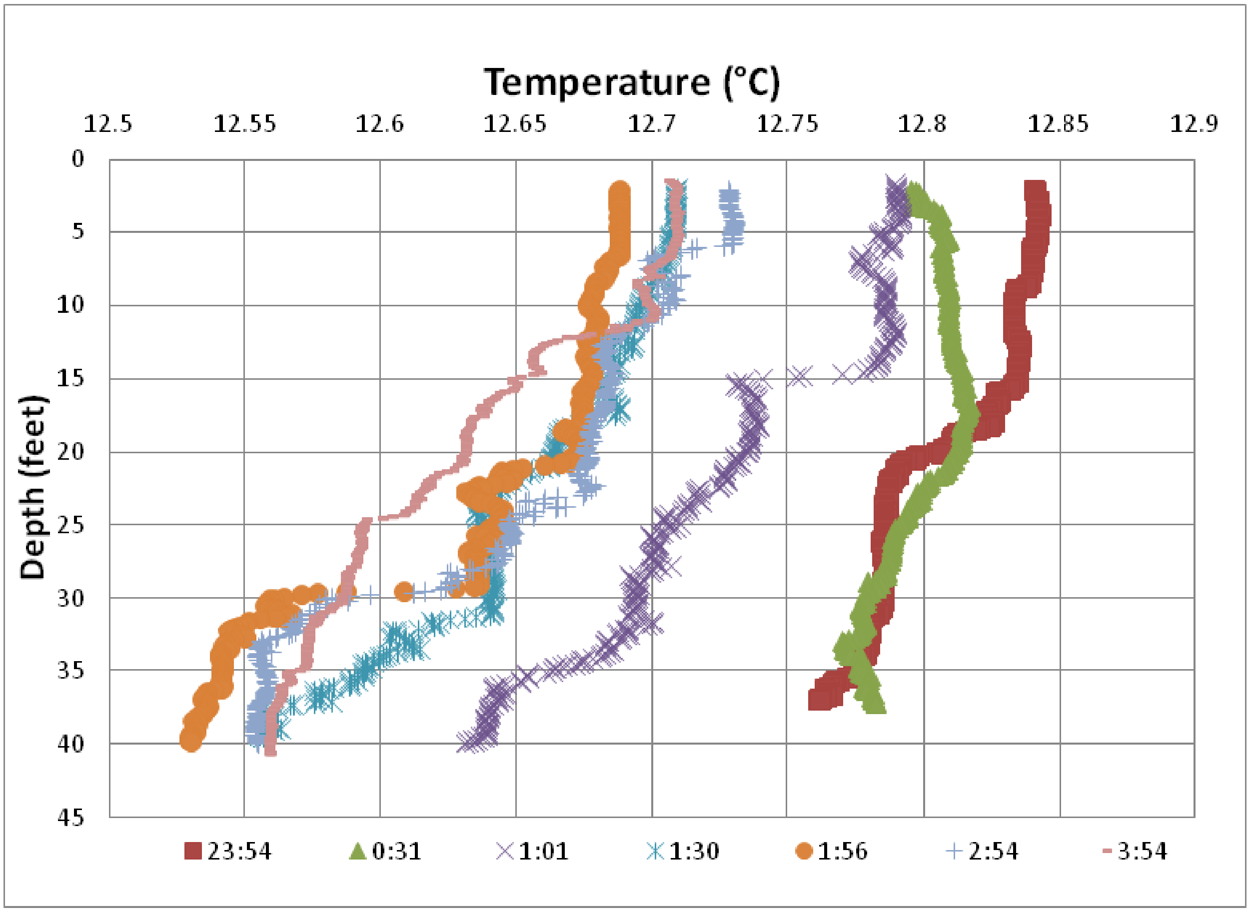


Figure 14. Vertical temperature profiles measured during an ebb tide on November 23, 2011 at the entrance to the Turning Basin Tributary (Channel Point).

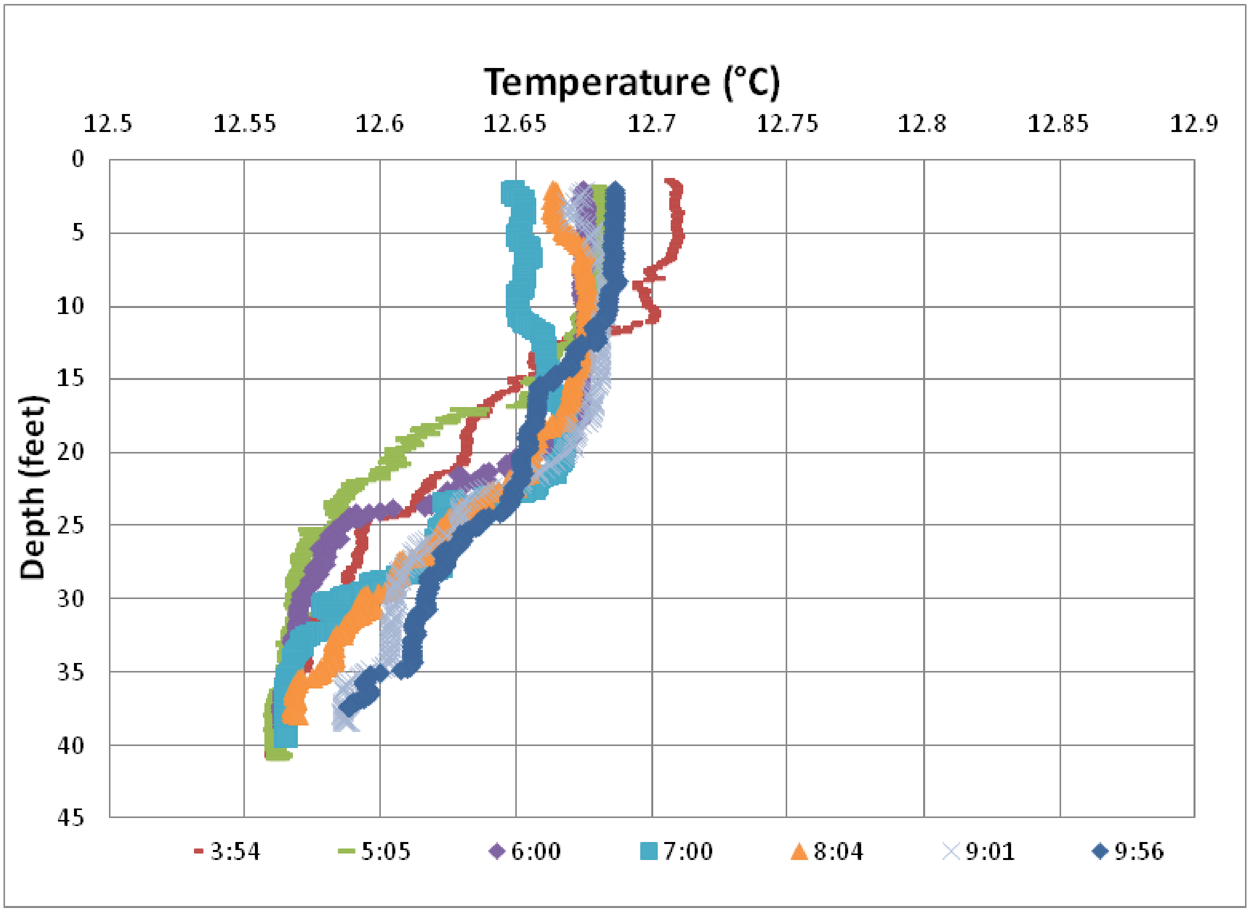


Figure 15. Vertical conductivity profiles measured during a flood tide on November 22-23, 2011 at the entrance to the Turning Basin Tributary (Channel Point).

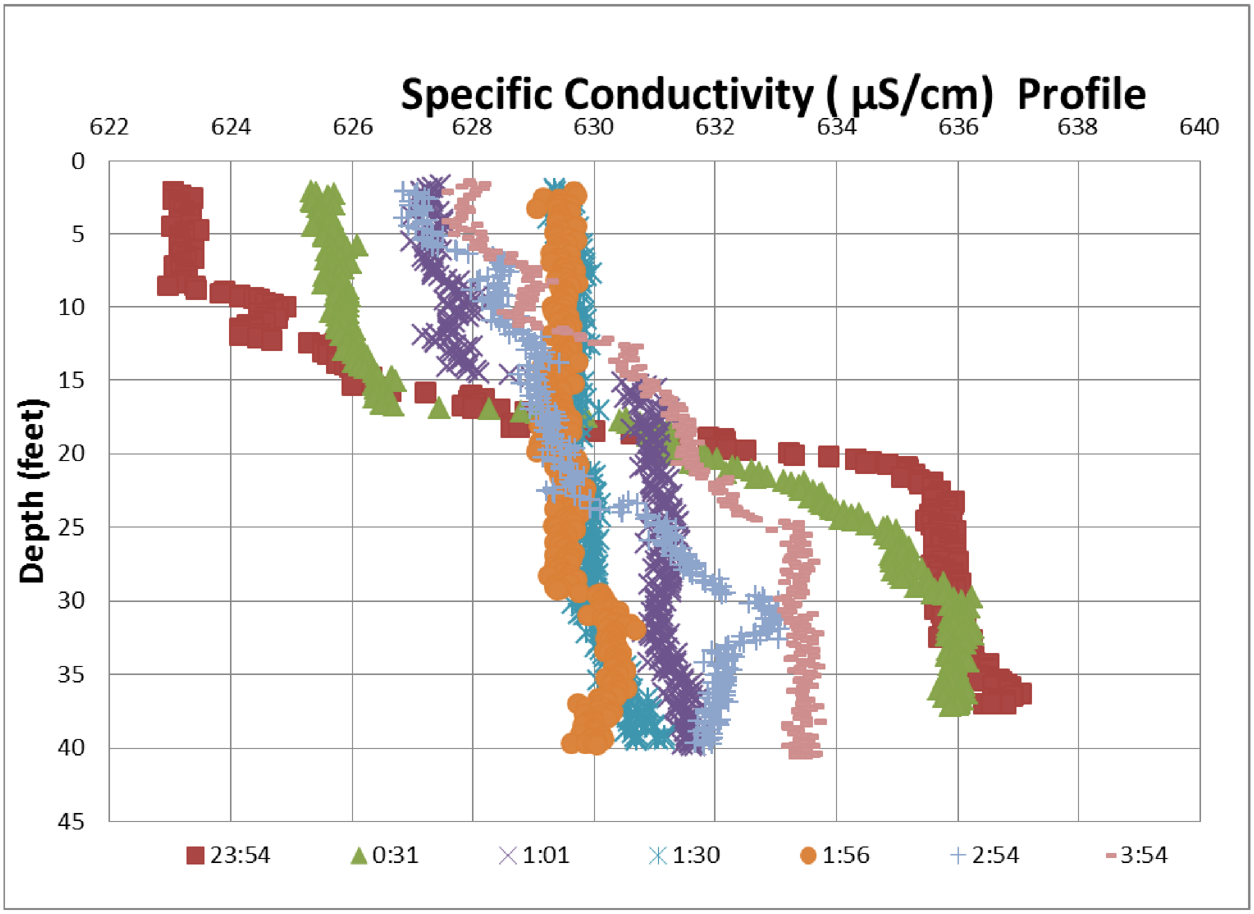


Figure 16. Vertical conductivity profiles measured during an ebb tide on November 23, 2011 at the entrance to the Turning Basin Tributary (Channel Point).

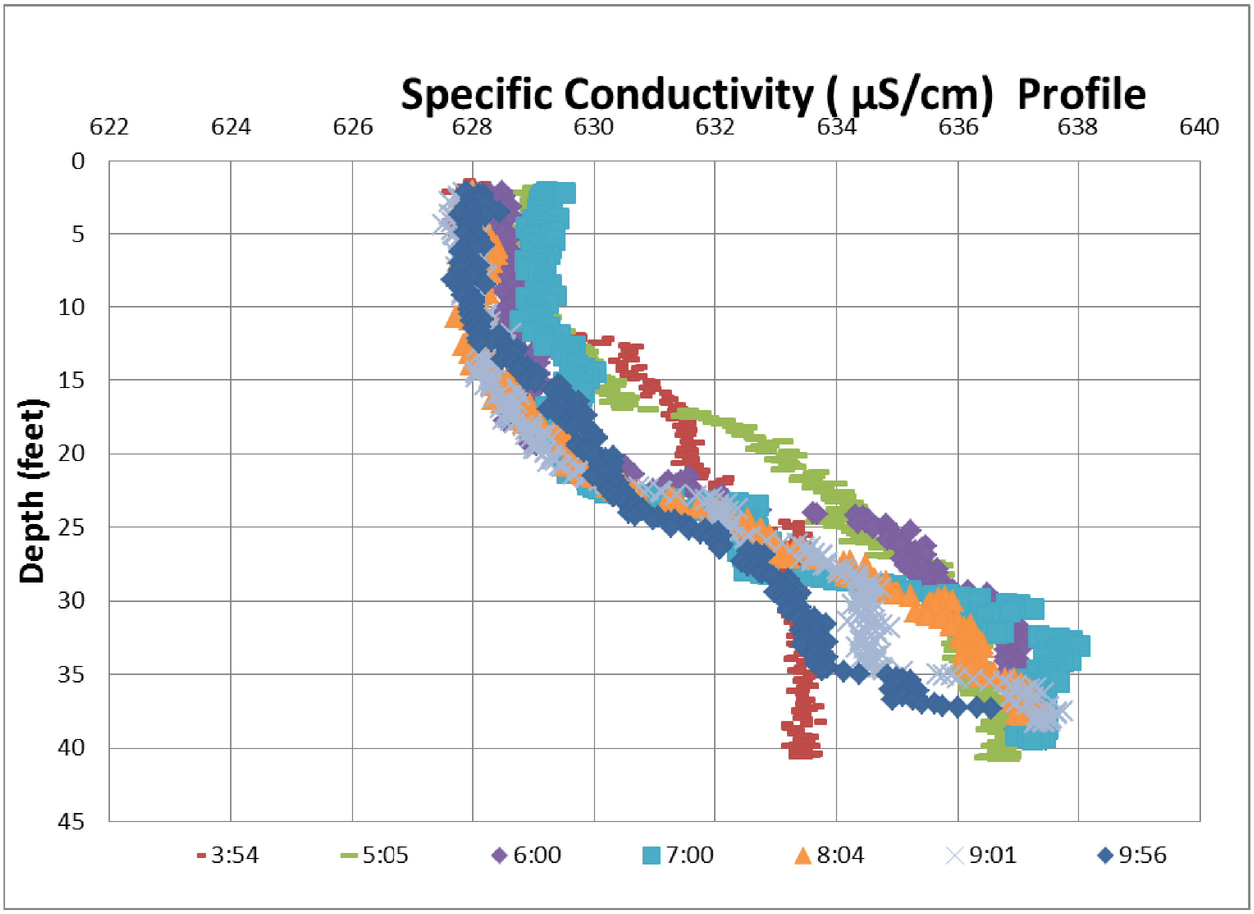


Table A-1. Site characteristics for all sampling sites

Site type	Station	Channel width (ft)	Average Channel depth (ft)	Emergent Vegetation	Trees on bank	Islands	Land Use
DWSC	430	265	42.2	No	Only on south bank	No	agriculture (50% fallow)
DWSC	402	243	34.0	No	No	No	agriculture
DWSC	425	130	16.5	No	Only on south bank (sparse)	No	agriculture (25% fallow)
DWSC	404	100	23.0	No	Sparce on both banks	No	agriculture
DWSC	428	232	37.6	Yes	Only on south bank (sparse)	No	agriculture
DWSC	403	68	12.3	Yes	Only on south bank	No	50% agriculture, 50 % vegetated island
DWSC	406	210	34.8	No	Sparce on both banks	No	agriculture (50% fallow)
DWSC	407	55	9.0	Yes	Sparce on both banks	No	agriculture (50% fallow)
DWSC	427	182	36.1	No	North Bank only (sparse)	No	50 % industrial (RRI) and 50% park
DWSC	408	43	5.1	No	Yes	No	50% park, 50% residential
DWSC	LT 48	160	35.0	No	Yes (some)	No	50% park, 50% industrial
DWSC	CP	150	40.7	No	North Bank only (sparse)	No	50% fallow agriculture, 50% industrial
DWSC	WS	225	36.0	No	Yes (some)	No	Industrial
Tributaries	401	225	16.6	No	No	Yes	agriculture
Tributaries	423	120	25.0	Yes	Yes (some)	Yes	agriculture
Tributaries	433	120	13.9	No	Sparse	Yes	agriculture
Tributaries	424	94	11.0	Yes	No	Yes	agriculture
Tributaries	410	30	5.4	Yes	North Bank only (some)	Yes	25% industrial, 25% agricultural, 25% residential, 25% vegetated island
Tributaries	420	17	2.2	Yes	Yes (some)	No	75% residential, 25% agricultural
Tributaries	421	15	2.0	No	Yes	No	50% residential, 50% park
Tributaries	412	17	2.0	No	Yes	No	50% residential, 25% agricultural, 25% high school
Tributaries	411	8	3.0	Yes	North Bank only (some)	No	residential
Tributaries	405	32	2.5	Yes	Yes (some)	Yes	Residential (next to the University)
Tributaries	413	105	2.8	No	Yes (some)	No	park
Turning Basin	TBD	135	38.0	No	North Bank only (sparse)	No	Industrial
Turning Basin	TB	102	39.3	No	Yes (some)	No	Industrial
Turning Basin	TBU	80	13.0	No	Yes (some)	No	Industrial
Turning Basin	409	120	20.0	No	Sparse	No	industrial
Turning Basin	426	102	9.5	No	Yes (some)	No	Industrial
Turning Basin	414	160	12.0	No	No	No	Park, parking, baseball/hockey stadiums
Upstream SJR	SJR at Burns	60	17.5	No	Yes (some)	No	50% industrial, 50% fallow land
Upstream SJR	SJR at Navy	62	19.2	No	No	No	50% industrial, 50% fallow land
Upstream SJR	1	82	17.4	No	Only on south bank (sparse)	No	agriculture
Upstream SJR	127	64	10.1	No	Yes (some)	No	agriculture
Upstream SJR	11	40	3.1	Yes	Only on south bank	No	50 % golf course, 50% fallow agriculture
Upstream SJR	2	63	8.8	No	East Bank only (some)	No	agriculture
Upstream SJR	4	97	6.1	No	Yes (some)	No	25% bare land for development, 25% parking/industrial, 50% agriculture

Table A-2. Averaged data from all the sites 2009-2012.

Site	Average of North (latitude)	Average of West (longitude, absolute value)	Average of Total zoo mass (ug/L)	Min of zoo mass (ug/L)	Max of Total zoo mass (ug/L)2	Number of samples Total zoo mass (ug/L)	Average of Total zoo density (count/L)	Average of Rotifer density (count/L)	Average of Rotifer Mass (ug/L)	Average of Cladoceran density (count/L)	Average of Ciliata dens (count/L)	Average of P forbesi and E Affinis density	Average of Cladoceran mass (ug/L)	Average of Copepod density (count/L)	Average of P forbesi and E Affinis mass	Average of Copepod Mass (ug/L)
2	37.83076	-121.312	2.83	0.10	10.19	14	26.99	22.33	0.89	0.32	0	0.19	0.23	4.34	0.07	1.71
4	37.7871	-121.308	3.58	0.39	26.30	13	47.04	42.19	1.53	0.07	0	0.28	0.03	4.76	0.22	2.02
11	37.91942	-121.312	6.18	0.17	17.10	12	26.78	13.51	0.31	1.04	0	0.84	0.73	12.21	0.59	5.13
127	37.86501	-121.324	18.89	0.01	105.16	17	61.92	36.16	2.52	1.18	0	2.27	0.94	24.57	2.41	11.17
401	38.04149	-121.478	6.51	4.09	7.78	3	13.97	0.59	0.02	0.00	0	4.77	0.00	13.39	3.25	6.49
402	38.02586	-121.468	17.50	0.36	103.40	23	32.07	3.75	0.16	1.79	0	7.97	1.25	26.52	7.29	14.61
403	38.00163	-121.406	11.87	8.00	19.60	3	33.93	7.74	0.09	2.98	0	5.37	0.98	23.21	4.00	10.82
404	37.99251	-121.453	3.87	3.00	5.00	3	11.30	1.79	0.15	0.59	0	0.60	0.11	8.93	0.26	3.59
405	37.98132	-121.314	28.67	0.40	148.70	19	127.49	67.99	0.97	7.79	0	2.97	6.41	51.72	1.98	21.29
406	37.98383	-121.389	18.19	2.00	79.77	23	61.18	29.79	0.97	1.94	0	6.50	2.00	29.45	5.76	14.79
407	37.96245	-121.378	9.00	1.80	14.40	3	29.13	7.14	0.16	0.59	0	2.67	0.46	21.43	1.43	8.38
408	37.95864	-121.344	7.17	1.80	14.70	3	42.27	25.89	0.67	1.49	0	0.00	0.62	14.88	0.00	5.86
410	38.0432	-121.371	13.20	2.90	48.20	16	57.78	30.01	1.98	2.01	0	1.89	0.69	25.75	1.12	10.52
411	38.0283	-121.332	6.44	6.44	6.44	1	18.80	6.25	0.16	3.57	0	2.70	2.43	8.93	1.36	3.86
412	38.0129	-121.34	55.40	55.40	55.40	1	358.90	269.64	22.53	31.25	0	4.50	8.90	58.04	2.52	23.95
413	37.9674	-121.307	74.51	0.10	835.50	16	274.73	150.67	10.49	90.74	0	5.73	46.89	33.32	6.32	17.14
414	37.95402	-121.295	6.60	6.60	6.60	1	68.80	60.71	3.42	0.00	0	0.00	0.00	8.04	0.00	3.21
420	38.0325	-121.365	6.72	0.06	36.00	15	27.30	11.33	0.31	0.49	0	0.55	0.17	15.47	0.31	6.24
421	38.0138	-121.349	79.67	2.60	372.20	12	260.32	168.29	26.03	22.18	0	14.46	15.23	69.84	16.95	38.40
423	38.0471	-121.47	2.90	2.90	2.90	1	10.70	3.57	0.03	0.00	0	0.00	0.00	7.14	0.00	2.86
424	38.006	-121.398	17.09	1.80	57.10	16	43.84	6.27	0.16	2.70	0	6.44	1.61	34.88	4.31	15.33
425	37.9852	-121.468	8.34	1.10	25.90	15	22.91	5.60	0.12	0.92	0	3.37	0.67	16.40	2.41	7.55
427	37.95409	-121.346	23.89	0.40	158.50	20	95.07	53.54	1.59	2.66	0	6.59	2.39	38.86	7.92	20.18
428	37.99365	-121.433	23.51	1.40	99.50	22	72.99	29.70	0.78	4.54	0	11.56	3.58	38.74	9.56	19.89
430	38.0524	-121.509	7.90	7.90	7.90	1	22.30	4.46	0.07	1.79	0	2.70	1.15	16.07	1.32	6.68
433	38.0442	-121.42	19.30	3.30	69.10	14	91.86	50.61	1.15	4.75	0	3.93	2.78	36.51	2.61	15.38
CP	37.95122	-121.333	8.43	1.94	29.70	19	57.13	19.35	0.28	0.00	0	8.47	0.00	37.80	4.64	13.89
LT 48	37.95226	-121.338	5.60	4.10	8.50	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SJR_Burns	37.94283	-121.345	5.13	0.80	13.30	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SJR_Navy	37.94644	-121.34	2.90	2.90	2.90	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TB	37.95287	-121.311	52.92	0.80	285.10	31	300.37	212.21	4.05	33.84	0	11.22	11.12	54.33	13.73	30.45

Table A-3. Detailed sampling locations for the spatial distribution study on 8/27/11.

Station	River Mile	Channel Lateral Position	Latitude (decimal degrees)	Longitude (decimal degrees)	Water Depth (ft)
402	**30.19**	**Mid**	**38.02561**	**121.46900**	**41**
402	30.22	NB	38.02621	121.46786	23
402	30.16	SB	38.02537	121.47013	18
428	**33.31**	**Mid**	**37.99341**	**121.43253**	**39**
428	33.30	NB	37.99452	121.43263	11
428	33.32	SB	37.99264	121.43243	13
406	**35.84**	**Mid**	**37.98475**	**121.38972**	**42**
406	35.85	NB	37.98488	121.38915	18
406	35.83	SB	37.98429	121.39050	8
427	**39.07**	**Mid**	**37.95414**	**121.34655**	**32**
427	39.06	NB	37.95502	121.34630	10
427	39.07	SB	37.95391	121.34673	19
Turning Basin (TB)	**39.70**	**Mid**	**37.95247**	**121.31656**	**41**
Turning Basin (TB)	39.70	NB	37.95360	121.31630	38
Turning Basin (TB)	39.73	SB	37.95126	121.31641	39
127	**47.72**	**Mid**	**37.86433**	**121.32316**	**12**
127	47.50	EB	37.86523	121.32679	15
127	47.42	WB	37.86628	121.32749	20

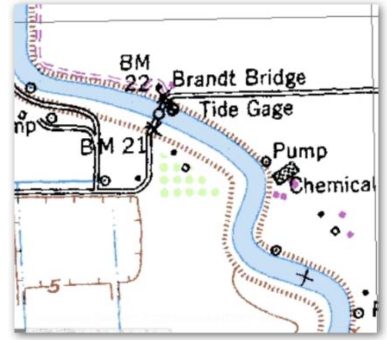
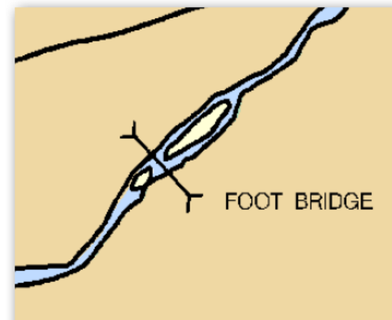
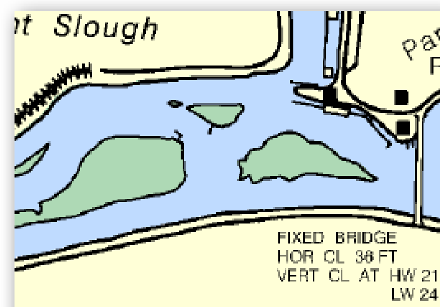
Table A-4. Sampling locations and survey type during the October 23, 2011 monitoring at the Turning Basin of the Stockton DWSC.

Station	Date/Time	Latitude (decimal degrees)	Longitude (decimal degrees)	Tide Condition at RRI
CP	3:00-3:35	37.95226	121.33845	High-high slack to ebb tide
TBD	4:00-4:29	37.95251	121.32122	Ebb tide
TBU	4:30-5:00	37.95319	121.31183	Ebb tide
CP	5:10	37.95182	121.33357	Ebb tide
Lt 48	5:25	37.95226	121.33845	Ebb tide
SJR at Burns	5:45	37.94283	121.34487	Ebb tide
SJR at Burns	8:05	37.94283	121.34487	Ebb tide
TBU	8:35	37.95319	121.31183	Ebb tide approaching low-low slack
TB	9:10	37.95255	121.31751	Ebb tide approaching low-low slack
TBD	9:30	37.95251	121.32122	Ebb tide approaching low-low slack
WS	9:50	37.95207	121.3277	Ebb tide approaching low-low slack
CP	10:15	37.95182	121.33357	Low-low slack tide
Lt 48	10:35	37.95226	121.33845	Low-low slack tide
SJR at Navy	11:00	37.94644	121.34018	Flood tide after low-low tide
TBU	13:05	37.95319	121.31183	Flood tide
TB	13:15	37.95255	121.31751	Flood tide
TBD	13:35	37.95251	121.32122	Flood tide
WS	13:55	37.95207	121.3277	Flood tide
CP	14:10	37.95182	121.33357	Flood tide
Lt 48	14:30	37.95226	121.33845	Flood tide
SJR at Navy	14:50	37.94644	121.34018	Flood tide approaching high slack tide

Table A-5. Monitoring conditions at CP during a flood tide and ebb tide excursion on November 22 and 23, 2011.

Date	Time	Location	Latitude (decimal degrees)	Longitude (decimal degrees)	Tidal Conditions
11/22/2011	23:00	CP	37.95203	121.33217	Low slack tide (2.18 ft at RRI)
11/22/2011	23:30	CP	37.95203	121.33217	Flood tide
11/23/2011	0:00	CP	37.95203	121.33217	Flood tide
11/23/2011	0:30	CP	37.95203	121.33217	Flood tide
11/23/2011	1:00	CP	37.95203	121.33217	Flood tide
11/23/2011	2:00	CP	37.95203	121.33217	Flood tide
11/23/2011	3:00	CP	37.95203	121.33217	Flood tide
11/23/2011	4:05	CP	37.95203	121.33217	High slack tide (4.97 ft at RRI)
11/23/2011	5:00	CP	37.95203	121.33217	Ebb tide
11/23/2011	6:00	CP	37.95203	121.33217	Ebb tide
11/23/2011	7:00	CP	37.95203	121.33217	Ebb tide
11/23/2011	8:00	CP	37.95203	121.33217	Ebb tide
11/23/2011	9:00	CP	37.95203	121.33217	Low slack tide (3.00 ft at RRI)

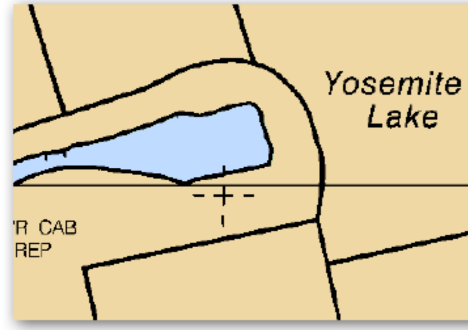
Table A-6. Survey of sites with highest zooplankton concentrations.

Site number	Site Description	GoogleEarth Image	Nautical map
127	Main Channel SJR, at Brandt ave Channel width 205 ft, Mid channel depth = 12 ft, East channel = 15 ft, West channel = 20 feet. Dense on south bank (bottom of figure), agricultural land use surrounding area. Bends in the river up and downstream of the sample site may affect flow velocity.		
405	Tributary Calaveras River Islands and vegetation. Channel width 106 m, depth 2.5 ft		
433	Tributary Paradise Marina Islands and vegetation. Channel width 400 ft, depth 14 ft		

413 Tributary

Smith Canal/Yosemite Lake.

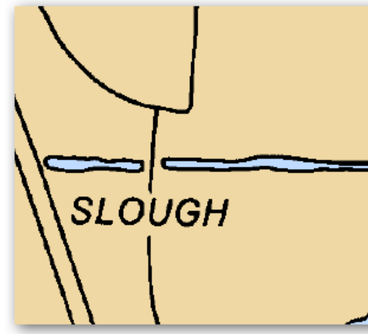
Vegetation located at the end of a long canal. Channel width 350 ft, 2.8 ft deep. Highest zooplankton concentration observed at this site on 4/26/12.



421 Tributary – Five mile slough

Heavy vegetation, on edge of park.

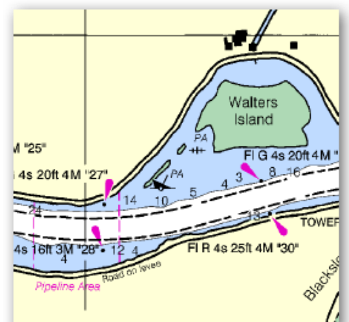
Channel width 50 ft, depth 2 ft



428 DWSC

RM 33.2, Acker Is, Light 28

Channel width 766 ft, 38 ft deep. Sampling site downstream from island

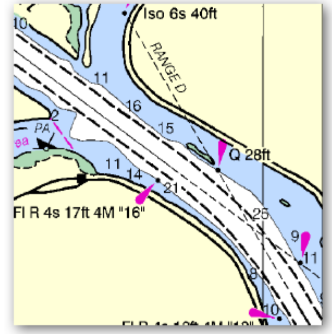


402

DWSC

Light 18

Channel width 802 ft, depth 36ft. Shallow area near bank and island near sampling site

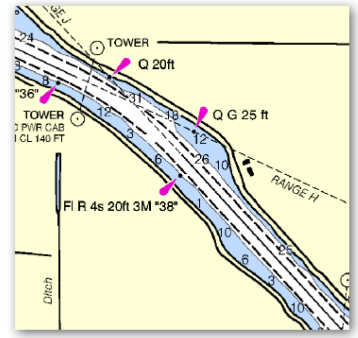


406

DWSC

RM 35.8, Light 38

Channel width 693 ft, depth 37 ft. Shallow area near banks, widening of the river may slow flow.

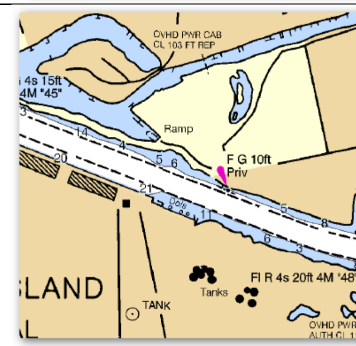


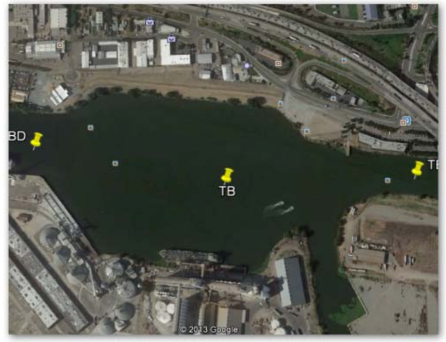
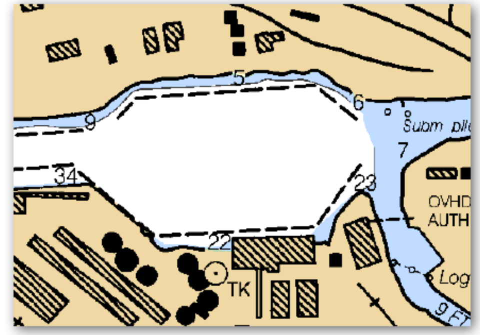
427

DWSC

RM 39 near Louis Park. Channel width 600 ft, depth 40 ft.

High zooplankton concentrations probably due to location directly downstream from TB.



TB	DWSC Turning Basin Channel width 336 ft, depth 40.5 ft.		

Appendix Figures

Figure A-1. Stage in the DWSC (RRI) and 8 miles upstream of the DWSC (SJR at Brandt Bridge, BDT) and flow entering the DWSC measured 1.5 miles above the DWSC on August 27, 2011.

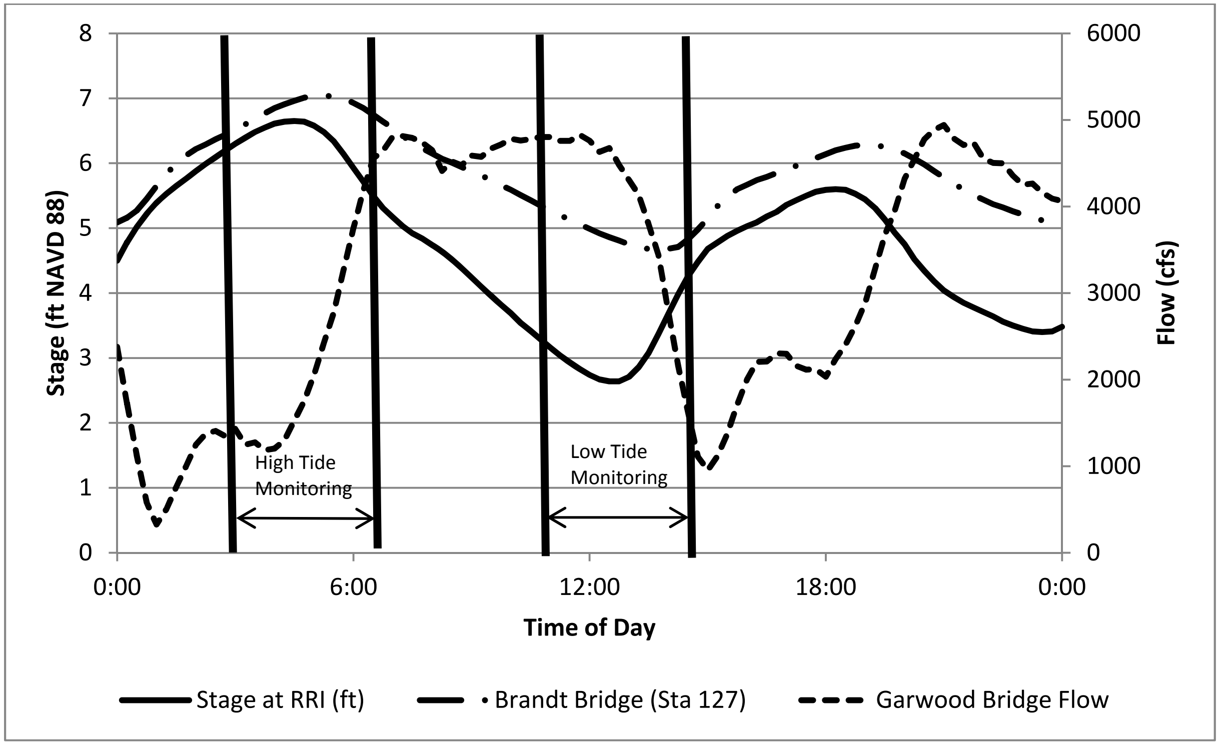


Figure A-2: Stage in the DWSC (RRI) and 1.5 miles above the DWSC (SJG) and flow entering the DWSC measured 1.5 miles above the DWSC on October 23, 2011.

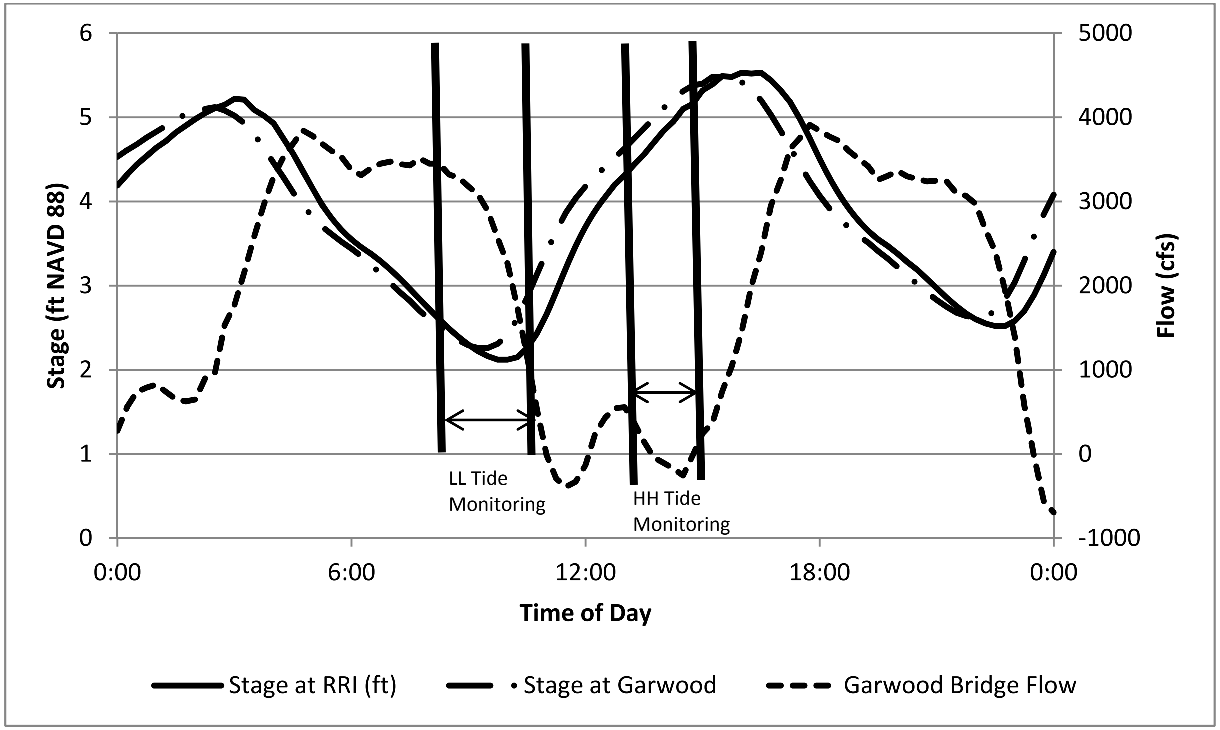


Figure A-3: Stage in the DWSC (RRI) and 1.5 miles above the DWSC (SJG) and flow entering the DWSC measured 1.5 miles above the DWSC on November 22 and 23, 2011.

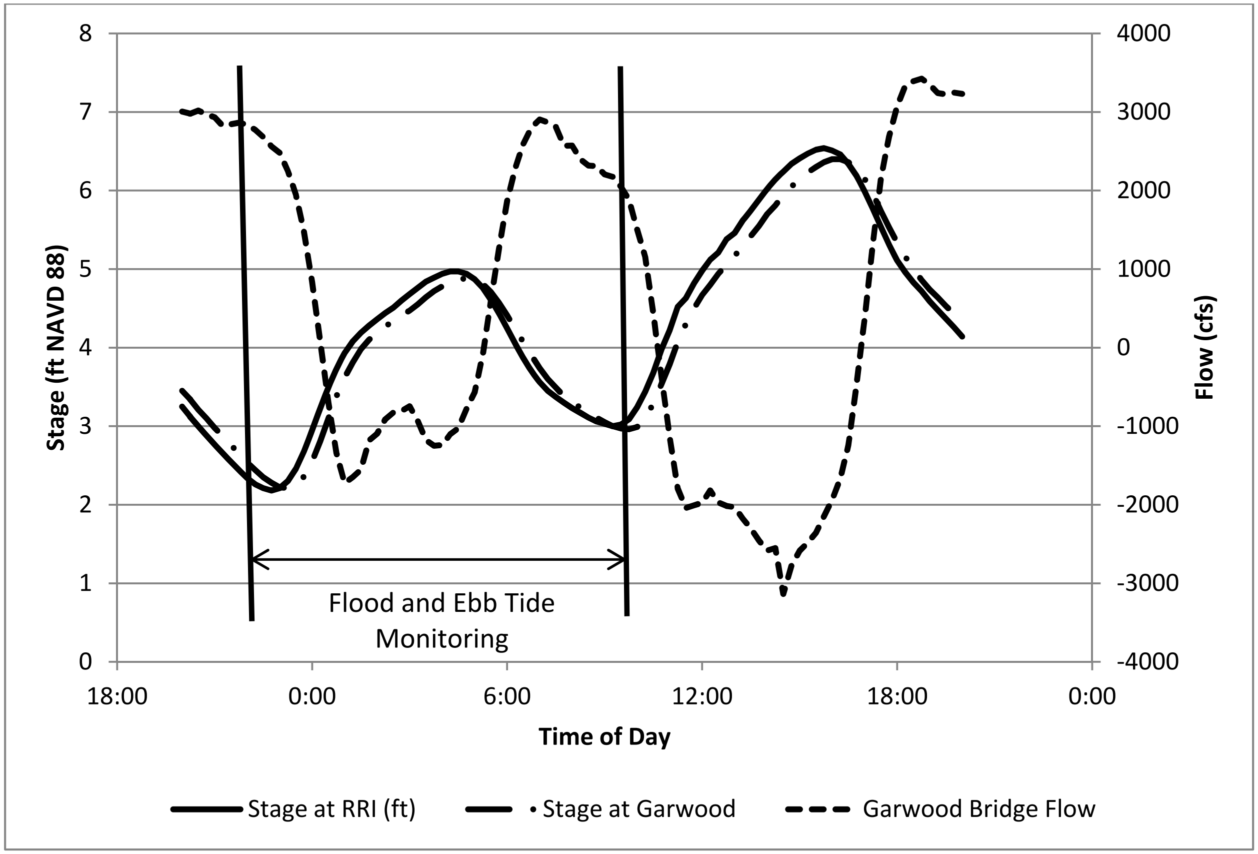


Figure A-4: Stage in the DWSC (RRI) and 8 miles above the DWSC (Brandt Bridge, BDT) and flow entering the DWSC measured 1.5 miles above the DWSC on July 11, 2012.

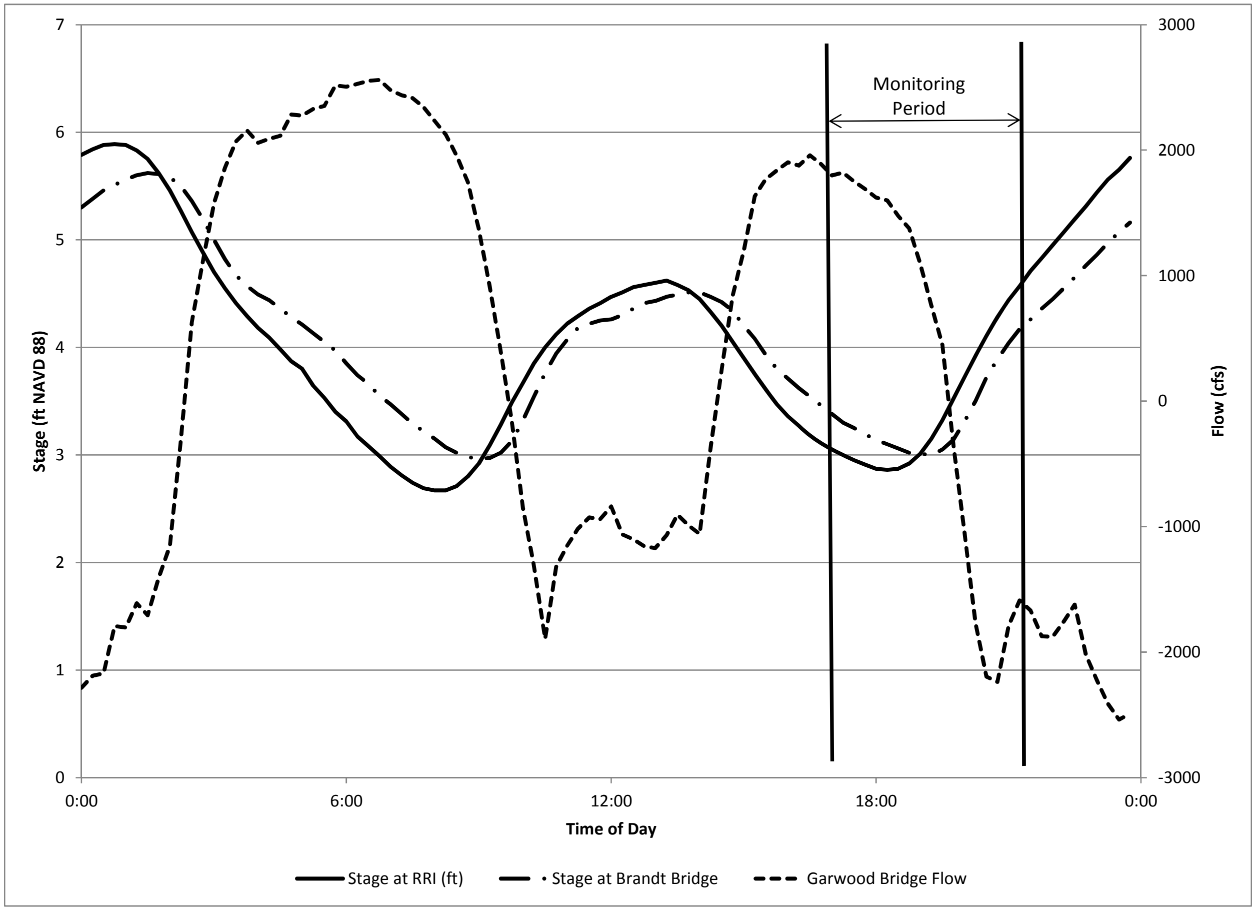


Figure A-5. Stage in the DWSC (RRI) and 8 miles above the DWSC (SJR at Brandt Bridge, BDT) and flow entering the DWSC measured 1.5 miles above the DWSC on August 19 and 20, 2012.

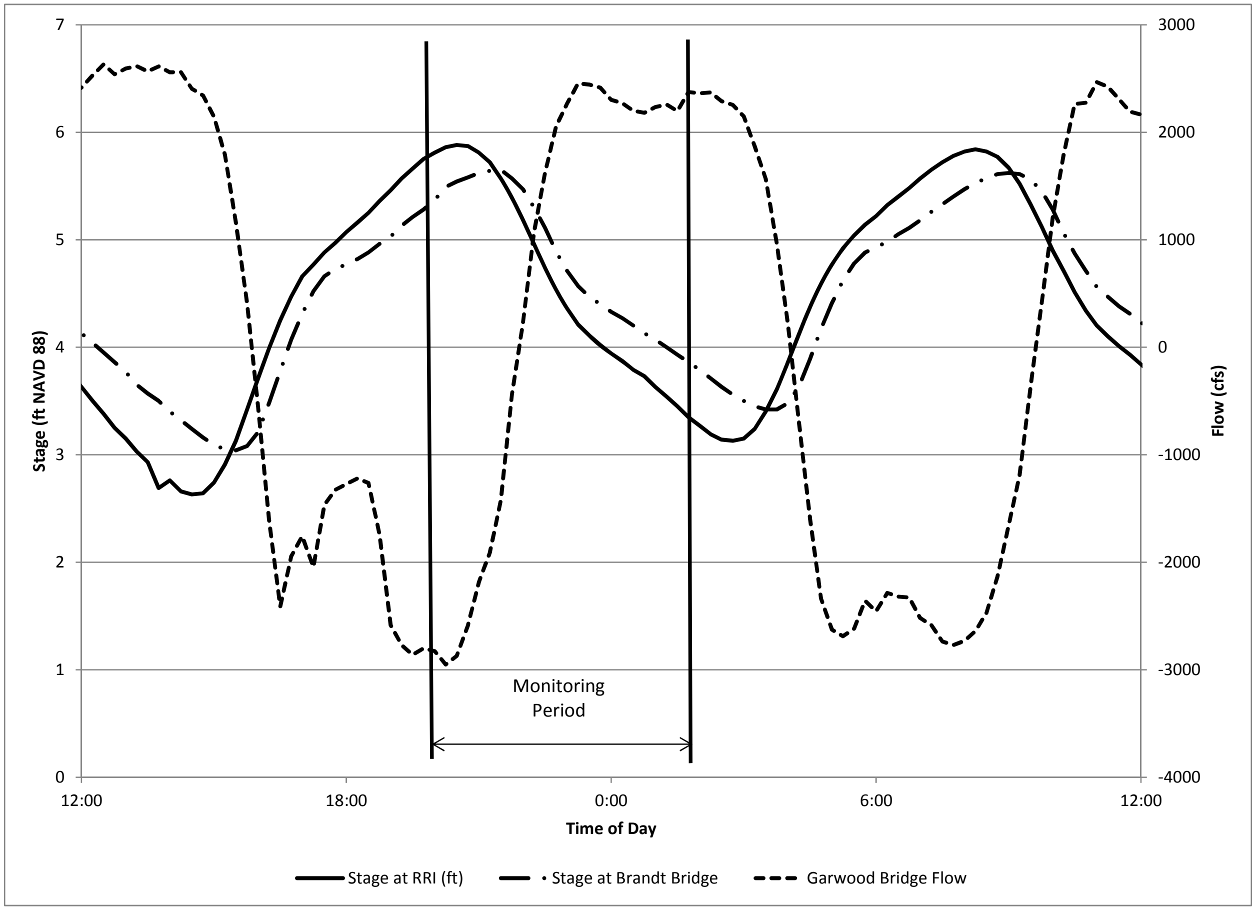


Figure A-6. Stage in the DWSC (RRI) and 8 miles above the DWSC (SJR at Brandt Bridge, BDT) and flow entering the DWSC measured 1.5 miles above the DWSC on September 7, 2012.

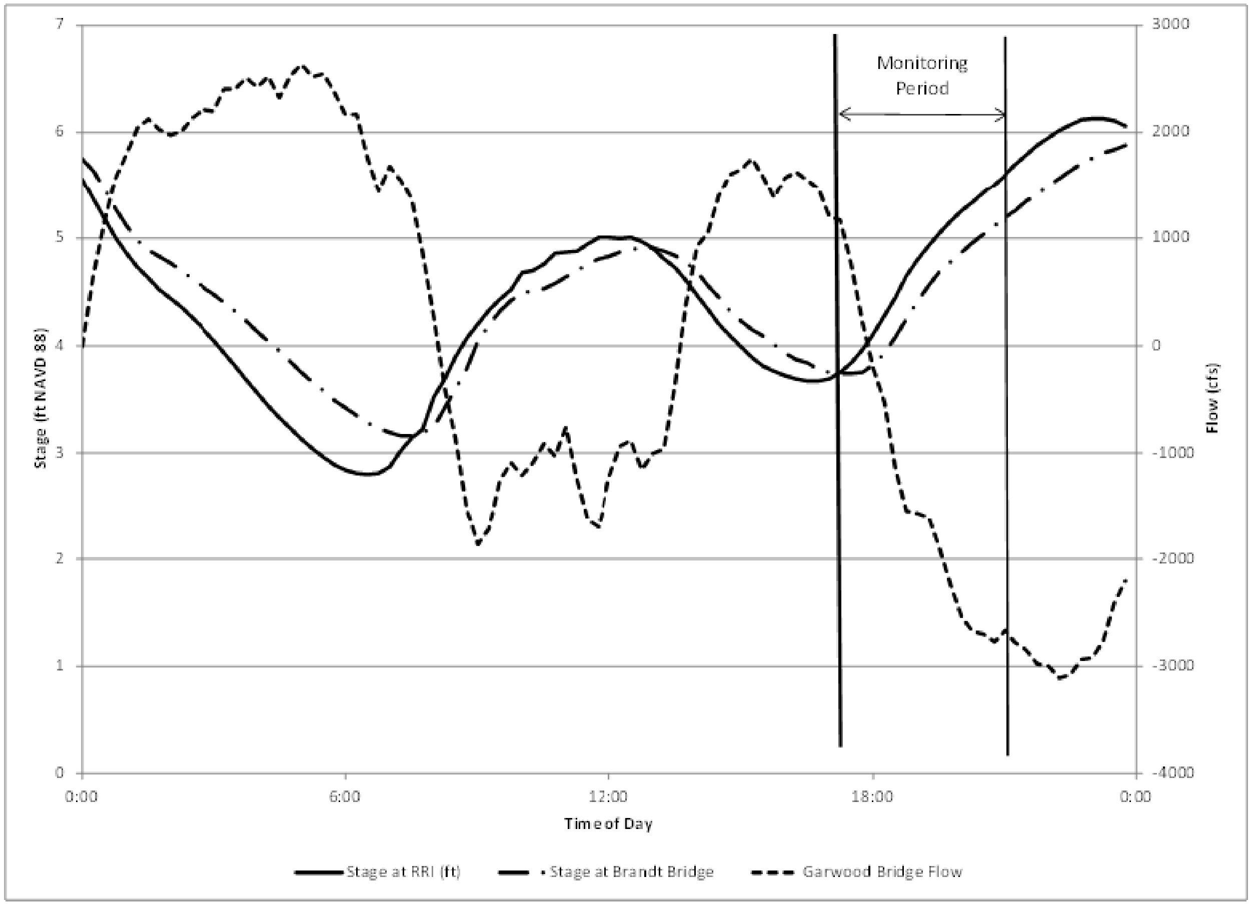


Figure A-7. Stage in the DWSC (RRI) and 8 miles above the DWSC (SJR at Brandt Bridge, BDT) and flow entering the DWSC measured 1.5 miles above the DWSC on November 26, 2012.

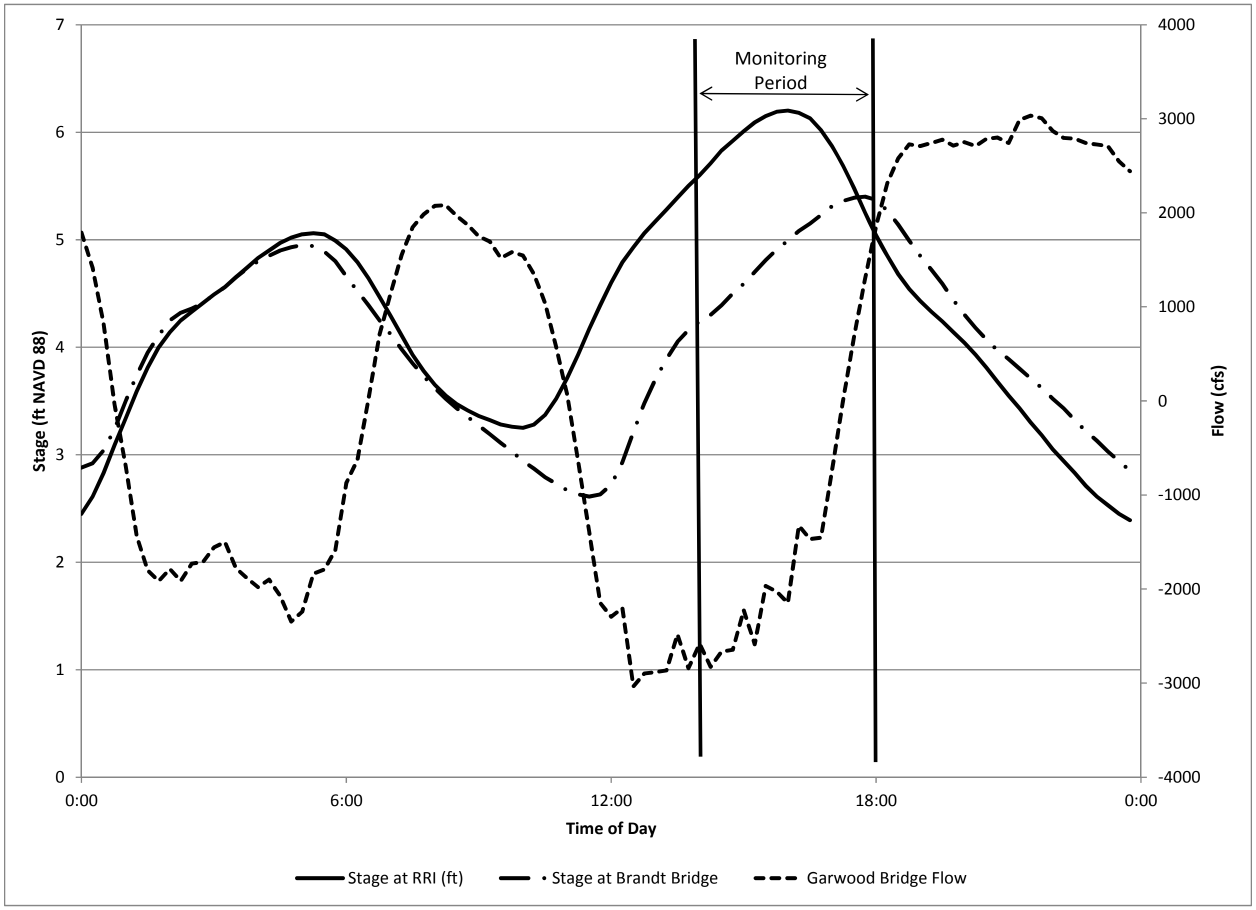


Figure A-8. Temperature profiles measured on August 27, 2011 at RM 30.2 (Station No. 402).

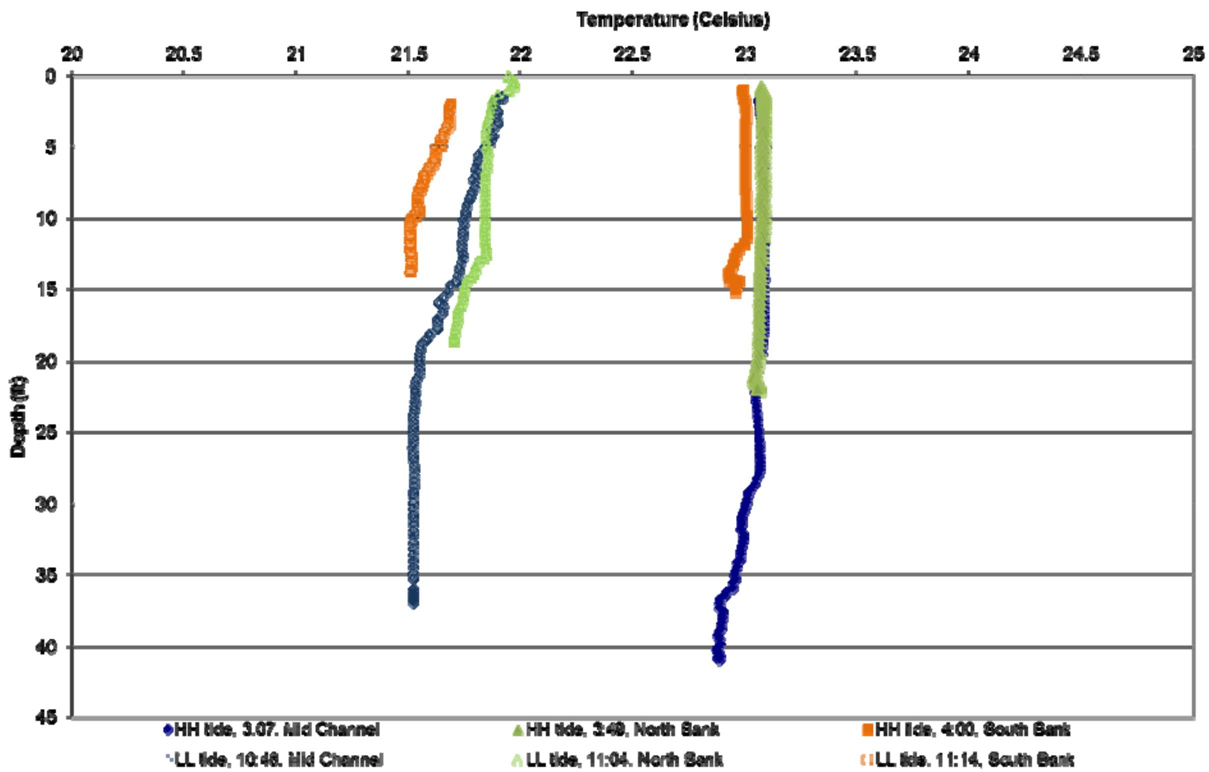


Figure A-9. Temperature profiles measured on August 27, 2011 at RM 33.3 (Station No. 428).

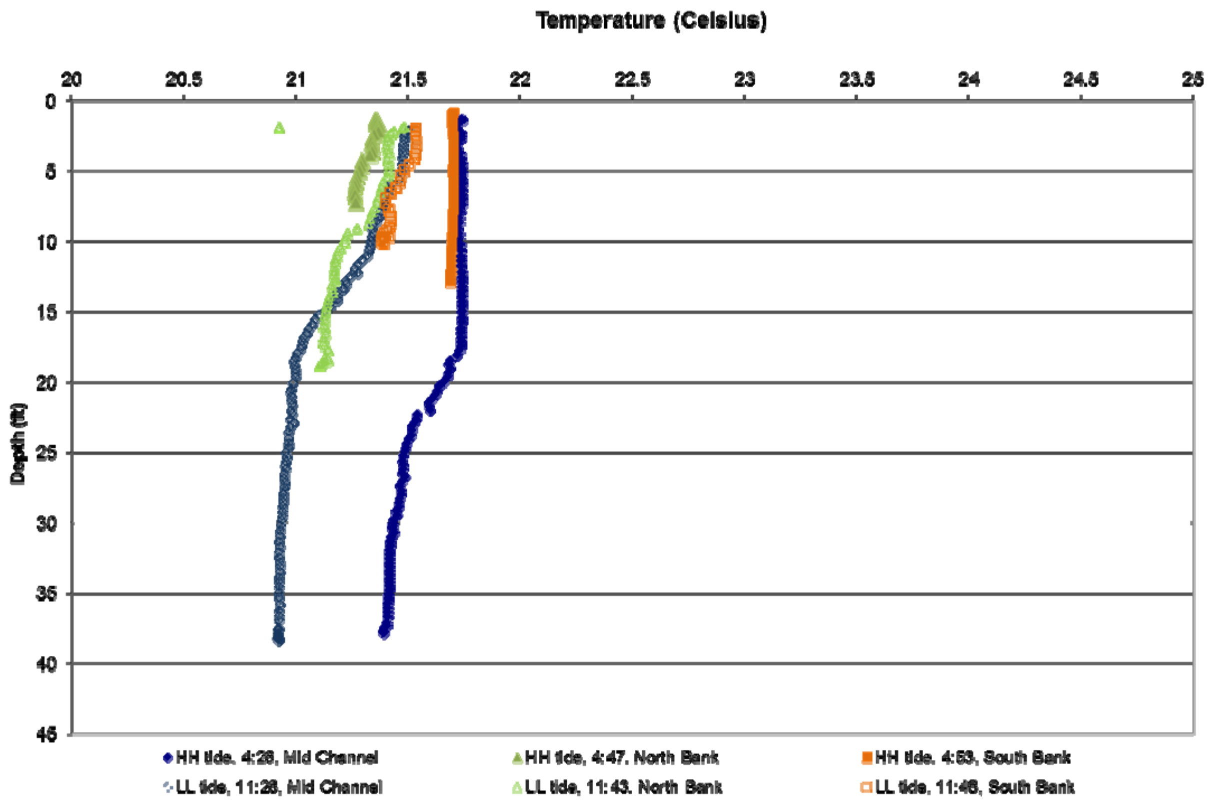


Figure A-10. Temperature profiles measured on August 27, 2011 at RM 35.8 (Station No. 406).

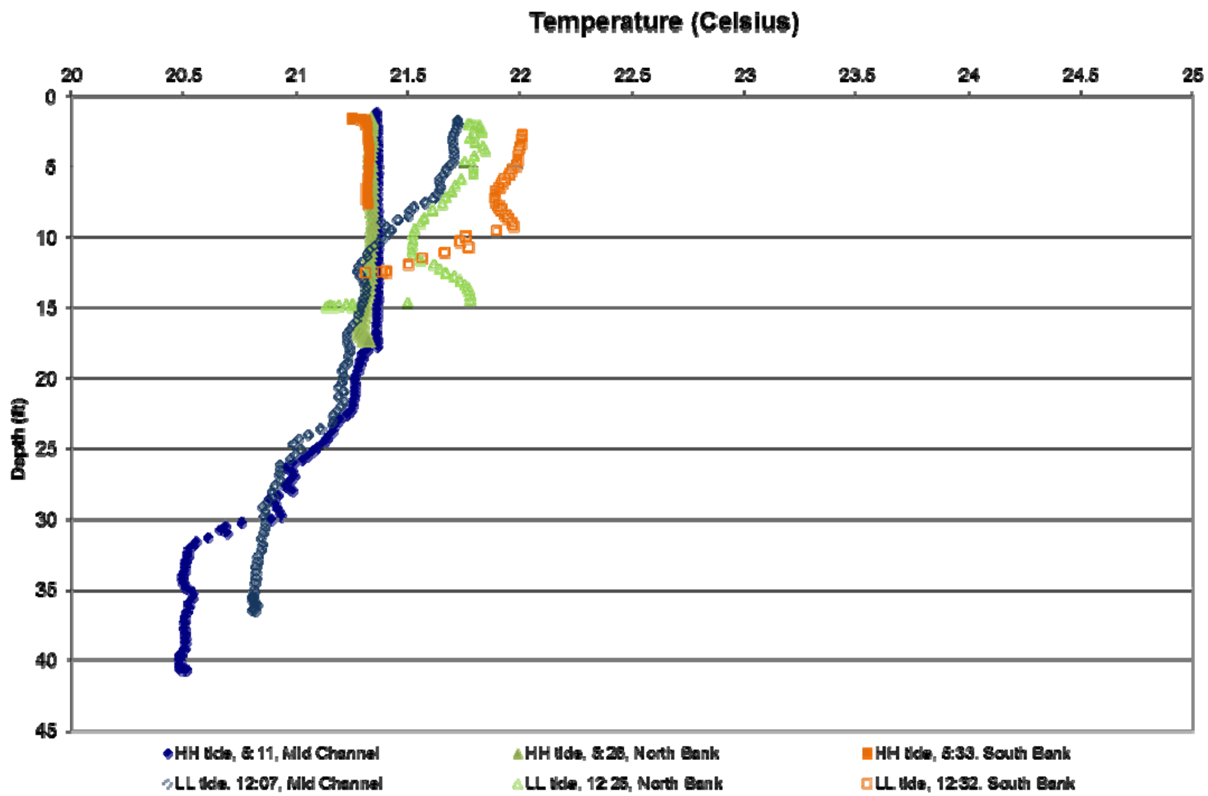


Figure A-11. Temperature profiles measured on August 27, 2011 at RM 39.0 (Station No. 427).

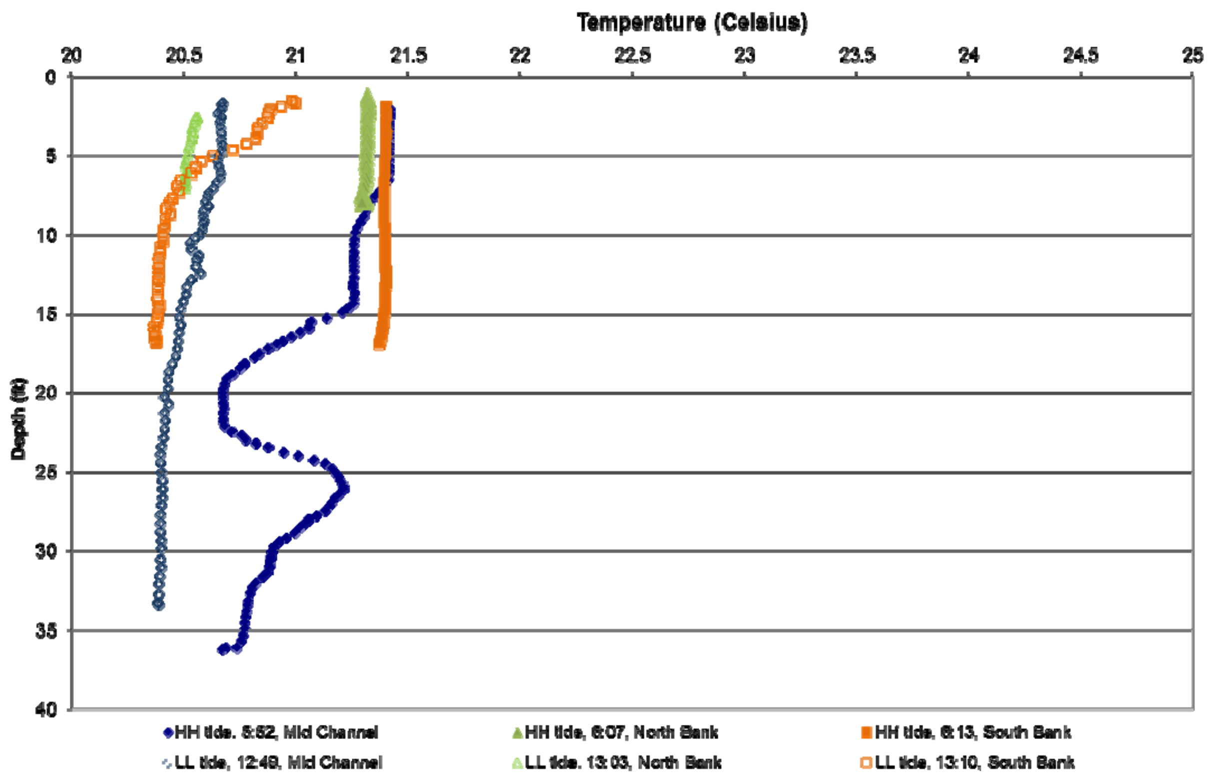


Figure A-12. Temperature profiles measured on August 27, 2011 at the Turning Basin.

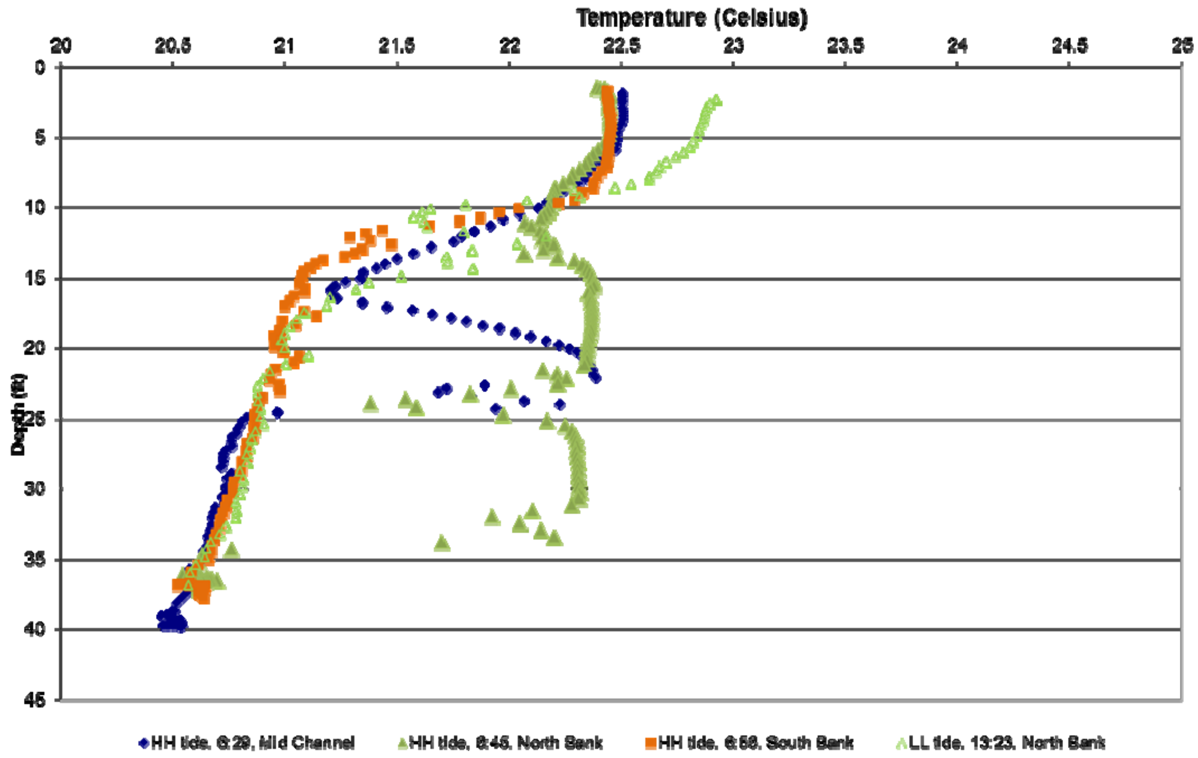


Figure A-13. Temperature profiles measured on August 27, 2011 at the RM 47.7 (Station No. 127, DWR Station Brandt Bridge).

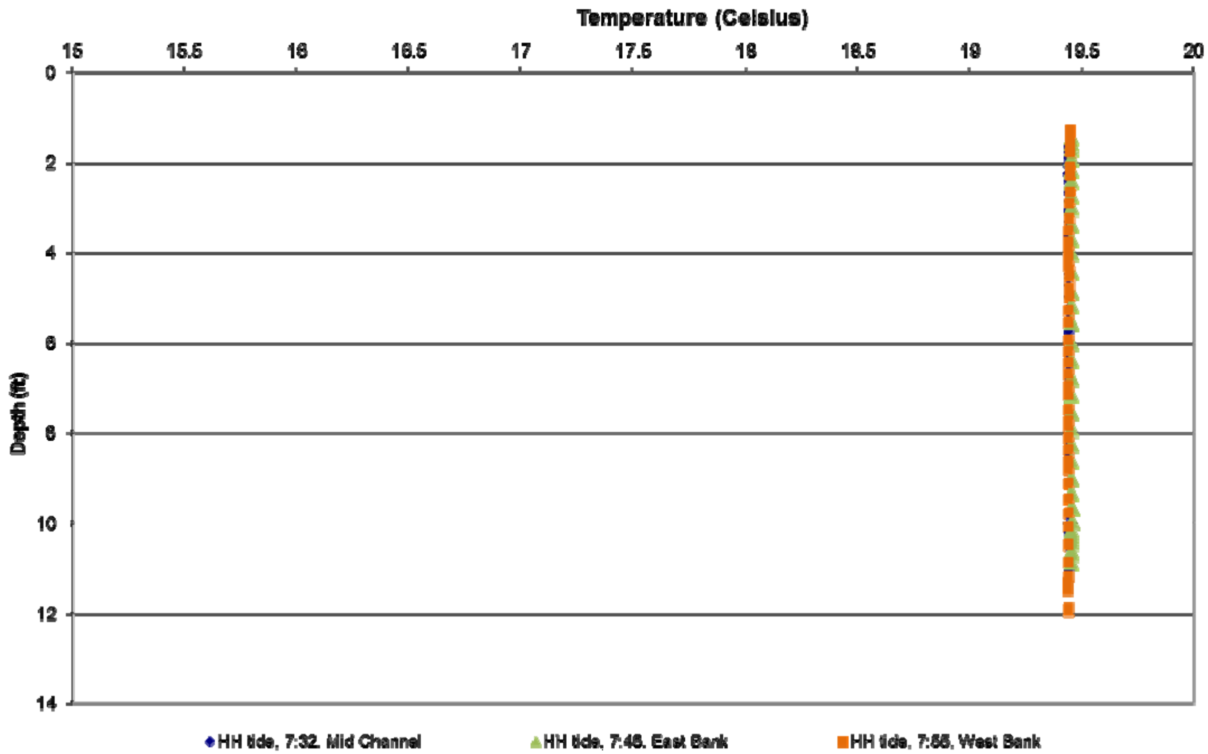


Figure A-14. Conductivity profiles measured on August 27, 2011 at RM 30.2 (Station No. 402).

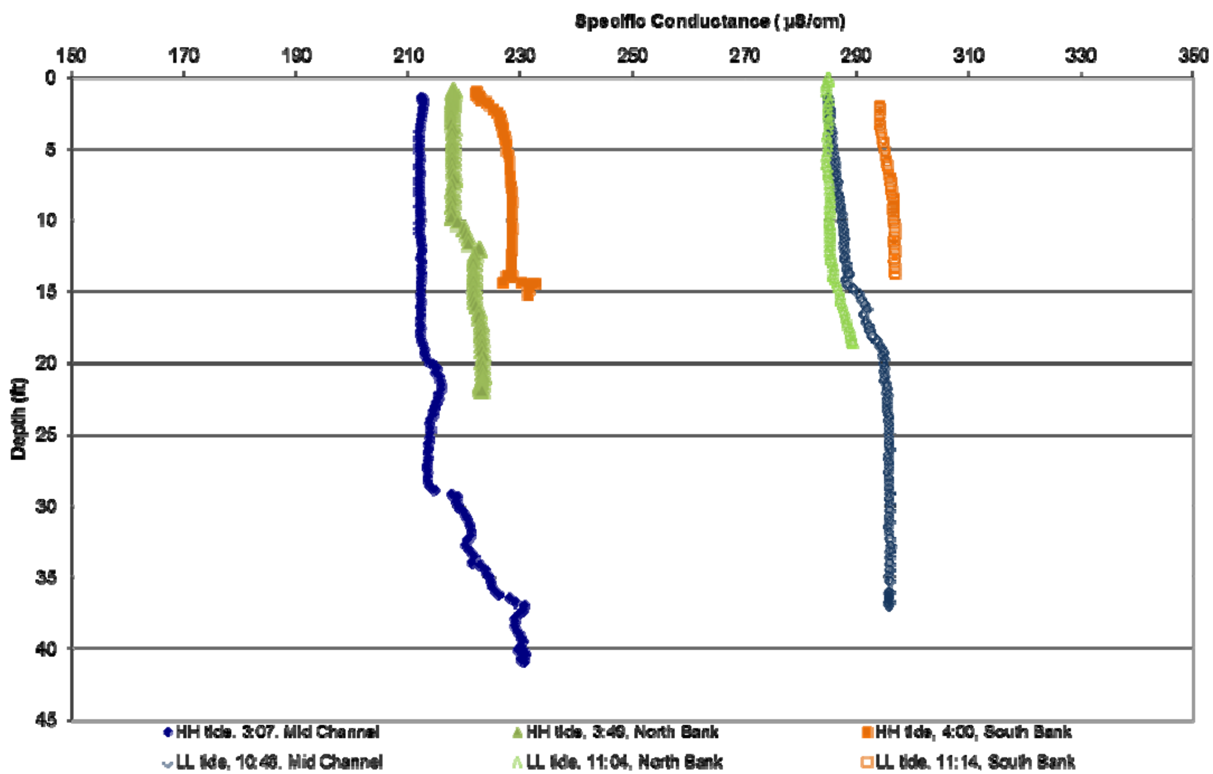


Figure A-15. Conductivity profiles measured on August 27, 2011 at RM 33.3 (Station No. 428).

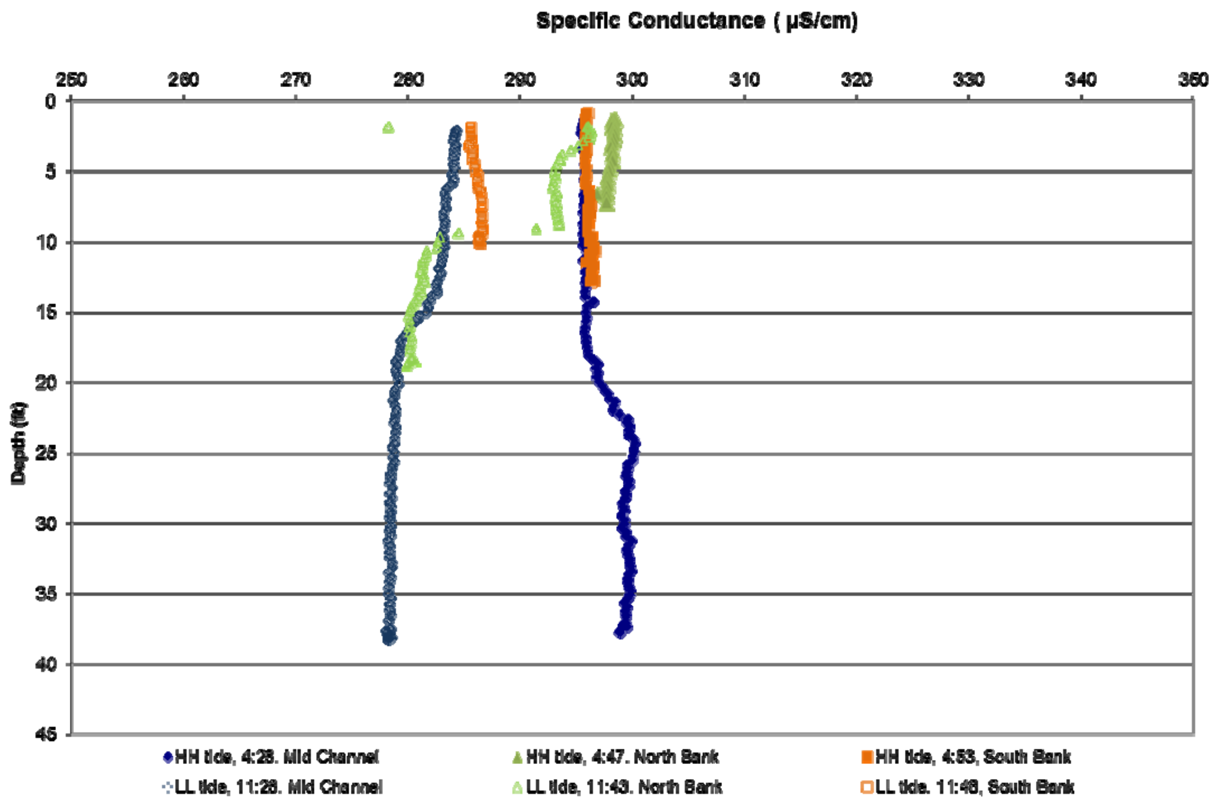


Figure A-16. Conductivity profiles measured on August 27, 2011 at RM 35.8 (Station No. 406).

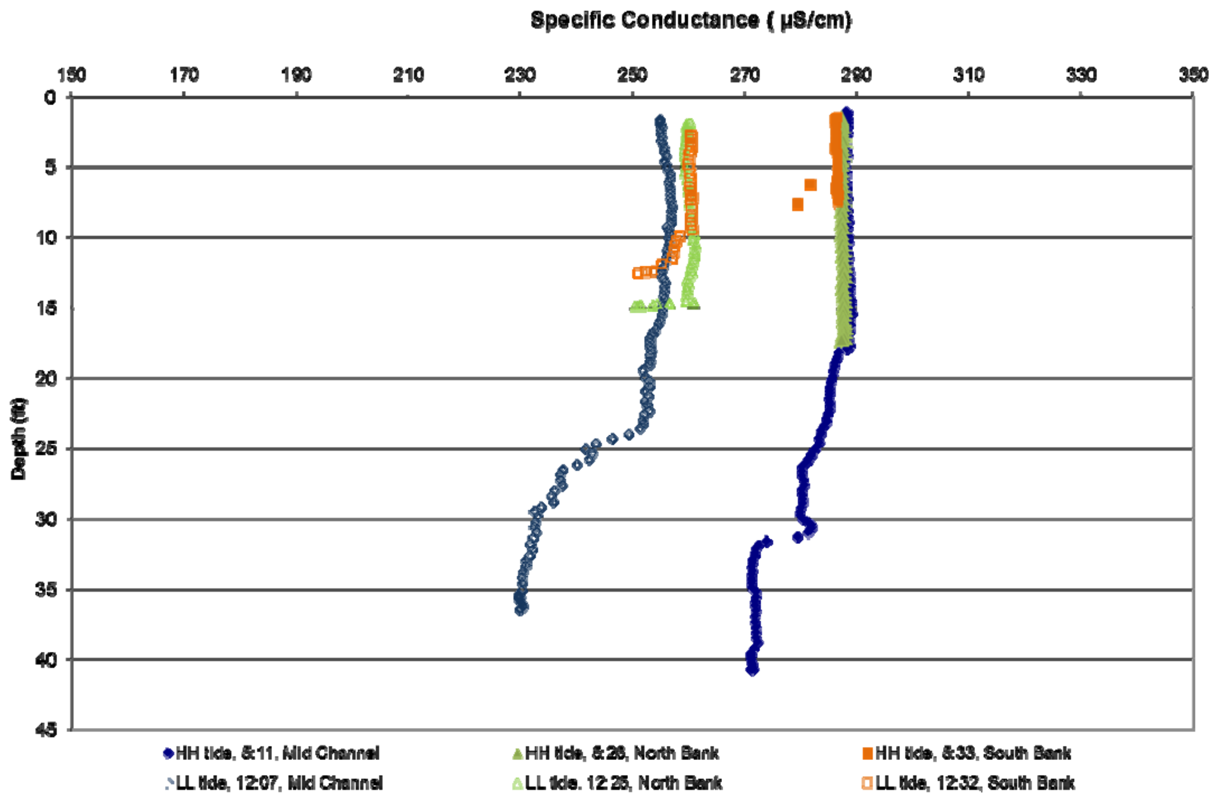


Figure A-17. Conductivity profiles measured on August 27, 2011 at RM 39.0 (Station No. 427).

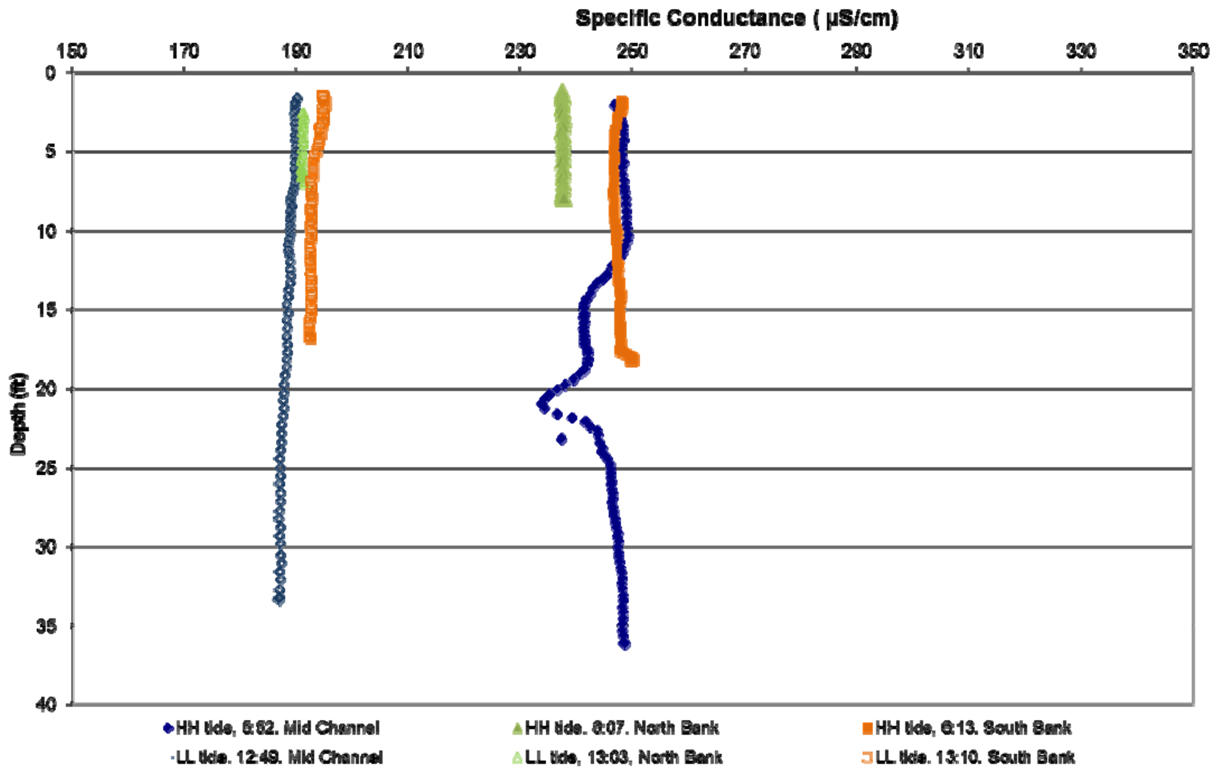


Figure A-18. Conductivity profiles measured on August 27, 2011 at the Turning Basin.

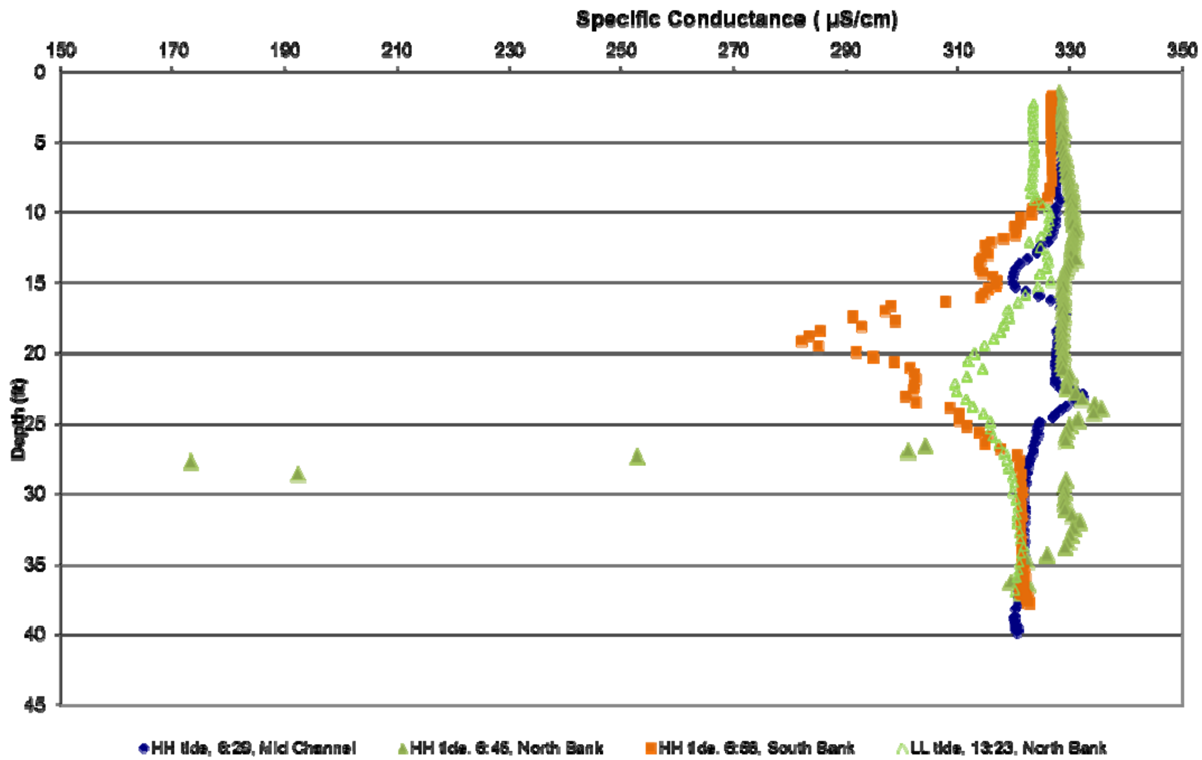


Figure A-19. Conductivity profiles measured on August 27, 2011 at the RM 47.7 (Station No. 127, DWR Station Brandt Bridge).

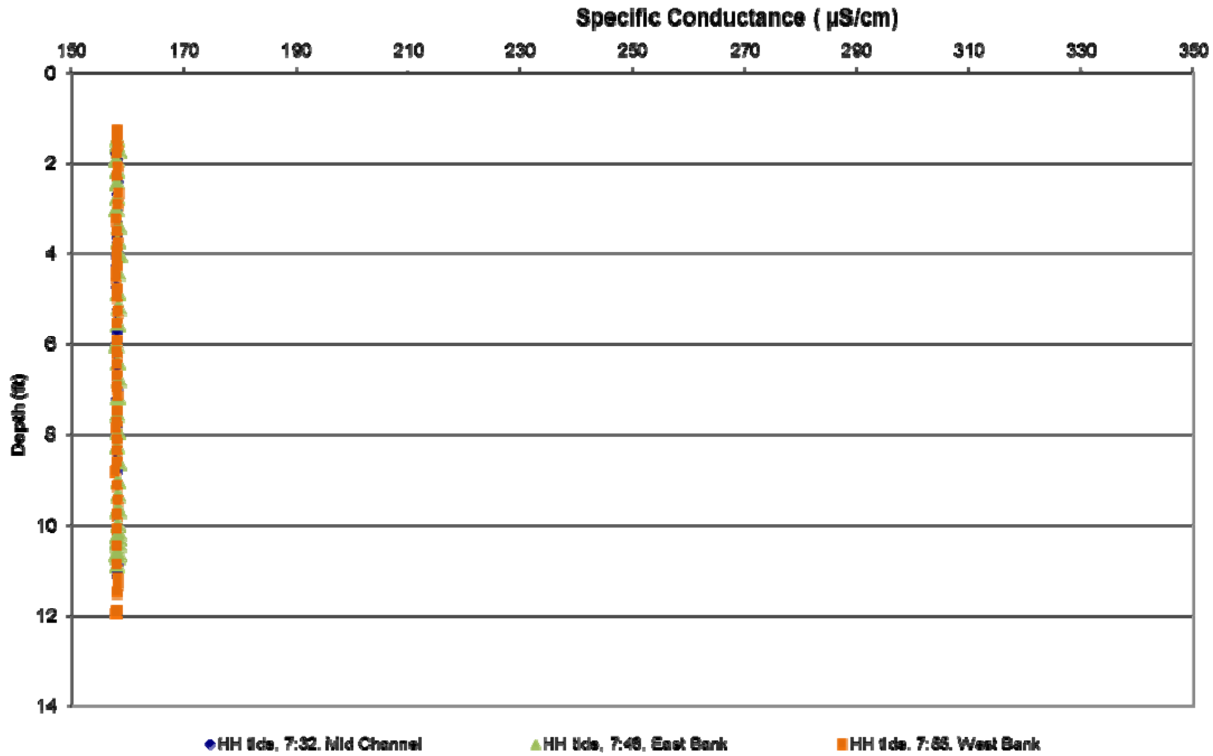


Figure A-20. Chlorophyll *a* profiles measured on August 27, 2011 at RM 30.2 (Station No. 402).

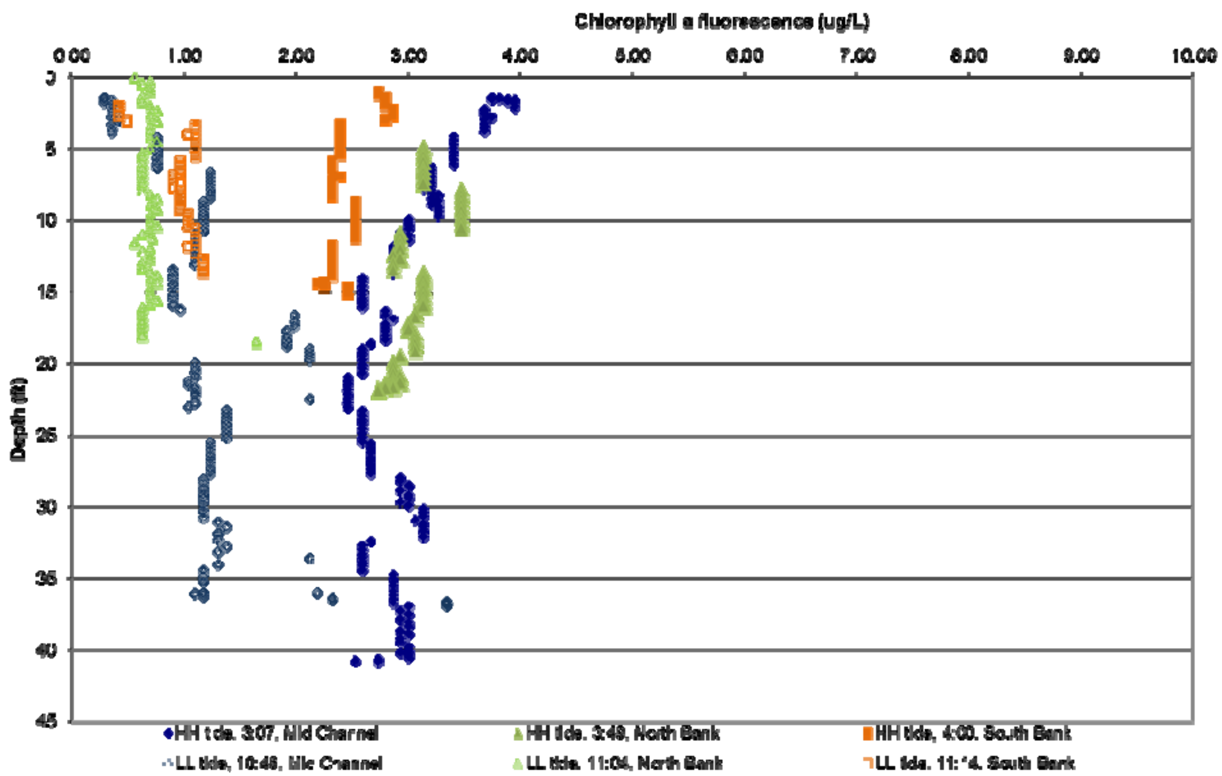


Figure A-21. Chlorophyll *a* profiles measured on August 27, 2011 at RM 33.3 (Station No. 428).

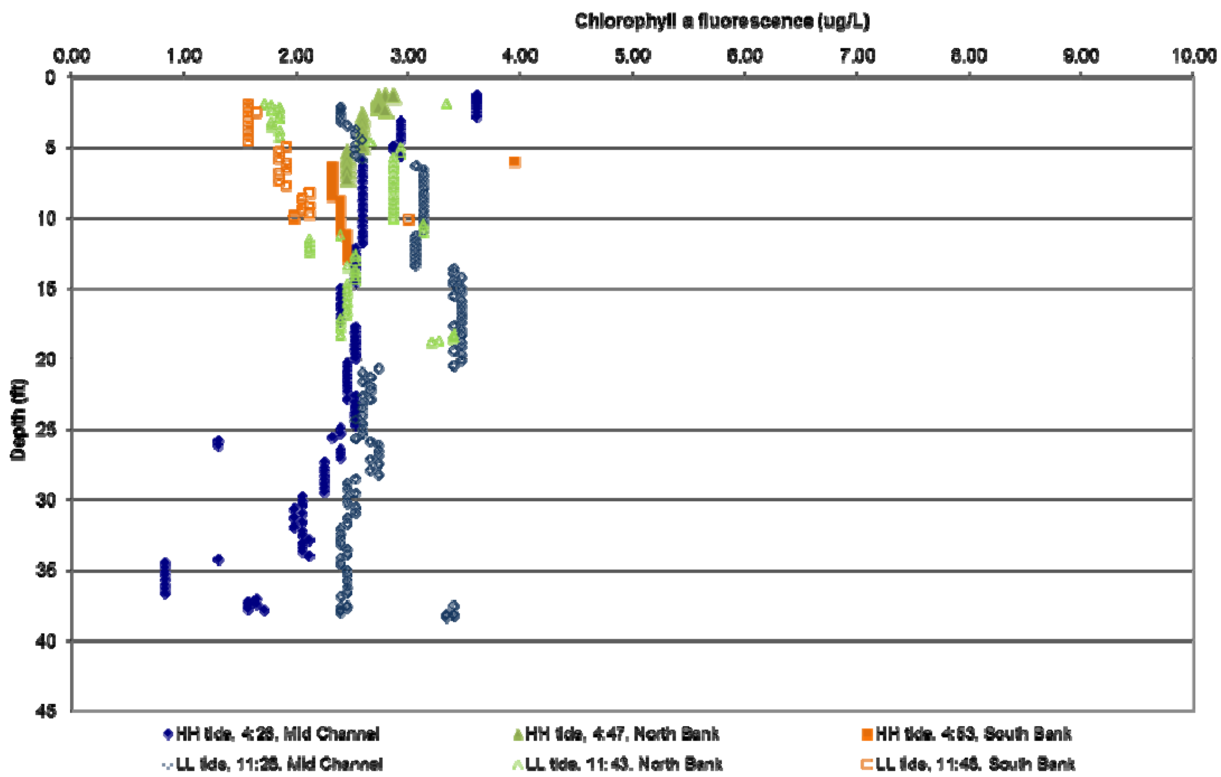


Figure A-22. Chlorophyll *a* profiles measured on August 27, 2011 at the RM 35.8 (Station No. 406).

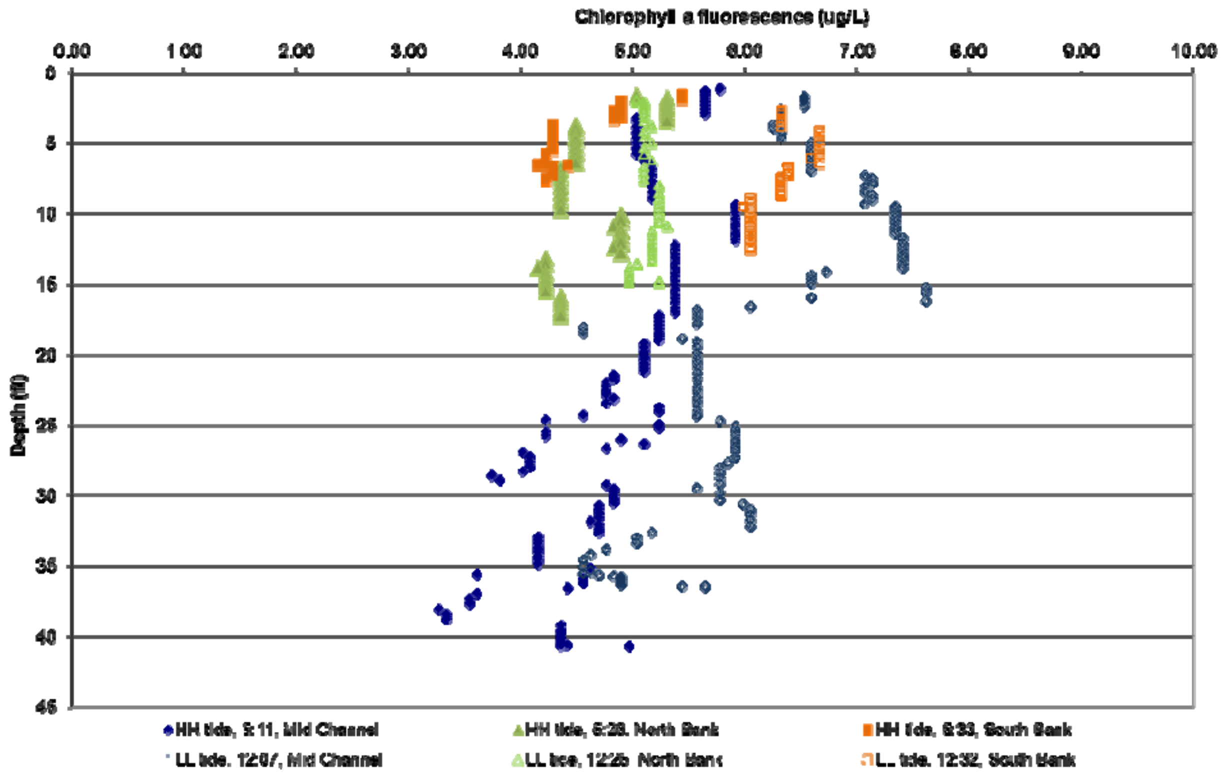


Figure A-23. Chlorophyll *a* profiles measured on August 27, 2011 at RM 39.0 (Station No. 427).

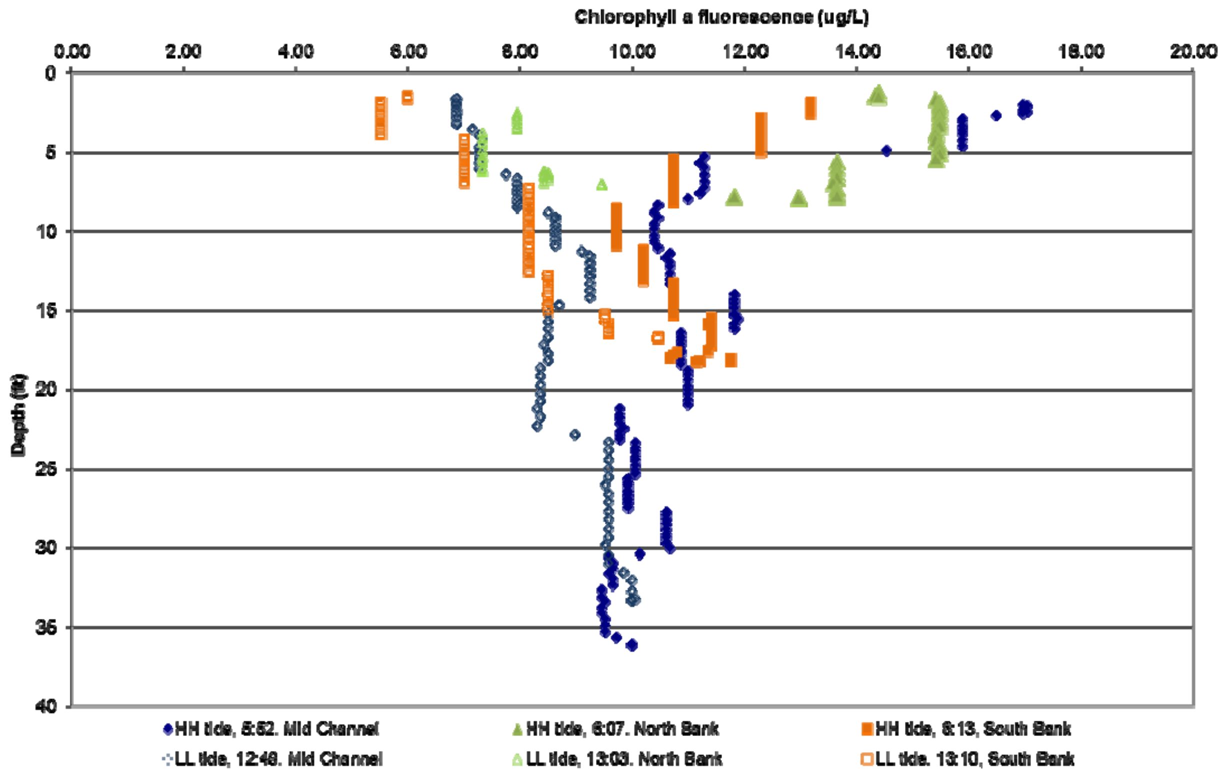


Figure A-24. Chlorophyll *a* profiles measured on August 27, 2011 at the Turning Basin .

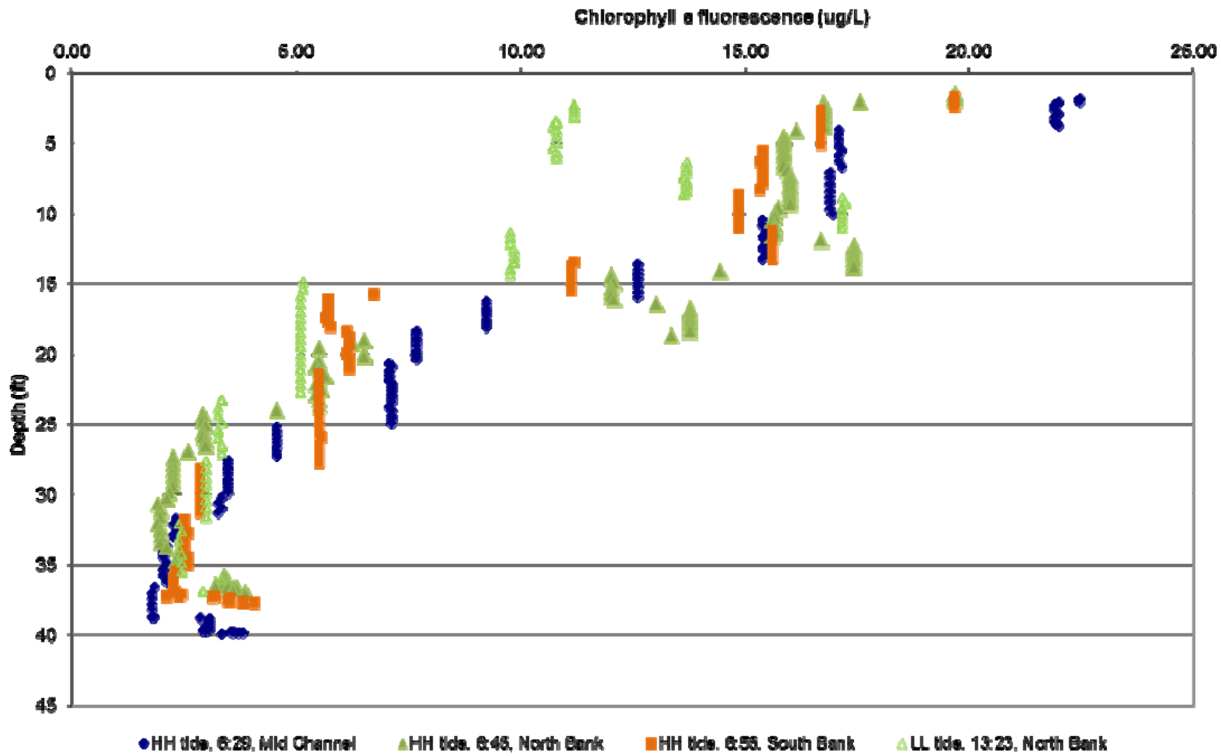


Figure A-25. Chlorophyll *a* profiles measured on August 27, 2011 at the RM 47.7 (Station No. 127, DWR Station Brandt Bridge).