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Monongahela and Youghiogheny Rivers, Pools 2 and 3 Riverbank Geology, Conditions, and Access Reports

Phase 2 - 2001

MONONGAHELA AND YOUGHIOGHENY RIVERS, POOLS 2 AND 3
RIVERBANK GEOLOGY, CONDITIONS, AND ACCESS REPORTS

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Abstract

The intent of the 3R2N terrestrial study is to describe and document conditions of riverbank geology, accessibility, preservation, and restoration potential along the Monongahela and Youghiogheny Rivers in Pools 2 and 3, Allegheny County, Pennsylvania. Data collected during the 2001 field season includes bank and berm slopes, heights, material types and grain sizes, material conditions, accessibility potential, and floodplain identification. Data was collected along 1/10th mile sections of each bank, which were identified in the field with a Global Positioning Receiver (GPS). This data was entered into a database for later GIS and ARCINFO analysis. Riverbank access was graded into three categories, and mapped with ARCVUE computer software. Preservation data was also graded into three categories, and mapped. The data from the access and preservation maps was filtered through a Boolean truth chart, and riverbank sections worthy of restoration were identified, graded, and mapped. Riverbank grain sizes and materials distribution were plotted for each pool, and the resulting trends discussed.

GEOLOGICAL SETTING

A Geological History of the Monongahela River

The present-day Monongahela River flows northward from West Virginia, to its confluence with the Ohio and Allegheny Rivers at Pittsburgh, Pennsylvania. It is slowly eroding and downcutting through the bedrock of the Pittsburgh region, which consists of flat-lying sedimentary beds of shale, sandstone, limestone, clay stone, and coal that were originally deposited during the Pennsylvanian Period of geological time (about 300 million years ago). During this time of rock formation, the river drainage system and topography were totally different from that seen today; the ancestral rivers flowed West into a shallow sea that covered Western Pennsylvania and Eastern Ohio. The climate was tropical, as the equator was very close to the Pittsburgh area due to continental drift. Figure 1 is a map of Pennsylvania, as of 300 million years ago.

The history of the Monongahela as we know it today probably began back at the beginning of the Cenozoic Era, about 60 million years ago (Wagner, 1970). During this time, Western Pennsylvania was a broad, flat plain similar to those now seen in the Midwestern United States. There was probably very little topographic relief; that is there was little elevation difference between the tops of any hills and the water level of the Monongahela. The topographic relief in Pittsburgh is now nearly 700 feet, as the level of the water in the Monongahela at the Point is 710 feet above sea level, and the tops of the highest hills are almost 1400 feet above sea level.

During the late Cenozioc era (about 5 million years ago) geological processes slowly uplifted the Pittsburgh area, increasing the slope of the Monongahela River, allowing it to start downcutting erosion. The erosional style during the early Cenozoic Era was one of sidecutting, with large river meander loops. As the Monongahela flowed faster due to uplifted land, and a greater downslope river gradient (with a larger resulting erosive capability), the river's course straightened out somewhat and sideways erosion was abandoned to greater downward erosion. Deep valleys were then cut, about 400 feet below the elevation of the plain formed during the early Cenozoic Era. If one looks out at the Pittsburgh landscape from a high point (such as the USX Tower downtown) one can see that all the hilltops are level, and represent the remnants of this old plain (figure 2). The downcutting action of the Monongahela continued until the river's water level was about 200 above that seen today.

There was a temporary hiatus of the downward erosion of the Monongahela, and this was effected by the advance of the great ice sheets that covered Northwestern Pennsylvania during the "ice ages". There were four ice sheet advances during this time period, but the next to the last ice advance radically changed the courses of some of our rivers.

The Monongahela has always flowed north, emptying into the Ohio River along with the Allegheny. Before the third ice advance, the Ohio river originally flowed north into Lake Erie, in the valley of the present-day Beaver River. The ice sheet advance dammed the north-flowing Ohio River, and water impounded behind it forming a large valley-fill lake. This lake, called "Lake Monongahela", probably formed between 750,000 and 970,000 years ago (Marine and Donahue, 2000). Thick deposits of sand, mud, gravel, and cobbles can be seen in certain places within Pittsburgh, at about 920 feet above sea level; this deposit is known as the “Carmichaels Formation”, or the “Parker Strath” (Wagner, 1970). These unconsolidated sediments represent material deposited by the Monongahela when it was impounded by glacial ice to the north. Figure 3 represents these terrace deposits and abandoned loops in the Pittsburgh area. Marine and Donahue (2000) have found evidence for this lake as far south as present-day West Virginia. The Cathedral of Learning (University of Pittsburgh) and the Carnegie Museum of Natural History both rest on the Carmichaels Formation deposits. Sometime during this high water event, the southern portion of the Ohio River eroded through its divide, and started to flow southward. Figure 4 shows the pre-glacial river drainage in Western Pennsylvania.

As the glacial ice finally retreated, the old divide was eroded through, and all the water from the Monongahela flowed southward to the Mississippi River, as it does presently. Lake Monongahela drained, and the river started again on its downcutting action. There was a fourth ice advance that did not greatly affect the Monongahela. Downcutting remains the major erosional style of the Monongahela, even though there is still some meandering and sidecutting. The water level of the Monongahela dropped about 200 feet, since the third ice advance; this may give an idea of how slow erosional processes are on a major waterway. Figure 5 is a map of the present drainage in Western Pennsylvania.

DATA ACQUISITION AND ANALYSIS

Field Methods

The field work for Year 2 of the project was confined to Pools 2 and 3 of the Monongahela River, and 9 miles of the Youghiogheny River, upstream from its mouth at McKeesport, Pennsylvania. Pool 2 of the Monongahela River starts at Lock and Dam #2 in Braddock, PA, and ends at Lock and Dam #3 at Elizabeth, PA. Pool 3 was described from its downstream end at Elizabeth PA, up to the Allegheny County boundary line near Donora, PA.

Both banks of the Monongahela River and the Youghiogheny River were divided into $1/10^{th}$ mile sections. These section’s start and stop points were programmed in to a GPS (Global Positioning System) receiver unit as latitude and longitude points. This GPS receiver was used aboard the field vessel to determine each section’s starting and ending point.

The geology and geometry of the riverbank and/or berm was decribed for each $1/10^{th}$ Mile section. If a berm was present in a section, its slope was reported (in degrees) and the average grain size distribution data was recorded. A modified version of the Wentworth-Udden scale of grain sizes was used to report data for this study (Boggs, 1987) which is:

- Boulder Size ⇢ 256 mm.
- Cobble Size ⇢ 64 mm., ⇠ 256 mm.
- Pebble Size ⇢ 4 mm., ⇠ 64 mm.

- Coarse Sand Size ⇢ 1 mm., ⇠ 4 mm.
- Sand Size ⇢ 1/16 mm., ⇠ 1 mm.
- Silt Size ⇢ 1/256 mm, ⇠ 1/16 mm.
- Clay Size ⇠ 1/256 mm.

Along with the grain size distribution data, and the berm slope in degrees, the percentages of natural and manmade materials were recorded for each section. Manmade materials include slag, cement, steel, wooden bulkheads, gabion, stone block, rubble, and “other”.

Natural materials (if not moved and deposited by human operations) were classified as bedrock, boulders, cobbles, gravel, sand, mud, and “other”.   Driftwood piles and other garbage that deposited or dumped on the berm was not included in any of the geological descriptions.

The descriptions for the riverbanks were described using the same procedure as the berm; the bank slope was reported in degrees, the grain size distribution of the bank materials was determined, and the percentages of the natural and manmade materials was recorded for each 1/10th mile bank section.

The condition of the berm and bank materials was reported as “consolidated” or “unconsolidated”. An example of a consolidated bank would be a steel bulkhead, or a stone block wall. Unconsolidated natural bank and berm materials include sand, gravel, cobbles, silt, and mud. Manmade materials can also be unconsolidated, including slag piles, and coal mine waste dumps.

Along with the berm and bank slope steepness number (in degrees), four categories of Steepness were recorded. The first, “vertical”, implies a 90° “slope”. A “steep” bank or berm is one that has a slope greater than 45°, but is not vertical. A “moderate slope is less than 45°, but greater than 22°; and a “slight” bank or berm slope is less than or equal to 22°.

The bank and berm slopes were measured using a wooden Jacob’s Staff, and a geological compass that has a built-in clinometer. The Jacob’s Staff was placed parallel with the slope to be measured, and the compass was placed on the staff, and an angle in degrees was then recorded. Most berm slopes were less than 25°, and bank slopes usually were greater than 45°. The bank height measurements were determined by line-of-sight from the opposite bank, or the middle of the river, using an object with a known height (such as a building, or a railroad freight car) for comparison. Bank heights were also determined by climbing the bank, noting its slope, and estimating height using simple trigonometric relationships.

Bank and berm accessibility was reported as “easy”, “moderate”, and “no access”. Easy access (from the water side of the bank and/or berm) usually had a berm with a slope of less than 22°, and a material grain size distribution that allowed easy landing from a boat. Large boulders inhibit access, as thick soft deposits of mud and silt. The berms that had the easiest access had a large amount of sand, coarse sand, and pebble sized material, and a small amount of cobble sized grains. Steep banks with no berms (and bank slopes greater than 45°) generally had more difficult access, and a vertical wall or bulkhead was classified “no access”.

Grain size distributions for the bank and berm materials were measured by picking one spot of the bank or berm (about 1 meter square) if the rest of the 1/10th mile section had similar material characteristics. If the grain size of the bank and/or berm material changed significantly in one section, then an overall size distribution average was reported. Banks that were covered by dense vegetation were sampled with a shovel to determine materials and grain size ranges. Berm and bank areas that appeared to be in a natural state were sampled, and the material was sieved to determine grain size distribution ranges.

Figures 6, 7, and 8 show riverbanks that are vertical, and have consolidated materials that are manmade. These banks are classified under the “no access” category. Figure 6 is a high cement bulkhead alongside the Clairton Coke Works of USX Inc., at Clairton, PA. This wall is over 25 feet high. Figure 7 is a combination steel and concrete bulkhead below the Duquesne Light Company powerplant near Monongahela, Pa. These walls are also over 25 feet high. The third photograph (Figure 8) is an example of a vertical high wall built from consolidated slag. Many steel making sites along the Monongahela River utilized an unsaleable waste product as a building aggregate, increasing the amount of level land above high flood stage.

Other areas of “no access” include the riverfront adjacent to lock and dam structures, and portions of the bank blocked by shipping activity (Figure 9).

Figures 10, 11, and 12 are areas that have difficult, but possible access. There is a lack of berm in these examples, the grain sizes of the bank materials are very coarse (boulder sizes), and the bank slope is steep, prohibiting easy landing from the water. Figure 10 is a portion of bank where large boulders (known as rip-rap) were dumped along a railroad right-of-way edge to help stabilize the bank and prevent erosion. Figures 11 and 12 depict a similar situation as Figure 10, but there is no railroad right-of-way nearby. These banks were intentionally stabilized for some other reason.

Figures 13, 14, 15, 16, and 17 all show bank and berm conditions along the Monongahela River that have “easy” access conditions. Figure 13 is a photograph of a wide berm, with a slight bank in the background. This is “easy” access, but not ideal access, as the berm has a high concentration of silt and mud, making a boat landing slightly unpleasant, due to soft conditions. Figure 14 has ideal accessibility; the berm slope is slight, and the materials consist of sand and course sand, making boat landing easy and pleasant. The steep bank (about 12 feet high) is also very sandy, and this is a typical low floodplain deposit, usually seen on the inside of river bends. This is also known as a “point bar” deposit. The berm shown in figure 15 is of coarser material than in the previous two photographs; most of the material is pebble size, with about 20% of the berm as cobble size grains. Over 50% of this berm consists of coal, that was probably dumped from an old mining or coal loading facility. This berm has easy access, as landing here was not difficult or unpleasant. Figures 16 and 17 also show easy access, which has been improved by the addition of boat launching ramps. In both cases, the bank heights are low, the berm is wide with a slight slope and sandy.

Many other intermediate bank and berm conditions were observed during the 2001 field season on pools 2 and 3 of the Monongahela River. A stone block highwall and culvert is shown in Figure 18, along the old Pennsylvania Railroad right-of-way near Bunola, PA. Figure 19 shows an area of easy access, that has been improved with the addition of a riverside grandstand. The berm here is mostly pebble sized material, with some cobbles and boulders lying on top of the berm. The bank slope is about 35°. In figure 20, a well-defined berm can be seen, consisting of pebble sized material, with minor cobbles and one boulder. The bank is very typical of a railroad line that is close to the water's edge; the bank is steep (about 65°) and is composed of rubble and fill that was imported to build the right-of-way up above the river. Most "railroad rubble" consists of a mixture of crushed stone (as track ballast), slag (as fill) and coal mine waste (as fill). Large boulders are sometimes added for bank stability (see figure 21). Figure 22 is also a very typical railroad embankment, with a narrow berm. A third railroad embankment is seen in Figure 23; here the berm is wide, and consists of over 65% coal. The bank is 22 feet high, and slope is 70°, making it very steep. Most banks on the outside bends of the Monongahela River (where there is a railroad present) show similar bank geometries.

A sandier berm is seen in figure 24. The bank is lower than along a railroad, and there is little evidence of introduced bank and berm material here. A row of old wooden piling stumps by the water's edge bears testimony to the past existence of an old dock. The bank and berm in figure 25 is a mixture of sand, silt, and mud, with concrete blocks and other rubble. This is a small point bar deposit, on the inside of a river bend.

Figures 26 and 27 are areas affected by small streams entering the Monongahela River. The sediment load these streams carry during storm events is deposited where the steam flow suddenly decreases. (Note the large percentage of cobble sized grains.) Figure 28 is a close-up photograph of one of these small stream deltas that is dominated by cobble sized stones. The velocity of the stream water during a heavy rain does not allow the finer grains to settle out of the water. All of the mud, silt, and sand were deposited farther out into the Monongahela River.

DISCUSSION

Data Analysis

The data from each 1/10th mile section of pools 2 and 3 of the Monongahela River, and 9 mile portion of the Youghiogheny River were entered into a computer database, to be used in conjunction with the GIS and ARCINFO mapping programs.

The three major areas of inquiry using the geological dataset and the computer mapping programs are:

1) Describing which sections of the riverbank have easy, moderate, and no access;

2) Determining which riverbank sections are the best preserved, or which are closest to "pristine" condition, with minimum anthropogenic influence

3) Using datasets generated from sections 1 and 2 to find riverbank sections that are worthy of restoration and/or other improvements.

Access

Two different cases of river access were generated; s) access from the water onto the berm, and 2) access from the water onto a man-made vertical riverbank. Each case has three grades of access; grade 1 is easiest access, and grade 3 is the most difficult access. For the case of berm access:

- Grade 1 - Berm materials = 50% to 100% sand

- Grade 2 - Berm materials = 25% to 50% sand
- Grade 3 - Berm materials = less than or equal to 50% mud and/or less than or equal to 20% boulders

Three grades of access are described for case two, which consists of man-made riverbank material that has a vertical angle. Access is determined by bank height only.

- Grade 1 - 0 feet to 3 feet bank height
- Grade 2 - ⇢ 3 feet, to 5 feet bank height
- Grade 3 - ⇢ 5 feet bank height

These conditions were entered into the mapping program, and maps with the two cases of access were generated (figures 29 and 30). The above conditions for grading access were based on ease of landing a boat from the water's edge of the berm, or docking at a vertical man-made riverbank.

Preservation

Three different grades of riverbank preservation were created, with the idea of determining which sections were best preserved in their natural state. There are no high banks which are still in their natural condition, (as perhaps would have been seen before European settlement in the Pittsburgh area). All the high banks have been extensively modified, especially by railroad building activity over the past 150 years. Much material was imported as fill, to raise trackbeds above the floodplain level. The Monongahela and Youghiogheny rivers both had railroads along their banks and still do, although to a lesser extent, than when Pittsburgh was an industrial center.

The riverbank areas that are in their natural state are those that have their materials reworked by flooding action. The low lying banks and berms are affected by periodic floods to a greater extent than the higher ones; since there is constant dynamic change from erosion and deposition of material, these low sections represent the most “natural” portions of the riverbank.

To determine which areas qualify as best preserved, the height and frequency of flooding along the Monongahela River has to be taken into account. The typical 1 year (annual) flooding event has a water level height range of zero to 6 feet (US Army Corps of Engineers, 1987). The 2 year floods have average water levels up to 9 feet above normal pool elevation, and the 5 year flood has an average crest of 13 feet above pool. Any banks or berms below these elevations will have their materials and geometries reworked and changed due to the erosive and depositional action of the water. Hence, these low lying portions of the banks can be interpreted as the closest to natural state.

Another criteria used to determine preservation is the amount of manmade material present. If there is a smaller manmade material percentage in the bank or berm makeup, this can be interpreted as existing closer to a natural state.

The three grades of riverbank/berm preservation and their criteria for selection are:

Value	Physical Condition	Material Condition
• **Best Preservation** -	0 -6' Above Pool,	100% natural materials
• **Moderate Preservation** -	0 -6' Above Pool,	0 - 25% manmade materials
• **Poor Preservation** -	6 -9' Above Pool,	0 - 25% manmade materials

These data operators were entered into the ARCINFO computer mapping program, and maps of the riverbank section's preservation potential were plotted.

Restoration

The restoration potential is contingent on bank height (and potential floodplain affect) as well as soil composition. As depicted in the table below, restoration values have been identified by physical condition in relationship to the material condition of the banks. A third element, access to the site from both land-based communities and water-use communities has not been considered in the current study.

Value	Physical Condition	Material Condition
• **Best Restoration** -	0-6' Above Pool,	0 - 5 0% Manmade materials
• **Moderate Restoration** -	0-6' Above Pool,	5 0 - 100 % Manmade materials
• **Poor Restoration** -	6 -13' Above Pool,	0 - 5 0% Manmade materials

For example, a physical condition of 0-6' above pool places the bank in relationship to the one-year flood pattern. Combined with a natural/manmade soil mix of 50% or greater natural soils the restoration potential is high. Meaning that restoring the river banks to natural state is very possible as the physical and material conditions are in place to support native plant materials. This is the condition for our best restoration scenario. The moderate scenario, assumes the same bank heights of 6 - 9' above pool with 50 - 100 % manmade bank materials. The physical condition is in place for a natural system restoration. The relatively poor material condition of the banks can be amended. The lowest restoration value represents a physical condition of 6 -13' above pool with 0 - 5 0% manmade material. Although there is still potential for restoration, proximity to public access, use or contiguous existing habitat would come into play when making a decision to restore.

Figure 29 is a map of a portion of the Year 2 study area, showing the riverbank sections that have easy, moderate, or no access. Figure 30 is the same area as figure 29, with the riverbank sections that are candidates for preservation. Figure 31 shows the riverbank restoration potential for the same area. All of the above maps were generated from field data, and filtered using GIS and ARCINFO computer programs. Additional information gathered this way can be applied to any portion of the study area, at many scales.

RIVERBANK GRAIN SIZE AND MATERIAL TYPE TRENDS

Grain size attributes are important descriptive properties of riverbanks. Riverbank morphology can be predicted based on grain size measurements and material makeup. Grain size can also predict river hydrological dynamics; erosional cutbanks versus depositional sand bar banks. This prediction holds true for natural or man-made materials. Grain size distribution trends in a riverbank also reflect watershed drainage, which depends on land use, geology, and climatic factors.

Figure 32 is a chart that shows the grain size distribution for pools 1, 2, and 3 of the Monongahela River, and figures 33, 34, and 35 show grain sizes for riverbank material in pool 1 of the Allegheny, Ohio, and Youghiogheny Rivers, respectively. Clay content is about the same for the Ohio, Allegheny, and Monongahela Rivers; the Youghiogheny River has a higher clay proportion, probably due to land use patterns. Boulder, cobble, and pebble sized grains are comparable in percentage all three major rivers, and the Youghiogheny River has less of the course material in proportion to silts and clays. Sand and course sand sized grains have a negligible percentage in all four rivers.

Figures 36, 37, 38, and 39 show the grain size distributions for natural bank materials for the Monongahela, Allegheny, Ohio, and Youghiogheny Rivers. The prevailing natural bank material in all four rivers is mud; the Youghiogheny has a smaller sand component in comparison to the other three rivers.

Man-made bank materials in the four major rivers are predominantly rubble/fill, which was used for railroad right-of-way construction. The Monongahela River has a much higher percentage of slag in the riverbanks, compared to the other three rivers due to the steelmaking that was the major industry in the Monongahela Valley. See figures 40, 41, 42, and 43. The Youghiogheny has a very high percentage of rubble/fill, from railroad construction.

Figures 44 through 47 chart the proportions of natural riverbank materials versus man-made bank material. The average ratio for the Monongahela, Allegheny, and Ohio Rivers is about 27% natural material, and 73% man-made. The Youghiogheny has 35% man-made bank material, and 65% natural material. This trend is due to the relatively light industrialization and poor navigability compared to the three major rivers. The grain size data for the Monongahela River was further divided to reflect the trends found in each pool.

Figures 48, 49, and 50 are riverbank grain size distribution graphs for pools 1, 2, and 3 of the Monongahela River. In general, riverbank grain size decreases upriver. For example, the clay and silt percentages increase from pool 1 to pool 2, to pool 3. Cobble and pebble size percentages decrease upriver. These trends are not consistent with natural free-flowing rivers; usually bank grain size increases upstream.

Figures 51, 52, and 53 show natural river bank material percentages for pools 1, 2, and 3 of the Monongahela River. Mud and sand are the predominate materials and grain size decreases upstream.

Figures 54, 55, and 56 show the composition of man-made bank materials. Due the predominance of the steel industry in the Mon valley for over a century the most abundant material is slag, a by-product of the steel making process put to good use as a stabilizer of river banks. Many of the old industrial sites are bounded by high cement walls, which are a component if man-made riverbank materials. The rubble/fill is present due to railroad construction.

The percentages of natural to man-made riverbank materials is illustrated by Figures 57, 58, and 59; these charts show data for pools 1, 2, and 3 of the Monongahela River. Natural material concentrations increase upstream, due to less impact from past heavy industrial activity. Pool 1 has 6% natural riverbank material. Pools 2 and 3 have 28% and 57% natural materials respectively.

The techniques used for grain size and material data analysis can applied down to the 1/10th mile bank section scale, if needed.

APPENDIX A

Fluvial Geomorphology

Fluvial systems are complex and incorporate many interactive features. Any successful integrated model of such a system must take into account and reflect salient features impacting the system. The model proposed in this project is theoretically based on the principles of fluvial geomorphology.

Fluvial systems serve many functions. Geomorphically, they are important agents of physical erosion responsible for major alteration of landscapes. Physical weathering and erosion are largely caused by moving water. This surface water driven erosion is the greatest factor responsible for landscape geomorphology as expressed in the classic model by Davis (1899). Davis' model describes geomorphic evolution throughout time, as rugged tectonically induced landscapes are reduced to relatively flat erosional surfaces called peneplains or pedeplains (Schumm, 1977). Ecologically, fluvial systems provide habitats for continental biota.

The classical role assigned to rivers is depicted by the hydrological cycle. This cycle is driven by the potential energies of solar heat and gravity, converted into kinetic energy manifested by precipitation, and the flow of surface and subsurface waters. There are two interrelated components of fluvial systems: the *terrestrial watershed drainage basin* area (which provides water, sediment, and organic material), and the *stream channel* with its own physical properties (Schlosser, 1991).

The watershed drainage basin area, or the catchment area, is the geographical area of production, from which water drains. Fluvial systems can be more fully understood in the context of this watershed concept. Watersheds are characterized by fluvial patterns dictated by many variables such as tectonism, underlying geology, and climate. Attribute features of watersheds include basin topography, geology, and vegetational characteristics. Characteristics associated with stream channels include sinuosities, valley types, floodplains, levee banks, types of bars, substrate, pools, riffles, water depth and velocity. Fluvial systems (watersheds and channels) are categorized by stream order, a somewhat arbitrary method of classifying streams, and by watershed size, channel measurement, and discharge (Strahler, 1964).

Fluvial waters chemically reflect the composition of runoff surfaces and subsurfaces through which groundwater flows. Water is an important component of chemical weathering. During precipitation, depending on duration, intensity, soil type, rock type, vegetation, slope and other factors, some water may infiltrate the substrate surface and undergo chemical reactions. Most chemical reactions at the earth's surface include water. Such reactions include: oxidation reactions where iron bearing minerals react with the oxygen in water; hydrolysis reactions involving decomposition in the presence of water; hydration, the addition of a water molecule to the molecular structure of a mineral; and carbonation, the reaction of minerals with carbon dioxide dissolved in water (Bloom, 1978). The fluvial characteristics mentioned above and the aquatic habitats therein can be best understood only as products of the watershed area as a whole. A watershed is generally considered to be a geomorphologic feature which integrates several processes: atmospheric, geologic, fluvial and lacustrine.

Streams are crucial to watershed quality. There are two main sources of water in a stream: ground water flow and surficial flow (Horton, 1945). Precipitation either flows overland into streams, or it infiltrates the soils and rocks of the basin, and accumulates as ground water, supplying streams with base flow. The amount of water which enters the subsurface depends on infiltration rates (Horton, 1945). If the amount of precipitation exceeds the infiltration rate, water flows over the surface in sheets and rills, and ultimately accumulates in first-order streams.

Rates of infiltration and overland flow are all dependent on the surface and subsurface compositions of basins, which may include, impermeable clay-rich soils, pastures, forested areas, and exposed rocks. However, the amount of water yielded by a watershed basin is influenced by several variables in addition to landscape "texture", or composition. Drainage density and ratio, area, and drainage relief (steepness of slopes) are important watershed characteristics (Strahler, 1957). Schumm (1967) considers several other variables to be important, such as time, geology, climate, vegetation, denudation, relief, hydrology (runoff and sediment yield per unit area), and drainage network morphology. Gregory and Walling (1973) categorize the myriad of watershed variables into three main groups: 1) topographic characteristics which include watershed area, stream orders, stream network density, basin and channel length, basin and channel shapes, and basin and channel relief; 2) geological characteristics; and 3) vegetational characteristics.

The frequency of first-order streams within a watershed is of primal importance, "few first-order tributaries and negligible overland flow enters a trunk stream directly, and these are the original source of most of the sediment load" (Bloom, 1978: 218). Most erosional work within a watershed basin takes place at the first-order level, where "during erosion of a drainage basin the zone of maximum erosion migrates toward the head of the basin" (Schumm, 1977: 69). All streams of higher orders are, in essence, trunk streams which act to transfer sediment and discharge waters produced and accumulated in the first-order drainage basins which make up the great majority of the watershed area.

The formation of the watershed is a product of water movement. Drainage density increases with relief. Relief and slope effect the movement of water through a basin. The formation of the watershed is a product of water movement. The resulting drainage network, recursively, impacts the manner in which water and sediment are discharged. Accurate expression of basin and slope aspects of watersheds has been difficult, and several solutions have been proposed. The Relief Ratio is a simple widely-used method. Horton's Mean Slope is also a simple, easy-to-calculate index. Unfortunately, these two dimensional indices do not adequately describe a three-dimensional system, such as a watershed basin. The Mean Slope index, which is obtained by dividing the elevation difference of a stream's source and mouth by the length of the stream, will provide the same value for many different stream profiles (Gregory and Walling, 1973).

Watershed shape and drainage pattern are highly interrelated factors. When comparing two watershed basins with the same channel size and roughness, but different long profile slopes, the hydrographs would show higher discharges, shorter discharge increase times and shorter lag times for the basin with the higher relief ratio. Higher energy provided by steeper relief yield greater amounts of sediment.

Watershed area is the single most significant characteristic because it is always related to other watershed characteristics and parameters. In a theoretical geographic area, where all other topographic characteristics (geology, climate and vegetation) are homogeneous and precipitation inputs are uniform, discharge intensity would be dependent on area only (Morisawa, 1962), Such a theoretically uniform geographic area is rarely found in actual fluvial settings; nonetheless, the discharge-to-area relationship [Q = _ (A)] has been used for many years to predict flooding events. However, this simple discharge-to-area equation can be problematic. For example, if mean annual flooding is measured per unit area ($m^3/s/km^2$) within the watershed, then flooding decreases with unit area. This inverse relationship is mainly due to the fact that discharge rates and sediment yields are greater in smaller, steeper, watershed basins.

Watershed basin drainage densities, relief, slope, shape, drainage pattern, and area all reflect the lithologic structural control exerted by the geologic composition of the watershed. Rivers that drain areas of different rock types and soils manifest different morphologies, due to differences in lithologic porosity, permeability, and erodibility (crystalline vs. sedimentary rocks) (Schumm, 1977). Porosity and permeability of rocks allow for storage of water, thus affecting watershed discharge. Conversely, impermeable aquicludes facilitate runoff discharges. Rock types affect the rate of weathering, sediment yields, and chemical solutes supplied to the channel.

Climate, soil and vegetation are also highly interrelated factors of watershed dynamics. Amount of precipitation is a function of climate which, in turn, determines the quantity of water which is available as input to the watershed system. Climate (P-E index = Mean monthly precipitation * Intensity of precipitation) is a key factor in determining watershed flow regimes such as drainage density. Water is essential to chemical and physical weathering of parent material, which in turn, contributes to the formation of different soils. Climate is also important in influencing the vegetational cover of the watershed.

Pedogenesis can be attributed to the combined influences of climatic, biotic, and topographic factors. Soils can be formed *in situ* from parent rock or deposited as allochtonous material by glaciers. The fundamental significance of soil in watershed dynamics is that it acts to either contain or discharge water (Gregory and Wallis, 1973). Precipitation will either runoff the surface of soils or it will infiltrate the soil profile. Infiltration rate is the maximum rate at which water can enter the soil. The proportion of runoff discharge or infiltration will depend on several factors such as type of soil, topography, precipitation intensity, and land use. The manner in which water is stored and transmitted through soils influences the production of sediment and water-borne solutes which, in turn, ultimately influences the hydrologic and morphologic make-up of the stream channel.

Vegetation affects the amount and movement of water and sediment through the watershed system (Gregory and Wallis, 1973). Vegetation in the watershed basin is important because it influences 1) water input by the processes of interception and evaporation; 2) water storage within the soil and plant mass; and 3) output of water and sediment into the stream channel. Vegetational cover intercepts the amount of water that can reach the ground by precipitation. The reduction of interception caused by the removal of vegetation (clear-cutting or burning) increases runoff and loose soil detachment. The time-to-peak-flow is shortened by loss of vegetational canopy cover density during a small storm, (but there is no change in time-to-peak-flow in the same watershed during a large storm). Water and sediment yields increase with decrease in canopy cover density, although differences due to variable precipitation intensities are quite evident. Infiltration is increased by vegetation which resists runoff. Maximum infiltration is found in fully established forests, and minimum infiltration and maximum runoff occur in vegetationally denuded areas. Evapo-transpiration is the water which is returned to the atmosphere following uptake by plants and evaporation from leaf surfaces. Land use is understood to be an alteration of the composition of the watershed landscape due to human activity (Trimble, 1997). These anthropogenic processes change the vegetational, pedogenic, and morphologic composition of the watershed. Therefore, they influence water runoff, infiltration, evapotranspiration, and erosional dynamics of the basin. These changes, affect the amount and composition of water and sediment delivered to streams.

The River Channel

Rivers can be classified according to several criteria. Tectonic-geologic controls separate most rivers into two groups depending on their ability to adjust shape and gradient. Bedrock-controlled rivers adjust channel banks and beds to lithologic conditions produced by tectonic processes. Alluvial rivers, however, adjust channel banks and beds to material transported and deposited by the rivers themselves (Schumm, 1977). River channel morphology depends largely on two variables which are the two major products of watershed dynamics already discussed: discharge and sediment. Discharge dictates stream channel size, capacity and competence. Sediment is sorted according to size by channel hydrological dynamics during the transportation process.

Transported sediment, termed "sediment load", is one variable by which channels are very often classified. The term "sediment load" not only defines the type of sediment (clay, silt, sand, cobble, boulder), but it also implies the mode of transportation (bed-load or suspended-load), which is discharge dependent. Alluvial channels can primarily be classified according to sediment load: bed-load, mixed-load, suspended-load (Schumm, 1977). The channel types, although they exist along a continuum, exhibit a range of straight, meandering, and braided channel forms. Straight channels are bed-load channels, meandering channels are suspended-load channels, and braided channels are bed-load rivers with islands of deposited sediment (Schumm, 1977).

Channel Forms

River channel systems can be classified into a continuous spectrum of river types where the two end members are meandering rivers and braided rivers (Boggs, 1987). Meandering rivers, unlike braided rivers, tend to be confined to a single channel, though anastomosing rivers such as the Amazon, are a type of multiple channel meandering rivers. Meandering rivers tend to have a low gradient (the Amazon, for example, drops only 65 meters over 3000 km), low velocity, and carry light, fine grained sediment. Braided rivers, on the other hand, are high energy systems. Rust (1978), however, classified rivers, in a more rigorous way, according to the degree of channel meandering (sinuosity) and channel braiding (multiplicity). Sinuosity is the ratio of the thalweg (depth at the deepest part of the channel) to the valley length. A ratio of 1.5 is the boundary between low and high sinuosities. The braiding value of "1" is a single channel river, more then "1" constitutes multiple channels. Therefore, the Rust classification of rivers is subdivided into 4 types of rivers:

1) meandering where sinuosity is ⇢ 1.5 and braiding is ⇠ 1
2) braided where sinuosity is ⇠ 1.5 and braiding is ⇢ 1
3) straight where sinuosity is ⇠ 1.5 and braiding is ⇠ 1
4) anastomosing where sinuosity is ⇢ 1.5 braiding is ⇢ 1

The most common river types in nature are braided and meandering (Rust, 1978). Friend (1983) classifies rivers either by channel patterns or sediment loads. Channel patterns are described as braided, meandering, or straight. Sediment loads are designated as suspended and dissolved loads, mixed bed and suspended loads, and, lastly, heavy and coarse bed-loads.

Schumm (1977), defined two parameters which control river geometries: (i) load characteristics such as suspended, mixed, or channel bed loads, and (ii) stability which is dependent on sediment size, sediment load velocity or stream power. Suspended load rivers are characterized by high sinuosity. Mixed load (channel bed and suspended loads) rivers tend to be meandering. Bed load rivers tend to have a braided character. Rivers which are sinuous single channel or anastomosing are confined by the deposition of mud and silty waters carrying a high proportion of fine suspended loads.

Meandering rivers can be classified into five categories: muddy fine grained, sand beds with mud, sand beds without mud, gravelly sand beds, and coarse gravel, and no sand (Jackson, 1978). Sediment deposits in meandering rivers accumulate in several different depositional settings: channels, point bars, levees, flood basin, oxbow lakes, and chutes.

These settings move laterally due to meander migration and become superimposed and laterally stacked. Coarse lag deposits are overlain by sandy fining-upward point bar deposits, which are again overlain by finer silty muddy sediments, producing a fining upward sequence. However, Jackson (1978) maintains that this upward-fining standard is too simplistic and does not represent the complexity of sedimentary facies of many meandering streams. Many diagnostic features that typify braided streams are found in meandering streams: negligible mud, large facies changes over short lateral distances, vertical sequences that do not fine upward, and no natural levees (for example, the Monangahela River). A detailed study of the sedimentary facies of the lower Mississippi River concluded that meander channels are preserved as backswamp, levee, splay deposits, avulsions, and sheet floods. Furthermore, channels are established following a sequence: 1) pre-avulsion stage, 2) an avulsion stage, 3) an early channel stage and 4) a late channel stage (Farrell, 1987).

Braided rivers are in the distal parts of alluvial fans, glacial outwash plains, and mountainous reaches of watersheds. These environments are often sediment rich, vegetation poor and with high water discharge. Depositional structures most evident are longitudinal, transverse, and lateral bars.

In an ideal river model, however, a river evolves longitudinally, from a straight type in the upper reaches of the watershed, to a meandering river in the lower portions of the river. In such a river, the bar structures change accordingly down-stream, from mid-channel compound bars, to bank-attached compound bars, to point bars at the lower reaches (Brierley, 1991).

For example, a study done by Davies et al. (1978), on the river systems that drain the active Fuego volcano in Guatemala, showed that channel patterns, morphologies and flow characteristics change in response to rapid down stream gradient change. Fluvial sediments in transport show downstream changes in texture and composition which are closely related to fluvial mechanics. Decreasing slope results in major downstream modification in grain size and sorting. Sediment composition is also modified. There is an exponential downstream decrease in abundance of volcanic rock fragments. Mechanics of grain transport such as impact and saltation influence particle fragmentation (Davies et al., 1978).

Concepts In Stream Ecology

An integrative fluvial environmental management model which focuses upon the watershed system is best approached by the hierarchical, holistic multidisciplinary philosophy embodied by "landscape ecology". To appreciate the value of this, general integrative lotic model it is essential to provide the necessary background of existing lotic ecological models.

According to Minshall (1985, 1988), holistic approaches to the study of stream ecology began with the work of Howard Odum in the 1950's. Over the past few years several ecological concepts have combined biotic and physical attributes (both natural and man-made) into holistic models describing the ecology of lotic systems. Two main historical concepts are the river-continuum concept (RCC) (Vannote et al., 1980) and the flood-pulse concept (Junk et al., 1989).

During the past few years, the holistic approach of "landscape ecology" pioneered by German geographer Carl Troll has made an impact on integrative approaches to ecology. American proponents of landscape ecology, Forman and Grodon (1986: 595), defined landscape as "the study of the structure, function and change in a heterogeneous land area composed of interacting ecosystems". A landscape is described as a "mosaic where the mix of local ecosystems or land uses is repeated in similar form over a kilometers-wide area" (Forman, 1995: 13). These landscape mosaics, which can be of different scales, are, in turn, composed of homogenous areas (mosaics) called *patches*. Patches and patch dynamics are central concepts of landscape ecology.

Rivers as Continua

The river-continuum concept (RCC)(Vannote et al., 1980), based on geomorphological principals (Leopold et al., 1964), states that in lotic systems, there exists a physical gradient that changes longitudinally along the length of the stream from the headwaters, through the middle reaches, to the confluence or delta. For example, substrate sizes change longitudinally from coarse in the headwaters to fine in the low reaches. Using the stream classification of Strahler (1957), headwater streams are characterized as 1-3 ordered streams, medium size streams were 4-6, and large rivers are greater then 6th-order streams. The derivation of the concept was based on the notion that biological communities adjust and become established in accordance to the physical longitudinal changes and adjustments of stream width, depth, velocity, sediment load, and other stream channel parameters.

According to the RCC, the headwaters streams are influenced by riparian vegetation much more than are the lower reaches. In the headwaters, therefore, there is more allochthonous detritus material contributed to the stream and more shading of the stream which reduces autotrophic production. Autotrophic organisms, such as green plants, are more prevalent in more "open" and light intense mid-reaches. This relation is reversed in the lower reaches where stream size increases and riparian contribution of allochthonous organic material decreases and within-channel autotrophic primary production increases. This change is measured by the change of the gross primary production over respiration ratio (P/R).

The RCC further postulates that this biological gradient is evidenced by the "morphological-behavioral adaptions of running water invertebrates that reflect shifts in types and locations of food resources with stream size" (Vannote et al., 1980: 132). These morphological differences of invertebrates are functionally categorized as: shredders, collectors, scrapers and predators. Shredders feed on coarse particulate organic matter (CPOM, ⇢1mm). Collectors filter from the water column or from the substrate fine particulate organic matter (FPOM, micron-1mm) and ultra-fine particulate organic matter (UPOM, 0.5-50 microns). Scrapers specialize in grazing on algal-rich surfaces. Predators are mostly invertivors and piscivors.

Shredders and collectors are found mostly at the headwaters where CPOM, FPOM, UPOM have a predominantly riparian provenance. Therefore, the RCC postulates the importance of riparian contribution in the headwaters. "Headwater streams represent the maximum interface with the landscape and therefore are predominantly accumulators, processors, and transporters of materials from the terrestrial system" (Vannote et al., 1980: 133). With the increase of stream size, the nutrient particles decrease and the number of collectors increases. Stream size increase also indicates an increase in autotrophic production and number of scrapers.

According to the RCC, mostly collectors are found In the low reaches of the river. Predators are ubiquitous through out the system. Most predators in the headwaters are invertivors, and downstream, both invertivors and piscivors. Mid-size rivers have the broadest range of abiotic parameters and, therefore, the greatest diversity (Johnson et al., 1995). "Major bioenergetic influences along the stream continuum are local inputs (allochthonous litter and light) and transport from upstream reaches and tributaries. As a consequence of physical and biological processes, the particle size of organic material in transport should become progressively smaller down the continuum...and the stream community response reflect progressively more efficient processing of smaller particles" (Vannote et al., 1980: 133).

In every part of the stream continuum there is organic material processed, stored and released. In the RCC, released material is defined as "leakage". The released material is transported downstream where other communities are structured to capitalize on this "windfall". Over evolutionary time, according to the RCC, the lotic community evolves to reduce this leakage of organic matter. In this time scale, there was a spacial shift of communities. This shift has two components: 1) a down stream vector that involves aquatic insects, and 2) an upstream vector which includes molluscs and crustaceans. Over evolutionary time, insects, believed to be of terrestrial provenance, most likely made the transition into aquatic environments via fluvial headwaters where there was a pronounced interface between land and water. The bivalves and the crayfish, conversely, shifted upstream from marine environments. This is the reason why, according to RCC, maximum species diversity is found along the midreaches of streams (Vannote et al., 1980:135).

The RCC has two additional corollaries: the resource-spiraling concept and the serial discontinuity concept. The resource-spiraling concept (Elwood et al., 1983, Mulholland et al., 1995, 1985, Newbold et al. 1981, 1982, 1983), maintains that resources do not just flow downstream uninterrupted. Rather, resources are absorbed by organisms and released as detritus and waste, and then re-absorbed and re-released further downstream creating a virtual spiraling effect (Johnson et al., 1995). Nutrients are transported downstream by recycling. Upstream nutrient cycling affects nutrient concentration which, in turn, will have downstream effects on communities which rely on those nutrients. Therefore, as the RCC deals with the longitudinal transport of material downstream as a combined effect of physical and biotic factors, the resource-spiraling concept deals with the downstream transport of nutrients in a conceptualized helical process (Newbold et al., 1982). "The term spiraling refers to the interdependent processes of cycling and downstream transport of nutrients in a stream ecosystem" (Newbold et al., 1983: 1249).

The river continuum concept is generally thought to be applicable to uninterrupted, continuous, unregulated natural streams. Since most streams are regulated by dams and dikes, Ward and Stanford (1983), formulated the serial discontinuity concept. Regulated streams, according to the concept, result in lotic systems that in reality are alternating lotic and lentic reaches. The serial discontinuity concept, is based upon four presuppositions: "(1) The river continuum and the nutrient spiraling hypotheses are conceptually sound and their underlying assumptions are valid. (2) The watershed is free of pollution and other disturbance, except impoundment. (3) The remaining lotic reaches were not disturbed during reservoir construction (i.e., riparian vegetation and substrate were not modified). (4) Unless otherwise stated, the impoundments are assumed to be deep-released storage reservoirs, which thermally stratify and which do not release oxygen-deficient or gas-supersaturated waters" (Ward and Stanford, 1983: 30). Dams induce major geomorphic changes such as channel incision or aggradation, modification of sediment loads, modification of channel type (channel straightening), reduced lateral migration of the channel bed, loss or encroachment of riparian zones, etc. (Ligon et al., 1995). The invertebrate feeding groups in these impounded systems reflect those alterations. A dam in the headwaters would, for example, reduce the number and diversity of shredding invertebrates. A dam in a mid-size stream would reduce overall aquatic community diversity. A dam on the lower reaches of rivers would lower the suspended sediment load, which would settle out in the lentic environment behind the dam. This would reduce turbidity below the dam and increase aquatic plant life, shifting the characteristics of the lotic system towards a middle reach-like river (Ward and Stanford, 1983; Johnson et al., 1995).

The Flood Pulse Concept

The river continuum concept (RCC) deals with the longitudinal physical relationships between the headwaters and mouth of a stream, and how biotic communities have adapted to those geomorphic parameters. The flood pulse concept (FPC), however, hypothesizes lateral relationships between the stream channel and the floodplain, and their effects on stream biota.

According to Junk et al. (1989), the RCC has two limitations: (1) formulation of the RCC was based on temperate streams, which usually are strongly anthropogenically impacted, and then extrapolated to all rivers;

and (2) the RCC was restricted to aquatic environments that are permanent and lotic. The flood pulse concept (FPC), however, explains the relationship between the physical habitat and biota based on evidence gathered on unmodified, pristine temperate, subtropical, and tropical large river-floodplain systems (Bayley, 1995).

The flood pulse concept (FPC) proposes that the "overwhelming bulk" of riverine animal biomass is derived from autochthonous floodplain production of organic matter and not organic matter derived from downstream transport, as postulated by the RCC. The concept also holds that, under the same hydrological regime, the longitudinal position of the floodplain along the drainage network is of little importance. Junk et al. (1989) go one step further: "We postulate that if no organic material except living animals were exchanged between floodplain and channel, no qualitative and, at most, limited quantitative changes would occur in the flood plain" (Junk et al., 1989: 112). The concept deals only with predictable, seasonal, time-dependent flood pulses. Under these circumstances floodplain biota develop various adaptive life cycle and production strategies designed to take advantage of the raised hydrological input of the "moving littoral" (Bayley, 1995). Floodplain, according to the concept is defined as "areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by the direct precipitation or groundwater; the resulting physicochemical environment causes the biota to respond by morphological, anatomical, physiological, phenological, and/or ethological adaptions, and produce characteristic community structures" (Junk et al., 1989: 112). Thus, "Life cycles of biota utilizing floodplain habitats are related to the flood pulse in terms of its annual timing, duration, and the rate of rise and fall" (Junk et al., 1989: 116). The floodplain is termed the "aquatic/terrestrial transition zone" (ATTZ). The term "river floodplain system", within the concept, includes the channel and the ATTZ. The flood pulse, according to Bayley (1995), is not to be thought of as a disturbance, whereas man-made flood control structures such as levees, and dams, are considered disturbances.

The FPC emphasizes, therefore, the existence of two phases in the floodplain cycle: the flooding aquatic phase, and the inter-flooding terrestrial phase. During the flooding phase, in inundated areas, lentic environments develop which are dominated by main channel floodwaters. Conversely, during base flow, the floodplain reverts back to a terrestrial habitat dominated by local conditions, such as rainwater, spring water, and not by the main channel. Biota adjust accordingly, although there are species that are not easily categorized by terms such as "aquatic" or "terrestrial" because they are equally productive during both phases (Bayley, 1995).

Although, according to the FPC, the floodplain clearly receives organic and inorganic nutrients from the channel, which reflects the chemical composition of the drainage basin, most of the nutrients found in the floodplain, however, are due to autochthonous processing and production and are quite different from the main channel.

For example, Junk et al. (1989) point out that gaseous inorganic compounds such as CO_2, O_2, H_2S, CH_4, and N_2 are produced and consumed in floodplains differently than in main channels. They cite examples of the Amazon River floodplain where floodwaters quickly become thermally stratified. Decomposing organic material on the bottom of these high temperature inundated floodplains consume more oxygen and release greater amounts of CO_2 than main channel waters. Initially during the flooding phase (Figure 4.4) primary production is greater then decomposition; however, as water levels stop rising the rate of decomposition rises and this decreases the concentration of dissolved oxygen (DO). When drawdown takes place, nutrient runoff and concentration increases phytoplankton production. The amounts of organic compounds such as carbon, although transported to the floodplain from the channel, are negligible in comparison to autochthonous, in situ floodplain production (Junk et al., 1989; Bayley, 1995).

Dissolved solids such as halite, due to high rates of evaporation, have a higher concentration in the floodplain than in the main channel. In addition, levels of dissolved solid nutrients are never limiting factors in the main channel, whereas, in the floodplain nutrients such as phosphorous and nitrogen can limit productivity. In-suspension inorganic particulate matter, however, is less important in the channel then in the floodplain. Suspended sediment increases turbidity, hindering photosynthetic production in the channel. However, in the floodplain, due to lower hydraulic energies, suspended particulates settle out on the floodplain, and possibly increase fertility.

GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Over the past few years, the use of geographical information systems (GIS) grew proportionally with a widening range of applications in government, industry, and academics dealing with management, planning, and research in engineering, business, health, natural resources and environment. GIS is a vital tool for the succesful implemention of environmental management and research.

Environmental and ecological applications are many and varied. For instance, GIS was used in the assessment of ecosystem "health" in the agricultural Rio Grande Valley to discover which features in the intensively impacted landscape were important to maintain native flora and fauna diversity (Whitford et al., 1996).

In 1995 the U.S. Forest Service conducted the Southern Appalachian Assessment (SAA) to help resource managers plan and manage 37 million acres covering seven states of the Southern Appalachian region. The region is complex in land use patterns (agriculture, forestry, mining, urban, recreational), and natural ecosystems which support a wide variety of wildlife species (Fehringer et al., 1997). GIS technology figure prominently in this study, as well.

What is a GIS and why is it proven to be so useful in resource management and conservation? According to Environmental Systems Research Institute (ESRI), a GIS is: "An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" (ESRI, 1990: 1-2). The National Science Foundation's (NSF) National Center for Geographic Information and Analysis (NCGIA) defines a GIS as "...a computerized data base management system for capture, storage, retrieval, analysis, and display of spatial (locationally defined) data" (Huxbold, 1991: 29). Geographic information systems "contain map information stored in digital form in a data base" (Huxbold, 1991: 25). A geographic information system, in other words, is a digital amalgamation of geographic maps and data base management system (DBMS). Traditional cartographic maps representing a certain geographical area provide a limited amount of information. By including a data base management system, digitized graphic map images provide much greater information about geographic spatial features and attributes. Although statistical, spreadsheet, and drafting software applications can be used to handle spatial data, only GIS can carry-out spatial analysis by processing queries and operations on georeferenced data.

An answer to he query: "How many access areas are there along the Monongahela River?" does not require georeferenced data. However, a question such as "How many access areas, and where are they along the Monongahela River in the Pittsburgh pool?" requires georeferenced data (latitude and longitude) about the access areas. These queries can only be answered by using GIS (ESRI, 1990). "The reference to *spatial* and *analysis* most often applied to GIS implies not only an ability to map information and refer to features that can be located, but also to identify relationships among mapped features and process their geometric characteristics for analyzing data in a spatial context" (Huxbold, 1991: 29). In essence, a GIS system is composed of a data-base management system (DBMS), and the capabilities to perform spatial analysis. A database management system is software that allows for the use and modification of data in a database.

Building the Database

Central to a GIS is a digital map. Converting a cartographic map into a digital map requires the "digitizing" process. GIS software enables serial digital data, from a digitizing board, to be accumulated into a file which is then displayed as a graphic on a CRT screen, and then reproduced in hard copy on a plotter. A digitizing board, which is connected to the host computer via a RS-232 interface, consists of a sensing grid of wires which detect the position of an electromagnetic cursor (a mouse or pen stylus) and these signals are sent to the microprocessor.

The microprocessor software, in turn, computes the position of the cursor signals as XY coordinates. There are two ways in which graphics are stored in memory: *raster* and *vector graphics*. In raster graphics, also referred to as bit-mapped graphics, the display represents lines as a combination of dots (pixels) very close together. Each pixel is represented by a set of bits in memory. The shortcoming in bit-mapped/raster graphics lies in the fact that the resolution of the graphic images are limited by the pixel density of the device being used. Low pixel densities tend to produce graphics aliasing which have the undesirable stair-stepped look of diagonal graphic lines. Scaling up a graphic image also causes aliasing distortions. Bit-mapped/raster graphics also consume large amounts of memory. Vector graphics, however, also known as object-oriented graphics, are superior to bit-mapped raster graphics because there is no distortion when resizing or editing the images and they consume less memory. Object-oriented/vector graphics are stored in memory as mathematical formulas for directional lines (vectors) which form the graphic image. Computer aided design (CAD) and GIS software packages, for example, use vector/object-oriented graphics.

The digitizing process, a time consuming expensive process, converts hard copy printed cartographic maps into digital vector graphic images. The conversion process can be automated, to a certain extent, by scanning the map images. Scanners convert printed maps into bit-mapped/raster graphic images. These images are then converted, under human supervision, into vector graphic formats using "raster-to-vector" transformation programs.

In the "real world" any geographical area can be represented by many maps such as hydrology, topography, land use, soils, etc. There are two types of map information about map features: spatial and descriptive. Map features can represent telephone poles, streams, lakes. A feature such telephone pole, which from a map perspective has negligible area, is represented by a point. In the case of a stream, too narrow to be displayed as an area, the feature would be represented on a map by a line. Lastly, a lake feature, with sizable area, would be depicted on a map as a polygon.

All spatial features, in this particular project, are located on the planet earth which itself is represented as a spheroid. This makes the representation of the earth's surface a complicated subject. In geodesy, the earth is not considered as spherical but rather an elliptical spheroid: an ellipsoid. Ellipses are mathematically described by two parameters: the major axis which is a plane of the equator, and the minor axis which is the plane containing the two poles. The ellipsoid has a geographic reference system: latitude and longitude. Mathematical conversions (map projections), convert latitude and longitude to Cartesian coordinates. Depending on which map projection is used, these flat maps have planar coordinate systems, where the x-axis runs East-West, and the y-axis runs North-South. On planar maps, products of the same map projection, lengths, angles, and areas have constant dimensions.

Geographic Information Systems, such as ARC/INFO™, use several different map projections. However, map projections involve distortions that are specific to the map projection used (ESRI, 1990; Ewing and Mitchell, 1970; from training class notes, 1980, Offshore Navigation Inc., New Orleans, LA.).

The digitizing process produces arcs which are "a continuous string of x,y coordinate pairs (vertices) beginning at one location and ending at another location, having length but no area. One line feature may be made up of many arcs" (ESRI, 1990: xxv). Map features represented by points, lines and polygons have certain connecting or adjacent spatial relationships which are mathematically depicted using topology. Topology aids in feature data processing. In ARC/INFO there are three main concepts governing topological relationships: 1) arcs connect to each other at nodes known as connectivity; 2) arcs that connect forming a polygon define an area; 3) arcs are defined by direction and left and right sides, this is called contiguity.

The above discussion centered on the spatial characteristics of features. However, as mentioned before, features are also characterized by descriptive data. Descriptive data about a feature is called an attribute. An attribute is defined as "a characteristic of a map feature described by numbers or characters, typically stored in tabular format, and linked to the feature by a user assigned identifier" (ESRI, 1990: xxvi). The tabular format is called an attribute table. For example, the attributes of different road features can be described by surface (asphalt, concrete), width, number of lanes, road names.

Database Management Systems (DBMS)

Geographical Information Systems, are data base management systems that provide convenient access, storage, and efficient processing of a large variety of feature attribute data from many sources. In order to fully understand ARC/Info GIS it is important to understand some of the basic principles of the relational data base model.

The relational database system model is a tabular system, i.e. a collection of tables or files. Each table/file, in turn, is a collection of common data features (for example, roads). Each row in each table/file represents a set of values that are related. So a table is composed of related data. Each table, however, has a column of data that is common with a column of data in another table. These two tables are related by their common data column and can be joined, using data structures such as pointers. These systems are very flexible in forming relationships among map feature attributes (Ullman, 1982; Korth and Silberschatz, 1986; Huxbold, 1991).

Spatial Analysis

"Analyzing data involves the determination of patterns of data associated with locations and the manipulation of location related data to derive new information from existing data" (Huxbold, 1991: 57).

Spatial analysis involves defining the dynamic relationships among topological data structures (points, lines, polygons) in terms of distance, direction, and connectedness (contiguity). Just as the data-base analysis of attributes involves data entry, data retrieval, sorting, etc. Therefore, it is spatial analysis in conjunction with data-base manipulation what makes GIS a unique tool. GIS can answer two basic questions: "1) Where is...(an object)?, and 2) what is at...(a certain location)?" (Huxbold, 1991: 58). A map can provide information about the first question only if the object sought is plotted on the map. However, a GIS can find the object and from its attribute cartographic data locate the object on a map. The second question is more difficult to answer from a map because it depends on the attribute, or set of attributes, plotted on the map at a particular location. A GIS system, on the other hand, can have a data-base with information about many different attributes for a single geographic location (Huxbold, 1991). For example, spatial analysis of a single geographic coordinate may have information about a certain power line tower (point entity), along a road (line entity), built on a certain geological formation (polygon entity).

Global Positioning System (GPS)

Remote positioning systems using the satellite based Global Positioning System (GPS) have become integral tools for building GIS databases. A GPS receiver is an important tool used in this project. Therefore, it is important to, briefly, discuss GPS technology. Electronic positioning began during World War II with equipment such as Shoran (short range navigation) manufactured by RCA to position aircraft using trilateration between receivers on-board and shore stations. After the war these systems were used commercially for geodetic and seismic surveys. Shoran, for example, was upgraded to Hiran (high accurate Shoran) in 1949 and used extensively until the late 1970's in seismic surveys by companies such as Offshore Navigation Inc. (ONI) of New Orleans, La.

Other highly accurate electronic positioning systems, using a variety of frequencies and electronic designs, were Raydist, Argo, Syledis, Maxiran, etc. There were several disadvantages to these radio positioning systems: these systems were bulky (Shoran and Hiran equipment, for example, weighed 100kg/unit, and shore station equipment including generators weighed 500kg/installation); positioning accuracy and maximum ranges were local (on the order of 400 km); the logistics of establishing and maintaining a far-flung and remote radio positioning net were daunting.

The launching of Sputnik in 1957 by the Soviet Union launched new era in geodesic positioning. By 1964 the U.S. Navy had already established a satellite based positioning system known as TRANSIT or the Navy Navigational Satellite System (NNSS). The system had six satellites orbiting in circular orbits at altitudes of nearly 1100 km. The TRANSIT system had two major shortcomings: 1) large time gaps in positional coverage (it was not a 24 hour positioning system); and 2) low accuracy (Hofmann-Wellenhof et al.,1994; Laurila, 1976).

In 1973 the Department of Defence (DoD) directed the Joint Program Office (JPO) to develop and launch a satellite based positioning system to replace TRANSIT. The result of this directive was the Navigation System with Timing and Ranging (NAVSTAR) Global Positioning System (GPS). Although the primary goals of GPS were military, civilian use was also promoted. The system is designed to provide high accuracy positioning 24 hours a day any place on earth, under any weather conditions.

From 1978 to 1985 eleven satellites were launched with Atlas launch rockets. These first eleven satellites, designed for a 4.5 year life span, were known as the Block I Satellites. Since then several blocks (II, IIA, IIR, and IIF) of satellites have been launched. Presently, the satellite constellation is composed of 24 operational satellites. The satellites circle the earth in orbits inclined 55_ to the equator 20,200 km above the earth with 12 hour sidereal periods. The satellites act as platforms for radio transceivers, atomic clocks (rubidium, cesium, and the Block IIR and IIF's are equipped with hydrogen maser on-board time standards), and microprocessors (Hofmann-Wellenhof, 1994).

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Appendix B - Photos / Figures

3R2N Riverabank Geology, Phase 2 - 2001

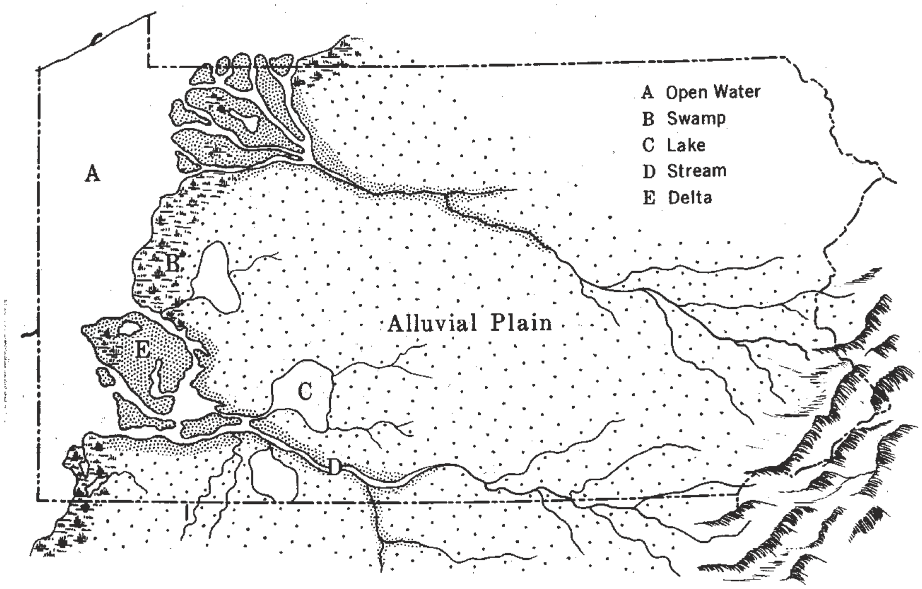


Figure 1

Probable geography of Pennsylvania when rocks of Allegheny County were deposited.

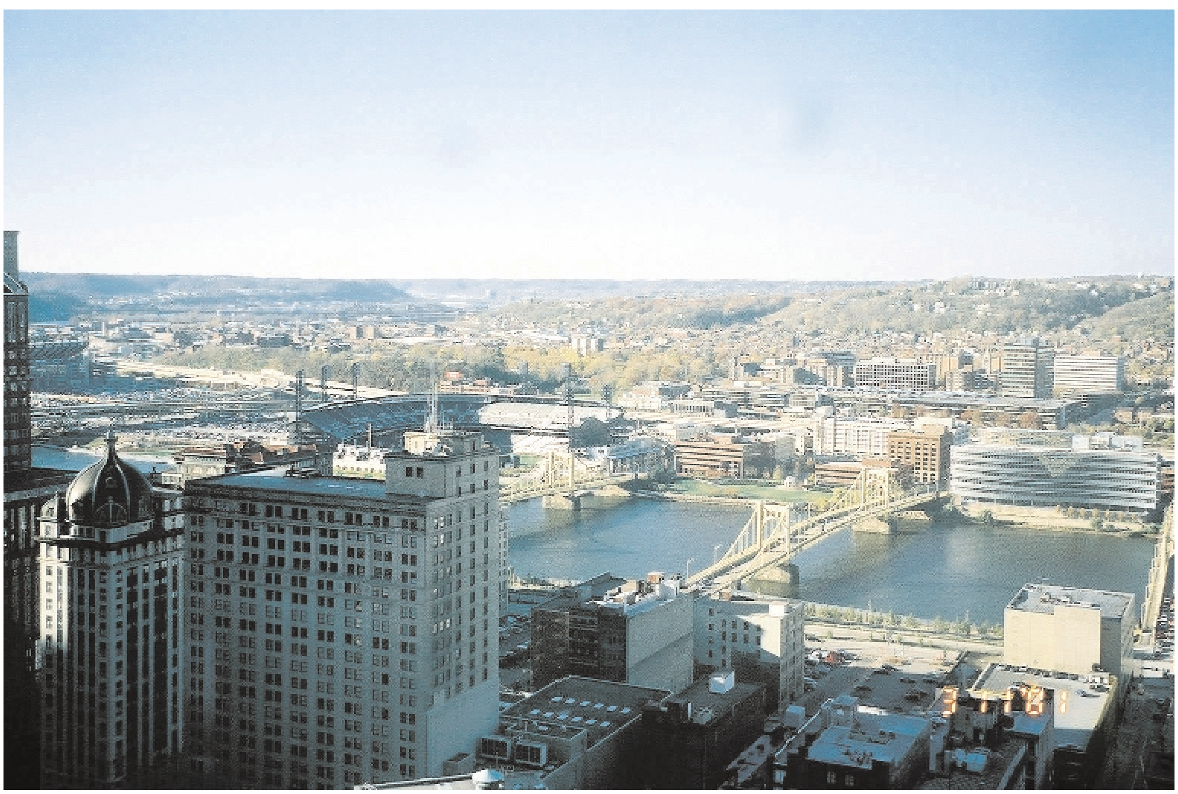


Figure 2

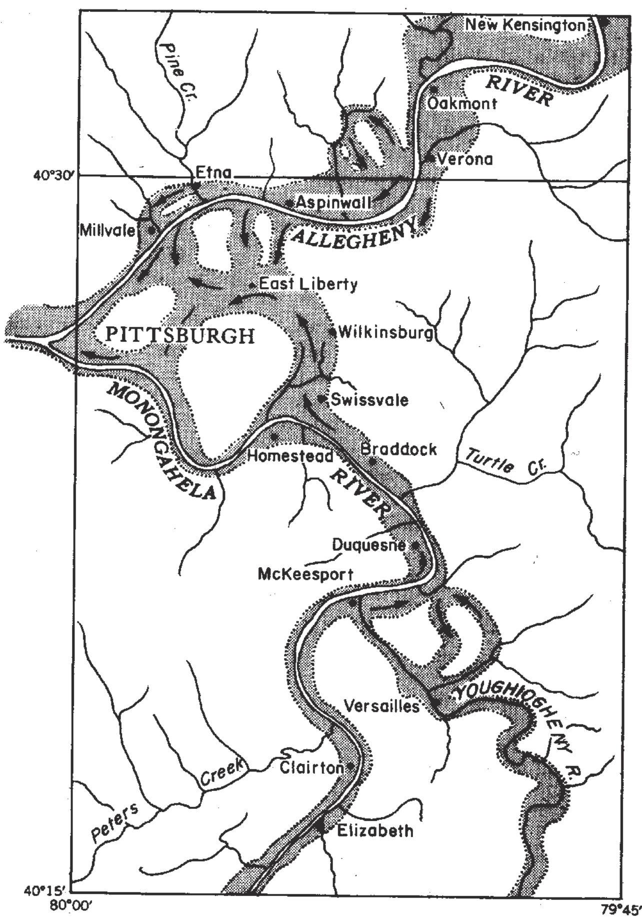


Figure 3

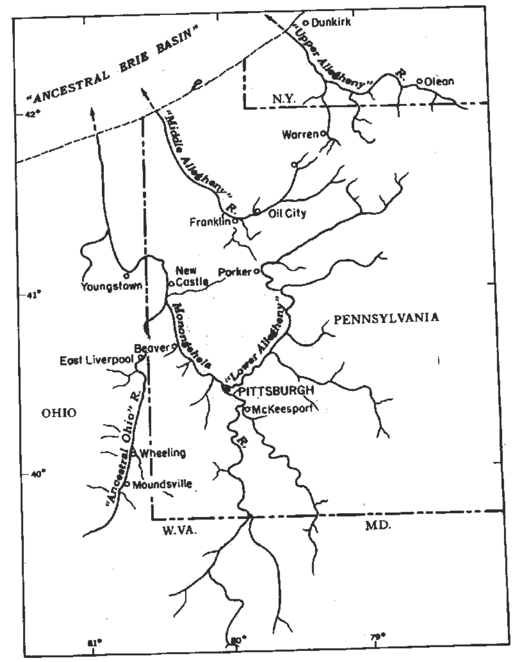


Figure 4

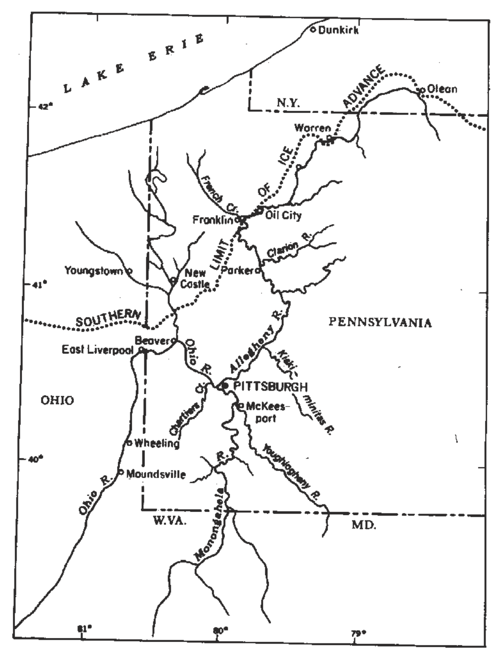


Figure 5

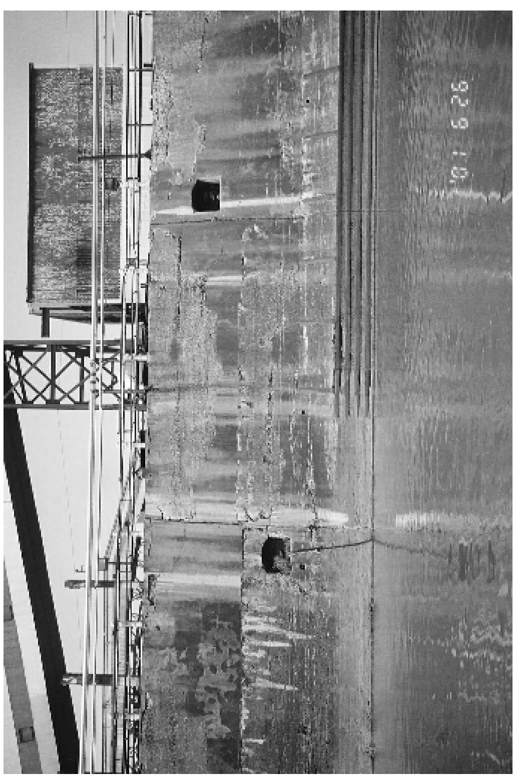


Figure 6


Figure 7


Figure 8


Figure 9

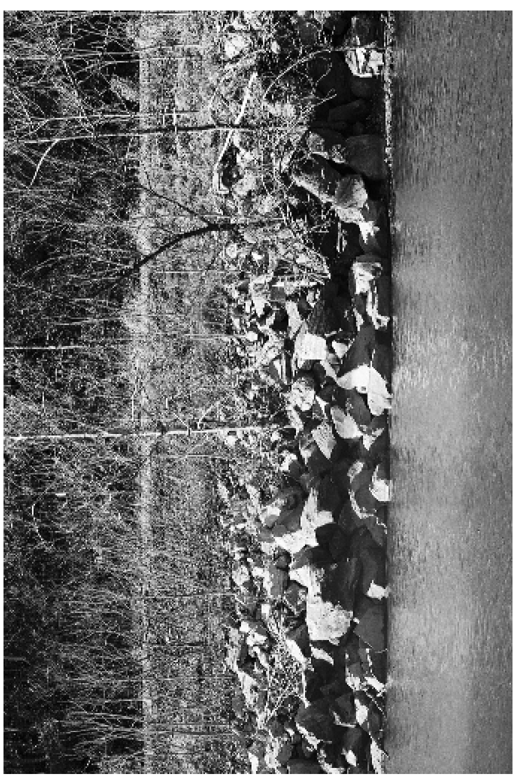
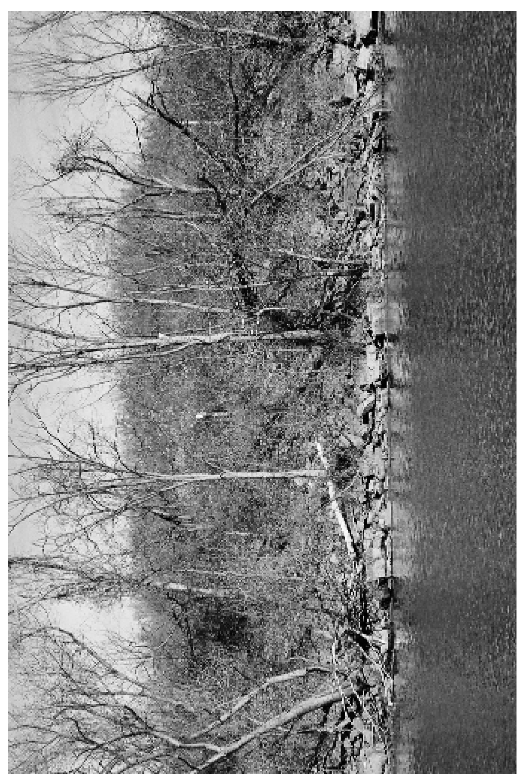


Figure 10

Figure 11



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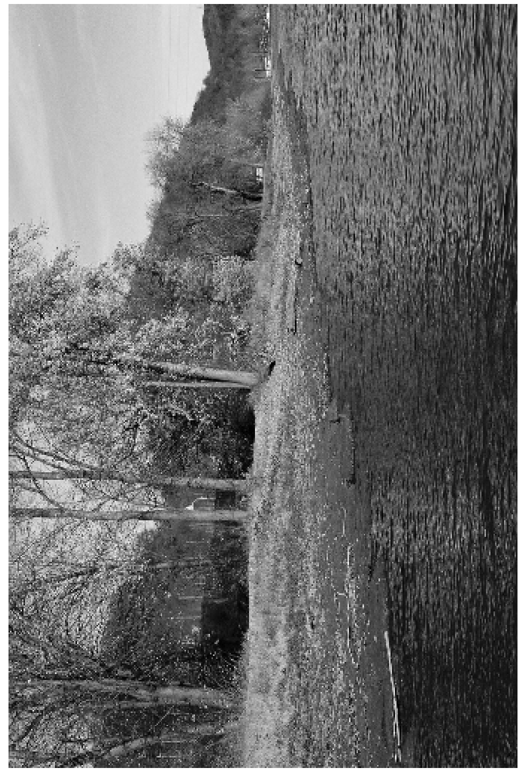


Figure 13

Figure 14

Figure 15

Figure 16

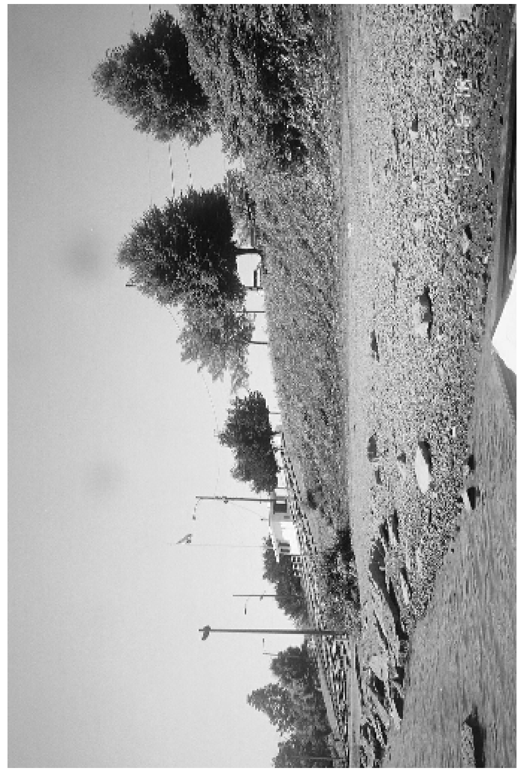


Figure 17

Figure 18

Figure 19

Figure 20

Figure 21


Figure 22


Figure 23

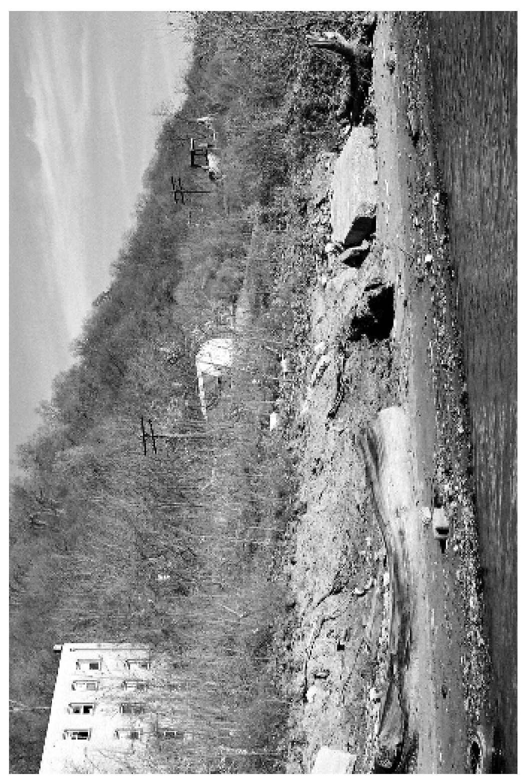


Figure 24


Figure 25

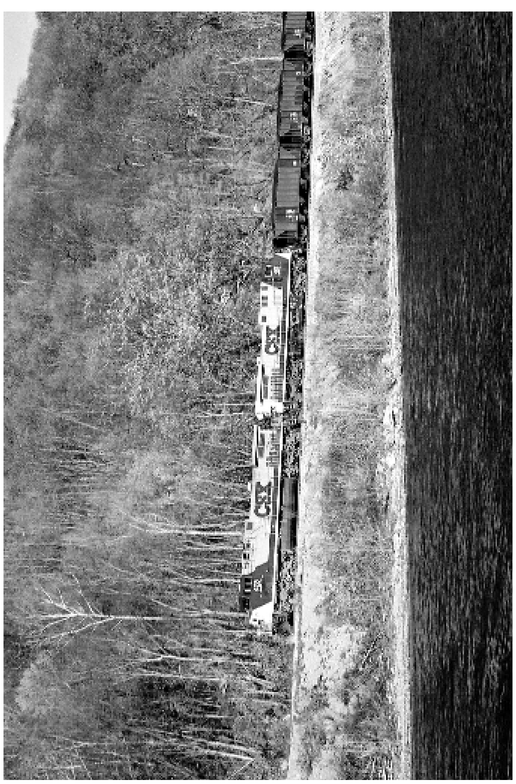


Figure 26

Figure 27

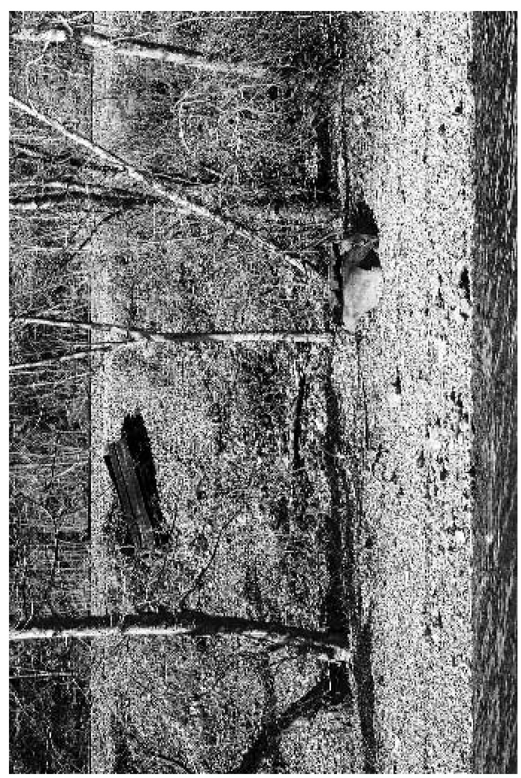


Figure 28

Appendix C - GIS Maps

3R2N Riverabank Geology, Phase 2 - 2001

Appendix D - Tables

3R2N Riverabank Geology, Phase 2 - 2001

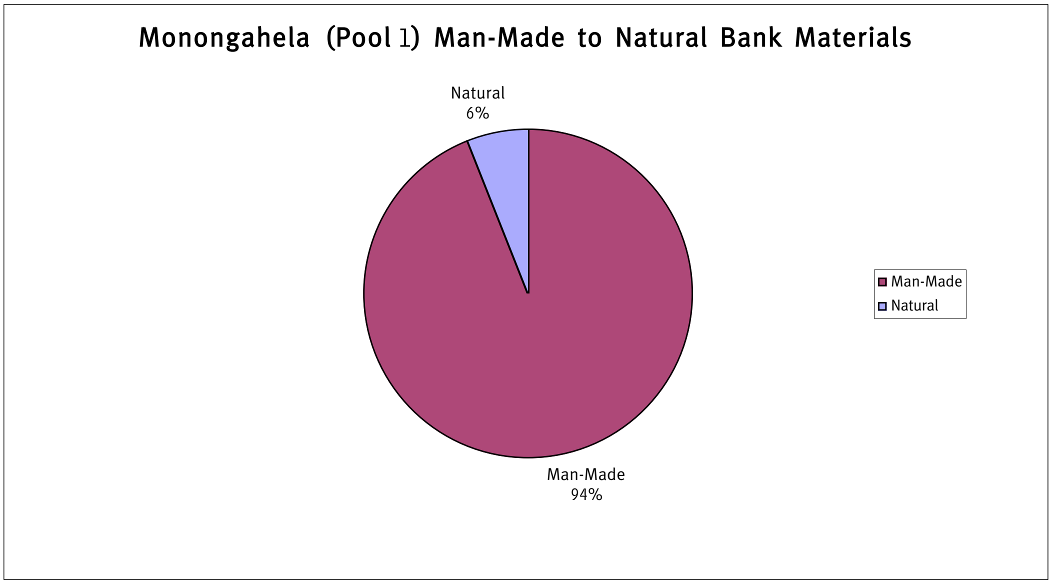


Figure 32

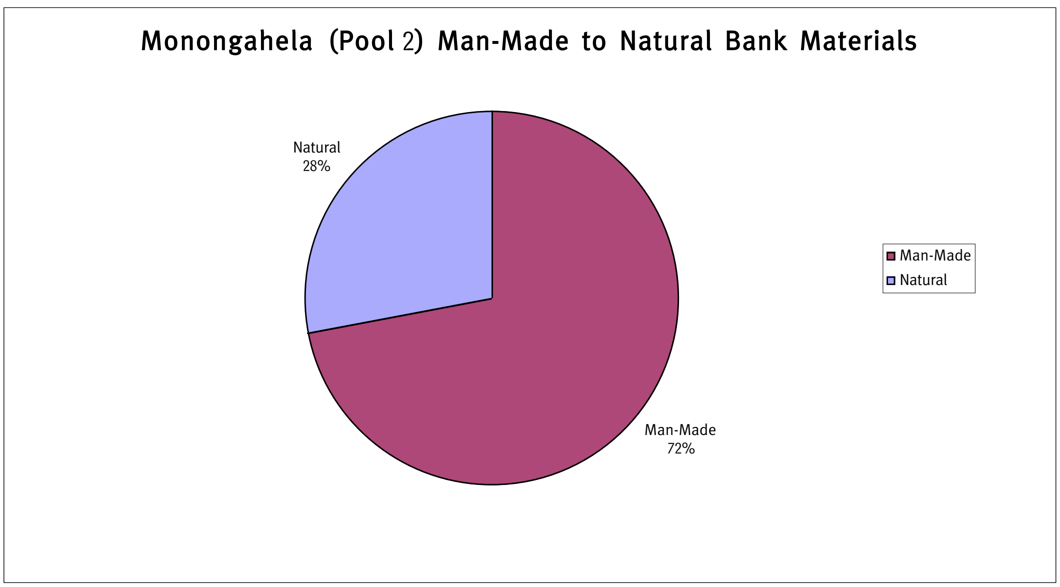


Figure 33

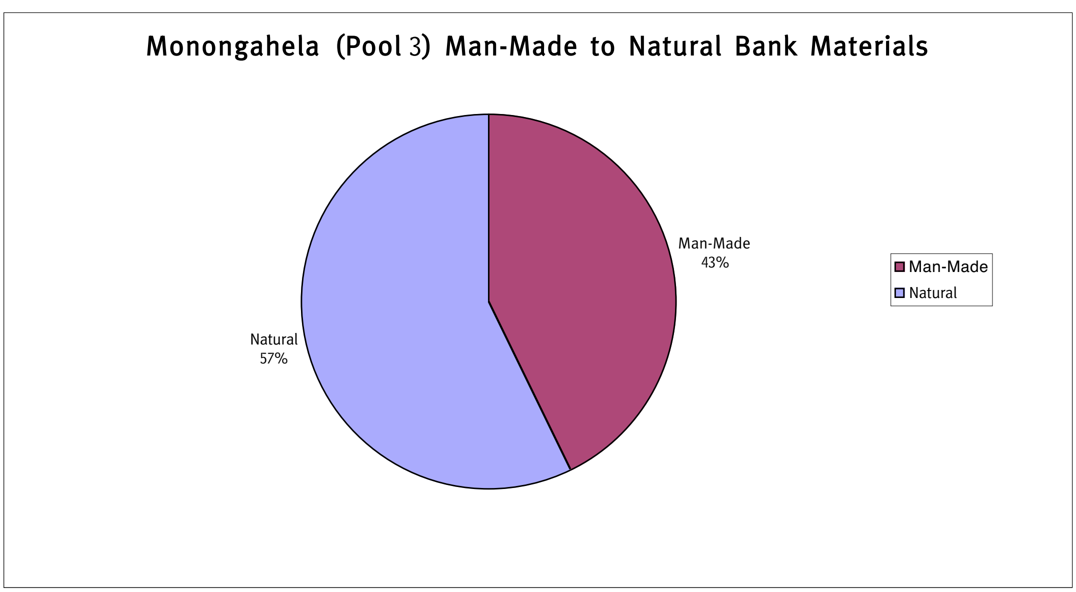
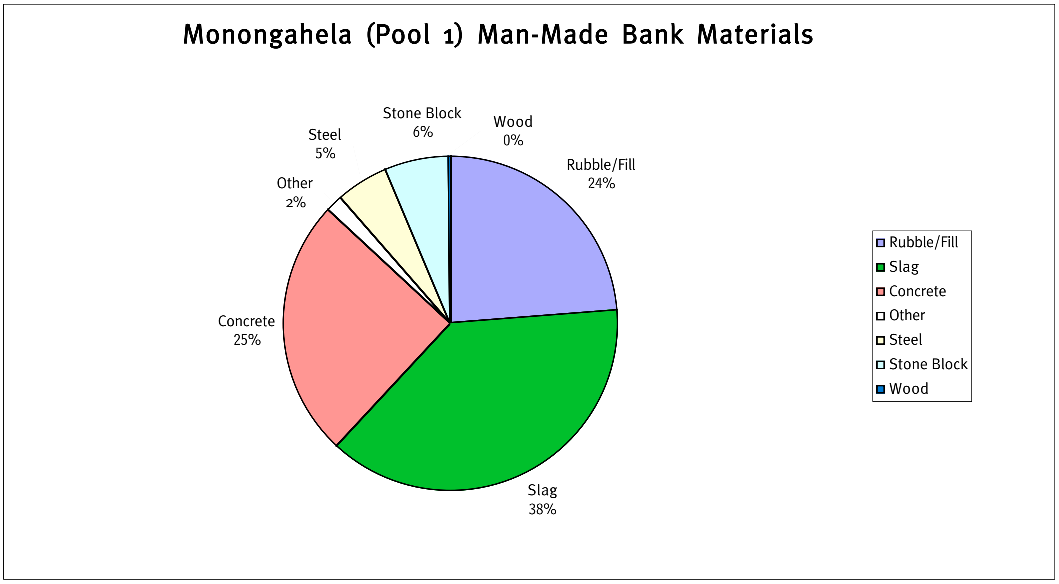


Figure 34

Figure 35



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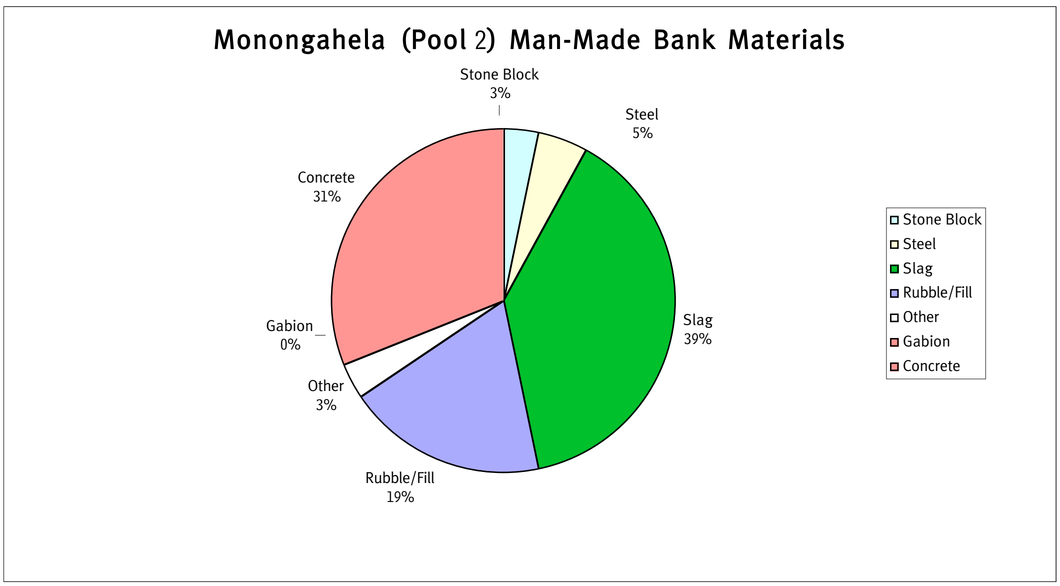

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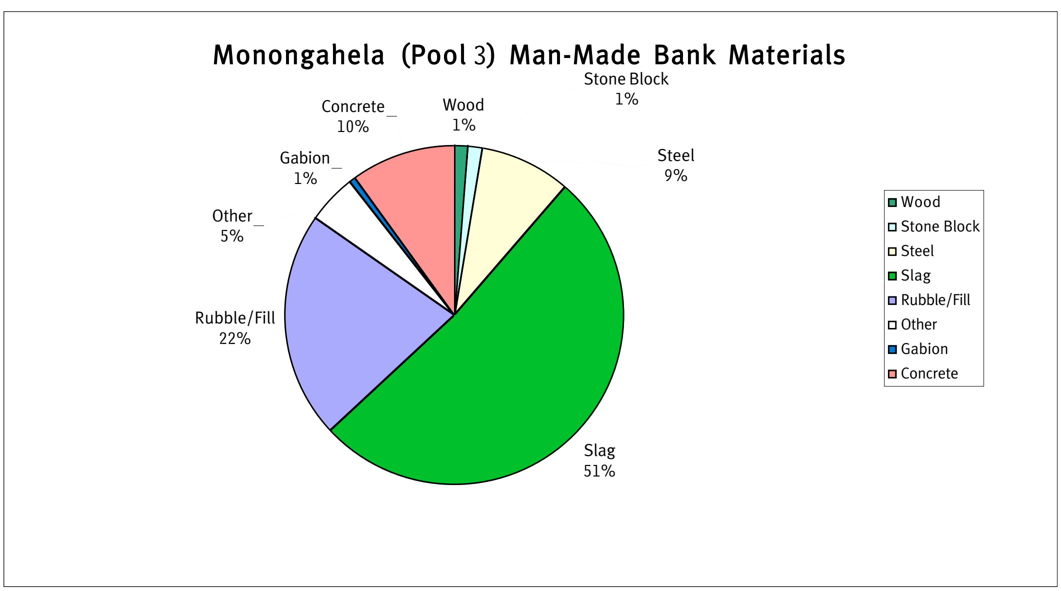


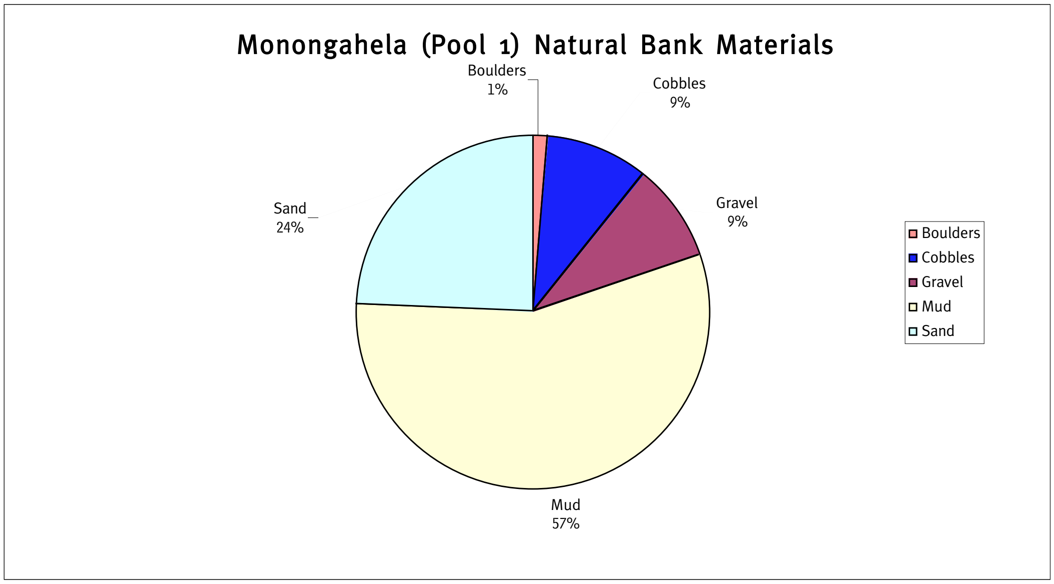


Figure 38

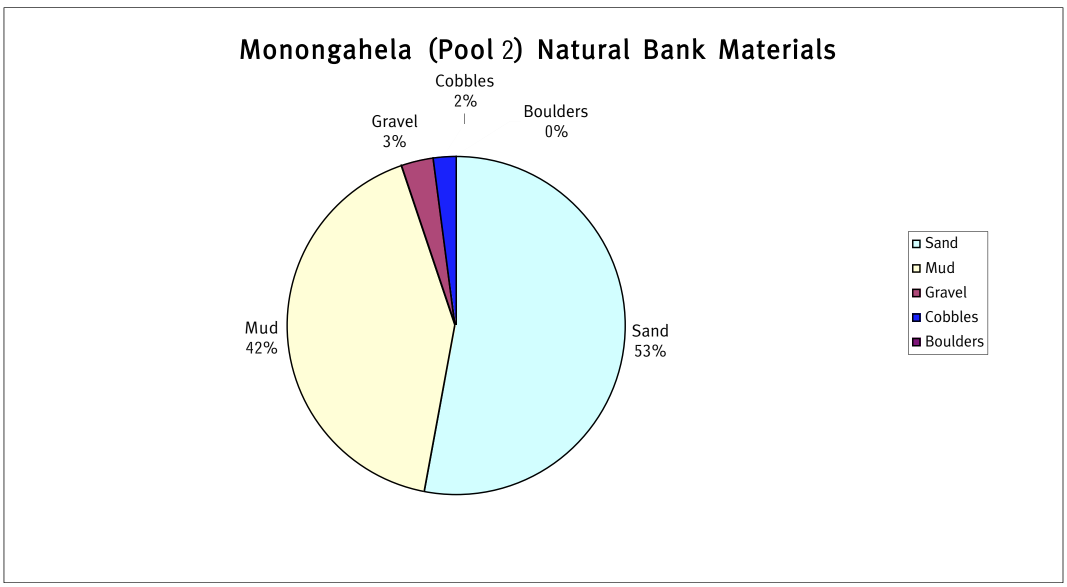
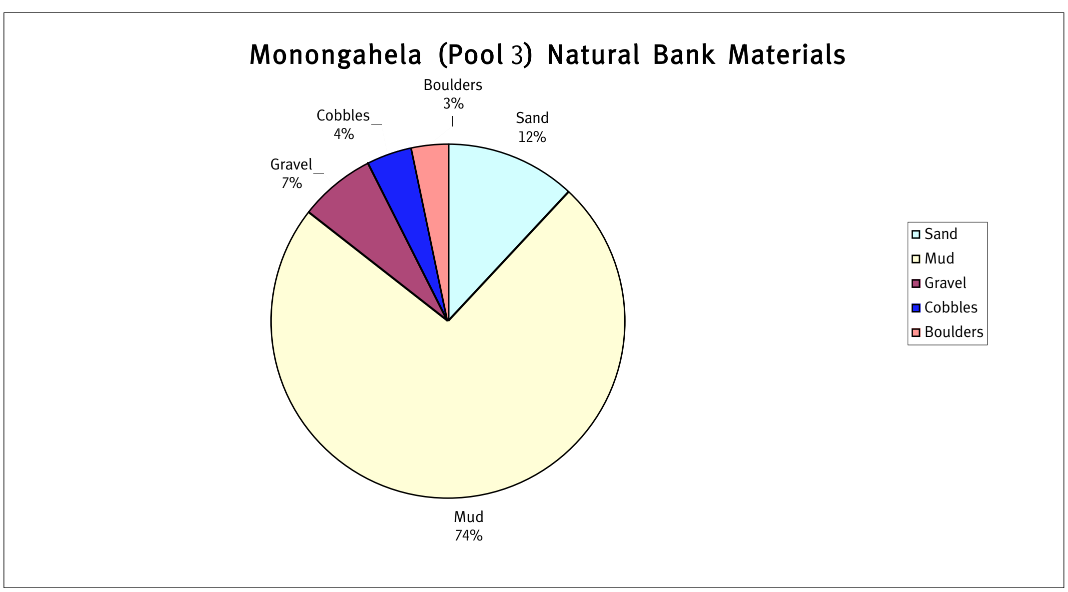


Figure 39



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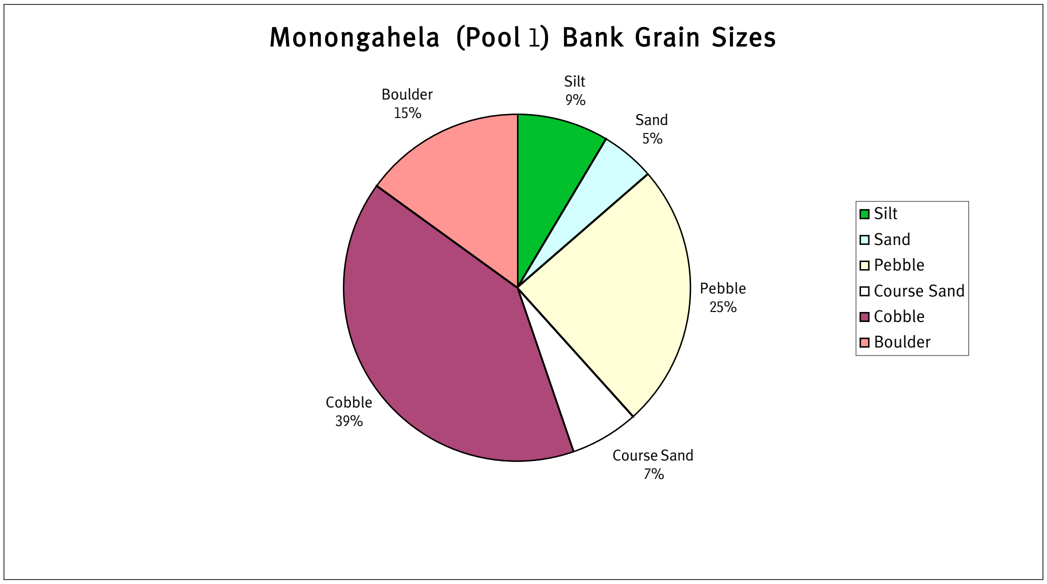

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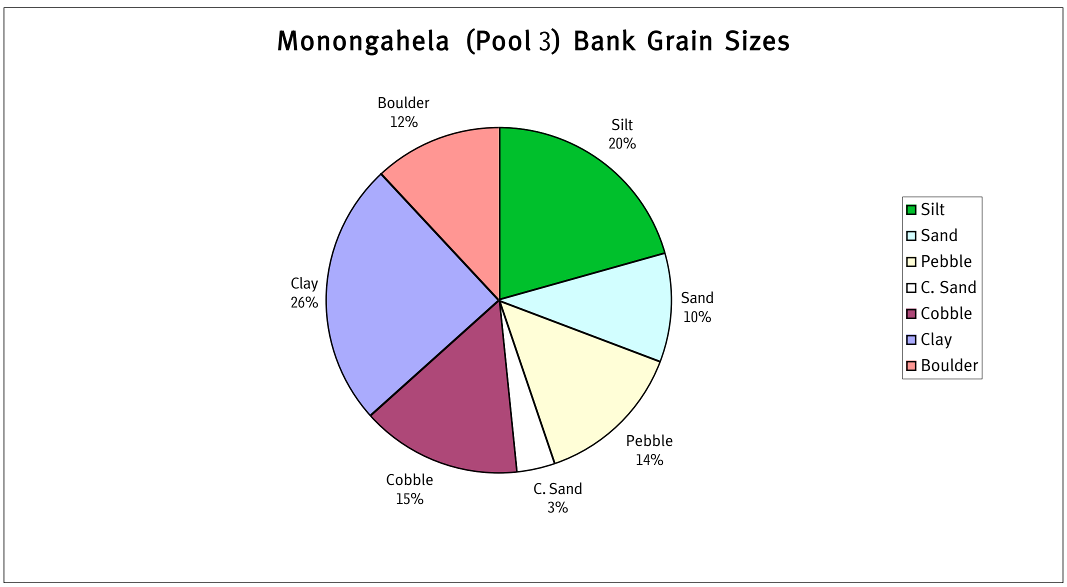
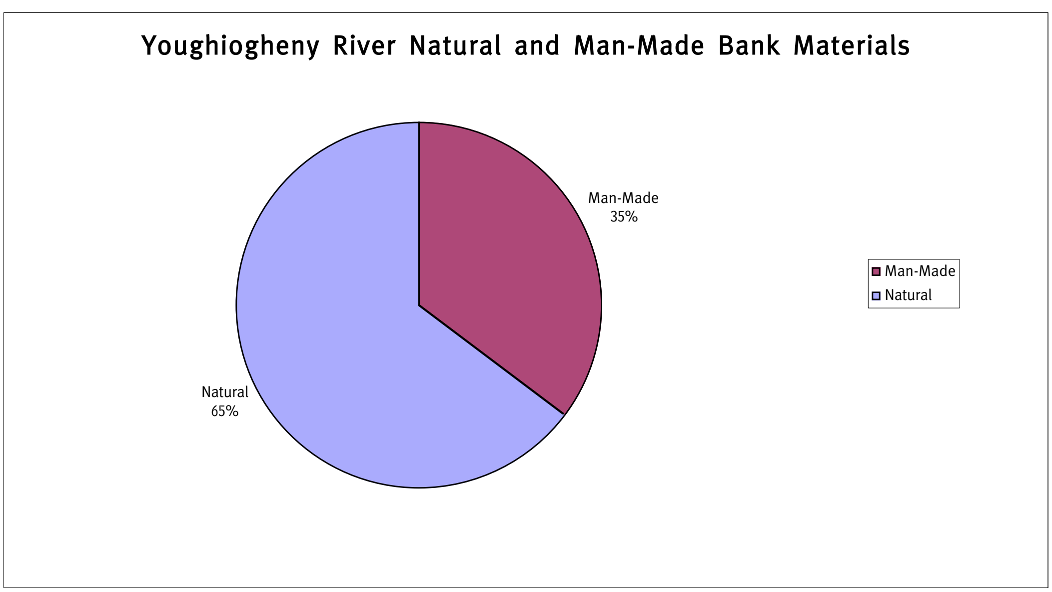


Figure 42



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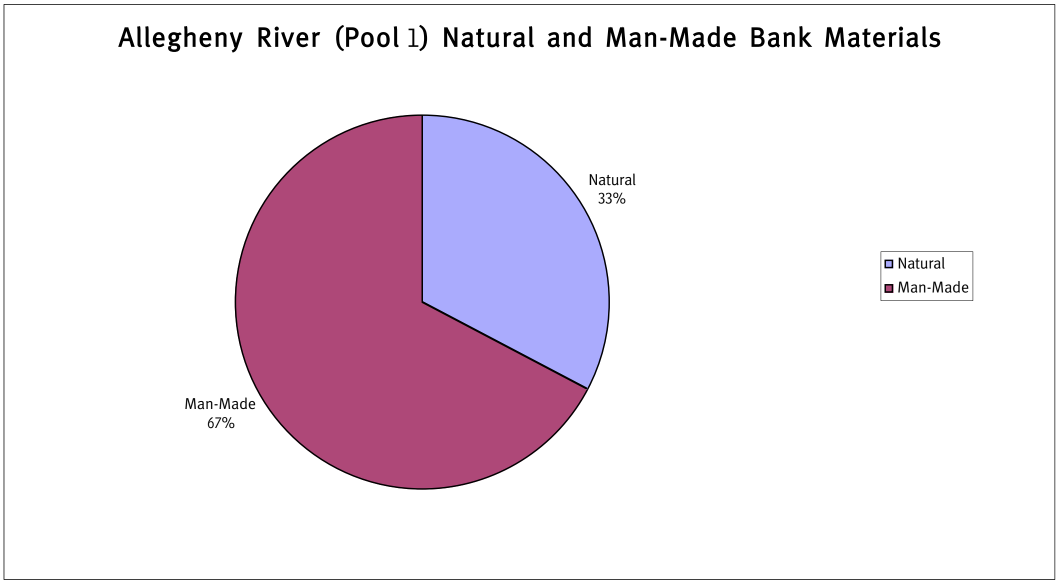

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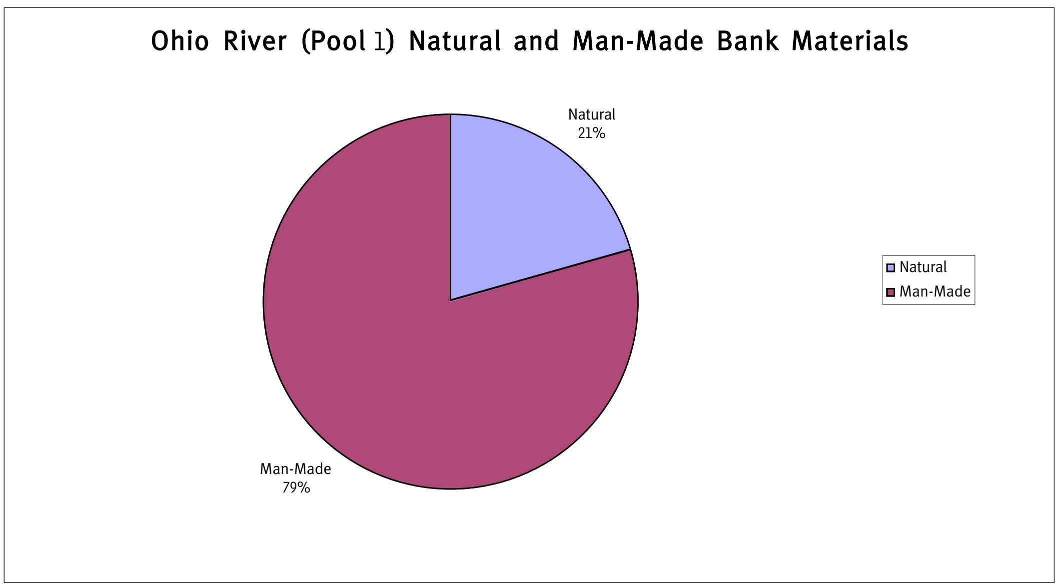

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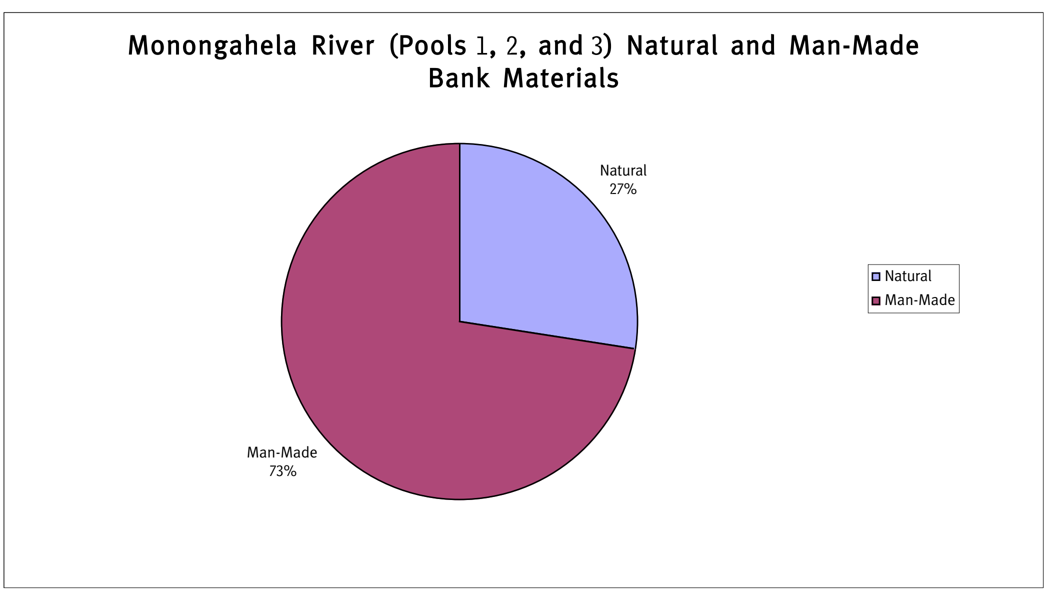
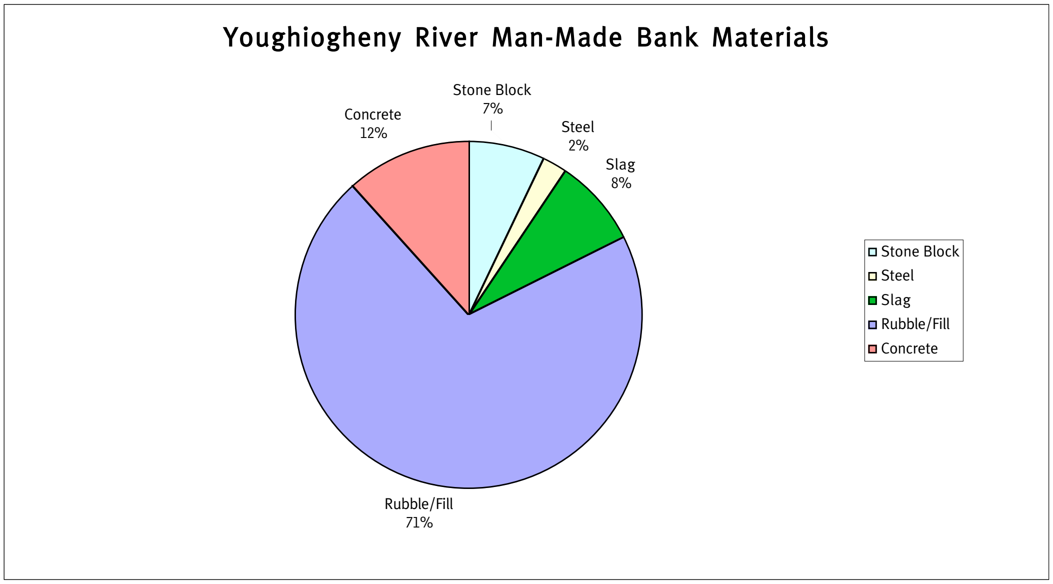


Figure 46

Figure 47



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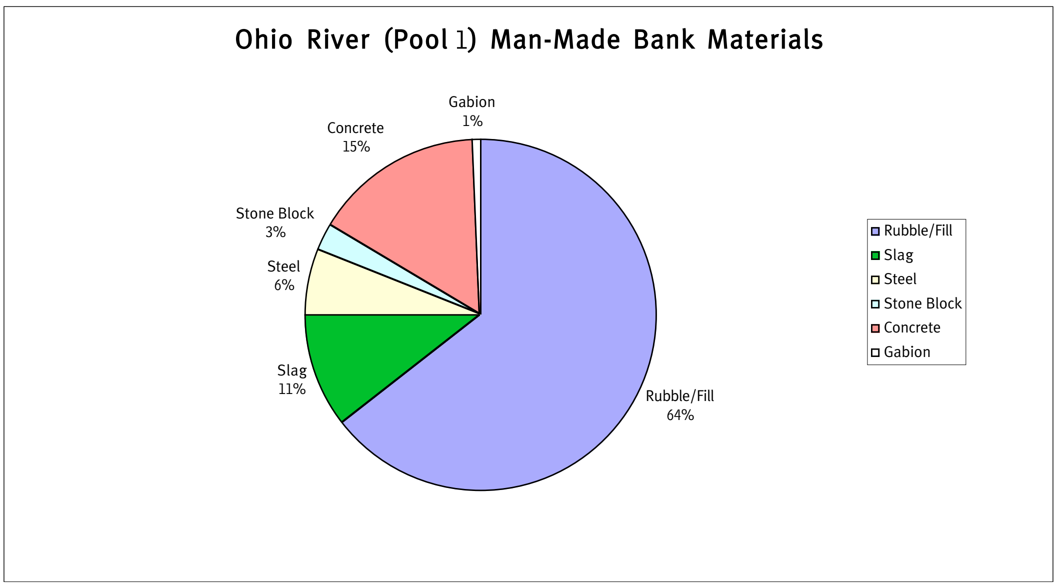
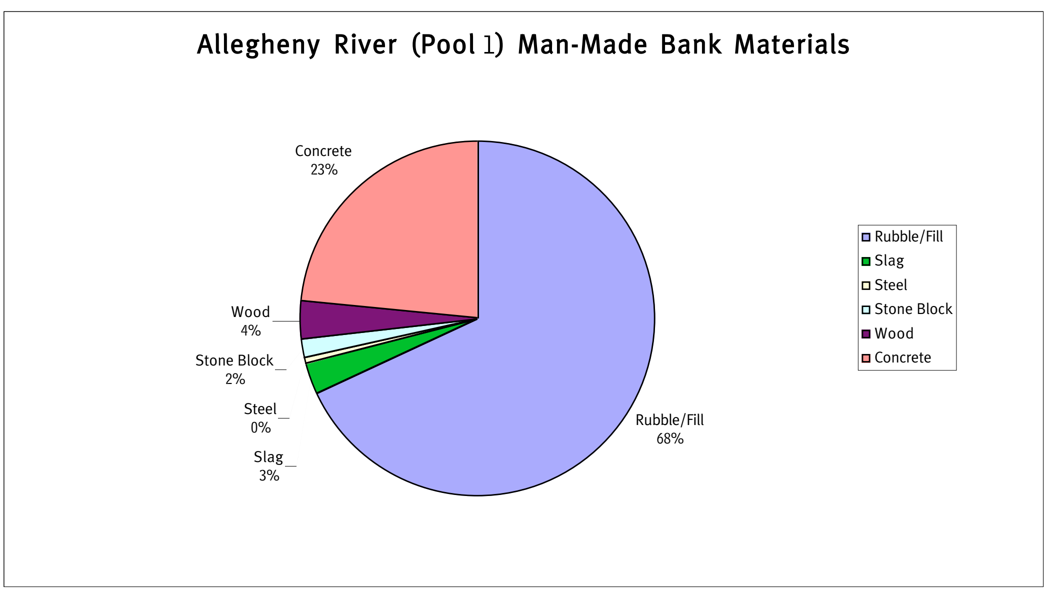
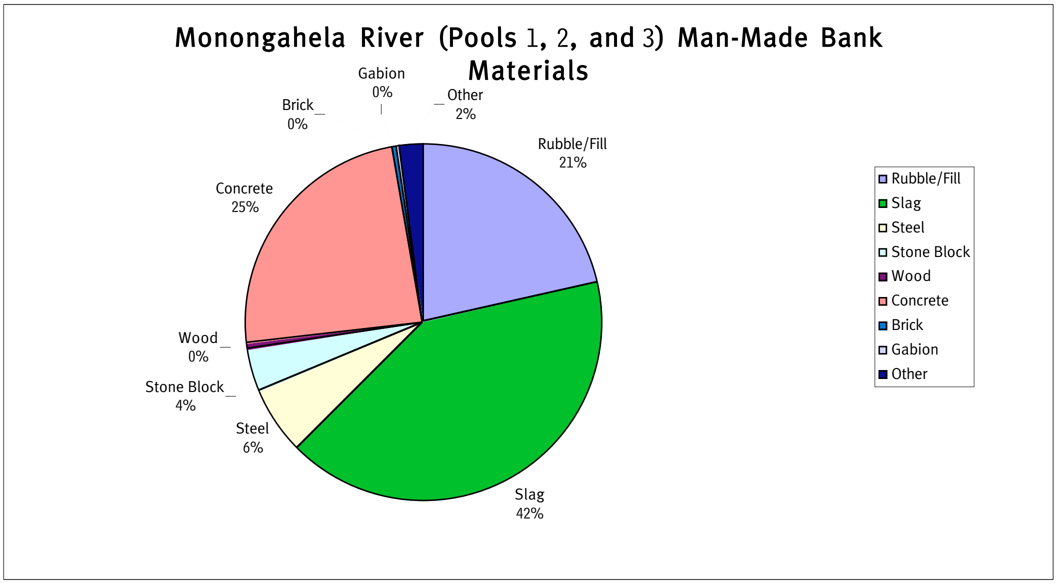


Figure 49





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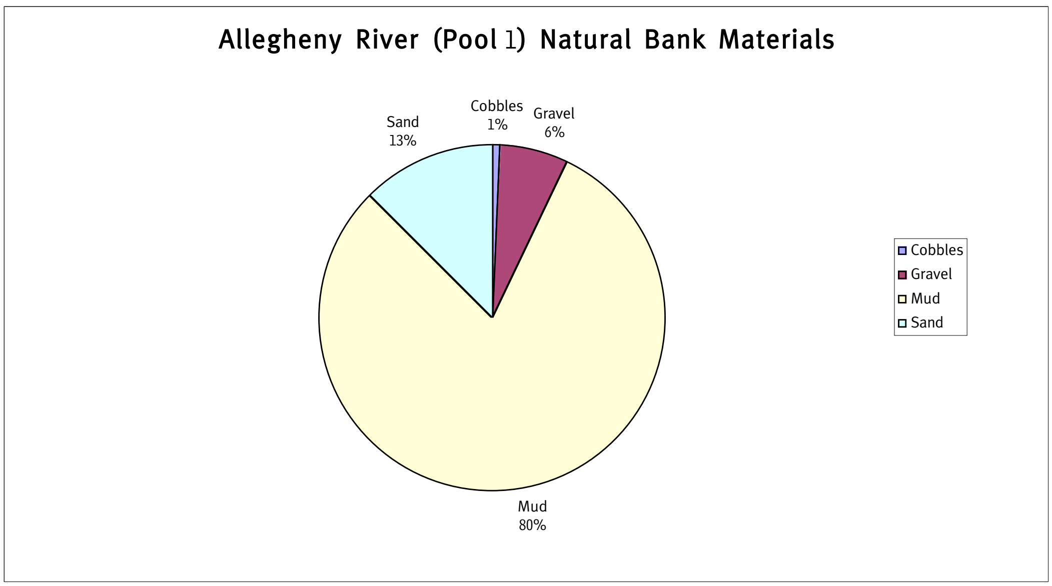
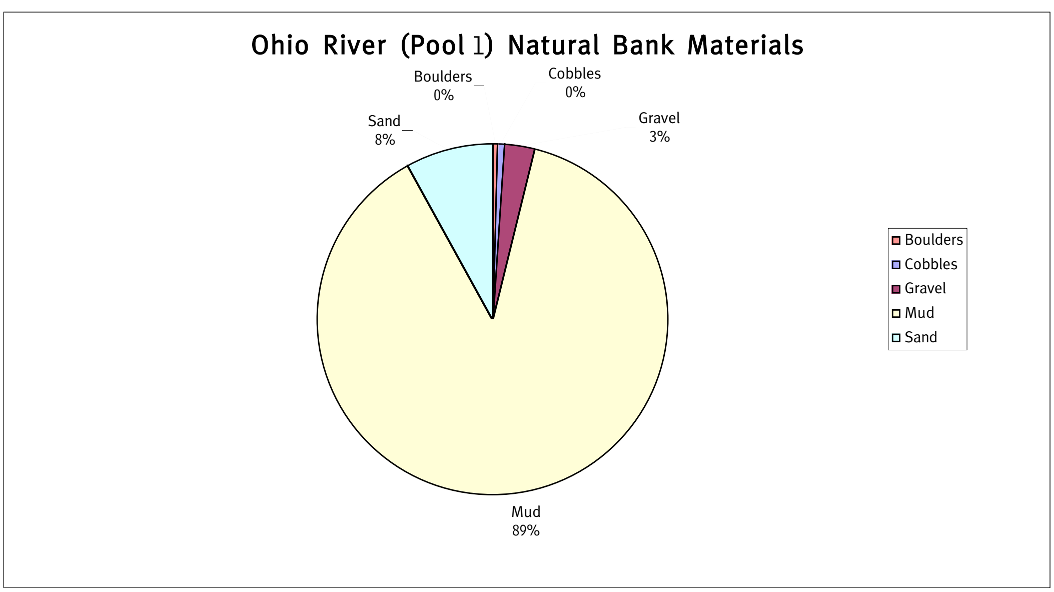


Figure 51



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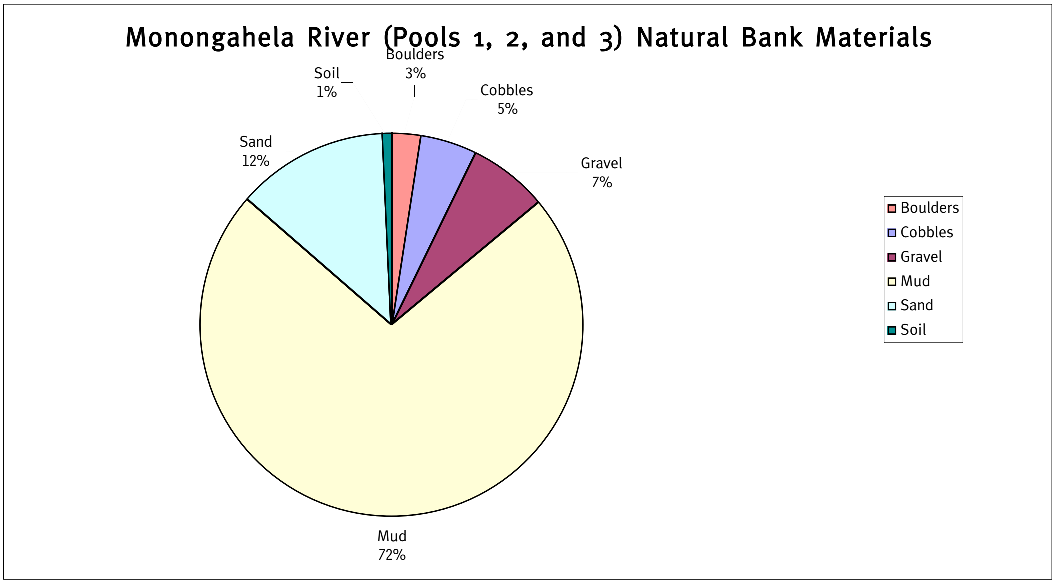

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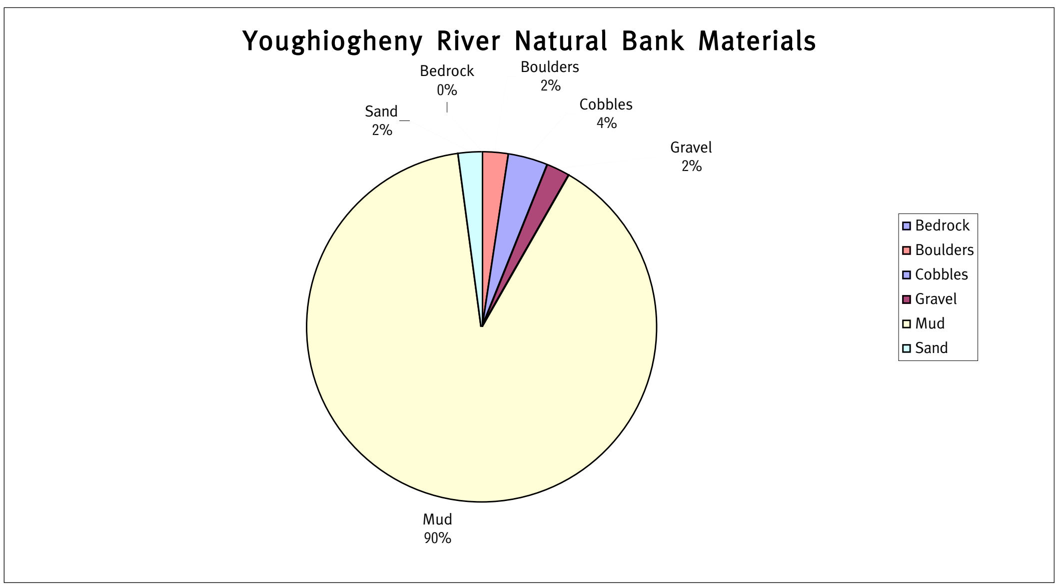

Figure 54

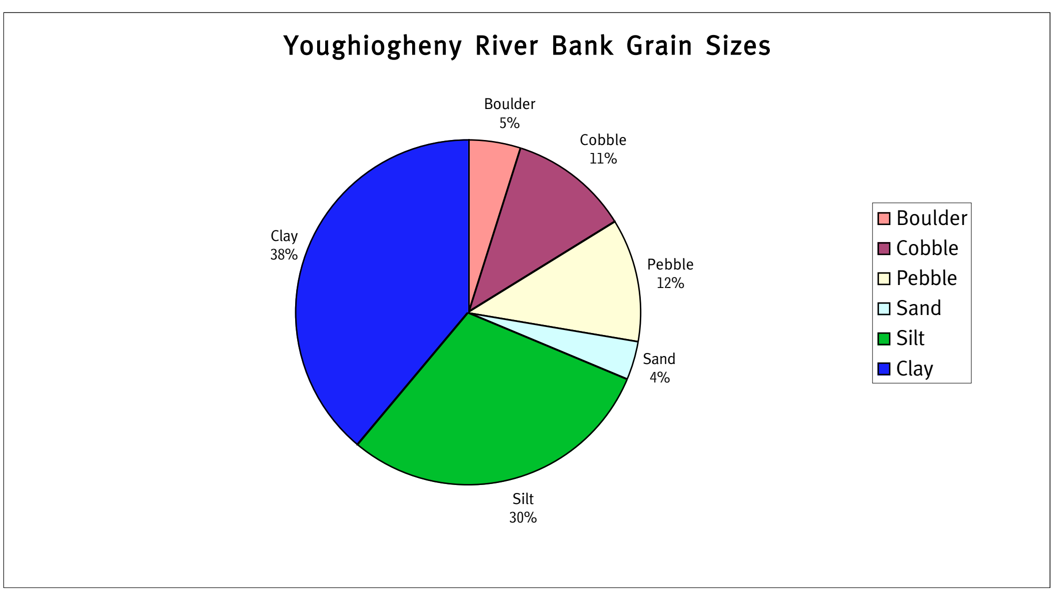

Figure 55

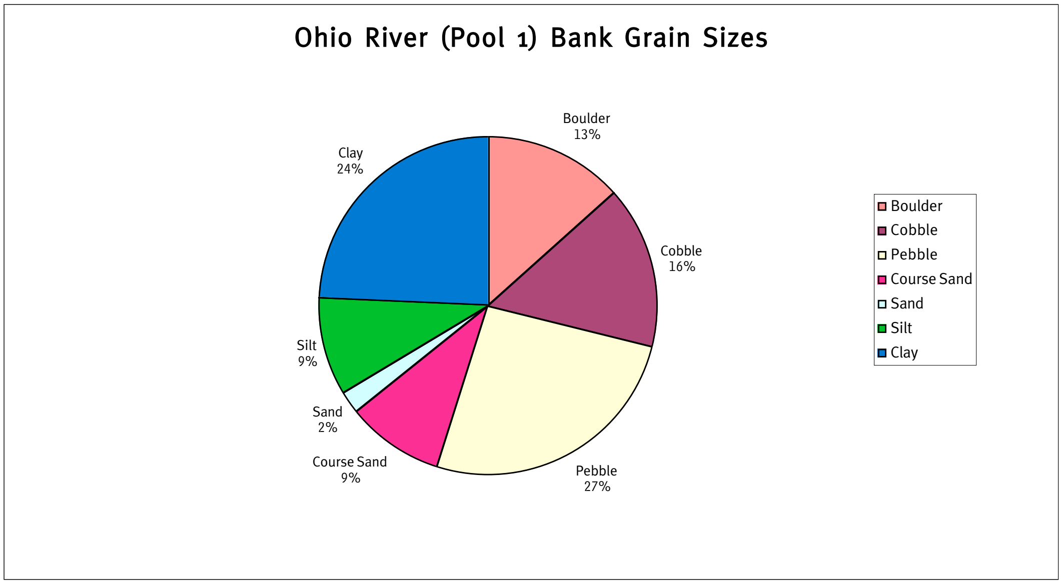

Figure 56

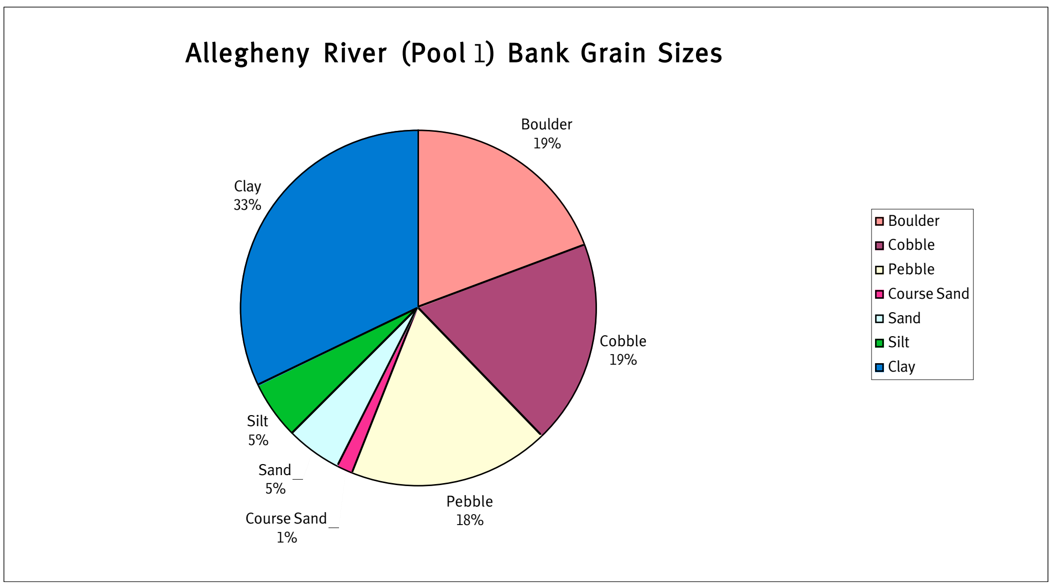

Figure 57

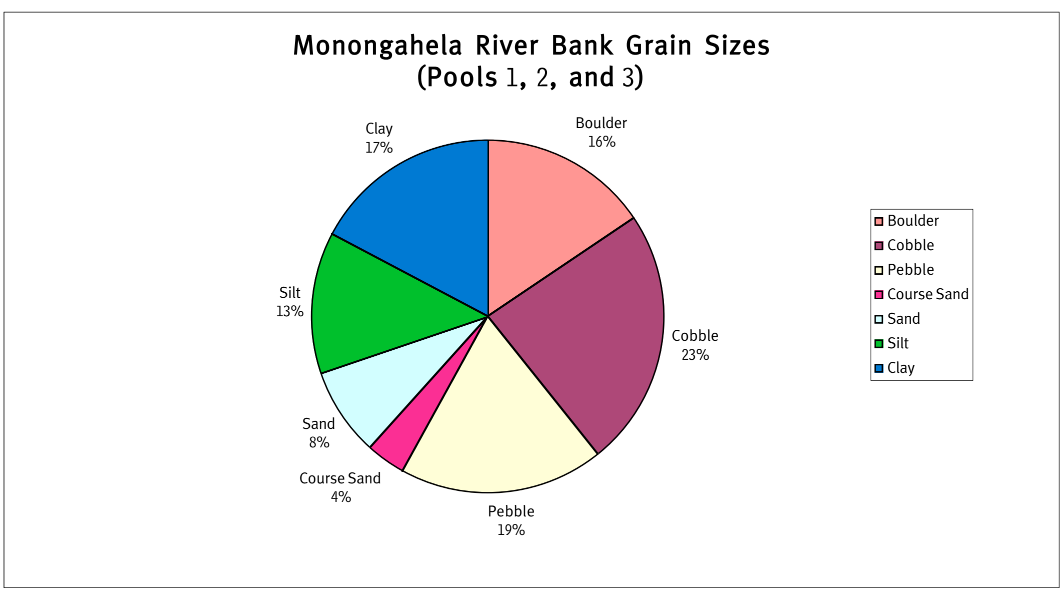

Figure 58