DISCHARGE RATING, CONFIRMATION AND UPDATES OF SEDIMENT TRANSPORT REGRESSION CURVES, AND WATER QUALITY FOR SELECTED SITES IN THE D'OLIVE CREEK WATERSHED, BALDWIN COUNTY, ALABAMA

Mobile Bay National Estuary Program

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By

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Funding for this project was provided by the
Mobile Bay National Estuary Program

January, 2017

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INTRODUCTION AND SCOPE

The D'Olive Creek watershed including parts of the cities of Daphne and Spanish Fort in west-central Baldwin County is one of the fastest growing areas in Alabama. Rapid economic development, land-use conversion, and construction combined with the unique hydrogeology of the area resulted in increased runoff and stream discharge, excessive erosion and sedimentation, and increased concentrations of nutrients in the watershed.

Previous investigations performed by the Geological Survey of Alabama (Cook, 2007, Cook and Moss, 2008) evaluated discharge, water quality, and erosion and sediment transport at 10 sites in the D'Olive and Tiawasee Creeks watershed. These investigations employed regression analysis techniques that resulted in regression curves for stream discharge and suspended and bed sediment transport volumes. These data were used to identify several reaches of streams in the D'Olive Creek watershed with excessive erosion and sediment transport, which were included in the Alabama Department of Environmental Management, 2008 Clean Water Act 303-d list for siltation (habitat alteration). The listed streams are D'Olive Creek from its source to D'Olive Bay, Joes Branch from its source to D'Olive Creek, Tiawasee Creek from its source to D'Olive Creek, unnamed tributary to D'Olive Creek from its source to D'Olive Creek, and unnamed tributary to Tiawasee Creek from its source to Tiawasee Creek (ADEM, 2016).

In 2016, to document changing water quality and conditions impacting water quality in the D'Olive Creek watershed, the Mobile Bay National Estuary Program (MBNEP) developed a stream water-quality monitoring strategy involving deployment of continuous monitoring and data logging sondes at selected sites in the D'Olive and Tiawasee Creeks watershed. Five sondes were deployed that continuously collect water temperature, specific conductance, turbidity, dissolved oxygen, and water depth. The selected sites are in downstream reaches of D'Olive and Tiawasee Creeks and Joes Branch. The MBNEP strategy requires each monitoring site to be rated for discharge and to have a regression analysis for sediment and nutrients.

Since 2008 strategic watershed plans were completed and funding obtained to remediate and restore parts of listed streams. Several restoration projects were scheduled for stream reaches in the D'Olive and Tiawasee Creek watersheds. To have the most recent stream discharge, water quality, and sediment transport data to assess pre-restoration and baseline conditions, an update to the 2006-2008 data was needed. Therefore, the following assessment was performed by Marlon Cook, Polyengineering, Inc., and Polyenvironmental Corporation (geochemical laboratory), to update suspended and bed sediment transport rate regression curves, develop discharge rating curves, and estimate loadings for sediment and nutrients for each sonde deployment site. Data were collected from October 2015 to March 2016, which was prior to restoration projects in Joes Branch, Tiawasee Creek, and D'Olive Creek that are now completed. Additional restoration projects will be initiated during 2017.

ACKNOWLEDGMENTS

Ms. Roberta Swann, Director; Ms. Amy Newbold, former Deputy Director; and Mr. Tom Herder, Watershed Protection Coordinator, Mobile Bay National Estuary Program, provided administrative and coordination assistance for the project. Ms. Renee Collini, NGOM Sentinel Site Cooperative Coordinator and Ms. Ashley Campbell, Environmental Programs Manager, city of Daphne provided technical support, and Mr. Bruce Bradley, President, Polyengineering, Inc., provided administrative assistance.

PROJECT AREA

The area for this project includes six previously assessed sites in the D'Olive Creek, Tiawasee Creek, and Joes Branch watersheds in the cities of Spanish Fort and Daphne in west-central Baldwin County (fig. 1). The project also includes two additional sites on D'Olive Creek that were not previously monitored (fig. 1).

PROJECT SITES

Eight sites were evaluated during the project period. Three sites were on the main stem of D'Olive Creek (sites DC3, DCB, and DGA) and one was a D'Olive Creek tributary site (DC1) (fig. 1). Two sites were on the main stem of Tiawasee Creek (TC7 and TC8), one was on an unnamed Tiawasee Creek tributary (TC9), and one was on Joes Branch (JB10) (fig. 1).

Site DC3 (D'Olive Creek at US Highway 90) was established during the first D'Olive Creek assessment in 2006 (fig. 1). The site has measurable bed sediment and is immediately downstream from the recently completed D'Olive Creek restoration (fig. 1).

Site DC1 was also established in 2006 and is on an unnamed tributary to D'Olive Creek near Wingate Circle in Lake Forest Subdivision (fig. 1). The stream at site DC1 has a sand bed and measurable bed sediment and is immediately downstream from a scheduled restoration project (fig. 1).

Site DCB is on the main stem of D'Olive Creek at Bayview Drive in the Lake Forest Subdivision at the upper end of Lake Forest Lake (fig. 1).

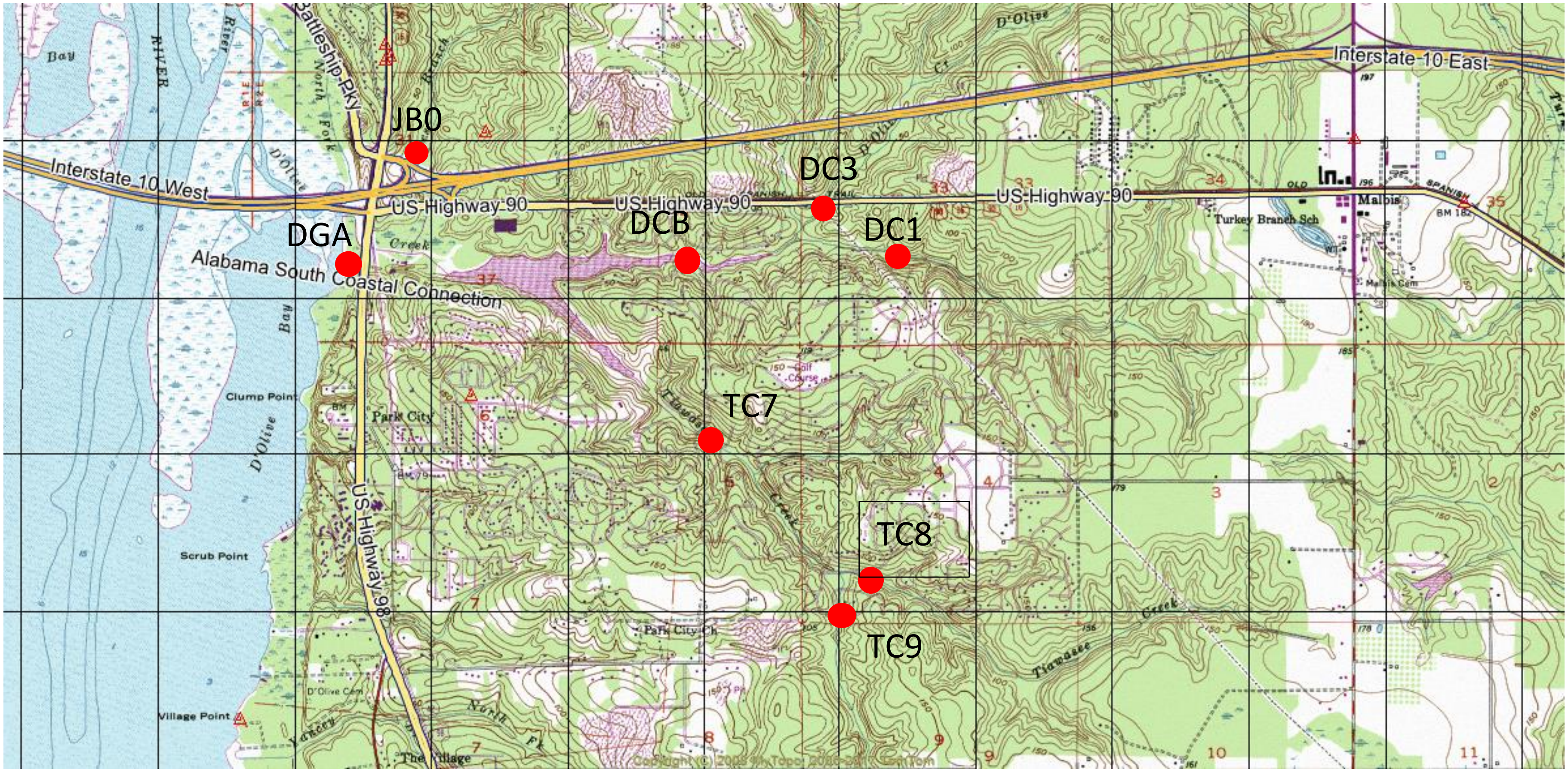


Figure 1.—Monitoring sites in the D'Olive Creek watershed.

Site DGA is immediately upstream from the mouth of D'Olive Creek at the city of Daphne boardwalk, which crosses the creek downstream from North Main Street (fig. 1).

Site TC7 is on the main stem of Tiawasee Creek at Bayview Drive in Lake Forest Subdivision, 1,700 feet (ft) upstream from Lake Forest Lake and was established in 2006 (fig. 1).

Site TC8 is on the main stem of Tawasee Creek at Ridgewood Drive in Lake Forest Subdivision, about 1.9 miles downsteam from the headwaters (fig. 1). The site was originally established in 2006.

Site TC9 is on an unnamed tributary of Tiawasee Creek at Greenwood Drive in Lake Forest Subdivision immediately downstream from a recently completed restoration project now owned and managed by the city of Daphne (fig. 1). The site was originally established in 2006.

Site JB0 is on the main stem of Joes Branch immediately upstream from the culverts that convey Joes Branch under I-10 (fig. 1). The site was originally established in 2006 at the downstream end of the I-10 culverts but was moved in mid-2016 due to changing stream channel conditions that rendered the original location unusable.

CONSTITUENT LOADING IN PROJECT STREAMS

Sediment and nutrient data were collected to update discharge and constituent regressions and to estimate annual loadings for suspended and bed sediment, nitrate, and phosphorus for 2015-2016.

The basic concept of constituent loads in a river or stream is simple. However, the mathematics of determining a constituent load may be quite complex. The constituent load is the mass or weight of a constituent that passes a cross section of a stream in a specific amount of time. Loads are expressed in mass units (e.g., tons, kilograms) and are considered for time intervals that are relative to the type of pollutant and the watershed area for which the loads are calculated. Loads are calculated from concentrations of constituents obtained from analyses of water samples and stream discharge, which is the volume of water that passes a cross section of the river in a specific amount of time.

The computer model Regr_Cntr.xls (*Regression with Centering*) was selected to calculate constituent loads for suspended sediment and phosphorus for this project. The program is an Excel implementation of the USGS seven-parameter regression model for load estimation (Cohn and others, 1992). It estimates loads in a manner very similar to that used most often by the

Estimatr.exe (*USGS Estimator*) program. The Regr_Cntr.xls program was adapted by R. Peter Richards at the Water Quality Laboratory at Heidelberg College (Richards, 1999).
The program establishes a regression model using a calibration set of data composed of concentrations of the constituent of interest and discharge values measured at the time of water sampling. Constituent loads can be estimated for any year for which mean daily discharge data are provided.

The Regr_Cntr.xls computer model was developed to accept constituent concentrations in milligrams per liter (mg/L) and discharge in cubic feet per second (cfs). However, bed sediment (measured in tons per day) and nitrate (forms negative regressions with discharge) loads were estimated using annual average daily discharge and annual average daily bed sediment transport rates to determine daily loads, which are summed for any 365 day period to determine an annual load.

SEDIMENTATION

Sedimentation is a process by which eroded particles of rock are transported primarily by moving water from areas of relatively high elevation to areas of relatively low elevation, where the particles are deposited. Upland sediment transport is primarily accomplished by overland flow and rill and gully development. Lowland or flood plain transport occurs in streams of varying order, where upland sediment joins sediment eroded from flood plains, stream banks, and stream beds. Erosion rates are accelerated by human activity related to agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed. Excessive sedimentation is detrimental to water quality, destroys biological habitat, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to structures.

Precipitation, stream gradient, geology, soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in the Fish River watershed were evaluated and quantified by tributary, to evaluate factors impacting erosion and sediment transport at a localized scale. Estimates of sediment loads for this assessment are based on measured sediment and stream discharge. Therefore, a stream flow dataset composed of values ranging from base flow to flood is desirable.

Sediment loads in streams are composed of relatively small particles suspended in the water column (suspended solids) and larger particles that move on or periodically near the streambed (bed load). Five of eight D'Olive Creek watershed monitoring sites had measurable suspended and bed sediment loads (DC1, DC3, DCB, TC7, TC8). Only suspended sediment could be measured at the other three sites due to flow and channel conditions (DGA, TC9, JB0). Sites TC9 and JBO have hard surfaced stream beds that makes possible estimation of total sediment loads from suspended sediment data. Site DGA is a deep water estuary site with no measurable bed sediment.

SUSPENDED SEDIMENT

The basic concept of constituent loads in a river or stream is simple. However, the mathematics of determining a constituent load may be quite complex. The constituent load is the mass or weight of a constituent that passes a cross-section of a stream in a specific amount of time. Loads are expressed in mass units (tons or kilograms) and are measured for time intervals that are relative to the type of pollutant and the watershed area for which the loads are calculated. Loads are calculated from concentrations of constituents obtained from analyses of water samples and stream discharge, which is the volume of water that passes a cross-section of the river in a specific amount of time.

Suspended sediment is defined as that portion of a water sample that is separated from the water by filtering. This solid material may be composed of organic and inorganic particles that include algae, industrial and municipal wastes, urban and agricultural runoff, and eroded material from geologic formations. These materials are transported to stream channels by overland flow related to storm-water runoff and cause varying degrees of turbidity. Concentrations of total suspended solids (TSS) in mg/L were determined by laboratory analysis of periodic water grab samples. Stream discharge was measured simultaneously with sample collection.

TSS and discharge for each site measured from 2006 to 2008 were plotted to form regression curves (Cook, 2007, Cook and Moss, 2008). Additional data collected in 2015 and 2016 resulted in TSS and discharge points that were added to the previous regression to determine changes (if any) to suspended sediment transport. Updated suspended sediment regression curves are shown in figures 2 and 3 (2015-2016 points in red). Sites TC9, TC8, and DC3 showed little or no change from the original 2006-2008 regression (fig. 2). When compared to the original regression at site TC7, the updated regression shows little or no change for discharge from 1 to 20 cfs. Above 20 cfs, the updated regression deviates from the original and shows increased TSS from 5 times at 30 cfs to an order of magnitude increase at 50 cfs (fig. 3). Comparison of updated regression points and the original regression at site DC1 indicates no change in TSS for discharge up to 6 cfs. Above 6 cfs the updated regression shows an increase in TSS from about 4 times at 8 cfs to 7.5 times at 200 cfs (fig. 3). Comparison of original and

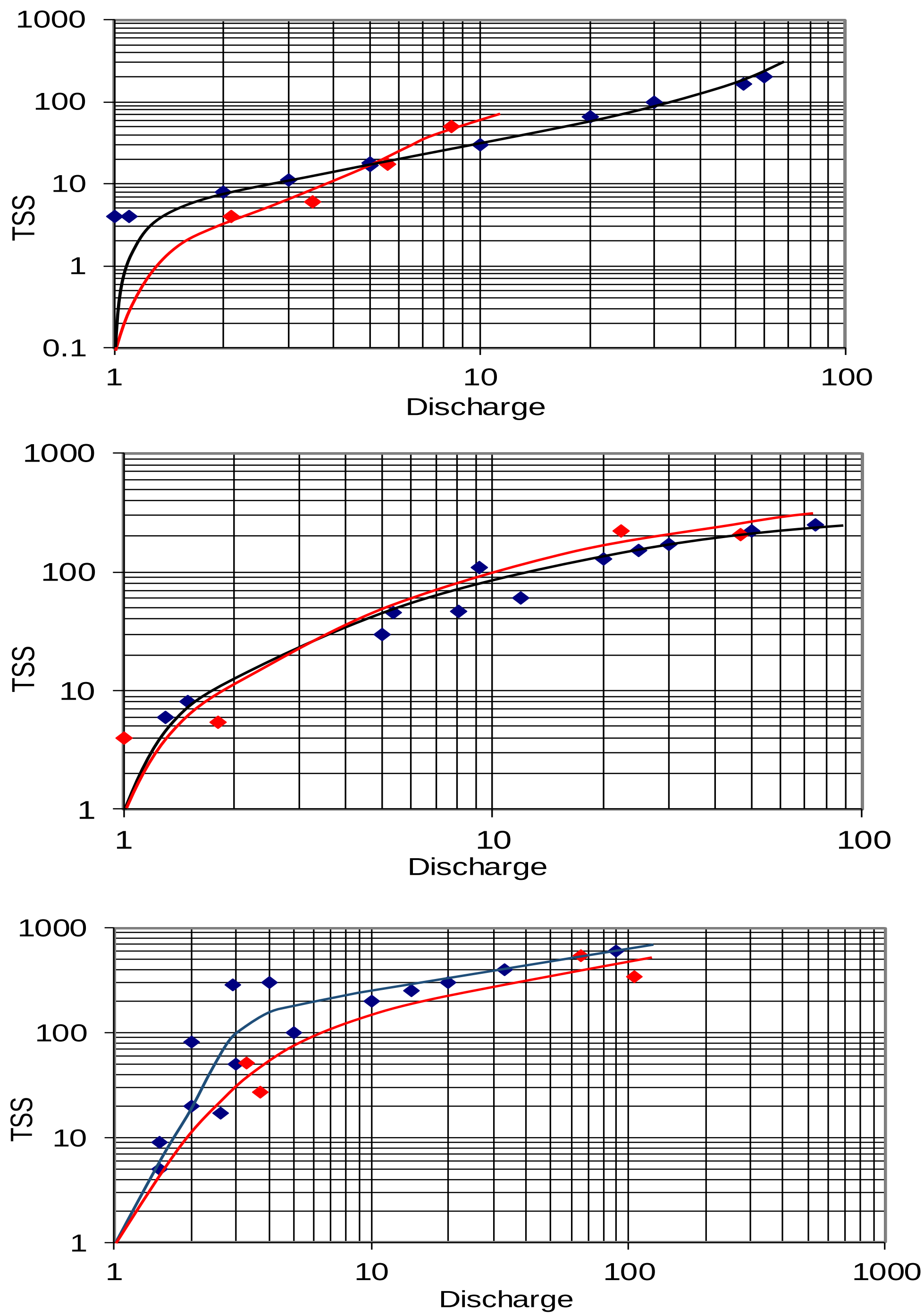


Figure 2.—Regressions for discharge and TSS for 2006-2008 (blue points and line) and 2015-2016 (red points and line) showing little or no change for sites TC9 (top), TC8, and DC3 (bottom).

updated TSS regressions at site JBO shows that updated TSS decreased by 80% at 8 cfs, 62% at 20 cfs, 40% at 40 cfs, and no change at discharge greater than 70 cfs (fig. 3).

Comparisons of original and updated TSS regressions provide information concerning suspended sediment transport conditions for common magnitude discharge events, whereas

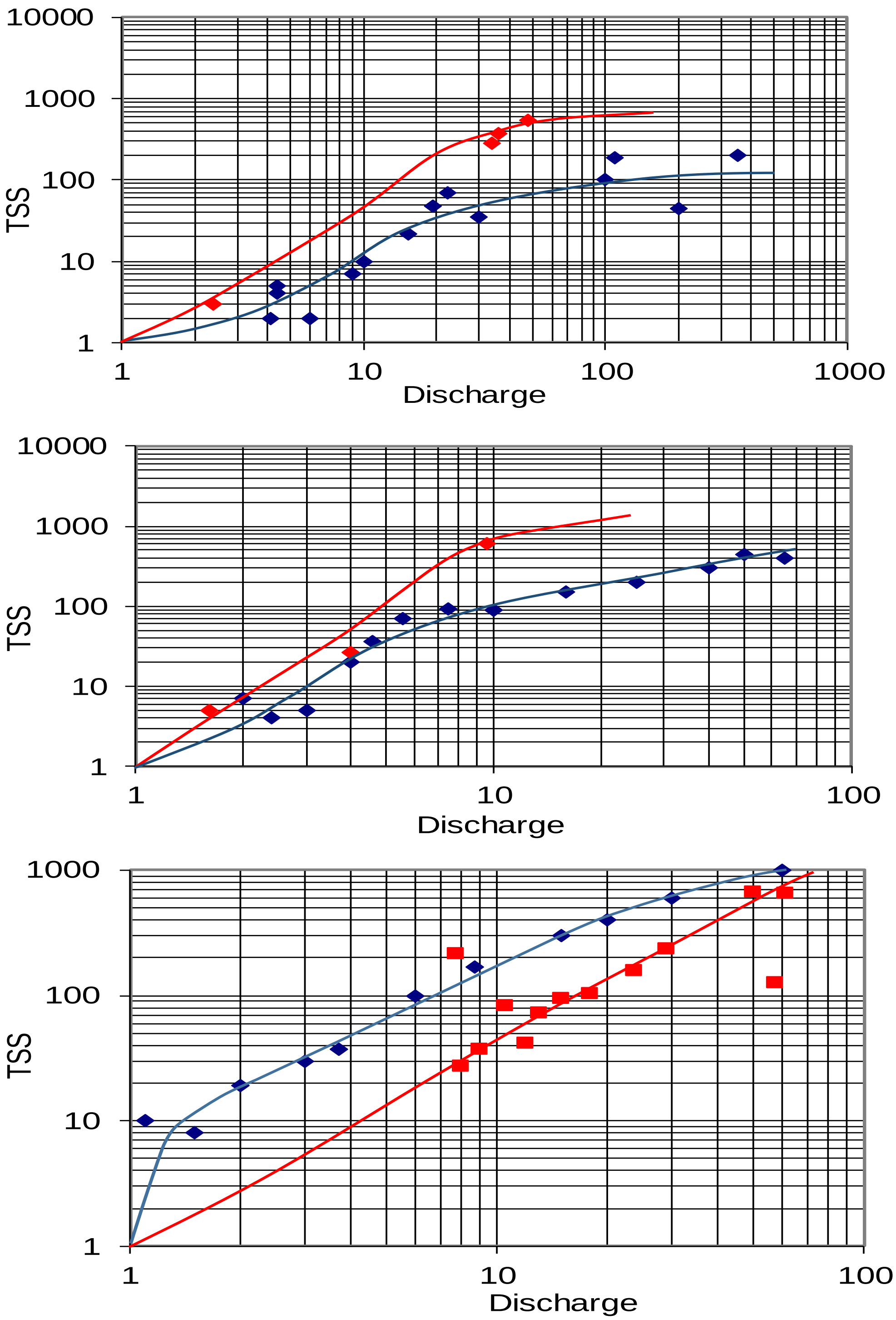


Figure 3.—Regressions for discharge and TSS for 2006-2008 (blue points and line) and 2015-2016 (red points and line) showing change for sites TC7 (top), DC1, and JB0 (bottom).

annual suspended sediment loads are based on annual average daily discharge. Therefore, cumulative precipitation for compared years can portray quite different results. This is particularly true when comparing drought and normal precipitation years as with 2006-2008 and 2015-2016. For example, average annual daily discharge for site TC7 was 8.4 cfs in 2006-2007 and 25.5 cfs in 2015-2016. Also, economic conditions during the period 2006-2008 led to reduced construction and erosion in the D'Olive Creek watershed. Annual suspended sediment loads for sites TC7, DC1, and JB0 for 2015-2016 were 8,753, 3,247, and 3,681 t/yr, respectively compared to 835, 563, and 303 t/yr, respectively for the earlier period.

BED SEDIMENT

Transport of streambed material is controlled by a number of factors including stream discharge and flow velocity, erosion and sediment supply, stream base level, and physical properties of the streambed material. Most streambeds are in a state of constant flux in order to maintain a stable base level elevation. The energy of flowing water in a stream is constantly changing to supply the required power for erosion or deposition of bed load to maintain equilibrium with the local water table and regional or global sea level. Stream base level may be affected by regional or global events including fluctuations of sea level or tectonic movement. Local factors affecting base level include fluctuations in the water table elevation, changes in the supply of sediment to the stream caused by changing precipitation rates, and/or land use practices that promote excessive erosion in the floodplain or upland areas of the watershed. Bed sediment loads are composed of particles that are too large or too dense to be carried in suspension by stream flow. These particles roll, tumble, or are periodically suspended as they move downstream.

Bed sediment was measured at sites DC1, DC3, TC7, and TC8 during previous assessments in 2006-2008 and were updated in 2015 and 2016, prior to initiation of restoration projects. Three to six measurements were done for low, moderate, and high flows and the resulting volumes were plotted on the previous regressions to determine changes (if any) in bed sediment transport rates. The graphs on figure 4 show bed sediment transport rate regressions for the 2006-2008 assessments and updated regressions for rates measured in 2015 and 2016.

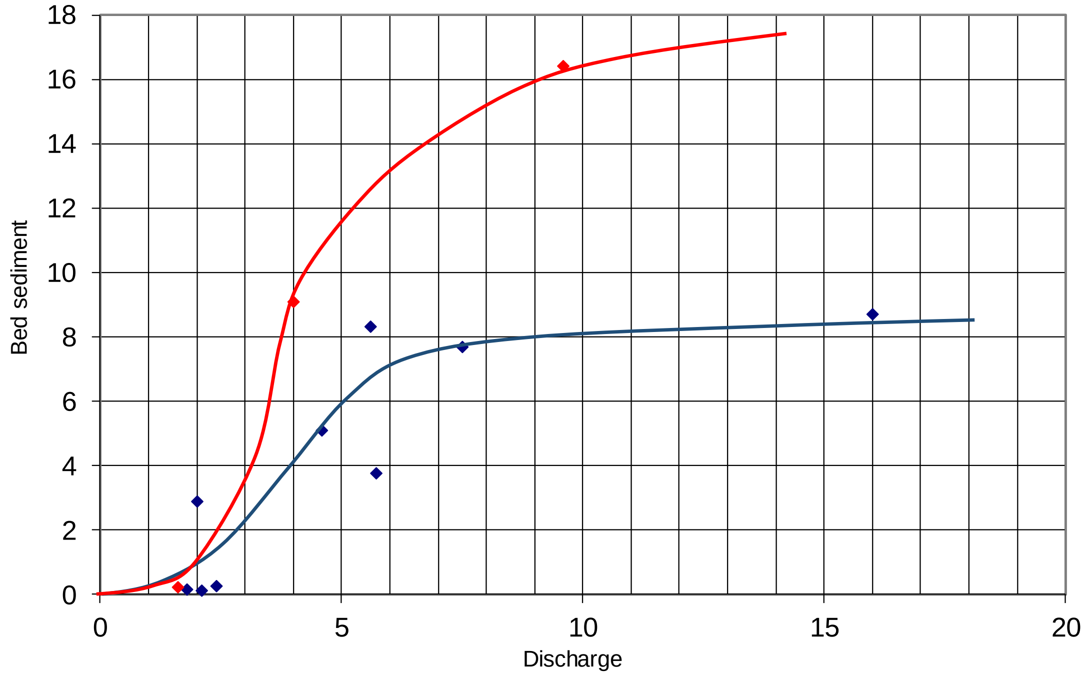
The regression comparison indicates that bed sediment transport rates for site DC1 are unchanged for low flows (less than 3 cfs). However, during moderate and high flows, bed sediment transport doubled relative to the 2006-2008 rates for discharge greater than 10 cfs (fig. 4). The increase in bed sediment indicates that erosion in the watershed upstream from site DC1 increased between 2008 and 2016. Comparison of estimated loads for the two-time periods confirmed the increase of 100% from 1,665 tons per year (t/yr) to 3,366 t/yr. Origins of excessive bed sediment have been identified and a restoration project is scheduled upstream of site DC1 in the near future.

Figure 4 shows that bed sediment transport rates at site DC3 during 2015-2016 showed no change at low flows (less than 3 cfs) but rates continually decreased with increasing flows to 3% of the 2006-2008 rates at flows greater than 60 cfs. Comparison of estimated loads for the two-time periods confirmed a 68% decrease from 3,097 t/yr to 995 t/yr. Major channel erosion occurred upstream from site DC3 prior to and after the 2006-2008 assessment period. A channel stabilization project was completed immediately downstream from the I-10 culverts to stop head cutting erosion that threatened the interstate highway. Although this project was not totally effective, the combination of remediation and establishment of a lower base level downstream from the remediation and upstream from site DC3 decreased erosion and resulting bed sediment transport. Severe channel erosion upstream from site DC3 was remediated by a second, more comprehensive watershed restoration project between I-10 and US Highway 90. If the restoration remains stable and erosion is prevented upstream from the restoration, sedimentation rates will continue to decrease. Future monitoring will document improvements and will be used in consideration on removing the stream from the ADEM-Clean Water Act 303-d list.

The regression drawn from individual measured bed sediment transport rates at site TC7 for the 2015-2016 period decreased by 90% at 3 cfs to 70% at 50 cfs, relative to the 2006-2008 regression (fig. 5). However, when annual bed sediment loads for the two-time periods were compared, the 2015-2016 load (595 t/yr) was 44% lower than the 2008 load (983 t/yr).

Rates at site TC8 were unchanged at flows less than 10 cfs but continually increased from 10 cfs to more than double at 25 cfs (fig. 5). Although no comparable measured discharge and bed sediment rates were available for the 2006-2008 period, a rate of 100 tons per day (t/d) for a discharge event of 47 cfs was measured on November 18, 2015. Comparison of estimated loads for the two-time periods indicated a 640% increase from 567 t/yr in 2006-2008 to 3,650 t/yr in 2015-2016. A subsequent field inspection in mid-2016 by Ms. Ashley Campbell, city of Daphne

Environmental Programs Manager, revealed severe channel and bank erosion upstream from site TC8.



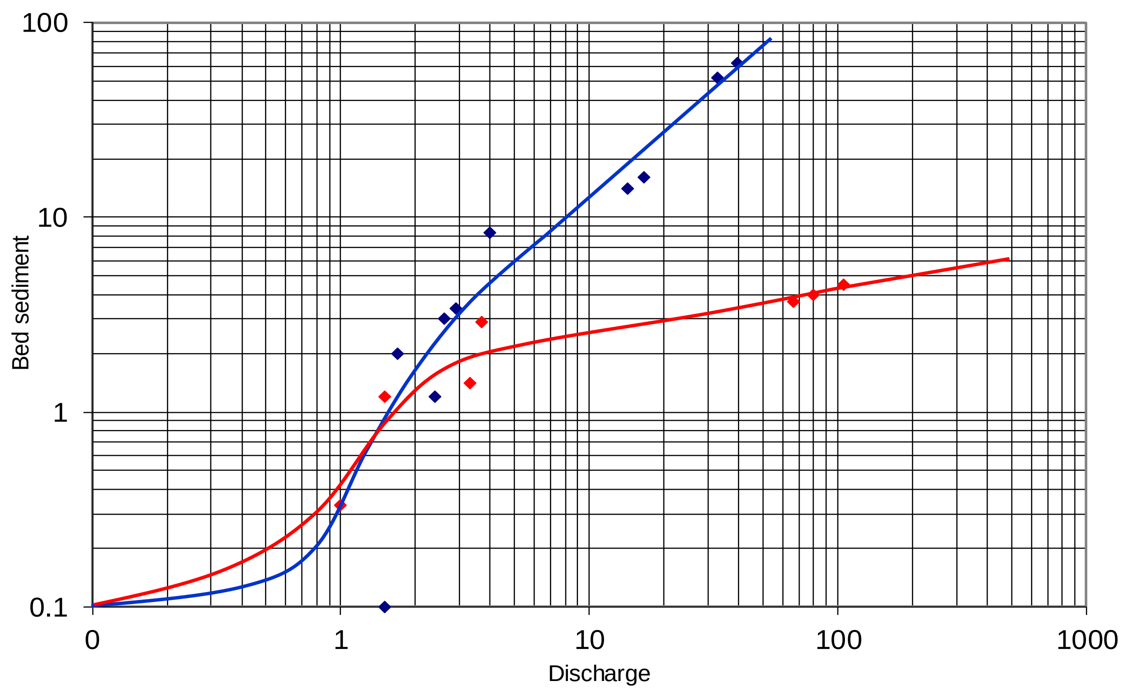


Figure 4.-- Regressions for discharge and bed sediment for 2006-2008 (blue points and line) and 2015-2016 (red points and line) showing change for sites DC1 (top) and DC3 (bottom).

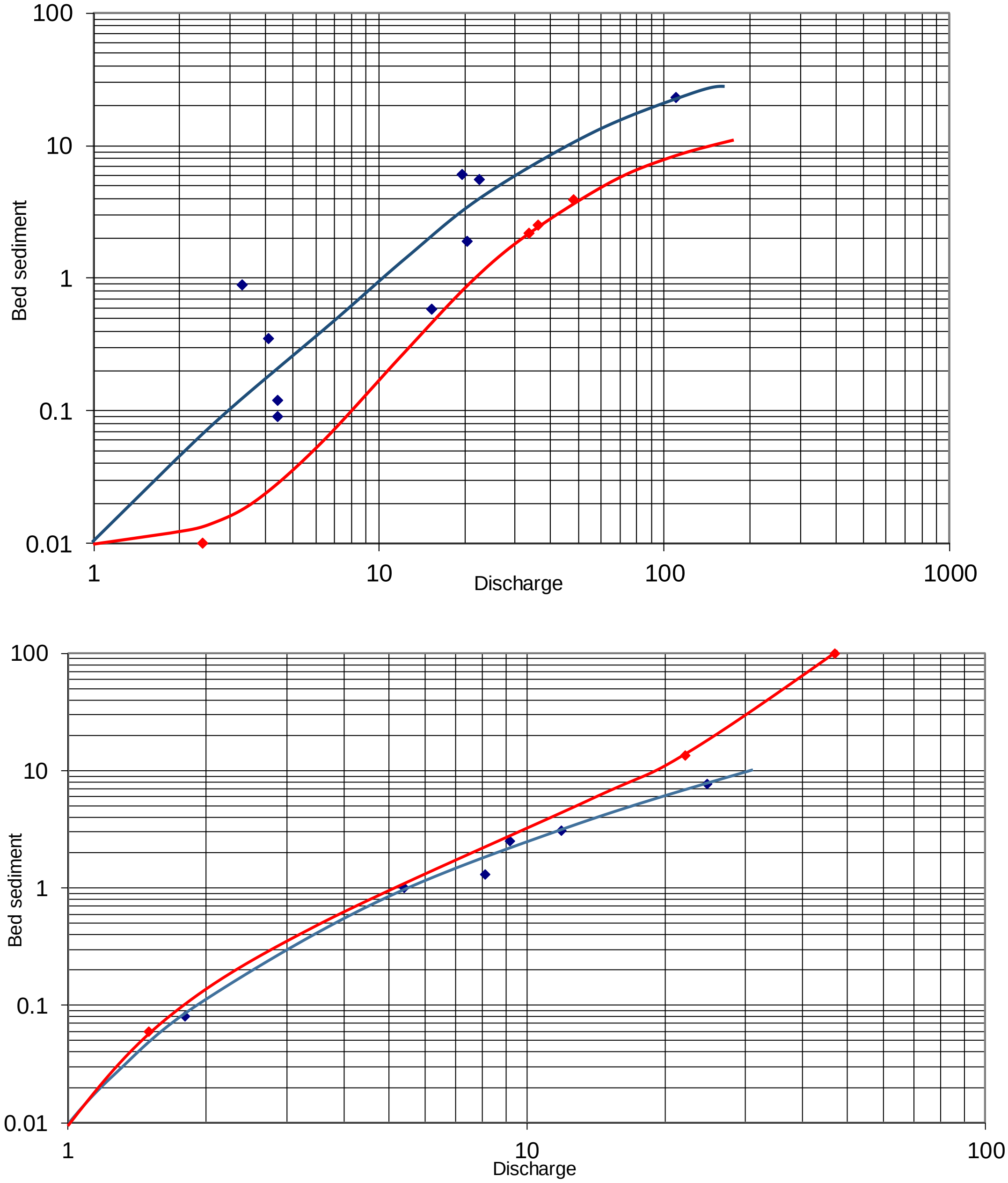


Figure 5.-- Regressions for discharge and bed sediment for 2006-2008 (blue points and line) and 2015-2016 (red points and line) showing change for sites TC7 (top) and TC8 (bottom).

WATER QUALITY FOR D'OLIVE CREEK CONTINUOUS MONITOR SITES DCB AND DGA

Sites DCB and DGA were established in 2015 to continuously monitor water quality in downstream D'Olive Creek reaches at the upper end of Lake Forest and at the mouth of D'Olive Creek, immediately downstream from Lake Forest and upstream from D'Olive Bay. Data collected at these sites will show cumulative upstream water quality impacts and will be essential in determining the effectiveness of upstream restoration and remedial actions in the watershed.

Data collected from November 2015 through March 2016 shows that average water temperature was 19.0 degrees Celsius (°C) at site DCB and 18.3 °C at site DGA. Average specific conductivity (SC) at site DCB was 66 and 113 at site DGA. Site DGA is subject to tidal influence shown by the elevated average SC, however the maximum SC at site DGA was 325, which shows the dominance of freshwater in the D'Olive Bay estuary. Although average discharge for site DGA was 441 cfs compared to 188 cfs at site upstream site DCB, average turbidity was 138 NTU for site DGA and 272 NTU for site DCB. This shows the impact of Lake Forest as a sediment retention basin and the effectiveness of restoration projects in the Joes Branch watershed, upstream from site DGA. These factors are reflected in suspended sediment loads for sites DCB (7,033 t/yr or 1,327 $t/mi^2/yr$) and DGA (5,284 t/yr or 423 $t/mi^2/yr$).

Site DCB is a deep-water site, therefore, bed sediment was measured immediately upstream, so the estimated load, representative of bed sediment transport at site DCB is 6,213 t/d or 1,172 $t/mi^2/yr$. This relatively large bed sediment load compared to the reduced load upstream at site DC3 is most likely caused by evacuation of bed sediment from the D'Olive Creek channel and stream bank erosion by relatively clear water flowing from the remediated upstream reach.

NUTRIENTS

Excessive nutrient enrichment is a major cause of water-quality impairment. Excessive concentrations of nutrients, primarily nitrogen and phosphorus, in the aquatic environment can lead to increased biological activity, increased algal growth, decreased dissolved oxygen concentrations at times, and decreased numbers of species (Mays, 1996). Nutrient-impaired waters are characterized by numerous problems related to growth of algae, other aquatic vegetation, and associated bacterial strains. Blooms of algae and associated bacteria can cause taste and odor problems in drinking water and decrease oxygen concentrations to eutrophic levels. Toxins also can be produced during blooms of particular algal species. Nutrient-impaired water can dramatically increase treatment costs required to meet drinking water standards. Water samples were collected for discharge events from base flow to bank full from November 2015 through March 2016 at MBNEP newly established continuous monitoring sites DCB and DGA. Samples were analyzed for nitrate (NO_3-N) and phosphorus (P-total).

NITRATE

The U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for nitrate in drinking water is 10 mg/L. Typical nitrate (NO_3 as N) concentrations in streams vary from 0.5 to 3.0 mg/L. Concentrations of nitrate in streams without significant nonpoint sources of pollution vary from 0.1 to 0.5 mg/L. Streams fed by shallow groundwater draining agricultural areas may approach 10 mg/L (Maidment, 1993). Nitrate concentrations in streams without significant nonpoint sources of pollution generally do not exceed 0.5 mg/L (Maidment, 1993). Samples were analyzed for nitrate as N. The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993). Nitrate analytical results are shown in table 1.

Fifty percent of samples collected at site DCB and 75 percent of samples collected at site DGA were below the laboratory detection limit (table 1). Although the distribution of discharge for sampled events was good, samples were collected during fall and winter, which was not optimum for the presence of nutrients. Annual loads for nitrate at either site could not be estimated due to insufficient nitrate concentrations.

Table 1.—Measured nitrate as N concentrations and estimated loads for continuous monitored sites on D'Olive Creek.

Monitored site	Average nitrate as N (mg/L)	Maximum nitrate as N (mg/L)	Minimum nitrate as N (mg/L) (% samples BDL[1])	Samples above 0.5 mg/L criterion (%)	Estimated nitrate as N load (t/yr)	Estimated normalized nitrate as N load (t/mi^2/yr)
DCB	0.16	0.74	BDL (50)	10	N/A[2]	N/A
DGA	0.08	0.32	BDL (75)	0	N/A[2]	N/A

[1] Below detection limit
[2] Insufficient data for load estimation

PHOSPHORUS

Phosphorus in streams originates from the mineralization of phosphates from soil and rocks or runoff and effluent containing fertilizer or other industrial products. The principal components of the phosphorus cycle involve organic phosphorus and inorganic phosphorus in the form of orthophosphate (PO_4) (Maidment, 1993). Orthophosphate is soluble and is the only biologically available form of phosphorus. Since phosphorus strongly associates with solid particles and is a significant part of organic material, sediments influence water column concentrations and are an important component of the phosphorus cycle in streams.

The natural background concentration of total dissolved phosphorus is approximately 0.025 mg/L. Phosphorus concentrations as low as 0.005 to 0.01 mg/L may cause algae growth, but the critical level of phosphorus necessary for excessive algae is around 0.05 mg/L (Maidment, 1993). Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances (Maidment, 1993). ADEM established a reference standard for total phosphorus for level IV ecoregion 65f (including the Fish River watershed) of 0.04 mg/L. In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed "phosphorus limited."

Eleven percent of samples collected a site DCB and 75 percent of samples collected at site DGA were below the detection limit for total phosphorus (table 2). Maximum concentrations of total phosphorus were 1.50 mg/L at site DCB and 0.07 mg/L at site DGA (table 2). Eighty-eight percent of samples collected at site DCB were above the ADEM reference concentration of 0.04 mg/L. Phosphorus loads for sites DBC and DGA are 15.4 and 3.9 t/yr, respectively, which compares to the largest phosphorus load in the Fish River watershed at site FR9 (Fish River at Baldwin County Road 48), 15.1 t/yr (Cook, 2016). When normalized relative to drainage area, the loads at sites DCB and DGA are 2.9 and 0.3 t/mi^2/yr respectively, compared to the largest normalized load in the Fish River watershed at site FR8 (Pensacola Branch at Baldwin County Road 48), which is 0.83 t/mi^2/yr.

Table 2.—Measured total phosphorus concentrations and estimated loads for continuous monitored sites on D'Olive Creek.

Monitored site	Average total phosphorus (mg/L)	Maximum total phosphorus (mg/L)	Minimum total phosphorus (mg/L) (% samples BDL)	Samples above 0.04 mg/L ADEM criterion (%)	Estimated total phosphorus load (t/yr)	Estimated normalized total phosphorus load (t/mi^2/yr)
DCB	0.20	1.50	BDL (11)	88	15.4	2.9
DGA	0.02	0.07	BDL (75)	25	3.9	0.3

DISCHARGE RATING FOR CONTINUOUS MONITOR SITES

Stream discharge rating is the relation of water level at a given point in a stream to a corresponding volumetric rate of flow. When numerous measurements of discharge and water level are made over a wide range of discharge events, a rating curve can be established that allows determination of flow volume for any measured water level. MBNEP continuously monitored sites are equipped with instruments that measure a variety of parameters including stage (water level). However, it is important to know the volumetric discharge rate in cfs. Therefore, one of the tasks for this assessment was to establish rating curves for each of the sites. The task was not totally completed due to repositioning of monitoring equipment and drought conditions during the project period that prevented measurement of higher volume flows. Rating curves for sites TC7, DC3, DCB, DGA, and JB0 shown in figures 6- 9 will be completed during early 2017 with additional measurements as a wider range of discharge events become available.

The slope of a rating curve provides information about water movement in a stream including, stream gradient and channel and floodplain morphology as well as discharge volume. Rating curves can be complex, with changing slopes with stage increase, showing stream bed character, channel shape, and floodplain characteristics including shape and vegetative cover.

The rating curve for site TC7 (Tiawasee Creek at Bayview Drive) has a 67% slope for a range of stage from 0 to 1 ft (1.5 cfs at 1.0 ft) and a 3% slope from 1 ft to 2.5 ft (58 cfs at 2.5 ft) (fig. 6). The 67% slope shows the impact of riprap armoring and vegetation on the stream bed at and upstream from the monitoring device, which causes rapid increases in stage relative to discharge. Stages from 1 ft to 2.5 ft, totally inundate riprap and vegetation in the bed but are contained in the channel so that increases in discharge are relatively constant with rising stage. Stages above 2.5 ft and corresponding discharge will be measured during early 2017 and added to the existing rating curve.

The rating curve for site DC3 (D'Olive Creek at US Highway 90) has a 10% slope for a range of stage from 0 to 1 ft (10 cfs at 1.0 ft) and a 3% slope from 1 ft to 4.5 ft (120 cfs at 4.5 ft) (fig. 7). The 10% slope shows the impact of stream bed friction and point bar deposits immediately downstream from the monitoring device, which causes rapid increases in stage relative to discharge. Stages from 1 ft to 4.5 ft, overcome bed friction but are contained in the channel so that increases in discharge are relatively constant with rising stage. Stages above 4.5 ft and corresponding discharge will be measured during early 2017 and added to the existing rating curve.

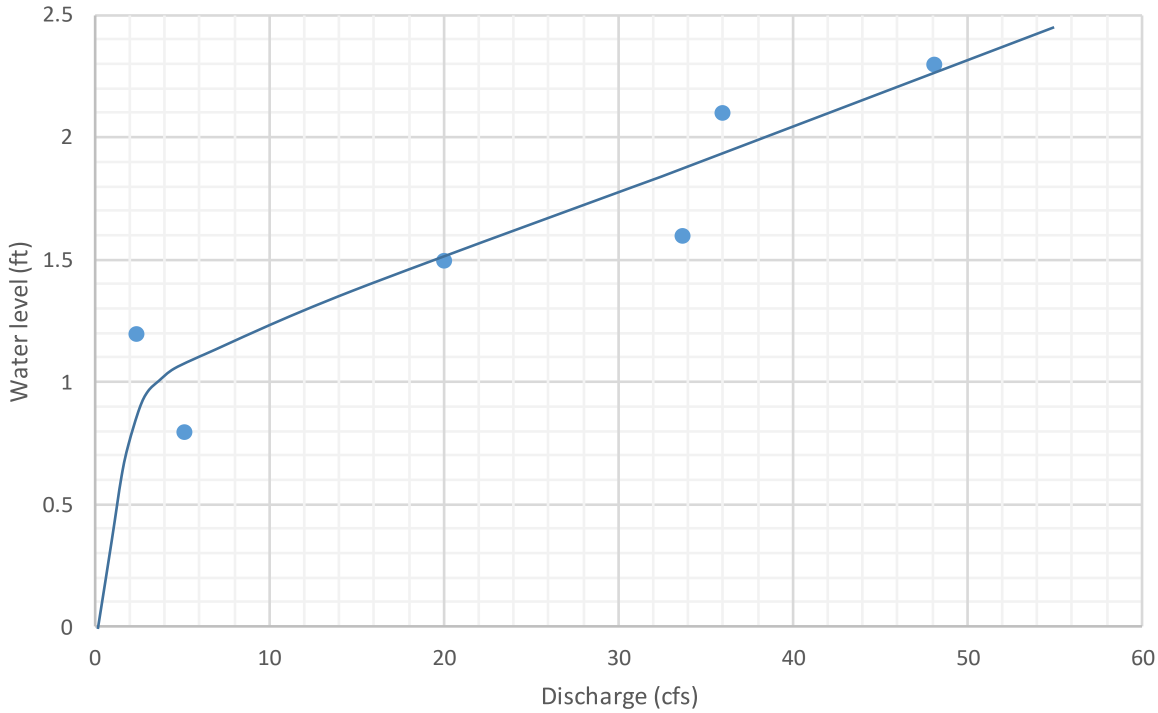


Figure 6.—Discharge rating curve for site TC7 (Tiawasee Creek at Bayview Drive).

The rating curve for site DCB (D'Olive Creek at Bayview Drive) has a 5% slope for a range of stage from 0 to 4.5 ft (100 cfs at 4.5 ft) and a 0.4% slope from 4.5 ft to 8 ft (1,000 cfs at 8 ft) (fig. 8). The 5% slope shows the impact of impoundment (Lake Forest) at the monitoring

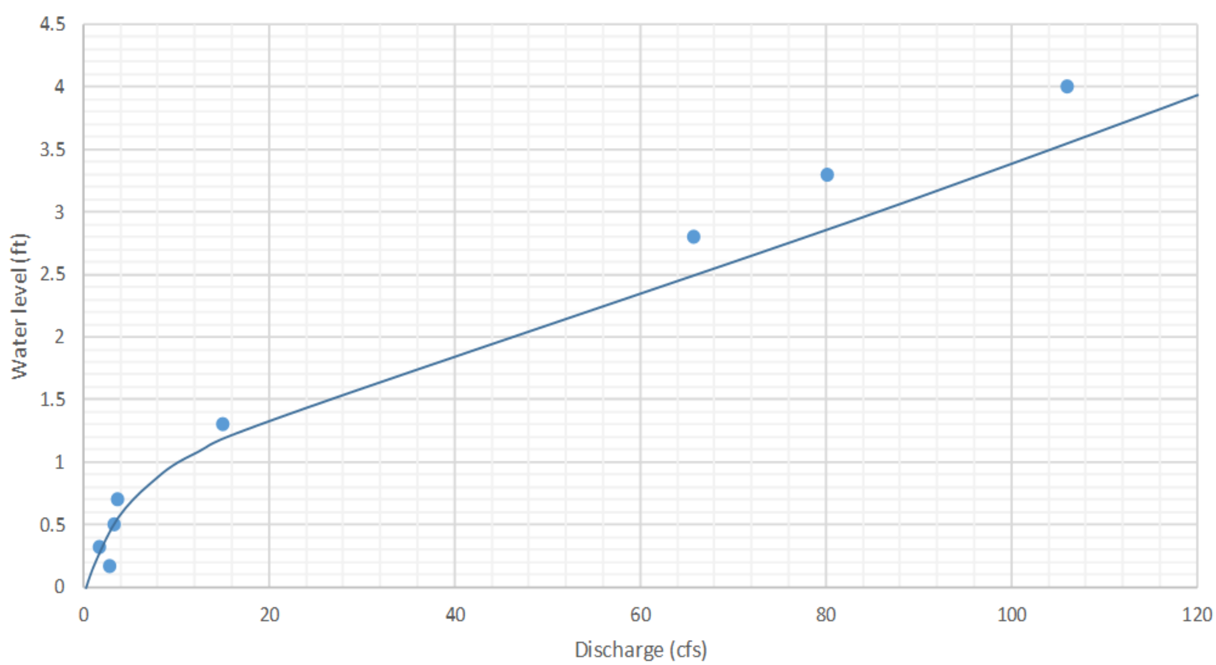


Figure 7.—Discharge rating curve for site DC3 (D'Olive Creek at US Highway 90).

site, which causes rapid increases in stage relative to discharge. Stages from 4.5 ft to 8 ft, overcome the impoundment so that increases in discharge are relatively constant with rising stage. Stages above 4.5 ft and corresponding discharge will be measured during early 2017 and added to the existing rating curve.

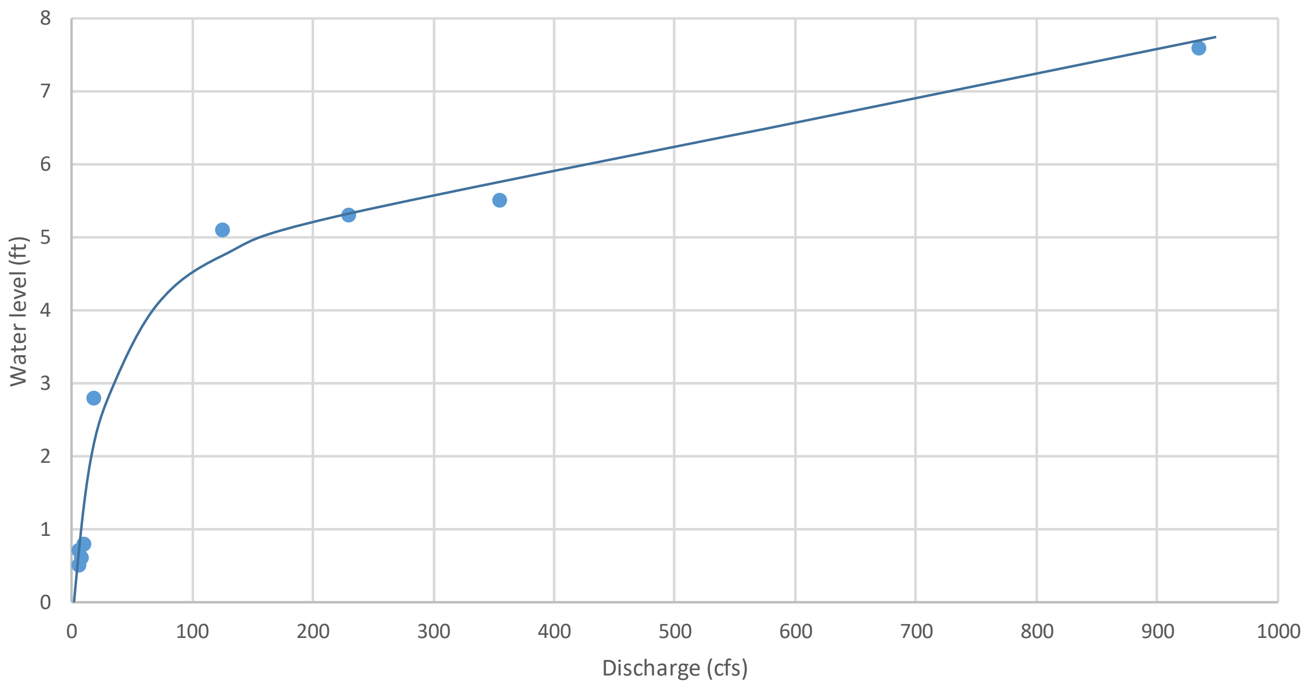


Figure 8.—Discharge rating curve for site DCB (D'Olive Creek at Bayview Drive).

The rating curve for site DGA (D'Olive Creek near US Highway 98) has a 12% slope for a range of stage from 9.8 to 10.9 ft (10 cfs at 10.9 ft) and a 0.03% slope from 10.8 ft to 11.7 ft (1,300 cfs at 11.7 ft) (fig. 9). The 12% slope shows the impact of backwater from D'Olive Bay that restricts downstream flow. Stages from 10.8 ft to 1.7 ft, overcomes backwater effects so that increases in discharge are relatively constant with rising stage. Stages above 11.7 ft and corresponding discharge will be measured during early 2017 and added to the existing rating curve.

The rating curve for site JB0 (Joes Branch at North Main Street) was completed, however the continuous monitoring equipment was moved about 900 ft upstream due to the failure of a concrete channel and weir at the original site. A rating curve at the new site will be established during 2017.

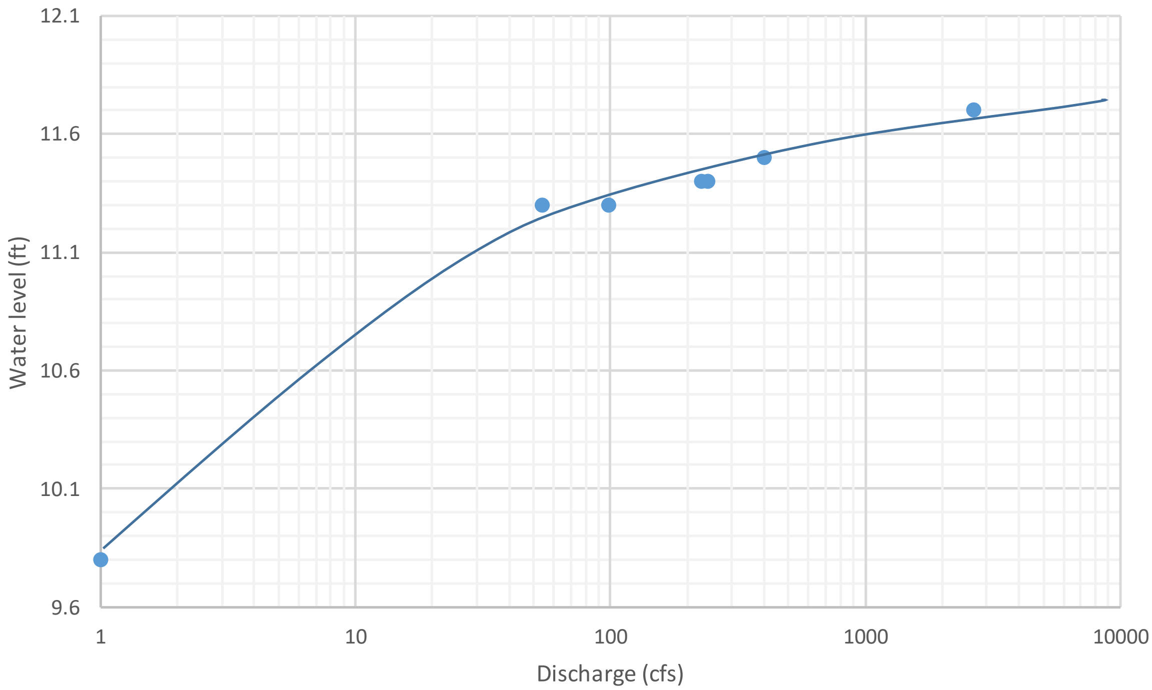


Figure 9.—Discharge rating curve for site DGA (D'Olive Creek at North Main Street).

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APPENDIX A

FIELD AND ANALYTICAL DATA

DC1								
Unnamed Tributary to D'Olive Creek near Wingate Circle in Lake Forest								
			Water Quality					
Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	TSS	Bed Sediment Load
		cfs	°C	mS/cm	NTU		mg/L	T/d
10/26/2015	1520	9.6	21	140	264	5.8	615	16.4
11/3/2015	1620	3.3	17	176	12	5.3	7	0.23
11/17/2015	1630	3	21	131	2	6.5	6	4
11/18/2015	1230	6	21	54	145	6.6	81	12
12/14/2015	420	4	18.3	54	54	5.7	26	9.1

DC3									
D'Olive Creek @ US Highway 90									
Rating				Water Quality					
Date	Time	Discharge	Water Level	Temperature	Conductance	Turbidity	pH	TSS	Bed Sediment Load
		cfs	ft	°C	mS/cm	NTU		mg/L	T/d
10/26/2015	1350	65.7	2.8	20.4	52	281	5.6	544	3.7
11/3/2015	1620	3.3	0.5	17	176	12	5.3	51	1.4
11/18/2015	1140	15	1.3	21	35	183	6.7	101	
12/14/2015	500	3.7	0.7	17.8	84	71	5.8	27	2.9
12/22/2015	1220	106	4	18.1	46	540	6.3		4.3
3/11/2015	1730	80.1	3.3	19.6	44	198	7.1		4
6/28/2016	1010	1.7	0.32						
7/11/2016	1755	2.8	0.17						

DCB									
D'Olive Creek at Bayview Drive									
Rating				Water Quality					
Date	Time	Discharge	Water Level	Temperature	Conductance	Turbidity	pH	TSS	Bed Sediment Load
		cfs	ft	°C	mS/cm	NTU		mg/L	T/d
11/18/2015	830	18.1	2.8	22.9	68	99	6.5	49	10
11/18/2015	1300	355	5.5					500	170
12/2/2015	1040	6.4	0.7	17.9	97	6	5.8	2.4	0.5
12/10/2015	1645	6	0.5	19	126	7	5.8	7	1.6
12/14/2015	530	10.2	0.8	17.1	63	48	5.9	27	5.4
12/17/2015	1300	8	0.6	17.5	64	25	6	7	2
12/22/2015	45	125	5.1	18.1	43	539	6.4	390	68
12/23/2015	850	935	7.6	18	21	900	5.4	600	350
3/24/2016	1455	230	5.3	20.4	57	748	6.8	469	110
3/27/2016	2000	369		20	54	75	6.8		
6/28/2016	940	5.9							

DGA											
D'Olive Creek at North Main Street											
Rating				Water Quality							
Date	Time	Discharge	Water Level	Temperature	Conductance	Turbidity	pH	Salinity	TSS	Nitrate	Total Phosphorus
		cfs	ft	°C	mS/cm	NTU		ppt	mg/L	mg/L	mg/L
11/18/2015	1330	400	11.5			105					
12/2/2015	1640	120	9.8	18	325	25	6.2	0.01	3.6	0.31	0
12/10/2015	1715	229	11.4	16.8	79	7	5.7		2.8		0.05
12/14/2015	600	54.2	11.3	17.9	118	8	6		4	0.32	0
12/17/2015	1330	98	11.3	17.5	95	20	5.9		4		0
12/22/2015	150	240	11.4	18	59	155	6.4		39	0	0.05
12/23/2015	840	2,660	11.7	18.1	27	680	5.6		330		0.12
3/24/2016	1440	700	9	19.8	57	144	7.1		78.4	0	0.066
3/27/2016	1945	228	9.75	20.4	144	61	6.1		20		
6/28/2016	810	58	9.8			12			3.3		

TC7									
Tiawasee Creek @ Bayview Drive									
Rating				Water Quality					
Date	Time	Discharge	Water Level	Temperature	Conductance	Turbidity	pH	TSS	Bed Sediment Load
		cfs	ft	°C	mS/cm	NTU		mg/L	T/d
10/26/2015	1425	48.1	2.3	20.3	54	210	5.6	544	3.9
11/17/2015	1630	2.4	1.2	21.4	131	3	5.8	1	0
11/18/2015	1230	36	2.1	21.3	54	145	6.6	300	2.5
12/22/2015	2400	33.7	1.6	18.2	44	103	6.1	260	2.2
6/28/2016	910	5.1	0.8						

TC8								
Tiawasee Creek @ Ridgewood Drive								
			Water Quality					
Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	TSS	Bed Sediment Load
		cfs	°C	mS/cm	NTU		mg/L	T/d
11/4/2015	1300	1	17	82	7	5.8	0	0.01
11/18/2015	1115	47	21.4	50	238	6.6	205	100
12/14/2015	350	1.8	18.3	81	17	5.7	5	0.08
12/21/2015	1120	22.2	18	38	250	6		13.5

TC9							
Unnamed Tributary to Tiawasee Creek @ Greenwood Drive							
			Water Quality				
Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	TSS
		cfs	°C	mS/cm	NTU		mg/L
11/4/2015	1240	2.1	17	73	6	5.9	4
11/18/2015	1140	8.4	21.3	35	183	6.7	50
12/14/2015	330	5.6	18.6	133	64	5.6	17.5
12/21/2015		3.5	16.8	79	7	5.7	6
			17.9	118	8	6	
			17.5	95	20	5.9	

JB0								
Joes Branch at North Main Street								
Date	Time	Discharge	Water Level	Temperature	Conductance	Turbidity	pH	TSS
		cfs	ft	°C	mS/cm	NTU		mg/L
5/29/14	15:30	5		24	58	40	7.2	27
7/10/14	18:00	12.2		26	72	111	6.6	103
10/13/2014	0:20	41.6		24.6	84	234	5.7	157
11/17/2014	5:30	20.1		18	79	212	5.9	94
1/23/2015	0:50	48.1		11.9	61	260	5.5	600
2/4/15	16:10	12.86		11	95	72	5.8	54
4/13/2015	19:00	47.3		22	61	180	6.1	630
5/26/2015	0:15	12.3		24.3	82	220	5.9	72
7/9/2015	16:00	23.7		27.0	63	215	5.6	234
8/17/2015	12:00	7.7		27.2	104	60	5.8	213
9/21/2015	14:10	6.13		23.7	137	85	5.4	37
10/26/2015	13:20	49.6		20.2	50	225	5.7	664
1/22/2016	715	25	1.2	18	207	27	6.9	20
2/2/2016	1445	12	0.95	18	148	64	7.5	40
2/15/2016	1730	61	1.55	16.1	70	225	6.5	650
2/22/2016	1015	10.5	0.9	18.5	152	98	7.1	95
3/11/2016	1650	57	1.5	19.9	59	120	7.3	140