Suspended Sediment Inputs to Jordan Lake
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Bulk Sediment Inputs and Outputs

Objective: To document the spatial (lake-wide) and temporal (hours to years) input of suspended sediments to Jordan Lake.

Suspended sediments in Jordan Lake are a problem for several reasons. In addition to making the lake less appealing, high suspended sediment concentrations (SSC) in lake waters makes it more difficult to filter for water intakes causing additional problems for municipal water supplies. High SSC in surface lake waters limits the light that is able to penetrate into the deeper layers of the lake and is a limiting factor for photosynthesis in the lake. Also, various forms of contaminants and nutrients are associated with sediments that enter the lake. As sediments settle to the bottom of the lake they carry these contaminants and nutrients with them to deeper waters and to the lake bottom where oxygen and temperature conditions are different from conditions in surface waters. This change in conditions can result in the release of contaminants and nutrients from lake bottom sediments into lake bottom waters.

Questions:

a. What is the input flux of sediments into Jordan Lake?
b. What is the temporal pattern of SSC flux to Jordan Lake (daily, weekly, monthly, seasonally and annually)?
c. What is the temporal pattern of flux out of Jordan Lake (over the dam at the spillway)
d. What are the special patterns of SSC flux to Jordan Lake from north (New Hope Creek, Morgan Creek, Northeast Creek) and south (Haw) inputs?
e. What is the relationship between rates of water discharge and sediment discharge at each of the lake inputs?

Approach and Methods:

SSCs are being measured in waters entering the lake from creeks and rivers at four inputs sites. North of the lake, three sites (Morgan Creek, New Hope Creek, Northeast Creek) are being sampled weekly at locations adjacent to the most lake-ward USGS station, where water discharge is measured. South of the lake, the Haw River is being sampled weekly at the Bynum USGS monitoring site. Weekly samples are also being collected at the outflow from the lake at the dam in Moncure. The units used for SSC is mg l^{-1}. The SSC at each of these sites is multiplied by the rate of water discharge (recorded by the USGS) to calculate the suspended sediment discharge rate for each site at the time of sampling.

Each week, all river/creek input sites and the outflow site at Jordan dam are sampled the same day within a 5-hour period. Weekly, triplicate (one liter) samples are collected at each site for lab analyses. In the lab, suspended sediments in each replicate sample is concentrated by vacuum filtration (pre-weighed 0.22 micron filters). Filters are dried and then re-weighed to determine the mass (milligrams) of sediments in each liter of water (SSC). The SSC (mg l^{-1}) determined at each sampling site/time is multiplied by the water discharge rate Q_w (cubic meters per second; m^3 s^{-1}) recorded for the sampling time and location by the USGS. This product yields the sediment discharge rate Q_s (mg s^{-1} or g hr^{-1}). Water discharge from the USGS is reported in units

of cfs or cubic feet per second. We convert this to cubic meters per second. One *cubic feet per second* is equal to 0.028316847 *cubic meter per second*. 1 cubic meter = 1000 liters.

Results to date:

<u>Water discharge (period 1/1/17 to 8/11/17)</u>
The water discharge data source for all stations reported in this study are from the U.S. Geological Survey Water Resources.

Morgan Creek
The mean water discharge rate at Morgan Creek for this period was 1.69 $m^3 s^{-1}$ with 10 event peaks over 5 $m^3 s^{-1}$ and a maximum for the period of 61 $m^3 s^{-1}$ on 4/25/17 (Figure 1).

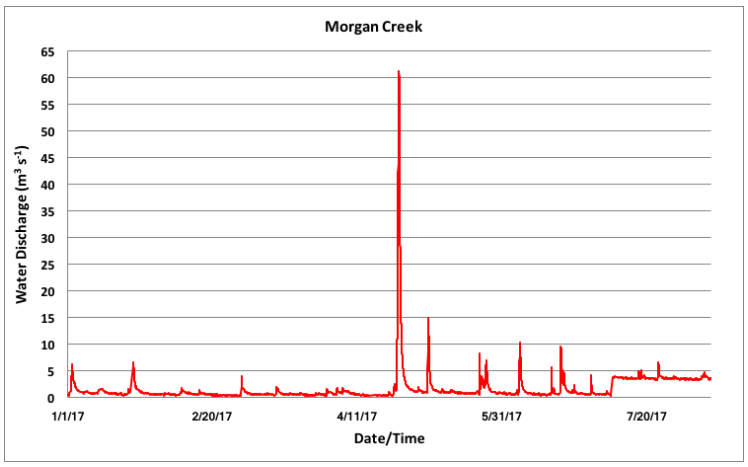

Figure 1. Water Discharge rate for Morgan Creek (1/1/17 to 8/11/17)

New Hope Creek
The mean water discharge rate at New Hope Creek for this period was 2.79 $m^3 s^{-1}$ with 12 event peaks over 5 $m^3 s^{-1}$ and a maximum for the period of 236 $m^3 s^{-1}$ on 4/25/17 (Figure 2).

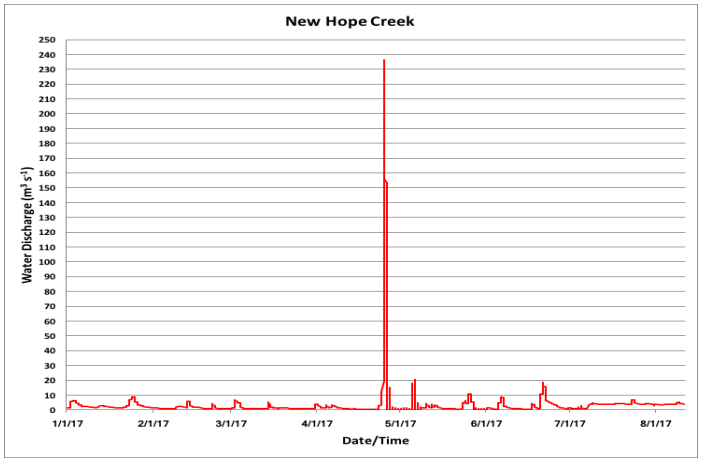

Figure 2. Water Discharge rate for New Hope Creek (1/1/17 to 8/11/17)

Northeast Creek
The mean water discharge rate at Northeast Creek for this period was 1.08 $m^3 s^{-1}$ with 10 event peaks over 5 $m^3 s^{-1}$ and a maximum for the period of 106 $m^3 s^{-1}$ on 4/25/17 (Figure 3).

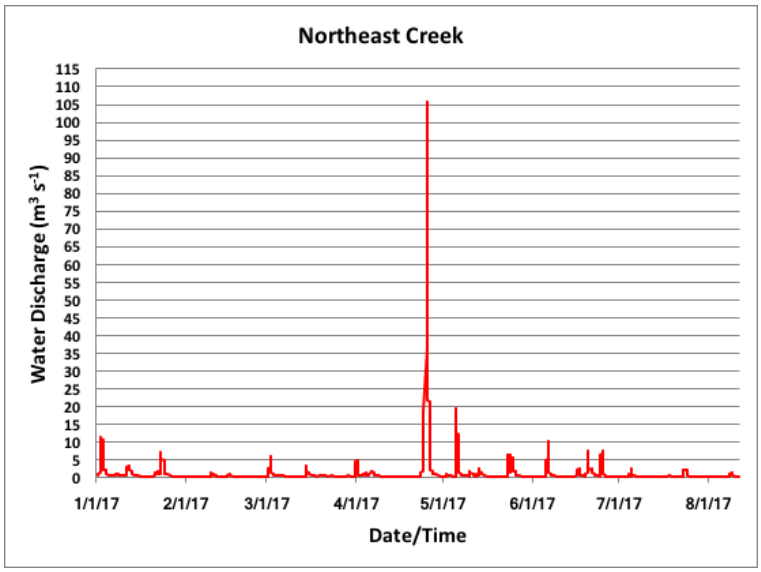

Figure 3. Water Discharge rate for Northeast Creek (1/1/17 to 8/11/17)

Haw River
The mean water discharge rate at Haw River for this period was 37.81 $m^3 s^{-1}$ with 6 event peaks over 100 $m^3 s^{-1}$ and two maxima for the period of 1226 $m^3 s^{-1}$ on 4/25/17 and 1025 $m^3 s^{-1}$ on 6/20/17 (Figure 4).

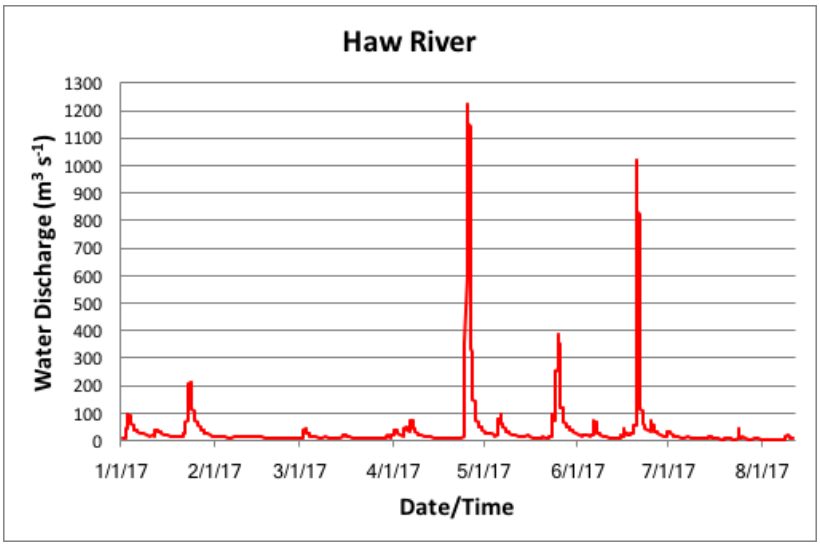

Figure 4. Water Discharge rate for Haw River (1/1/17 to 8/11/17)

Suspended sediment concentrations (period 1/1/17 to 8/11/17)

Morgan Creek

The average SSC in Morgan Creek during this sampling period was 5.77 mg l^{-1} with a range from 1.9 mg l^{-1} to 15.7 mg l^{-1} (Figure 5). The mean water discharge rate for the times sampled at this location was 5.04 m^{-3} s^{-1}. This compares to water discharge rates for the entire period which was 1.69 m^3 s^{-1} with 10 event peaks over 5 m^3 s^{-1}. The mean standard deviation for triplicate SSC values for this state is 16% indicating that Morgan Creek waters are relatively homogeneous on small spatial scales during sampling. The logarithmic trendline shown in Figure 5 has an R^2 value of 0.70, which indicates that a simple logarithmic relationship between SSC and Water Discharge rate describes the relationship reasonably well for SSC and Water Discharge rate ranges that have been sampled to date.

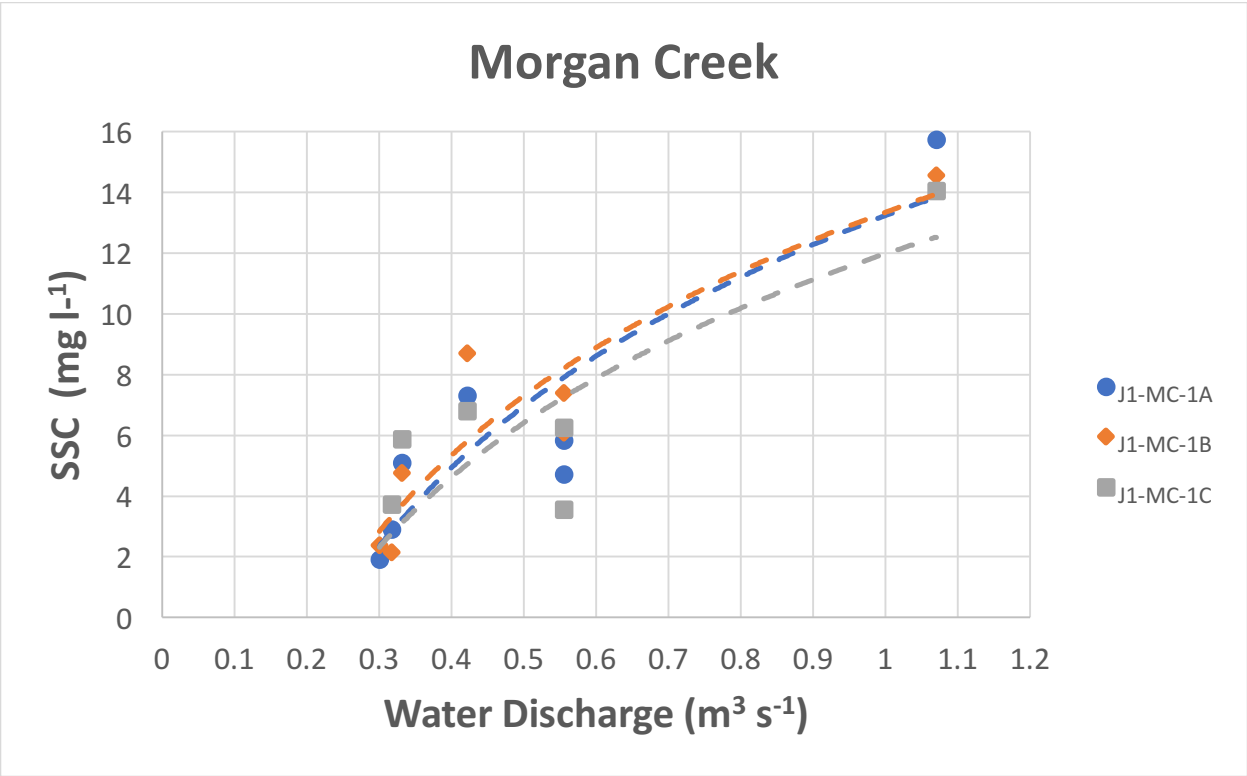

Figure 5. SSC (mg l^{1}) as a function of Water Discharge rate for Morgan Creek (1/1/17 to 8/11/17). 1A, 1B, and 1C are triplicate samples for each sampling time. Logarithmic trendline is indicated by the dashed lines.

New Hope Creek

The average SSC in the New Hope Creek during this sampling period was 22.66 mg l^{-1} with a range from 7.4 mg l^{-1} to 31.4 mg l^{-1} (Figure 6). The mean water discharge rate for the times sampled at this location was 11.92 m^{-3} s^{-1}. This compares to water discharge rates for the entire period which was 2.79 m^3 s^{-1} with 12 event peaks over 5 m^3 s^{-1}. The mean standard deviation for triplicate SSC values for this state is 21% indicating that New Hope Creek waters are relatively homogeneous on small spatial scales during sampling. The logarithmic trendline shown in

Figure 6 has an R^2 value of 0.16, which indicates that a simple logarithmic relationship between SSC and Water Discharge rate poorly describes the relationship for the SSC and Water Discharge rate ranges that have been sampled to date. Note that no intermediate water discharge rates (>1 and <5 $m^3 s^{-1}$) were sampled during this period, which may be partially responsible for the lack of a clear relationship between SSC and water discharge.

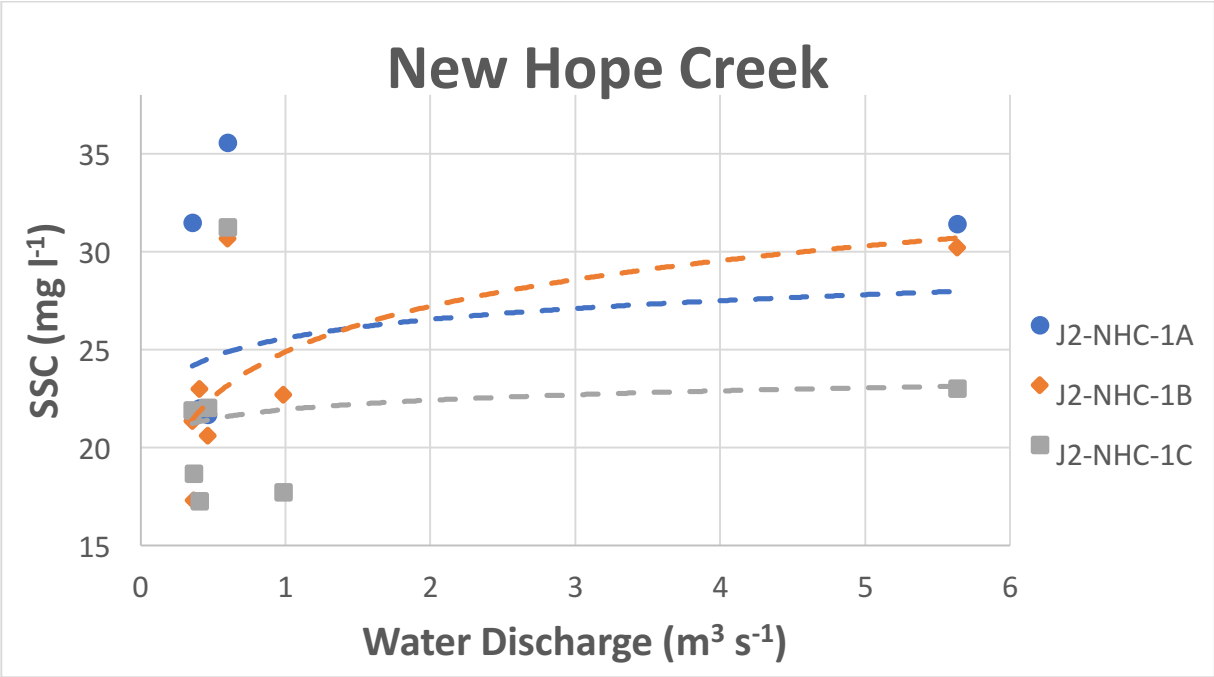

Figure 6. SSC (mg l^{-1}) as a function of Water Discharge rate for New Hope Creek (1/1/17 to 8/11/17). 1A, 1B, and 1C are triplicate samples for each sampling time. Logarithmic trendline is indicated by the dashed lines.

Northeast Creek

The average SSC in Northeast Creek during this sampling period was 49.29 mg l^{-1} with a range from 18.9 mg l^{-1} to 117.6 mg l^{-1} (Figure 7). The mean water discharge rate for the times sampled at this location was 2.05 $m^{-3} s^{-1}$. This compares to water discharge rates for the entire period which was 1.08 $m^3 s^{-1}$ with 10 event peaks over 5 $m^3 s^{-1}$. The mean standard deviation for triplicate SSC values for this state is 4% indicating that Northeast Creek waters are very homogeneous on small spatial scales during sampling. The logarithmic trendline shown in Figure 7 has an R^2 value of 0.02, which indicates that a simple logarithmic relationship between SSC and Water Discharge rate very poorly describes the relationship for the SSC and Water Discharge rate ranges that have been sampled to date.

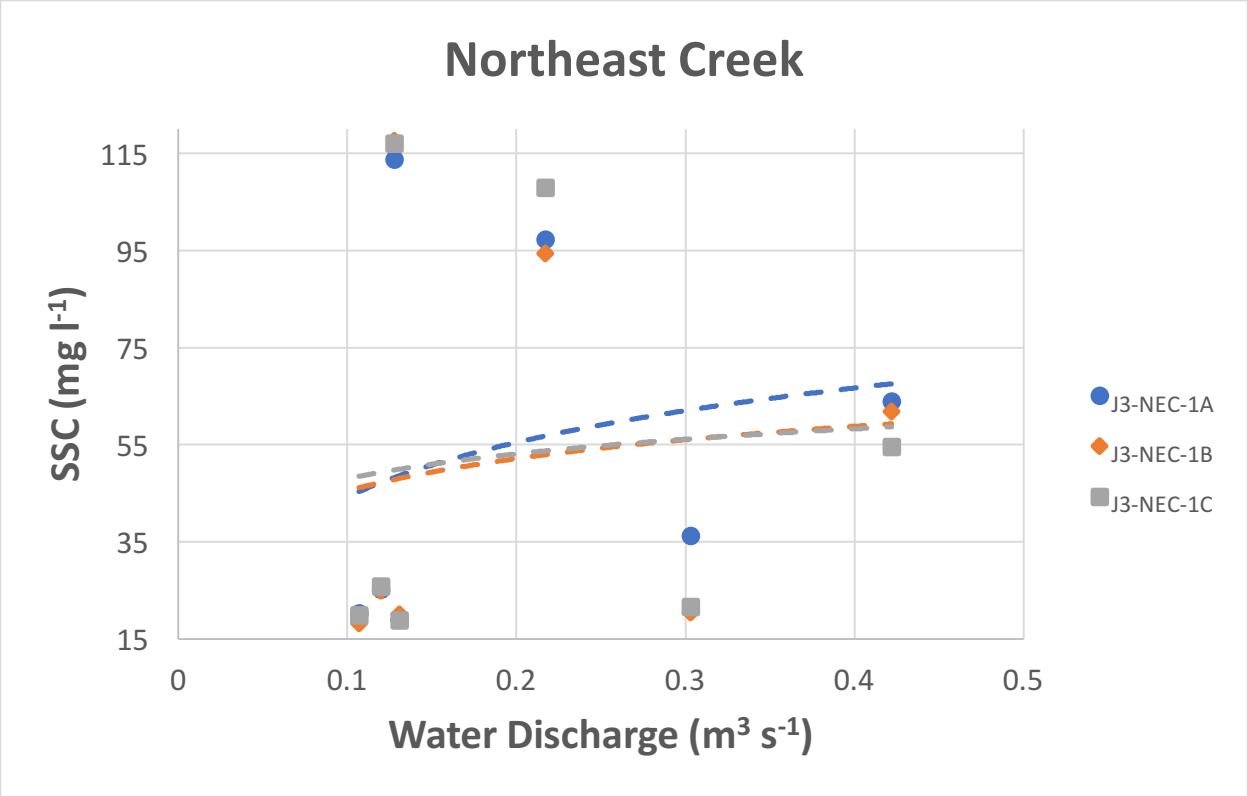

Figure 7. SSC (mg l^{-1}) as a function of Water Discharge rate for Northeast Creek (1/1/17 to 8/11/17). 1A, 1B, and 1C are triplicate samples for each sampling time. Logarithmic trendline is indicated by the dashed lines.

Haw River

The average SSC in the Haw River during this sampling period was 13.42mg l^{-1} with a range from 2.1 mg l^{-1} to 43.9 mg l^{-1} (Figure 8). The mean water discharge rate for the times sampled at this location was 231.3 m^{-3} s^{-1}. This compares to water discharge rates for the entire period which was 37.81 m^3 s^{-1} with 6 event peaks over 100 m^3 s^{-1}. The mean standard deviation for triplicate SSC values for this state is 11% indicating that Haw River waters are relatively homogeneous on small spatial scales during sampling. The logarithmic trendline shown in Figure 8 has an R^2 value of 0.775, which indicates that a simple logarithmic relationship between SSC and Water Discharge rate describes relatively well the relationship for the SSC and Water Discharge rate ranges that have been sampled to date. This relationship is for Haw River water discharges less than 800 m^3 s^{-1}. The full range in water discharge during the 1/1/17 to 8/11/17 period exceeded 1200 m3 s-1 and historically Haw River water discharge rates can exceed 10,000 m^3 s^{-1}, therefore this sampling range does not include the maximum discharge rates that characterize annual flood events. Large flood events can yield disproportionally high SSC values and therefore disproportionally high sediment discharge rates. Special attention should be paid to future high discharge events when rates exceed 1000 m^3 s^{-1}.

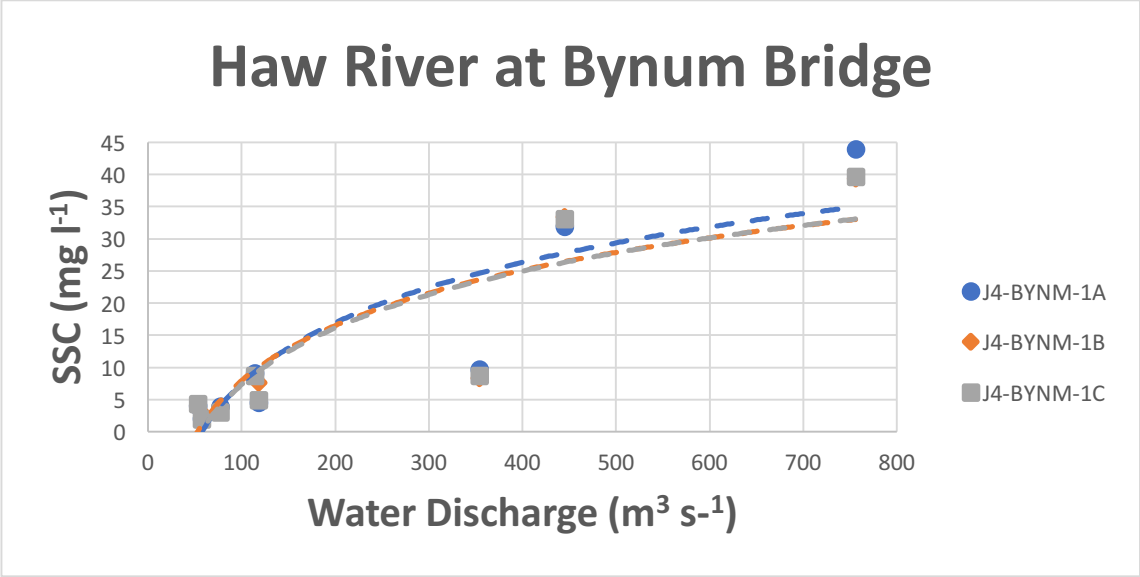

Figure 8. SSC (mg l^{-1}) as a function of Water Discharge rate for the Haw River at Bynum (1/1/17 to 8/11/17). 1A, 1B, and 1C are triplicate samples for each sampling time. Logarithmic trendline is indicated by the dashed lines. R^2 values are approximately 0.775.

Since high temporal resolution water discharge rates are readily available for the Haw River at Bynum, the construction of a rating curve that relates water discharge rate to sediment discharge rate. If the rating curve is well constrained (high R^2 value) then it could be used to predict sediment discharge rates by applying the known water discharge rates (from USGS) to the formula.

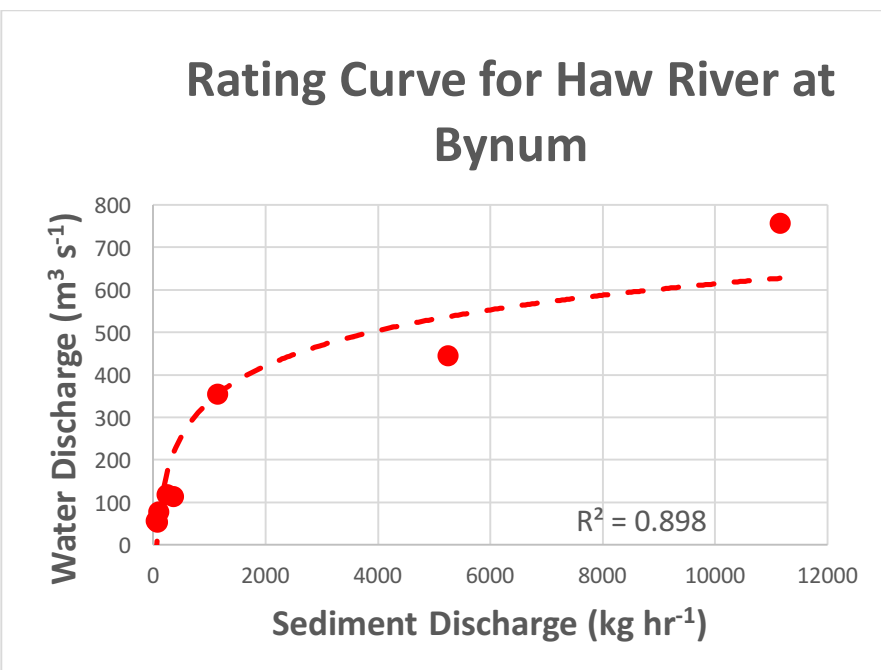

Figure 9. Preliminary rating curve for the Haw River at Bynum (1/1/17 to 8/11/17). Trendline is a logarithmic fit with an R^2 of 0.898.

The rating curve constructed for the Haw River at Bynum with samples collected to date (Figure 9) exhibits a logarithmic fit with an $R^2 = 0.898$. It characterizes a water discharge range from o.6 $m^3 s^{-1}$ to 760 $m^3 s^{-1}$. This is a promising start to building a robust rating curve. However, the full range in water discharge during the 1/1/17 to 8/11/17 period exceeded 1200 $m^3 s^{-1}$ and historically Haw River water discharge rates can exceed 10,000 $m^3 s^{-1}$, therefore this sampling range does not include the maximum discharge rates that characterize annual flood events. Large flood events can yield disproportionally high SSC values and therefore disproportionally high sediment discharge rates. Special attention should be paid to future high discharge events when rates exceed 1000 $m^3 s^{-1}$ to build a more robust rating curve.

Jordan Dam outflow

The path between the location of the Haw River entrance to lake near Bynum to the Dam outflow near Moncure is a relatively short (5 km) and straight one. To examine if there is a relationship between the sediment flux into the lake at Bynum and the sediment flux out of the lake at the Dam outflow, we calculated sediment fluxes (kg min^{-1}) at both locations during each sampling period. Sediment fluxes are calculated by multiplying the SSC (mg l^{-1}) times the water discharge rate ($m^3 s^{-1}$) at each location on the day of sampling. The time between sampling the Haw River input and the Dam output was less than 0.5 hours and so are assumed to be synchronous. Milligrams are converted to kilograms and seconds are converted to minutes to derive a sediment flux (kg min^{-1}). To examine the relationship between the input and out flow at these sites, the ration of Haw River flux to Dam outflow flux are plotted as a function of Haw River water discharge and the time of sampling (Figure 9). For the times sampled to date sediment flux ratios range from 0.7 to 46.9 and Haw River Water Discharge ranges from 52.7 to 756.1 $m^3 l^{-1}$. Within this water discharge range for the Haw, the flux ratio (Haw input to Dam outflow) has a logarithmic relationship with an R^2 of 0.883 (Figure 9). One interpretation of this is that, at low Haw River discharge rates, the mass of sediment entering the lake from the Haw and the mass of sediments exiting the lake via the dam are very similar. As the Haw River discharge increases, sediment inputs far exceed sediment outputs, inferring a large rate of sediment deposition within the lake. This relationship assumes a very short residence time from the input and outflow locations. This preliminary relationship also does not include Haw River discharge rates above 800 $m^3 l^{-1}$.

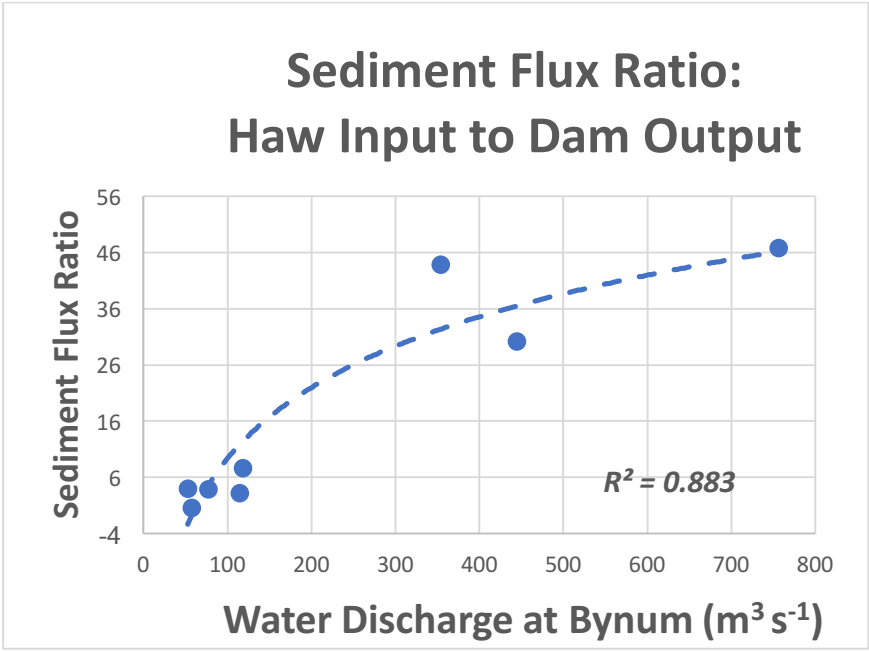

Figure 10. The sediment flux ratio (Haw River Input to Jordan Dam Outlet) as a function of Water Discharge rate for the Haw River at Bynum (1/1/17 to 8/11/17). Trendline is a logarithmic fit with an R^2 of 0.88.

Sediment Discharge Inputs to Jordan Lake

Table 1 reports the sediment flux rates for the creeks and rivers entering Jordan Lake. These sediment fluxes (g hr^{-1}) are calculated by multiplying the SSC (mg l^{-1}) times the water discharge rate (m^3 s^{-1}) at each location on the day of sampling and then converting from second to minutes and milligrams to kilograms.

Table 1. Sediment Flux measurement for Rivers and Creeks entering Jordan Lake

Site	*Morgan Creek*	*New Hope Creek*	*Northeast Creek*	*Haw River*
Mean SSC (mg l^{-1})	5.77	22.66	49.29	13.42
Mean Water Discharge (m^3 s^{-1})	5.04	11.92	2.05	37.81
Sediment Flux (kg min^{-1})	1.75	16.21	6.02	186.00

New Hope Creek has the highest SSC and the middle water discharge rate of the three creeks entering the northern boundary of Jordan Lake and therefore has the largest sediment flux of the northern creeks. Morgan Creek has the lowest SSC and middle water discharge rate of the Northern Creeks. It provides 26% of the combined water discharge of the northern creeks but only 7% of the sediment flux. Northeast Creek has the largest SSC and lowest water discharge rate for all the northern creeks and therefore has the middle sediment flux. Northeast Creek has only 17% of the water discharge of New Hope Creek but over twice the SSC. As a result, Northeast Creek has 37% of the sediment flux of New Hope Creek and 3.5 times the sediment

flux of Morgan Creek (Table 1). The combined sediment flux for the sampling times during this period was 24.01 kg min^{-1}.

Fluxes to Jordan Lake from the northern creeks are small compared to fluxes to the lake from the Haw River. The sediment input flux from the Haw River is 7.7 time the combined sediment fluxes of the northern creeks. The Haw River sediment flux accounts for 89% of the sediment entering Jordan Lake during the times sampled during this period. The water discharge from the Haw river is approximately twice that of the combined northern creeks and accounts for 66% of the water discharge to Jordan Lake.

Overall Accomplishments and Findings (period 1/1/17 to 8/11/17)

These are the first high resolution SSCs and sediment flux rates reported for the northern creeks entering Jordan Lake (Morgan Creek, New Hope Creek and Northeast Creek). This is also the first report comparing synchronous Haw River sediment input fluxes with Jordan Dam sediment output fluxes. These are among the few Haw River suspended sediment data ever reported.

Among the significant findings so far are as follows:

1) Since the beginning of 2017, all freshwater inputs to Jordan lake (Morgan Creek, New Hope Creek, Northeast Creek and the Haw River) have exhibited low water discharge rates punctuated by occasional higher discharge pulses (approximately every 2-3 weeks) with one very large discharge pulse (4/25/17) in all inputs, with an additional large pulse (6/25/17) in the Haw River.

2) In general, suspended sediment concentration (SSC) increases in input creeks and river as water discharge increases. For Morgan Creek and the Haw River this increase closely follows a logarithmic relationship, with SSC rising faster than water discharge rates.

3) Continued data collection in Morgan Creek and the Haw River are needed to formulate a rigorous water-to-sediment discharge rating curve for future predictions of sediment discharge using readily available water discharge data from the USGS. High correlation rating curves for these two input sites show promise, however high flood pulses have thus far not been rigorously sampled on short time scales.

4) For New Hope Creek, the SSC values reported cover only low water-discharge rates (< 1 m^3 s^{-1}) or high water-discharge rates (> 5m^3 s^{-1}) with no data in between. This may be partly responsible for the poor fit to a logarithmic relationship. There is a large range in SSC values within the low water-discharge periods (< 1 m^3 s^{-1}). This may be the result of cycles of sediment trapping and release within the extensive New Hope floodplain during low flows.

5) Northeast Creek has a disproportionately high SSC for it low water-discharge conditions. Observations during sampling indicate that a lot of new construction activity within the Northeast Creek basin and indications of high concentrations of sediments from these areas washing into the creek during storms.

6) A preliminary rating curve for the Haw River was constructed (water discharge rate vs. sediment discharge rate). Since high temporal resolution water discharge rate information is readily online from the USGS, a robust rating curve would enable researchers and managers to predict sediment discharge rates by fitting the water discharge values into the formula derived for the rating curve. The logarithmic rating curve constructed has a trendline fit with an R^2 =0.898. This is a very promising start, however the water discharge values used so far are less than 1000 $m^3 s^{-1}$. The full range in water discharge during the 1/1/17 to 8/11/17 period exceeded 1200 $m^3 s^{-1}$ and historically Haw River water discharge rates can exceed 10,000 $m^3 s^{-1}$, therefore this sampling range does not include the maximum discharge rates that characterize annual flood events.

7) At low Haw River discharge rates, the mass of sediment entering the lake from the Haw and the mass of sediments exiting the lake via the dam are very similar. As the Haw River discharge increases, sediment inputs far exceed sediment outputs, inferring a large rate of sediment deposition within the lake. This relationship assumes a very short residence time from the input and outflow locations. This preliminary relationship also does not include Haw River discharge rates above 1000 $m^3 l^{-1}$.

8) Fluxes to Jordan Lake from the northern creeks are small compared to fluxes to the lake from the Haw River. The sediment input flux from the Haw River is 7.7 time the combined sediment fluxes of the northern creeks. The Haw River sediment flux accounts for 89% of the sediment entering Jordan Lake during the times sampled during this period. The water discharge from the Haw river is approximately twice that of the combined northern creeks and accounts for 66% of the water discharge to Jordan Lake.