12005

S-K Final Report

Project Title: Examination of Coastal Aquaculture Effluent and Receiving Water Quality throughout the Tidal Cycle

Grant Number: NA03NMF4270087

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Date: October 31, 2005

Abstract

The purpose of this study was to evaluate changes in both facility effluent and receiving water quality throughout the tidal cycle. The two sampled facilities represent different ends of the spectrum of aquaculture in South Carolina. One of the facilities is the largest shrimp farm on the East coast, has over 120 acres of growout ponds and seasonal effluent that is typically greatest during autumn harvests. The receiving water for this facility is an intercoastal water way. The second facility is a small operation with 8 to 10 holding tanks for a variety of target crops, and has a relatively stable discharge volume that passes through a small settling pond prior to discharge. The receiving water for this facility is near the headwaters of a small tidal creek. Water quality parameters were measured during two consecutive tides (i.e., approximately 25 hours) during three shrimp pond harvests at the larger facility, and during two 25 hour periods at the smaller facility. Samples were collected in both facility discharges and in receiving waters, approximately 200 ft from discharge entry, and thus were downstream during one half of the tide cycle and upstream during the other half of the tide cycle. No changes in receiving water quality could be confidently attributed to facility effluent. At the larger facility, depth in the discharge canal exhibited a strong tidal pattern while salinity remained near constant, indicating the collection of discharge water in the canal throughout flood tide, with effluent release only during ebb tide. Indications of a similar pattern were seen at the smaller facility. At both facilities, salinity and TSS ranges were greater in receiving water than in discharge, and nitrogen measurements were 3 to 5 fold greater in discharge than in receiving waters. At the small facility, BOD was no more than 2 mg/l higher in discharge effluent (after the settling pond) than in receiving waters, and dissolved oxygen in discharge water exhibited a strong diel pattern ranging from 2.8 during darkness to 10 mg/L in daylight. In contrast, receiving water dissolved oxygen appeared to be more tidal influenced with DO ranges from 4 mg/L to 8 mg/L. At the larger facility, BOD in discharge ranged from about 6 to 16 mg/l, while it varied from <2 to 6 in receiving waters. DO in the discharge ranged from 2.5 to 6.5 mg/L, while it varied from 5 to 8.5 in the receiving water. While variations of some parameters (i.e., TSS and salinity) are greater in receiving water than in discharge from the sampled aquaculture facilities, BOD and nitrogen discharge concentrations were consistently greater than receiving water throughout the tidal cycle. Variations in discharge BOD and nitrogen appeared to correlate with diel light cycles and water depth (tide cycle), while variations in receiving water BOD and nitrogen appeared to correlate with water mass movement (as distinct from tidal depth in receiving waters with multiple substantial tributaries) and sediment disruption.

Executive Summary

This final report provides an introduction and purpose for this study to evaluate changes in both facility effluent and receiving water quality throughout the tidal cycle. A detailed description of sampling sites at the two facilities in this study is provided, in addition to detailed descriptions of sample collections and analyses for TSS, TN, TAN, BOD, and Chlorophyll, and semi-continuous (every 10 minutes) measurements of DO, temperature, and salinity. This is follow by a sample of the findings for this study, which allow comparison of the ranges and correlations of the measurements parameters between sites and throughout the tidal cycle. Results shown in this report do not include measurements of chlorophyll and velocity (the later of which further supports net ebbward flow in facility drainage). Changes in this study from the initial proposal were due to circumstances that include the local shrimp market and consequential number of coastal aquaculture facilities operating water exchange, and reductions in SC DHEC budget that precluded them from providing a boat and expertise for dye studies. Additional work that would provide a more complete study includes the missing dye studies. However, the overall goal of this project, to assess changes in facility and receiving water quality throughout the tidal cycle were achieved.

Purpose

The demand for edible seafood is expected to increase with world population. Aquaculture can provide an affordable source of edible seafood without increasing pressure on wild stocks, and has been the fastest growing segment of U.S. agriculture for more than 10 years (Timmons, et al., 2001). However, continued growth in aquaculture must be conducted in an environmentally sound manner (Hopkins, et al., 1995; Browdy, el al., 2001). In the US, environmentally sound aquaculture practices have been the topic of recent regulatory re-assessment (U.S. Environmental Protection Agency, 2002). Sustainable development of receiving waters in coastal zones may require recognition of the variations in receiving water quality and volume throughout the tidal cycle. This recognition may assist in the development of best management practices (BMPs) that can reduce water quality impacts based upon scientific analyses. BMPs that are sensitive to tidal changes in the receiving waters may include coordinating facility effluent releases with the tidal cycle to reduce the possibility of significant impacts on the receiving waters.

Although there can be relatively large changes in the water quality of tidal creek receiving waters throughout the daily tide cycle, outfall permits in these areas are typically based on creek assimilative capacities and dilution factors determined from tidally averaged volumes (SC DHEC, Wade Cantrell, Water Quality Modeler). The extremes of the daily tidal cycle are not specifically considered. However, the effect of an effluent source may be quite different during low tide, when both immediate receiving water volume and water quality may be relatively low, compared to mid or high tide periods

In recent years, daily water exchange of shrimp growout ponds has been greatly reduced to mitigate a combination of environmental (Hopkins, et al 1995; Goldburg and Triplett, 1997) and disease concerns (Flegel, et al. 1995, 1997; Fast and Menasveta, 2000). In South Carolina, daily water exchange rates at aquaculture facilities (both shrimp and fish) typically range from zero to about 5% of the pond volume. Exchange rates and facility discharge are generally greatest during the last portion of the growout season, and at many facilities, the largest discharge occurs during harvest. For some aquaculture crops (i.e., marine shrimp), ponds must be rapidly drained at harvest to maximize harvest efficiency and product quality. The potential best management practice of sedimentation of shrimp pond harvest effluent was assessed along with water quality improvements that may be achieved by passage through the facility drainage canal (Bratvold et al). Large variation was found in the water quality of harvest effluent between ponds, regardless of whether or not the ponds are at the same facility, and managed similarly. Furthermore, water quality improvements that occurred during passage through the drainage canal at one facility was found to be equal or greater than water quality improvements achieved with 20 hour sedimentation of harvest water.

The importance of the development of best management practices through collaborations of regulators, researchers, and the aquaculture industry was recently highlighted to many in the aquaculture industry during EPA's data collection effort for the development of effluent guidelines for the aquatic animal production industry. A paucity of data on many potential best management practices for aquaculture rendered many options to be speculative, with uncertain benefits and costs.

The purpose of this study was to evaluate changes in both facility effluent and receiving water quality throughout the tidal cycle. The natural water quality of tidal creeks is considerably variable both between creeks and within a creek throughout the tidal cycle. Recognizing that facility outfall permits and best management practices generally consider average tidal volume rather than tidal extremes, the goal of this project will be to provide information suggesting the importance of consideration of tidal fluctuations in the development of best management practices and effluent regulations.

APPROACH

Detailed Description of Work

Site Description

The two facilities sampled as part of this study represent different ends of the spectrum of aquaculture in South Carolina. One of the facilities, Paradise Shrimp Farm (PSF), is the largest shrimp farm on the East coast, had over 120 acres of growout ponds operating in 2003 (stocking density: 50 to 60 postlarvae/m^2; average production: 4500 lbs/acre), and has seasonal effluent that is typically greatest during autumn harvests. The second facility, Swimming Rock Fish Farm (SRFF), is a relatively small facility that typically operates 8 to 10 holding tanks and occasionally a couple small ponds for a variety of animals including mud minnows, eels, shrimp, etc. This facility has a relatively stable effluent volume throughout the year.

At PSF, one pond was harvested during each of the 24-hour sample periods. At PSF, water samples were collected in the discharge canal, immediately prior to it's outfall to a connection waterway that leads to the inter-coastal waterway, joining the Edisto River to North Creek and the Dawho River, between Jehossee and Little Edisto Islands. The connection waterway abruptly begins about one hundred feet from the discharge canal outfall, making it essentially an extension of the discharge canal. However, samples colleted for the facility's NPDES permits are collected at the discharge canal outfall, and thus this was our most intensely sampled site at PSF. Throughout all sample periods, samples were also collected from the inter-coastal waterway, approximately 200 ft (towards the Edisto River) from where the connection waterway enters the inter-coastal waterway. During two of the four sample periods, additional samples were collected at the connection waterway outfall to the inter-coastal waterway.

Effluent from the second farm, SRFF, passes through a small (ca 0.1 ha) settling pond prior to entering a discharge pipe (ca 100 ft) and then a ditch (ca 100 ft) with outfall to the inter-tidal region of Toogoodoo Creek. The primary creek bed is about 100 feet from the SRFF outfall to the marsh, and retains standing water during all low tides. The direction of water flow in the discharge pipe varies with the tide cycle. During the more extreme high tides, drain pipe water flow may be towards the sedimentation pond for as much as three hours of the tide cycle. During lower (neap) high tides, water direction in the drain pipe may be entirely towards the creek. Samples were also collected from the primary creek bed, about 200 m upstream from SRFF outfall.

Sample Collections

During each 24-hour sample collection period, an auto-sampler (Isco Sampler, Model 6712) collected water samples every eighth of a tide cycle (i.e., approximately 95 minutes) at discharge and receiving water sites. The intake line for the SRFF discharge was placed along the bottom of the drain pipe. At the SRFF receiving water site, the sample line was placed about one-third of the way across the creek bed, and about 10 cm from the bottom.

The intake line at the PSF discharge site was placed mid-stream, approximately 10 cm from the bottom of the canal. During the two sample periods at PSF when the connection waterway was sampled, the intake was placed approximately 10 m from the high-tide shores of the inter-coastal waterway, one-third of the way across the connection waterway, and about 20 cm from the bottom. This relatively high position was to minimize sample collection-related disruption of the loose, light-weight sediment at this site. At the receiving water site in the inter-coastal waterway, the sample line intake was placed 50 feet from the high bank, on a gradual sloping mud plateau, approximately 50 feet away from the sharp slope into the boat channel. Cable length limitations and boat traffic concerns prevented sampling in the deeper portions of this waterway. During some low tides, a significant portion of the mud plateau is exposed to the air, preventing the collection of samples during these events.

At two sites during each sample period, temperature, salinity, and dissolved oxygen were monitored semi-continuously (i.e., every 10 minutes) with a YSI 600R Multi-Parameter Water Quality Monitor, with the probes placed at the locations described above for the auto-sampler intake lines. At PSF, temperature, salinity, and dissolved oxygen were monitored during several additional time periods to better assess the variation in these parameters over many dates. The sample periods and number successful collections per sample period is summarized in Table 1, below. Monitoring data were screened and data that appeared to be collected with probe exposure to air (i.e., during some low tides, based upon rapid increase in DO, and sharp decreases in salinity and temperature) were removed as well as some additional salinity data that did not recover as the tide rose (this is suspected to be due to creation of an air pocket in the probe's chamber).

Table 1. *In situ* measurements and samples collected throughout the sampling period. (-- no measurement)

	Measurement during sample period DO, Temperature, Salinity			Number of samples collected TAN, TN, TSS, turbidity		
Sampling Period	**Discharge**	**Waterway outfall**	**Receiving waters**	**Discharge**	**Waterway outfall**	**Receiving waters**
Paradise Shrimp Farm						
10/14 to 10/15	Semi-continuous	semi-continuous	--	18	18	17
10/25 to 10/26	Semi-continuous	semi-continuous	--	18	18	14
11/08 to 11/09	Semi-continuous	--	semi-continuous	--	--	--
11/09 to 11/12	--	--	semi-continuous	--	--	--
11/13 to 11/17	Semi-continuous	--	semi-continuous	--	--	--
11/18 to 11/19	Semi-continuous	--	--	17	--	15
Swimming Rock Fish Farm						
10/28 to 10/29	Semi-continuous	--	semi-continuous	14	--	17
11/04 to 11/05	Semi-continuous	--	semi-continuous	16	--	11

Sample Analyses

Auto-sampler collections were kept in an ice bath until sample processing, which was within 2 to 8 hours of sample collection. Five-day biochemical oxygen demand (BOD_5) was measured in all discharge samples (i.e., 16 to 17 samples per 24-hour sampling period) and in high and low tide samples at other sites (i.e., 7 to 8 samples per 24-hour sampling period). Unseeded duplicate 300 mL BOD bottles with 60 mL sample water and 240 mL dilution water prepared with Hach BOD Nutrient Buffer Pillows, following the methods of APHA et al. (1995), with daily DO monitoring (YSI DO Meter Model 5000, with YSI 5010 BOD probe), and re-aeration when needed. Turbidity was measured with a colorimeter (Hach DR/890). Samples for total ammonia nitrogen (TAN) were prepared by passage through a 0.7 um glass fiber filter (Gelman, Type A/E), acidified with concentrated sulfuric acid, and frozen until autoanalyzer analysis using the phenolate method. Samples for total nitrogen were frozen until autoanalyzer analysis using alkaline persulfate digestion and the cadmium reduction method for analysis. Total suspended solids (TSS) were collected on pre-weighed 0.7 um filters (Gelman, Type A/E), rinsed with 10 ml distilled water to remove salts, dried at 105 C, and re-weighed (APHA, 1995). Chlorophyll was collected on 0.7 um (Gelman, Type A/E), and analyzed using the freeze-thaw method with acetone extraction and fluorometric measurement (Glover and Morris, 1979).

Project Management

The project manager was Delma Bratvold. The technician for both field sampling and laboratory measurements was Mr. Frank Nemeth. Collaborators at aquaculture facilities include Mr. Rick Eager of Swimming Creek Fish Farm, and Mr. Drew Ambose and Dr. Anantapur Rafiuddin of Paradise Shrimp Farm. Mr. Al Stokes of SCDNR provided guidance identification of commercial facilities. SCDHEC was unable to provide assistance regarding trace dye studies of effluent movement as a result of reductions in the agency budget.

FINDINGS

Actual Findings

Figure 1, displays TSS and relative depth during the first sampling period, at the end of the PSF discharge canal, at the end of the connector waterway, and in the inter-coastal waterway (receiving waters). This graph exemplifies the similarity often seen in measurements from the discharge and from the connector waterway, and a lack of correlation between inter-coastal waterway TSS and discharge TSS. None of the PSF sites exhibited a strong correlation between TSS and the tide cycle (i.e., relative depth). Figure 1 also displays a greater variation in TSS in the receiving waters than in the discharge, with both lower minimum TSS and higher maximum TSS seen in the inter-coastal waterway. Figure 2, 3, and 4 show BOD, TAN, and TN, respectively, during the first sample period at PSF. The discharge and connector correlate well with each other for TAN and TN, and correlate moderately with the tide cycle, but do not correlate with TAN and TN in the receiving waters. In the receiving waters, TN and TSS correlate with each other, but not with the tide cycle. Receiving water TAN levels were consistently low, with little variation. Both TN and TAN levels in the receiving waters were consistently lower than in the discharge and connector waterway. The BOD range observed in the receiving water (i.e, 2 to 6 mg/L) is substantially lower than the BOD range observed in the discharge (i.e., 6 to 16 mg/L).

Figure 1. PSF TSS in the discharge, connector, and receiving waters, and relative depth, 10/14 to 10/15.

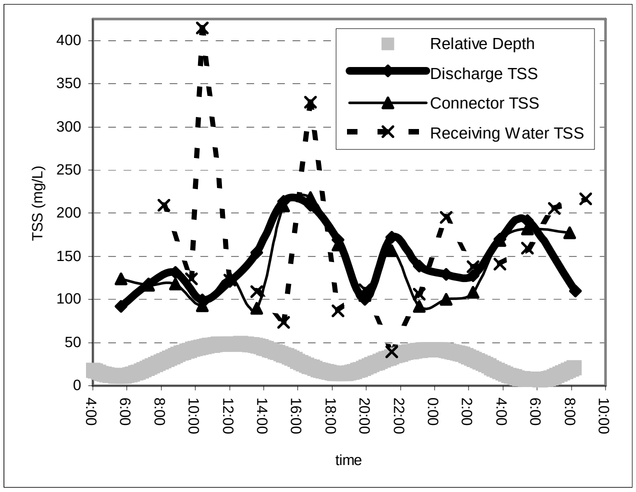


Figure 2. PSF BOD in the discharge, connector, and receiving waters, and relative depth, 10/14 to 10/15.

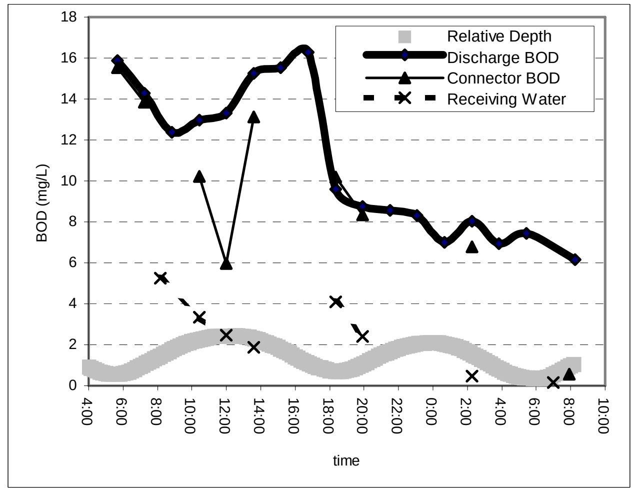


Figure 3. PSF TAN in the discharge, connector, and receiving waters, and relative depth, 10/14 to 10/15.

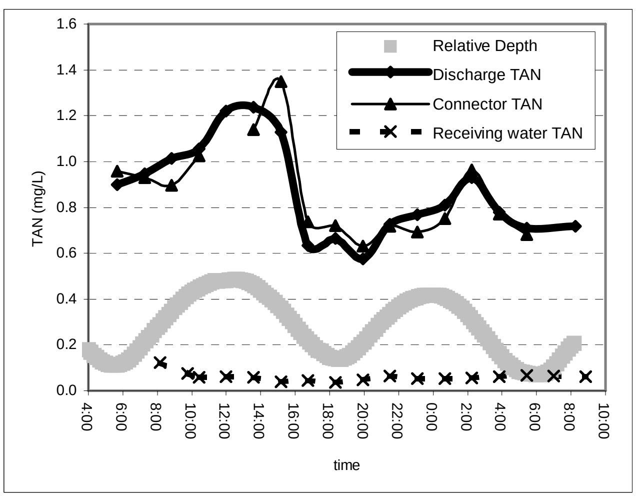


Figure 4. PSF TN in the discharge, connector, and receiving waters, and relative depth, 10/14 to 10/15.

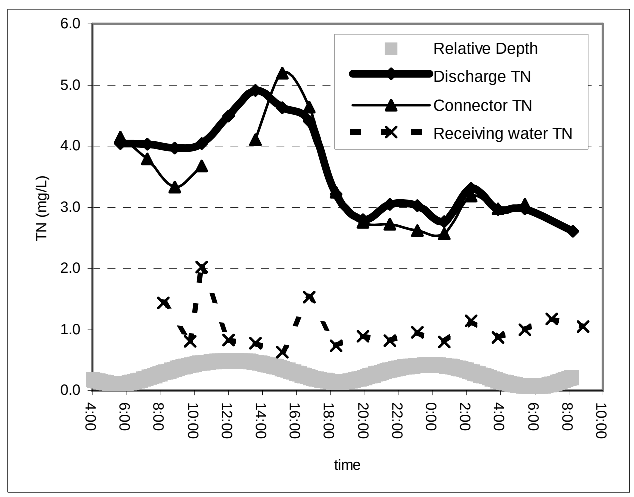
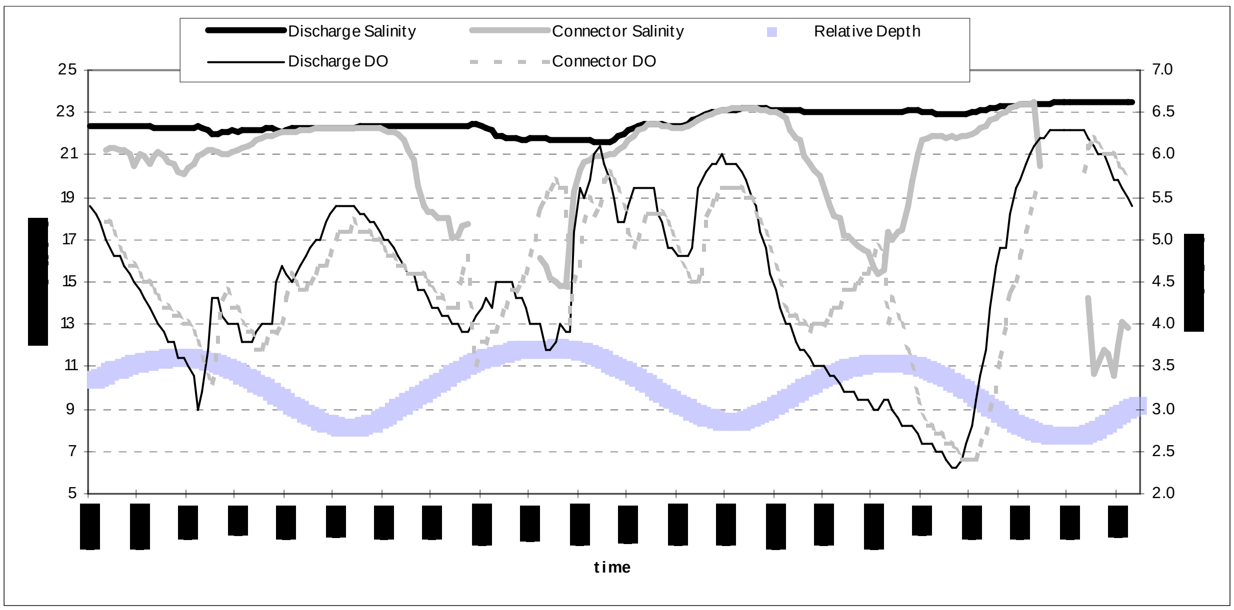


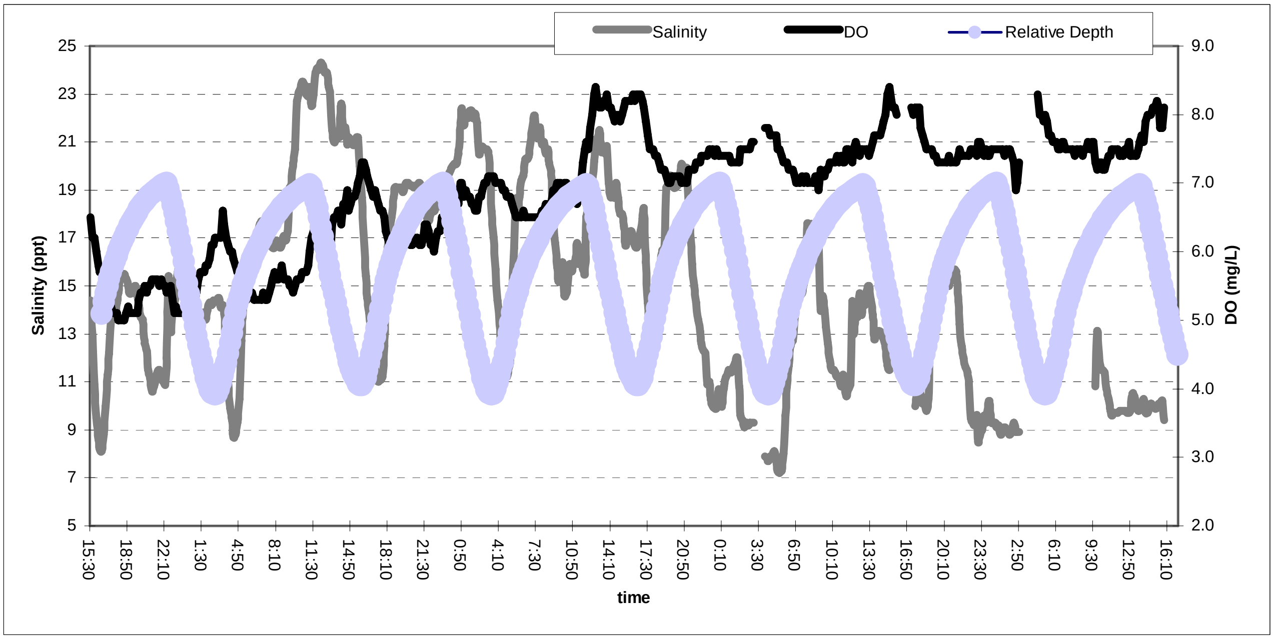
Figure 5 shows DO and salinity measurements in the discharge and connector waterway during the first sample period at PSF. Relative depth measurements were made only at the discharge site. The water depth (tidal) extremes at the discharge are approximately 10 minutes later than at the receiving water site. Changes in pond drainage during the sampling period did not cause measurable changes in discharge canal depth. During this sampling period, the lower salinity water from the inter-coastal waterway is seen during high tide at the connection waterway site, but not at the discharge canal site. At the discharge site, DO drops during high tide in conjunction with stable salinity and increasing depth suggest that during flood tide, discharge water piles up in the discharge canal and connection waterway. The discharge and connector DO range during this sampling period was between 2 and 6.5 mg/L, with lower DO occurring during high tide (particularly nighttime high tide). This is consistent with a high tide pile-up of discharge water that is consuming oxygen (i.e., BOD).

Figure 5. PSF salinity and DO in the discharge and connection waterway, and relative depth, 10/14 to 10/15.



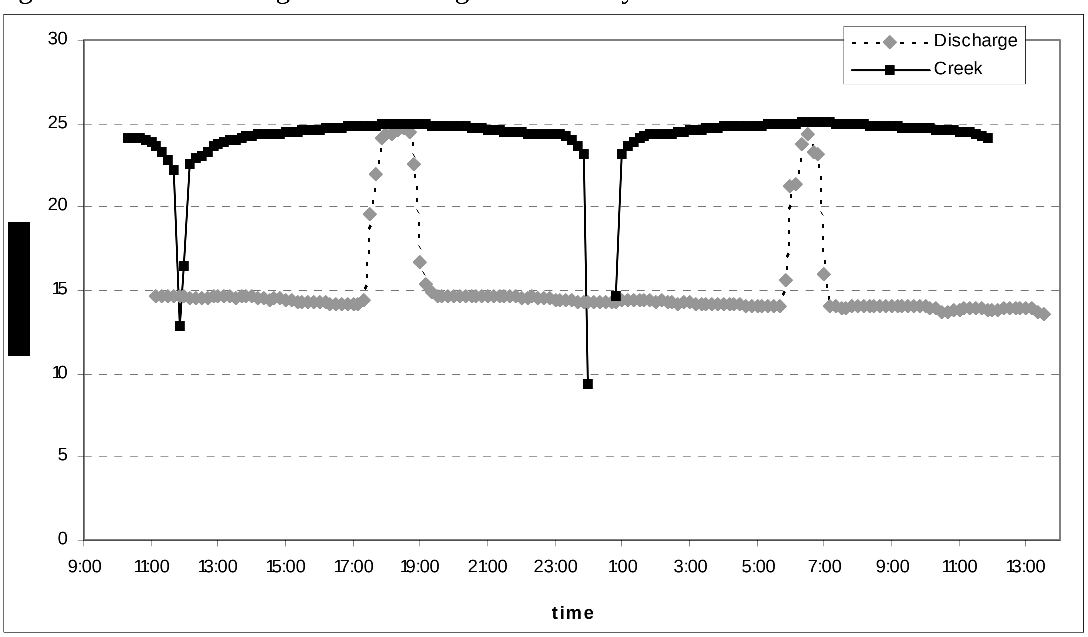
An example of inter-coastal waterway (PSF receiving water) DO and salinity is shown in Figure 6. From 11/8 to 11/12, DO ranged from 5 to 8.5, and salinity ranged from 7 to 24. During the low tides of this period, DO was high and salinity low compared to high tide measurements. Increases in DO during low tide, regardless of time of day (i.e., photosynthetic oxygen production) may be due to better mixing and aeration of the shallower water. Salinity levels in the inter-coastal waterway exhibit a bimodal pattern, likely due to influences from the two tidal river systems the waterway is connecting. Variations in the amount of time between the salinity peaks of these two modes may be due to a variety of factors, including tide magnitude and wind effects.

Figure 6. PSF salinity and DO in the receiving water, and relative depth, 11/8 to 11/12.



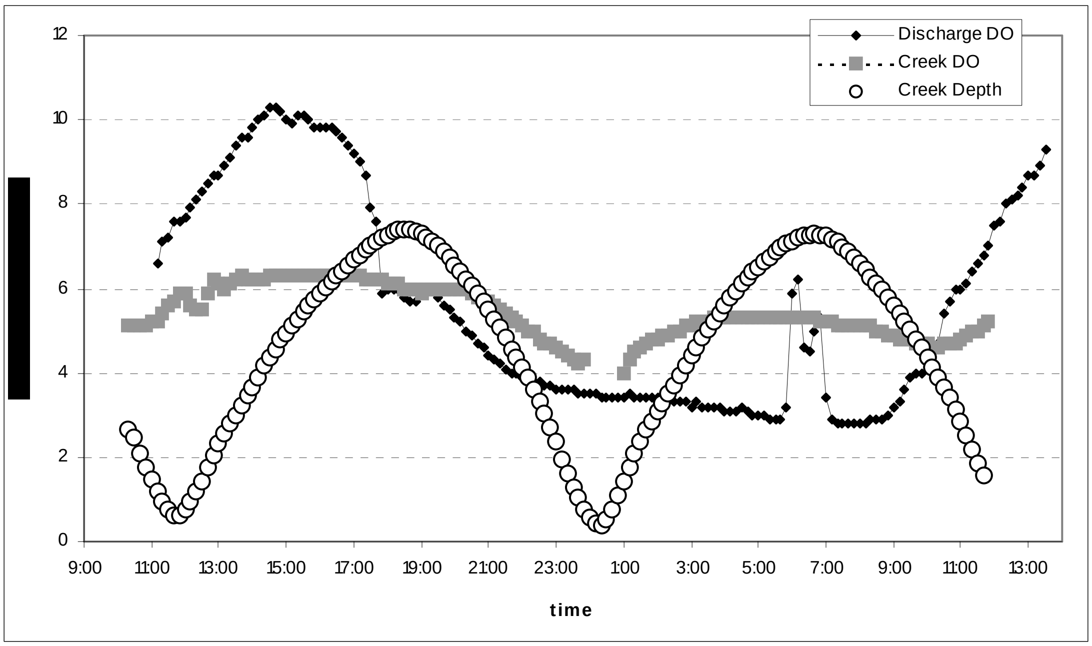
At SWFF, the drainage canal exhibited sharp salinity increases at high tide (i.e., from 15 to 25 ppt) as shown in Figure 7. In contrast, receiving water salinity as stable at 25 ppt except during low when salinity fell to 0 to 10 ppt. Substantial salinity increases during high tide in the drainage canal indicate that tidal flood water overwhelms effluent, likely allowing effluent discharge only during ebb tide. The absence of salinity measurements around midnight in Figure 6 is due to salinity probe exposure to air during this low tide.

Figure 7. SWFF discharge and receiving water salinity 11/4 to 11/5.



Dissolved oxygen in the SWFF discharge (Figure 8) indicates both diel and tidal influences. Oxygen is higher during daylight periods, presumably due to photosynthetic production in the settling pond prior to the discharge pipe. During some high tides, discharge pipe DO is increased by tidal flood waters. The range of discharge DO was greater than in receiving waters. The absence of creek DO measurements around midnight is due to exposure of the salinity probe to air during this low tide.

Figure 8. SWFF discharge and receiving water (creek) dissolved oxygen and receiving water depth 11/4 to 11/5.



B. Describe any significant problems

The original proposal was to examine effluent from 5 aquaculture facilities over two consecutive tide cycles (i.e., 25 hours). Low shrimp prices reduced the number of active shrimp farms in SC, and five facilities operating with water exchange could not be identified. Despite the SCDHEC letter of intent to assist with this study (attached to the original proposal), SCDHEC was unable to provide assistance regarding trace dye studies of effluent movement as a result of reductions in the agency budget, hence the dye study portion of the initial proposal was not conducted because it required a boat. Additional semi-continuous measurements of water depth and velocity were conducted to partially compensate for the missing dye studies.

C. Description of need for additional work

At both facilities assessed, no significant effects of effluent on receiving water quality were observed. However, the study suggests that effluent release to receiving waters is essentially restricted to half of the tidal cycle (i.e., ebb tide). In this study, receiving water sampling was conducted at one location at each facility. Particularly at the larger facility (with larger volume receiving waters), it is possible that water currents transporting effluent were not well-represented at the chosen location. Further studies using dyes should be conducted to map and measure effluent dilution in the receiving waters.

EVALUATIONS

A. Describe the extent to which project goals were attained

1. Were goals attained?

The primary goal of assessing water quality in aquaculture discharge and in tidal receiving waters throughout the tidal cycle was achieved.

2. Were modification made to goals and objectives?

Effluent and receiving water quality were assessed at only two facilities rather than the originally proposed five facilities. However, measurements were repeated over three 25 hour periods at one facility, and over two 25 hours periods at the second facility. While fewer facilities were assessed, this design change has benefits in that the confidence in conclusions at each facility was improved by additional measurements. Proposed dye studies were not conducted due to SC DHEC budget cuts and consequential loss of critical DHEC collaboration.

B. Dissemination of project results:

Project results have been discussed with SC DHEC representatives and will be published in a peer review journal.

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