Sedimentation Study of Dickinson Bayou Tidal (Segment 1103)

Prepared in cooperation with the Texas Commission on Environmental Quality
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Environmental Institute of Houston
University of Houston – Clear Lake

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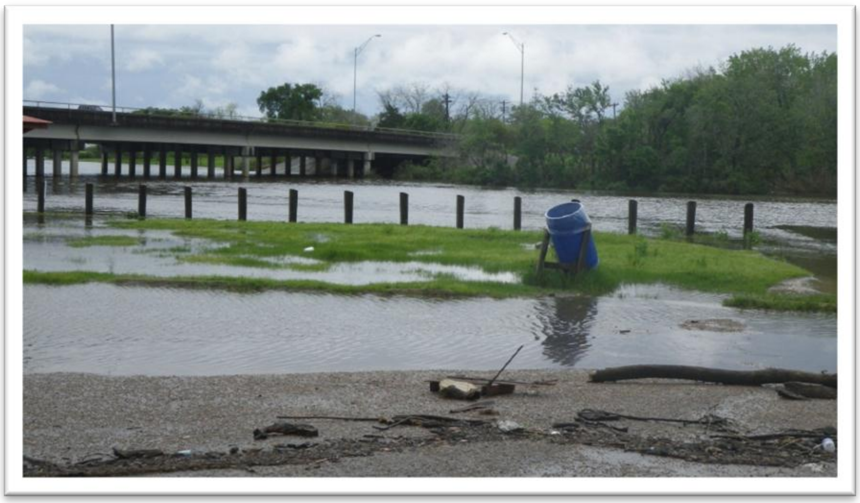

Prepared by Environmental Institute of Houston, University of Houston – Clear Lake

George Guillen, Executive Director
Jenny Oakley, Environmental Scientist
Misty Shepard, Research Associate
Kristen Vale, Research Associate

Principal Investigator

George Guillen, Executive Director (guillen@uhcl.edu)
Environmental Institute of Houston
University of Houston – Clear Lake
2700 Bay Area Blvd.
Box 540
Houston, TX., 77058

Prepared in cooperation with and for the Texas Commission on Environmental Quality

Roger Miranda, Project Manager (roger.miranda@tceq.texas.gov)
12100 Park 35 Circle
MC 203
Austin, TX 78753

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Executive Summary

The Texas Commission on Environmental Quality (TCEQ) is in the process of refining ongoing total maximum daily load (TMDL) modeling efforts associated with Dickinson Bayou Tidal (segment 111) to better understand sediment-associated nutrient and dissolved oxygen dynamics. In particular this data is needed to derive needed input for the Environmental Fluid Dynamic Code (EFDC) sediment process model. The EFDC sediment process model incorporates three basic processes including (1) depositional flux of particulate organic matter (POM), (2) diagenesis of POM, and (3) the resulting nutrient flux from sediments. The sediment model is driven by net settling of particulate organic carbon, nitrogen, phosphorus, and silica from the overlying water to the sediments (depositional flux).

The primary goal of this project was to collect necessary water, sediment and sediment chamber data that will be used in future TMDL development tasks including refinement of the EFDC model. The primary objective of this study was to measure total sediment and organic carbon deposition rates at three separate areas of Dickinson Bayou Tidal (segment 1103) during, at least, two sampling events. In order to complete this objective, the University of Houston Clear Lake – Environmental Institute of Houston (UHCL-EIH) collected and analyzed 1) ambient water, 2) stream bottom sediment, and 3) recently deposited sediment and particulate-associated total and organic carbon, and nutrients (phosphorus and nitrogen), using sediment traps deployed in segment 1103 during four sampling events, including two wet weather and two dry weather event. These data were used to produce estimates of the sedimentation rates and constants necessary to calibrate dynamic water and sediment quality models. One site was located near the upper boundary with Dickinson Bayou Above Tidal (segment 1104). This site was used to represent upper boundary conditions within segment 1103. The other two sites were located in the middle portion of the segment 1103, where depressed dissolved oxygen conditions have been documented. The sampling sites are described in Table 2 and shown in Figure 3. Except where noted in this report, all field sampling and laboratory analyses were conducted in accordance with the project QAPP.

Due to the extensive state-wide drought occurring in Texas during 2011 and errors committed during laboratory analysis we relied primarily on data generated during March and April 2012 for generating estimates of sedimentation during wet and dry weather conditions. Estimates of sedimentation rates for total solids, total carbon, total organic carbon, total nitrogen and phosphorus were successfully generated during this study. The results of this study provide critical information on the physical and chemical composition of suspended sediment and deposited sediment in the upstream reaches of Dickinson Bayou Tidal. Information and estimates of deposition rates of total solids, total carbon, total organic carbon, total nitrogen and total phosphorus are provided in Table 9 and Table 10 and Figure 60-Figure 67. These estimates varied according to site and streamflow regime. In general deposition rates of total solids were higher during wet weather events during the descending limb of the hydrograph versus dry weather events. However, with the exception of particulate-associated carbon, deposition rates of sediment-associated TOC, silicates, TN and TP were higher during dry weather events. This was due to the higher percentage of sediment-associated forms of these chemical constituents during dry weather conditions. This may be due to processes occurring at higher flows, during which the particulate forms of these chemicals are composed of both resuspended bottom sediments and new sediments that have runoff into the bayou.

A major process that may influence the dynamics of sediment deposition in Dickinson Bayou is the presence and magnitude of turbidity maxima. This occurs at the frontal zone between the fresh and saline water. In a wide range of estuaries, stable turbidity maxima can be observed at the upstream tip of the salt wedge. These estuarine turbidity maxima (ETM) are formed by high concentrations of suspended particulate matter where increased deposition occurs. Reduced and reversing current velocities due to tides, changes in flow velocity due to stream morphology, and changes in pH and salinity have all been cited as primary mechanisms for this phenomenon. The presence of the estuarine turbidity maxima can complicate the estimation of deposition rates since immediately upstream and downstream of this zone, deposition rates can change significantly. Future studies focused on determining the possible presence and lateral extent of this zone may be appropriate for gaining a better understanding of suspended sediment dynamics in Dickinson Bayou.

The methodology used by this investigation proved to be adequate for accomplishing the study objectives. Future studies should include concurrent deployment of automated salinity and turbidity meters, and sediment deposition samplers in a vertical array to gain a better understanding of depositional processes within the waterbody.

Introduction

Problem Statement

Historical surface water quality monitoring indicates that dissolved oxygen (DO) concentrations in Dickinson Bayou Tidal (TCEQ Segment 1103) are lower than the criteria used to evaluate attainment of the high aquatic life use designated to Segment 1103 and the intermediate aquatic life use designated in Segment 1104 (TCEQ 2008a). Hypoxia (dissolved oxygen levels below 3.0 mg/L) and anoxia (lack of dissolved oxygen) have been documented in tidal portions of Dickinson Bayou since the early 1970’s (Knudson and Belaire 1975). These early studies documented frequent oxygen depletion and related fish kills, caused by dense algal blooms, which occurred during summers in the six-kilometer portion of Dickinson Bayou directly upstream from two sewage treatment plants near state highway 3. Elevated nutrients were cited as a major cause of impairment and eutrophication in this portion of Dickinson Bayou (Kirkpatrick 1986b, a). Associated conditions including numerous algae blooms and depressed dissolved oxygen have continued, although the frequency of fish kills have declined (Quigg et al. 2009). Physical conditions including relatively deep (> 10 feet) bottom depths and low tidal flushing rates have been identified as major contributing factors associated with ongoing hypoxia events.

Dickinson Bayou Tidal (Segment 1103) was first officially identified as a water body exhibiting impaired water quality for low dissolved oxygen in 1992 (Texas Water Commission 1992). Portions the non-tidal segment of Dickinson Bayou (segment 1104), were also recently listed for not meeting dissolved oxygen standards starting in 2006(Texas Commission on Environmental Quality 2008a). Dickinson Bayou is currently listed on the 2008 and draft 2010 Texas 303(d) list for non-attainment of dissolved oxygen criteria (Texas Commission on Environmental Quality 2008a, 2010). This is based in part on historical surface water quality monitoring data which indicates that dissolved oxygen (DO) concentrations in Dickinson Bayou are lower than the criteria used to evaluate attainment of the high aquatic life use designated in Segment 1103 and the intermediate aquatic life use designated in Segment 1104 (Texas Commission on Environmental Quality 2008a).

In response to these documented conditions, a total maximum daily load (TMDL) project was initiated to evaluate causes and the effects of low dissolved oxygen on aquatic life and to determine the actions necessary to maintain water quality in the non-tidal and tidal portions (Segments 1103 and 1104) of Dickinson Bayou (Texas Commission on Environmental Quality 2008c). The draft total maximum daily load (TMDL) for dissolved oxygen in both Dickinson Bayou segments was issued in 2008 (Texas Commission on Environmental Quality 2008c). The TMDL described the relationship of pollutants associated with dissolved oxygen (DO) in Dickinson Bayou Tidal (Segment 1103) and Dickinson Bayou above Tidal (Segment 1104). The TMDL analysis also showed that the bottom depth pattern of Dickinson Bayou contributed significantly to the non-attainment of DO criteria as currently applied to the bayou and recommended a reassessment of the criteria or the criteria assessment methodology applied to the bayou. During the public review of the draft TMDL, TCEQ decided that additional data on sedimentation rates and associated processes including sediment nutrient levels and fluxes were needed to refine the Environmental Fluid Dynamics Code (EFDC) model predictions (Tetra Tech Inc. 2006, 2007a, b, Rifai 2010).

In a parallel effort, the TCEQ has partnered with the steering committee of the Dickinson Bayou Watershed Partnership and AgriLife Extension to develop a watershed protection plan (WPP) for Dickinson Bayou (Dickinson Bayou Watershed Partnership 2009). In May 2009, the TCEQ accepted the Dickinson Bayou Watershed Partnership's WPP and submitted it to the EPA for approval. The EPA recommended several revisions to the plan, but gave preliminary approval to implement several major projects included in the plan.

The TCEQ concluded that additional data was needed for estimation of sedimentation rates and partitioning of nutrients. To obtain this information additional field collection of ambient water, stream bed sediment and recently deposited sediments was needed. Therefore plans were made to collect these data in 2011 and later in 2012 at several sites extending from the upper to middle portions of the tidally-influenced segment of Dickson Bayou (Segment 1103). This data will be used to determine sedimentation rates and associated water quality parameters in the upper and middle portions of the tidally-influenced segment of Dickinson Bayou (TCEQ Segment 1103). This data was needed by TCEQ for refinement of ongoing TMDL modeling associated with this segment to better understand nutrient and associated dissolved oxygen dynamics. In particular this data is needed to derive needed input for the Environmental Fluid Dynamics Code (EFDC) model (Tetra Tech Inc. 2006, 2007a, b).

Study Area

The study area is located within TCEQ Segment 1103, Dickinson Bayou Tidal. This segment is part of the Dickinson Bayou watershed which is located within the San Jacinto-Brazos Coastal Basin. Dickinson Bayou originates near the city of Alvin, south of Houston, and flows east through Dickinson before discharging into Dickinson Bay, a tributary of the Galveston Bay system (

Figure **1**). Dickinson Bayou is a 22.7 mile long. The Dickinson Bayou watershed has a drainage area of 105 square miles (Dickinson Bayou Watershed Partnership 2009). It encompasses portions of nine cities (Alvin, Dickinson, Friendswood, Kemah, League City, Manvel, San Leon, Santa Fe and Texas City) and two counties (Galveston and Brazoria).

Dickinson Bayou is composed of two TCEQ "designated" segments: the non-tidal portion, Segment 1104, which is approximately 7 miles in length, and the tidally influenced portion, Segment 1103 (Dickinson Bayou Watershed Partnership 2009). The Texas Surface Water Quality Standards describe the non-tidal Segment 1104 as flowing "from a point 4.0 km (2.5 miles) downstream of FM 517 in Galveston County to FM 528 in Galveston County" (30 TAC §307, Appendix C). The tidal segment, 1103, is defined as located "from the Dickinson Bay confluence 2.1 km (1.3 miles) downstream of SH 146 in Galveston County to a point 4.0 km (2.5 miles) downstream of FM 517 in Galveston County".

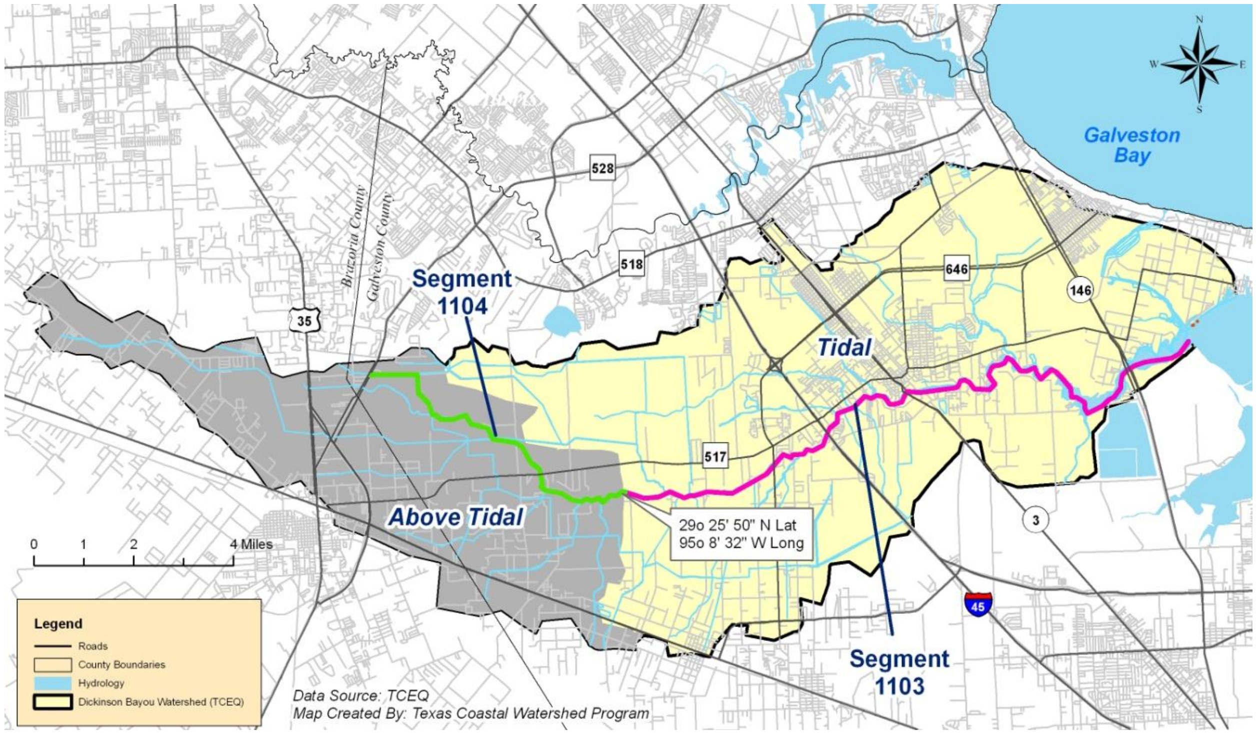


Figure 1. Dickinson Bayou, Texas watershed depicting TCEQ designated segment boundaries and watershed area. Map source: (Dickinson Bayou Watershed Partnership 2009).

The climate in the Dickinson Bayou watershed is classified as subtropical, which is defined as having hot, humid summers and dry winters. The Dickinson Bayou watershed is within the Gulf Coastal Prairies and Marshes ecoregion, an area characterized as containing nearly level, un-dissected plains with native vegetation types composed of tall grass prairie and post oak savanna (Dickinson Bayou Watershed Partnership 2009). About 55% of the watershed is within the 100-year flood plain (the area of the flood plain which has a 1% chance of flooding in any given year). Two major irrigation canals (the Gulf Coast Water Authority's American Canal and Galveston System) cross the watershed (Dickinson Bayou Watershed Partnership, 2009).

Dickinson Bayou is perennial throughout most of its course. Dickinson Bayou Above Tidal (Segment 1104) is a small coastal prairie stream. Flow in the uppermost reaches of Segment 1104 is sustained by wastewater effluent generated southeast of the City of Friendswood (WQ0013632-001 Meadowland Utility Corp. and WQ12935-001 K.C. Utilities-Pine Colony).

Rainfall runoff from rural creeks and ditches north of the City of Alvin and south of the City of Friendswood results in large seasonal flow variations. Flow velocities are typical of a shallow coastal prairie stream but decrease dramatically downstream of the confluence with Segment 1103 as depth increases and the stream becomes tidally influenced.

The entire Dickinson Bayou watershed has been undergoing increased drainage modification and urbanization over the past 20 years (Dickinson Bayou Watershed Partnership 2009). Dickinson Bayou above Tidal has been highly modified, and serves as a portion of the water conveyance system for the Galveston County Consolidated Water Drainage District. Rice farming in the area created many diversion canals in this segment. Prior to 1990, irrigation return flows from rice farming and other irrigated row crop production in this portion of the watershed also produced high seasonal flows (Texas Water Quality Board (TWQB) 1976). Since 1990, rice farming has diminished significantly in this portion of the watershed and irrigation return flows currently account for only a small portion of flow in the segment. Within the watershed, the major land development is concentrated in Segment 1103 around the cities of Dickinson and League City and along the Interstate 45 corridor. The remainder of the watershed is rural and undeveloped. Commercial development is light to medium industrial and office warehouses along with retail merchandizing. The dominant land use classification for the Dickinson Bayou watershed is open space/agriculture (≤1 dwelling unit per 20 acres), which accounts for approximately 50% of land use in the watershed (Dickinson Bayou Watershed Protection Plan, 2009).

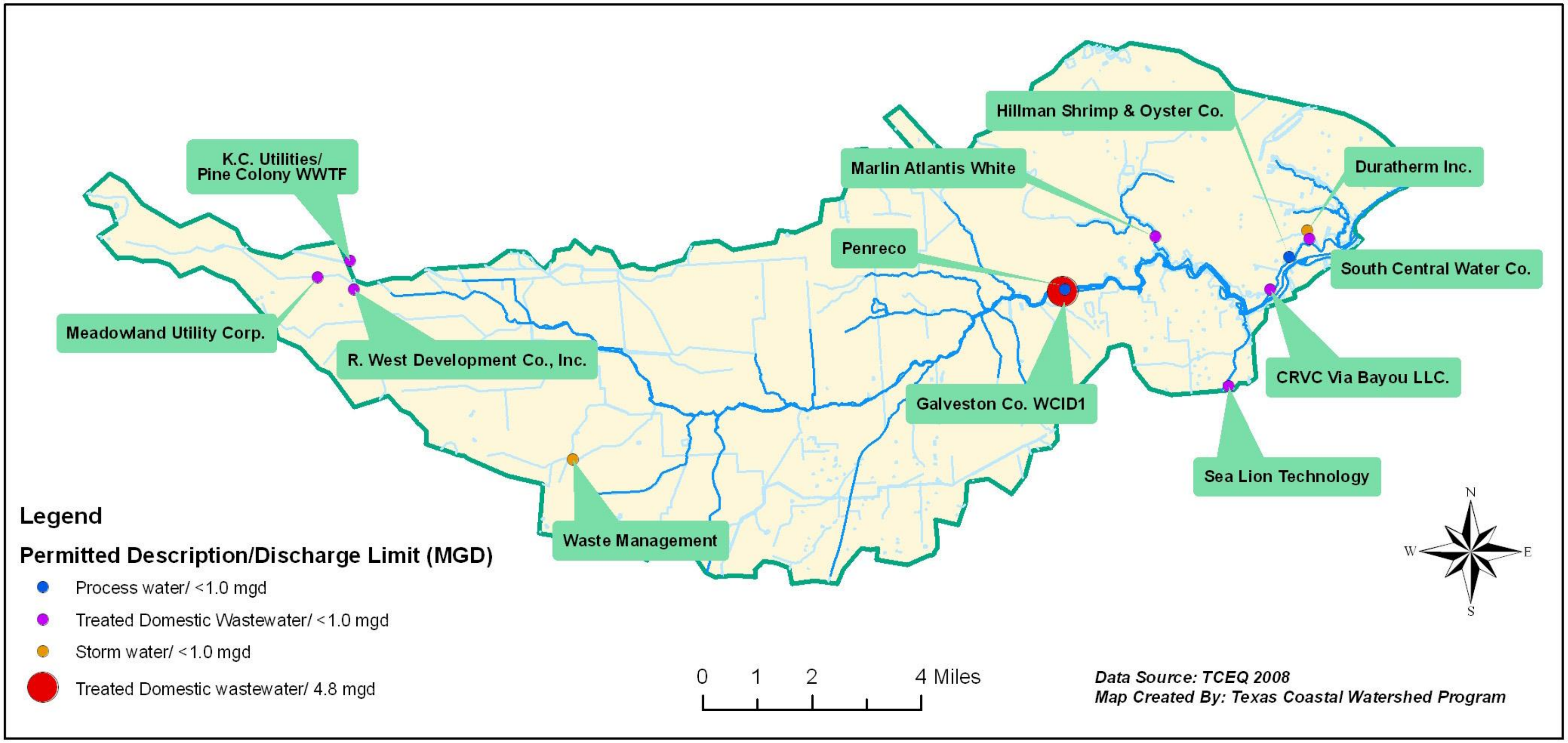
There are five active discharge permits in Dickinson Bayou for domestic wastewater (sewage) treatment facilities and five active permits for discharge of industrial wastewater (Texas Commission on Environmental Quality 2008c, Dickinson Bayou Watershed Partnership 2009)(Table 1 and Figure 2). The permit issued to Galveston County WCID #1 allows the largest discharge of wastewater into Dickinson Bayou at 4.8 million gallons per day (MGD). The next largest permitted discharge is for 0.95 MGD held by R. West Development Co., Inc. although this facility is not currently in operation. The remaining permitted domestic wastewater facilities currently in operation in the watershed each have permitted flows below 0.1 MGD.

As previously mentioned, Dickinson Bayou tidal has experienced low dissolved oxygen levels which do not support the designated aquatic life uses (Houston Galveston Area Council 2006, Texas Commission on Environmental Quality 2008a, c). Various factors influence dissolved oxygen dynamics in surface water bodies, including in-situ production, biochemical oxygen demand (BOD), point and non-point source pollution, reaeration, sediment oxygen demand, suspended sediments and sedimentation, temperature, and streamflow/tidal regime. However, other factors that control the deposition of sediment in surface water bodies also affect dissolved oxygen dynamics indirectly. The water quality of the tidal portion of Dickinson Bayou can also change due to changes associated with tidal movement and changing salinity regime. Salinity in this portion of the bayou near the study area have ranged between 0.2 and 16.9 ppt with a median value of 6 ppt (Houston Galveston Area Council 2006). Salinity is however vertically stratified and may form a distinct halocline (salt wedge) which can alter the vertical movement of some dissolved and suspended constituents. For example, the presence of a salt wedge is also often associated with a “turbidity maximum,” which is a zone of maximum sediment flocculation and deposition due to cancellation of particle charges and deposition of fine sediments (Dyer 1997). The turbidity maximum is a zone of high concentrations of suspended sediment, higher than in the river or in the estuary, downstream. Turbidity maxima are located at, or near, the head of the tidal salt intrusion. Historical data collected in the tidal portion of Dickinson Bayou has documented the presence of a distinct vertical salinity gradient which is most pronounced during dry weather and low streamflow (Houston Galveston Area Council 2006).

Table 1. Permitted wastewater facilities in the Dickinson Bayou watershed. Data sources: (Texas Commission on Environmental Quality 2008c) cited in: (Dickinson Bayou Watershed Partnership 2009).

TPDES Permit Number	Facility	Average Discharge 2007 (MGD)	Permitted Discharge Limit (MGD)	$CBOD_5$ (mg/L)	Total Suspended Solids (mg/L)	Ammonia-N (mg/L)	Dissolved Oxygen (mg/L)	Description of Discharge
WQ0013632-001	*Meadowland Utility Corp*	*0.007*	*0.0234*	*10.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*
WQ0012935-001	*KC Utilities, Pine Colony Wastewater Treatment Facility*	*0.03*	*0.05*	*10.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*
WQ0014440-001	*R. West Development Co Inc*	*na*	*0.95*	*10.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*
WQ0003416-000	*West Management of Texas, Inc.*	*0.13*	*Report*	*na*	*na*	*na*	*na*	*Storm water/ground water*
WQ0010173-001	*Galveston Co. WCID1*	*2.26*	*4.8*	*7.0*	*15.0*	*1.5*	*6.0*	*Treated Domestic Wastewater*
WQ0000377-000	*Penreco (outfall 001)*	*0.06*	*0.075*	*14.6 (lbs/day)* BOD_5	*20.0*	*na*	*na*	*Process water*
WQ0014570-001	*Marline Atlantis White*	*na*	*0.5*	*5.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*
WQ0014326-001	*CRVC Via Bayou LLC.*	*0.001*	*0.02*	*10.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*
WQ0003749-000	*Hillman Shrimp & Oyster Co*	*0.003*	*0.07*	*10.0*	*15.0*	*3.0*	*4.0*	*Process water*
WQ0003479-000	*Sea Lion Technology (outfall 201)*	*0.07*	*0.02*	*10* BOD_5	*na*	*3.0*	*na*	*Treated Domestic Wastewater*
WQ0004086-000	*Duratherm Inc.*	*0.08*	*Report*	*na*	*na*	*na*	*na*	*Treated stormwater*
WQ0014804-001	*South Central Water Co.*	*na*	*0.95*	*10.0*	*15.0*	*3.0*	*4.0*	*Treated Domestic Wastewater*

Figure 2. Location of permitted discharges within the Dickinson Bayou watershed. Map and data sources: (Dickinson Bayou Watershed Partnership 2009).



Study Objective

The TCEQ concluded that additional data was needed for estimation of sedimentation rates, including carbon and nutrients. This data will be used to develop sediment partitioning models needed to conduct a TMDL. To obtain this information additional field collection of ambient water, bulk stream bed sediment and recently deposited sediments was needed. Therefore plans were made to collect these data in 2011 and if needed 2012 at several sites extending from the upper to middle portions of the tidally influenced segment of Dickson Bayou (segment 1103). This data will be used to determine sedimentation rates and associated water quality parameters in the upper and middle portions of the tidally influenced segment of Dickinson Bayou (TCEQ Segment 1103). This data was needed by TCEQ for refinement of ongoing TMDL modeling associated with this segment to better understand nutrient and associated dissolved oxygen dynamics. In particular this data is needed to derive needed input for the EFDC sediment process model (Tetra Tech Inc. 2006, 2007a, b). The EFDC sediment process model incorporates three basic processes including (1) depositional flux of particulate organic matter (POM), (2) diagenesis of POM, and (3) the resulting sediment flux (DiToro and Fitzpatrick 1993, Park et al. 1995, United States Environmental Protection Agency 2005). The sediment model is driven by net settling of particulate organic carbon, nitrogen, phosphorus, and silica from the overlying water to the sediments (depositional flux).

The primary goal of this project is to collect necessary water, sediment and sediment chamber data that will be used in future TMDL development tasks including refinement of the EFDC model. The primary study objective of this project was to measure the total sediment and organic carbon deposition rates at three separate areas of Segment 1103 during at least two sampling events including a wet and dry weather event. In order to complete this objective, the University of Houston Clear Lake – Environmental Institute of Houston (UHCL-EIH) collected and analyzed total sediment and organic carbon deposited in sediment traps deployed in Segment 1103 during four sampling events, including two wet weather and two dry weather events, during April-June 2011 and March-April 2012 in order to produce estimates of the sedimentation rates and constants necessary to calibrate a dynamic water-sediment quality model. Ultimately due to errors in laboratory analysis the majority of data used for this analysis was derived from the data collected during the 2012 monitoring events. The furthest upstream location sampled was located near the upper boundary with Segment 1104. This site was used to represent upper boundary conditions within Segment 1103. The other two sites were located in the middle portion of the Segment 1103, where depressed dissolved oxygen conditions have been documented. Additional data on total nitrogen and phosphorus levels and flux rates were also measured and calculated for recently deposited sediment. Particles size distribution in bottom sediment and sediment traps were also determined to differentiate cohesive particles (<0.0625 mm) from non-cohesive sediment (> 0.0625 mm)(Milburn and Krishnappan 2003, Huang et al. 2006). All field sampling and laboratory analyses were conducted in accordance with the project's quality assurance project plan (QAPP)(Guillen 2012).

Methods

Site Selection and Description

The sampling design rationale for this study was to select several sites within the water body, extending from the upper portion to the middle portion of Segment 1103 (Table 2 and Figure 3). These represent main-stem sites and include three previously established TCEQ monitoring stations that have been used to assess water quality in Dickinson Bayou in the past. The use of these three sites provides critical information on intra-bayou variability and spatial trends in measured water and sediment quality variables. This is extremely important for deriving important process variables that will be used in future modeling efforts. These locations span the upstream extent of the tidal portion of this water body and are located at mid-stream near the thalweg and deepest portion of the stream. These sites were selected in consultation with the TCEQ project manager to insure that data collected during this effort is representative of stream conditions.

Table 2. Location of sampling sites on Dickinson Bayou.

Site	TCEQ Site ID	Site Description	Latitude	Longitude	TCEQ Segment
1	11464	Dickinson Bayou tidal at Arcadia-Cemetery Road north of Arcadia	29.429613	-95.114744	1103
2	18649	Dickinson Bayou 1.20 km upstream of I 45 Bridge and 140 M downstream of County Ditch No 9 Confluence NR Chapparal Rec Assn Golf Club at Ave J	29.439848	-95.082001	1103
3	11461	Dickinson Bayou Tidal at Benson Bayou Confluence	29.456511	-95.057452	1103

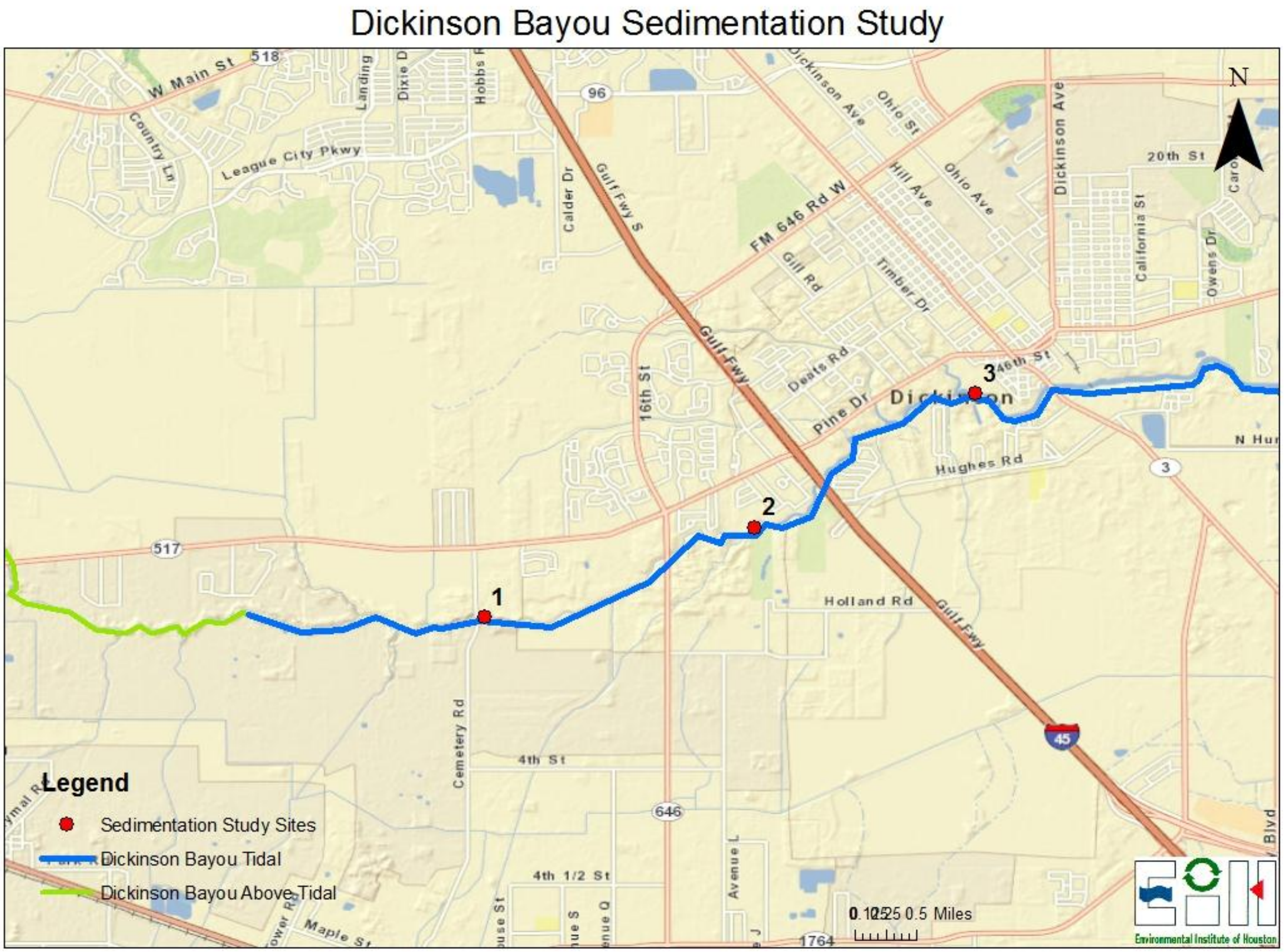


Figure 3. Location of sedimentation sampling sites in Dickinson Bayou. (refer to Table 2 for site descriptions).

Sampling Dates

Between April and June of 2011, UHCL collected water, suspended sediment and bottom sediment samples in Dickinson Bayou as part of this project and under the version of the project's QAPP document approved in March of 2011 (Table 3). Although the water and bottom sediment samples collected by UHCL were analyzed in accordance with the methods specified in the QAPP, several of the results of the analyses of suspended sediment samples did not meet the quantification limits and/or the precision requirements specified in the (2011) QAPP. Moreover, the analysis of particle-associated total carbon (TC) and total organic carbon (TOC) collected during the wet weather event of June 24, 2011 was not usable, because the wrong method was used to analyze these samples (i.e., the samples were analyzed as water samples instead of sediment samples).

UHCL re-sampled the settled sediment under one dry and one wet weather condition in March and April 2012 to collect the data to replace the 2011 data that was rendered un-useable due to the laboratory deficiencies and non-conformances described above. Two sampling events occurred during a period of relatively low flows, stable water levels and no precipitation for at least 3 days prior to sample collection (Table 3). The other two sampling events occurred during wet weather conditions. Wet weather was considered an event where recent rainfall was sufficient to increase water levels and increase suspended sediment within a short period of time (a single or prolonged storm event within a 24 hour period which produced observable storm influenced hydrology such as increased downstream velocity and rise in water level). Ambient water sampling was also conducted during all events. Duplicate ambient water and sediment trap samples were collected at each site. During 2011, bulk stream bed samples were also collected once during dry weather conditions.

Table 3. Sampling dates, sites and sample types collected during the Dickinson Bayou sedimentation study. River kilometers (km) are approximate and based on GIS analysis.

Date	Wet/ Dry	Site Number	TCEQ Station ID	Site Description	Latitude	Longititude	River km	Sediment Sample	Water Sample	Sediment Trap Sample
April 20- May 5, 2011	Dry	1	11464	Dickinson Bayou at Cemetary Road	29.42961	-95.114744	21.21	X	X	X
		2	18649	Dickinson Bayou at Ditch # 9	29.4398	-95.082000	17.42	X	X	X
		3	11461	Dickinson Bayou downstream of Bensons Bayou	29.45651	-95.057452	14.00	X	X	X
June 22-24, 2011	Wet	1	11464	Dickinson Bayou at Cemetary Road	29.42961	-95.114744	21.21		X	X
		2	18649	Dickinson Bayou at Ditch # 9	29.4398	-95.082000	17.42		X	X
		3	11461	Dickinson Bayou downstream of Bensons Bayou	29.45651	-95.057452	14.00		X	X
March 20- 22, 2012	Wet	1	11464	Dickinson Bayou at Cemetary Road	29.42961	-95.114744	21.21		X	X
		2	18649	Dickinson Bayou at Ditch # 9	29.4398	-95.082000	17.42		X	X
		3	11461	Dickinson Bayou downstream of Bensons Bayou	29.45651	-95.057452	14.00		X	X
April 24-27, 2012	Dry	1	11464	Dickinson Bayou at Cemetary Road	29.42961	-95.114744	21.21		X	X
		2	18649	Dickinson Bayou at Ditch # 9	29.4398	-95.082000	17.42		X	X
		3	11461	Dickinson Bayou downstream of Bensons Bayou	29.45651	-95.057452	14.00		X	X

Sampling Methods

Precipitation and Stream Stage

The primary source of information on forecasts, current and historical weather used for this study was the National Weather Service. Data on precipitation that occurred prior to and during sampling was obtained from the League City National Weather Service (NWS) Station (DickinsonWFO:http://www.srh.noaa.gov/productview.php?pil=HGXCF6HGX&version=9&max=61). This site is located close to the three project sampling sites. Rainfall at this station is considered representative of the Dickinson Bayou watershed and has been used in previous hydrological and water quality studies (East and Hogan 2006). Data from at least the previous 7 days prior to sampling was compiled to document site conditions. Wet weather conditions occurring after significant local thunderstorms were targeted for two of the sampling events. We attempted to conduct wet weather sampling during the period after the peak flow occurring during the descending portion of the hydrograph. Wet weather is broadly defined as a rain event within the watershed that causes a significant rise in water levels in the tidal portion of Dickinson Bayou. We mobilized monitoring resources and deployed sediment traps whenever a storm had occurred where a single or prolonged storm event within a 24 hour period which produced observable storm influenced hydrology such as increased downstream velocity and rise in water level after a period of at least 72 hours without rain. The instrumentation and sediment traps were deployed as soon as possible after peak flows were observed.

Relative water level (gage height) was measured at the Dickinson Bayou at a previously installed continuous monitoring TCEQ station deployed at a bridge on State Highway 3 (see Figure 3 for location of State Highway 3 in relation to the sampling stations). The primary intent of water level monitoring is to document and validate hydrological conditions during each sampling event. The gage site on State Highway 3 is tidally influenced. Gage height (stage) is defined as the water surface measured in feet above a local reference point, or “gage datum.” For the Dickinson Bayou the gage datum was arbitrarily chosen and referenced to a temporarily installed staff gage nearby. Gage height data was measured using pressure transducers manufactured by In-Situ Inc. A vented pressure transducer, level TROLL 500, was used (In-Situ Inc. 2010) to measure water levels. These instruments are extremely sensitive to changes in water depth, with accuracy of 1 cm or less (0.1% full-scale) (In-Situ Specification sheet, http://www.in-situ.com/force_download.php?file=985, accessed July 2010 and In-Situ Inc. 2010). Water level was electronically recorded at 15-minute intervals by internal data-collection software over the period of surveillance. Data was downloaded from the instruments into a computer using the *Win-Situ* software package and processed and analyzed for trends.

Because a stage-discharge relationship cannot be developed for Dickinson Bayou at State Highway 3, due to the fact that the bayou is tidally influenced in this location and also due to the non-standard methodology used to obtain data for relative stage measurements, this data was not reported to the TCEQ’s SWQMIS database.

In addition, metallic staff gages were installed at each of the monitoring sites to evaluate relative water levels during each sampling event. These values were standardized, that is an initial reading was set to zero and all subsequent measurements converted to differences from the initial reading or delta values, to increase the comparability of site readings with TROLL gage readings.

Streamflow and Water Quality Sampling

The project included simultaneous monitoring of streamflow, ambient water, bottom sediment, and suspended sediment deposition samples collected from static sampling tubes (i.e., sediment traps) at three sites during four sampling events in Dickinson Bayou. The University of Houston-Clear Lake followed the field sampling procedures documented in the TCEQ Surface Water Quality Monitoring Procedures Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment and Tissue for the collection of hydrology, ambient water quality and bottom stream sediments (Texas Commission on Environmental Quality 2008b). Amounts of sample required, containers, preservation and holding time are listed in Table 4. Additional field sampling procedures outlined in this section reflect specific monitoring requirements under this TMDL Project. These additional procedures are consistent with TCEQ field sampling procedures. All sampling was conducted in accordance with the project QAPP.

During deployment and retrieval of sediment traps, and collection of water and stream sediment samples, vertical profiles of water quality, including water temperature, conductivity, salinity, pH and dissolved oxygen were conducted with a multi-parameter water quality meter to characterize site conditions that might affect ambient samples. Surface turbidity was characterized using a secchi tube and a nephelometer. Stream velocity profiles and streamflow were estimated using a Sontek River Surveyor M9 instrument (SonTek/YSI 2009). Multiple velocity transects were conducted at each monitoring site which yielded replicate stream velocity profiles and streamflow estimates. Stream velocity profiles were extracted and total streamflow (Q) was estimated for each transect using Sontek River Surveyor Live v.1 software. Average streamflow (Q) was then calculated using this information.

Table 4. Field sampling and handling procedures used during the project, including container types, minimum sample volume, preservation requirements, and holding times (Texas Commission on Environmental Quality 2007, 2008b).

Parameter	Matrix	Container	Preservation (includes Ice)	Sample Volume	Holding Time
Residue, Total Nonfilterable	water	Plastic or glass	Cool to < 6°C but not frozen	1000 ml	7 days
Volatile Suspended Solids	water	Plastic or glass	Cool to < 6°C but not frozen	1000 ml	7 days
Carbon, Dissolved Organic, DNPC (DOC)	Water	Plastic or glass	2 mL 1:1 H_2SO_4 to pH < 2 and cool to < 6^oC but not frozen	100 ml	28 days
Carbon, Total Organic, NPOC (TOC)	water	Plastic or glass	2 mL 1:1 H_2SO_4 to pH < 2 and cool to < 6^oC but not frozen	100 ml	28 days
Solids Volatile in sediment	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Total Organic Carbon	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Total Carbon	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Solids in sediment, percent by weight (dry)	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Phosphorus Total, Bottom Deposits	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Organic Phosphorus, Total, Bottom Deposits	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Nitrogen,Total, Bottom Deposits	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Organic Nitrogen, Total, Bottom Deposits	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Silica	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days
Sediment Particle Size	Sediment & Sediment Trap	Plastic or glass	Ice, Cool to < 6°C, dark	500 grams	28 days

Stream Sediment Collection

Stream bed sediment samples were collected during dry weather events in 2011 using either an Ekman or Ponar dredge following standard sediment sampling methods (Texas Commission on Environmental Quality 2008b)(Table 4). These water quality and sediment bed samples were collected in part to evaluate the comparability and representativeness of data obtained from sediment traps and to develop estimates for model processes. Clean sampling containers were provided by the contract laboratory.

Sediment Deposition Sampling

Sediment trap sampling procedures used in this study to estimate sediment and carbon flux rates are not listed in the current TCEQ standard monitoring procedures manuals (Texas Commission on Environmental Quality 2008b). Instead, we adopted and used, with minor modifications, a research method developed by the USGS for sediment trap sampling (Kiesling 2006, Roussel et al. 2007). The USGS study was conducted under contract to the TCEQ and had an approved QAPP (Kiesling 2006). The non-standard protocols used in this project included the estimation of volume and settling velocity of suspended solids and organic carbon. To accomplish this *sedimentation traps* were used to estimate carbon flux from the euphotic zone into bottom waters and general sedimentation rates. Sediment traps typically collect dead phytoplankton and zooplankton, fecal pellets of zooplankton and fish, sediment, and detritus. All of these items contribute to the total amount of suspended solids that ultimately settle out of the water column.

Sedimentation is the vertical rate of flux of particulate materials from the water column to the solid bed underlying it. The rate at which material settles in the water column is of critical importance to estimates of material flux and algal mortality within the context of water quality models. Sedimentation rates represent the transport of particulate chemical species vertically through the water column with the assumption that these materials reach the sediments. Sediment traps were used to measure the deposition of particulates over a set period by integrating particle rain through time inside the trap chamber.

The sediment sampler used in this study was modeled after units used by the USGS on the Arroyo Colorado (Kiesling 2006, Roussel et al. 2007)(Figure 4). Our original sediment collector consisted of two cylindrical sediment traps connected together. Cylindrical traps of similar ratios (diameter:length) have been shown to produce the most accurate vertical sedimentation rates (Bale 1998). Based on the scientific literature the recommended ideal ratio is 1:7 (diameter:length) which is the ratio we used (Hargrave and Burns 1979, Bloesch and Burns 1980, Mudroch and MacKnight 1994). Our traps were constructed with clear PVC to facilitate visual inspection of the contents (Figure 5). This sampler design was used at sites 2 and 3 and is described in the following pages along with its physical dimensions including surface areas and volumes.

Figure 4. Sedimentation chambers used during USGS studies (Roussel, et al. 2007).

Figure 5. Original sediment collector design used at sites 2 and 3 during the study.

Original sedimentation collector

1 collector = two large tube traps bound together

Surface opening inner diameter of one tube trap = 4.00" = 10.16 cm; radius = 5.08 cm

Height of a trap = 71.12 cm

Ratio D/H of trap = 10.16/71.12 = 1/7 = 0.143

Surface area of trap opening = πr^2 (area of circle) = $\pi * (5.08)^2$ = 81.07319 cm^2 = 0.0081073 m^2

Total surface area of openings for 2 trap tubes = 1 collector = ($\pi r^2 * 2$) = 81.07319 cm^2 * 2 = 162.1464 cm^2 = 0.0162146 m^2

Inner cylinder surface area of trap = (πr^2 * 2 = area of ends) + (2πrh =area of the inner wall of tube trap) = (162.1464 cm^2) + (2 * π * 5.08 cm*71.12 cm) = 2,270.05 cm^2

Total inner cylinder area for two trap cylinders = 4540.10 cm^2

Total volume of one trap cylinder = $\pi r^2 h = \pi (5.08)^2(71.12)$ = 5,765.93 cm^3 = 5.76593 L

Total volume of two trap cylinders = 1 collector = 2 * 5,765.93 = 11,531.85 cm^3 = 11.53185 L

Shallow water sedimentation collector

Due to shallow depths encountered at site 1, UHCL/EIH re-engineered the sediment collector array used at this site by reducing the total height of the tubes, using narrower tubes, but also adding more tubes (eight) to the array (Figure 6). In addition, white PVC pipe was used, because the clear was not readily available. The resulting dimensions, areas and volumes for each PVC sediment trap tube and sampler (8 total tubes per sampler) were calculated using the formulas below.

1 collector = 8 cylinder traps bound together

Inner Diameter of trap = 2.00" = 5.08 cm; radius = 2.54 cm

Height of trap = 14" = 35.56 cm

Ratio D/H of trap = 5.08/35.56 = 1/7 = 0.142

Surface area of opening of trap = πr^2 = (area of circle) = $\pi*(2.54)^2$ = 20.2683 cm^2 = 0.0020268 m^2

Surface Area for opening of 8 cylinder traps = 8* 20.2683 = 162.1464 cm^2 = 0.0162146 m^2

Inner cylinder surface area = (πr^2 = area of circle) x 2 + (2πrh = area of side) = 608.04 cm^2

Total inner cylinder surface area of 8 cylinders in one sampler = 4,864.3918 cm^2

Total volume for one cylinder trap = $\pi r^2 h = \pi(2.54)^2(35.56)$ = 720.7407 cm^3 = 0.0720740 L

Total volume for all 8 cylinder traps = one collector = 5765.9256 cm^3 = 5.765926 L

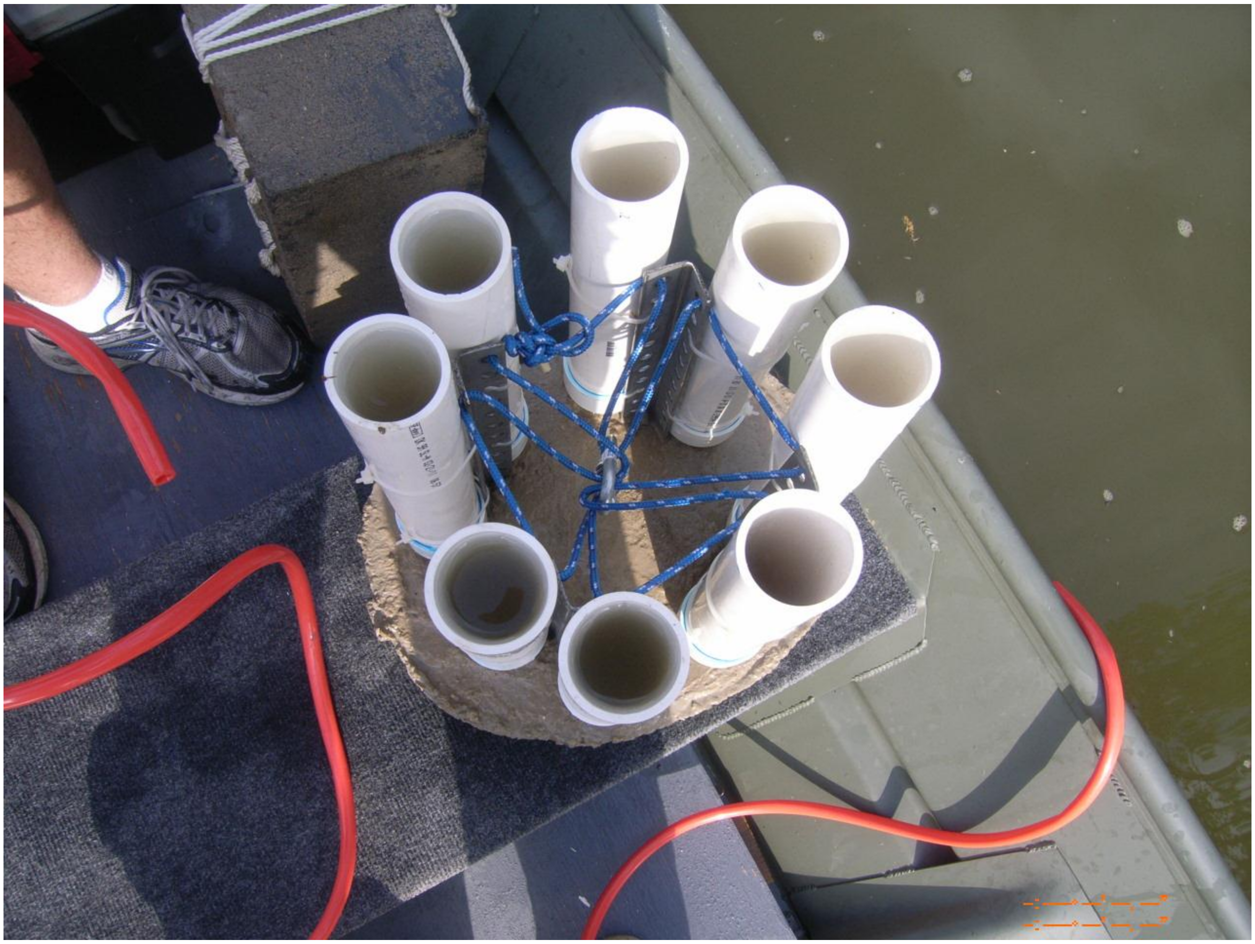


Figure 6. Alternative shallow water sediment sampler used at site 1 (TCEQ Station 11464).

The samplers, consisting of paired sediment traps or bundled, were suspended near the sediment/water interface by attaching them to a line that had floats on the surface and a weight at the bottom to keep the samplers vertical. At each site, duplicate samplers were deployed within 10-20 feet of each other. After a specified period of time, approximately 120 hours for dry weather and 48 hours for wet weather the traps were retrieved. For wet weather events we attempted to collect sediment throughout the declining portion of the hydrograph since suspension and deposition of sediments will vary asymmetrically due to hysteresis (Knighton 1998). The exact time of deployment and retrieval were noted for each trap to allow for the computation of a flux. For retrieval, traps were pulled to the surface, ensuring the collectors remained vertical. The cylinders were then emptied into 7.6-liter carboys. Distilled water was used to rinse the cylinders as needed to ensure that all solid material collected was transferred to the carboys. The number of carboys needed per replicate sampler and site varied but were noted in the chain of custody records. These 7.6 liter carboys were delivered to the laboratory for chemical and physical analysis of settled material and sediment. Prior to analysis, the contents from each carboy within each replicate sample were composited to yield one composite sample per replicate sampler per site.

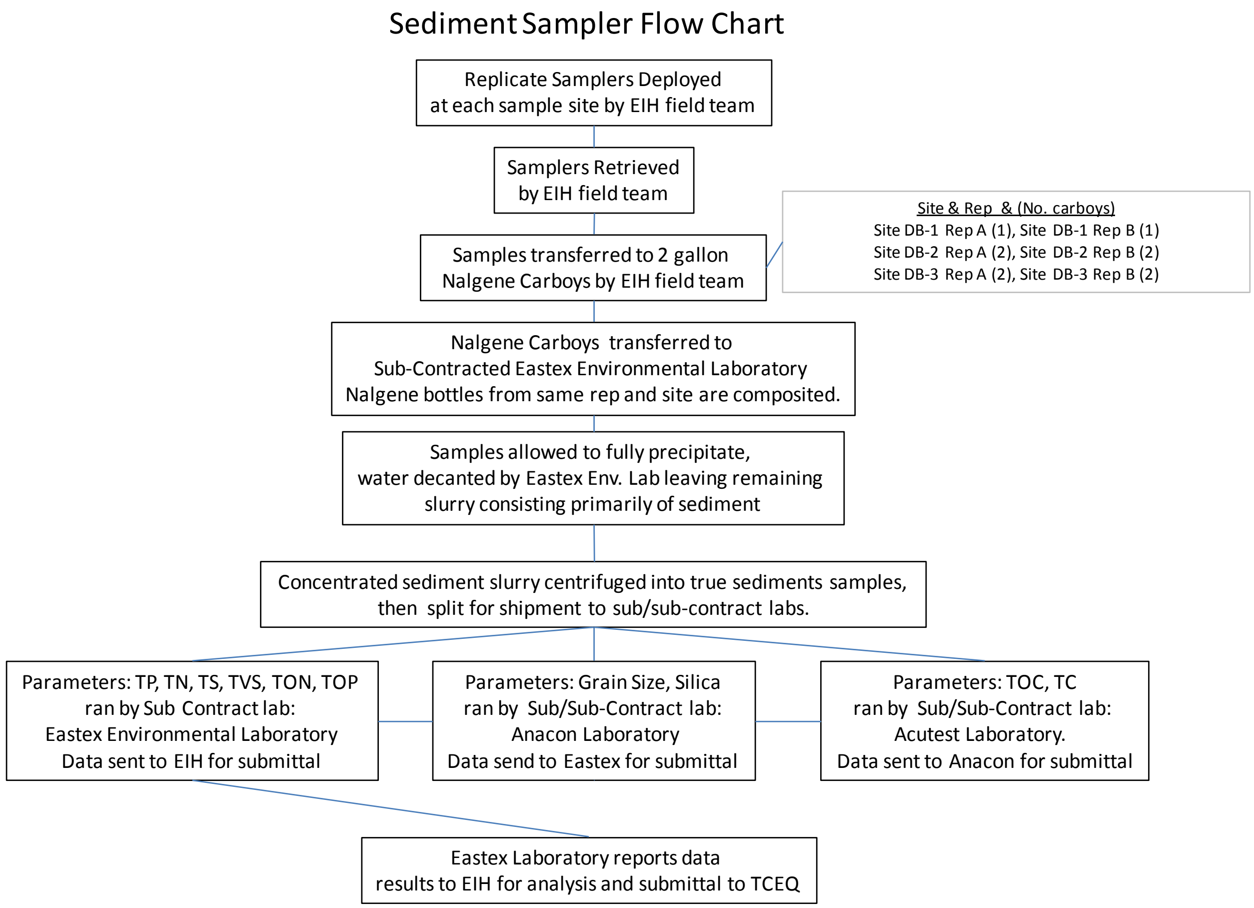


Figure 7. Flow chart showing the routine processing of sediment deposition collector samples during the study.

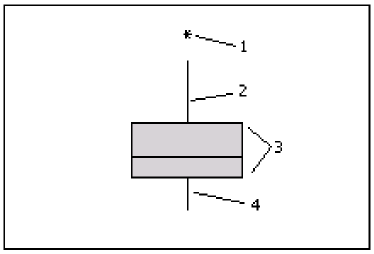
Laboratory Analysis

Ambient water, stream bed sediment and sediment collector samples were submitted to the primary contract laboratory, Eastex Environmental for measurement of chemical and physical variables listed in Table 5. The material in the carboys was allowed to settle and the overlying supernatant was decanted. The settled material was transferred to centrifuge vials and centrifuged for a period of at least 10 minutes. The centrifuge vials was decanted and their settled content transferred manually to trays of known weight. The samples were dried and weighed to obtain dry weights. The samples were then analyzed for their physical and chemical composition (Figure 7).

For some parameters, the samples were sent from Eastex Environmental to subcontract laboratories operated by Anacon and Accutest. Particles size distribution in bottom sediment and sediment traps was determined by the laboratory to differentiate cohesive particles (<0.0625 mm) from non-cohesive sediment (> 0.0625 mm)(Milburn and Krishnappan 2003, Huang et al. 2006). Sediment cohesiveness is one of the major parameters evaluated by the EFDC model.

Data Analysis

Data collected during this study is provided in Appendices 2-4, including both information reported to SWQMIS and non-standard parameters not reported to SWQMIS. Variables measured during this study are summarized in tabular and graphical format in the following sections. Graphical presentation of important variables by site, date, depth and rainfall/flow regime are presented to facilitate comparison of site and collection conditions. This included the use of boxplots to describe the distribution of data (Figure 08). Formal statistical correlation analysis and regression analysis were also used to evaluate the relationship of selected variables. All statistical analyses were conducted with the Minitab® statistical software package.



1 **Outlier (*)** – Observation that is beyond the upper or lower whisker

2 **Upper whisker** – Extends to the maximum data point within 1.5 box heights from the top of the box

3 **Interquartile range box** – Middle 50% of the data
- Top line – Q3 (third quartile). 75% of the data are less than or equal to this value.
- Middle line – Q2 (median). 50% of the data are less than or equal to this value.
- Bottom line – Q1 (first quartile). 25% of the data are less than or equal to this value.

4 **Lower whisker** – Extends to the minimum data point within 1.5 box heights from the bottom of the box

Figure 8. Description of boxplot used in report.

Calculated flux rates of sediment, organic carbon and nutrients were calculated from laboratory values, duration of deployment and the surface area of the opening to the sediment collector surface. The mass of collected material divided by the collection area and the deployment time of the traps was used to compute the sedimentation flux. The quantity of material collected by the sediment trap divided by the collection area and the time the traps were deployed gives the sedimentation rate or particle flux (Equation 1).

Equation 1. Calculation of sedimentation flux rates

Weight/area/time (flux) = weight of accumulated sediment ÷ time sampler/collectors deployed ÷ area of sampler opening

In addition, by analyzing the amount of sediment-associated nutrients and total carbon (TC) and total organic carbon (TOC) we were also able to estimate the deposition rate of sediment-associated organic carbon, and nutrients. Original and derived data including estimated flux rates may be used as input for future TMDL models. The particular model that is being considered by TCEQ for TMDL development is the Environmental Fluid Dynamic Code (EFDC) model (Tetra Tech Inc. 2006, 2007a, b). Collected data will be used to estimate partitioning and sedimentation rates of various forms of nitrogen, phosphorus, carbon, silica and suspended sediments. These estimated rates of deposition are needed to run EFDC's sediment process sub-model. In addition, the potential influence of salinity gradients and associated estuarine sediment maxima and the differential transport of suspended sediments throughout the stormwater hydrograph (hysteresis) are discussed in the following sections.

Table 5. Measurement performance specifications for water and sediment quality parameters evaluated during the study.

Parameter	Units	Method	Parameter Codes	Matrix	AWRL	Limit of Quan-titation (LOQ)	LOQ Check Standard %Rec	Precision (RPD of LCS/ LCSD)	BIAS (% Rec. LCS/ LCSD mean)	Laboratory Performing Analysis
					Field Parameters					
pH	s.u.	*EPA 150.1and TCEQ SOP v1*	*00400*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
DO	*mg/L*	*EPA 360.1and TCEQ SOP v1*	*00300*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Specific Conductance (Conductivity)	*uS/cm*	*EPA 120.1and TCEQ SOP v1*	*00094*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Temperature	*°C*	*EPA 170.1and TCEQ SOP v1*	*00010*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Transparency, Secchi Disc (meters)	*meters*	*TCEQ SOP v1*	*00078*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Days since last significant precipitation	*Days*	*TCEQ SOP v1*	*72053*	*Other*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Flow Stream, Instantaneous (cubic feet per second)	*cfs*	*TCEQ SOP v1*	*00061*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*field*
Flow measurement method	*1-gage, 2-electric, 3-mechanical, 4-weir/flume, 5-doppler*	*TCEQ SOP v1*	*89835*	*Other*	*NA*	*NA*	*NA*	*NA*	*NA*	*Field*
Flow Severity	*1-no flow,2-low,3-normal,4-flood, 5-high,6-dry*	*TCEQ SOP v1*	*01351*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*Field*
Salinity	*ppt*	*SM 2520 and TCEQ SOP v1*	*00480*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*Field*
Depth of bottom of water body at sample site	*Meters*	*TCEQ SOP v2*	*82903*	*Water*	*NA*	*NA*	*NA*	*NA*	*NA*	*Field*

Parameter	Units	Method	Parameter Codes	Matrix	AWRL	Limit of Quan-titation (LOQ)	LOQ Check Standard %Rec	Precision (RPD of LCS/ LCSD)	BIAS (% Rec. LCS/ LCSD mean)	Laboratory Performing Analysis
Conventional Parameters – Water										
*Residue, Total Nonfilterable, mg/l ****	*mg/L*	*SM 2540 D*	*00530*	*Water*	*4.0*	1	*NA*	*20*	*NA*	*Eastex*
*Residue, Volatile Nonfilterable mg/l ****	*mg/L*	*EPA 160.4*	*00535*	*Water*	4.0	1	*NA*	*20*	*NA*	*Eastex*
Carbon, Dissolved Organic, DNPC (DOC) mg/l	*mg/L*	*SM5310*	*00681*	*Water*	1.0	1	*70-130*	*20*	*70-130*	*Eastex*
Carbon, Total Organic, NPOC (TOC) mg/l	*mg/L*	*SM5310*	*00680*	*Water*	1.0	1	*70-130%*	*20*	*70-130*	*Eastex*
Conventional Parameters ***Sediment trap and sediment****										
*Solids volatile in sediment (%)****	*%*	*SM 2540 G*	*85207*	*Sed.*	*NA*	*0.1*	*NA*	*20*	*NA*	*Eastex*
Total Solids Collected (dry weight)	*mg*	*NA*	*NA***	*Sed.*	*NA*	NA	*NA*	*NA*	*NA*	*Eastex*
Total Organic Carbon, NPOC(TOC), Sed Dry Wt, mg/kg	*mg/kg*	*EPA 9060*	*NA***	*Sed.*	*NA*	1000****	*70-130*	*20*	*70-130*	*ACCUTEST*
*Total Carbon ***	*mg/kg*	*EPA 9060*	*NA***	*Sed.*	*NA*	1000****	*70-130*	*20*	*70-130*	*ACCUTEST*
*Solids in sediment, percent by weight (dry) ****	*%*	*SM2540G*	*81373*	*Sed.*	*NA*	*0.1*	*NA*	*20*	*NA*	*Eastex*
Phosphorus, Total, Bottom Deposits (mg/kg dry wt.)	*mg/kg*	*SM 4500 P E*	*00668*	*Sed.*	*NA*	*0.06*****	*70-130*	*20*	*70-130*	*Eastex*

Parameter	**Units**	**Method**	**Parameter Codes**	**Matrix**	**AWRL**	**Limit of Quan-titation (LOQ)**	**LOQ Check Standard %Rec**	**Precision (RPD of LCS/ LCSD)**	**BIAS (% Rec. LCS/ LCSD mean)**	**Laboratory Performing Analysis**
*Organic Phosphorus, Total, Bottom Deposits (mg/kg dry wt.)***	*mg/kg*	*SM 4500 P E*	*NA***	*Sed.*	*NA*	*0.06*****	*70-130*	*20*	*70-130*	*Eastex*
Nitrogen, Total, Bottom Deposits(mg/kg-n dry wt)	*mg/kg*	*SM 4500 NC*	*00603*	*Sed.*	*NA*	*0.05*****	*70-130*	*20*	*70-130*	*Eastex*
Organic Nitrogen, Total, Bottom Deposits (mg/kg-n dry wt)	*mg/kg*	*SM 4500 N org A*	*NA***	*Sed.*	*NA*	*0.05*****	*70-130*	*20*	*70-130*	*Eastex*
*Silica ***	*ug/kg*	*SW 846-6010*	*NA***	*Sed.*	*NA*	20,000****	*70-130*	*20*	*70-130*	*Anacon*
Sediment prtcl.size class >2.0mm gravel %dry wt	*% fraction*	*ASTM422*	*80256*	*Sed.*	*NA*	NA	*NA*	*NA*	*NA*	*Anacon*
Sediment prctl.size class,sand .0625-2mm % drywt	*% fraction*	*ASTM422*	*89991*	*Sed.*	*NA*	NA	*NA*	*NA*	*NA*	*Anacon*
Sediment prtl.size class.< .0625 mm silt and clay %dry wt**	*% fraction*	*ASTM422*	*NA***	*Sed.*	*NA*	NA	*NA*	*NA*	*NA*	*Anacon*

* Sediment trap data will not be reported to SWQMIS database; it was used to calculate model parameters. However the analytical methods are identical to those shown for the (bottom sample) sediment analysis methods.
** No TCEQ parameter code available; only data with a valid TCEQ parameter code was stored in SWQMIS.
*** These parameters do not have LCS/LCSD associated with them. Where no LCS/LCSD is analyzed the RPD limit will apply to the precision between sample and sample duplicate results.
**** LOQ is the reportable value of the instrument in mg/L. Lowest reportable value for samples will vary depending on the percent solid of the sample and the volume of the sample analyzed.

References for Laboratory Methodology:

(American Public Health Association (APHA) et al. 1998)

(American Society for Testing and Materials (ASTM) 2007)

(United States Environmental Protection Agency 1983)

(United States Environmental Protection Agency 2010)

The methodology and data quality requirements used for development of the EFDC TMDL model are outlined in the TCEQ-approved QAPP submitted to the TCEQ by the University of Houston on October 6, 2010 and approved by the TCEQ on October 20, 2010 (Rifai 2010). The sediment process sub-model, simulates the diagenesis and resulting fluxes of inorganic substances (ammonium, nitrate, phosphate and silica) and sediment oxygen demand on the water column of particulate organic matter deposited from the overlying water column (Tetra Tech Inc. 2007b). The coupling of the sediment process model with the water quality model not only enhances the model's predictive capability of water quality parameters but also enables it to simulate the long-term changes in water quality conditions in response to changes in nutrient loadings.

Results

Meteorology and Hydrology

Precipitation and Stream Water Levels 2011

A major challenge faced by this study was the prolonged intense drought that had occurred in Texas and continued throughout the initial study period from March to August 2011 (Figures 9 and 10). Beginning in October 2010, the Houston-Galveston region had been suffering from one of the worst droughts on record (Houston Galveston Area Council 2012). Though the rains in late 2011 and early 2012 made significant progress toward overcoming the rain deficit, as of February 21, 2012, most of the region was still classified as being under drought conditions (Houston Galveston Area Council 2012). The drought severity was moderate and increased to exceptional levels by the end of the study period. We had established late June 2011 as the deadline to accomplish the wet weather sampling during 2011 in order to allow time to obtain laboratory analysis results and to conduct our data analysis and review and report preparation. Rainfall recorded in the Dickinson Bayou watershed documents the influence of the drought on precipitation and the occurrence of a minor rainstorm on June 22, 2011 (Figure 11).

It was very difficult to determine the response of Dickinson Bayou water levels to the wet weather event during June 2011. Water levels, although elevated on June 22, 2011 during the rainstorm event, were not outside the range of conditions previously observed during dry weather conditions (Figures 13 and 14). Based on our analysis of tide and stream levels a large percentage of the variation in fluctuations in water level was probably due to normal tide fluctuation (Figures 15 and 16). During June 22, 2011, the highest water levels were recorded at 11:00 following peak rainfall amounts that morning (Figure 17). However, the fluctuation in water level appears to be driven primarily by tidal variation (Figure 18). The observed pattern suggests that there was a 1 ½ hour delay between high tide in Dickinson Bay and the observed maximum water levels at Dickinson Bayou at SH 3. Therefore based on the observed rainfall pattern, tide, and river levels it is likely that the rainstorm that occurred on June 22, 2011 only slightly affected stream water levels.

Precipitation and Stream Water Levels 2012

During 2012, precipitation appeared to increase over comparable periods in 2011 (Figure 19). We identified and monitored one wet and one dry weather monitoring event during March and April 2012, respectively. Water levels measured at State Highway 3 with the TROLL gage increased in response to elevated rainfall during March 11, March 21, April 4, and April 16 and April 20 (Figure 20). However, similar to monitoring results in 2011, stream water levels in Dickinson Bayou were also strongly correlated with tide levels in Dickinson Bay.

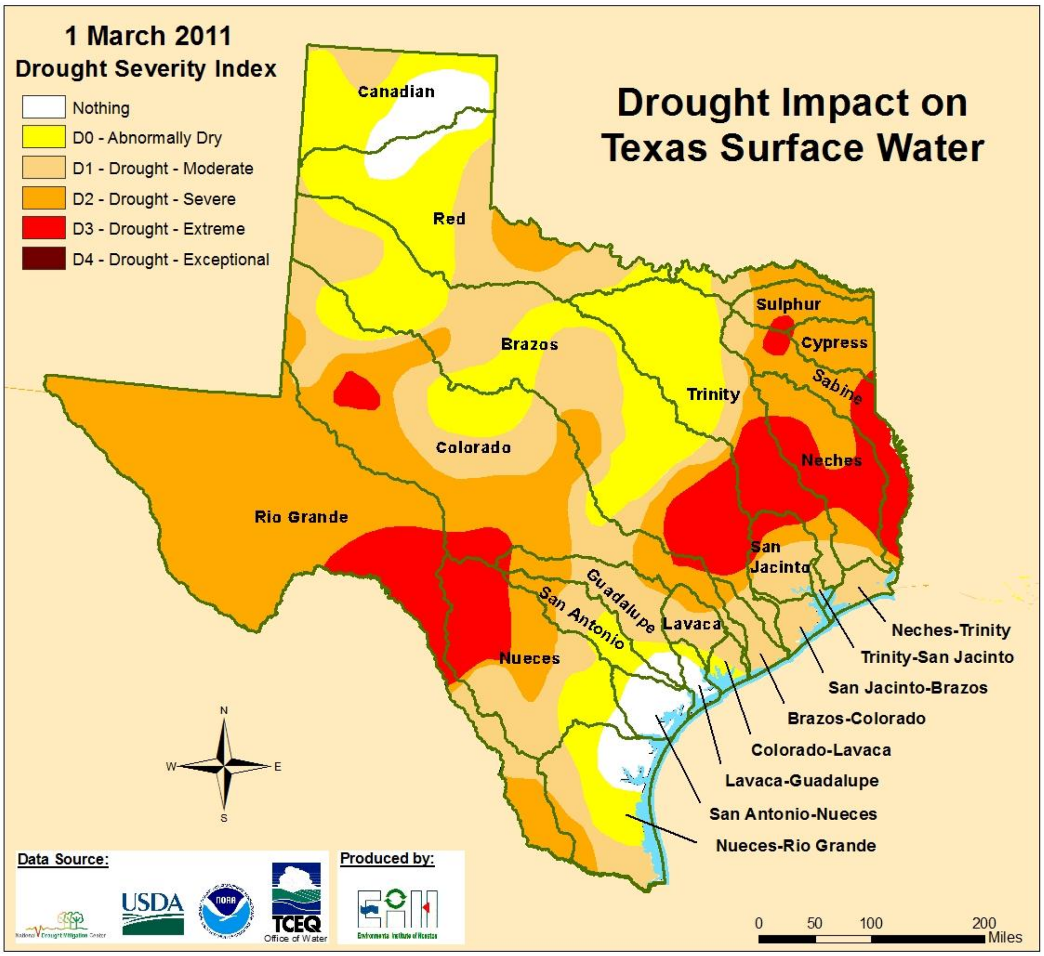


Figure 9. Drought severity index produced by USDA for March 2011. Dickinson Bayou was within the moderate drought zone.

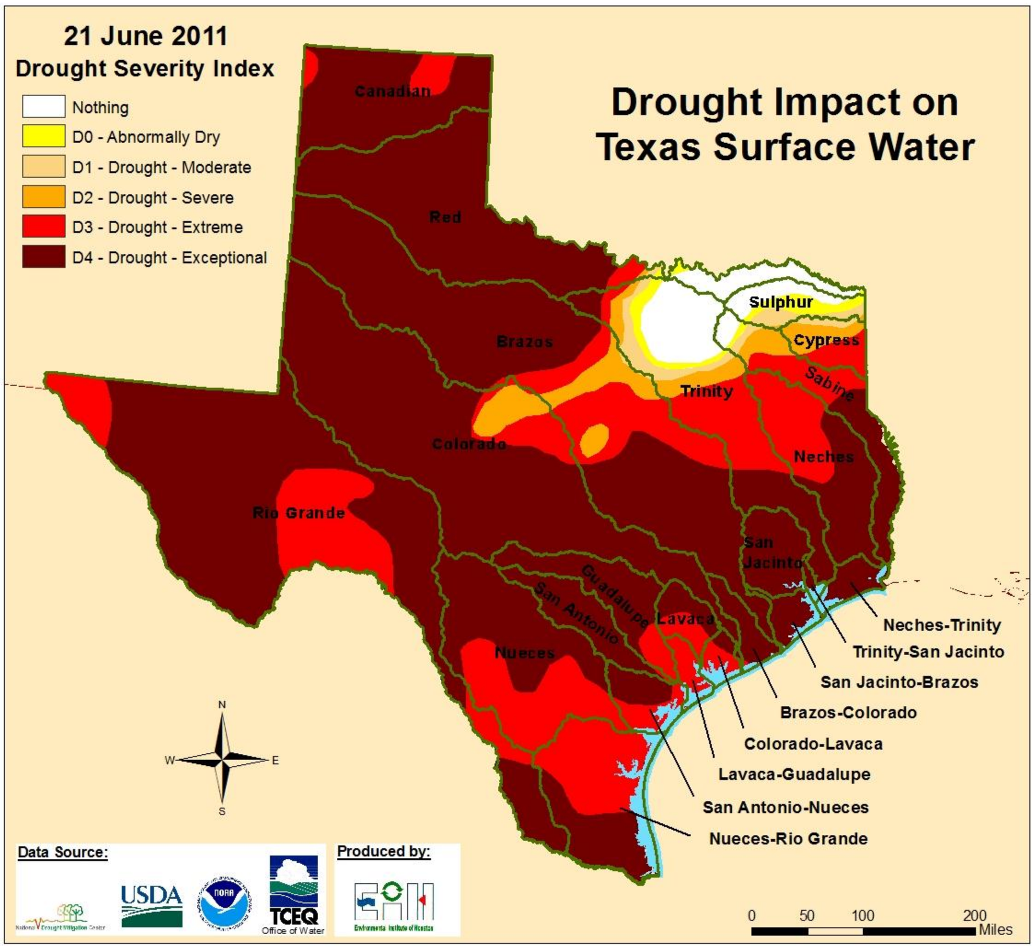


Figure 10. Drought severity index for the wet weather sampling period starting June 21, 2011. Dickinson Bayou was within the exceptional drought zone. Source: USDA.

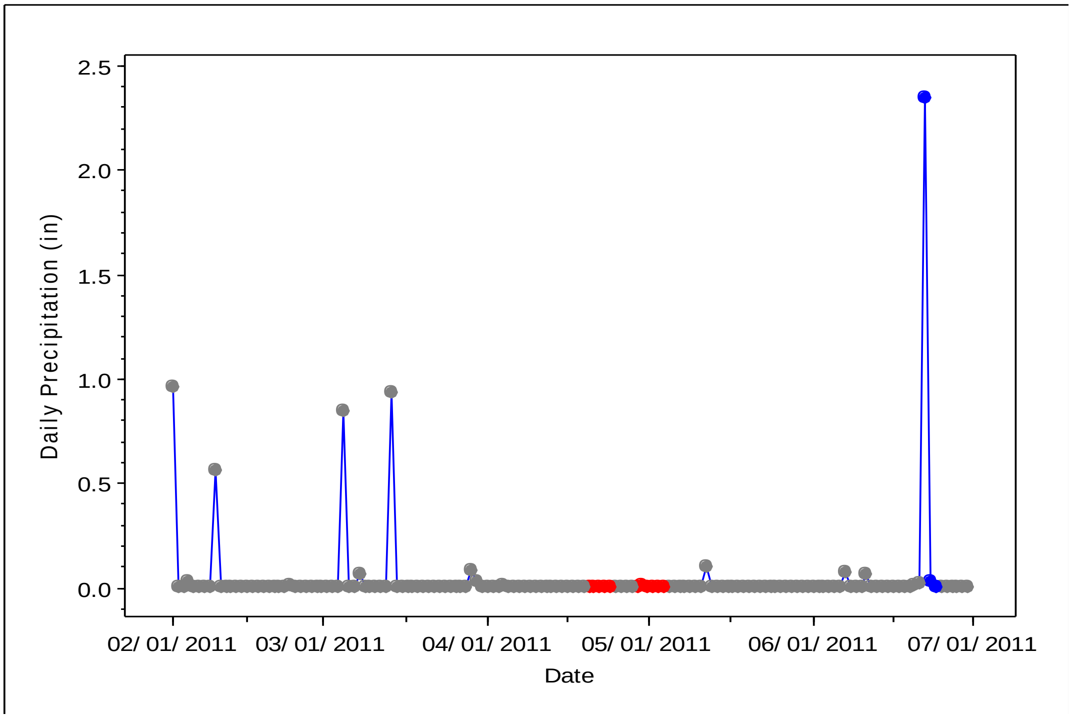


Figure 11. Daily precipitation recorded from 2/1/11 to 7/1/12 at the League City National Weather Station, League City, Texas. Wet and dry weather monitoring dates are denoted by blue and red dots respectively.

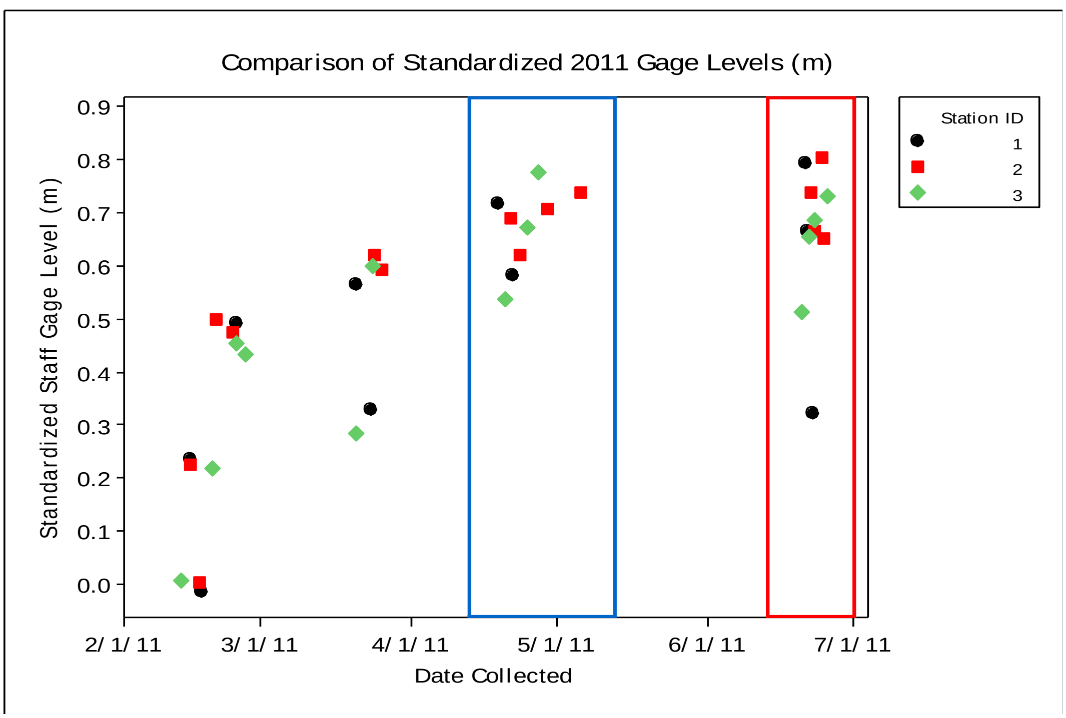


Figure 12. Standardized gage staff levels measured during 2011. Blue and red rectangles denote dry and wet weather sampling periods respectively.

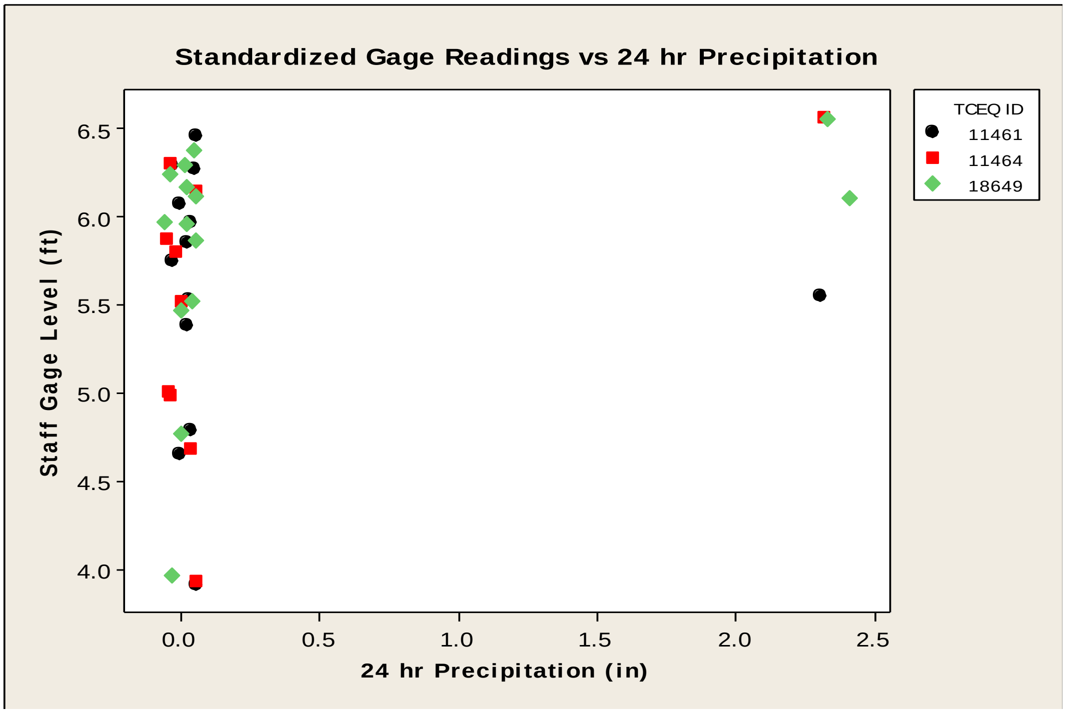


Figure 13. Standardized staff gage levels versus cumulative 24 hour precipitation levels recorded at the League City National Weather Station during monitoring conducted in 2011.

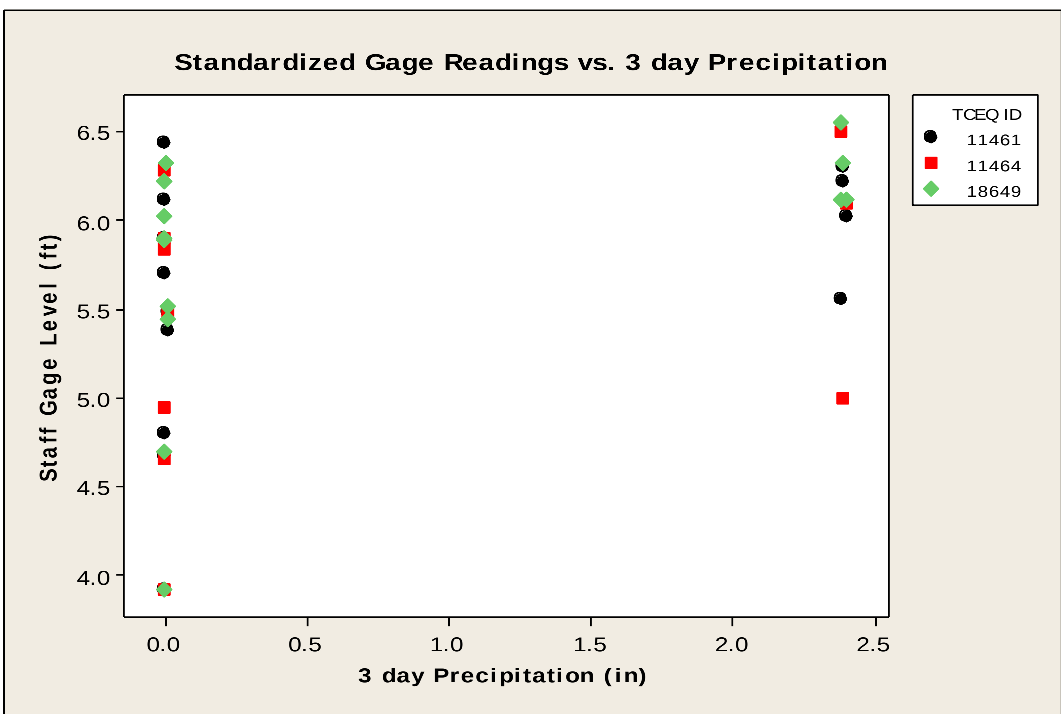


Figure 14. Standardized staff gage levels versus cumulative 3 day precipitation levels recorded at the League City National Weather Station, during monitoring conducted in 2011.

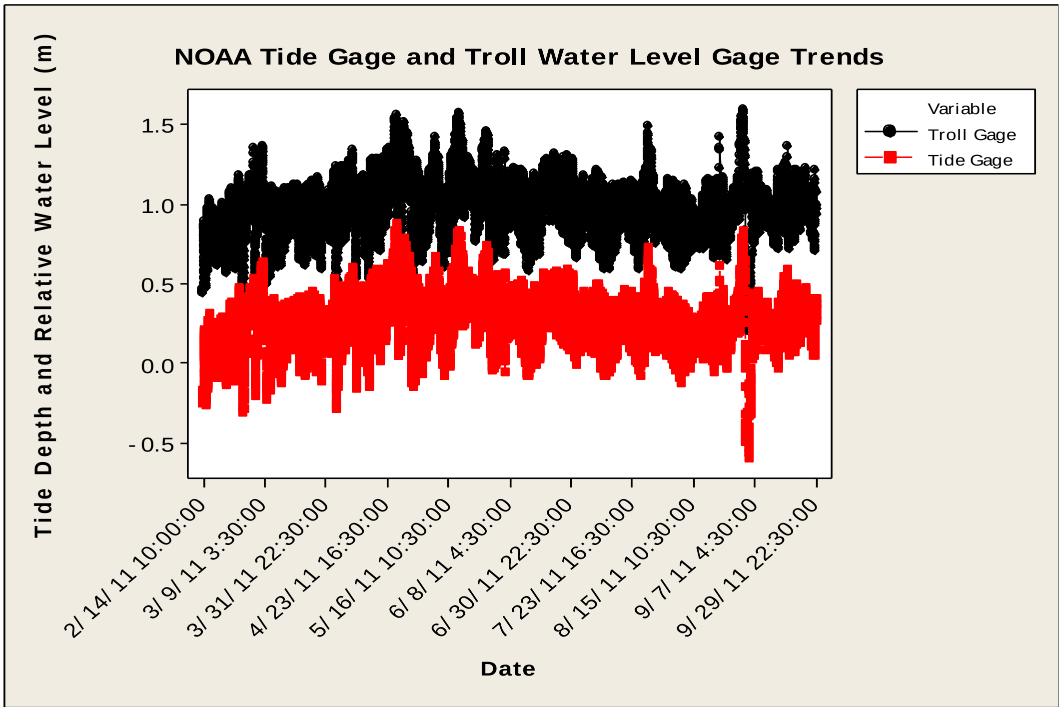


Figure 15. NOAA Dickinson Bay tide gage and TROLL water level gage measurements at HWY 3 during February 14 through September 29, 21011.

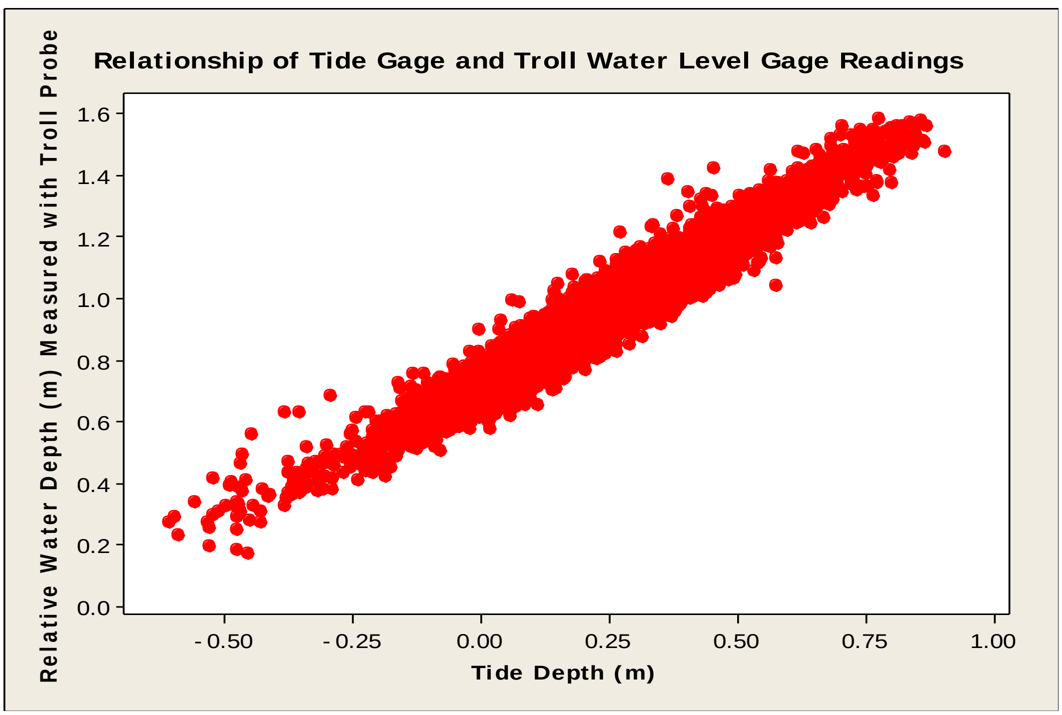


Figure 16. Relationship between NOAA tide gage (8771013 Eagle Point, TX) and water level readings from the TROLL gage at SH 3, collected during 2011. (r) = 0.979; p-value = 0.000.

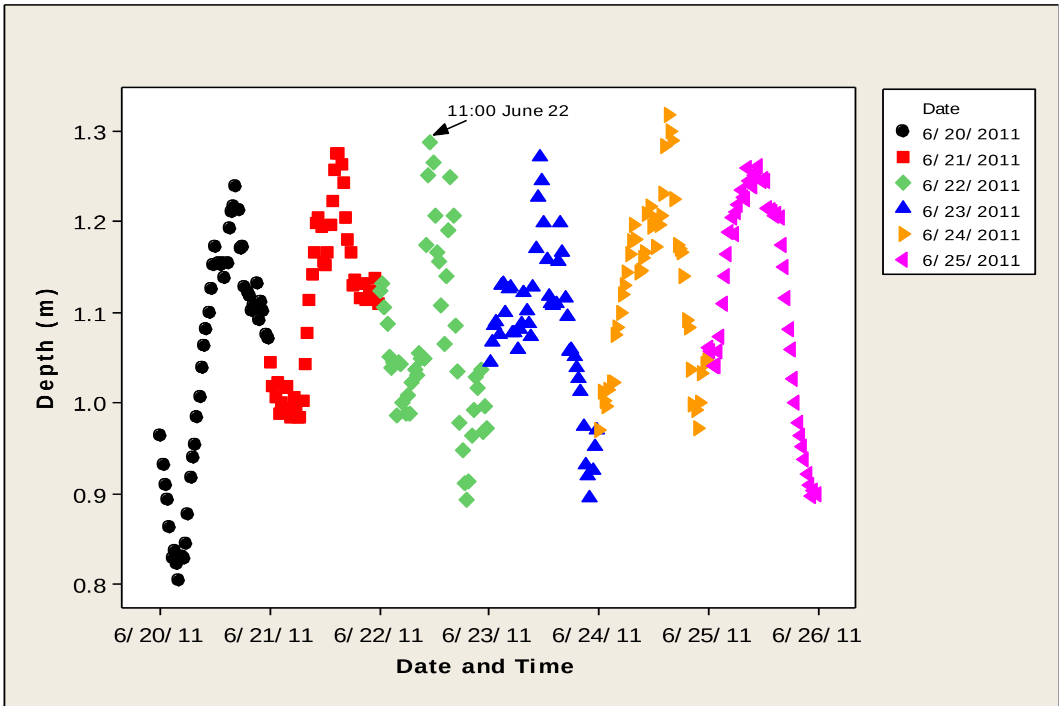


Figure 17. Water level fluctuations recorded at the SH 3 bridge with the TROLL gage on June 22, 2011 during the wet weather sampling event.

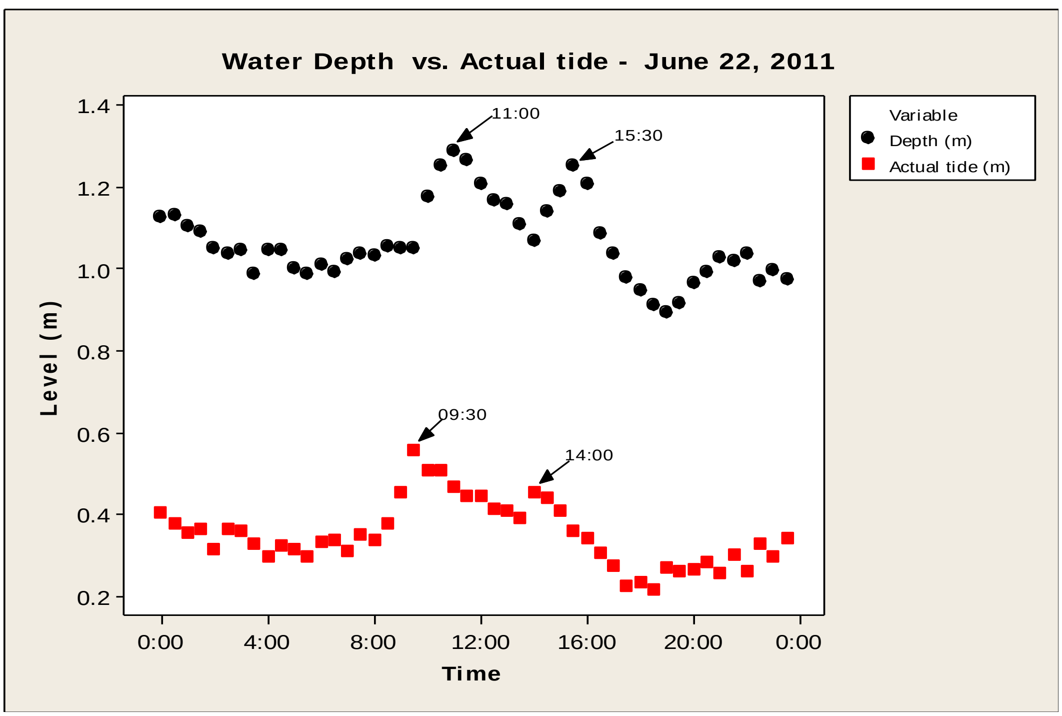


Figure 18. Relationship of recorded water level with TROLL gage versus tide levels in Dickinson Bayou recorded by the NOAA tide gage (8771013 Eagle Point, TX). Data suggests a lag period of 1.5 hours between tide levels and water depth/levels measured at Hwy 3.

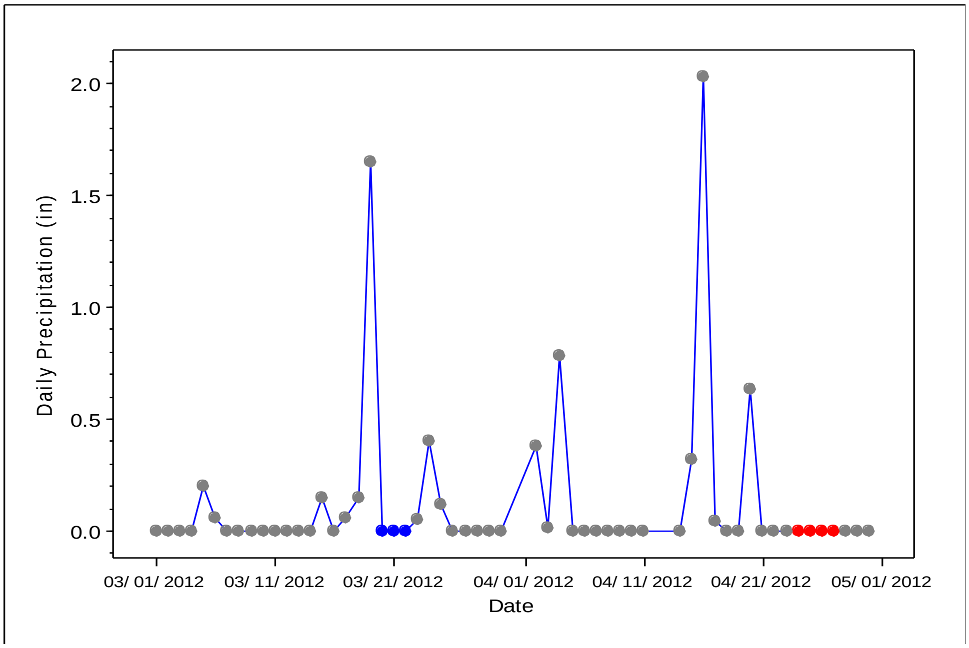


Figure 19. Daily precipitation recorded from 3/1/112 to 4/20/12 at the League City National Weather Station, League City, Texas. Wet and dry weather monitoring dates are denoted by blue and red dots respectively.

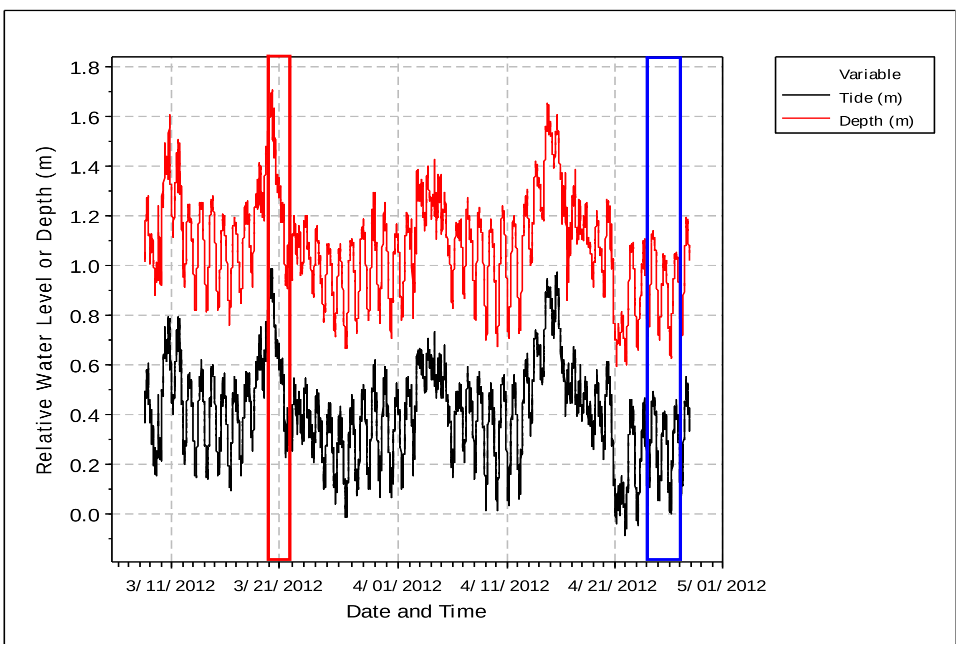


Figure 20. Relationship of recorded water level with Troll level gage at Hwy 3 and tide levels recorded at Eagle Point in Dickinson Bay by the NOAA (8771013 Eagle Point, TX) tide gage. Areas in blue and red squares denote wet and dry weather sampling periods. Pearson correlation (r) of tide (m) and depth (m) = 0.979 p-value ≤ 0.000.

Streamflow and Velocity Profiles 2011

During 2011 streamflow was elevated during June 22-24, 2011 when wet weather sampling was conducted (Figure 21). However, streamflow at site 1, which is the furthest downstream, was near zero or negative indicating a strong tidal influence or weak stream flow. The highest streamflow was observed at site 3. In contrast the dry weather event monitored during April and early May 2011 occurred during a period when streamflow was negative suggesting a strong tidal (flood tide) influence.

We evaluated the velocity field generated from the ADCP during wet and dry weather sampling in 2011 (Figures 21 - 33). During dry weather monitoring the majority of water columns at all sites were dominated by negative flow velocities (Figures 22 - 27). The most extreme negative velocities were generally observed at mid-depth and near the bottom. However, velocity direction was often observed fluctuating horizontally and vertically. The fluctuating direction may be indicative of the upstream extent of a salt wedge.

Streamflow and Velocity Profile 2012

During 2012 streamflow was elevated during March 20-22, 2012 when wet weather sampling was conducted (Figure 21 and Table 6). These levels were even greater than those observed during the June 2011 wet weather sampling event. Highest flows were observed at site 3 during 2012. In contrast, the dry weather event monitored during April 24 - 27, 2012 occurred during a period when streamflow was low or negative suggesting a strong tidal (flood tide) influence.

We evaluated the velocity fields generated from the ADCP during wet and dry weather sampling in 2012 (Figures 34- 44). During March 2012 the majority of velocity fields yield positive values throughout the water column (Figures 34- 38). During dry weather monitoring the majority of water column at all sites were dominated by negative flow velocities (Figures 39-44). The most extreme negative velocities were generally observed at mid-depth. However, velocity direction was often observed fluctuating horizontally and vertically. The fluctuating velocity direction may be indicative of the upstream extent of a salt wedge influencing the hydrology at the sites.

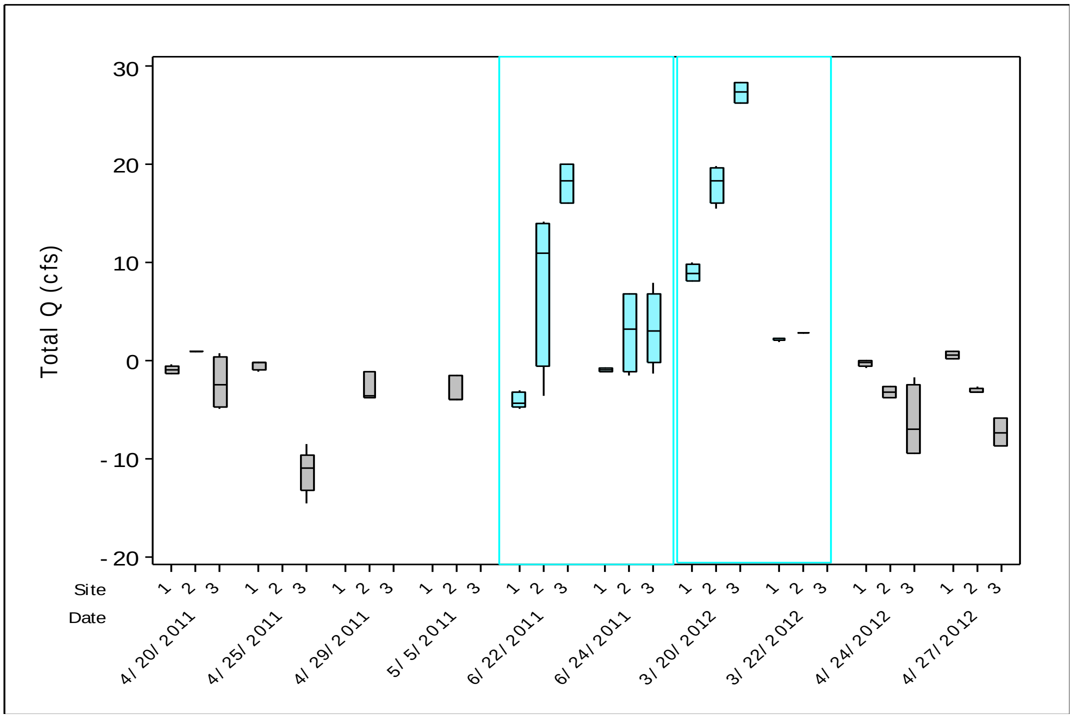


Figure 21. Streamflow measured at each site during the study period. Blue boxplots and areas in the rectangles represent wet weather sampling periods.

Table 6. Summary data on measured streamflow during 2011 and 2012 sedimentation sampler deployment and retrieval periods.

			Average Flow		
Year	Type	Site	Deploy	Retrieve	Avg (both)
2011	Dry	1	-8.95	-0.471	-0.66
2011	Wet	1	-4.117	-0.983	-2.55
2011	Dry	2	-1.87	-3.107	-2.399
2011	Wet	2	8.12	2.95	5.54
2011	Dry	3	-2.26	-11.426	-7.35
2011	Wet	3	18.26	3.19	9.65
2012	Dry	1	-0.253	0.605	0.176
2012	Wet	1	8.957	2.1375	5.55
2012	Dry	2	-3.173	-3.07	-3.121
2012	Wet	2	18.073	2.93	15.04
2012	Dry	3	-6.27	-7.33	-6.799
2012	Wet	3	27.47	*	27.47

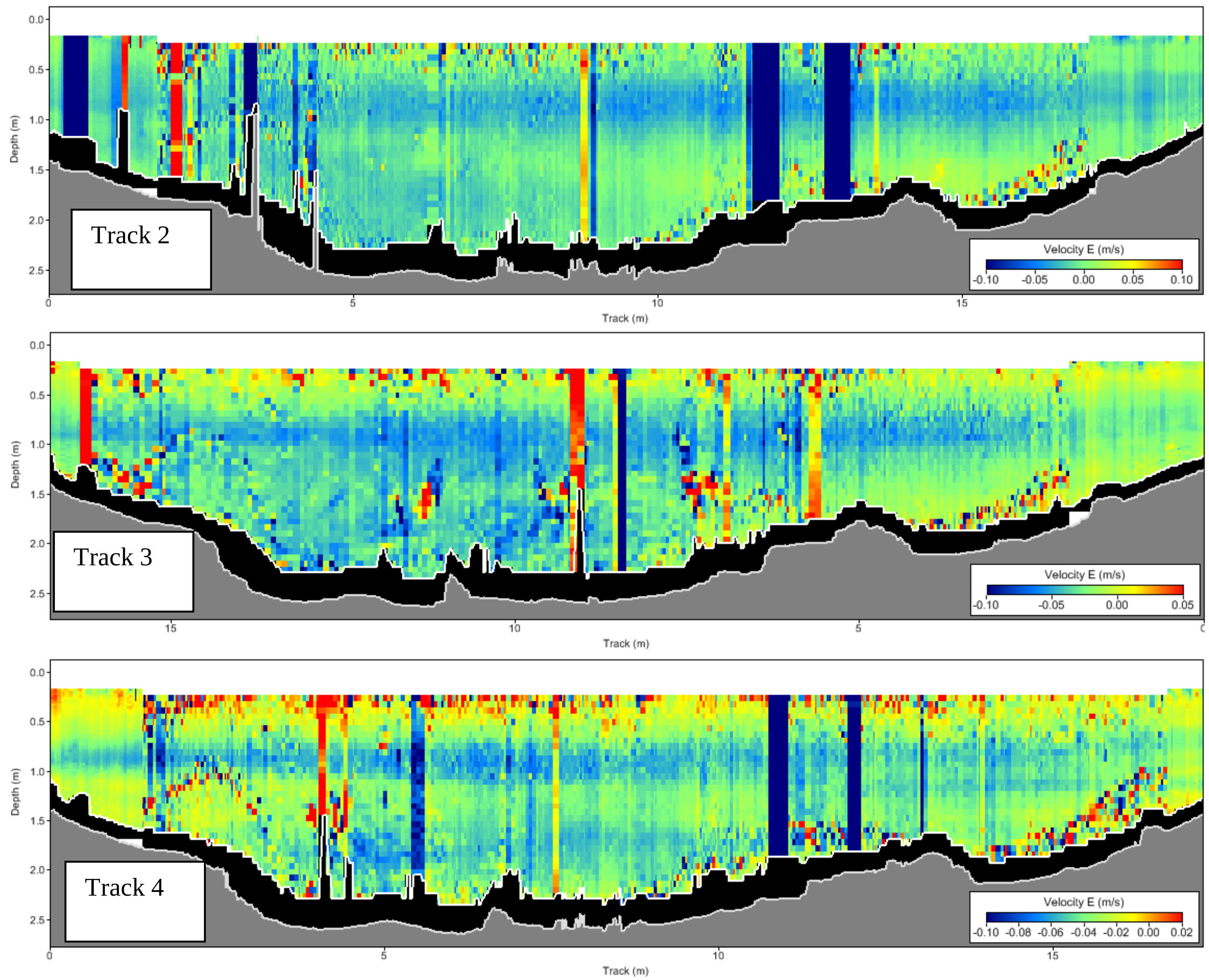


Figure 22. River surveyor velocity profiles obtained during site 1 dry weather sediment sampler deployment on April 20, 2011.

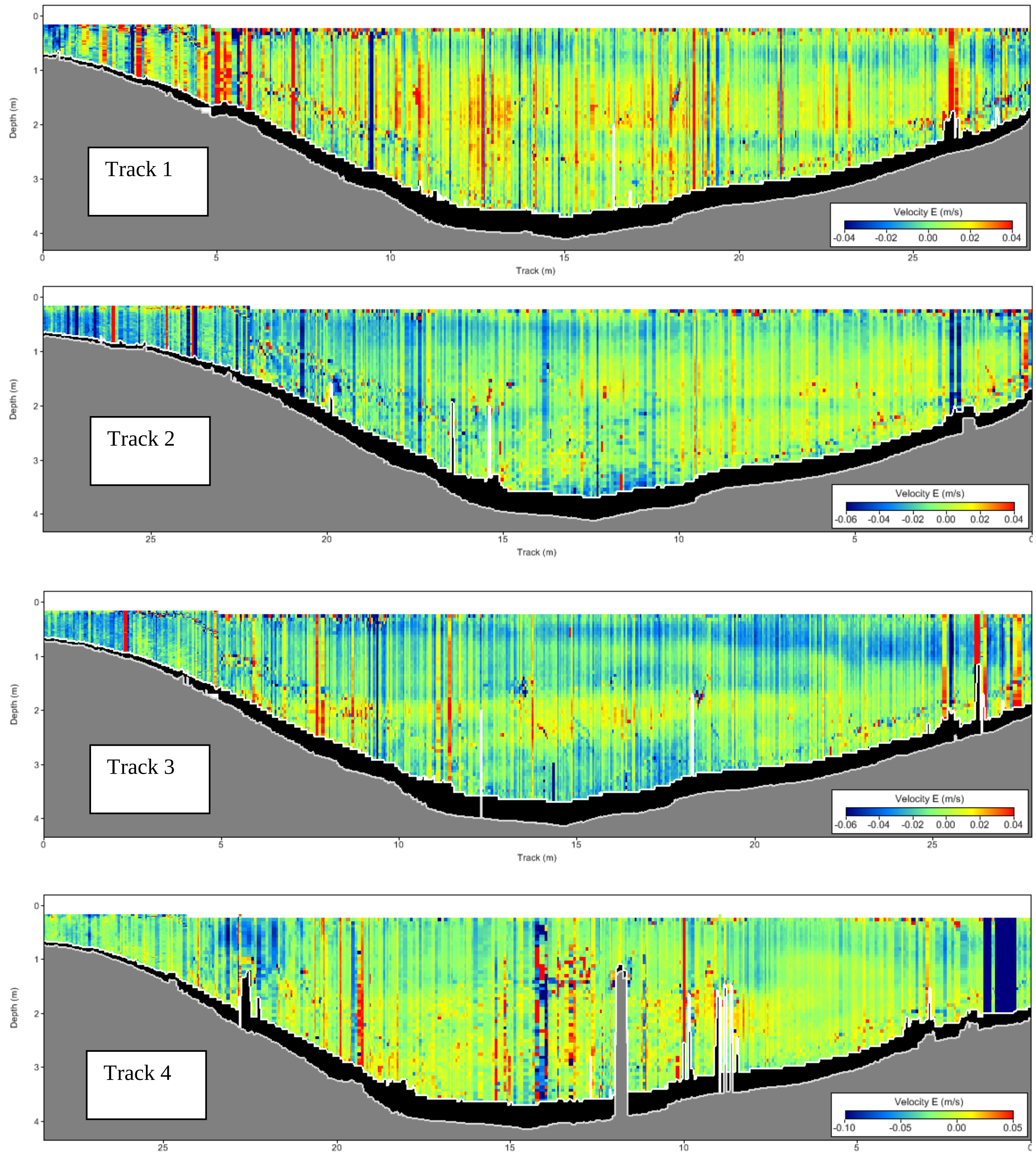


Figure 23. River surveyor velocity profiles obtained during site 2 dry weather sediment sampler deployment on April 29, 2011.

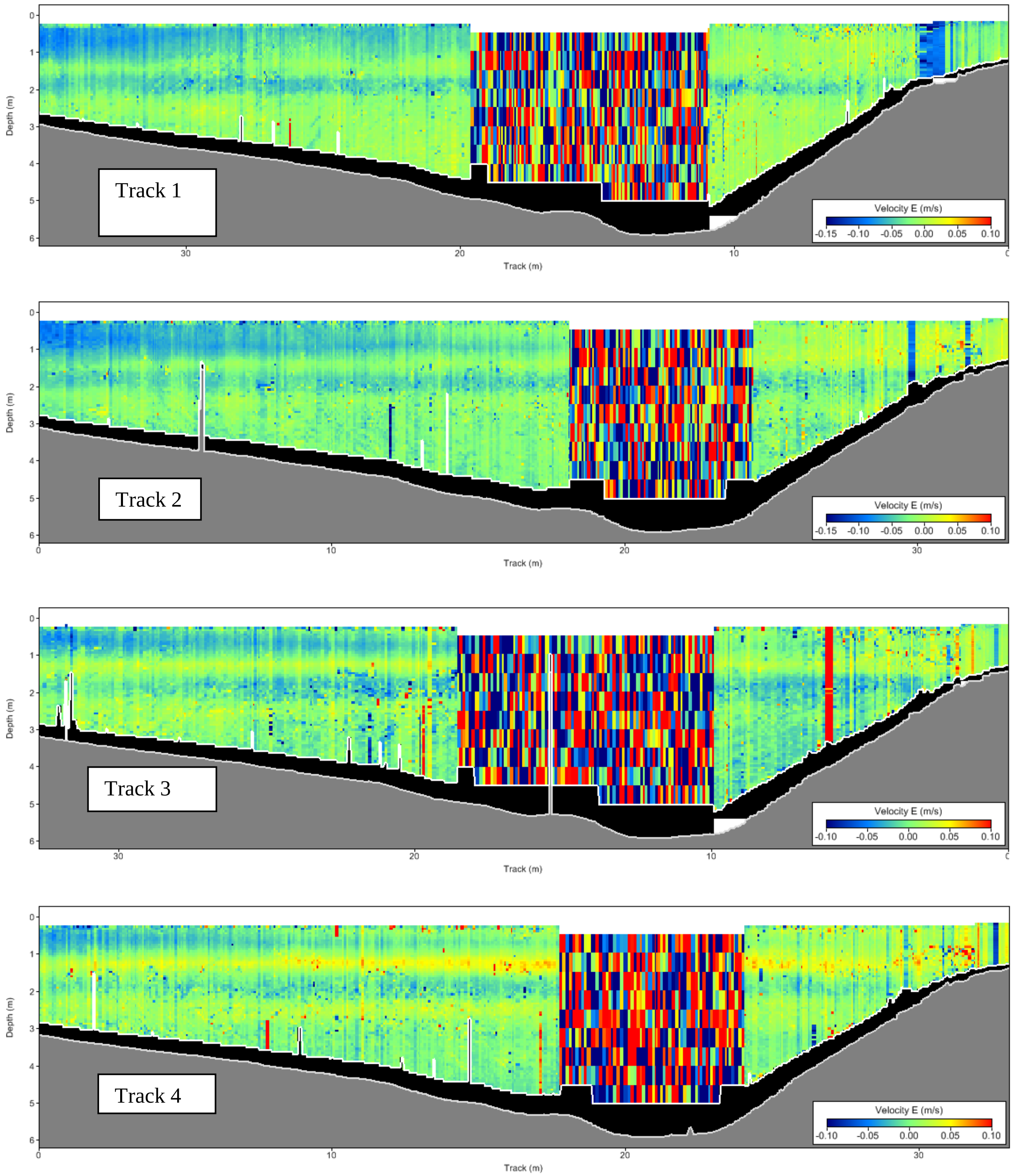


Figure 24. River surveyor velocity profiles obtained during site 3 dry weather sediment sampler deployment on April 20, 2011.

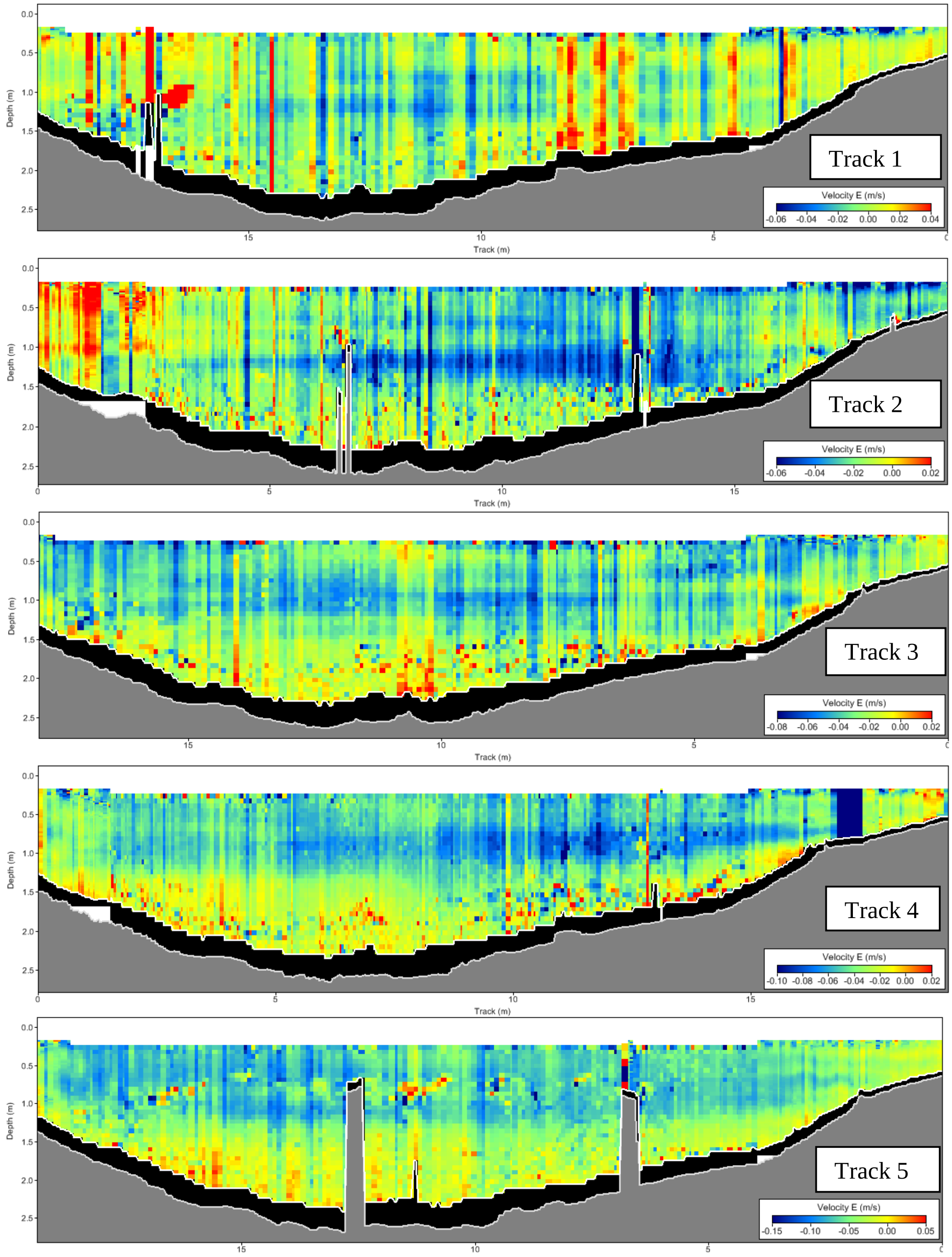


Figure 25. River surveyor velocity profiles obtained during site 1 dry weather sediment sampler retrieval on April 25, 2011.

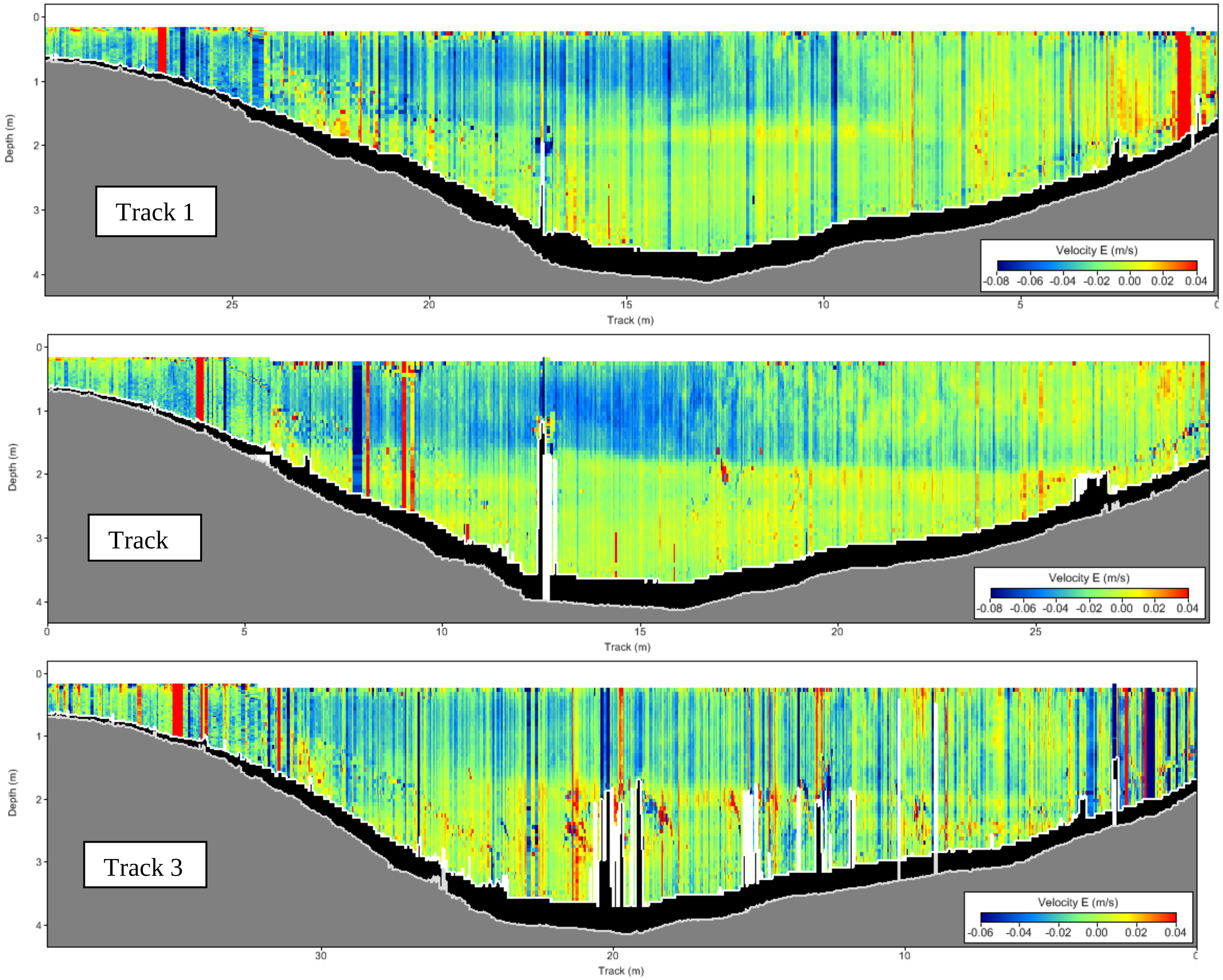


Figure 26. River surveyor velocity profiles obtained during site 2 dry weather sediment sampler retrieval on May 4, 2011.

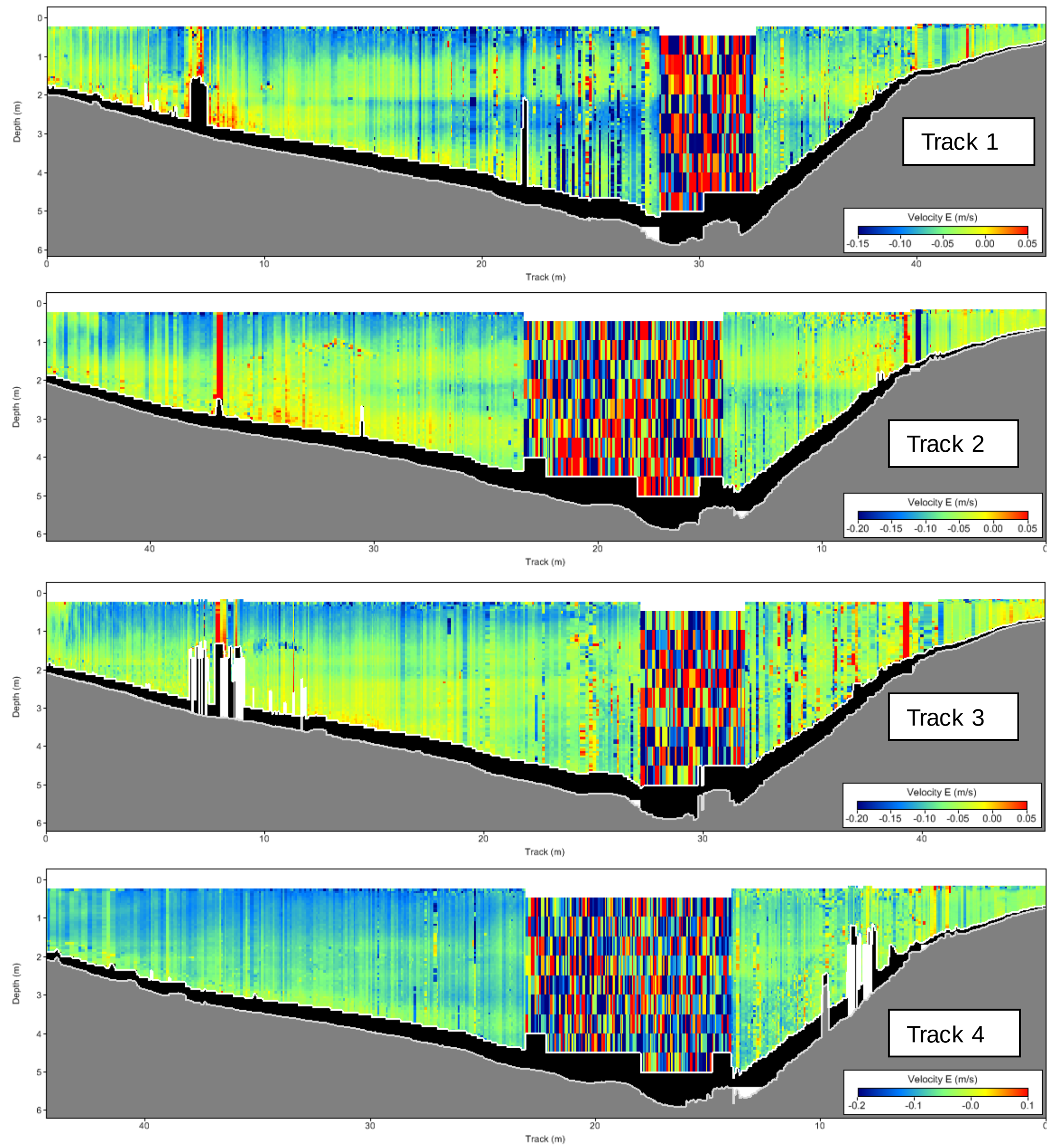


Figure 27. River surveyor velocity profiles obtained during site 3 dry weather sediment sampler retrieval on April 25, 2011.

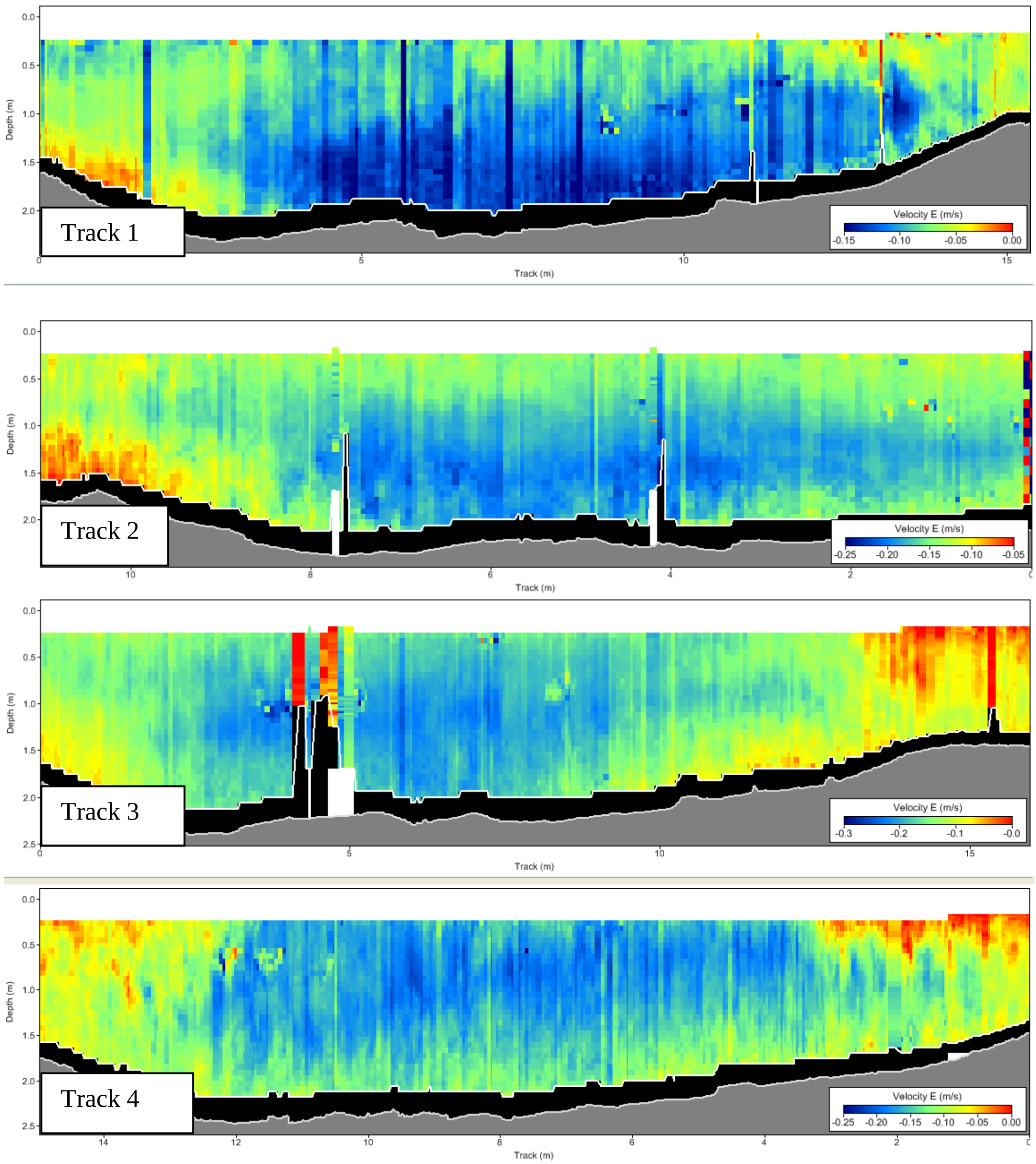


Figure 28. River surveyor velocity profiles obtained during site 1 wet weather sediment sampler deployment on June 22, 2011.

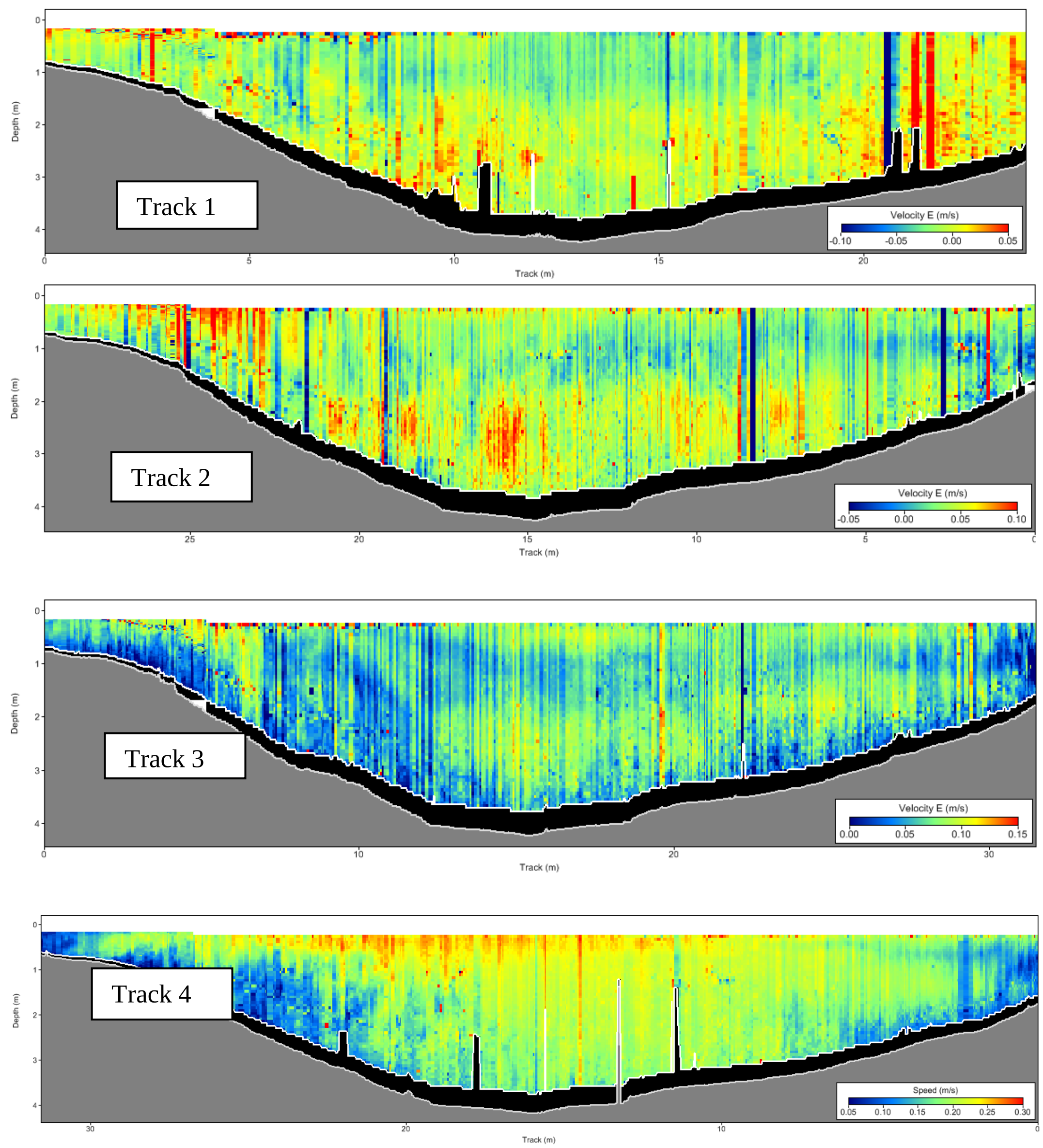


Figure 29. River surveyor velocity profiles obtained during site 2 wet weather sediment sampler deployment on June 22, 2011.

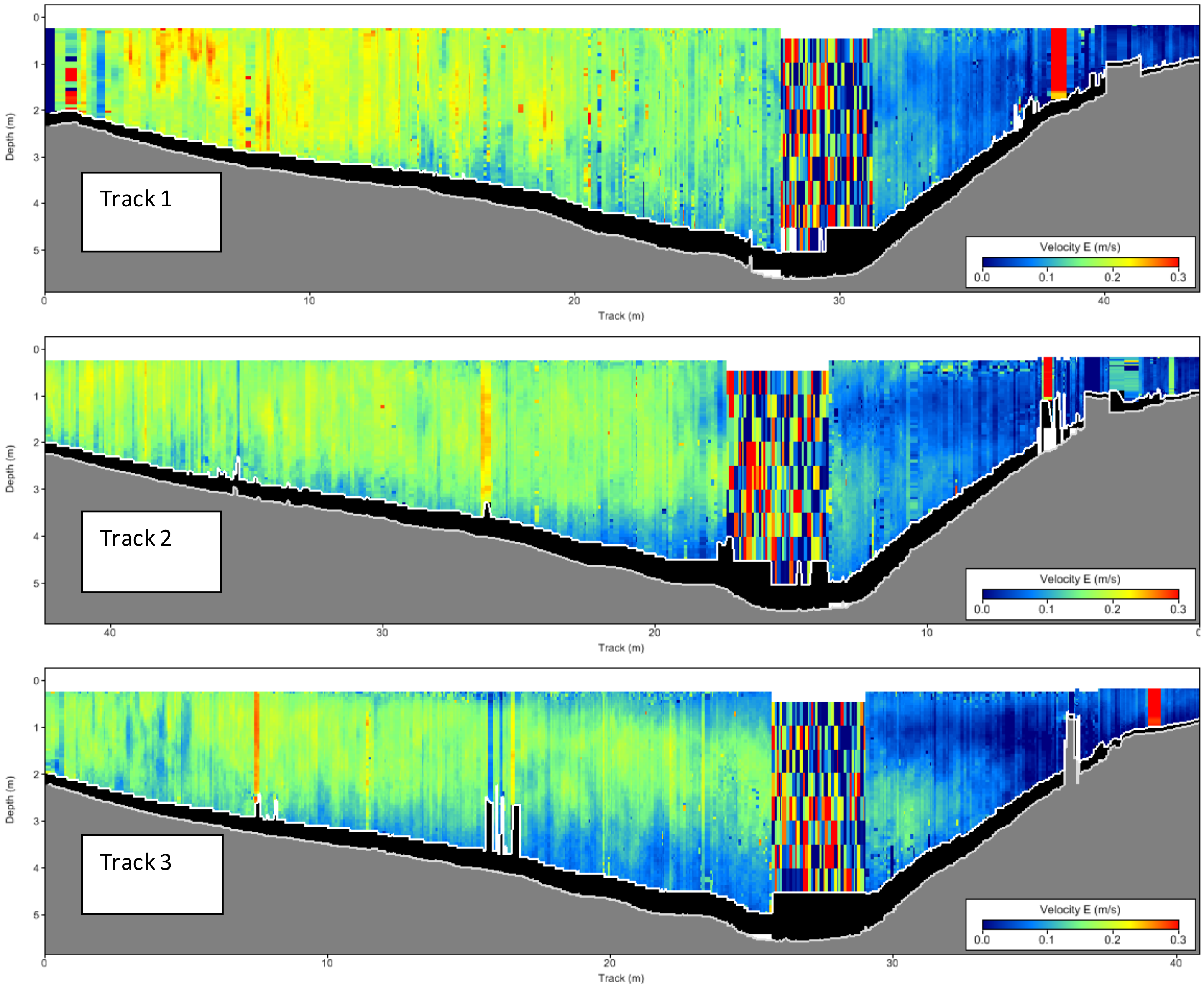


Figure 30. River surveyor velocity profiles obtained during site 3 wet weather sediment sampler deployment on June 22, 2011.

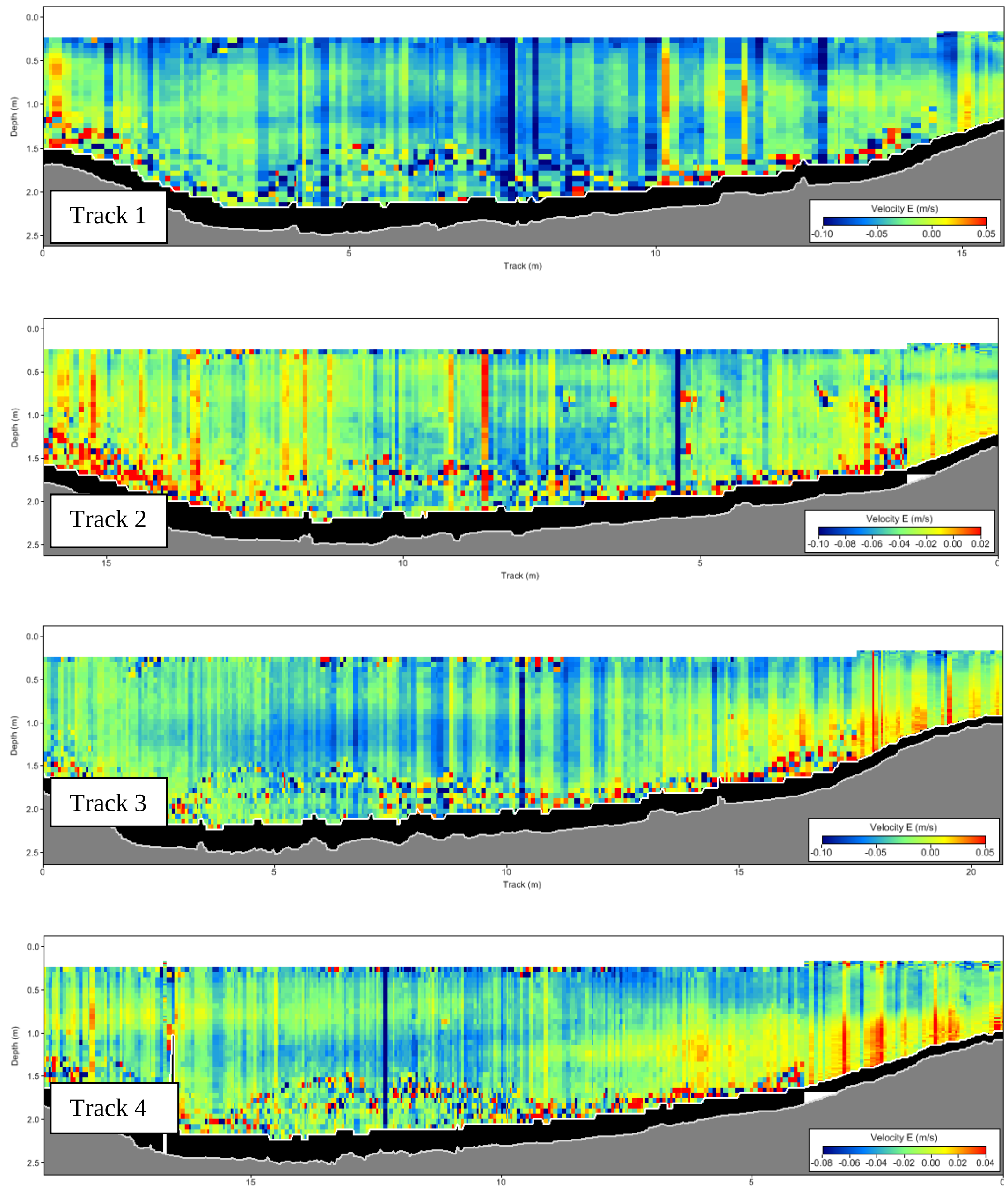


Figure 31. River surveyor velocity profiles obtained during site 1 wet weather sediment sampler retrieval on June 24, 2011.

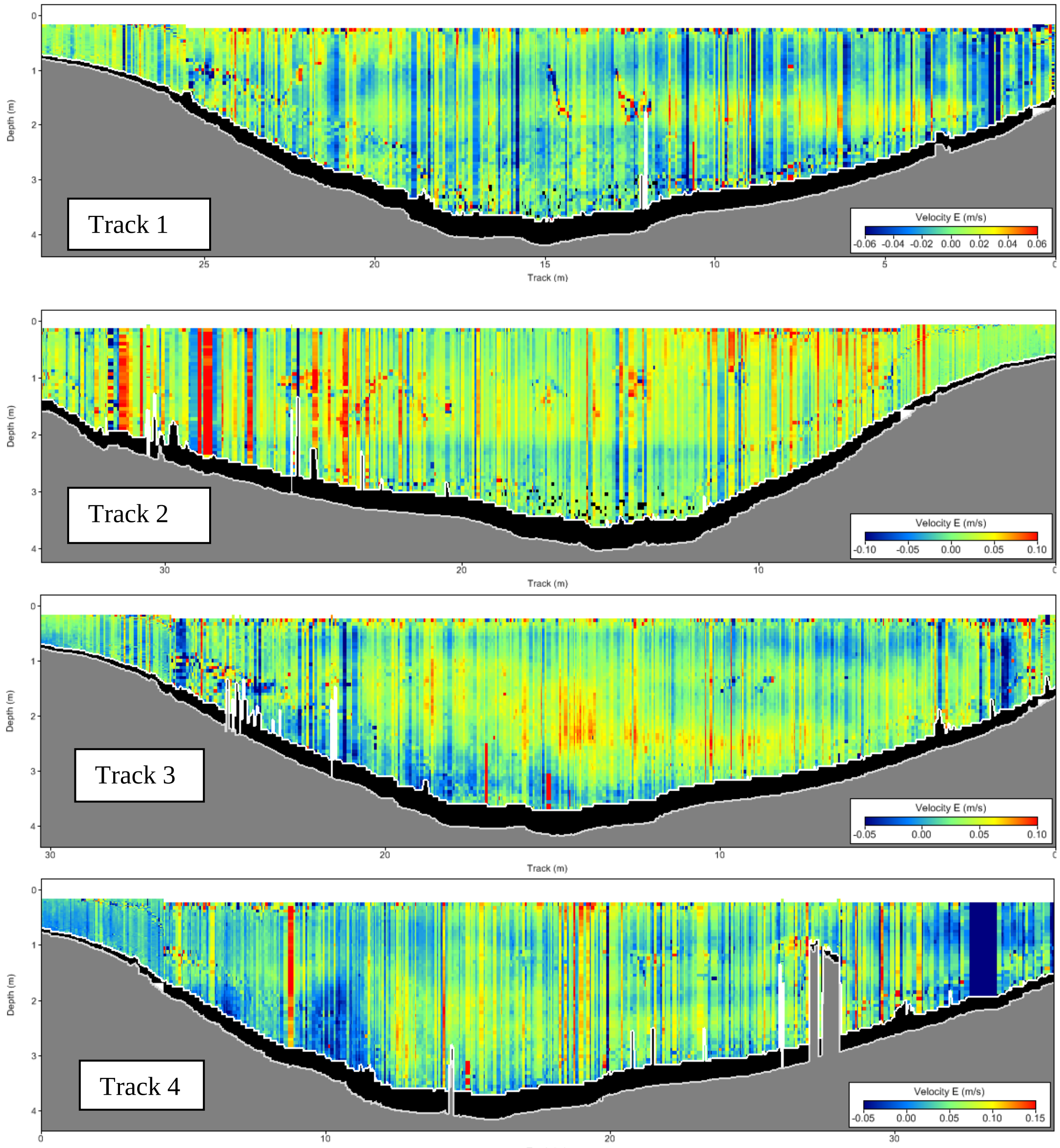


Figure 32. River surveyor velocity profiles obtained during site 2 wet weather sediment sampler retrieval on June 24, 2011.

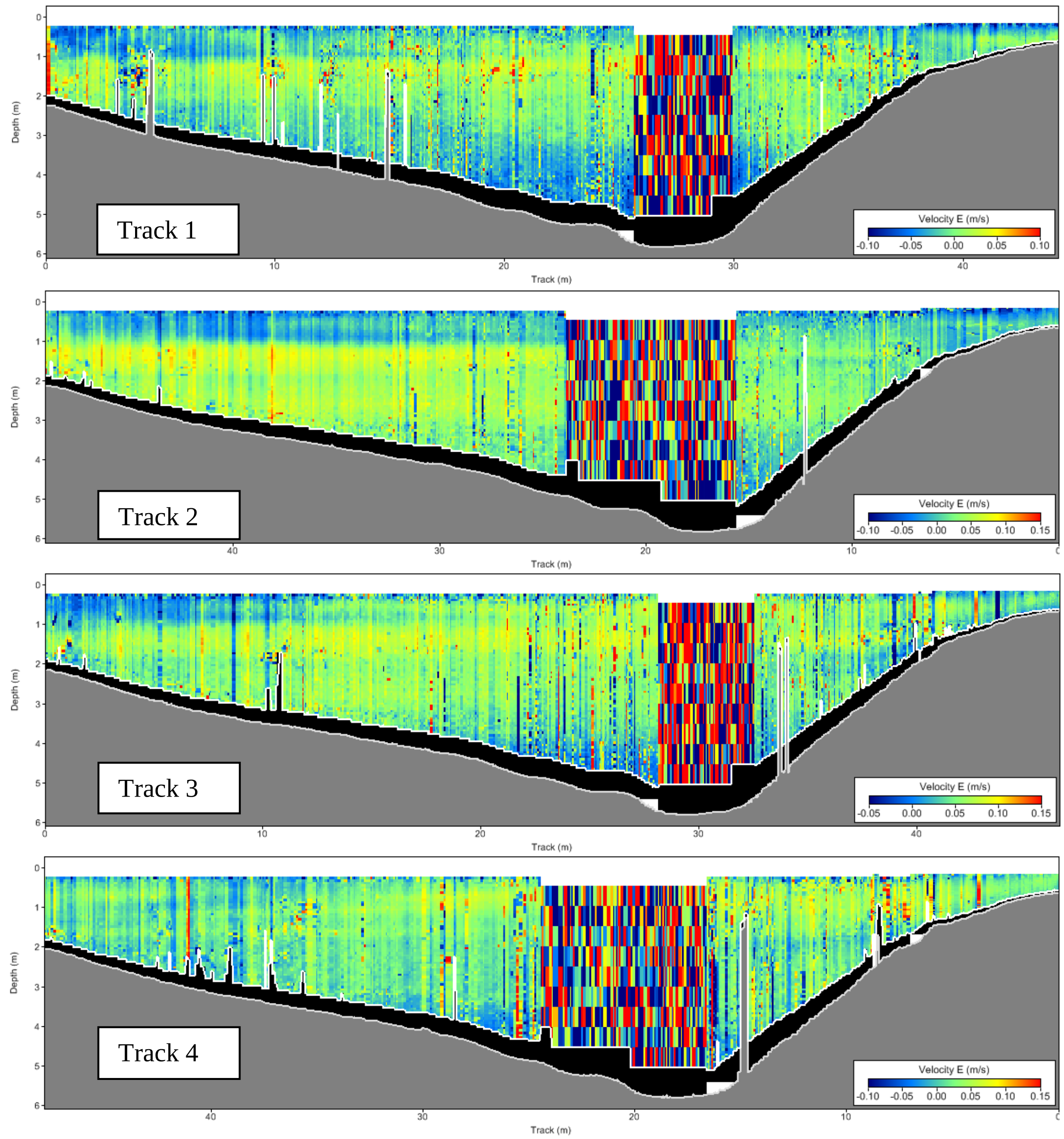


Figure 33. River surveyor velocity profiles obtained during site 3 wet weather sediment sampler retrieval on June 24, 2011.

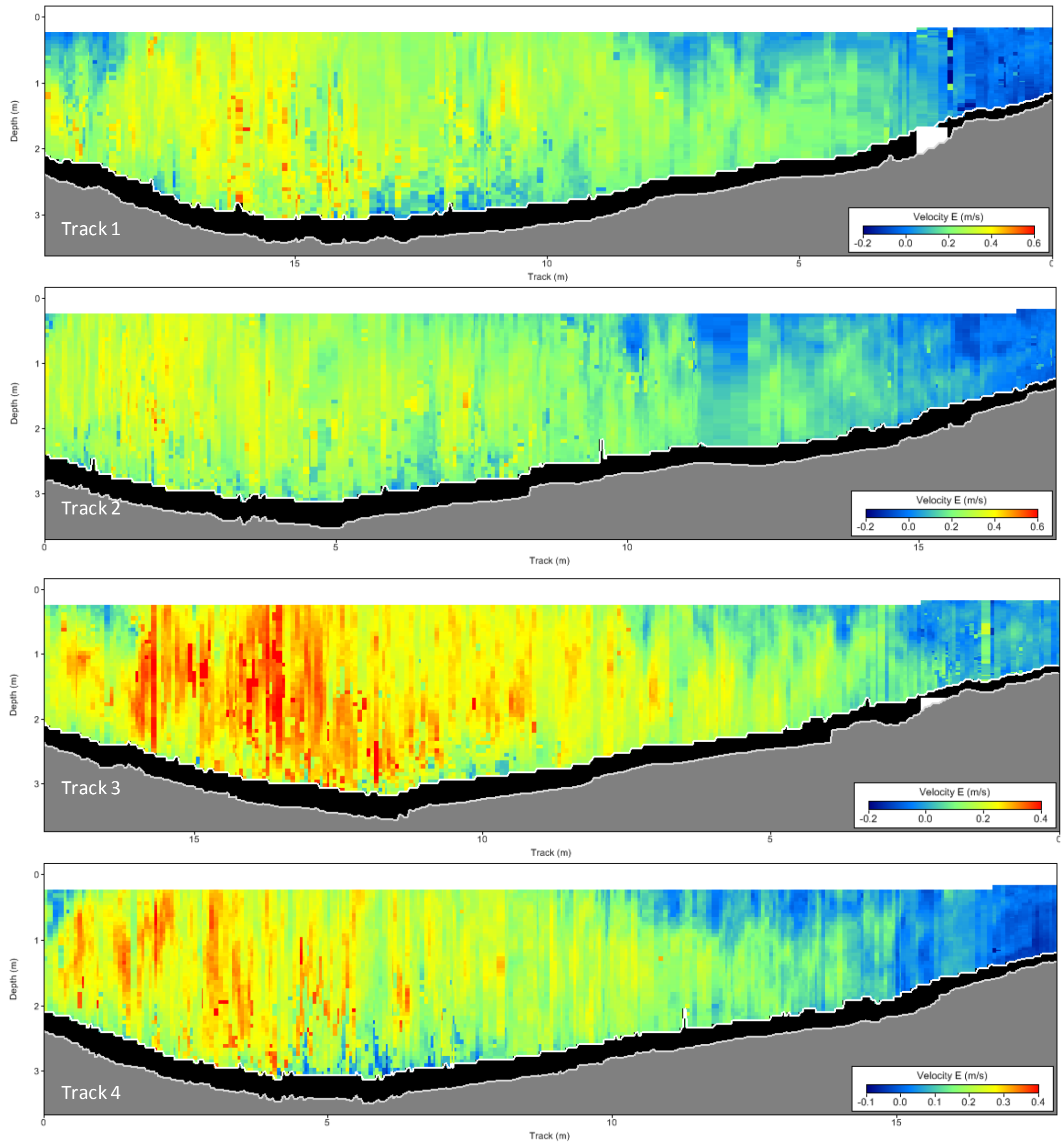


Figure 34. River surveyor velocity profiles obtained during site 1 wet weather sediment sampler deployment on March 20, 2012.

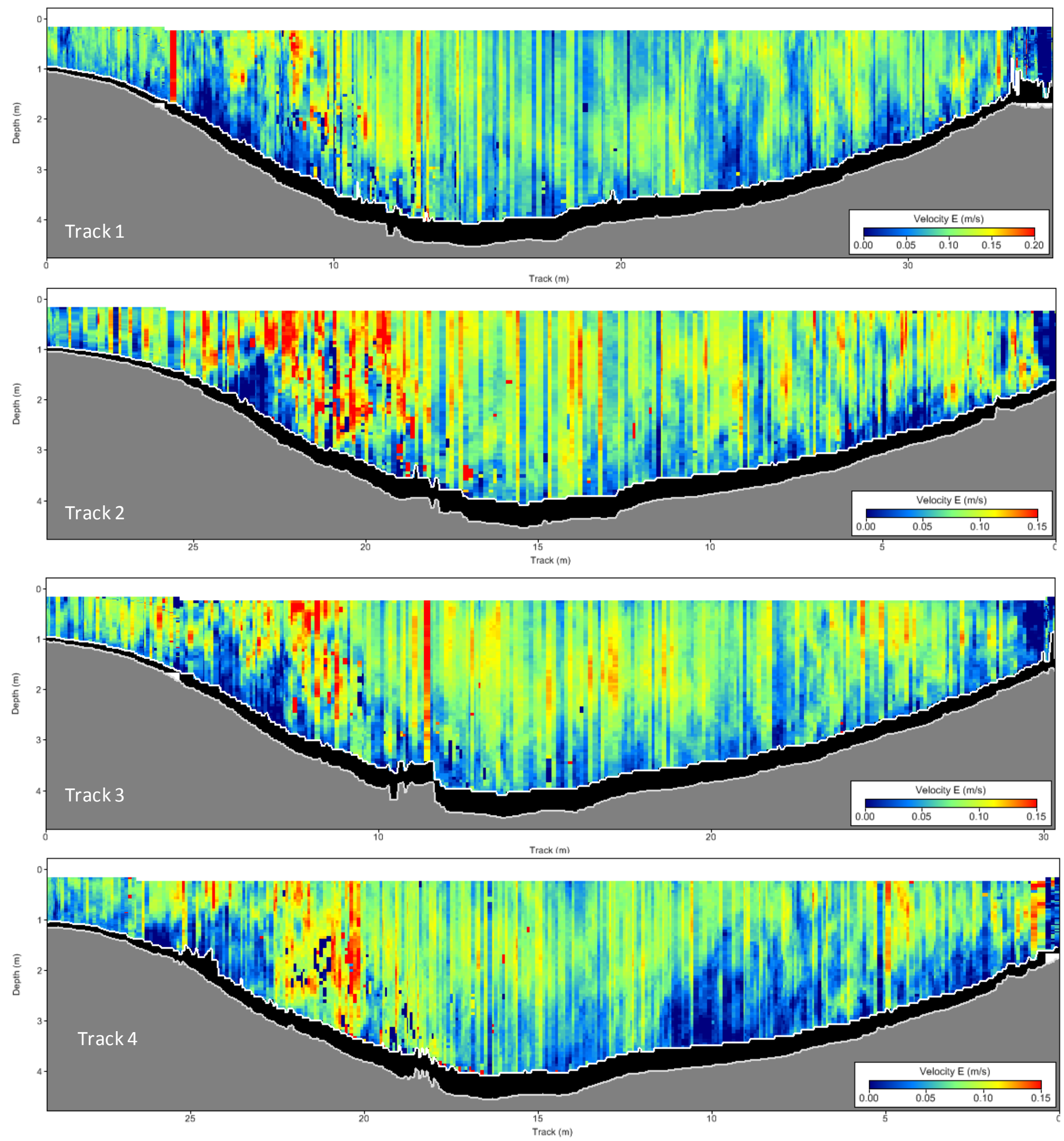


Figure 35. River surveyor velocity profiles obtained during site 2 wet weather sediment sampler deployment on March 20, 2012.

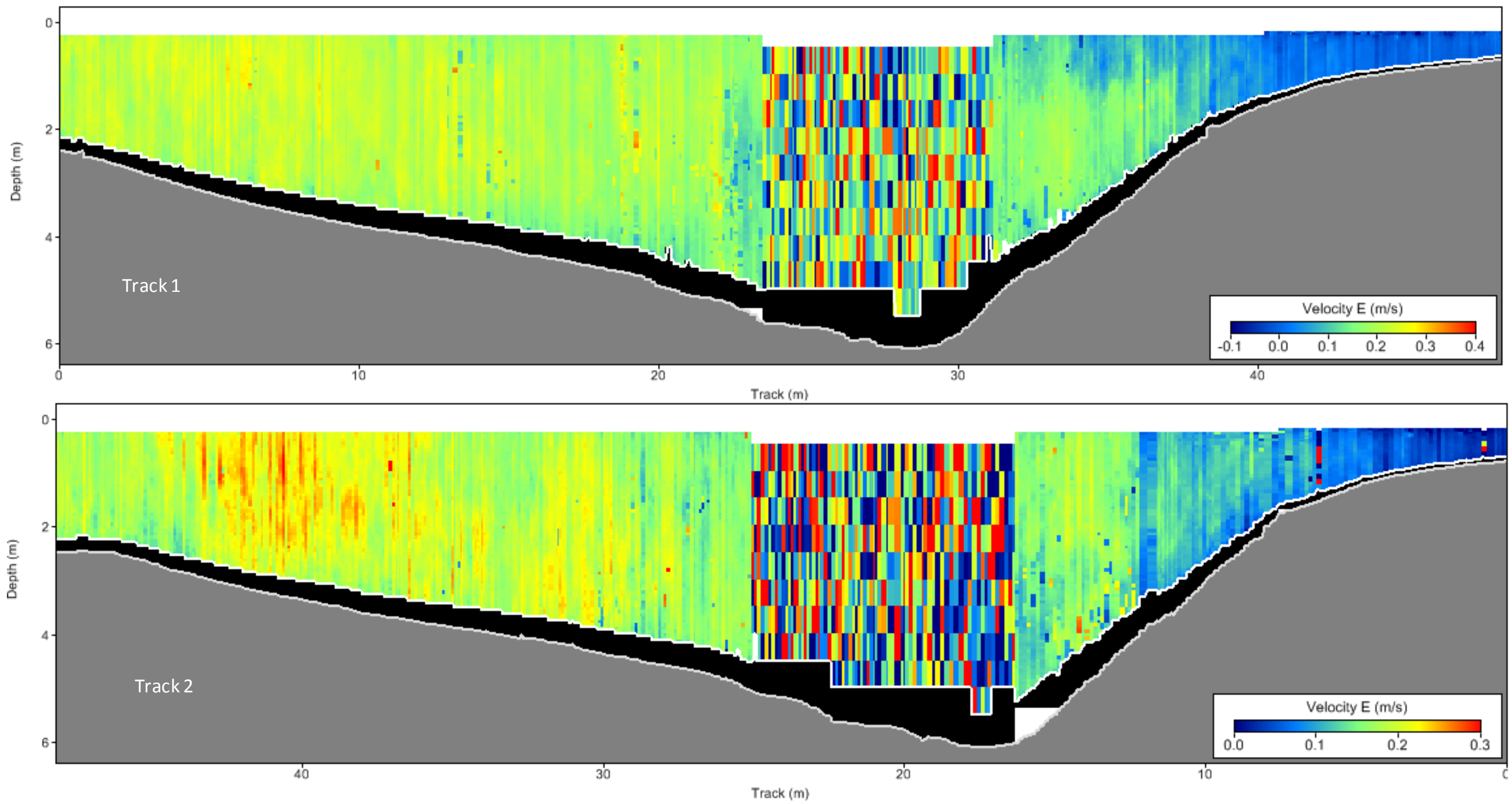


Figure 36. River surveyor velocity profiles obtained during site 3 wet weather sediment sampler deployment on March 20, 2012. Only two transects were monitored due to loss of battery power.

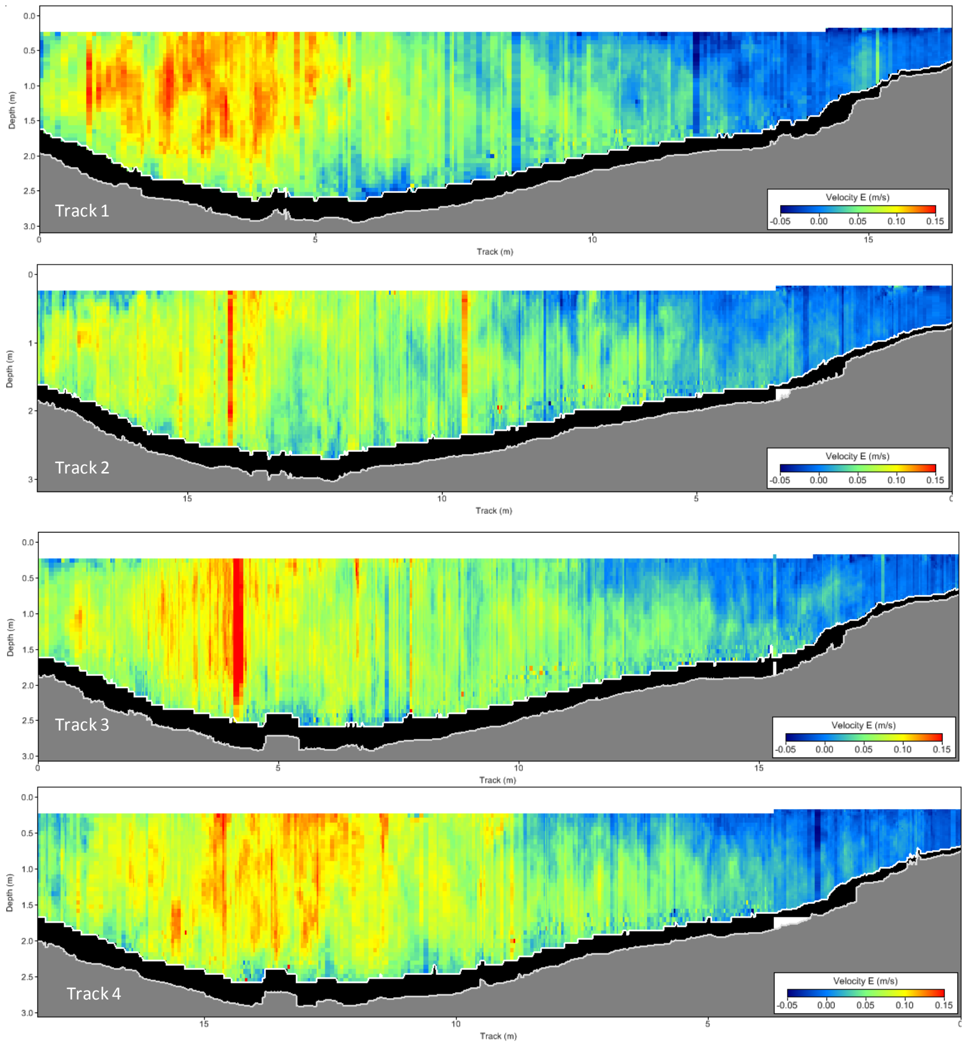


Figure 37. River surveyor velocity profiles obtained during site 1 wet weather sediment sampler retrieval on March 22, 2012. Flow samples were not taken at sites 2 and 3 due to loss of battery power.

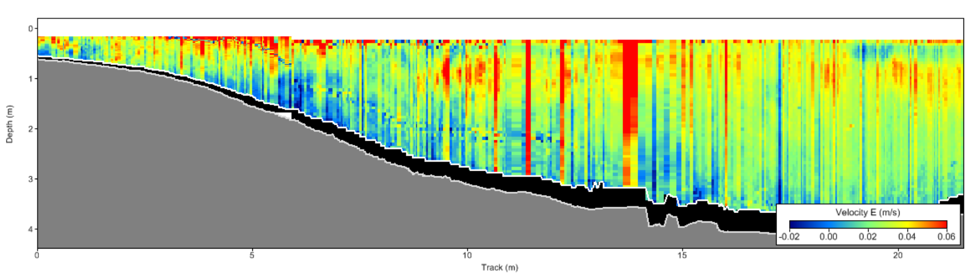


Figure 38. River surveyor velocity profiles obtained during site 2 wet weather sediment sampler retrieval on March 22, 2012. This site was incompletely sampled due to loss of battery. Flow samples were not taken at site 3 due to continued loss of power.

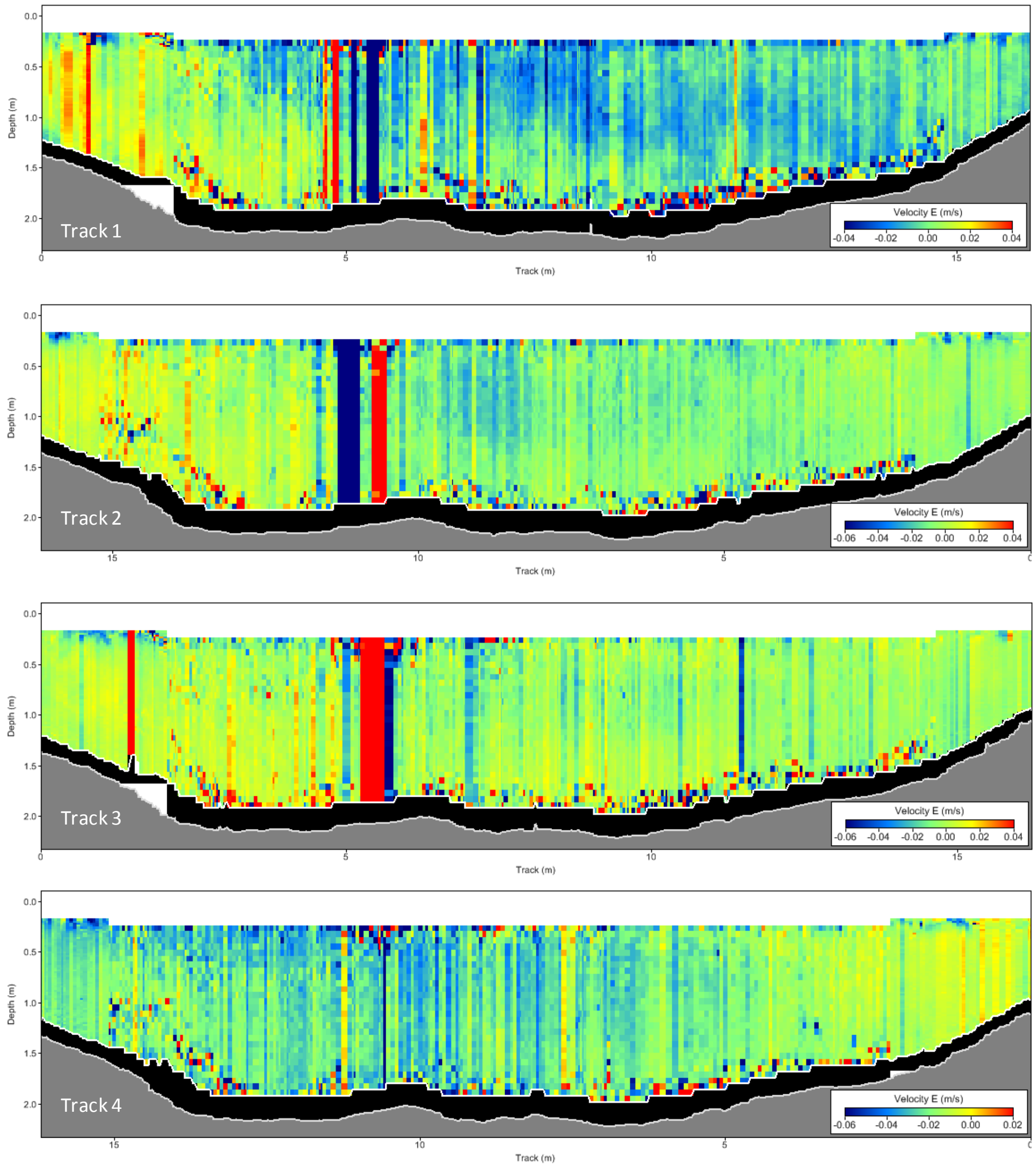


Figure 39. River surveyor velocity profiles obtained during site 1 dry weather sediment sampler deployment on April 24, 2012.

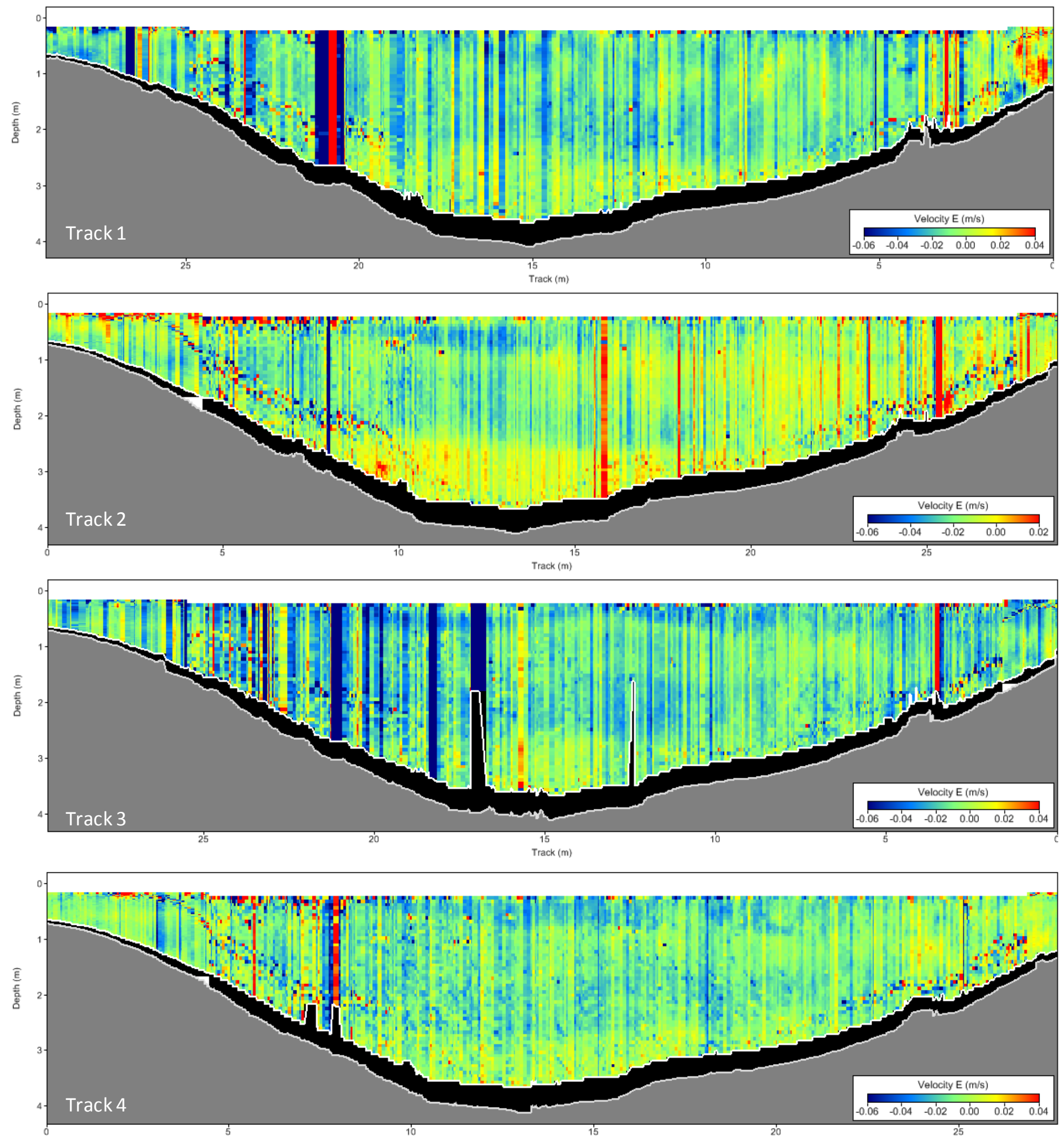


Figure 40. River surveyor velocity profiles obtained during site 2 dry weather sediment sampler deployment on April 24, 2012.

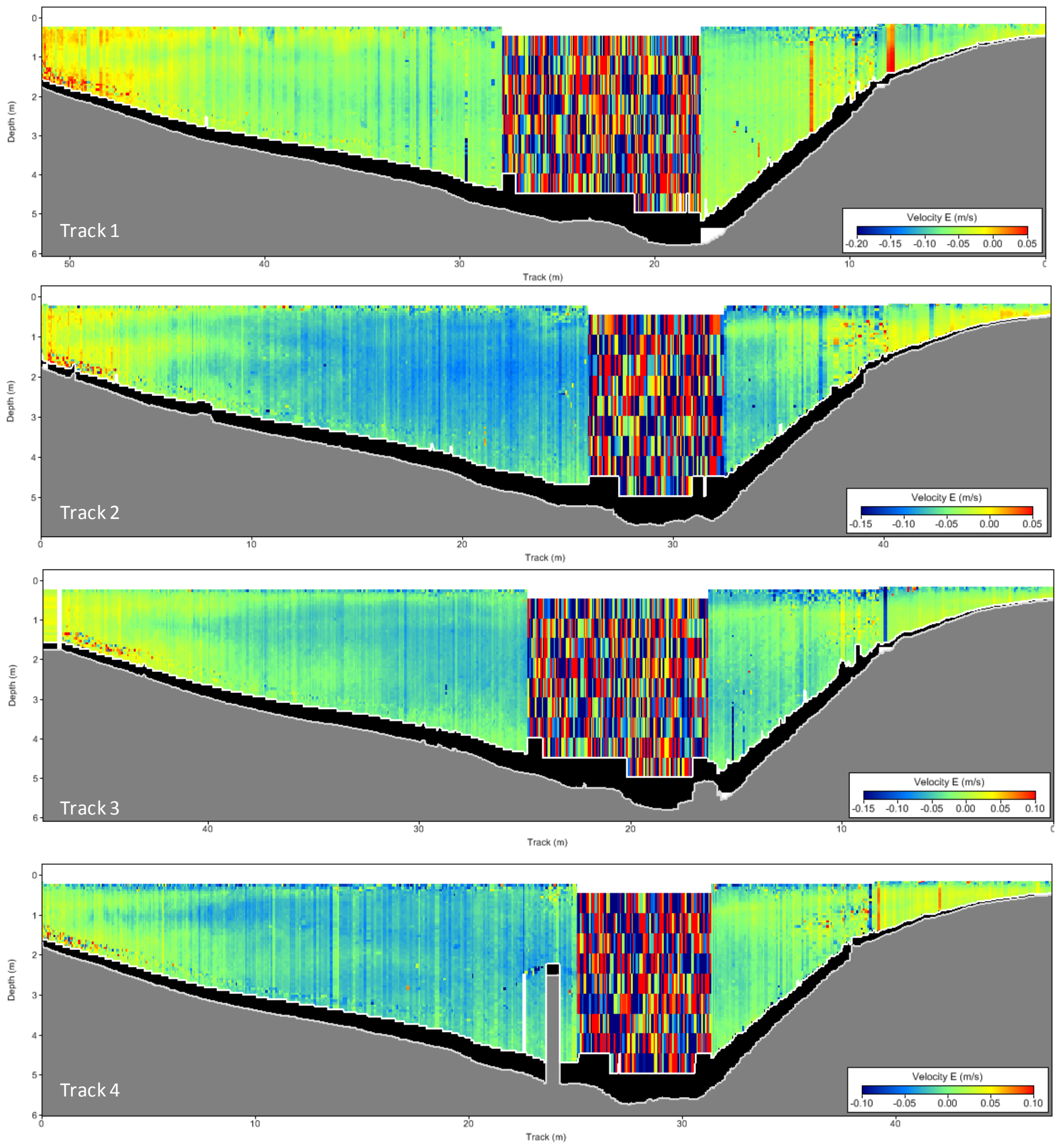


Figure 41. River surveyor velocity profiles obtained during site 3 dry weather sediment sampler deployment on April 24, 2012.

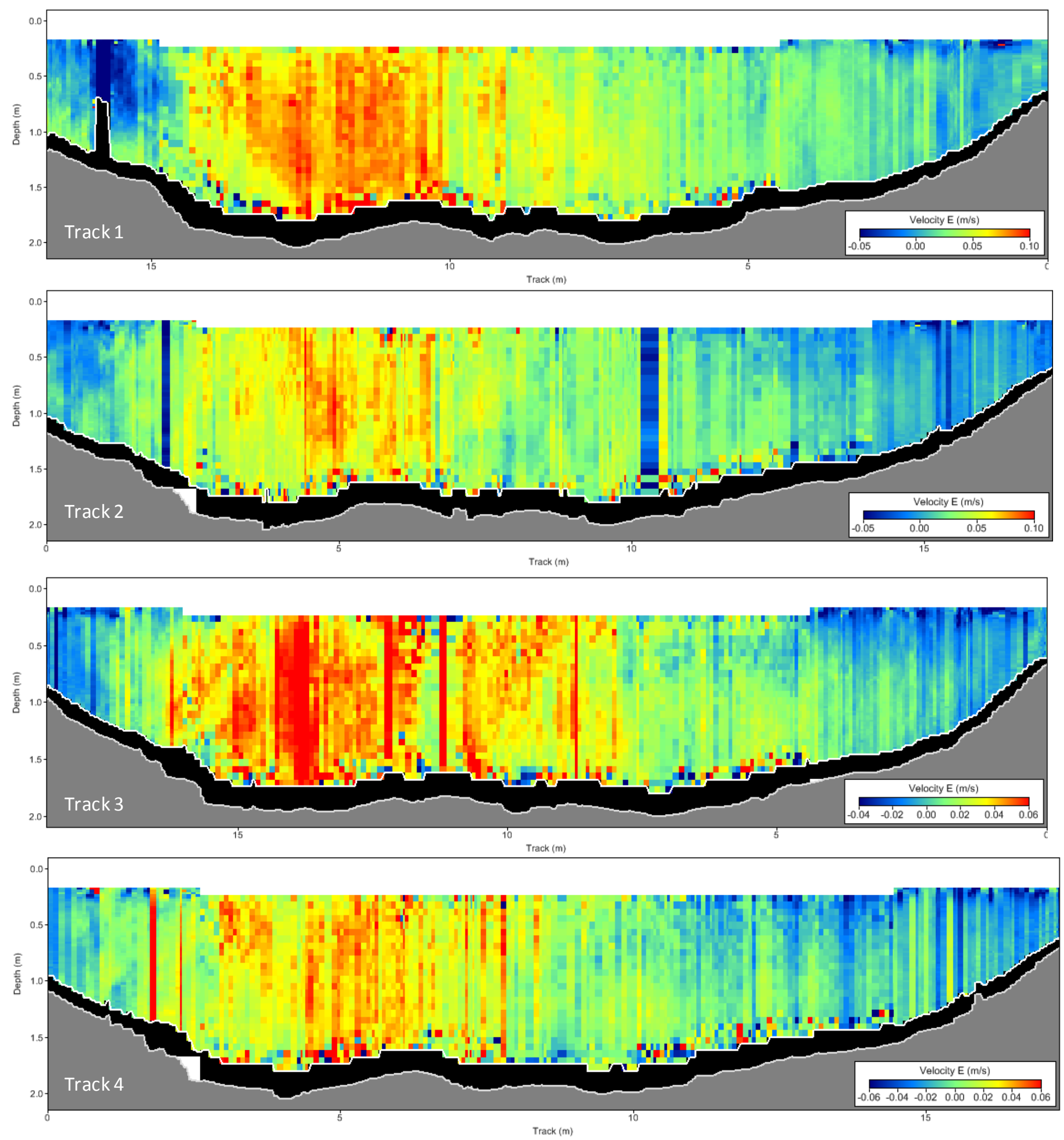


Figure 42. River surveyor velocity profiles obtained during site 1 dry weather sediment sampler retrieval on April 27, 2012.

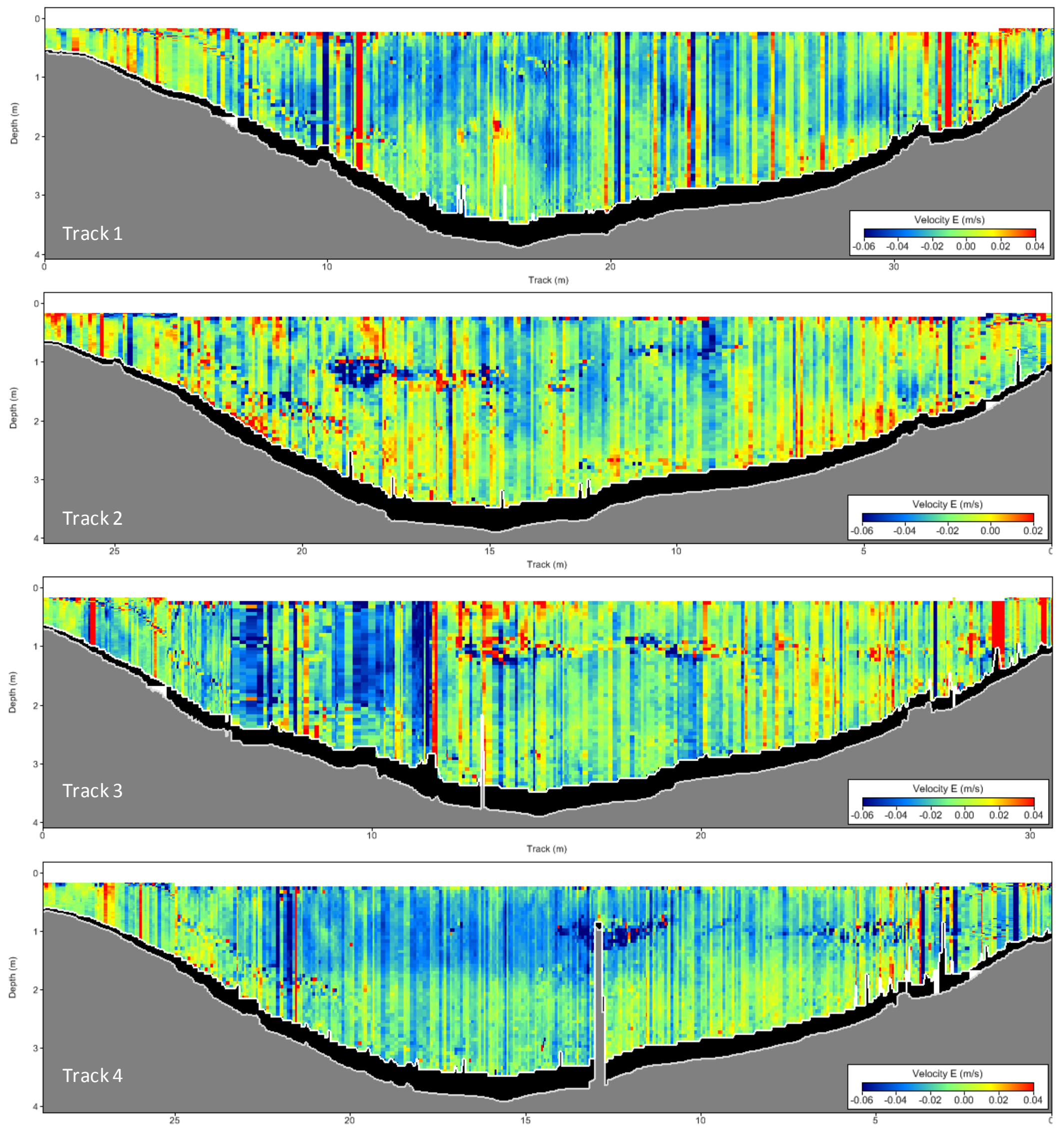


Figure 43. River surveyor velocity profiles obtained during site 2 dry weather sediment sampler retrieval on April 27, 2012.

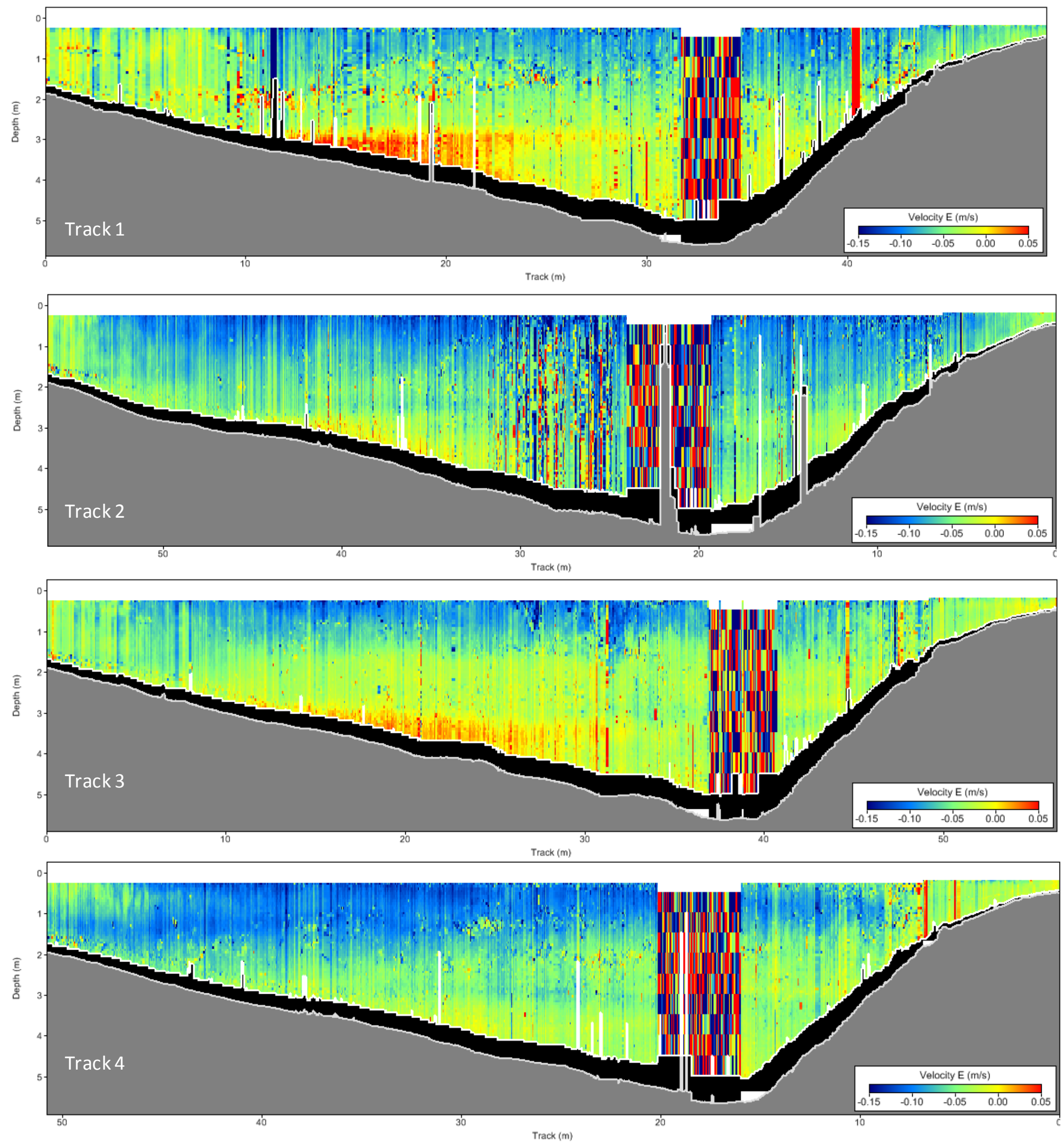


Figure 44. River surveyor velocity profiles obtained during site 3 dry weather sediment sampler retrieval on April 27, 2012.

Water Quality Results

A summary of important water quality variables measured during the sedimentation study are discussed below. Specific conductance (uS) and salinity (psu or ppt) generally increased in a downstream direction from site 1 to 3 during 2011 (Figures 45 and 46). Specific conductance and salinity also increased with depth, ranging between 1 to 3 PSU (ppt) from surface to bottom. Interestingly, higher specific conductance and salinity in general were observed during the wet sampling period in June 2011 versus the April-May 2011 dry period, further reinforcing the concept that water fluctuations during the 2011 sampling events were more likely due to tidal forcing versus runoff from rain. This may also reflect the movement of freshwater over marine water.

During both years of the study, surface measurements of secchi disk transparency (SD) were generally higher during dry versus wet weather periods at sites 1 and 2 (Figure 47). Little difference was seen at site 3, the most downstream location. This provides evidence that, during wet weather events, sediment loads were most likely higher causing lower transparency. Also, the lower overall transparency values recorded in 2012, in contrast to 2011, indicates a higher degree of sediment resuspension most likely due to elevated streamflow, but also possibly due to higher overall primary productivity in the second year.

As expected, surface turbidity (NTU) followed similar spatial and temporal trends to secchi disk transparency (Figure 48). During both years of the study, turbidity was generally lower during dry versus wet weather periods at sites 1 and 2. Little difference was seen at site 3, the most downstream location. This provides evidence that, during wet weather events, sediment loads were most likely higher causing greater turbidity. Also, the higher overall turbidity values recorded in 2012, in contrast to 2011, may indicate a higher degree of sediment resuspension most likely due to elevated streamflow, but also possibly due to higher overall primary productivity in the second year.

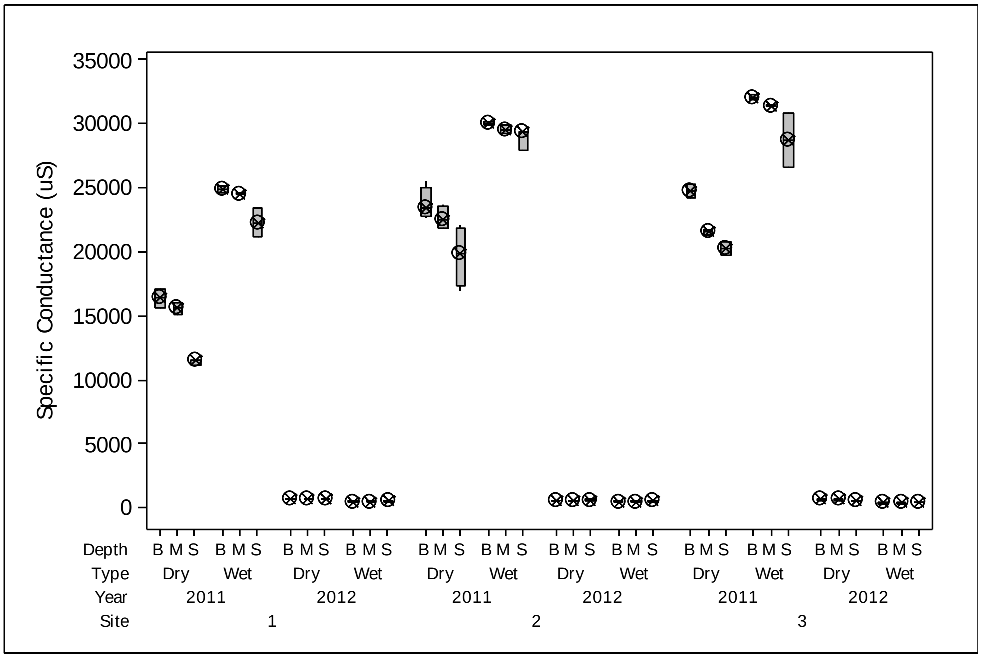


Figure 45. Specific conductance (uS) measured at each site during 2011 and 2012, during wet and dry sampling events at bottom (B), middle (M) and surface (S) depths.

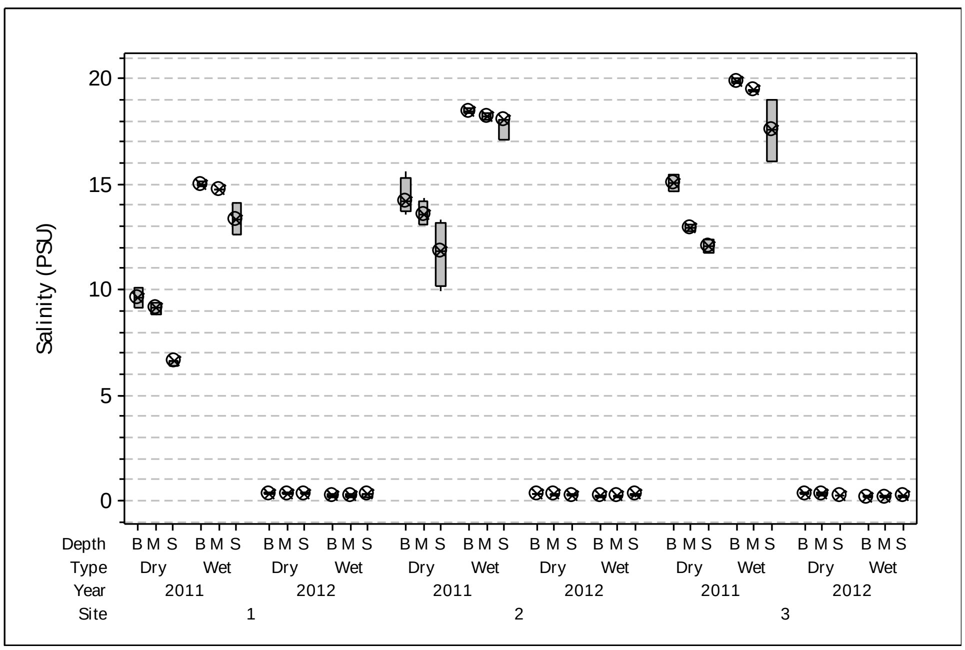


Figure 46. Salinity measured at each site during 2011 and 2012, during wet and dry sampling events at bottom (B), middle (M) and surface (S) depths.

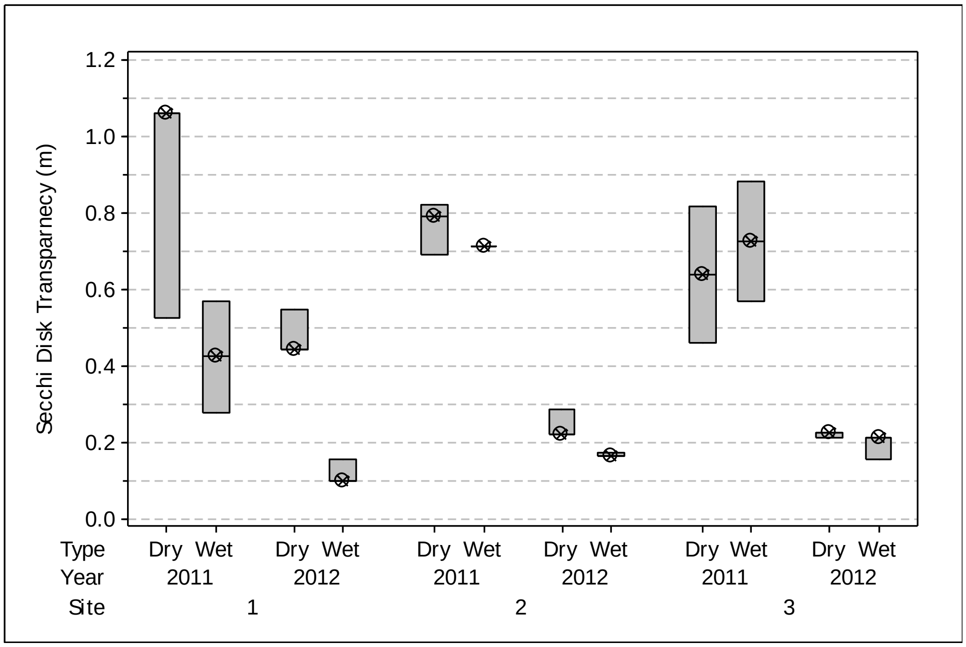


Figure 47. Secchi disk transparency (SD) measured at each site during 2011 and 2012, during wet and dry sampling events.

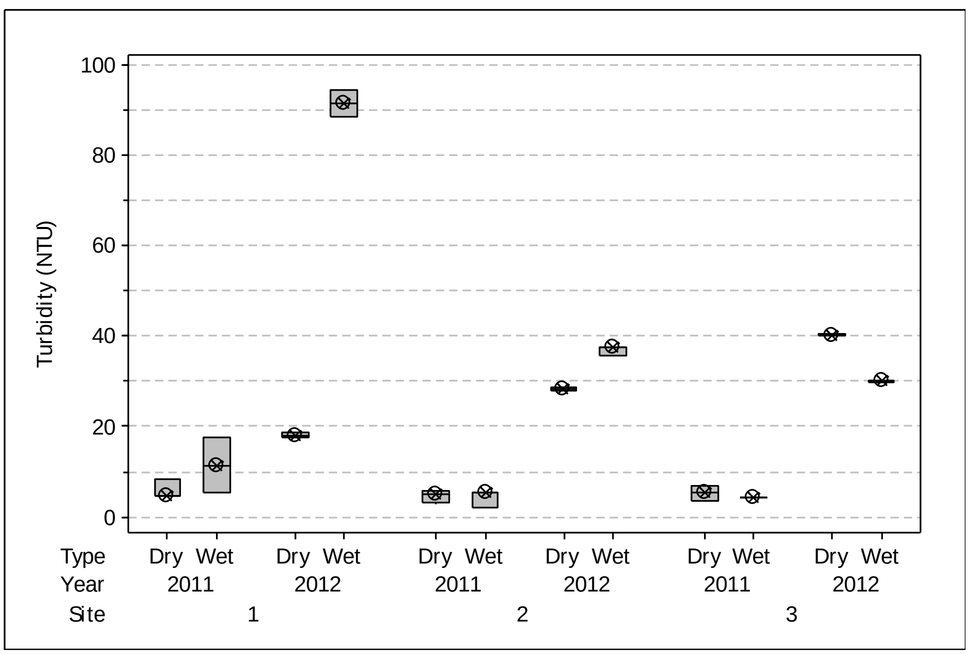


Figure 48. Turbidity (NTU) measured at each site during 2011 and 2012, during wet and dry sampling events.

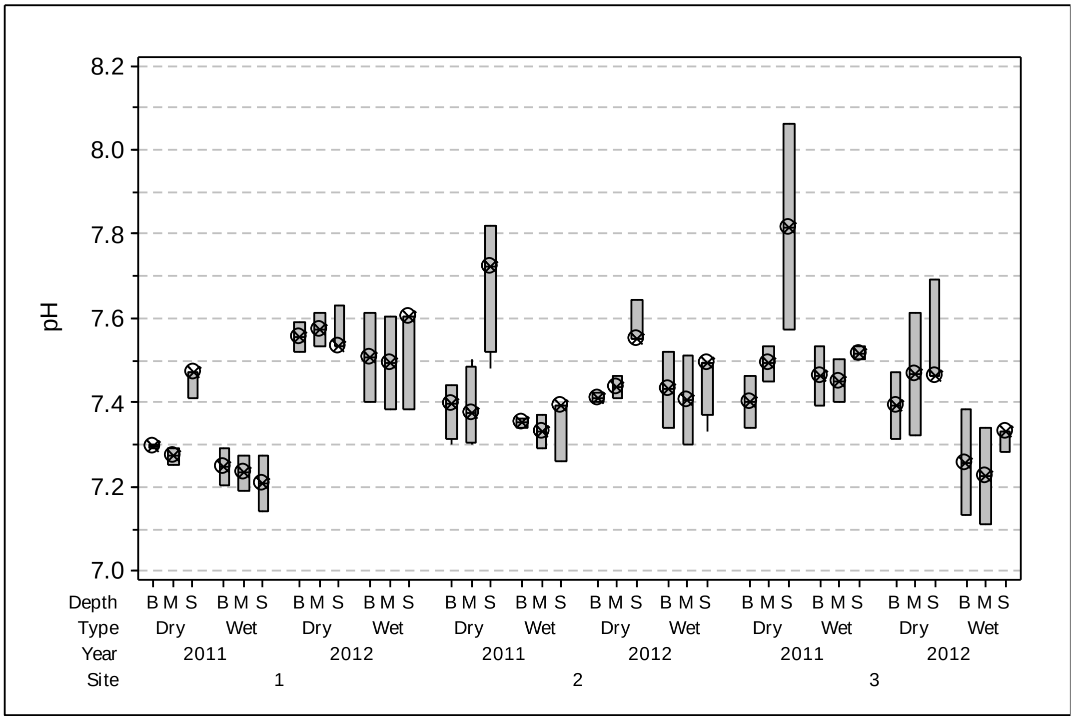


Figure 49. The pH measured at each site during 2011 and 2012, during wet and dry sampling events at bottom (B), middle (M) and surface (S) depths.

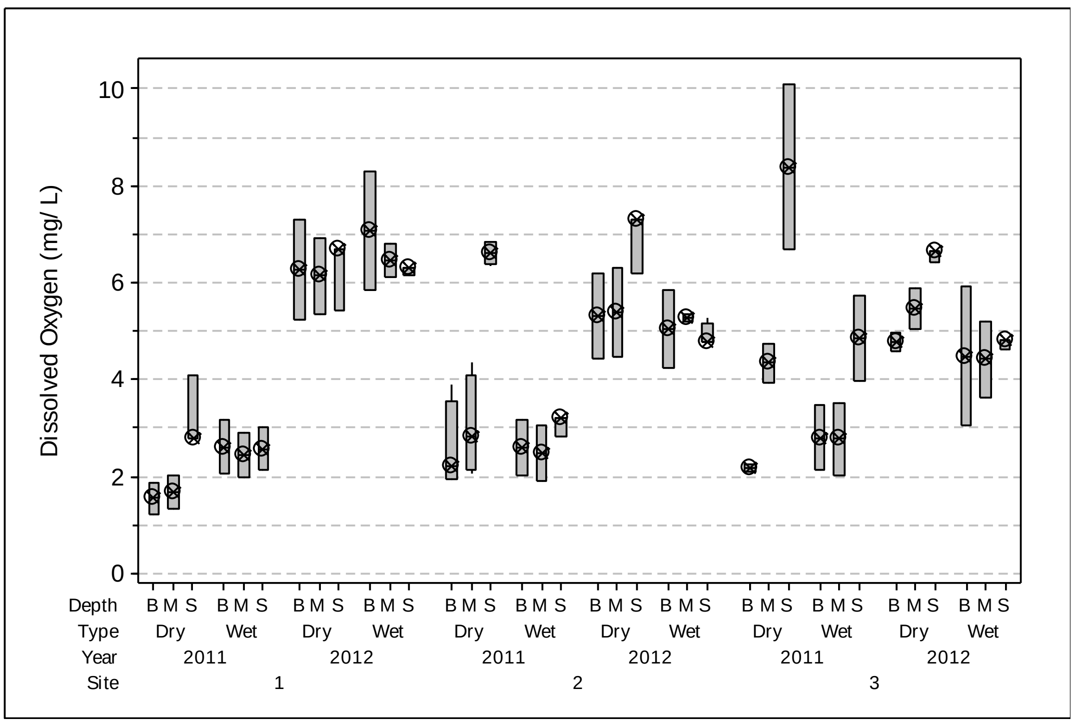


Figure 50. Dissolved oxygen (mg/L) measured at each site during 2011 and 2012, during wet and dry sampling events at bottom (B), middle (M) and surface (S) depths.

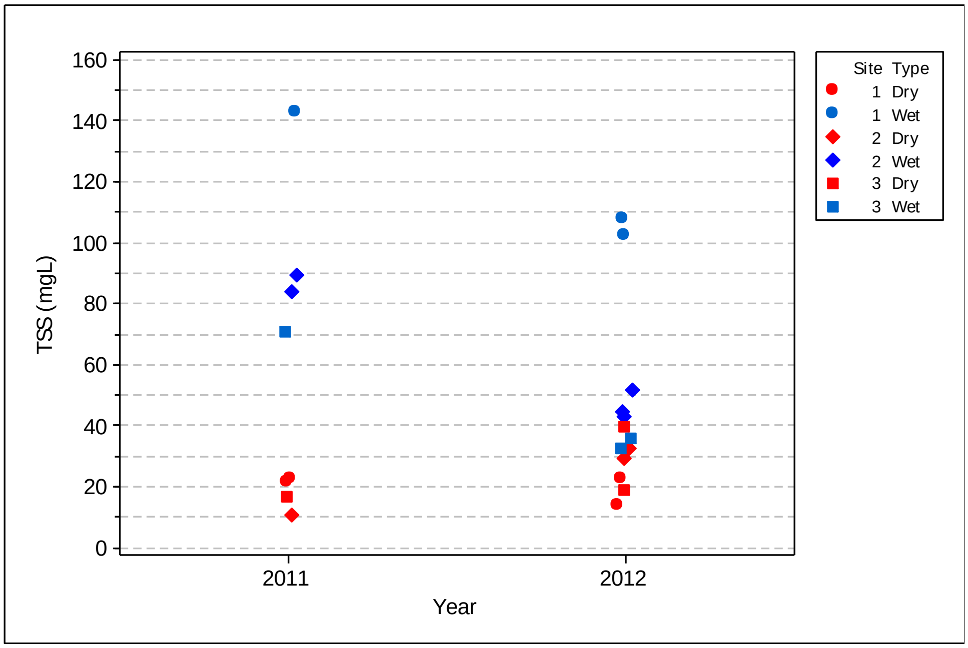


Figure 51. Total suspended solids (mg/L) measured at each site during 2011 and 2012, during wet and dry sampling events.

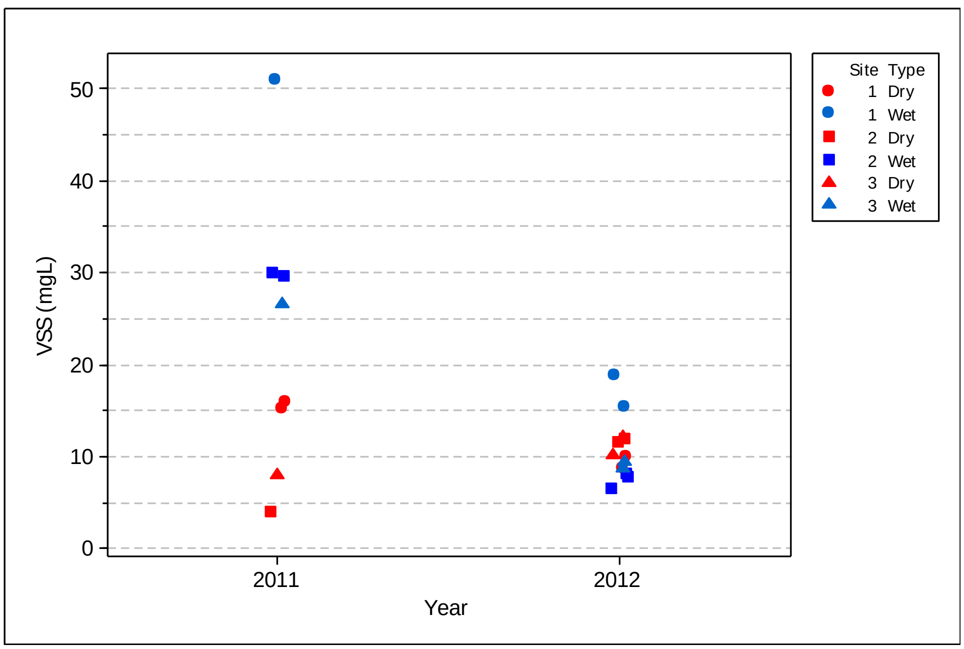


Figure 52. Volatile suspended solids (mg/L) measured at each site during 2011 and 2012, during wet and dry sampling events.

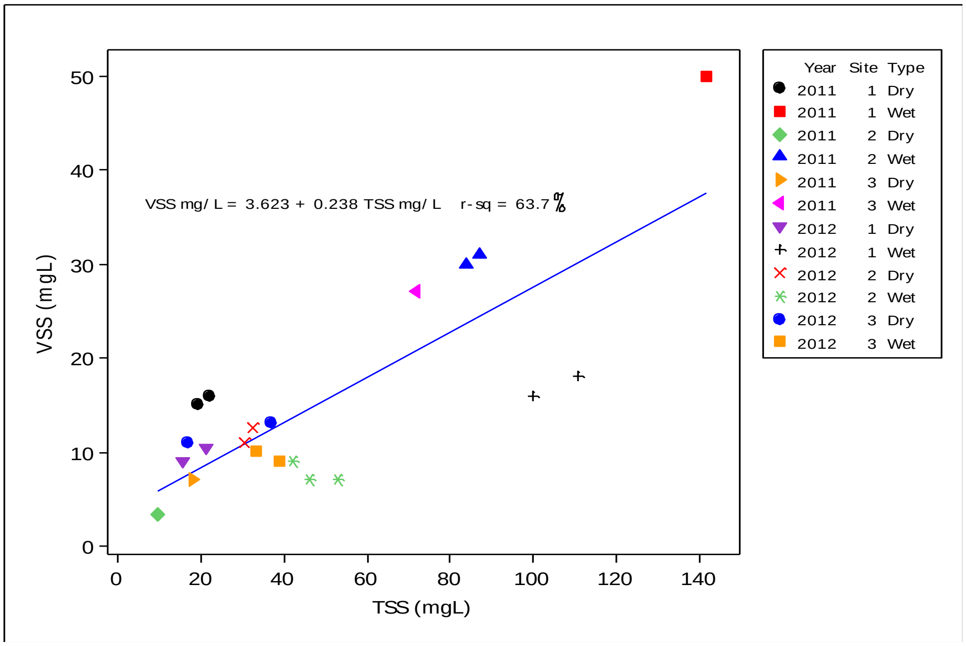


Figure 53. Relationship between VSS and TSS levels measured on samples collected in Dickinson Bayou during wet and dry weather sampling during 2011 and 2012.

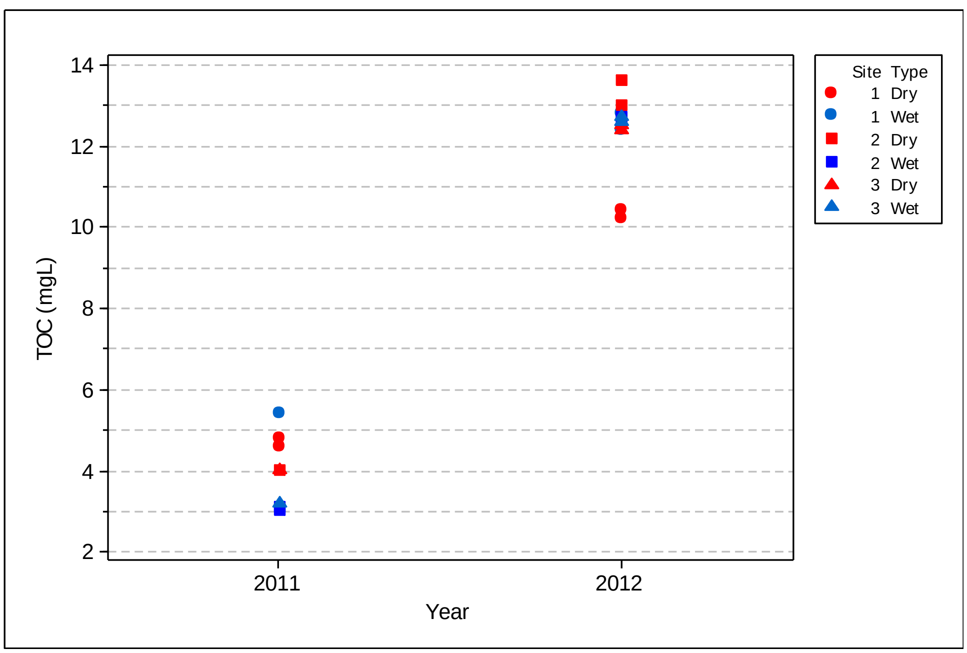


Figure 54. Total organic carbon (mg/L) measured at each site during 2011 and 2012, during wet and dry sampling events.

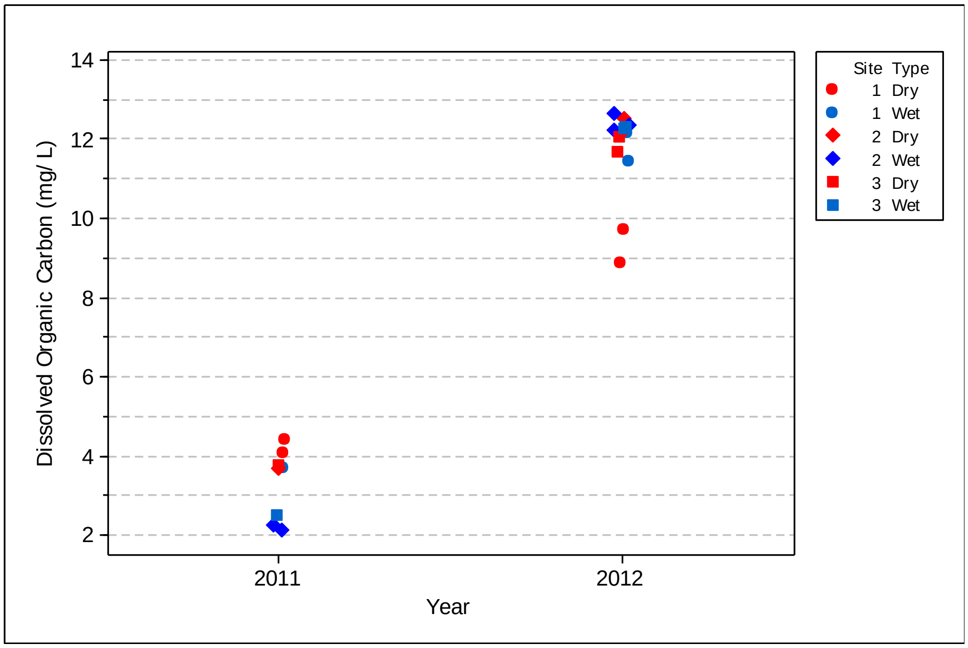


Figure 55. Dissolved organic carbon (mg/L) measured at each site during 2011 and 2012, during wet and dry sampling events.

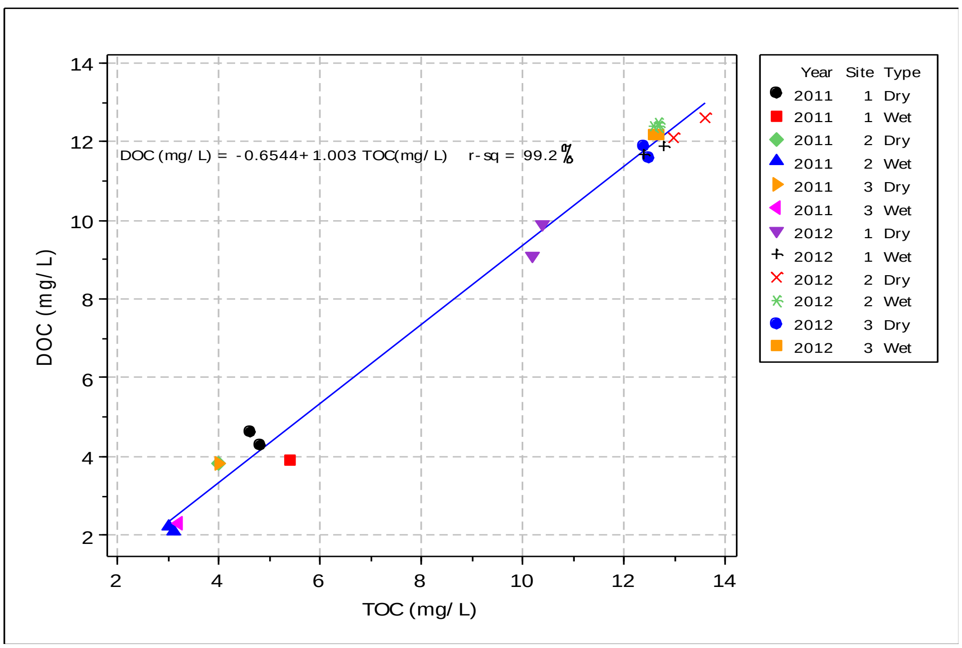


Figure 56. Relationship between DOC and TOC levels measured on samples collected in Dickinson Bayou during wet and dry weather sampling during 2011 and 2012.

Sediment Results

During April 2011, stream bed sediment sampling was conducted at the 3 sites (Table 7). The majority (85.9-96.5%) of sediment present was fine clays and silts (grain size < 0.0626 mm). The amount of silicates measured further documents the low amount of sand in sediment. Approximately 6.9 to 9.6% of the bed sediment is composed of volatile solids. A high amount of the sediment is composed of carbon of which at least 78.6% to 97% is organic. The majority (>96%) of nitrogen in stream sediment consisted of organic forms at all three sites. In contrast, only 83 to 62 percent of the total phosphorus is in the organic form. These data suggest that Dickinson Bayou stream bed sediments are primarily composed of fine clays and silt containing high amounts of organic material. During high flow periods many of these sediments would be easily remobilized into suspension due to their small size and low settling velocities (Brown et al. 1999). This would suggest that the predominant uncompacted bottom sediment present in Dickinson Bayou is highly susceptible to erosion at relatively low stream velocities.

Table 7. Bulk stream bed sediment physical and chemical properties collected at each site on April 20, 2011.

Site	Date Collected	% Total Solids	GS >2.0 mm (%)	GS 0.0625 - 2.0 mm (%)	GS <0.0625 mm (%)	SiO_2 (mg/kg)	TVS (%)	TC (mg/kg)	TOC (mg/kg)	TN (mg/kg)	TON (mg/kg)	TP (mg/kg)	TOP (mg/kg)
1	4/20/11	29.4	0.2	9.50	90.3	1,460	6.90	26,900	26,300	3,238	3,095	105	74.40
2	4/20/11	25.2	3.2	10.9	85.9	1,310	7.10	36,700	32,000	3,433	3,317	171	141.20
3	4/20/11	19.6	0.0	3.50	96.5	2,120	9.60	42,600	33,500	2,200	2,032	135	84.00

Sediment Trap Results

Due to laboratory errors associated with post sample processing of sediment trap samples, much of the sediment trap data collected during 2011 is not usable for the purposes of this study. For example, the total sediment estimates were contaminated with excessive moisture (i.e. wet sediment weight) versus properly concentrated (centrifuged) and dried weights. However, some laboratory measurements were properly conducted and where appropriate and useful for interpreting sediment dynamics, we have included this data in our analysis and it is presented in this section. All data, however, is provided in the electronic appendices that accompany this report.

Due to the low amount of sediment collected overall, only samples during 2011 and two wet weather samples collected at site 1 in March 2012 provided a sufficient amount of sediment to calculate size distribution (Figures 57 - 59). Based on the data collected the largest fraction of sediment collected was very fine (<0.0625 mm) cohesive silts and clay particles (Figure 57). This sediment size distribution measured in the collectors (85.9 to 96.5 %) was similar to the values obtained from the bulk stream bed sediment samples (82 to 99.6%) (Table 7). Therefore, it appears that the sediment deposition samplers collected sediment that was similar in physical composition to recently deposited stream bottom sediments (Table 7). The percentage of fine sediment (<0.0625) was higher in wet weather collections (Figure 57). Conversely, the percentage of larger sediment size classes declined during wet weather monitoring (Figure 58). Larger sediment (>2.0 mm) fractions were absent in all sediment trap samples (Figure 59).

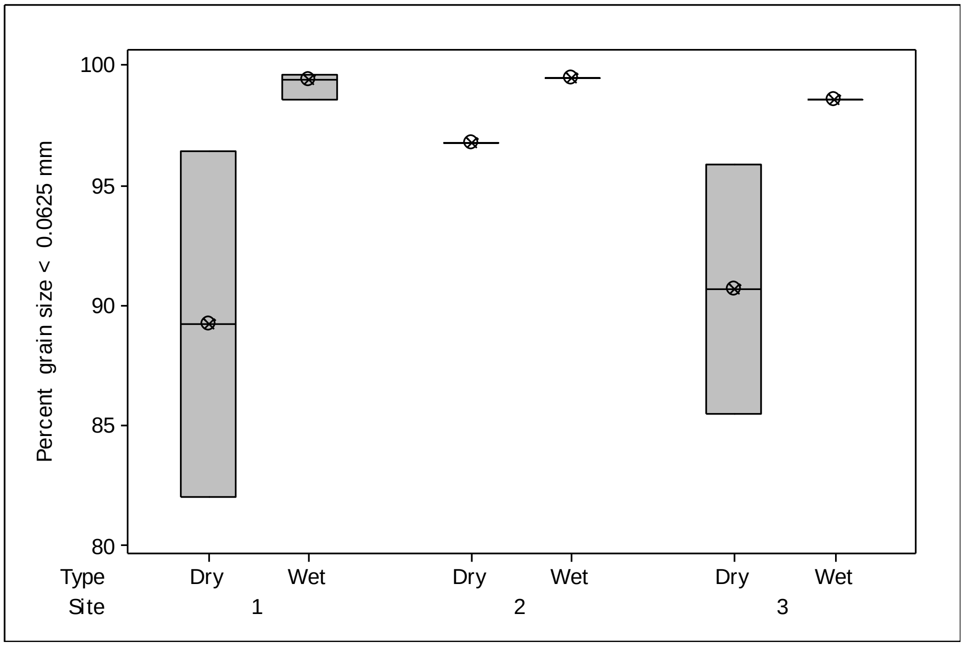


Figure 57. Percent grain size < 0.0625 mm diameter (silt and clay fraction) in settled solids from each sediment sampler during April, May and June 2011 monitoring.

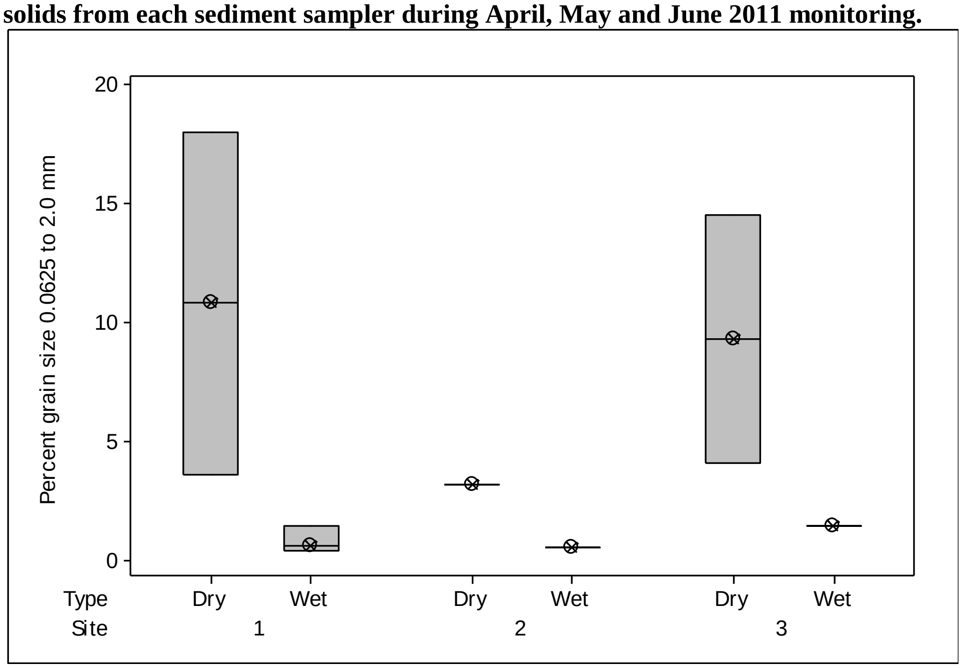


Figure 58. Percent grain size < 0.0625 to 2.0 mm diameter in settled solids from each sediment sampler during April, May and June 2011 monitoring.

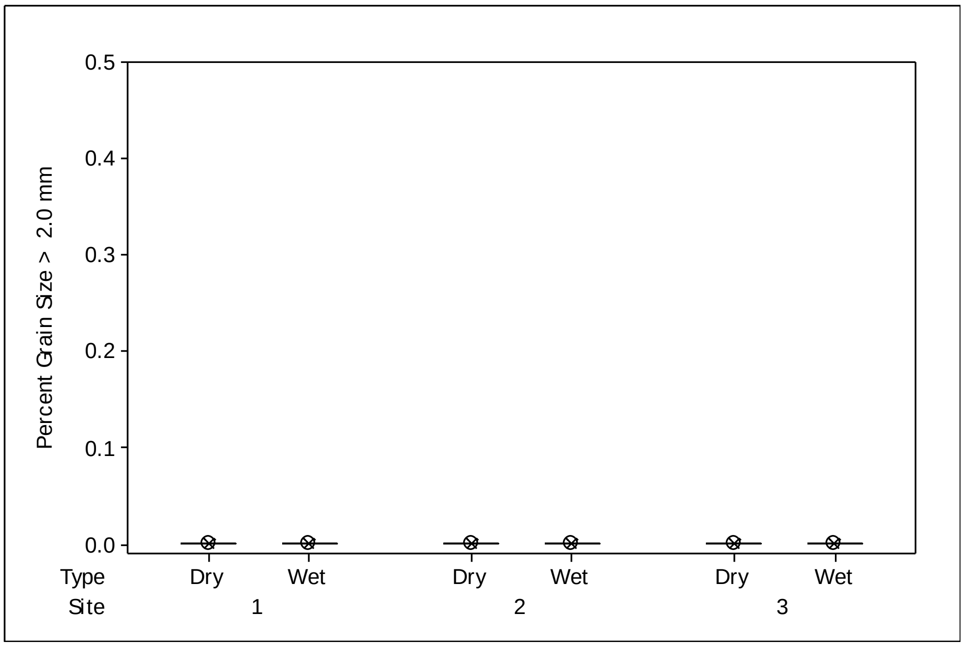


Figure 59. Percent grain size > 2.0 mm diameter in settled solids from each sediment sampler during April, May and June 2011 monitoring.

The remainder of the sedimentation collector data is based solely on data collected during 2012. Summary tables showing the distribution of measured values and estimated deposition rates are provided (Tables 8 and 9). During dry weather sampling the sediment collectors were deployed for a range of 70.7 to 71.2 hours. Wet weather sampling ranged between 45.8 to 46.7 hours. The total amount of sediments collected by each sampler array at each site is summarized in Figure 60 and Table 8. In general, the highest amount of total solids was collected during wet weather sampling. The highest amount of solids was collected at site 1 during wet weather sampling. The calculated sedimentation rates during this study ranged between 1.860 to 4.740 g/hr/m^2 during dry weather conditions, and 10.5 to 66.7 g/hr/m^2 during wet weather (Figure 61). The majority of the deposited sediment was composed of non-volatile fractions (Figure 62). Volatile deposited sediment ranged between 2.5 and 14.4%. This is similar to the values reported in this study for bulk bottom stream sediment (6.9 to 9.6%) (Table 7).

Deposition rates of total carbon (TC) associated with particulate sediment ranged between 25.7 and 38.9 mg/hr/m^2 (Table 9 and Figure 63). Highest TC deposition rates were associated with wet weather periods. Deposition rates of total organic carbon associated with particulate sediment ranged 414 and 544.5 ug/hr/m^2 (Table 9 and Figure 64). Highest rates were associated with dry weather periods at site 2. Extremely low particulate-associated organic carbon was observed at site 1 during dry weather monitoring (Figure 64). Deposition rates of sediment-associated silicates ranged between 0.69 and 9.28 ug/hr/m^2 (Table 9 and Figure 65). Highest rates were associated with dry weather periods. This was primarily due to higher percentages of particulate-associated silicates during dry weather monitoring and not from high overall sediment deposition rates.

Deposition rates of total phosphorus associated with particulate sediment ranged between 0.30 and 17.88 ug/hr/m^2 (Table 9 and Figure 66). Highest rates were observed during dry weather periods. An extremely low particulate-associated phosphorus deposition rate (0.3 ug/hr/m^2) was observed at site 1 during wet weather monitoring (Figure 66). The lower rates observed during dry weather periods reflect the lower amount of particulate-associated phosphorus during wet weather sampling despite high total sediment deposition rates.

Deposition rates of total nitrogen associated with particulate sediment ranged between 6.64 and 72.55 ug/hr/m^2 (Table 9 and Figure 67). Highest deposition rates were associated with dry weather periods at all sites. This was due to the higher percentages of sediment-associated nitrogen during dry weather sampling and not from lower total sediment deposition rates. A very low rate of particulate-associated phosphorus deposition (6.64 ug/hr/m^2) was observed at site 1 during wet weather monitoring (Figure 67).

Deposition rates of total solids were elevated at higher average stream flows (Figure 68). However this rate was not linear and appeared to be highly influenced by location as well. Deposition rates of total carbon did not appear to differ considerably between high and low deposition rates of total solids, with the exception of site 1 (Figure 69).

Table 8. Measured physical and chemical characteristics of sediment collected in sedimentation samplers during March and April, 2012.

ID	Site	Rep	Type	Time hr	Area sq-m	Depth m	Total Solids g	TVS (%)	TP (mg/kg)	DL	T-Org P (mg/kg)	TKN (mg/kg)	DL	NO3+NO2 (mg/kg)	TN (mg/kg)	T-Org N (mg/kg)	SiO2 (mg/kg)	Total C (mg/kg)	T-Org C (mg/kg)
11464	1	A	Wet	45.75	0.016206419	3.060	49.43	13	20		2	610.4	<	1.5	610.4	112	59.1	36800	28200
11464	1	B	Wet	45.88	0.016206419	3.060	41.90	14.4	18		9	442.4	<	1.5	442.4	72.8	74.5	25700	27600
18649	2	A	Wet	45.93	0.016206419	4.317	8.91	6.4	25		2	1098	<	1.5	1098	375.2	82.4	32200	31500
18649	2	B	Wet	46.10	0.016206419	4.317	10.44	8.6	15		5	912.8	<	1.5	912.8	330.4	70.7	32000	31500
11461	3	A	Wet	46.37	0.016206419	5.681	7.86	7.4	22	<	0.02	677.6	<	1.5	677.6	280	71.1	37400	35800
11461	3	B	Wet	46.65	0.016206419	5.681	8.09	3	33		5	582.4	<	1.5	582.4	319.2	45.8	38900	36300
11464	1	A	Dry	70.85	0.016206419	2.003	2.14	7.8	20		1	3252		2.44	3253	2915	*	*	28700
11464	1	B	Dry	71.02	0.016206419	2.003	2.76	7.5	12		2	4835		2.31	4837	4466	*	*	30300
18649	2	A	Dry	70.73	0.016206419	4.031	5.43	2.5	18		9	3214		2.31	3215	2888	573	31300	27800
18649	2	B	Dry	71.08	0.016206419	4.031	4.21	9.1	63		60	3454		2.32	3456	3219	619	30900	28800
11461	3	A	Dry	70.96	0.016206419	4.671	4.18	11.3	65		48	3639		2.43	3641	3404	407	36000	35200
11461	3	B	Dry	71.20	0.016206419	4.671	5.07	8.3	22		2	2797		2.74	2799	2483	420	36300	36000

Table 9. Calculated sedimentation and chemical flux rates of sediment associated chemicals based on measured physical and chemical characteristics of sediment collected by sedimentation samplers during March and April, 2012. Note, for the estimated rates of chemical flux based on concentrations with less than the detection limits, we used one half the detection limit as the quantity used. These values are highlighted in yellow.

ID	Site	Rep	Type	Time hr	Area sq-m	Depth m	Deposition Rate (g/hr/m2)	TP (ug/hr/m2)	T- Org P (ug/hr/m2)	TKN (ug/hr/m2)	NO3+NO2 (ug/hr/m2)	Total N (ug/hr/m2)	T-Org N (ug/hr/m2)	SiO2 (ug/hr/m2)	TC (ug/hr/m2)	TOC (ug/hr/m2)
11464	1	A	Wet	45.75	0.016206	3.060	66.67	0.3000	0.0300	9.1559	0.0112	9.1559	1.6800	0.8865	551.9953	422.9964
11464	1	B	Wet	45.88	0.016206	3.060	56.35	0.3194	0.1350	6.6359	0.0112	6.6359	1.0920	1.1175	385.4967	413.9965
18649	2	A	Wet	45.93	0.016206	4.317	11.97	2.0887	0.0300	16.4699	0.0112	16.4699	5.6280	1.2360	482.9959	472.4960
18649	2	B	Wet	46.10	0.016206	4.317	13.97	1.0734	0.0750	13.6919	0.0112	13.6919	4.9560	1.0605	479.9959	472.4960
11461	3	A	Wet	46.37	0.016206	5.681	10.46	2.1033	0.0001	10.1639	0.0112	10.1639	4.2000	1.0665	560.9952	536.9954
11461	3	B	Wet	46.65	0.016206	5.681	10.70	3.0839	0.0750	8.7359	0.0112	8.7359	4.7880	0.6870	583.4950	544.4954
11464	1	A	Dry	70.85	0.016206	2.003	1.86	10.7311	0.0150	48.7796	0.0366	48.7946	43.7246	*	*	430.4963
11464	1	B	Dry	71.02	0.016206	2.003	2.40	5.0040	0.0300	72.5244	0.0346	72.5544	66.9894	*	*	454.4961
18649	2	A	Dry	70.73	0.016206	4.031	4.74	3.7998	0.1350	48.2096	0.0346	48.2246	43.3196	8.5949	469.4960	416.9964
18649	2	B	Dry	71.08	0.016206	4.031	3.65	17.2390	0.9000	51.8096	0.0348	51.8396	48.2846	9.2849	463.4960	431.9963
11461	3	A	Dry	70.96	0.016206	4.671	3.63	17.8829	0.7200	54.5845	0.0364	54.6145	51.0596	6.1049	539.9954	527.9955
11461	3	B	Dry	71.20	0.016206	4.671	4.39	5.0070	0.0300	41.9546	0.0411	41.9846	37.2447	6.2999	544.4954	539.9954

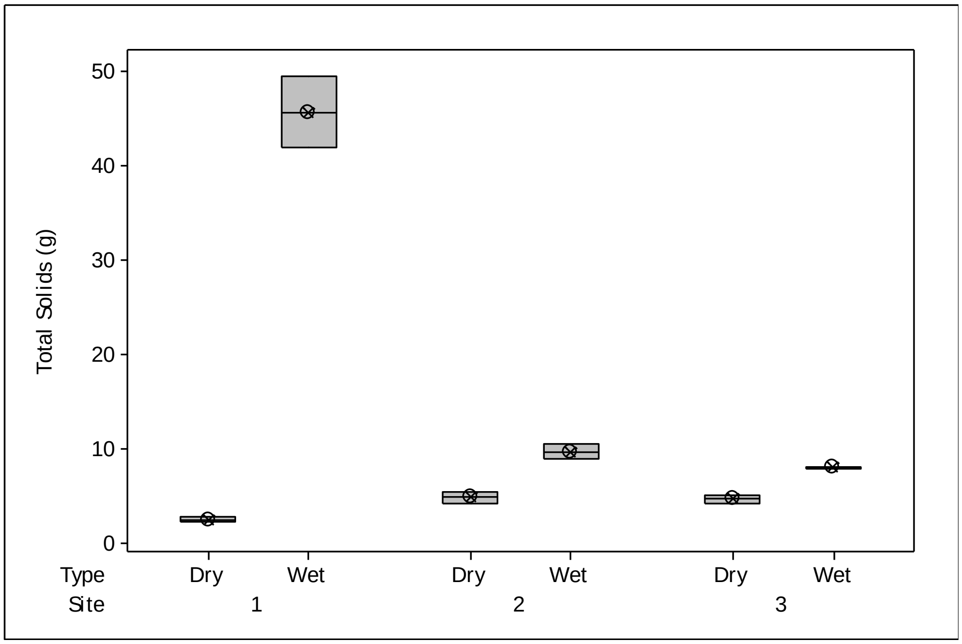


Figure 60. Total solids collected in each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

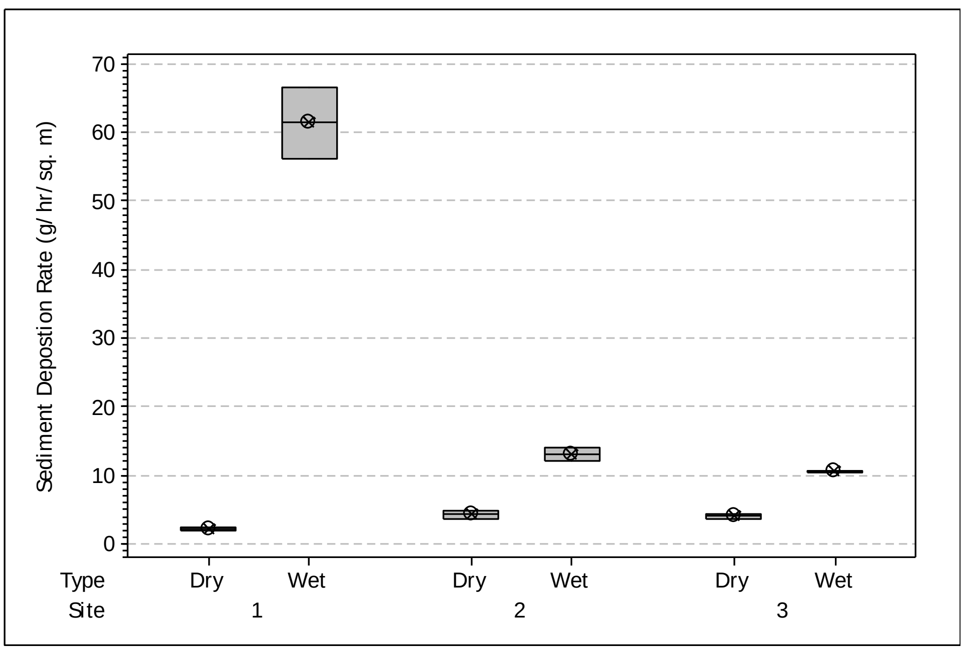


Figure 61. Estimated sediment deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

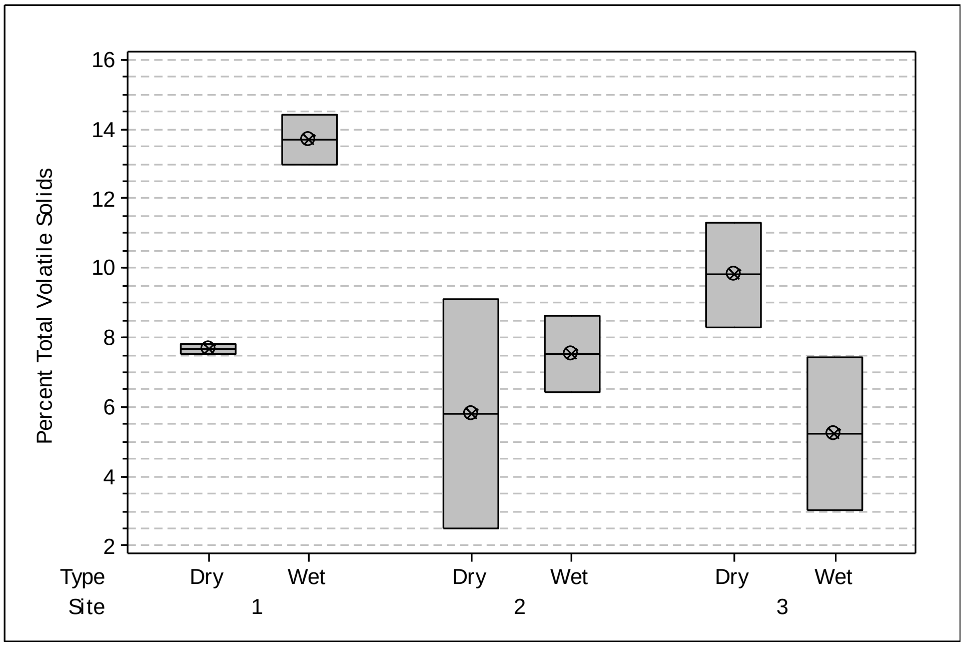


Figure 62. Percent total volatile solids (TVS) in deposited sediment at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

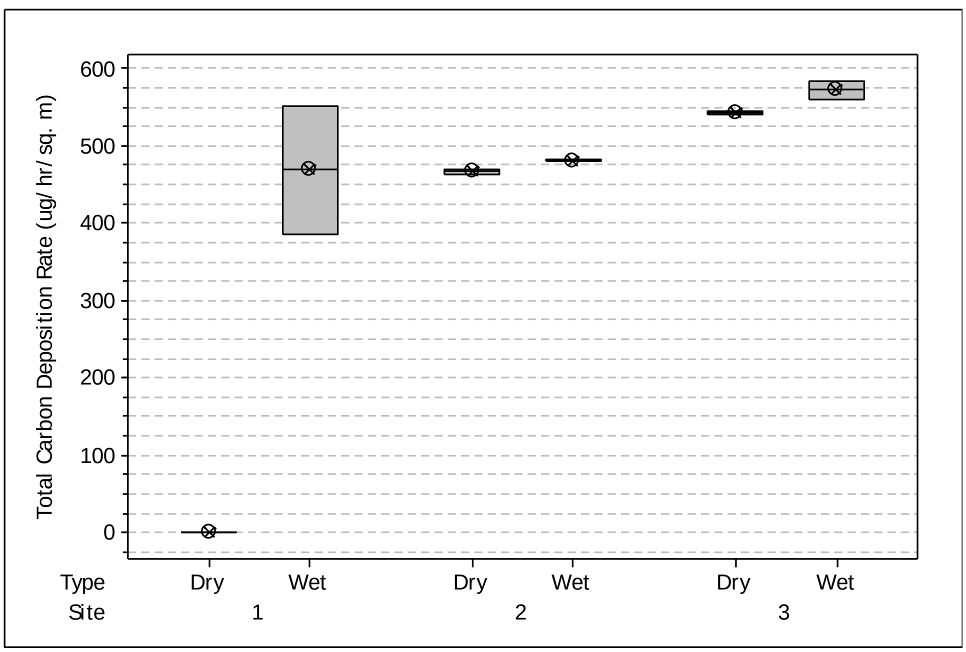


Figure 63. Estimated total carbon deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

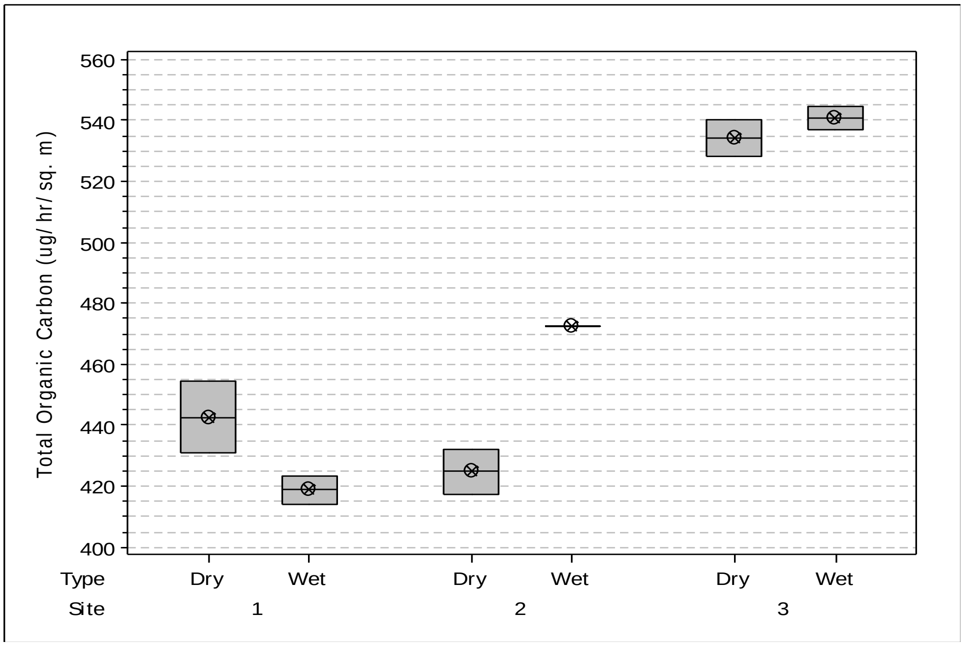


Figure 64. Estimated total organic carbon deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

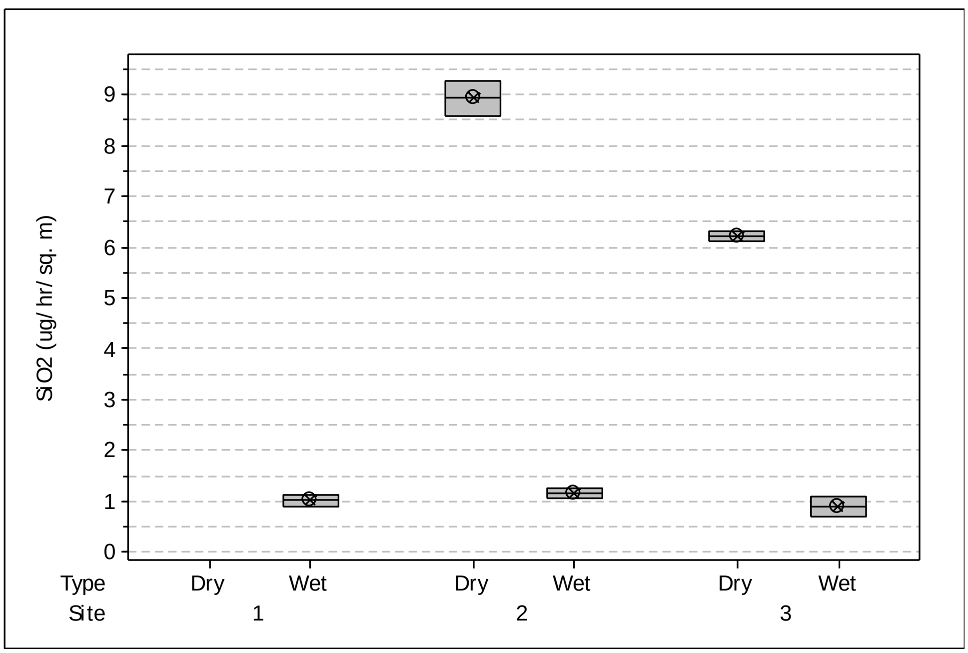


Figure 65. Estimated sediment-associated silicate deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

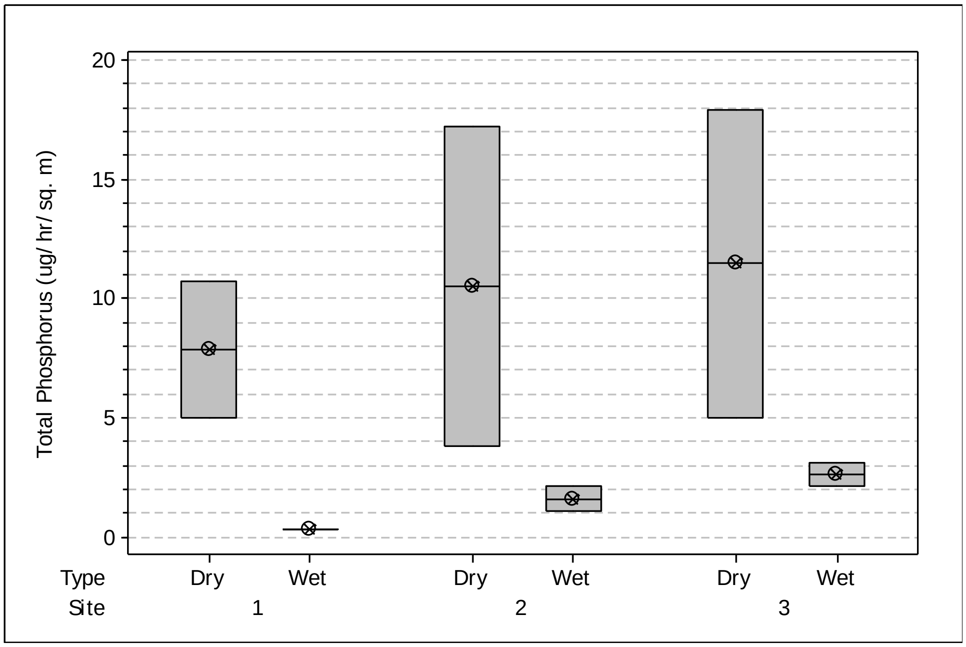


Figure 66. Estimated sediment-associated total phosphorus deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

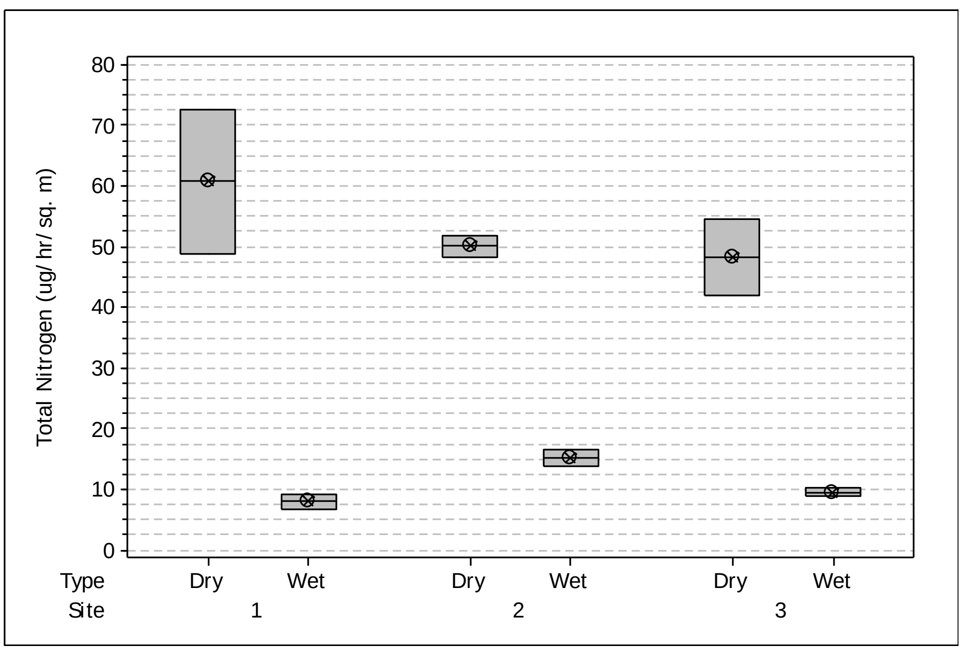


Figure 67. Estimated sediment-associated total nitrogen deposition rates at each sedimentation sampler during March and April 2012 dry and wet weather monitoring.

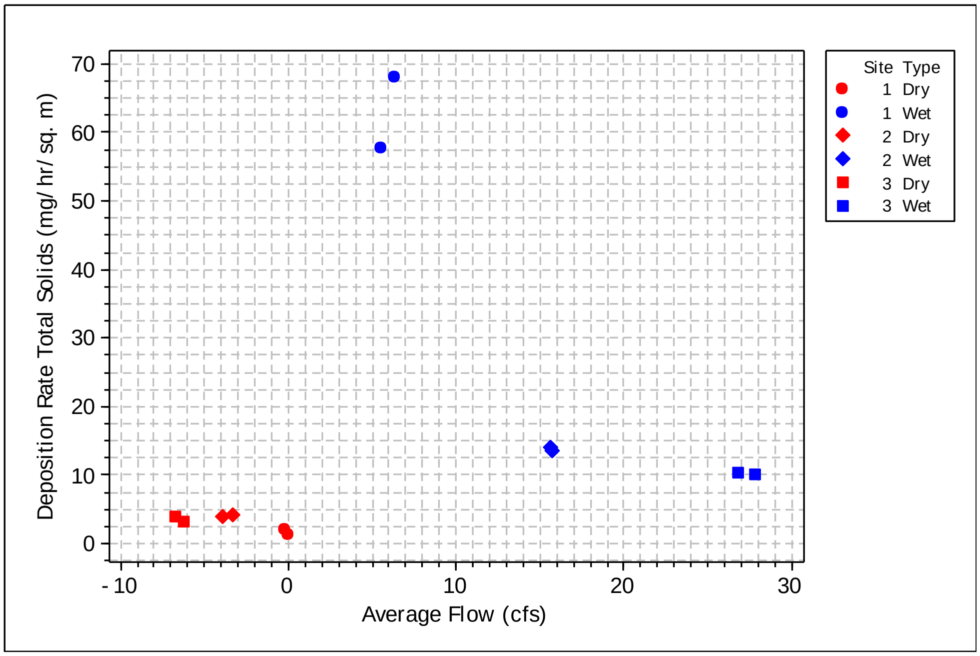


Figure 68. Relationship between average flow and estimated total solids deposition rate. Average flow calculated from measurements taken during deployment and retrieval of sampler.

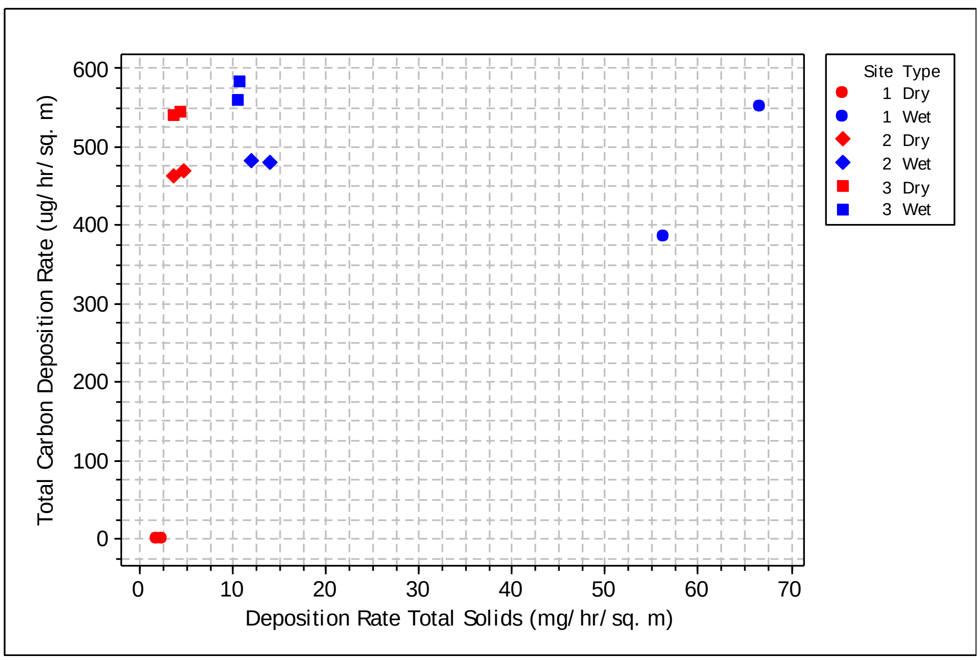


Figure 69. Relationship between estimated total solids and sediment-associated total carbon deposition rates.

Total carbon organic deposition rates did not appear to differ much between high and low total solid deposition rates (Figure 70). Highest organic carbon deposition rates occurred at the downstream site 3 at relatively low total solid deposition rates.

Total sediment-associated phosphorus deposition rates were considerably lower at high deposition rates of total solids during wet weather conditions. (Figure 71). Highest total phosphorus deposition rates occurred at sites 2 and 3 during dry weather conditions and low rates of deposition of total solids. Finally, deposition rates of total sediment-associated nitrogen were considerably lower at high deposition rates of total solids during wet weather conditions. (Figure 72).

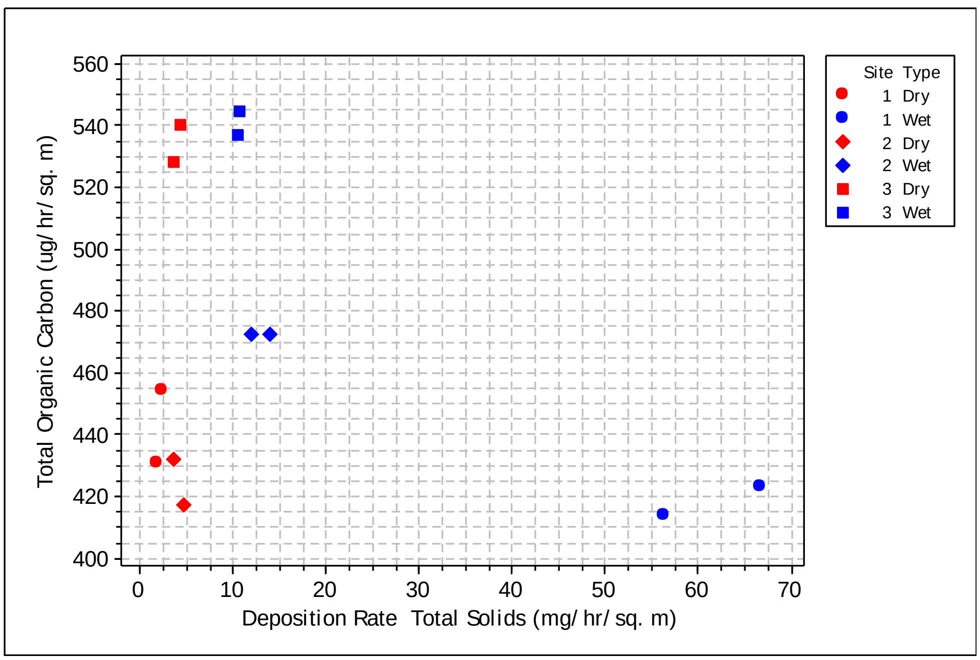


Figure 70. Relationship between estimated total solids and sediment-associated total organic carbon deposition rates.

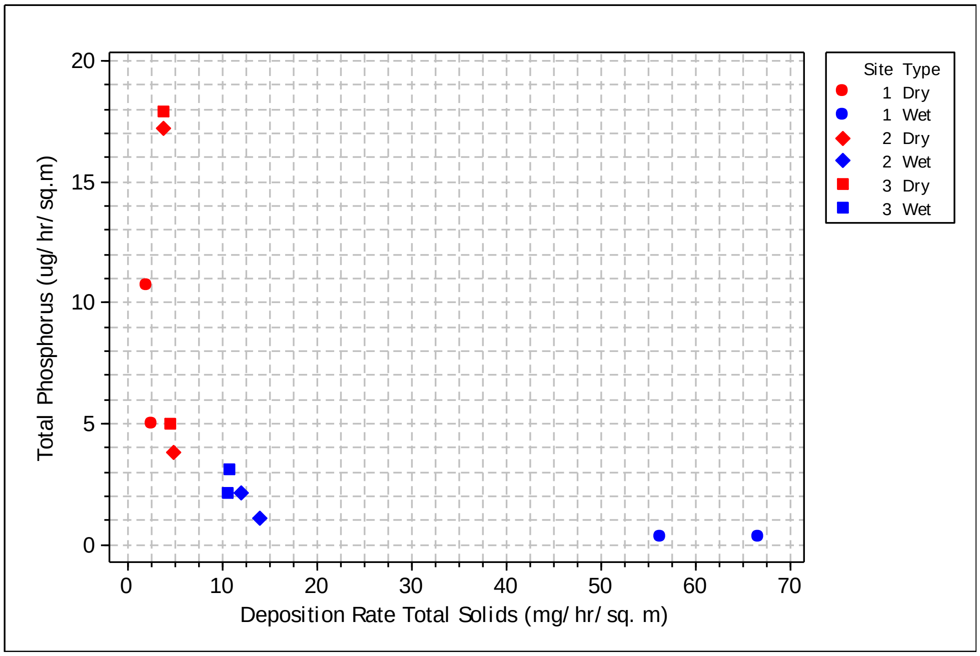


Figure 71. Relationship between estimated total solids and sediment-associated total phosphorus deposition rates.

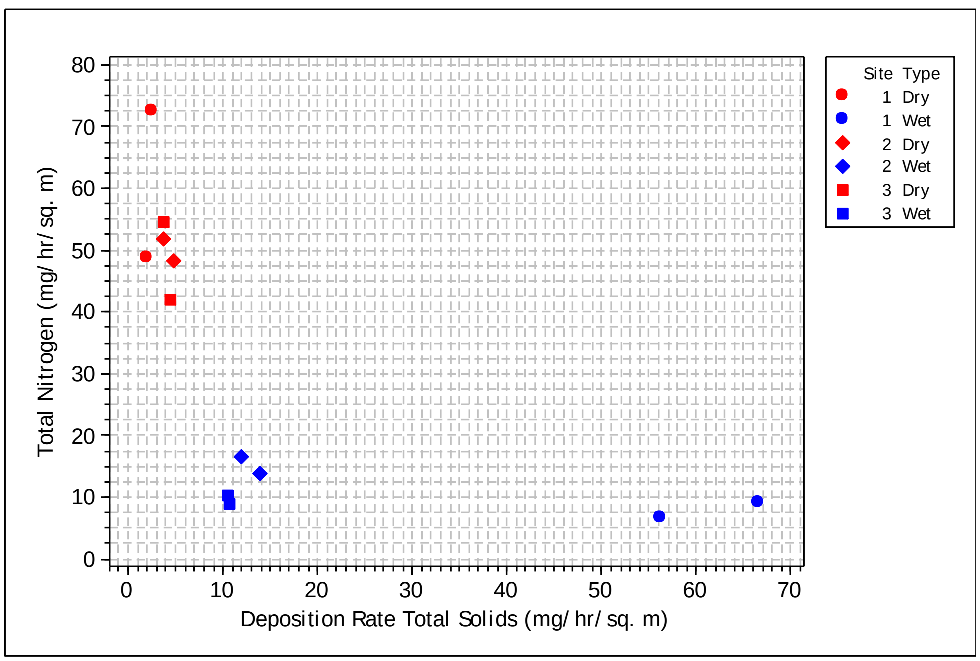


Figure 72. Relationship between estimated total solids and sediment-associated total nitrogen deposition rates.

Conclusions and Recommendations

The results of this study provide critical information on the physical and chemical composition of bed sediment and recently-deposited sediment in the upstream reaches of Dickinson Bayou Tidal. Information and estimates of deposition rates of total solids, total carbon, total organic carbon, total nitrogen and total phosphorus are provided in this report. These estimates varied according to site and streamflow regime. In general deposition rates of total solids were higher during wet weather events, during the descending limb of the hydrograph, versus dry weather events. However, with the exception of particulate-associated carbon, deposition rates of sediment-associated TOC, silicates, TN and TP were higher during dry weather events. This was due to the higher percentage of sediment-associated forms of these chemical constituents during dry weather conditions. This difference may be due to processes occurring at higher flows, during which the particulate forms of these chemicals are composed of 1) resuspended bottom sediments, 2) new sediments that have runoff into the bayou and 3) biogenically derived sources such as sinking algal particles. This mixture may not contain the same amount of particulate-associated chemicals compared to deposited sediment derived from new runoff and biogenically derived sources occuring only during low flow dry conditions. The higher sediment-associated nutrient and TOC values during dry conditions provide evidence that the majority of the sediment being deposited during these conditions is dead algae. This suggests that deposited sediments during dry periods may have originated primarily from land-derived sources and/or sinking dead algal cells, versus resuspension of bottom stream sediments and runoff. In other words, the initial influx of these sediment associated constituents probably originates from the watershed during wet weather events. These constituents are then transformed in the sediment bed and released back into the water column in dissolved form during dry conditions which stimulates algal growth. Upon death the sinking algal cells along with minimal amounts of new sediment derived from land runoff form the majority of particulate associated constituents that are deposited during dry periods. Although this scenario is consistent with plausible transport mechanisms, future studies are needed to confirm this. The estimated rates of sediment-associated constituent deposition generated from this study are summarized below in Table 10.

Table 10. Summary of sediment and associated chemical deposition rates. rkm = river kilometer.

TCEQ ID	Site	rkm	Rep	Type	Total Solids (g/hr/m2)	Total P (ug/hr/m2)	Total N (ug/hr/m2)	SiO2 (ug/hr/m2)	Total Carbon (ug/hr/m2)	Total Org-C (ug/hr/m2)
11464	1	21.2	A	Wet	66.67	0.3000	9.1559	0.8865	551.9953	422.9964
11464	1	21.2	B	Wet	56.35	0.3194	6.6359	1.1175	385.4967	413.9965
18649	2	17.42	A	Wet	11.97	2.0887	16.4699	1.2360	482.9959	472.4960
18649	2	17.42	B	Wet	13.97	1.0734	13.6919	1.0605	479.9959	472.4960
11461	3	14	A	Wet	10.46	2.1033	10.1639	1.0665	560.9952	536.9954
11461	3	14	B	Wet	10.70	3.0839	8.7359	0.6870	583.4950	544.4954
11464	1	21.2	A	Dry	1.86	10.7311	48.7946	*	*	430.4963
11464	1	21.2	B	Dry	2.40	5.0040	72.5544	*	*	454.4961
18649	2	17.42	A	Dry	4.74	3.7998	48.2246	8.5949	469.4960	416.9964
18649	2	17.42	B	Dry	3.65	17.2390	51.8396	9.2849	463.4960	431.9963
11461	3	14	A	Dry	3.63	17.8829	54.6145	6.1049	539.9954	527.9955
11461	3	14	B	Dry	4.39	5.0070	41.9846	6.2999	544.4954	539.9954

A major process that can influence the dynamics of sediment deposition is the presence and magnitude of any turbidity maxima (Dyer 1997). This occurs at the frontal zone between the fresh and saline water. (Biggs et al. 1983) found that upstream turbidity maxima usually occurred in Delaware at a salinity of 1 ppt. In many estuaries this front can be characterized by a salt wedge moving in the upstream-downstream direction with the semidiurnal tidal cycle. In a wide range of those estuaries, stable turbidity maxima can be observed at the tip of the salt wedge. These estuarine turbidity maxima (ETM) are formed by high concentrations of suspended particulate matter (SPM) where increased deposition occurs (Figures 73 - 76). Reduced and reversing current velocities due to tides, changes in flow velocity due to stream morphology, and changes in pH and salinity have all been cited as primary mechanisms for this phenomenon.

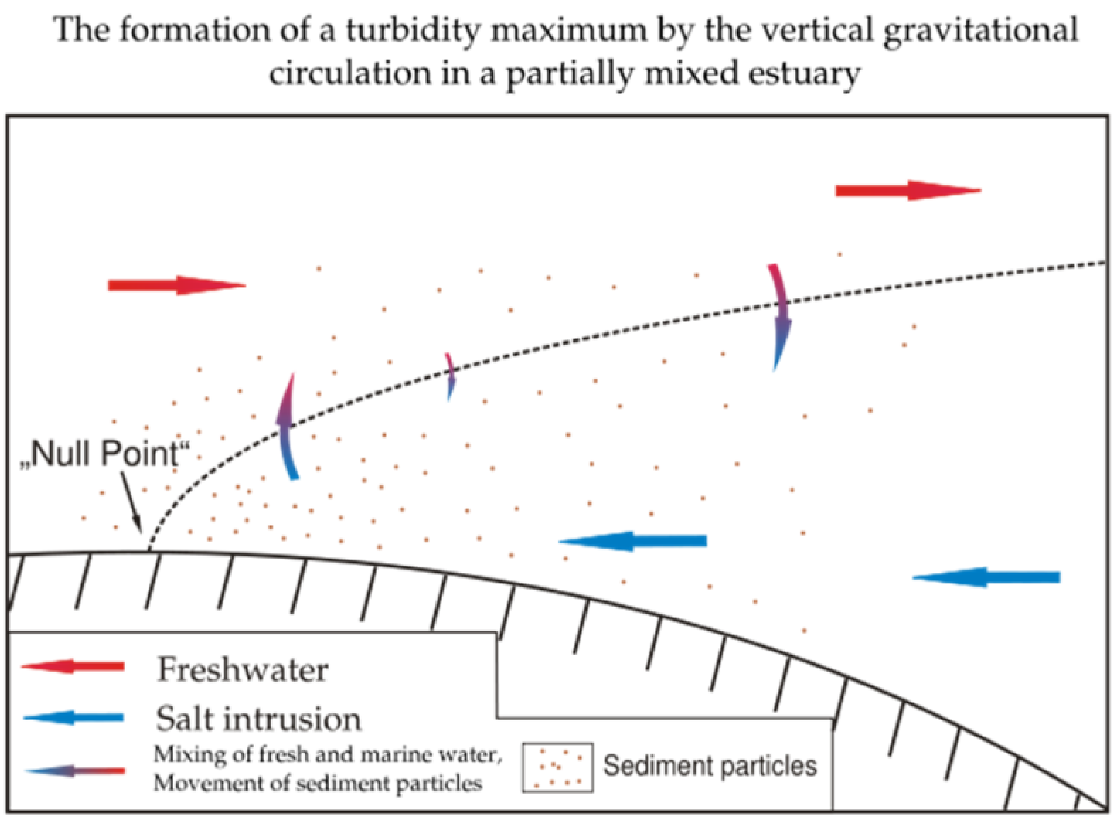


Figure 73. Example of estuarine turbidity maxima showing zone of maximum turbidity and deposition. Diagram source: http://upload.wikimedia.org/wikipedia/commons/thumb/c/c3/Turbidity_maximum_in_a_partially_mixed_estuary.svg/602px-Turbidity_maximum_in_a_partially_mixed_estuary.svg.png

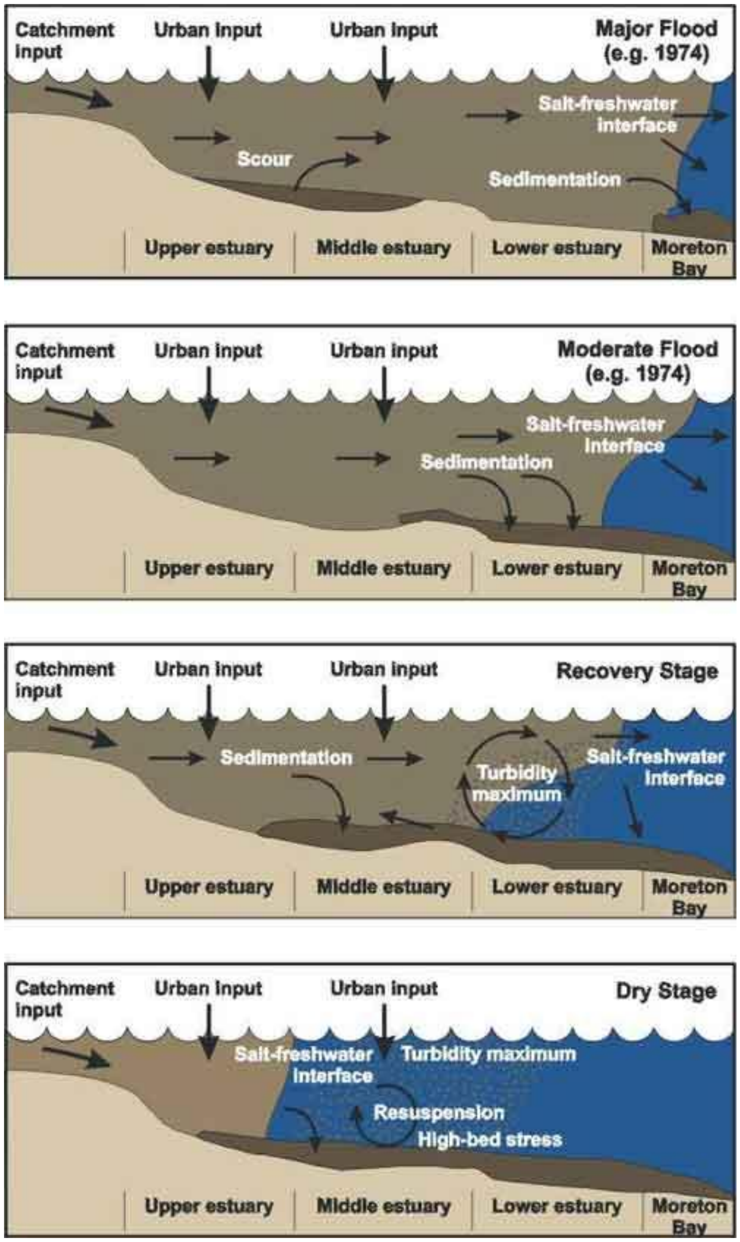


Figure 74. Influence of tides and freshwater inflow on the position of the estuarine turbidity maxima. Figure source: http://www.ozcoasts.gov.au/indicators/images/MB_turbid.jpg

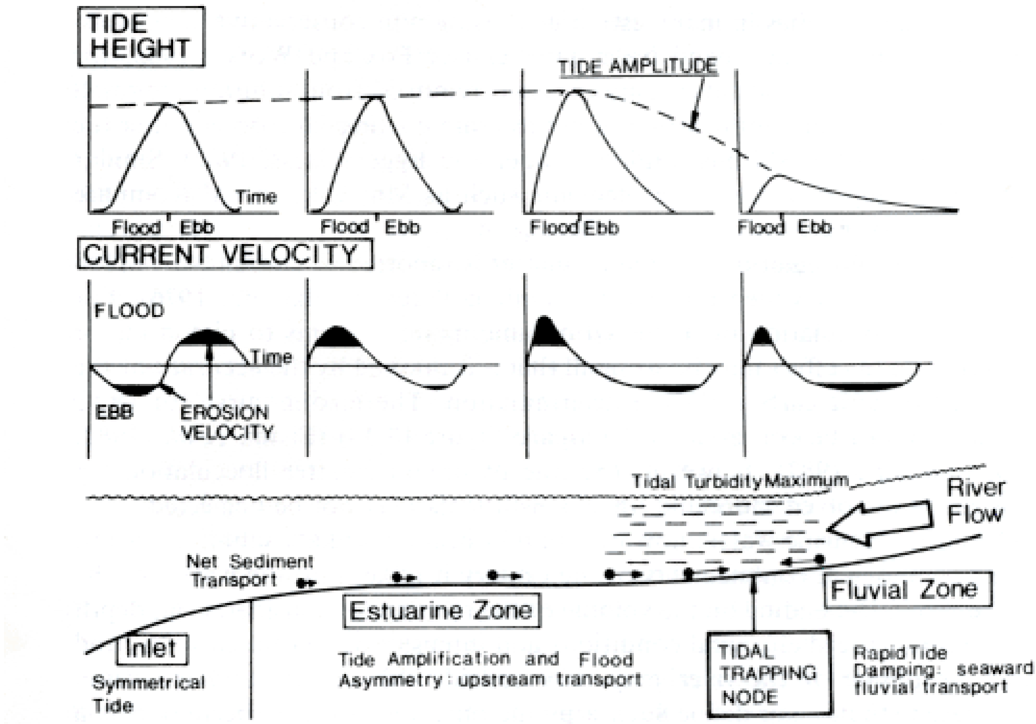


Figure 75. Relationship of tide height, tidal amplitude and freshwater inflow on the location of the turbidity maxima. Figure source: http://www.scopenvironment.org/ downloadpubs/scope35/Fig13.5.gif

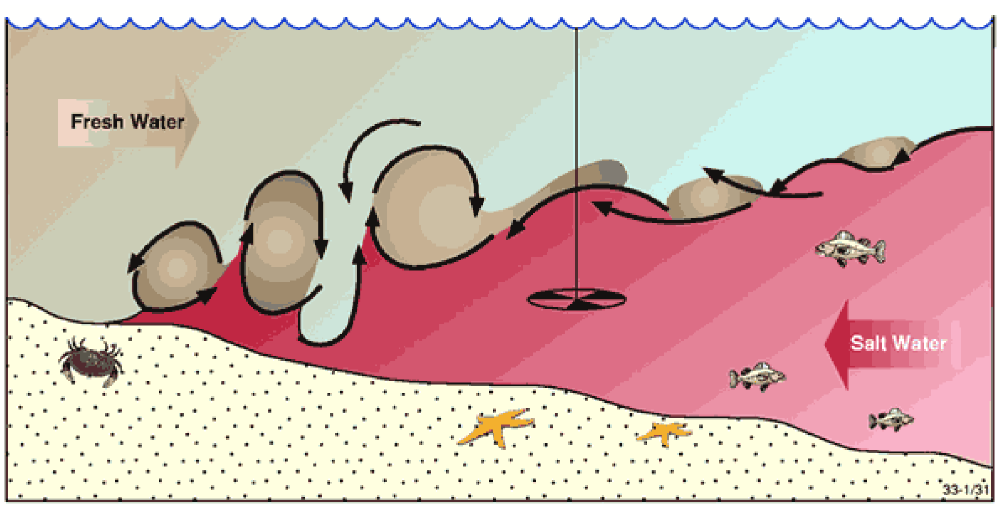


Figure 76. Influence of turbidity maxima on suspended sediment levels and measurements of turbidity. Figure source: http://www.ozcoasts.gov.au/indicators/ images/turbidity_fwsw.gif

The presence of the estuarine turbidity maxima can complicate the estimation of deposition rates since immediately upstream and downstream of this zone, deposition rates can change significantly. It appears that the upper tidal portion of Dickinson Bayou may be close to this zone given the difference in surface and bottom salinities and the overall salinity pattern which is approaching 1 ppt. Future studies focused on determining the possible presence and lateral extent of this zone may be appropriate for gaining a better understanding of suspended sediment dynamics in Dickinson Bayou.

The methodology used by this investigation proved to be adequate for accomplishing the study objectives. Future studies should include concurrent deployment of automated salinity and turbidity meters, and sediment deposition samplers in a vertical array to gain a better understanding of depositional processes within the waterbody. For example, changes in suspended solids and sediment deposition will vary according to when sampling is conducted within the storm hydrograph due to the phenomenon of hysteresis (Knighton 1998). That is, the concentration of suspended solids will not vary symmetrically around peak stream flows.

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Appendix 1. Field Data

Electronic Supplement: included in attached compact disk

- Dickinson Sediment Database (Excel)
- Dickinson Sediment Field Datasheets (PDF)

Appendix 2. Flow Data

Electronic Supplement: included in attached compact disk

- FOLDER: Dry Weather Event
  - FOLDER: Event 1
    - FOLDER: Event_1_Deployment
      - Discharge Summaries by Site (PDF)
    - FOLDER: Event_1_Retrieval
      - Discharge Summaries by Site (PDF)
  - FOLDER: Event 2
    - FOLDER: Event_2_Deployment
      - Discharge Summaries by Site (PDF)
    - FOLDER: Event_2_Retrieval
      - Discharge Summaries by Site (PDF)

- FOLDER: Wet Weather Event
  - FOLDER: Event 1
    - FOLDER: Event_1_Deployment
      - Discharge Summaries by Site (PDF)
    - FOLDER: Event_1_Retrieval
      - Discharge Summaries by Site (PDF)
  - FOLDER: Event 2
    - FOLDER: Event_2_Deployment
      - Discharge Summaries by Site (PDF)
    - FOLDER: Event_2_Retrieval
      - Discharge Summaries by Site (PDF)

Appendix 3. Sonde Calibration

Electronic Supplement: included in attached compact disk

- Dickinson Sediment Calibration Logs (PDF)
- Dickinson Sediment Sonde Calibration Log (Excel)

Appendix 4. Photographic Record

Electronic Supplement: included in attached compact disk

- FOLDER: All Photos
    - Photos corresponding to Photo Record Sheet (JPEG)
- Dickinson Sediment Photo Record (Excel)
- Photographic Record Photo Contact Sheet (PDF)

Appendix 5. Rainfall Data

Electronic Supplement: included in attached compact disk

- NWS LC Daily weather 2-2011 to 6-2012 (Excel)

Appendix 6. Tide Data

Electronic Supplement: included in attached compact disk

- Compiled TROLL and Tide data 2-14-11 to 6-11-12 (Excel)