The anthropogenic impact of the Tennessee-Tombigbee Waterway: Stream impact of Tibbee Creek due to human disturbances

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Assessing water quality on impaired streams helps determine the magnitude of its impairment and identify the exact location where the impairment is most severe. Advances in remote sensing and geospatial technology have allowed researchers and environmental agencies to assess streams by monitoring large areas. Using both *in situ* measurements and aerial imagery, comparing the differences can provide a more specific view on the streams health. The main goal of this study was to demonstrate the use of aerial imagery in detecting water quality indicators in impaired streams. The Tennessee-Tombigbee Waterway (TTWW) was developed and constructed in the late 1970s through the early 1980s. It has been an economically important factor for northeast Mississippi, but has caused detrimental effects to the adjacent watersheds. One in particular, the Tibbee Watershed, has been directly affected by minimum flow rates of the Stennis Lock and Dam at Columbus Lake on the TTWW. A 3-mile segment of Tibbee Creek in Clay County, Mississippi, an impaired water body listed on the Mississippi 303(d) was selected for this study. Water samples were collected at different points along the river with transects at each point between May and July 2010. The temperature differences and dissolved oxygen levels were measured at each transect. Samples were tested for turbidity, total suspended solid concentration (TSS) and biological oxygen demand (BOD5). High resolution (0.5 m) aerial images that covered the entire study area were obtained in order to capture spatial differences along the channel. Along with the lab testing on a 3 mile section of Tibbee Creek, water quality parameters have been used along with historical flow rates to link the waterway to the impairment of the watershed, including Tibbee Creek. Due to minimum flows and levels (MFLs) during the summer months of Columbus Lake, Tibbee Creek has suffered from heavy sedimentation loads. The heavy sedimentation load is probably caused by excessive stream heights in the low periods during the summer months. Preliminary analysis shows that turbidity readings were higher in the downstream segment of the river during the early part of testing and toward the end of testing. This was not the case during the middle of the summer and after rain events. Relationships between spectral bands and observed water quality parameters were used to estimate the water quality parameters at different locations of Tibbee Creek. The results of this research are expected to assist in the development of near real-time maps for the evaluation and monitoring of water quality of streams and rivers, providing large spatial coverage resulting in significant cost-savings over conventional *in situ* water quality.

Key words: Water quality, water sediment, remote sensing

Literature Review

The following literature review is a culmination of sources that helped in determining the wanted approach to the abstract. Each source helped provide a better understanding of geospatial technologies and the usage of remote sensing in the field of water quality parameters and assessment.

Dekker et al. (2001) used methodology developed from Dekker et al. (1998) to estimate total suspended matter (TSM) concentrations in the southern Frisian Lakes in the Netherlands. The study presents an application of satellite based remote sensing and *in situ* data. It also takes into account a one-dimensional water quality model from Dekker et al. (1998). The Frisian lake system consist of primary shallow lakes, 1-2 meters (m) in depth, therefore surface TSM concentrations represent the entire depth. The geospatial data was collected from Landsat 5 and SPOT-HRV. Using the relationship between the irradiance reflectance spectra (IRS) in comparison with the satellites' bands, a method was developed to link a specific reflectance to *in situ* tested TSM concentrations. The geospatial data from Landsat 5 provided an analytical relationship between each of its bands. The higher the TSM concentration was, the higher the IRS was. Using the geospatial data referenced above, TSM concentration maps were created with an algorithmic representation of the sediment compared to the IRS. The research does provide an outlook to analytical optical modeling based on *in situ* and geospatial data. The research proves to be usable with different geospatial data, but proves to be less sensitive for TSM concentrations above 40 milligrams per liter (Dekker et al., 2001).

Doxaran et al. (2001) used an experimental methodology to interpret "color"(s) seen from geospatial data provided by the SPOT-HRV satellite over the Gironde estuary in France. A relationship was established between the suspended particulate matter (SPM) and the remotely sensed reflectance. In this experiment, the satellite data was corrected for atmospheric interference and effects such as false readings due to overexposure and/or clouds. The Gironde estuary was tested due to its SPM concentrations exceeding in some cases 2 grams per liter (g/l). Unlike previous research, Doxaran et al. (2001) used both geospatial data from SPOT and *in situ* measurements from a spectroradiometer. The spectroradiometer was used to measure upwelling radiance (reflectance from the water surface), downwelling radiance (reflectance from the water surface through a spectralon plate), and sky radiance. Sky radiance was tested to eliminate the error caused from the geospatial data from SPOT. The results found that saturation of the wavelength bands occurred at SPM concentrations above 250 mg/l. The bands were poorly correlated above 500 mg/l. Below this threshold, the bands increased properly from green to red and near infrared (NIR) with the increase of SPM concentration. It was also presented that the skylight reflections did not significantly affect the measurements and error from SPOT-HRV. The results did provide information about sedimentary flow from the Gironde estuary by providing excellent current markers. This further proved that using geospatial data to identify sedimentation loads can help locate maximum turbidity and its causes (Doxaran et al., 2001).

Karabulut & Ceylan (2005) used close range remote sensing to determine the effects of increased suspended sediment concentration (SSC) containing different levels of organic matter on algal spectral patterns. A 65 liter (l), 0.4 meter (m) deep tank made of black polyethylene was used for the experiment's water source. The tank was chosen black to eliminate any false internal reflectance. A spectroradiometer was used to obtain the radiant measurements from the water. The spectroradiometer was compared to any type of geospatial spectroradiometer, such as ESTAR; therefore, the research cited the usage of geospatial equipment. The results determined that most geospatial equipment could measure spectral reflectance from 350 nanometers (nm) to 1100 nm but only 400 nm to 900 nm was needed to determine spectral reflectance from turbid algae laden water. The research proved that as the suspended concentration increased, the red and near infrared (NIR) bands represented no correlation in peaking. Karabulut & Ceylan (2005) did cite that with less SSC more accurate results with the different bands were noticed.

Overall, the research analyzed 10 different levels of suspended sediment concentration and concluded that no matter the concentration the spectral patterns caused by algae will be seen. The only ability that geospatial data can provide is, as SSC increased, so did spectral reflectance (Karabulut & Ceylan, 2005).

Ritchie et al. (2003) incorporated former research conducted on suspended sediment, algae/chlorophyll, and plant growth. According to this research, substances in surface water changed the backscattering characteristics of said surface water. Using collected geospatial data, Ritchie et al. (2003) provides a relationship between reflectance and band wavelength, affected by the suspended sediment concentration (SSC). Landsat data provided the necessary geospatial data to interpret the backscattering effects caused by suspended sediment and other surface substances. The relationship between the reflectance from the backscattering and the SSC could not form a curvilinear relationship to provide accurate interpretation at higher values, due to the suspended sediment concentration's likelihood to saturate as its value peaked. In the lower ranges of suspended sediment, the relationship between the concentration and reflectance was linear. The saturation of the wavelength bands, caused at higher values was blamed on the current spatial resolution of satellite data. Ritchie and Schiebe (2000) claimed that as new satellites go into orbit, higher resolution will lead to better spectral data and more accurate assessment of the suspended sediments. The geospatial data collected from sources such as Landsat were inconclusive at higher suspended sediment concentrations (Ritchie et al., 2003).

Schmugge et al. (2002) accomplished large area remote sensing through visible and near-infrared data (NIR) to help estimate hydrometeorlogical fluxes such as evapotranspiration and runoff due to snowmelt. Many of hydrometeorlogical events are estimated from collected data (previous events) and Doppler radar. The goal of this research was to use standard variables (*in situ* testing and collected data) and remote sensing data to better estimate hydrometeorlogical events and minimize the dependency on the usage of Doppler radar in predicting events. The research determined such parameters as near-surface soil moisture and snow cover/water equivalency. The geospatial data was collected from multiple sources. ESTAR microwave radiometer with a 200 meters (m) resolution was used to collect data for soil moisture. ASTER thermal emission reflectance radiometer with a 90 meter (m) resolution was used to collected surface temperatures. The data sources were all used for GIS analysis. Many of the images collected were incorporated into watershed analysis in ArcGIS to predict the possible magnitude of the hydrometeorlogical events. By creating a multifaceted remote sensing approach, the limited capabilities provided by algorithms and existing remote sensing technologies is shadowed. Using these referenced geospatial data together provided the authors with valid data to prove the importance of multi-frequency data. The incorporation of multi-frequency data eliminates possible error (Schmugge et al., 2002).

The referenced information explains the current studies on using remote sensing and geospatial spectral values to determine water quality parameters. The research was used to study and better understand the field and its current research. Using it, the research helped provide a background to this abstract. The basis of the referenced abstract uses the idea of spectral reflectance and aerial remote sensing. The conducted research provides information about the remote sensing and geospatial spectral field that was directly connected to the abstract.

Introduction

Purpose

The purpose of this graduate project is to determine if the impoundment of Columbus Lake by the John C. Stennis Lock and Dam (anthropogenic impacts) has affected the ecological and environmental integrity of the watersheds surrounding the Tennessee Tombigbee Waterway. The watershed under consideration for this project was the Tibbee Watershed, containing Tibbee Creek. Tibbee Creek was used due to its location, ease of testing, heavy sedimentation load, and its placement on

Mississippi's 303 (d) list of impaired waterbodies, created by the Mississippi Department of Environmental Quality (MDEQ, 2010). Using gauge readings and water quality parameter testing done over the spring, summer, and fall of 2010, a comparison was created to show that minimum flow conditions are present at the John C. Stennis Lock and Dam (Irvin et al., 2010). It is assumed that the minimum flow conditions present have degraded the water quality in the surrounding watersheds, in particularly, Tibbee Creek. By preventing natural flow, the lock and dam impounding Columbus Lake affects headwaters by causing backflow during the summer months (Martin, 2010). The backflow does not allow the riverbed to dry out from winter flooding. This causes bank sloughing, which leads to heavy sedimentation loads (Thoma et al, 2006). The problem that was presented during this study was a way to find and provide past water quality parameters, since all of the current knowledge on Tibbee Creek had evolved since the late 1990s and 2000s, with its first placement on the Mississippi 303 (d) list of impaired streams in 1998. Because of the lack of water quality data, the research had to provide a plausible way of estimating water quality parameters prior to the construction of the lock and dam. The method must have proved to provide minimal error and be used at any point on Tibbee Creek.

General Information

The research project involved the study of the ecological and environmental effects of the Tennessee Tombigbee Waterway (TTWW). The plan for the TTWW came about during the Grant administration in 1874 to be used for the Southern Restoration, but was commercially impractical at the time. The proposed waterway was investigated for over 70 years before getting congressional approval in 1946. Even with its approval, funding did not come available until 1968 under the Johnson administration. The construction of the waterway began in 1974 almost 100 years later with current building tactics but from the original idea (Mississippi, 2007). The waterway was developed by the United State Army Corps of Engineers to serve as an alternate route to the Gulf of Mexico (USACE, 2010). Figures 1 and 2 represent the path of the waterway.

The TTWW's total cost was estimated to be around 2 billion dollars in 1985, accounting for inflation, respectively. The project included 234 miles of river and 27 miles of 300 feet wide and 9 feet deep navigable channel. 5 dams and 10 locks made up for the elevation drop of 341 feet. The project was the largest Earth moving project in the world totaling 310 million cubic yards. The TTWW project was the first water project designed and built under the National Environmental Policy Act (NEPA) of 1969 (Mississippi, 2007; USACE, 2010). Of the 5 dams and 10 locks on the TTWW, the John C. Stennis Lock and Dam impounds the largest area, known as Columbus Lake. The Stennis Lock and Dam shown in Figure 3 is a 5 gate dam, 27 foot lift lock that became operation in 1982 (Mississippi, 2007).

Columbus Lake, impounded by the Stennis Lock and Dam is the largest of the ten impoundments, covering over 8900 acres and approximately 23 miles long (Mississippi, 2007). The lake is fed by the waterway and four surrounding watersheds. Of the four watershed, two contain creeks on the 303(d) list referenced above (MDEQ, 2010) These water sheds, the Upper Tombigbee (03160101), Tibbee (03160104), Town (03160102), and Buttahatchee (03160103) Watersheds, along with the major creeks in the watershed are represented in bold in figure 4 (ADEM, 2008; McKee and McAnally, 2008). The Tibbee watershed was chosen for the project because Tibbee Creek has historically suffered from ecological and environmental impairment. The Tibbee Watershed, seen in figure 5, is a 715,096 acre watershed west of the TTWW covering portions of seven counties in Mississippi. Chickasaw, Clay, Lowndes, Monroe, Oktibbeha, Pontotoc, and Webster counties make up the area of the Tibbee Watershed. The dominate land use in the watershed is for pasture lands. It contains 847 miles of major rivers, 440 miles of the referenced rivers are on the 303 (d) list (NRCS, 2009). Tibbee Creek was placed on the 303 (d) list of impaired streams in 1998 and has been on the list since. It has been placed on the list for both fecal coliform and sedimentation loads (MDEQ, 2010).

Approach

Sample Area and Lab Testing

During the spring, summer, and fall of 2010, *in situ* testing and sample collection was conducted on a 3 mile section of Tibbee Creek. Ten points were chosen at the beginning of the project and marked by a Global Positioning System (GPS) unit. During each sampling time, 5 sub points at each of the ten points were selected at random, making up a transect for each point. The random sub points were marked by a GPS unit for map interpretation represented in figure 6. The red dots are sample points and the green dot is the NOAA gauging station.

At each individual sub point, *in situ* testing was conducted. The testing consisted of temperature and dissolved oxygen (D.O.) content of the creek. Along with the *in situ* testing, a total of 50 samples were collected on the creek during each sampling period. Each sample was taken 1 meter below the water surface and was approximately 250 milliliters in size. The samples were tested in lab for turbidity and total suspended solids or sediment (TSS) content. Turbidity was tested using a scattered light machine, responding in Nephelometric Turbidity Units (NTUs) and TSS content was tested using the Environmental Protection Agency's, Standard Methods and Practices of Suspended Solids (ESS Method 340.2). The standard methods consist of feeding the water sample through a Buchner Funnel onto pre weighed filter paper. The filter paper with the solids was weighed after being heated to dry (EPA, 1993). The TSS was presented in units of milligrams per liter (mg/l). An estimated value for each, turbidity and TSS, was predicted to be anywhere in the range of 0 to 200, respectively. After each test was run, the found values were attached to it proper GPS coordinate to allow map querying (Irvin et al., 2010).

Flow rates at lock and dam

The flow rates before the installation of the John C. Stennis Lock and Dam were collected by the gauges located at the dam. The gauges were used to prove that a minimum flow condition existed at the dam. Provided by the United State Geological Survey, the discharge gauge, which ran from 1900 up until September of 2009, is seen in figure 7, representing 1965 to 1985. The figure is shown with an insert citing the changes in flow conditions due to the lack of presence of the dam. The insert shows the levels not falling below 300 cubic feet per second (CFS) prior to 1982, the installation of the lock and dam (USACE, 2010; USGS, 2010).

Flow rates after the lock and dam was installed and operational show the possibility of minimum flow conditions (USACE, 2008). The conditions stay below 300 CFS from 1981 to the last recording date in 2009 in most years during the summer months (USGS, 2010). Represented in figure 8 is the same discharge figure shown with an insert citing the changes in flow conditions due to the operation date of the dam. The insert shows the levels falling below those prior to dam becoming operational starting in 1982 (the operation starting date of the Stennis lock and dam). This shows the proof of the minimum flow condition. (USACE, 2010; USGS, 2010).

The proof of minimum flow conditions at the Stennis Lock and Dam is one of the purposes of this project. The provided data has succeeded in showing the presence of such a condition. While minimum flow conditions are usually assumed to be ecologically and environmentally detrimental, no water quality parameters can be assumed or proven with just minimum flow levels (Wetzel, 2001). To prove the hypothesis for the remainder of this project, that the TTWW has directly impaired/impairs its surrounding watersheds, the water samples taken from Tibbee Creek were analyzed and compared to one another. The problem that presented an issue to the project was the lack of water quality data from Tibbee Creek prior to the 1990s (USACE, 2008; Wetzel, 2001).

Determining water quality parameters prior to 1982

With no water quality data prior to the 1990s and no assessments or issues addressed until the 2000s, water quality parameters for Tibbee Creek prior to the installation of the Stennis Lock and Dam were nonexistent for this project.

Remote sensing is defined as the acquisition of information by the use of recording or real-time sensing devices that are wireless. Since there was no previous data to work with, remote sensing was the only presentable option. This study used aerial imagery to determine water quality parameters at locations pinpointed on Tibbee Creek (Doxaran et al, 2001; Ritchie et al, 2003). The geospatial data portion of this study focused on the PAR (visible light) spectral band using red, green, and blue values and comparing those values with the tested turbidity and TSS concentration values (Dekker et al. 2001; Karabulut et al. 2005). A relationship was developed between the two by having both the red, green, and blue (RGB) and pinpointed GPS locations that provided the turbidity and TSS concentration values.

New aerial imagery had been taken during the spring, summer, and fall of 2010, for the graduate project. The imagery provides a 0.5 meter resolution (1.5 feet). The imagery was interpreted by establishing a 3 x 3 pixel grid around each point. The RGB values were determined and averaged together to obtain one RGB value per point. This value was compared to the tested values from samples taken the same day as the imagery. The image breakdown is seen in figure 9-11 (Irvin et al., 2010).

The collection and interpretation of old imagery was a challenge for the project. Most imagery prior to the late 1990s had poor resolution and could not be used for this type of analysis.

The National High Altitude Photography Program (NHAP) with 2 meters in resolution (6 feet) was used for the project. NHAP was a program that took aerial photography from 1980 to 1987 in efforts to minimize duplicate photography throughout the United States government. The photography was taken 40,000 feet above mean terrain elevation. It provided both black-and-white images and color-infrared images. The NHAP imagery was interpreted the same way as the new imagery, as seen in figures 12-14 (USGS, 1980). The GPS point on the pixel grid was one collected during the 2010 data collection and was synced to imagery via latitudal and logitudal data. The older imagery did present itself as dark, therefore the values may present some inconclusive error, which should be accounted for by decreasing the shadows (adding points to the RGB values).

To properly use and compare new aerial imagery with the old imagery a control was considered. Tibbee Lake, a healthy water body north of Tibbee Creek was used as the "minimum turbidity and TSS concentration" source for the experiment. Tibbee Lake had a recorded turbidity value of 6.91 NTUs and a TSS concentration value of less than 4 mg/l (Irvin et al., 2010). The lake was sampled just as the river was with the intention that it was going to be low turbidity and TSS concentration values. The interpretation of this imagery can be seen in figures 15-17 (Irvin et al, 2010).

Results

Turbidity and TSS Results

For the results, data from a transect, selected as point 3 ran on May 18, 2010, was the only interpreted data. The reasoning for this was based on time constraint and current scale of this project. Figure 18 represents all of the values collected from sampling May 18, 2010. The data included both turbidity and TSS concentration values for 10 transects including the standard deviation between each sub point. The values at transect 3 from May 18, 2010 were determined to be 165 NTUs for turbidity and 141 mg/l for TSS concentration. The turbidity values are all in NTUs and the TSS concentration values are all in mg/l, respectively (Irvin et al., 2010)

The values were seen to be substantially lower on transects 6 through 10, which were upstream points. The reasoning for this is still not fully understood, but could be linked to high flow rates which caused greater mixing. The river could have been flowing fast enough that the majority of sediment was found downstream. It could have also been caused by less sinuosity downstream which has a direct effect on flow rate and mixing (Wetzel, 2001).

Comparison of Tested Results to RGB Values

The individual comparison of the RGB values to the tested lab values of turbidity and TSS concentration was the final study for this project. If the values could be interpolated from the old imagery, it would be possible to determine within a marginal error if Tibbee Creek was free from ecological and environmental impairment prior to the development and operations of the Stennis Lock and Dam. A great deal was determined about the impairment of the creek by these values. Typically, higher red values represent high sedimentation content, and vice versa (Dekker, 2001). To show a stark difference, the RGB values of the new imagery and the Turbidity/TSS concentration values were compared to the similar values found from Tibbee Lake (the experiment control).

The result for the new imagery was an average RGB value of: R 152 G 142 B 154. On the imagery it was seen as a brownish grey tone. The water quality parameter values that correlate with this RGB value was 165 NTUs for turbidity and 141 mg/l of TSS concentration. This was in comparison with the Tibbee Lake value which was: R 84 G 85 B 123, 6.91 NTUs for turbidity, and less than 4 mg/l TSS concentration. The water in Tibbee Lake appeared blue (Irvin et al., 2010).

The old imagery average value was determined to be: R 49 G 70 B 106. Estimating for any error in the aerial photography, 20 points was added to each of all three bands to lighten the image. The corrected value was: R 69 G 90 B 126. After correction and interpolation, the values of the old imagery were found to be significantly lower than the new imagery (Irvin et al., 2010). This proves that prior to the installation of the John C. Stennis Lock and Dam, Tibbee Creek was not under ecological and environmental stress. With this connection and the minimum flow rates referenced above, it further proved the likelihood that the TTWW was the culprit for the damaged watersheds. Figures 19-21 show a comparison between the new imagery values and the old imagery values with the control values in the middle (figure 20) (Irvin et al., 2010; USGS, 1980).

Conclusion

With all of the data presented above, was the original question answered? Did the provided data prove that the Tennessee Tombigbee Waterway has caused watershed impairment? With the data and the interpretation of the aerial imagery, the outcome was yes. There was proof that the Stennis Lock and Dam has low flow rates caused by minimum flow condtions. Minimum flow rates can be a sign for impairment either downstream, or in the case of Tibbee Creeek, upstream; therefore the minimum flow conditions at Stennis Lock and Dam have probably caused ecological and environmental impairment upstream in Tibbee Creek (Martin, 2010; Wetzel, 2001). The discharge graph showed the drop in discharge levels during the summer months after the installation and operation of the dam (USGS, 2010; Wetzel, 2001). Prior to the installation and operation, it was seen that the flow rates never dropped below a certain point (300 CFS) except during those drought years (USGS, 2010).

It was also been proven that the tested turbidity and TSS concentration in Tibbee Creek were 23 to 35 times above the amount seen in Tibbee Lake and possibly that of Tibbee Creek prior to the Stennis Lock and Dam (Irvin et al., 2010). Even with a large assumed error, the old imagery supported the hypothesis of lower turbidity and TSS concentrations prior to construction (USGS, 1980).

With the hypothesis proven, the research for this project will be ongoing. All of the points will be averaged and compared, not just one. More sampling and testing will be conducted in particularly during the early winter and early spring months due to extreme mixing during these times (Doxaran et al., 2005; Ritchie et al., 2003).

The size of the project will also increase in scale. Expanding the sampling area past the 3 mile segment of Tibbee Creek will show a better lineral progression of sediment loads as Tibbee Creek runs into Town Creek, another impaired stream, and then into Columbus Lake (Irvin et al., 2010).

The project was kept small due to time and data restrictions, but in the case of more data, it can be assumed that the project will still have positive outcomes. The numbers and supporting data were too strong to not provide similar results, no matter the size of the experiment. The sampled data and lab test were never spotted or lack there of; therefore gross error was assumed to be eliminated.

Overall, the project was successful for its size. In future research, better imagery will possibly be analyzed. Near infrared (NIR) imagery will be considered, especially if the research involves extremely heavy sediment loads with plant materials mixed.

In conclusion, it was assumed with the data provided that the Tennessee Tombigbee Waterway has ecologically and environmentally impaired surrounding watersheds and those watersheds' waterbodies, including the tested area of Tibbee Creek, in Tibbee Mississippi. The anthropogenic impact has been caused by the low flow conditions present at the John C Stennis Lock and Dam.

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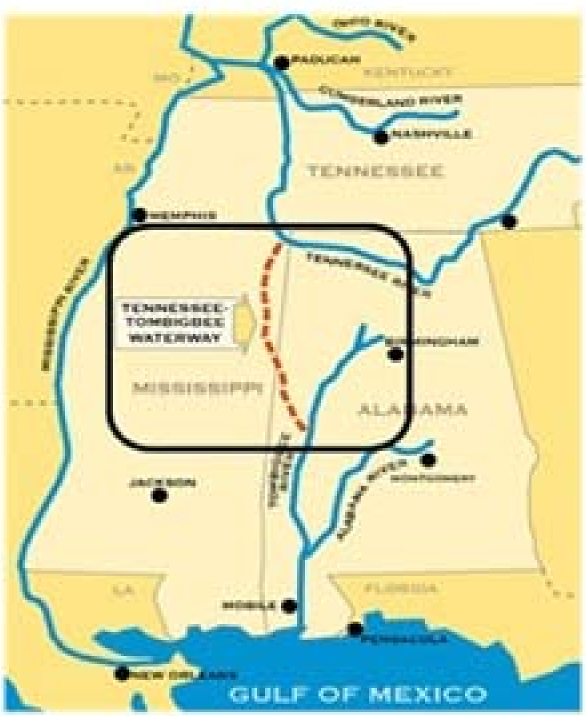
References

1. Alabama Department of Environmental Management, (2002). TMDL for Tombigbee River (Aliceville Reservoir) (AL/03160106-0402-102). Pickens, AL: ADEM.
2. Dekker, A.G., Vos, R.J., & Peters, S.W.M. (2001). Comparison of remote sensing data, model results and *in situ* data for total suspended matter (TSM) in the southern Frisian lakes. The Science of the Total Environment, (268), 197-214.
3. Doxaran, David, Froidefond, Jean-Marie, Lavender, Samantha, & Castaing, Patrice. (2001). Spectral signature of highly turbid waters application with spot data to quantify suspended particulate matter concentrations. Remote Sensing of Environment, (81), 149-161.
4. Environmental Protection Agency. (1993). Determination of Turbidity by Nephelometry. Environmental Monitoring Systems Laboratory. Office of Research and Development, Cincinnati, Ohio. (2): 1-10.
5. Google Inc. (2010). Google Maps. Retrieved from: http://www.maps.google.com
6. Irvin, Shane A., Joel O. Paz, Mary Love Tagert, Prem Parajuli, & Thomas Cathcart. (2010). Detecting water quality parameters in Tibbee Creek, Mississippi using aerial imagery. SRI 2010. Mississippi State University. Abstract.
7. Karabulut, Murat, & Ceylan, Nihal. (2005). The spectral reflectance responses of water with different levels of suspended sediment in the presence of algae. Turkish Journal of Engineering Environmental Science, (29), 351-360.
8. Maris (Mississippi Automated Resource Information Services). (2007). Raster Image Downloads. Retrieved from: http://www.maris.state.ms.us/HTM/DownloadData/RasterImages.html
9. Martin, James. (2010). Hydro-Environmental Analysis. Proceedings of CE 8573 Mississippi State, MS: Mississippi State University.
10. McKee, Jared K., & McAnally, William H. (2008). Water Budget of Tombigbee River -Tenn-Tom Waterway from Headwaters to Junction with Black Warrior River. Civil and Environmental Engineering, Mississippi State University, Mississippi State, Mississippi.
11. Mississippi Department of Environmental Quality. (2010). Mississippi 2010 Section 303 (D) List of Impaired Water Bodies. Commission on Environmental Quality. DRAFT. 18 March: 1-34.
12. Natural Resource Conservation Service. (2010). Tibbee Creek Watershed Conservation Security Program. Watershed Protection and Flood Prevention. Retrieved 10 September, 2010 from: http://www.ms.nrcs.usda.gov/programs/Tibbee.html
13. Ritchie, Jerry C., Zimba, Paul V., & Everitt, James H. (2003). Remote sensing techniques to assess water quality. Photogrammetric Engineering & Remote Sensing, 69(6), 695-704.

14. Schmugge, Thomas J., Kustas, William P., Ritchie, Jerry C., Jackson, Thomas J., & Rango, Al. (2002). Remote sensing in hydrology. Advances in Water Resources, (25), 1367-1385
15. Thoma, D.P, S.C. Gupta, & M.E. Bauer. (2006). Evaluation of Bank Erosion Inputs to the Blue Earth River with Airborne Laser Scanners. WRC Research 2001. 1-6.
16. Mississippi, State of. (2007). The Tennessee Tombigbee Waterway Development Authority. Retrieved from: http://www.tenntom.org/about/ttwconstruction.html
17. U.S. Army Corps of Engineers (USACE), U.S. Army Engineer District, Little Rock. (2008). Environmental Impact Statement. White River Basin, Arkansas, Minimum Flows. Little Rock, U.S. Army Corps of Engineers: 128.
18. U.S. Army Corps of Engineers (USACE), U.S. Army Engineer District, Mobile. (2010). Tennessee-Tombigbee Waterway, Mobile, AL: Retrieved from http://tenntom.sam.usace.army.mil/default.html.
19. U.S. Geological Survey (USGS). (1980). National High Altitude Photography Program (NHAP). Earth Resources Observation and Science (EROS) Center: Retrieved from: http://dds.cr.usgs.gov/pub/data/phoenix/nhap/5MYL/5MYL08032/5MYL08032_013.tif
20. U.S. Geological Survey (USGS), In cooperation with U.S. Army Engineer District, Mobile. (2010). Provisional Data from Tombigbee River at John C. Stennis L&D : Retrieved from http://waterdata.usgs.gov/nwis/nwisman/?site_no=02441390&agency_cd=USGS
21. Wetzel, Robert G. (2001). Limnology: Lake and River Ecosystem. San Diego, CA: Academic Press.



Figures 1 and 2. Waterway and surrounding rivers (Mississippi, 2007; USACE, 2010)

Figure 3. Stennis Lock and Dam with Columbus Lake (USACE, 2010).

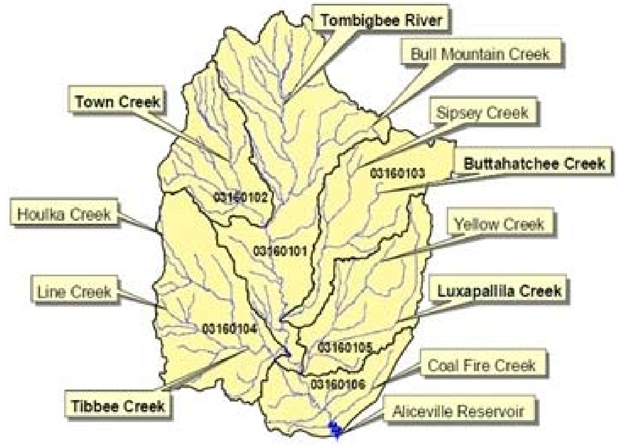


Figure 4. TTWW surrounding watersheds (ADEM, 2008).

Figure 5. Tibbee Creek Watershed (NRCS, 2010).

Figure 6. 3 mile segment of Tibbee Creek with sample points (Irvin et al., 2010)

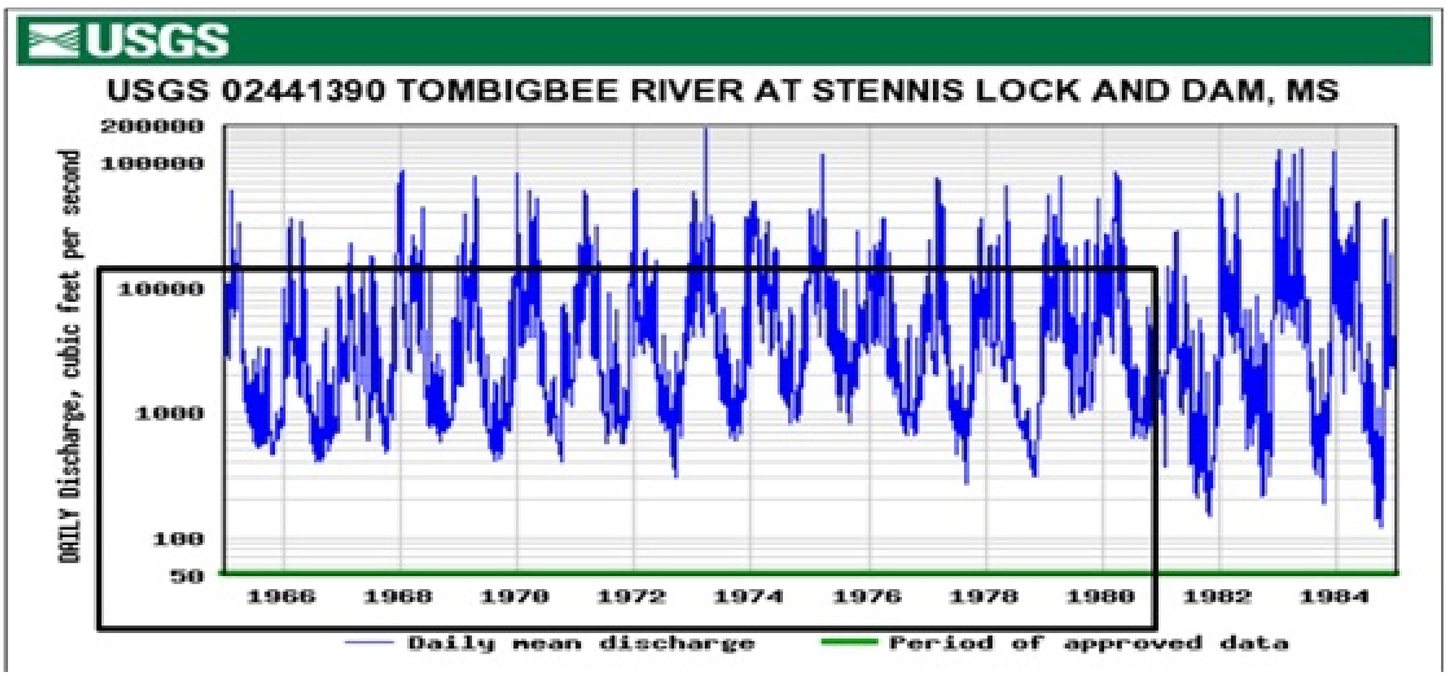


Figure 7. Discharge gauge 1965-1985. Insert shows gauge levels up to 1981 (USGS, 2010).

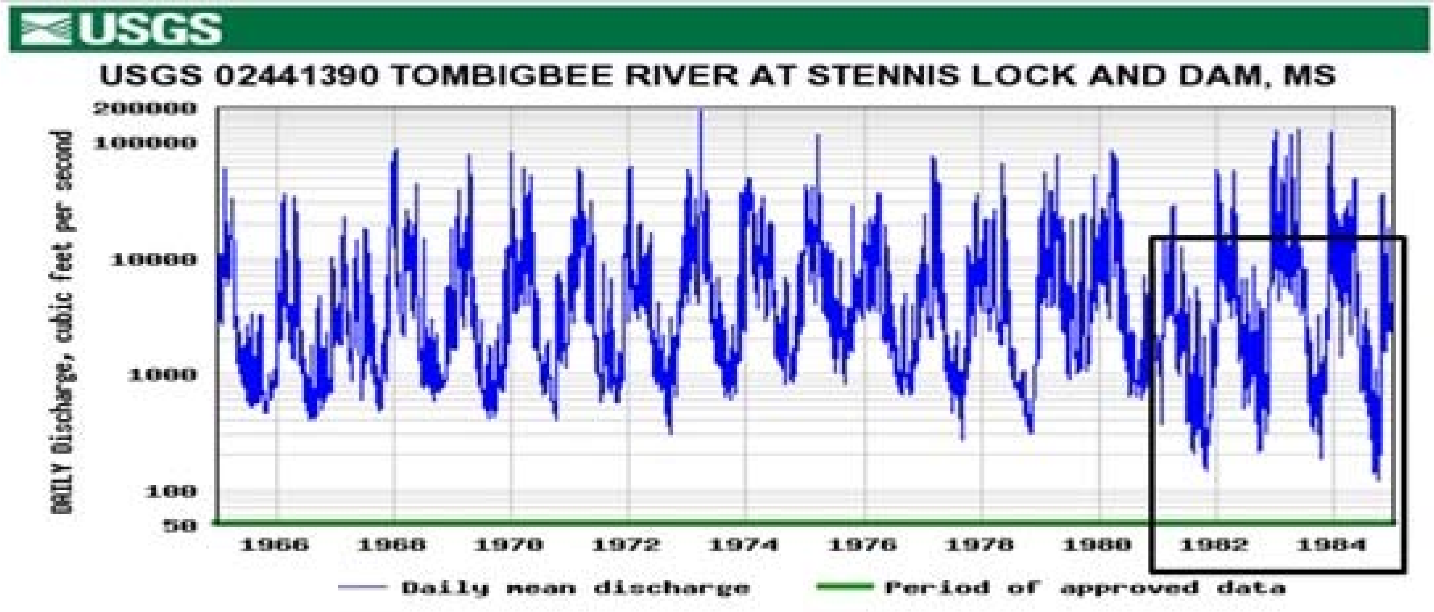
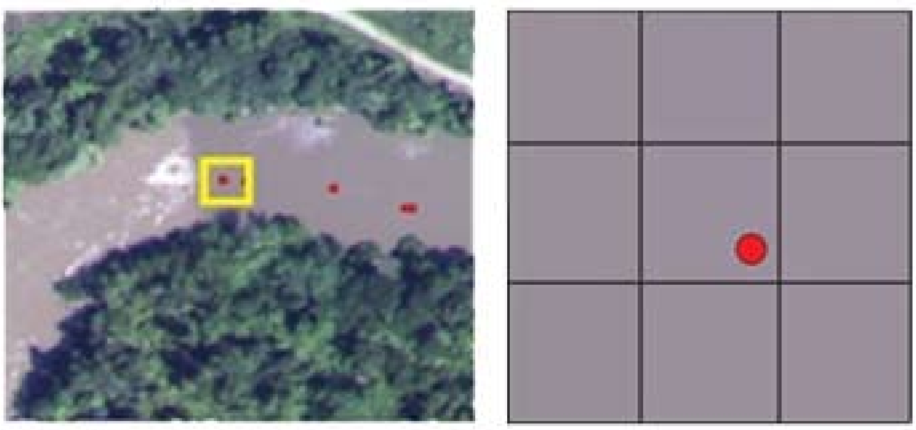


Figure 8. Discharge gauge 1965-1985. Insert shows gauge levels after 1981 (USGS, 2010).

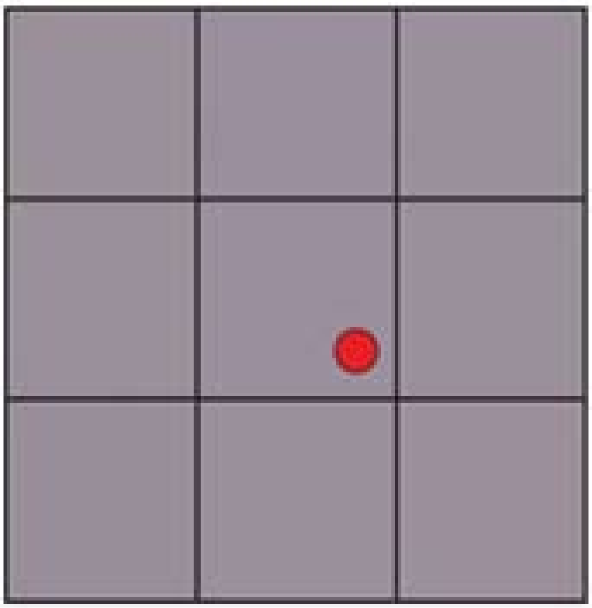


R 152 G 142 B 153	R 151 G 141 B 154	R 151 G 141 B 154
R 153 G 141 B 155	R 153 G 141 B 155	R 154 G 142 B 155
R 152 G 142 B 154	R 152 G 142 B 154	R 153 G 142 B 154

Figures 9-11. The interpretation of the “new” imagery (Irvin et al., 2010).

R 48 G 74 B 105	R 48 G 71 B 105	R 47 G 72 B 105
R 48 G 66 B 103	R 49 G 70 B 107	R 49 G 70 B 107
R 49 G 63 B 98	R 50 G 75 B 109	R 53 G 75 B 111

Figures 12-14. The interpretation of the “old” imagery (Irvin et al., 2010; USGS, 1980).



R 83 G 87 B 123	R 85 G 82 B 125	R 85 G 86 B 125
R 83 G 84 B 123	R 84 G 84 B 122	R 84 G 85 B 123
R 83 G 85 B 124	R 83 G 84 B 121	R 85 G 86 B 123

Figures 15-17. The interpretation of the "controlled" imagery (Irvin et al., 2010).

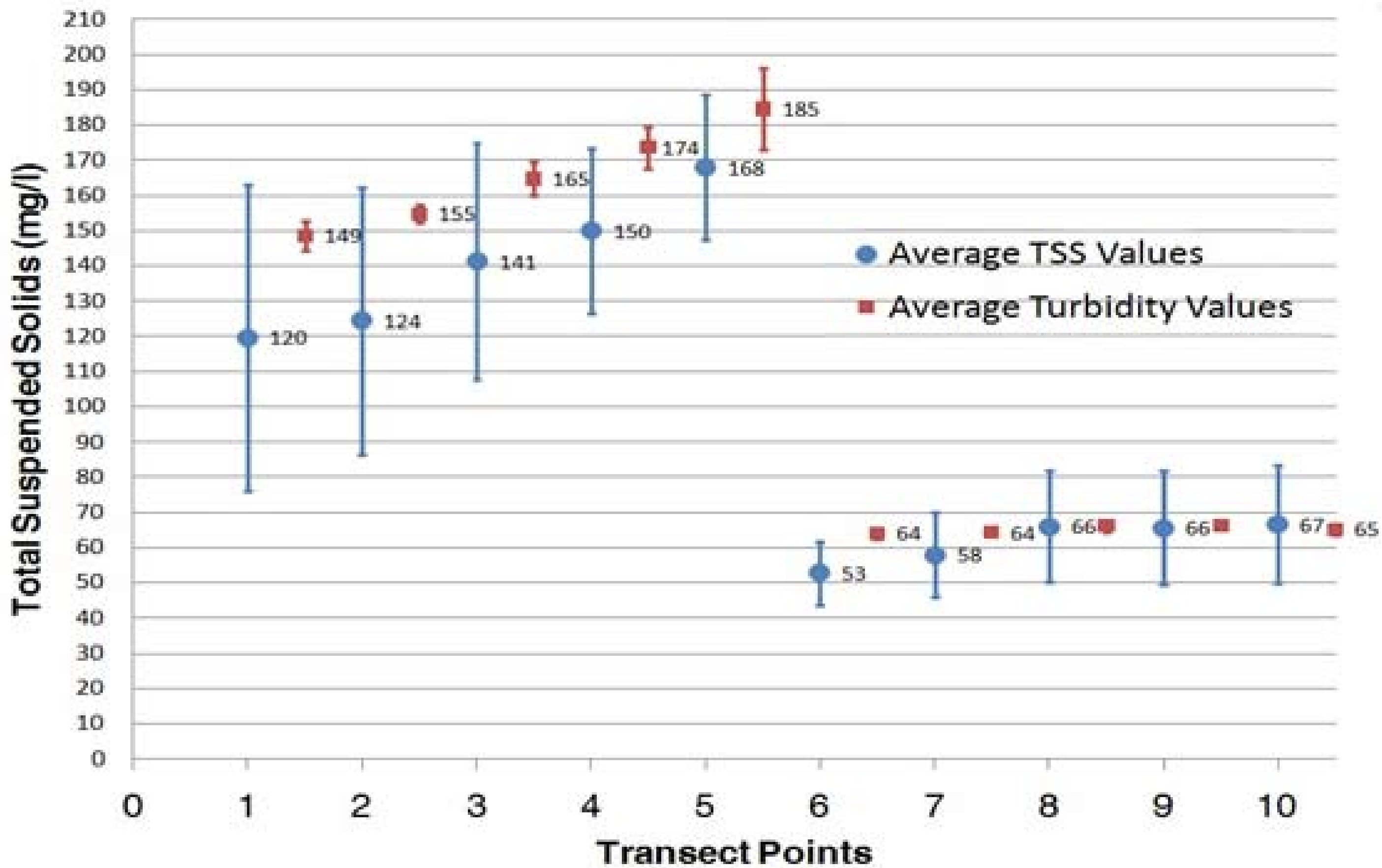
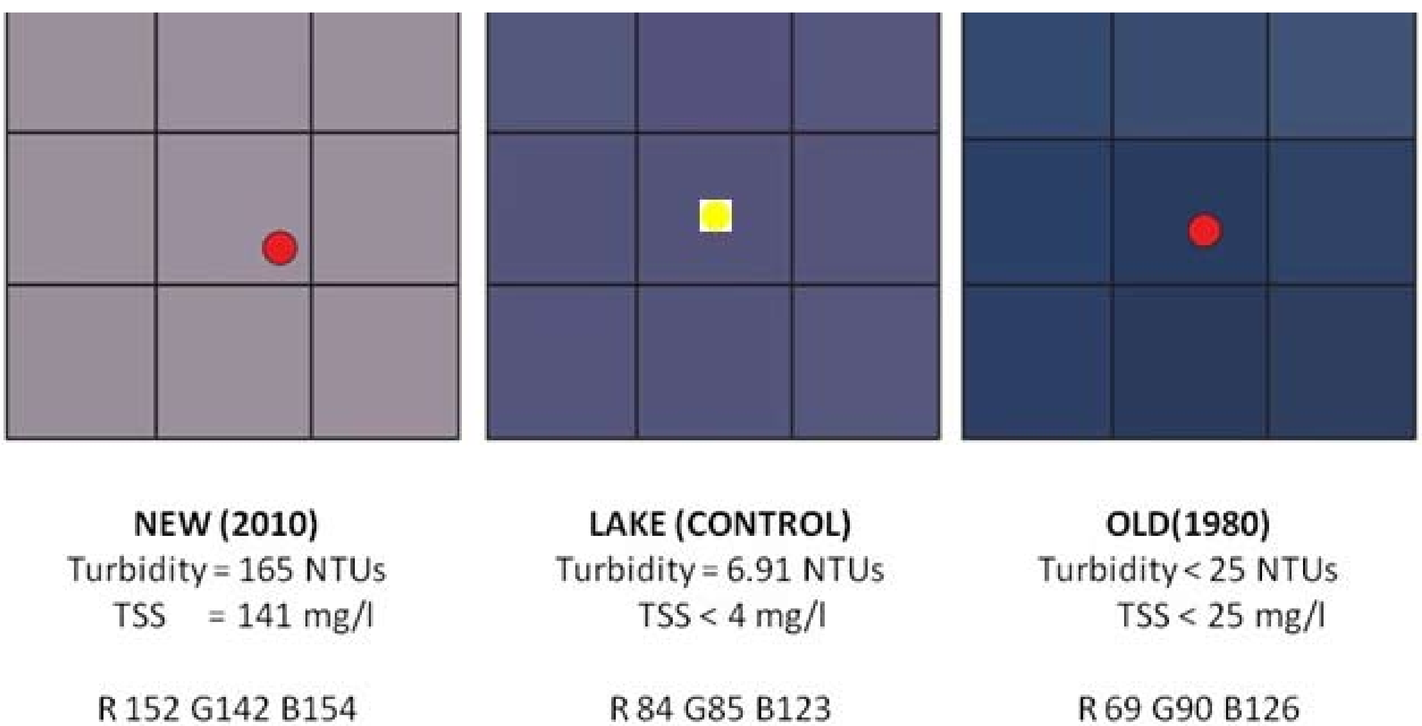


Figure 18. Turbidity and TSS values, transects 1-10, May 18, 2010 (Irvin et al., 2010).



Figures 19-21. The comparison of the "controlled" imagery to the new and old imagery (Irvin et al., 2010).