PLANFORM CHANGE RATES IN RIVERS WITH AND WITHOUT INSTREAM AND FLOODPLAIN SAND AND GRAVEL MINING: ASSESSING INSTABILITY IN THE PASCAGOULA RIVER AND TRIBUTARIES, MISSISSIPPI

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ABSTRACT

Floodplain and instream mining are activities that generally increase channel change or instability. To quantify this effect, it is necessary to have some idea of natural or baseline rates of change in rivers in the same region where stream have similar topography, climate, geologic units and vegetation. The Pascagoula River and its tributaries traverse a number of geologic units and the basin shows a diverse set of land cover and land uses, including two streams with considerable historical and recent mining activity. This study quantifies the rates of change in the Pascagoula and some of its tributaries, suggesting at which point planform changes are clearly modified, directly or indirectly, more so by human action. This is done by digitizing the larger and mined tributaries of this system in a GIS using varied sources of data (aerial photographs, topographic maps and digital ortho quarter quadrangles). Polygon areas derived from overlays characterizing changes (areas of erosion, deposition, no change, and areas between channels) in channel position and planform were extracted from the GIS and normalized for scale, so that larger rivers could be compared with the headwaters, as well as smaller rivers and creeks. This study provides insights into the natural factors and anthropogenic activities that influence channel changes in this basin, and thus where future change might be expected to occur. Those insights, in turn, can be applied to management and engineering in the basin.

INTRODUCTION

Rivers are dynamic by nature, changing in response to variations in discharge and sediment supply. Such changes are quite variable in space, depending in part upon position within the basin, and influenced by local variations in geology, soils, bank characteristics, vegetation, hydraulics, and other factors that influence vulnerability such as various types of land use. Additionally, channel changes are variable in time, depending somewhat on the timing of floods and droughts, and the timing of fires and land use changes, and other factors that would influence vulnerability. Human activities, including land use changes, affect discharge and sediment supply indirectly, typically by increasing peak flows and increasing the quantities of sediment considerably (Wolman and Schick 1967, Gregory and Walling 1973, Dury 1977, Allan 1995). In addition, dams and floodplain mining are some activities that also have indirect effects on channel form and hydrology. Other human activities have a direct impact on river systems, particularly channelization and instream mining. Resulting physical changes in rivers may include deposition of channel bars, transportation of coarser sediments, erosion of channel banks, shifting channel bottoms, and changes in channel position and pattern.

Particular human activities, such as removal of floodplain vegetation, have a second influence, decreasing the resistance of banks to erosion thus making rivers more susceptible to channel changes.   Various land use activities have been documented as having specific effects on river geomorphology, in addition to the effect associated just with vegetation removal. For instance, the presence of cows in riparian areas has been well documented as a notable geomorphic agent (Trimble and Mendel, 1995). Also, specific practices associated with floodplain and in-channel mining can promote various forms of instability.   For instance, pits and ponds created by mining provide various routes for diversions (changes in channel position), especially during floods (Mossa and McLean, 1997). Removal of large woody debris may also induce channel changes (Keller and MacDonald, 1995). Construction activity has been well documented as increasing sediment supply up to several orders of magnitude (e.g., Wolman and Schick, 1967). As a consequence, rivers with particular types of land uses are particularly dynamic and unstable in comparison with unmodified rivers.

While becoming increasingly common, the ramifications associated with river instability are numerous. Although there has been some qualitative study of the association of floodplain alterations and instability (Bull, 1973, Graf, 1979, Kondolf, 1994, Mossa, 1995, etc.), only few studies have examined this problem from a detailed quantitative and spatial perspective (Mossa and McLean, 1997).   Problems include: bank erosion and riparian property disputes associated with channel shifting, which sometimes leads to litigation; structural problems associated with undermining or filling at bridges and reservoirs; changes in channel capacity which affect flood patterns and increases the need for flood control; changes in floodplain habitat and effects to aquatic biota; and reductions in the quantity and diversity of fishes and mussels (e.g. Allan and Flecker, 1993; Brim Box and Mossa, 1999). Thus, it is important to riparian property owners, state and federal regulators, local communities and governments, industries, as well as other scientists and other individuals, to understand spatial and temporal variations of river channels, and how various factors contribute to instability and channel change.

RESEARCH OBJECTIVES

The stability of rivers and river reaches vary widely based on geologic and other natural factors. Based largely on curvature and the nature of bank sediments, some reaches are more prone to migration and cutoffs. The types and magnitude of anthropogenic impacts along rivers varies considerably. Scientists have had difficulty comparing the quantities of change, independent of scale. It is also difficult to classify the types of change in quantitative ways, and separate the background or natural rate(s) of change in a river system from change accelerated by direct and indirect human impacts. This paper discusses a technique that compares channel planform changes along and between rivers, independent of scale. The ratios characterize the types of change in quantitative ways, and can be used to separate the background or natural rate(s) of change in a river system from change accelerated by direct and indirect human impacts. The major rivers in the Pascagoula basin (Leaf, Chickasawhay, and Pascagoula) and two disturbed tributaries to the Leaf (Bowie River, Thompson Creek) are used as examples.

STUDY AREA DESCRIPTION

Natural Setting

The Pascagoula Basin is located in southeastern Mississippi and drains about 25,000 km^2 (9700 mi^2), of which the Leaf and Chickasawhay are the principal tributaries (Fig. 1). The Leaf occupies the northwestern portion of the basin and drains about 9280 km^2 (3580 mi^2), and the Chickasawhay occupies the northeastern portion of the basin with an area of about 7700 km2 (2970 mi^2). The Pascagoula River drains southward into the Mississippi Sound, which is connected to the Gulf of Mexico.   It drains all or parts of 21 counties in Mississippi. The state of Mississippi experiences abundant rainfall, with different locations in the basin averaging from 1300 to over 1700 mm (52 to 68 in) annually, yet on the Pascagoula, some years average four times the flow as other years (Lamonds and Boswell, 1985).

The topography of the Pascagoula basin is generally rolling to hilly with low to moderate relief, with the highest elevations in the northern part of the Chickasawhay basin exceeding 180m (600 ft). The basin has sediments of diverse lithologies that are Eocene and younger (Bicker, 1969) (Fig. 2). The mineralogy and lithology of these deposits in the central part of the basin is further characterized in Li and Meylan (1994) and Meylan and Li (1995).

Land Use/Land Cover, Changes and Disturbances

The total estimated surface area in the Pascagoula River watershed is 342,700 acres (U.S. Department of Agriculture-NRCS, 2005). Based on data extracted from the 1992 USGS Land Use/Land Cover classification, most of the land is in forest (67.8%) (Fig. 3). There are 542 farms within this watershed, and the average farm size is 94 acres. There are about 22,100 acres of cropland and 20,800 acres of pasture, each over 6% of the total area, and less than 3% of the basin is considered developed.

Different disturbances in the basin have affected the patterns and timing of sediment supply. The European history in the basin begins in the 1830s. Although the area has remained predominately forested there is a strong history of agriculture and timber harvesting. The first complete census of agriculture is from 1920. The census of agricultural data for the counties in the study area show a peak in agriculture related landuse in the 1950s. In the decades since the amount of cropland has declined. Timber harvesting began in the area in the 1840's but was limited to the banks of streams until the Mississippi timber boom that began in the 1890's. From 1904 to 1915, Mississippi was ranked third nationally in timber production (Howe, 2001). Although the boom ended in the 1930s, and the production of lumber declined since then, it is still a major source of revenue for the region. While agricultural and timber activity has declined in the region in recent years, other forms of land use have increased their impact. In-channel mining occurred on the Bowie River in 1946 and was prohibited in 1995. Floodplain sand and gravel mining presently occurs along the Bowie River, Thompson Creek and Leaf River. Concurrently, development has been occurring in many parts of the basin, including the cities of Pascagoula, Moss Point, Meridian, Hattiesburg and Laurel.
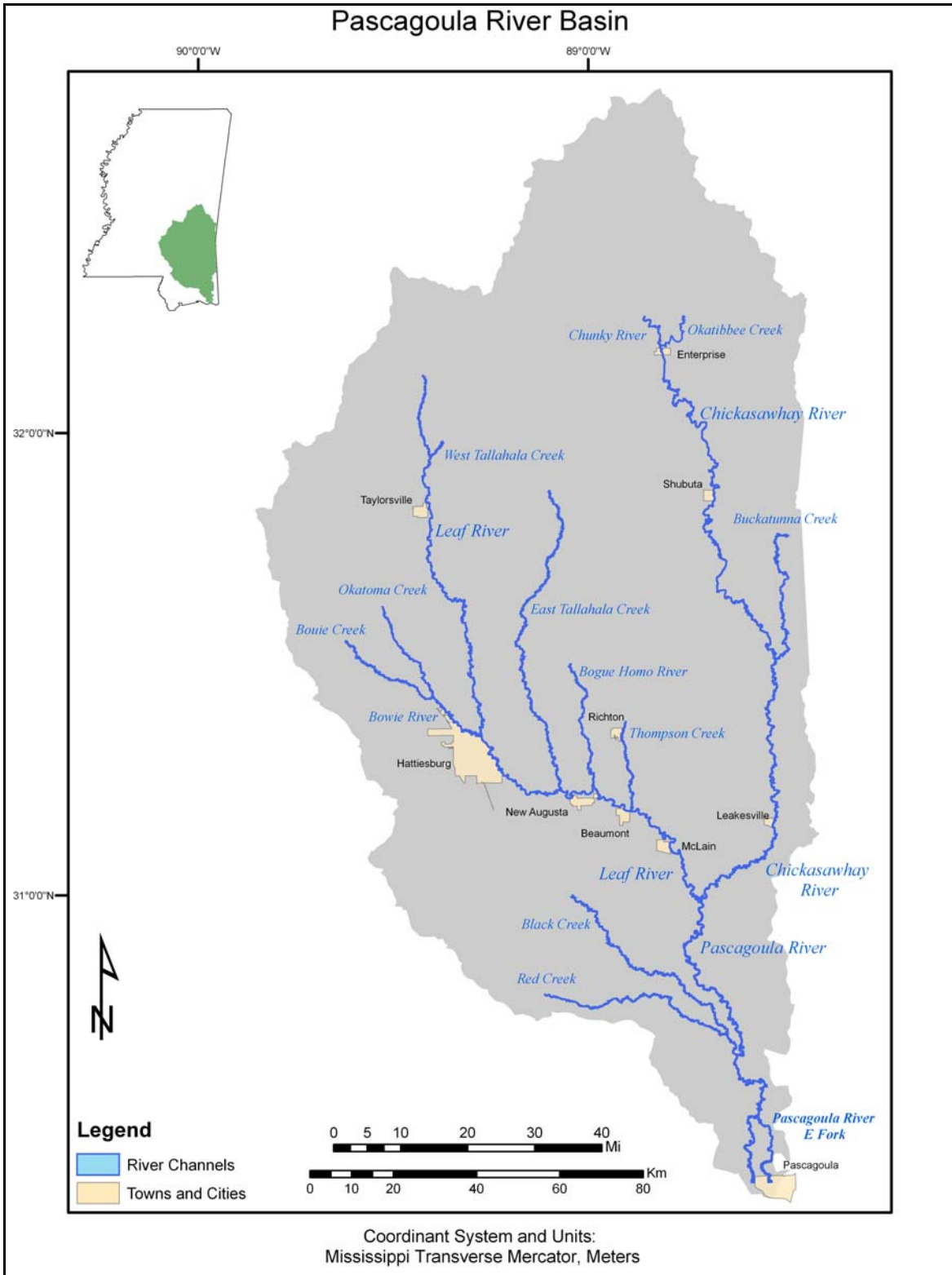
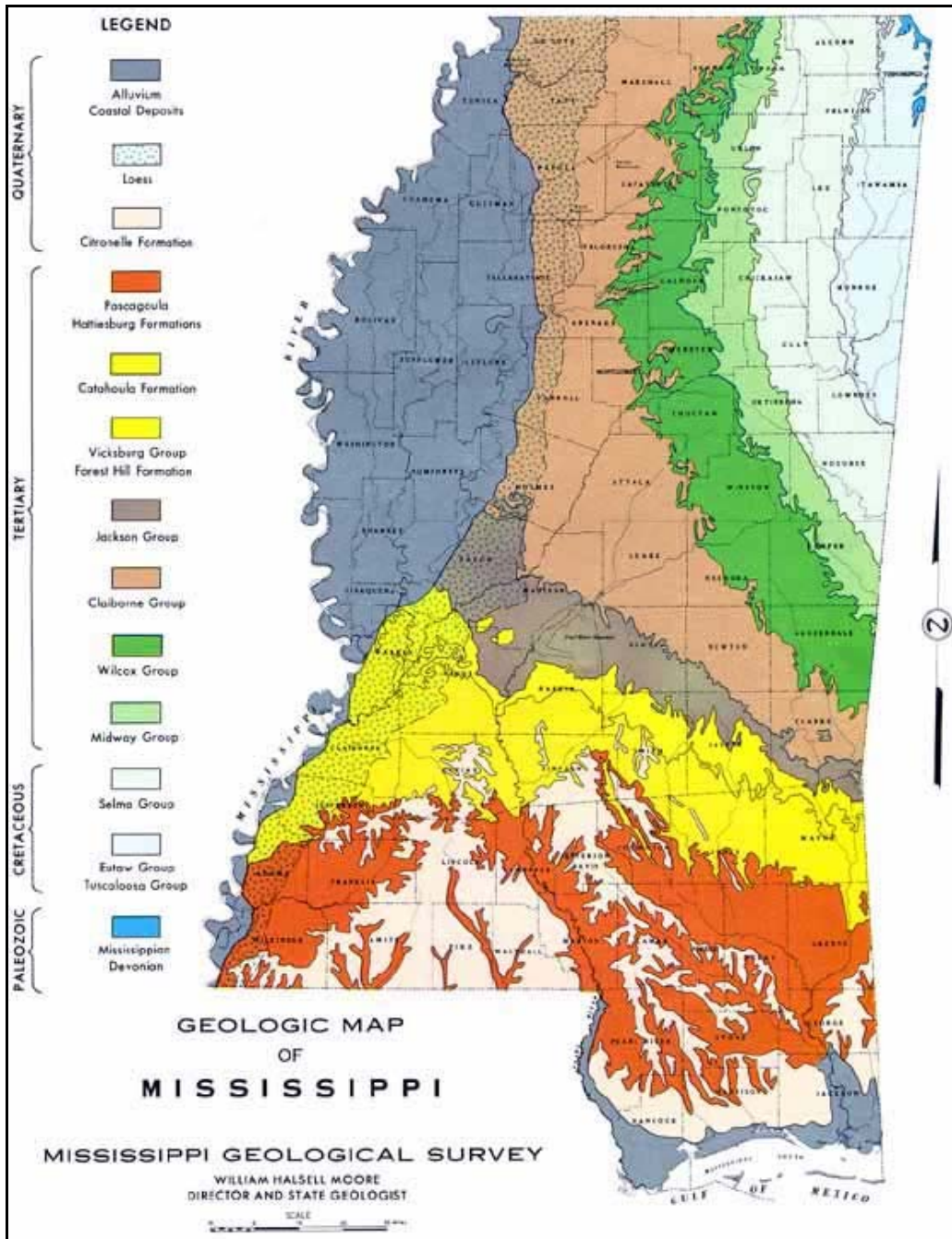Figure 1. Map showing the Pascagoula River drainage basin.

Figure 2. Map showing geologic formations in study area with county names and rivers, courtesy Mississippi Geological Survey. Source: **http://www.ces.clemson.edu/semaps/jpeg/8dmsr/8d2.html**
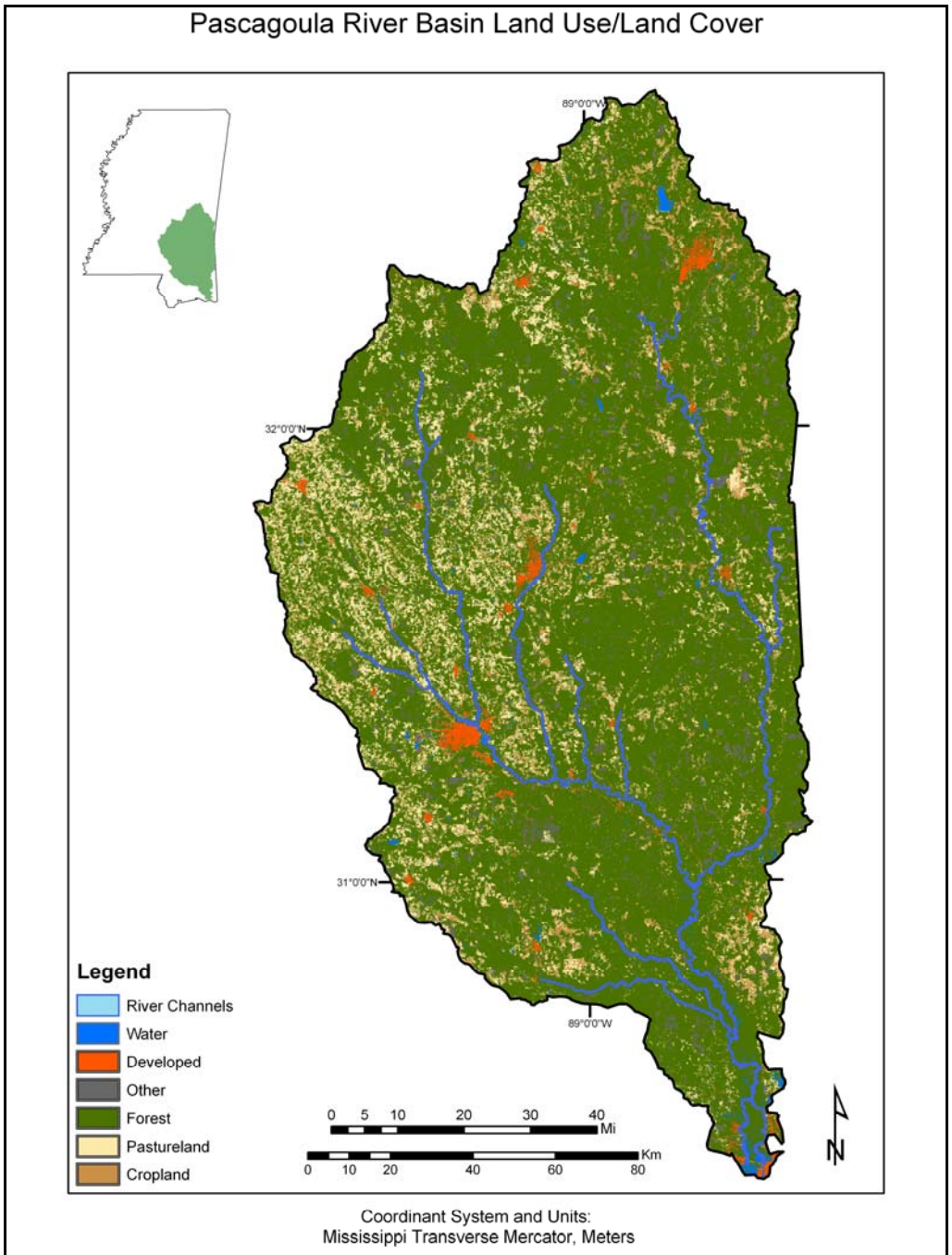
Figure 3. Land use/Land cover of the Pascagoula River Drainage basin.

METHODS

Mapping of Channel Boundaries for this Change Analysis

Over 2600 km (1640 mi) length of channel banks were digitized from the 1995-96 DOQQs. Given that only channels with both banks visible were digitized, this corresponds to over 1300 km (800 mi) river length and about 1000 km (600 mi) of valley length.   Comparable lengths were digitized for the 1982-86 channels. Somewhat less channel length was digitized for the 1955-1960 period because of image quality and difficulties discerning the channel under vegetative coverage in smaller tributaries and channels. Map coverage for the 1947-1951 period was spotty and concentrated largely in the southern portion of the basin, thus the least channel length was digitized. Best available geospatial methods were used and stream channels and other all other data digitized were checked for quality assurance and spatial accuracy. Channel change maps were presented in Mississippi State Transverse Mercator (MSTM, a custom projection). Specific information on coverage accuracy, registration procedures, channel boundary mapping, minimum mapping units and attribute data are in Mossa and Coley (2004).

The magnitude of work involved is better understood when compared to other studies. For example, the only other study in the basin involving planform change (Turnipseed, 1993) assesses about 4 km (2.5 mi) valley length total. Published studies involving GIS and channel change are of comparatively short reaches, including Cluett and Radford (2003) who examined 5.5 km (3.4 mi) of the Lower Ord River in Australia, Gurnell (1997) who examined 18 km (11.2 mi) of the River Dee in England and Mossa and McLean (1997) who examined 50 km (31.1) of the Amite River in Louisiana.

Channel Change Analysis

By producing overlays of channel boundaries in the same projection for different time periods, the degree and type of instability in various reaches could be assessed. The polygons produced by overlaying channel boundaries from two time periods were labeled according to whether and how they have changed from the prior time period into the following categories: E (erosion), D (deposition), B (between), or U (unchanged) (Mossa and McLean, 1997) (Fig. 4; Table 1).

Normalizing by initial channel area or I (also D+U) allows comparison of different size channels, either along-stream or between streams. Thus, the proportional area change ratios (U-I, D-I, E-I, B-I) compare the type and amount of areal planform change across space for different periods (Mossa, 1999). U-I shows what proportion is unchanged or in its initial position. D-I shows what proportion of it has been deposited or abandoned, E-I shows what proportion of the initial channel area has been eroded, and B-I is a measure of displacement through cutoffs, rapid migration, or local avulsions into pits and secondary channels. Because rivers migrate naturally, some erosion and deposition is expected in an interval of a decade or longer, but high values of B (area between channels), other than occasional cutoffs in sinuous reaches, are usually indicative of instability. As a number of other planform geomorphic variables, the above measures are somewhat stage- or discharge dependent and should be interpreted accordingly. However, B is less stage-dependent than U, D or E.
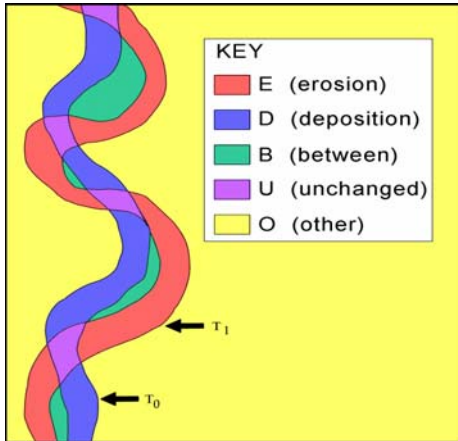
Figure 4. Channel boundaries for different time periods are used to make overlays in a GIS. Polygons are then labeled as E, D, B, or U according to whether and how they have changed from the prior time period.

Planform change variables and ratios (Table 1) were derived from reach blocks of 1km for small tributaries and 2 km for the major rivers in the system. This decision about reach block size was a compromise between reducing landscape noise and capturing local spatial variability. Different types of natural and disturbed reaches will change in different ways and their planform changes can be quantified using areal change ratios and visualized in Figures 5a and 5b.

Table 1. Planform change variables used in GIS overlays and computations AREAS
U: Portion or area of channel that is unchanged or remains in same position D: Portion or area of channel abandoned/deposited when comparing two periods E: Portion or area of channel created/eroded when comparing two periods B: Portion or area between channels when comparing two time periods,   Reflects amount of displacement from cutoffs, rapid migration or avulsions I: Area of channel during the initial period in reach block, also equals D + U
TIME INTERVALS
$\Delta T_{ly-ey} = T_{ly}$ (Latter year of comparison) - T_{ey} (Earlier year of comparison): Number of years between selected planform change comparisons, can be expressed in decimals if dates of photographs are known
PROPORTIONAL AREA CHANGE RATIOS
U-I: U divided by I, shows proportion of initial channel area in same position D-I: D divided by I, shows proportion of initial channel area abandoned E-I: E divided by I, shows proportion of initial channel area eroded or created B-I: B divided by I, shows proportion of initial channel area between channels
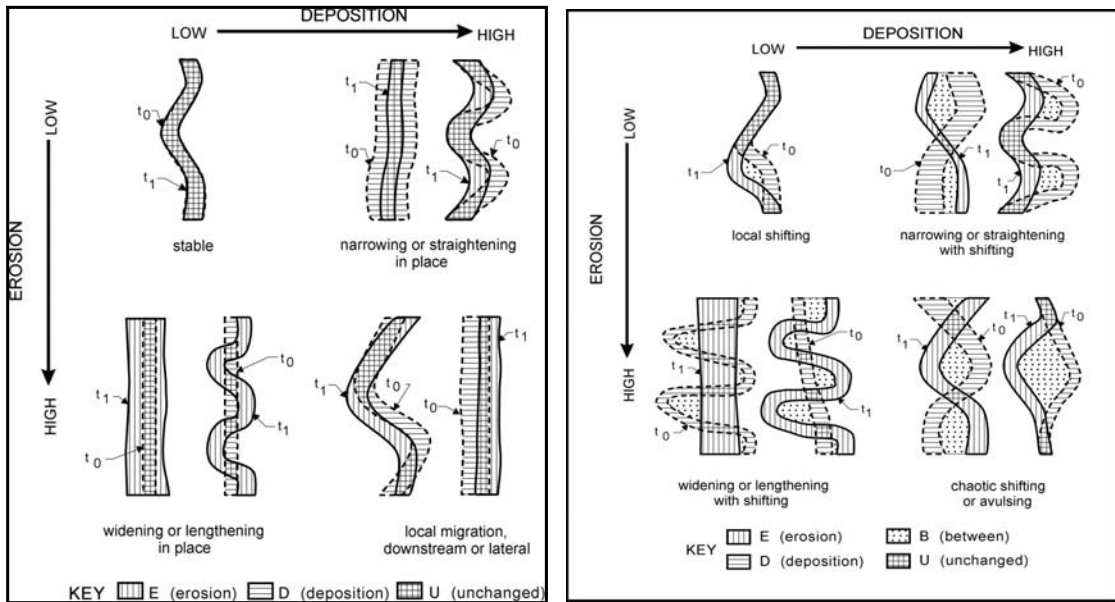
Figures 5a and 5b. Types of planform changes can be interpreted from the absolute/relative amounts of erosional and depositional areas (a, left) or the area between channels and the absolute/relative amounts of erosional and depositional areas (b, right).

RESULTS AND DISCUSSION

Major Rivers: Chickasawhay, Leaf and Pascagoula Rivers

For this paper, changes over an approximately 40-year period are compared for 5 rivers in the basin. Planform change indices using historical data on three major rivers, the Chickasawhay, the Leaf, and the Pascagoula, are evaluated. Two modified tributaries.

The Chickasawhay is for the most part a stable river. It crosses several different geologic units, some of which are far more cohesive than others. There are localized cutoffs, shown by B-I values up to 0.4, suggesting that the area between channels was as much as 40% of the initial channel area in places. In general, most of these cutoffs occur in areas where the bank sediments are noncohesive, and the channel is sinuous. The straight reaches tend to be semi-consolidated mudstones and show less change or migration than sandier materials. Over the 40 year time period, about 60-90% of the channel remained in the same position (U-I values >0.6), except for a few local reaches with more rapid migration (Fig. 6).

The Leaf is less stable than the Chickasawhay (Fig. 7). The reaches with cutoffs are more numerous shown by the peaks in B-I along the channel. Over the 40 year time period, about 60-80% of the channel remained in the same position, except for a few local reaches with more rapid migration. One of these areas occurs upstream of the juncture with the Bowie River where a headcut is likely moving upstream. Prior study showed that the Leaf River shows reduced stage elevations, decreased mean and thalweg elevations, and increased planform instability at and upstream of its juncture with the Bowie River, a tributary with considerable in-channel mining (Mossa, 2003). Degradation and planform change on the Leaf was likely due to in-channel mining in this tributary, where a pit boundary on the channel bed expanded migrated into adjoining mainstem waters and then upstream.

The Pascagoula is the most stable of the three major rivers, especially in the lower portion (Fig. 8) The stability, indicated by U-I, mostly hovers around or above 0.8 and in the lowermost reaches exceeds 0.95, suggesting that over 80%, and in places 95% of the channel was in the same position in 1992 as in 1955. The increasing stability in the lower reaches is likely in part related to the bank sediments becoming finer, more cohesive and less erodible downstream. However, over the 40 year time period, cutoffs have occurred in a few very sinuous meanders. B-I values spike at these locations because the areas between the former (deposited) and new (eroded) channels are quite substantive at these sinuous cutoffs. Concomitantly, E-I and D-I increase as new channels are created, and U-I plummets to 0.2 to 0.4.
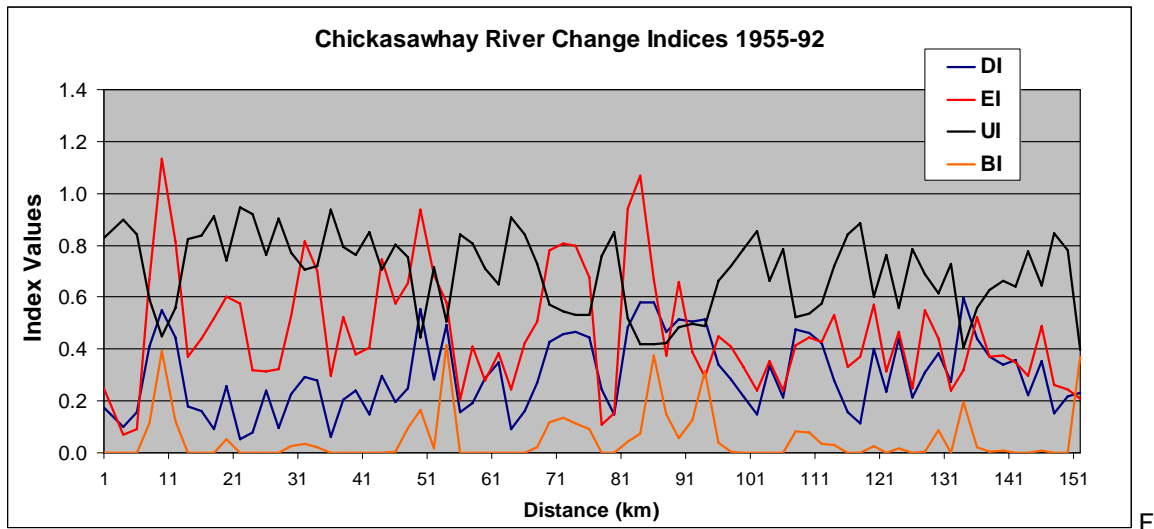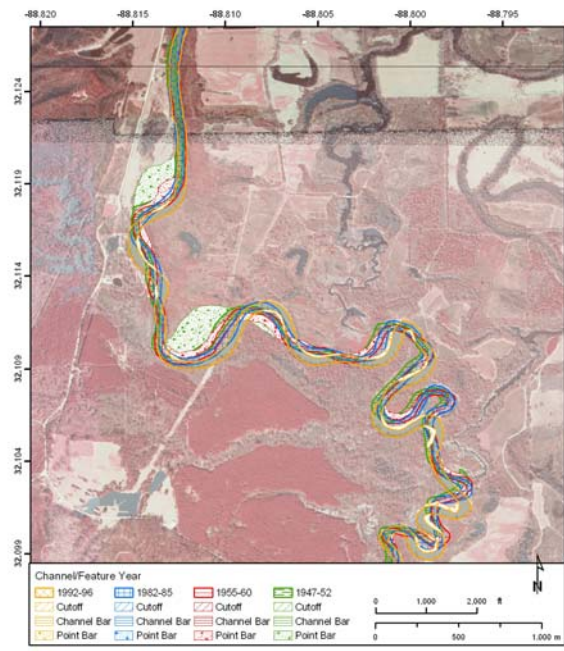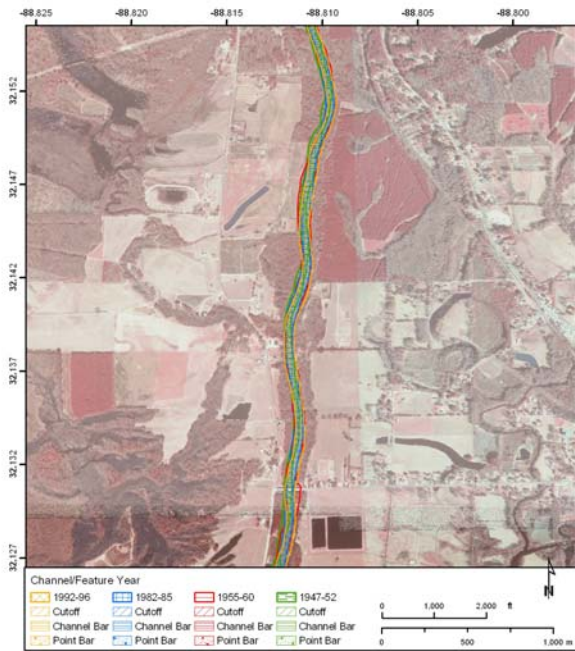
Figure 6. Planform change indices along the Chickasawhay River. Photos below show stability of straight reaches vs. greater migration in sinuous reaches.
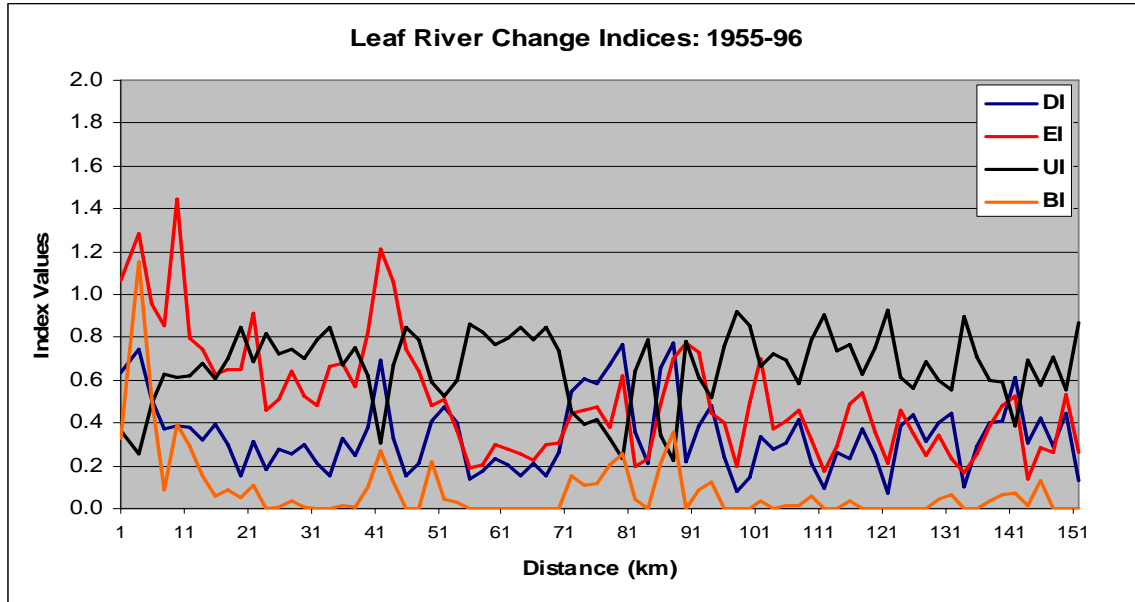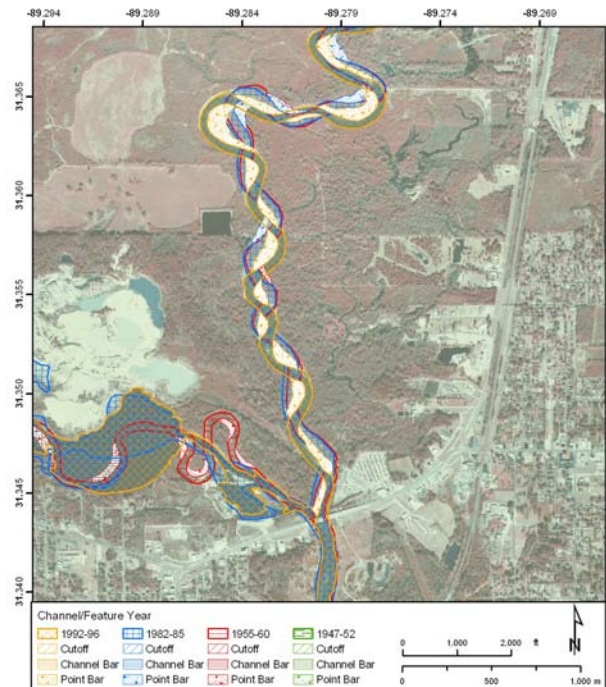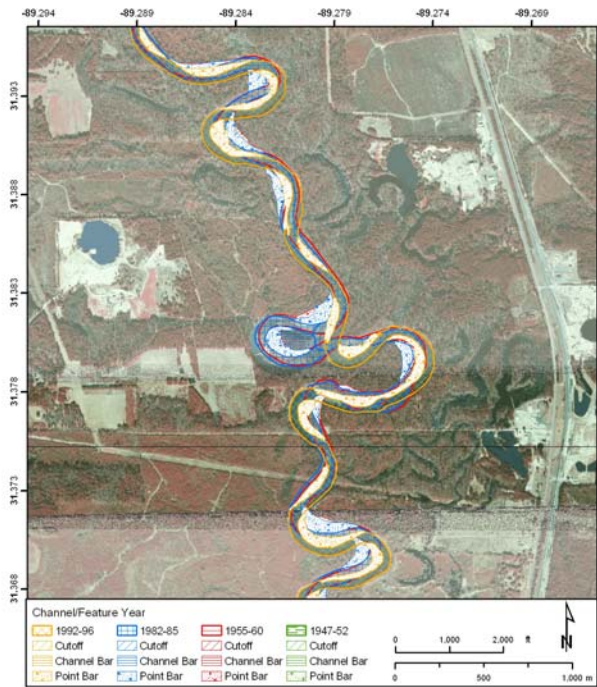
Figure 7. Planform change indices along the Leaf River. Photos below show recent instability just upstream of the juncture with the Bowie River.
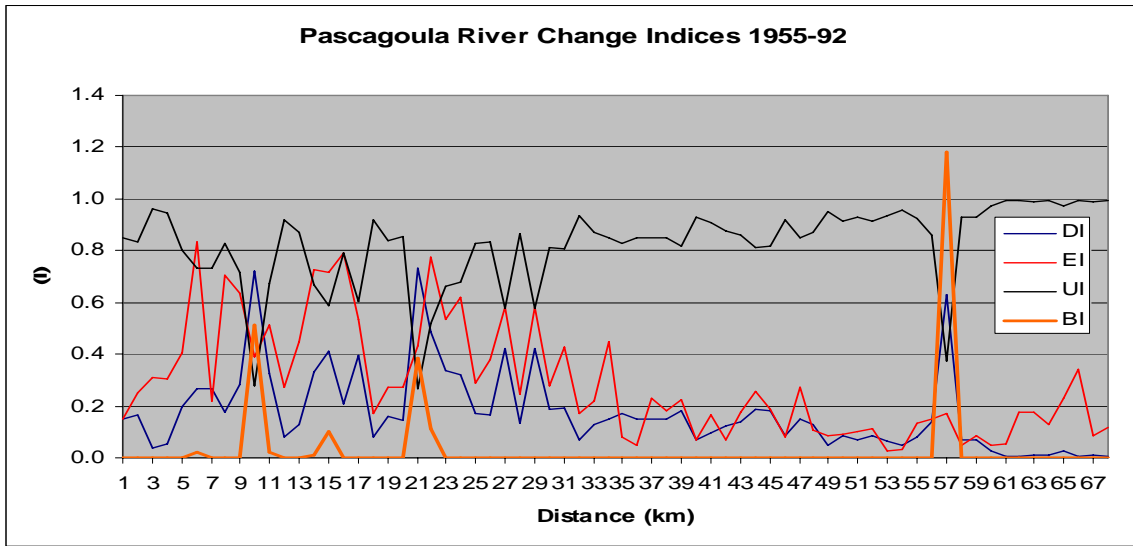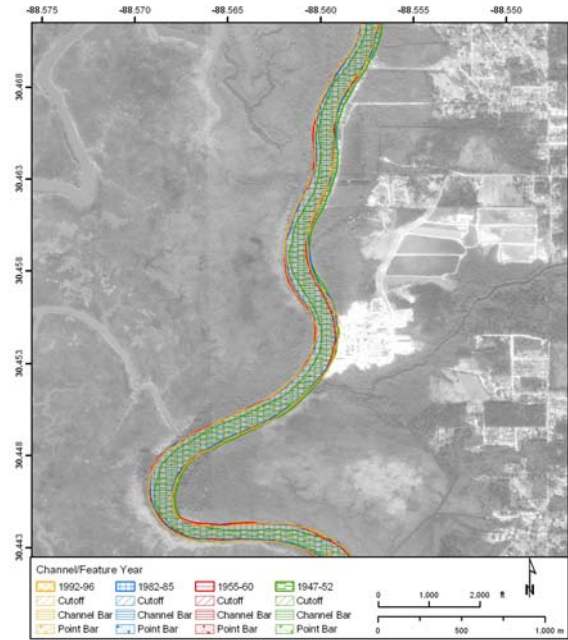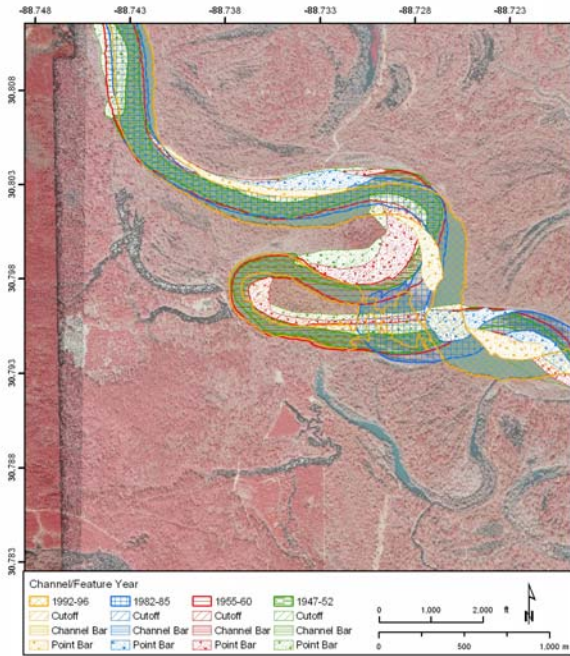
Figure 8. Planform change indices along the Pascagoula River. Photos below show a cutoff, a location where the B-I index would spike on the graph, and a very stable reach characteristic of much of the lowermost portion of the river where U-I values exceed 0.95 (95% of the channel is in the same position over the 40-year period).

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<u>Disturbed Rivers: Bowie River and Thompson Creek</u>

The Bowie River in southern Mississippi is a tributary to the Leaf River (Fig. 1) with a drainage area of 1732 km^2 (Mississippi DEQ, 2005a). The lower 5km before it joins the Leaf River has been altered by floodplain sand and gravel mining, but perhaps more so by historical in-channel mining that began in the 1940s and ended in 1995 by environmental regulation. On topographic maps, portions of the channel are several times wider than other portions such that the channel resembles a chain of lakes. This form is due to mining along the channel perimeter in selected reaches plus some avulsions into floodplain pits. Sections between mined reaches, and upstream of the mined stretch, tend to be fairly stable and in cohesive sediments. The planform change indices show enormous channel enlargement (high E-I values) due to instream mining of 4 to 5, about 400% to 500% increases from the initial channel area in locations (Fig. 9). There are also some avulsions into floodplain pits where the B-I values spike. Upstream reaches, and segments between the channel pits which resemble lakes, show much smaller variations. The rectangular box on the graph shows the range of variations in less modified reaches, which can be interpreted as the background values. Anything above this can be considered human impact, and clearly the mined areas show appreciable channel widening.

Thompson Creek is a relatively small tributary to the Leaf River (Fig. 1). Its drainage area is 493 km^2 (Mississippi DEQ, 2005b). The upper portions of the creek have had localized cutoffs and some channel shifting through migration. The middle and lower portion of the creek has had historical and active floodplain mining, with large bare areas, sandy mounds and pits on the floodplain. In some cases, the channel has avulsed into these pits, shown by the higher B-I values in the planform change indices (Fig. 10).   More change has occurred due to mining than these values suggest, because one photo (Fig. 10) shows that there was mining connected to the channel, giving it a large initial area, prior to 1955. For the most part, U-I values are 0.6 or lower, suggesting that only 60% or less of the channel was in the same location in 1996 as in 1955. Clearly, this creek is more disturbed than the larger rivers in this system, and the mined lower portion shows more change than the upper portion.
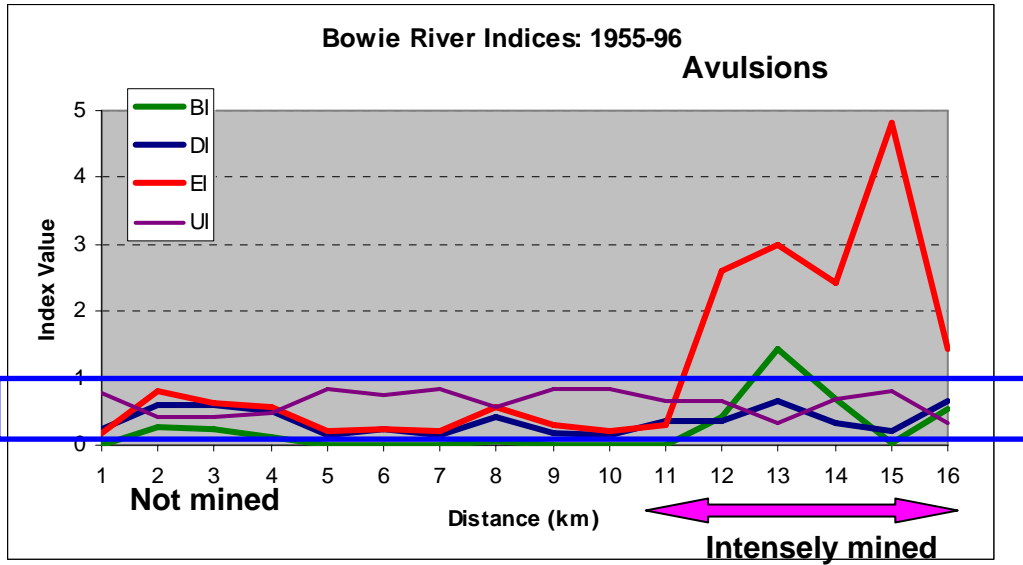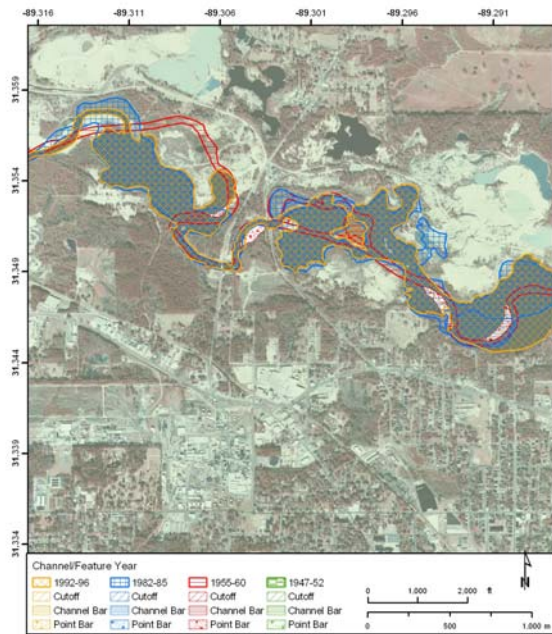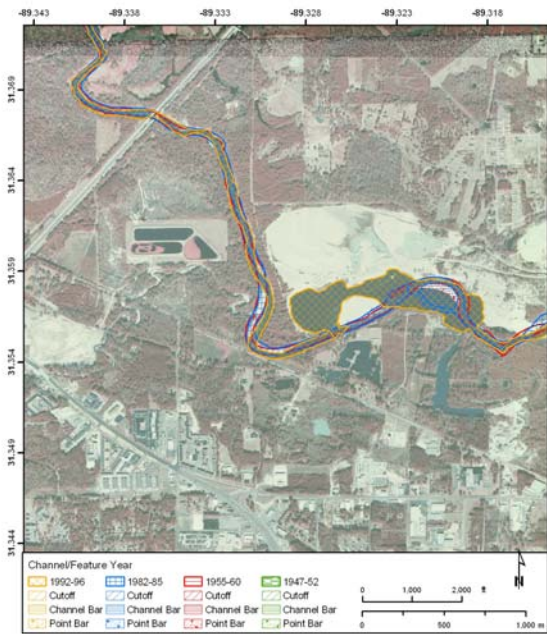
Figure 9. Planform change indices along the Bowie River. Photos below show enormous channel enlargement (high E-I values) due to instream mining, about 400% to 500% increases from the initial channel area in locations and some avulsions where the B-I values spike. The box shows the range of variations in less modified reaches, compared, and the intensely mined reach is well above these background values.
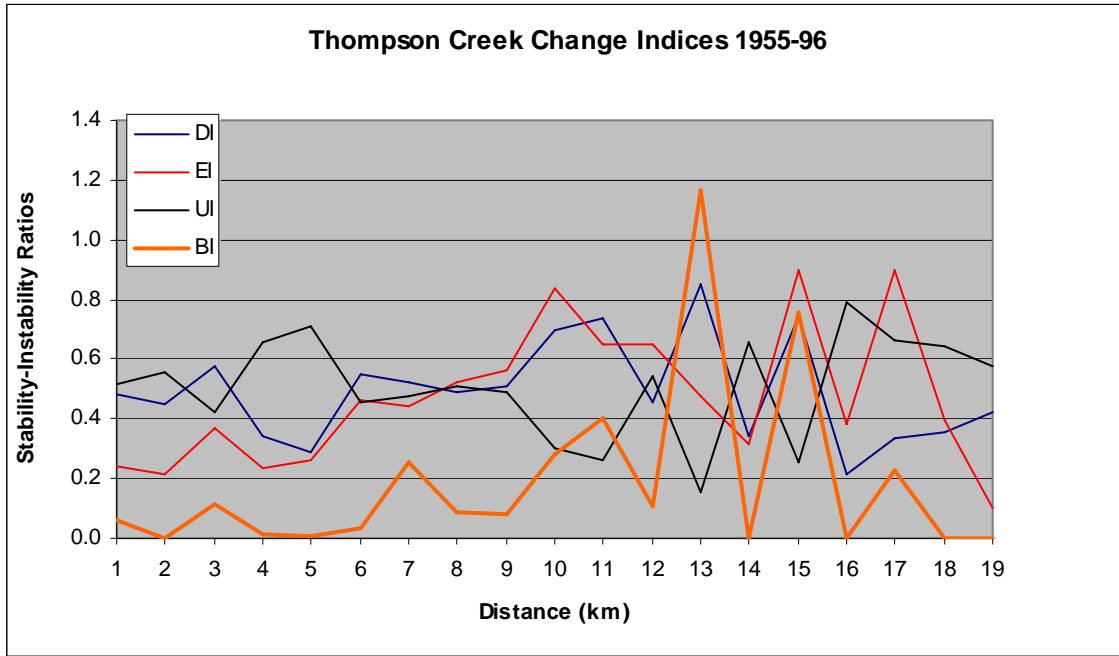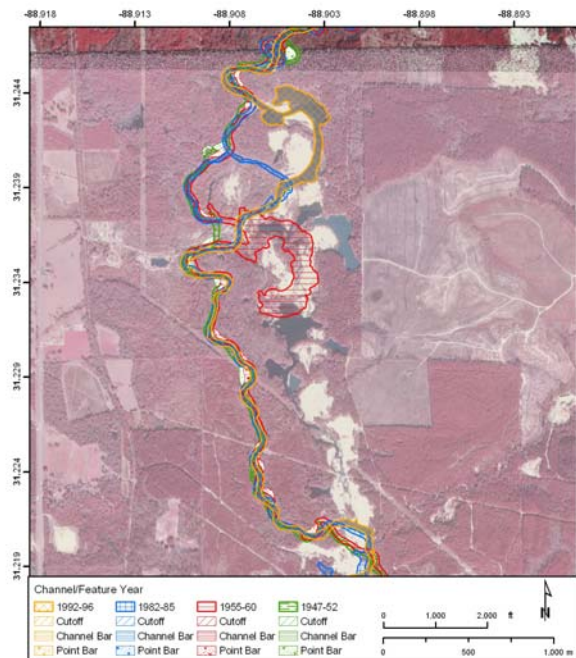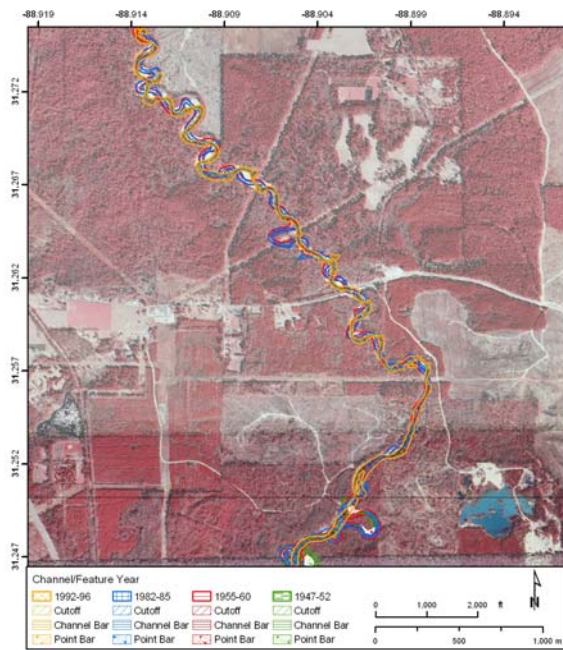
Figure 10. Planform change indices along Thompson Creek. Photos below show an area with that has changed, primarily due to natural factors, and an area with avulsions into floodplain pits associated with sand and gravel mining.

CONCLUSIONS

The major and minor tributaries in the Pascagoula system show a wide range in planform change indices or lateral stability-instability conditions, related to geology, anthropogenic alterations and other factors. Unstable reaches have varied forms, including reaches with cutoffs, reaches with avulsions, reaches with direct anthropogenic channel alterations such as channel widening due to instream mining, reaches with appreciable lateral migration, and reaches that have altered in width for other reasons. In some places, the cause of the instability is evident, and in other cases it is not.

Of the major rivers in the Pascagoula basin, the Leaf is the least stable. Some of its tributaries (especially Bouie River and Thompson Creek) are even less stable as channel planform changes greatly exceed background rates. For instance, appreciable channel enlargement (E-I values of 4 to 5) due to instream mining occurs on the Bowie, indicating about 400% to 500% increases from the initial channel area in locations. Both the Bowie River and Thompson Creek showed higher than background B-I values in locations associated with avulsions into floodplain pits. Besides the rivers in this paper, several other major tributaries in the basin have been digitized and mapped. Individuals interested in historical changes at specific locations in the basin should consult Mossa and Coley (2004), a report with over 200 color maps on the Pat Harrison Waterway District website (http://www.phwd.net/district_water_quality.asp, Year 2 final report).

Many places that have been unstable historically are likely to go through additional adjustments in the future. Further changes are likely in the Bowie River and Thompson Creek, and in the Leaf River upstream of the Bowie juncture. Application of best management practices for different land use/land cover categories, including the timber industry, agricultural practices for cropland and pastureland, and practices to limit the impacts of urbanization and development on runoff and sediments, such as retention-detention ponds and construction fencing, should be adopted to minimize future impacts. Mining has impacted a few streams in the basin and more work should be done to document which types of activities create the most serious impacts and to develop best management practices for this industry.

The methods described and applied herein, involving planform change indices using GIS, are useful for comparing the quantities of change, independent of scale, for classifying the types of change in quantitative ways, and for separating the background or natural rate(s) of change in a river system from change accelerated by direct and indirect human impacts. The maps and the change indices, when applied wisely, can be used in planning, management, engineering, and stream restoration in the basin.

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