
By

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A GEOGRAPHIC INFORMATION SYSTEMS ANALYSIS OF CHANNEL CHANGE ALONG
THE AMITE RIVER, LOUISIANA

By

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Chair: Joann Mossa
Major: Geography

This study sought to determine if there was a statistical link between sand and gravel
mining and channel change along the Amite River in southeastern Louisiana between 1976/1981
and 1998. The floodplain of the Amite River has many mining areas and pits due to the mining
of sand and gravel for construction projects. Data were obtained through digitizing the mining
areas and the river channel from USGS quadrangles and aerial photos from the two time series.
GIS was then used to process all of the data into distinct portions for statistical analysis. Reach
blocks of 1,000 meters were delineated and instability indices were calculated as a means of
determining channel change. To determine the spatial and serial relationships between the
mining related variables and channel change, Spearman’s Rank Correlation Coefficient adjusted
for ties was used. The results showed several significant values of correlation when comparing
the mining related variables to the variables reflecting channel change. However, the
relationships involving the number of point bars and mining-related variables had a statistically
significant but negative correlation even when accounting for a lag downstream. The lack of a
positive correlation may be explained with head cutting or bank erosion occurring upstream of
the mined reaches. The findings from this study could be used to improve present and future
management practices as well as educating agencies on the effects of sand and gravel mining.
And they could also be used for planning and engineering of bridges and flood mitigation. Analyzing spatial information resulted in the data being calculated and manipulated much quicker than using traditional manual methods.
A significant type of mining operation found throughout the state of Louisiana, and specifically the Amite River floodplain, is the mining of sand and gravel. Figure 1-1 shows the sand and gravel production near the Amite River (Mossa and Autin, 1997). These sand and gravel operations have been observed as a connection of increased sediment loads in rivers and streams (LDEQ, 1999). Mining along the Amite River floodplain is done with an open pit mine or a quarry. These floodplain mining activities may have several potential effects on the river system, including changes to the ecology, geomorphology, and hydrology (Mossa and Autin, 1997).

Sand and gravel mining can alter an ecological system in several ways both directly and indirectly. The aquatic life may decrease over time due to increased sedimentation, loss of habitat diversity, and the effects of pollution (Hartfield, 1993; Murphy et al., 1981). These influences can have serious biological impacts to the river system.

The most noticeable geomorphologic effect is channel position change. The riverbank can suffer erosion, cutoffs, avulsions, aggradation, and degradation. These impacts may affect existing structures such as bridges and pipelines. During a flooding event, the bridges may become undermined which are costly to repair and can be a concern for public safety (Mossa, 1995).

The changes in hydrology often go hand in hand with geomorphologic changes. The sediments eroded upstream are carried and deposited downstream. Sedimentation will decrease the channel capacity which can result in more widespread flooding (Mossa, 1995). Channel degradation can affect the groundwater levels as groundwater aquifers that discharge into a stream may be lowered because the deepened streambed acts as a drain (Sandecki, 1989).
Objectives

The objectives in this study concern channel change and their relationship to natural factors, mining, and magnitude of mining. The main objective is to determine if reaches with mining activity are more likely to result in channel change between the years 1976 and 1998. The channel change variables being investigated are point bars, lateral migration, channel width, and change index variables.

This study will document how changes over time in mining areas associated with sand and gravel mining on the Amite River floodplain relate to the magnitude and type of channel change on the river. It is hypothesized that there is a statistical link between floodplain mining and changes in channel position on the Amite River.

The results of this study are possibly useful for several reasons. Management, research, and education can be used to direct future exploration, and to improve operations of existing mines. Considerable thought should be given regarding how to balance the economic return and environmental effects. Government agencies could also use the results for flood mitigation and to set policies for management practices and reclamation of previously mined areas.

GIS Applications

Geographic Information System (GIS) is used to aid in quantitative processes as a tool for analyzing spatial relationships. Changes to the river and along the river floodplain can occur fairly rapidly. These changes are important and can be documented by historical data. Applications of GIS are used in this study to document and analyze these changes over time. This will give a digital representation of the study area which can be used for future research.

Study Site

The Amite River originates in southwestern Mississippi and travels through southeastern Louisiana before draining into Lake Maurepas (Figure 1-2). Its drainage basin covers
approximately 2,000 km². Sediments within the drainage basin consist mainly of unconsolidated and semi-consolidated clastic Quaternary sediments (Snead and McCulloh, 1984). The annual precipitation of the area is about 1,500 mm per year (Sanders, 1978), with floods being caused by frontal systems, tropical cyclones, and convective storms.

In 1848 the portions of parish (county) boundaries were drawn along the center of the historic Amite River channel. The modern channel no longer follows the parish boundary. However, maps from 1940 show the political boundary and the river were similar. Therefore, the most prominent changes have occurred since 1940. Mining is likely to be connected to the channel change since the time periods of extraction and channel change are coincident (Mossa, 1995).

The river shows a primarily meandering pattern in undisturbed reaches, changing to braiding where mining has taken place (Mossa, 1983). The floodplain consists mainly of riparian forest and bare agricultural land, with some urban areas as well (Mossa and McLean, 1997).

The study area begins at the border of Mississippi and Louisiana to the north and continues to the south until the intersection of the river with Interstate 12. This stretches from 31°0’N latitude south to 30°30’N. The United States Geological Survey (USGS) has four continuous gaging stations within the study area of the river. These are located at Darlington, Grangeville, Magnolia, and Denham Springs as shown in Figure 1-2. The city of Baton Rouge has continued to build up near the river and the city of New Orleans is located to the southeast.
Figure 1-1. Sand and gravel production near the Amite River (adapted from Mossa and Autin, 1997).
Figure 1-2. The Amite River area map (Courtesy of April Davis).
CHAPTER 2
LITERATURE REVIEW

Modern demands for sand and gravel require increased extraction rates which can increase the risk of environmental disruptions. Sand and gravel is an important material used in urban development projects, road construction, and industrial applications. River sediments often make excellent construction aggregate because the sand and gravel in the bed load is naturally graded, sorted, and rounded (Kondolf, 1994). The source material is usually also relatively close to its destinations or to the area where it will be transported. And, these active sediments are easily mined and require little processing (Rinaldi et al., 2005).

Recent concerns have developed over the physical impact of this resource exploitation. Gravel mining involves the physical removal of sand and gravel from either the riverbed or the surrounding floodplain. Widespread clearing, redirection of flow, stockpiling of sediment, and excavation of deep pits may be involved (Kondolf, 1994). The establishment of environmental regulations and an increased awareness of environmental change and erosional forces have driven support for a growing amount of environmental monitoring and research (James, 2006).

The active channel and floodplain are dynamic, and disturbances can spread upstream and downstream while the mine is active (Kondolf, 1994). The channel often changes in response to variations in discharge and sediment supply (Mossa and Coley, 2004). Gravel acts as an armor for the channel bed. Once this armor is removed, erosion leading to channel change is more likely to occur. Changes to the river channel due to mining may include localized adjustments, increased meandering or widening of the channel, and degradation of sections of the streambed. However, the full impact of mining may not be realized for several years (Kondolf, 1994). After a channel has been incised, the channel continues to widen and rework sediment stored in floodplain, thus maintaining elevated sediment loads (James, 2005). Poor documentation of the
harmful effects of mining in geomorphology and engineering fields can explain why officials neglected these potential issues (Rinaldi et al., 2005).

**Physical and Environmental Effects of In-stream Mining**

In-stream mining directly alters the channel geometry and bed elevation. It has substantial consequences on channel form, particularly by causing incision upstream and downstream of the extraction site. By removing sediment during instream gravel mining, the balance between sediment supply and transporting power is disrupted (Kondolf, 1994). This type of mining can be done in two ways; excavating trenches or pits in the gravel bed, or by gravel bed skimming which removes all the material in a gravel bar to a certain line that indicates low flow. Either way the channel morphology is disrupted, and a local sediment deficit is produced. These direct alterations induce channel incision, bed coarsening, and lateral channel instability (Kondolf, 1997). Over time the deep pits mined in the streambed tend to become smoothed out by flow in the channel. These pits trap the sediment, which can increase erosion to the channel bed and banks immediately downstream (Sandecki, 1989). The water low in bed load has additional energy and typically erodes the channel bed and banks to recover at least part of its sediment load (Kondolf, 1994). Also, sediment size distributions may be affected, resulting in an overall reduction in size of the material found at the site after mining and temporary increases in downstream deposits of silt may occur. The channel bed erosion, or degradation, from mining can weaken bridge foundations and pipelines because these structures were not designed to withstand streambed elevation lowering. Additionally with channel degradation, the groundwater levels may be affected (Sandecki, 1989). The alluvial water table may decline since the banks are more completely drained to a lower level (Kondolf, 1994). Multiple mining operations along the river channel tend to have a cumulative impact (Sandecki, 1989). The effects of in-stream mining can be especially severe and difficult to reverse especially when
mining coincides with other human activities that reduce upstream sediment delivery (Rinaldi et al., 2005).

Mossa and Coley (2004) found that the Pascagoula river system showed a wide range in lateral stability and instability conditions. Several reaches were revealed to show cutoffs, avulsions, channel widening, and lateral migration. One tributary showed a channel enlargement of 400-500% from the initial channel area due to in-stream channel mining.

**Physical and Environmental Effects of Floodplain Mining**

Floodplain mining alters existing lands, such as woodlands or agricultural lands, into open pits. This type of mining transforms large areas of floodplain into open water ponds. These areas are very near the active channel and may only be separated by a narrow strip of unmined land. In many cases, these pits have captured the channel during floods, and thus converting off channel mines to in-channel mines. This pit capture event occurs when the strip of land separating the pit from the channel is infringed by lateral channel erosion or by overflowing floodwaters. These pits offer the river a shorter course than the current active channel mainly through cutoffs and avulsions (Kondolf, 1997). As a result, channel length has been noted to shorten in reaches of the river that is disturbed by mining (Mossa, 1983). When a pit capture occurs, floodplain mining becomes in-stream mining. Therefore, all the effects of in-stream mining can be expected (Kondolf, 1997). These pits can and typically will intersect they water table which can lead to groundwater contamination and pollution (Rinaldi et al., 2005). Another important concern is the large sediment piles that may also be produced and stored near the mining site. These sediment piles can create large fans that may dam the river channel (James, 2005).

The erosional process, avulsion occurs when larger scale switching of the main flow occurs and new channels are cut or older ones reoccupied. This channel shifting or relocation occurs on
a larger floodplain scale and possibly over longer periods of time (Knighton, 1998). This gradual migration of the channel may shift into gravel pits that were once part of floodplain mining (Kondolf, 1994). This happens because the bottom of the pit is lower than the river bottom (Kondolf, 1993).

The geomorphic changes that occur downstream and upstream of the mined area due to floodplain mining include riverbank erosion, cutoffs, avulsions, aggradation, and degradation. These all have implications to humans. It could mean loss of property, roads, and buildings, difficulties of ownership and taxation, and disagreements between landowners over riparian property. Bridges along the main channel or along tributaries of mined rivers can be undermined during floods. These can be expensive to repair and represent crucial concerns for public safety (Mossa and Autin, 1998).
CHAPTER 3
METHODS AND MATERIALS

Geographic Information Systems (GIS) was used for the spatial analysis of all the datasets. Vector GIS was decided as the best tool for this study because it shows a greater accuracy for delineating boundaries of river banks and for calculating areas of irregular polygons such as mine pits. Vector GIS is also very efficient for overlaying and intersecting polygons. Overlaying polygons were fundamental for this project to see the river channel and mine pits from two different time periods.

Microsoft Excel spreadsheets were used for the quantitative analysis. This allowed for sorting of the data, creating graphs, and performing simple calculations. All statistical analysis was performed by NCSS.

Topographic quadrangles at a scale of 1:24,000 produced in 1976 and 1981 were used to represent the earlier time period. The names of the quads used were as follows progressing from the north end of the study area to the south: Chipola, Hatchersville, Pine Grove, Pride, Watson, Denham Springs, Praireville, and French Settlement. These quads meet the national map accuracy standards which states that the horizontal accuracy of 90 percent of the points tested must be accurate within 1/50th of an inch on the map. With the 1:24,000 maps used in this study, 1/50th of an inch is 40 feet (USGS, 1999). Digital Orthophoto Quarter Quadrangles (DOQQs) flown from January 28, 1998 to February 4, 1998 were used to represent the later time period. Each pixel in these photographs represent one meter square on the ground. These DOQQs meet the national map accuracy standards for a map published at 1:12,000. Therefore the horizontal accuracy of 90 percent of the points tested must be accurate within 1/30th of an inch. And 1/30th of an inch is 33 feet. Both sets of data were acquired digitally by Atlas: The Louisiana Statewide
GIS (LSU, 2009). All data created have a spatial reference set to NAD 1983 UTM Zone 15 North.

Discharge values were obtained from the United States Geological Survey (USGS) for the gage stations at Darlington and Denham Springs (USGS, 2009). The Darlington gage station is the northern most gage station of the study site, and the Denham Springs gage station is the southern most gage station of the study site. Both of these sites had discharge information for the earlier time period and the more recent time period. The two gage stations in the middle of the study area, Grangeville and Magnolia, did not have stage or discharge information available for both time periods so this information was not used for this study.

**Geographic Information System**

Channel boundaries were digitized from the DOQQs into a vector-based Geographic Information System (GIS), using ESRI ArcGIS version 8.3. Both banks of the Amite River were digitized in order to give the river width and the ability to do analyses based on area. The digitizing scale for the primary channel was set to 1:2,000 for the DOQQs. This scale was set so that one can still make out a reasonable channel boundary, but not zoomed out so much that important features of the river were missed. Digital line graphs (DLG) provided by the USGS were used to create the earlier channel boundary. The two lines representing the channel boundary were converted to polygon features by tracing over the lines to create a new feature.

Following the digitizing of the river channel, the areas of disturbed land and mining pits were digitized for both time periods. Digitizing the disturbed lands on the topographic maps was done by looking for the mining symbols, crossed shovels icon, and digitizing the area in white surrounding it. The maps were interpreted where symbols were not present. The floodplain mining pits were shown on the topographic maps as a contour line and words stating “sand and gravel pits” were next to it. These pits usually had water present in them, indicative of the high
water table. An example of one of the mining areas is shown in Figure 3-1. The disturbed land areas near the river channel were approximated on the DOQQs by areas covered by sand that appeared to be lacking of vegetation. These areas were digitized by completely covering the outer extent of these sandy areas. The mining pits were digitized by completely covering the area that is filled with water. The distance from the pits to the river channel was measured in ArcGIS by drawing a straight line from the edge of the pit to the closest position along the river’s boundary.

Point bars were found on the topographic maps by noting the white areas with brown dots near the primary river channel and digitized as a polygon feature. Point bars on the DOQQs were found and digitized by the sandy areas near the river channel that often occurred in the river’s bend. While digitizing the point bars, the edge was snapped to the river channel polygon to ensure a smooth transition between the two features. This was also the case if the point bars occurred next to the disturbed areas.

After all on-screen digitizing of shapefiles was complete, each shapefile was converted into a feature class in a personal geodatabase. A personal geodatabase was used to establish relationships between feature classes, establish topology rules, and to automatically keep track of the area of the polygon. All features classes were checked to ensure polygons snapped together properly and did not overlap or leave gaps.

The primary river channels for each year were added together using the union command in ArcGIS. The union command computes a geometric intersection of both primary channels. All features and attributes are kept in the output feature class. After the union was completed on the two primary channels, four areas were determined and labeled according to how they have changed from the prior time period or whether or not they have changed at all. The four areas
labeled are U for unchanged, E for erosion, D for deposition, or B for the area between the two channels. All areas outside the unioned channel boundaries are labeled O for other. Figure 3-2 shows an area of the river with the four indices labeled.

A valley centerline was made for the unioned channels. This centerline was produced in order to create transects or reaches perpendicular to the direction of flow. Once the valley centerline was created, reach blocks were made every 1,000 meters along the unioned channels. These reaches were formed by creating hatches within ArcGIS. If the reaches, or hatches, crossed more than one portion of the river, that individual hatch was moved north or south of the valley line, or rotated slightly to ensure it only crossed the river channel once. With the reach blocks created, the area can be summarized by reach and by indices. Figure 3-3 shows the Amite River with every tenth transect labeled, the USGS gage stations, major roads, and the city boundary of Baton Rouge.

After all the indices have been attributed and the transects created, the next step was to calculate the index values in order to quantify the degree of channel change. ArcGIS was used to aggregate by transect and by the four channel change areas of the river. The initial area of the river channel was calculated by adding the deposition and unchanged areas together, \( I = D + U \). Once the initial area is established, the index value is calculated by dividing the area of each of the indices by the initial area. This process results in the proportions of each area of the river channel. \( U/I \) shows the proportion that is unchanged or in its initial position. \( D/I \) shows what proportion of the channel has been deposited or abandoned. \( E/I \) shows what proportion of the initial channel areas has been eroded. \( B/I \) is a measure of displacement through cutoffs, rapid migration, or local avulsions into pits and secondary channels.
The channel centerline of the river was created in ArcGIS using the midpoint tool in the list of edit functions. Using the river polygon feature, clicking on each side of the polygon will create a vertex in the middle. This was done for the entire length of the river. Once the river centerline was created, the width of each transect was calculated using the formula below:

\[ \text{Width} = \frac{\text{Area}}{\text{Channel Length Centerline}} \]

The transect feature class was intersected with the river channel and the channel centerline to allow calculations for area and channel length by transect. All of these variables were calculated in ArcGIS.

Lateral migration was calculated using the methods described by Larsen et al. in 2006. The lateral migration process described by Larsen et al. takes the channel centerline from both time periods and calculates the area between the two centerlines. The area is then divided by the average length to compute the lateral migration from the earlier time period to the later time period. These calculations were all performed in ArcGIS and were computed for each reach block.

Avulsions or captures were determined by examining each of the mine pits from the earlier time period and comparing it to the more recent river channel. If the recent channel intersected an earlier mine pit, an avulsion had occurred and a point was placed at the site of intersection. The resulting avulsions were then attributed to where they occurred either inside or outside the meander bend. These pit captures were most likely the result of lateral channel erosion or a flood event. Figure 3-4 through Figure 3-11 show areas along the river where avulsions have taken place from the earlier time period to the more recent time period. The figures are arranged from the most upstream pit capture to the pit capture that occurs furtherest downstream.
**Statistical Analysis**

All of the data were then entered into a Microsoft Excel spreadsheet and sorted by reach block. These data were then imported into NCSS for all statistical analysis. The output of the statistical analysis was entered back into a spreadsheet for comparisons and to determine the critical values.

To compare the mining variables for the two time frames, Spearman’s Rank Correlation was chosen because it is a non-parametric statistic which does not require data to be normally distributed (Earickson and Harlin, 1994). The equation for Spearman’s Rank Correlation is as follows:

\[ R_s = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \]

The rank correlation can range in samples from -1 to +1. A negative one indicates complete discordance and a positive one indicates complete concordance. Values close to zero indicated little or no relationship between the two variables being compared. Spearman’s Rank Correlation were run on all variables considered to be potentially linked by physical processes.

The variables that were compared were:

- New Pit Area vs. Between Area
- New Pit Area vs. Old Channel Area
- New Pit Area vs. New Channel Area
- New Pit Area vs. Overlapping Old and New Channels
- New Number of Pits vs. Between Area
- New Number of Pits vs. Old Channel Area
- New Number of Pits vs. New Channel Area
• New Number of Pits vs. Overlapping Old and New Channels
• New Mining Area vs. Between Area
• New Mining Area vs. Old Channel Area
• New Mining Area vs. New Channel Area
• New Mining Area vs. Overlapping Old and New Channels
• Old Mining Area vs. New Point Bar Area
• Old Mining Area vs. New Number of Point Bars
• Old Number of Mining Pits vs. New Point Bar Area
• Old Number of Mining Pits vs. New Number of Point Bars
• New Mining Area vs. Lateral Migration
• New Number of Mine Pits vs. Lateral Migration
• Old Mining Area vs. New Channel Width
• Old Number of Mining Pits vs. New Channel Width
• Old Number of Mining Pits vs. New Number of Point Bars Lag 1
• Old Mining Area vs. New Number of Point Bars Lag 1
• Old Number of Mining Pits vs. New Point Bar Area Lag 1
• Old Mining Area vs. New Point Bar Area Lag 1
• New Number of Mine Pits vs. New Number of Point Bars Lag 1
• New Mining Area vs. New Number of Point Bars Lag 1
• New Number of Pits vs. New Point Bar Area Lag 1
• New Mining Area vs. New Point Bar Area Lag 1
• New Number of Pits vs. New Point Bar Area Lag 1
• Old Number of Mining Pits vs. New Number of Point Bars Lag 2
• Old Mining Area vs. New Number of Point Bars Lag 2
• Old Number of Mining Pits vs. New Point Bar Area Lag 2
• Old Number of Mining Pits vs. New Point Bar Area Lag 2
• Old Mining Area vs. New Point Bar Area Lag 2
• New Number of Pits vs. New Number of Point Bars Lag 2
• New Mining Area vs. New Number of Point Bars Lag 2
• New Number of Pits vs. New Point Bar Area Lag 2
• New Mining Area vs. New Point Bar Area Lag 2

These combinations were chosen based on likely geomorphic interactions. The mining area variables were used as independent variables to analyze the possibility of mined areas and pits being linked to channel change. The combinations of dependent variables and independent variables were chosen on the basis of results from an earlier study of the Amite River by McLean (1995). Lags were established with the variables new number of point bars and new point bar area to determine if mining in one reach would impact the number of point bars or the amount of area the point bar contains within a reach or two downstream. Lag 1 is spatially one reach block downstream, and lag 2 is two reach blocks downstream.

The values of Spearman’s r were tested for statistical significance using the t distribution. The t-value equation was modified by isolating the r, the critical value of Spearman’s r for statistical significance was calculated using the following equation (Rogerson, 2001):

$$\rho = \frac{t}{\sqrt{\frac{1}{n} - \frac{1}{2} + \frac{1}{t^2}}}$$

The t’s in this equation are the values for the t distribution for 67 degrees of freedom and n is the sample size. During the initial statistical analysis, it was realized there were many ties in the data and an adjustment for ties must utilized. Since tied ranks existed, the Pearson’s Product Moment Correlation Coefficient was used on the ranked data (Myers and Well, 2003). All of the combinations listed previously were run using the Pearson’s Correlation Coefficient on the ranked data.
Figure 3-1. An example of a mining area as shown on the topographic map. The mining area and mining pits can be distinguished (Courtesy of April Davis).
Figure 3-2. An example of the Amite River in two different time periods with each of the indices labeled (Courtesy of April Davis).
Figure 3-3. The middle Amite River broken out into transects (Courtesy of April Davis).
Figure 3-4. Pit capture occurring on the Amite River in transect 24 (Courtesy of April Davis).
Figure 3-5. Pit Capture occurring on the Amite River in transect 26 (Courtsey of April Davis).
Figure 3-6. Pit capture occurring on the Amite River in transect 30 (Courtesy of April Davis).
Figure 3-7. Pit capture occurring on the Amite River in transects 32 to 34 (Courtesy of April Davis).
Figure 3-8. Pit capture occurring on the Amite River in transects 36 and 37 (Courtesy of April Davis).
Figure 3-9. Pit capture occurring on the Amite River in transects 38 and 39 (Courtesy of April Davis).
Figure 3-10. Pit capture occurring on the Amite River in transects 43 and 44 (Courtesy of April Davis).
Figure 3-11. Pit capture occurring on the Amite River in transects 46 to 48 (Courtesy of April Davis).
CHAPTER 4
RESULTS

Mining related variables were investigated against the river’s index values, point bars, lateral migration and channel width. These were compared both spatially and temporally. Spatially, the variables were compared to each other to determine their interactive effects. And temporally, the variables were compared to see how they affected each other from one time period to another.

Correlation was used to compare the spatial and temporal relationship between mining variables and the other variables categorized along the river. The relationships between variables were analyzed using Spearman’s Rank Correlation with an adjustment for ties (Myers and Well, 2003). Several combinations of variables were analyzed and graphs of these variables showing distance downstream were created.

Figure 4-1 shows the area of the mining pits from 1976/1981 and 1998 by reach block. There is very little area of mine pits in the first 18 reach blocks. The area of the mining pits has generally increased from the earlier time period to the later time period for most reaches. The highest area values occur between reaches 19 and 46 for both time periods, with transect 37 having the highest area of mine pits. An increased area of mining exists between reach blocks 56 and 60. This may indicate a trend of mining activity occurring further downstream. There are 6 reach blocks in the later time period with over 40 hectares of mine pits, while there is only one reach block in the earlier time period with as much area.

Figure 4-2 shows the number of mine pits from 1976/1981 and 1998 by reach block. There are a high number of mine pits for both time periods from transects 23 to 50. The area from Figure 4-2 also indicates those transects as having the most area in mining pits. The highest number of pits from the older time period occurs in reach 66 with 15 mine pits, and the
highest number of pits from the later time period occurs at reach 47 with 16 mine pits. There are 9 reach blocks in the later time period with over 12 mine pits, while there are only 7 reach blocks in the earlier time period with as many mine pits. There are several new mine pits in the reaches upstream that were not there in the previous time period. There also appears to be transects where mining was prevalent in the earlier time period and now there aren’t quite as many pits in the later time period. The opposite is also true as reach blocks that have a high number of pits in 1998 had fewer pits in the earlier time period. In some of these instances, the older pits have been taken over by the river channel where pit captures, or areas of avulsion have occurred. Also, as shown in Figure 4-1, the area of the pits has increased with time which may indicate the mining industry is creating larger pits or combining pits. And of course, as areas are completely mined of sand and gravel, the mining companies will move onto another area.

Figure 4-3 characterizes the index values by reach blocks. The index values were created and used to aid in quantifying the degree of channel change. Variability is evident in all channel change values. The between index value (B/I) shows the greatest value at reach 20 with a value of 3.4 and shows very high variability between reaches 17 and 37. It then begins to taper off to 0 at reach 58. There are a total of five reaches with a B/I value of 2 or higher. This suggests that the area between channels was as much as or more than 200% of the initial area in those five reaches. High values of B/I are usually indicative of instability. The B/I values are used to indicate an avulsion away from the current channel. And as to be expected, the unchanged index value (U/I) is usually low when the B/I value is high and is higher when the B/I value is low. Over the 18 year time period, about 35% of the channel remained in the same position (U/I values > 0.35). Most of the stability occurs in the reaches further downstream which are likely related to the bank sediments becoming finer and more cohesive. The erosion index value (E/I)
also shows a period of being high between reach blocks 20 and 32. The values within these reaches range from 0.7 to 1.8. This shows a channel enlargement from 70% to 180% in these reaches from the initial channel area. The deposition index value (D/I) does show some variability between reach blocks 17 and 36, with values ranging from 0.4 to 0.9. These values indicate that between 40% and 90% of the channel has been abandoned within these reaches.

Figure 4-4 shows the area of total disturbance from 1976/1981 and 1998 by reach block. As in the previous figures, the high amount of disturbed or mining area occurs in the middle transects 18 to 48. The highest amount of disturbed area from the older time period occurs in reach 27 with a disturbed area of 220 hectares. The highest amount of disturbed area from the later time period occurs in reach 38 with 252 hectares. Areas that were previously disturbed do not have quite the amount of disturbance now, and areas that are now disturbed did not have quite as high of a disturbed area in the previous time period. However, the total amount of disturbed area has increased from 1976/1981 to 1998 as shown in Table 4-1 by over 1,000 hectares.

Figure 4-5 shows the number of point bars from 1976/1981 and 1998 by reach block. The number of point bars varied throughout the data set. However, the total amount of point bars has increased from 1976/1981 to 1998 by 89 as shown in Table 4-1. Even though there was a total increase in 1998, there was no clear area of increase or decrease for either time period. Although, it does seem if one time period was high then the other time period was low. The highest number of point bars from the older time period occurs in reach 15 with 8 point bars, and the highest number of point bars from the later time period occurs in reach 5 with 10 point bars. It is imperative to note the discharge rates at the northern most gage station with the discharge rates at the southern most gage station. Table 4-2 shows both gage stations at both time periods
with discharge rates. From the Darlington gage station, the discharge rate from the later time period is almost double the discharge rate from the earlier time period. The discharge rate in the earlier time period is 491 ft$^3$/s and in the later time period the discharge rate is 869 ft$^3$/s. However, the opposite is true with the Denham Springs gage station. The older time period shows a much higher discharge rate than the later time period. The discharge rate in the earlier time period is 2,970 ft$^3$/s, and in the later time period the discharge rate is 1,960 ft$^3$/s. Figures 4-6 to 4-9 show a graph of the discharge rates from one day prior to aerial imagery capture to one day after aerial imagery capture. At the Darlington and Denham Springs gage stations, both time periods show a trend of decreasing discharge rates. The discharge information is important to note with the number of point bars because a high discharge rate may indicate that a potential point bar is not exposed during the aerial imagery capture. The opposite can also be true with a low discharge rate. If the discharge rate is low, then more areas that appear as point bars may have been captured during the photo interpretation. Under ideal conditions, the discharge values would be very close at both time periods in order to perform the statistical analysis.

Figure 4-10 shows the area of point bars from 1976/1981 and 1998 by reach block. There tends to be an overall increase in the point bar area for most reach blocks in the more recent time period. This also concurs with Table 4-1 showing the total amount of point bar increasing by 139 hectares. The largest variance is between reach 15 and reach 36. With the largest area of point bars occurs at reach 22 in the older time period. The largest area of point bars in the later time period occurs at reach 32. There are 14 reach blocks in the later time period with an area over 10 hectares while there are only 5 reach blocks in the earlier time period with as much point bar area. It is important to realize this large amount of area occurs here because of the method implied that if a point bar crosses the transect line, the point bar is calculated with the transect to
the south. As with the number of point bars, the discharge information also plays a key role in the area of the point bars. A high discharge rate may show less point bar area, and a low discharge rate may expose more area that may be considered a point bar.

Figure 4-11 shows the channel width from 1976/1981 and 1998 by reach block. The channel width varies a lot between reaches 19 and 36 between the two time periods. The largest difference between the two channels occurs at reach 27 where there is approximately 62 meters of channel width increase from 1976/1981 to 1998. The reaches that show a high channel width increase from 1976/1981 to 1998 are the same reaches that show a high amount of disturbed area and mining pit area from Figures 4-2 and 4-4. There is an area of slight decrease from the new channel to the old channel from reach 46 to 67. However, the largest amount of decrease from 1998 to 1976/1981 is only 11 meters, so overall the channel width has increased much more than decreased.

Figure 4-12 shows lateral migration rates from 1976/1981 to 1998 by reach block. Lateral migration shows a lot of variability between reaches 18 to 44. And the highest amount of lateral migration occurs at reach 37 with almost 200 meters of lateral migration. The reach blocks showing the largest range are also consistent with the reaches that show a high amount of disturbed area and mining pit area in Figures 4-2 and Figure 4-4.

Several significant values for correlation were found when investigating the mining variables at the 95% confidence level. Spearman’s Rank Correlation with an adjustment for ties was utilized because it does not require the data to be normally distributed. The variable combinations are categorized by their independent variable. The relationships compared the mining related variables with one of the variables reflecting change in channel position. The results of the statistical analysis are included in Tables 4-3 and 4-4.
There were weak to moderate correlations for variable associations involving the index values as the dependent variable and mining related independent variables with the exception of the unchanged index value which was predicted to show no correlation or a negative correlation. There were also moderate correlations for variable associations involving lateral migration and channel width as the dependent variables and mining related independent variables. The highest coefficient values were produced with the earlier time period mining independent variables and the channel width of the more recent time period.

The relationships involving the point bar area variables were far weaker and less statistically significant than other variables that reflect a change in channel position including the number of point bars that occurred in the later time period. Lag variables were introduced to the point bar variables to see if there was a relationship between mining related variables occurring upstream and point bar formation occurring either one transect (lag 1) or two transects (lag 2) downstream. These values were tested because sediment load deposition will occur downstream due to large volumes of material introduced upstream (Knighton, 1998).

The relationships involving the number of point bars variable had a statistically significant but negative correlation when compared to the mining related independent variables. This occurred when comparing it to the earlier mining related variables, the later mining related variables, and when calculating it with the lag variables both with lag 1 and lag 2. This pattern is difficult to explain and deviates from the expected relationship. With such a high increase in the number of point bars delineated from 1976/1981 to 1998 (Table 4-1), one would expect to see a positive correlation with the mining related variables. This would especially be true since mining related activities can disrupt the surrounding floodplain and cause more sediment into the channel. The spatial lag of one or two transects downstream should incorporate this influx of
sediment load over time, and one would expect to see a positive correlation of mining related activities to number and area of point bars. However, the lack of a positive correlation may be explained with head cutting or bank erosion occurring upstream of the mined reaches. When a section of the river channel is deepened, more sediment is needed to fill up the hole that was excavated. As more erosion continues in the excavated areas, the more sediment is continuing to fill in and may cause the point bars to move upstream (OWRRI, 1995). The Leaf River showed an area of rapid migration upstream of the juncture with the Bowie River where a headcut is likely moving upstream (Mossa and Coley, 2004).

All of the relationships tested (with the exception of the point bar area mentioned previously) proved to be statistically significant. Therefore it can be said that there is a statistical link between floodplain mining and channel change on the Amite River. And mining related variables from the older time period do influence the river channel in the more recent time period.
Figure 4-1. Area of Mine Pits in hectares vs. Reach Blocks: 1976 – 1998
Figure 4-2. Number of Mine Pits vs. Reach Blocks: 1976 - 1998
Index Values by Reach Blocks

Reach Blocks
Distance Downstream of Mississippi State Line (km)

Index Values

Figure 4-3. Index Values vs. Reach Blocks. B index value is the area between the two channels, D index value is the deposition or old channel, E index value is the erosion or new channel, and U index value is the unchanged area or the overlapping old and new channel.
Figure 4-4. Disturbed Area in hectares vs. Reach Blocks: 1976 - 1998
Figure 4-5. Number of Point Bars vs. Reach Blocks: 1976 - 1998
Figure 4-6. Early time period daily discharge rate for the gage station near Darlington (USGS, 2009).

Figure 4-7. Later time period daily discharge rate for the gage station near Darlington (USGS, 2009).
Figure 4-8. Earlier time period daily discharge rate for the gage station near Denham Springs (USGS, 2009).

Figure 4-9. Later time period daily discharge rate for the gage station near Denham Springs (USGS, 2009).
Figure 4-10. Point Bar Area in hectares vs. Reach Blocks 1976 - 1998
Figure 4-11. Channel Width in meters vs. Reach Blocks: 1976 - 1998
Figure 4-12. Lateral Migration vs. Reach Blocks: 1976-1998
Table 4-1. Totals of Variables Compared from 1976/1981 Time Period to the 1998 Time Period.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Mine Pits</td>
<td>236</td>
<td>325</td>
</tr>
<tr>
<td>Disturbed Area (hectares)</td>
<td>2,347</td>
<td>3,434</td>
</tr>
<tr>
<td>Number of Point Bars</td>
<td>130</td>
<td>183</td>
</tr>
<tr>
<td>Area of Point Bars (hectares)</td>
<td>287</td>
<td>426</td>
</tr>
</tbody>
</table>
Table 4-2. Daily discharge rates from gage stations in cubic feet per second.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Darlington</td>
<td>491</td>
<td>869</td>
</tr>
<tr>
<td>Denham Springs</td>
<td>2,970</td>
<td>1,960</td>
</tr>
</tbody>
</table>
Table 4-3. Results of Spearman’s Rank Test for Correlation. The bold values represent the statistically significant values at the 95% confidence level.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Between Area</th>
<th>Old Channel Area</th>
<th>New Channel Area</th>
<th>Overlapping Old and New Channels</th>
<th>New Channel Width</th>
<th>Larsen Lateral Migration</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Pit Area</td>
<td>0.3164</td>
<td>0.4091</td>
<td>0.2616</td>
<td>-0.3358</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>New Number of Pits</td>
<td>0.2450</td>
<td>0.3704</td>
<td>0.2074</td>
<td>-0.2679</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>New Mining Area</td>
<td>0.3736</td>
<td>0.4518</td>
<td>0.3542</td>
<td>-0.4048</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Old Mining Area</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.5224</td>
<td>*</td>
</tr>
<tr>
<td>Old Number of Pits</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.4849</td>
<td>*</td>
</tr>
<tr>
<td>New Mining Area</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.6093</td>
</tr>
<tr>
<td>New Number of Pits</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.4418</td>
</tr>
</tbody>
</table>
Table 4-4. Results of Spearman’s Rank Test for Correlation with relationships involving point bar variables. The bold values represent the statistically significant values at the 95% confidence level.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>New Point Bar Area</th>
<th>New Number of Point Bars</th>
<th>New Point Bar Area Lag 1</th>
<th>New Number of Point Bars Lag 1</th>
<th>New Point Bar Area Lag 2</th>
<th>New Number of Point Bars Lag 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Mining Area</td>
<td>0.1228</td>
<td>-0.5224</td>
<td>0.2672</td>
<td>-0.5380</td>
<td>0.3685</td>
<td>-0.4929</td>
</tr>
<tr>
<td>Old Number of Pits</td>
<td>-0.0080</td>
<td>-0.5167</td>
<td>0.0972</td>
<td>-0.5771</td>
<td>0.2047</td>
<td>-0.5876</td>
</tr>
<tr>
<td>New Mining Area</td>
<td>0.2362</td>
<td>-0.5979</td>
<td>0.3228</td>
<td>-0.5938</td>
<td>0.3483</td>
<td>-0.5702</td>
</tr>
<tr>
<td>New Number of Pits</td>
<td>0.1101</td>
<td>-0.4903</td>
<td>0.1524</td>
<td>-0.5423</td>
<td>0.2284</td>
<td>-0.4646</td>
</tr>
</tbody>
</table>
CHAPTER 5
CONCLUSION AND FURTHER RESEARCH

Conclusions

The purpose of this study was to determine if there was a statistical link between sand and gravel floodplain mining and channel change on the Amite River in southeastern Louisiana between 1976 and 1998. To examine this relationship, GIS was used as a tool in the quantitative process. The channel boundaries, mining areas, and point bars were all determined from aerial photo interpretation and from USGS topographic maps. Reach blocks were then created in 1,000 m intervals in order to measure the degree of channel change. Areas within each reach block were attributed as belonging to the old channel or depositional area, the new channel or eroded area, the intersection of both channels or unchanged area, and the area between the old and new channel. These indices were used to quantify channel change over space and time.

Spearman’s rank correlation coefficient with adjustment for ties determined that there was indeed a statistical link between mined reaches of the river and reaches of the river which have undergone a change in channel position. This study has also shown that there is either no statistical link or a statistical significant but negative correlation between point bars and channel position along the mined reaches. The lack of several strong relationships may indicate that either several factors together are responsible for the channel position change or that there may be a substantial time lag between floodplain modification and channel change.

The use of GIS proved to be invaluable in this study. It allowed for a more efficient way of examining channel changes due to sand and gravel mining. Area and other measures were calculated very quickly and this technology will allow for the ability to develop and test further hypotheses concerning patterns and relationships of sand and gravel mining.
A statistical link has been shown to exist between areas that are mined and channel change through the use of GIS technology. Analyzing spatial information resulted in the data being calculated and manipulated much quicker than using traditional manual methods. Using GIS to examine the spatial component, proved to be important to the overall effect of the river.

**Limitations**

This study was limited by a few factors. Having two different sources, USGS topographic maps and aerial photos, immediately introduced a possible error. Photo interpretation is a skill that is highly subjective. One’s photo interpretation of the extent of a mining area may be completely different than another person’s photo interpretation of the mining area. Along the same lines, mapping the channel and point bars for each image or quadrangle can present a challenge due to the stage of the river. If the stage is high, the river channel may take up some of the area of point bars and vice versa; if the stage is low, the river channel may expose more of the area of the point bars giving an error in the area calculations and statistical analysis.

Also, the time difference between the earlier reference years may also be considered a possible limitation. For some of the USGS quadrangles, the reference year is 1976 while in other quadrangles it is 1981. There may have been channel change or mining areas occurring between those two years, which served as one reference year, that was not accounted for when comparing it to the 1998 aerial imagery.

Another source of potential limitation is the difference in scale between the two maps. The difference in scale may have an effect because of the difference in accuracy and the difference in the features mapped (McLean, 1995). Scale and accuracy may also play a part in what one photo interpreter interpreted versus another photo interpreter.

Finally, other variables leading to channel change were not analyzed in this study, and they may also have a geomorphic effect on the magnitude of channel change. The types of impacts
include large flood events between the two time periods, urbanization, and other human activities which may have a direct impact.

**Further Research**

Further research can be accomplished in several areas. First, a more detailed investigation on why the number of point bars had a statistically significant but negative correlation should be researched. Was the mining activity so great that it resulted in more erosion upstream? In this study, the point bars were studied with a lag 1 and lag 2 downstream. If a head cutting process had resulted, then the study area could be further examined with an upstream lag of one or two transects. Rinaldi et al. (2005) discuss the morphological effects of upstream incision. The excavation will steepen the slope of the channel bed upstream of the mined area, which will create a head cut that will likely move many meters or even kilometers upstream. Head cutting may also occur if the excavation is below the water level which can increase bed and bank erosion (Roell, 2003). Further investigation of the upstream lag may help explain where the new point bars are forming and why a downstream lag resulted in a negative correlation.

Another area for possible study is to further examine the avulsions that occurred within the two time frames of this study. More statistical analysis could be done to see where the avulsions are occurring, inside or outside the meander bend. An additional study could also be done to see what factors play in the occurrence of these areas of avulsions. Size of the mining pits, proximity to the river channel, and lower relative elevation could all be potential variables that may cause a pit capture or an area of avulsion. Using more recent aerial imagery, can show further areas of avulsions and give another time series to compare to the data that has already been collected.

One variable that could be looked into for further research is the mining pits distance to the river channel. This information was not considered for this study, but could be potentially useful
to predict future channel change or as a consideration of where sand and gravel mining could be located without having too much of an effect on the river system. Mining pits that are closer or further away from the channel could be given a weighting factor that correlates with distance. Knowing the statistical significance of distance from the mining pit area to the river channel, could assist environmental agencies in planning and setting up new regulations for sand and gravel mining.

Using Digital Elevation Models (DEMs) or Light Detection and Ranging (LiDAR) data could also prove to be useful in this study. Having the height data could be used to investigate the slope of the area as well as allowing for a calculation of volumetric analysis. It could also be used to determine the elevation of the mining pits to give a better idea of where possible avulsions may occur or to use as a variable during the statistical analysis of avulsions. As with the distance from the mining pits to the river channel, a weighting factor could be applied to the elevation data as well. Weights could be assigned based on the mining pit elevation. The elevation data may also be used to document how the channel change due to mining could be returned to its original state.

This study focused on a time series of approximately fourteen to eighteen years due to the data that were available. A significant amount of change in the channel and mining areas occurred between the study years of 1976/1981 and 1998. It could be potentially useful to study the same area, but with a shorter time series. This could allow environmental regulatory agencies to see how much of an effect mining has on a river channel during a short duration. It could be very important to identify how long it takes for the channel change process and areas of avulsion to occur. As technology continues to develop and the need for aerial imagery continues
to grow, there are no shortages of mapping vendors who fly the aerial photography for the area every few years.

In this study, the reach blocks were divided into 1,000 meter intervals. This gave a nice sample size to cover the study area. Another approach is to divide the area into different size reach blocks and compare the same variables to see if different size reach blocks also produce statistically significant results. Mitchell-Tapping (1998) divided the Bogue Chitto River into three separate reach block distances, 500 meter, 1 kilometer, and 2 kilometers and compared the same variables after the data were aggregated. The different size reach block intervals could also prove to be a useful methodology along the Amite River.

Looking at this study area after a major flood event, such as Hurricane Katrina, would allow one to see the time lag that occurs from a major flood event until channel change or avulsion occurs. This could also go back to having a shorter time series between study years. It is important to not only know about channel change as it relates to “average” rainfall years, but also to heavy flood events which could shape the floodplain at a much faster pace.

Further research could also allow for a more thorough investigation of the geology of the study area, especially the bank materials of the channel. The bank stratigraphy should be studied to see where the cohesive and non-cohesive materials lie. The grain size can have a direct influence on the transport of the sediment particles through the river channel. This can all play a part in the bank erosion and channel stability.
Appendix 1. Changes in channel position (reach blocks 1-10) for 1976/1981 and 1998 Amite River, southeastern Louisiana, 1000m blocks (Courtesy of April Davis).
Appendix 2. Changes in channel position (reach blocks 11-20) for 1976/1981 and 1998 Amite River, southeastern Louisiana, 1000m blocks (Courtesy of April Davis).
Appendix 5. Changes in channel position (reach blocks 41-50) for 1976/1981 and 1998 Amite River, southeastern Louisiana, 1000m blocks (Courtesy of April Davis).
Appendix 6. Changes in channel position (reach blocks 51-60) for 1976/1981 and 1998 Amite River, southeastern Louisiana, 1000m blocks (Courtesy of April Davis).
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

April H. Davis was born in June 1980 in Brandon, Mississippi. She received her bachelor’s degree in geosciences with an emphasis in geology from Mississippi State University in 2002. She began working for the Southwest Florida Water Management District as a GIS Analyst in August 2006.