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Total Maximum Daily Load Development
Paducah Gaseous Diffusion Plant: Background and Hydrology

Prepared by
Kentucky Research Consortium for Energy and Environment
233 Mining and Minerals Building
University of Kentucky, Lexington, KY 40506-0107

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February 2006

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Paducah Gaseous Diffusion Plant: Background and Hydrology

Prepared by
Murray State University
Mike Kemp
Andrew Kellie
Jane Benson
Michael Matthews
Matthew Phillip

February 2006

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INTRODUCTION

The Kentucky Research Consortium for Energy and the Environment (KRCEE) was created to support Department of Energy (DOE) efforts to complete expeditious and economical environmental restoration of the Paducah Gaseous Diffusion Plant (PGDP) and surrounding areas such as the Western Kentucky Wildlife Management Area. General activities include the following:

- Application of technical expertise to assess, and accelerate implementation of cost effective technologies and methodologies that result in accelerated clean-up and risk reduction.
- Establishment of problem-specific project teams drawn from disciplines of expertise at participating universities that work with DOE and its contractors to accelerate implementation of project concepts and plans. Project team focus is on risk prioritization and accelerated implementation of cost-effective remedial activities to minimize impacts on public health and the environment.
- Technical review of proposed remediation plans and any non-consensus technical issues associated with their implementation.
- Use of project teams to interface directly with DOE national laboratories, the United States Environmental Protection Agency (EPA), and state regulatory agencies to help forge consensus solutions to technical problems related to clean-up and ongoing operations of the PGDP site.
- Accomplishment of targeted long-term and short-term projects tasks designed to support the accelerated clean-up at PDGP.

KRCEE is administered through the University of Kentucky Tracy Farmer Center for the Environment (TFCE). Annual work plans, deliverables, and associated project budgets address short-term and long-term tasks relevant to ongoing remediation efforts. Project teams made up of faculty and professional staff were drawn from the University of Kentucky (the main campus and the Paducah campus), the University of Louisville, and Murray State University.

Currently, broad projects and issues related to DOE's activities at PGDP include the following: 1) Scrap metal removal and remediation of underlying surface soils, 2) Surface water remediation and release control including sediment control and Total Maximum Daily Load (TMDL) issues, 3) Groundwater remediation including groundwater modeling and proposed remediation technologies, 4) Waste disposal including C-746-U landfill issues, 5) Burial grounds including assessment remedial action feasibility, 6) Site wide soils and drainage ditch clean up using real-time characterization and remediation, 7) Demolition and debris including disposition of volumetrically contaminated metals, 8) seismic issues, and 9) risk assessment issues.

Specific Scope of Work
In support of the general goals of the KRCEE, Murray State University agreed to conduct work related to surface water issues.

To assess the surface water, a hydrologic characterization of the PGDP facility was conducted. The tasks for the project included developing and calibrating continuous simulation hydrologic models for Bayou Creek and Little Bayou Creek watersheds using the HSPF watershed model. Another task included developing a water budget the PGDP facility identifying and incorporating significant water inputs and outputs. Finally, available chemical data from PGDP outfalls and from sampling sites along both creeks were compiled, reviewed, and summarized.

The deliverables for the project included quarterly progress reports, quarterly presentations, and a summary report describing the development and calibration of the models, the plant water budget, and the chemical data.

Bayou Creek and Little Bayou Creek are on the Kentucky 2002 303(d) list of impaired waters. Under the provisions of the Clean Water Act, individual TMDLs must be developed for each creek. Constituents of concern for Bayou Creek include metals (iron, lead, copper, and mercury) and Technetium (^{99}Tc). Constituents of concern for Little Bayou Creek include metals (iron, lead, copper) and (^{99}Tc). The work included assessing which of these parameters might require TMDL development and may include actual TMDL development once agreement is reached between DOE and state regulatory agencies on how to proceed.

Acknowledgments

The authors would like to acknowledge with appreciation the assistance of Dr. Ramesh S V Teegavarappu and Dr. Chandramouli Viswanathan of Department of Civil Engineering at the University of Kentucky. Both provided unselfish assistance on the use and calibration of the HSPF model used in part of this research. Dr. Alan Fryer and Mr. Josh Sexton of the Department of Geology at the University of Kentucky kindly provided information on the losing and gaining sections of Bayou and Little Bayou Creeks that was very much appreciated. The authors also recognize the support of Dr. Daniel Claiborne of the Department of Industrial and Engineering Technology at Murray State University who arranged office space and staffing to accommodate project needs. Finally, the authors acknowledge the support provided by project director Dr. Lindell Ormsbee and assistant director Mr. Steve Hampson throughout the entire duration of this project.

BACKGROUND AND HYDROLOGY

Location and site description

The Paducah Gaseous Diffusion Plant (PGDP) is located on a 3,400-acre site in McCracken County approximately 15 miles west of Paducah, Ky., and approximately 3 miles south of the Ohio River. The PGDP was completed in 1953 with production starting as early as 1952. The facility enriches uranium through a diffusion cascade process that requires extensive support facilities. The diffusion process encompasses five buildings with approximately 740 acres fenced. Support facilities at the plant include cooling towers, a chemical cleaning and decontamination facility, water and wastewater treatment plants, a phosphate reduction facility, four electrical switchyards, a steam plant, and a laboratory. Including various contractors located on the site, the facility employed approximately 2,000 people at its peak. The PGDP is surrounded by a buffer of land owned by the Department of Energy (DOE) and leased to the Commonwealth of Kentucky.

The PGDP discharges treated wastewater and storm water runoff to both Bayou and Little Bayou Creeks, which drain northerly through privately owned land and the West Kentucky Wildlife Management Area (WKWMA) to the Ohio River. Effluent from the PGDP is a major source of flow in both Little Bayou Creek and Bayou Creek during low-flow periods.

The Bayou Creek and Little Bayou Creek watersheds, which comprise the study area herein, have a combined area of 26.9 square miles. The watersheds and are located in the northwestern quadrant of McCracken County, Kentucky and are included in U.S. Geological Survey (USGS) hydrologic unit code (HUC) 05140206. The two watersheds are included on the Heath (1978) and Joppa (1982) USGS topographic quadrangle sheets and on the Heath (1971) and Joppa (1982) geologic quads. The approximate centroid of the combined watersheds is 37°06'40" North 88°48'44"West.

Both streams flow in a northerly direction. Bayou Creek discharges into the Ohio River between river miles 947 and 948. Little Bayou Creek is now tributary to Bayou Creek. Little Bayou Creek discharges into Bayou Creek approximately 1,200 feet south of the confluence of Bayou Creek with the Ohio. The U.S. Geological Survey Joppa Geologic Quad, which uses a 1954 USGS base, shows Little Bayou Creek as discharging directly into the Ohio River approximately 3,100 feet east of its present confluence with Bayou Creek (Finch, 1967). According to Fryar, Wallin, and Brown (2000), sometime between 1953 and 1971 the lower reach of Little Bayou Creek was channelized to become a tributary of the Bayou Creek. A surface model with Bayou Creek and Little Bayou Creek watersheds delineated thereon is shown in figure 1.

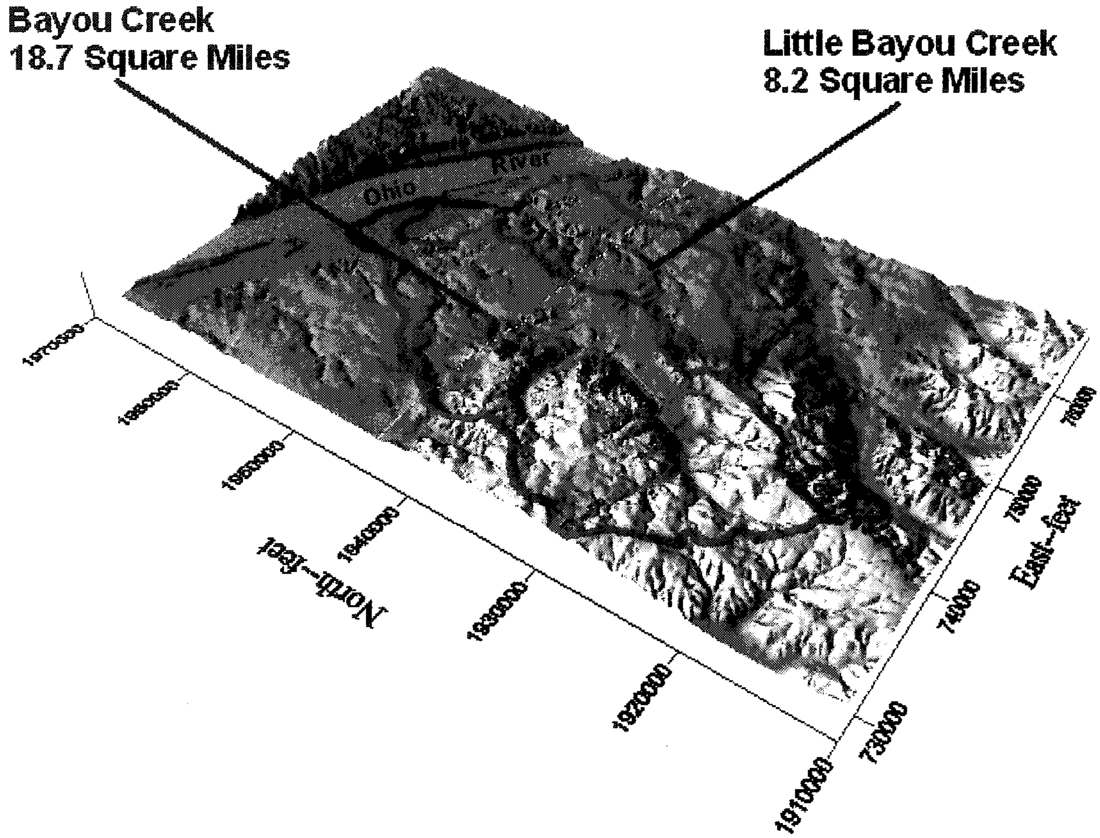


Figure 1. Watersheds of Bayou Creek and Little Bayou Creek, July 2004. Coordinates shown refer to Kentucky State Plane Coordinate System, South Zone.

The Bayou Creek and Little Bayou Creek watersheds are included in the Mississippi Embayment physiographic region of Kentucky. McGrain (1978) describes the topography of McCracken County as that of a gently rolling plain with large areas of level land. Highest elevations are in the southern part of the county. There is a gentle slope north to the Ohio River. Davis, Lambert, and Hansen (1987) describe the topography as being of low relief with "wide shallow valleys."

The climate of the study area is described by Davis, Lambert, and Hansen (1987) as the humid-continental type. They state that annual precipitation averages 45 inches. Monthly average temperatures vary from 37°F in January to 80°F in July. Fryar, Wallin, and Brown (2000) citing work by Thornthwaite and Mather (1957) note that actual evapotranspiration is less than potential and both exceed precipitation from June through September.

Weather data for the study area are collected at seven weather stations maintained by the National Oceanographic and Atmospheric Administration (NOAA). Due to the proximity of the PGDP to the Barkley Regional Airport, precipitation and temperature records for the airport station for the period October 1, 1997 to August 31, 2003 were used in this project. These data showed annual precipitation to vary from 43.2 inches (1999) to 61.9 inches (1997). Regional weather stations, together with their approximate radial distance from the study area are shown in figure 2. Due to proximity of Barkley Regional Airport to the study area, meteorological data from that site was used in this research.

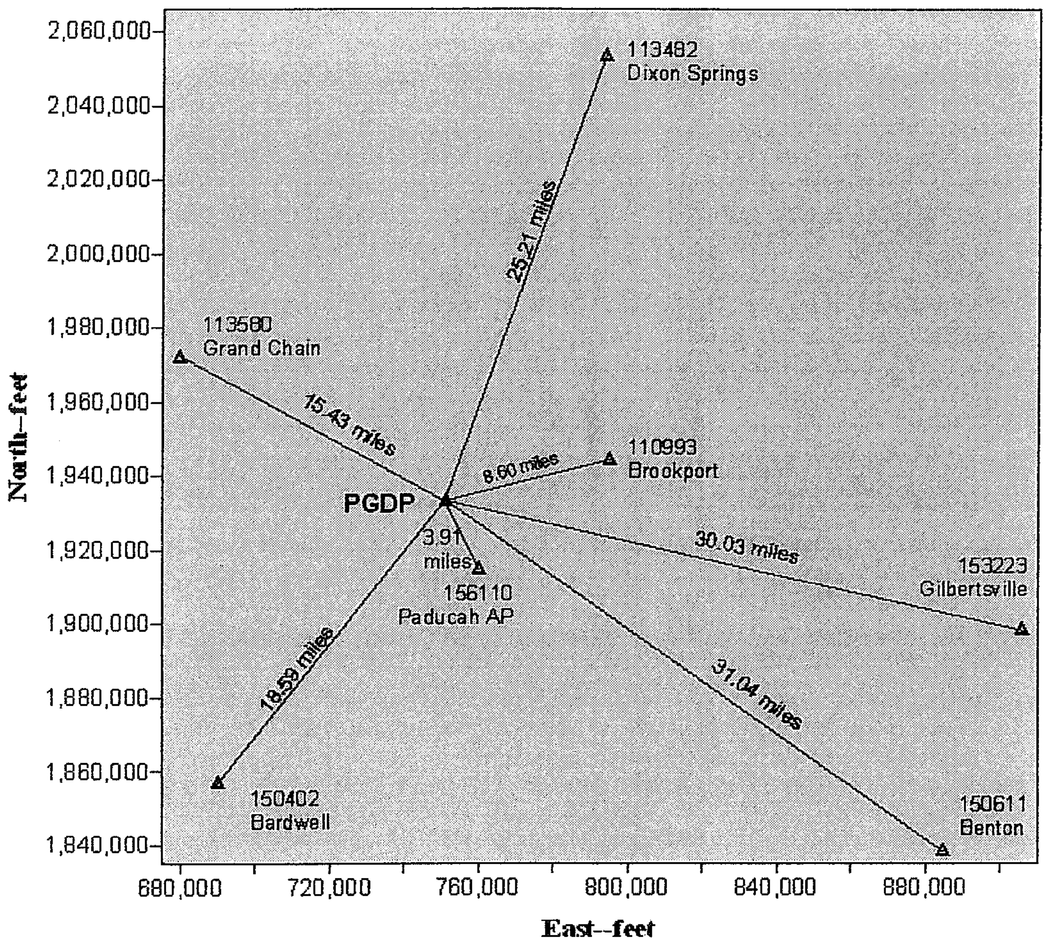


Figure 2. NOAA rain gage locations adjacent to the study area. Numbers at gage locations are NOAA coop designations. Coordinates shown refer to Kentucky State Plane Coordinate System, South Zone.

Geologic Information

The general geology of the Bayou Creek and Little Bayou has been discussed by several authors (Cushing, Boswell, & Hosman, 1964; Olive, 1972; Olive, 1966; Finch, 1967; Davis, Lambert, and Hansen, 1971). Structurally, Olive (1972) described the Mississippi Embayment as a "southerly plunging synclinal trough, the axis of which parallels the Mississippi River". Cushing, Boswell, and Hosman (1964) estimate dip of the strata as 35 to 50 feet per mile.

Strata in the Mississippi Embayment are generally unconsolidated and are of Cretaceous, Tertiary, and Quaternary age. Principal formations included: the Tuscaloosa and McNairy (Cretaceous); the Porters Creek, Wilcox, Claiborne, and Jackson (Tertiary); and Quaternary continental deposits of cherty gravel (Pliocene?), loess, and alluvium (Olive, 1972). (Note that in accordance with standard geological procedure the uncertainty of the date of the continental deposits is indicated by a question mark.)

Davis, Lambert, and Hansen (1971) discussed the subsurface geology of the Jackson Purchase with reference to ground water resources. These authors noted that Cretaceous deposits are primarily unconsolidated sands or clay. Pliocene(?) gravels and Pleistocene loess overlay the Cretaceous deposits (Davis, Lambert, and Hansen, 1971).

Maps provided by Davis, Lambert, and Hansen (1971) show the zone of saturation in the Eocene sands and the Pliocene(?) gravel on Bayou Creek and Little Bayou Creeks. Water levels and the zone of saturation in the Pliocene(?) gravel range in elevation from 310 to 330 feet along the north quarter of the watersheds. Water levels and the zone of saturation in the Eocene sands on the remainder of the watersheds range in elevation from 360 to 400 feet.

Hydrologic Information

As measured from the Joppa and Heath U.S. Geological Survey (USGS) 7 ½ minute topographic quadrangle sheets, Bayou Creek watershed has a main stem length of 62,300 feet and an area of 18.7 square miles. Fryar, Wallin, and Brown (2000) described Bayou Creek as a second-order stream. Principal subwatersheds include Forestdale Creek, Ordinance Works Creek, and Brushy Creek. Two USGS stream gaging stations are located on Bayou Creek. Gage 03611800 (37°05'58"North, 88°49'27"West) is located on South Acid Road west of route 1154. Gage 03611850 (37°08'41"North, 88°49'38" West) is located on route 358 at Rossington.

Little Bayou Creek watershed has a main stem length of 37,900 feet and an area of 8.2 square miles based on measurements from the Joppa and Heath USGS 7 ½ minute topographic quadrangle sheets. Fryar, Wallin, and Brown (20000) described Little Bayou Creek as a first-order stream. A single USGS stream gage, 03611900 (37°08'22" North, 88°47'26" West), is located on Anderson Road. The Bayou Creek and Little Bayou Creek subbasins are shown in figure 3.

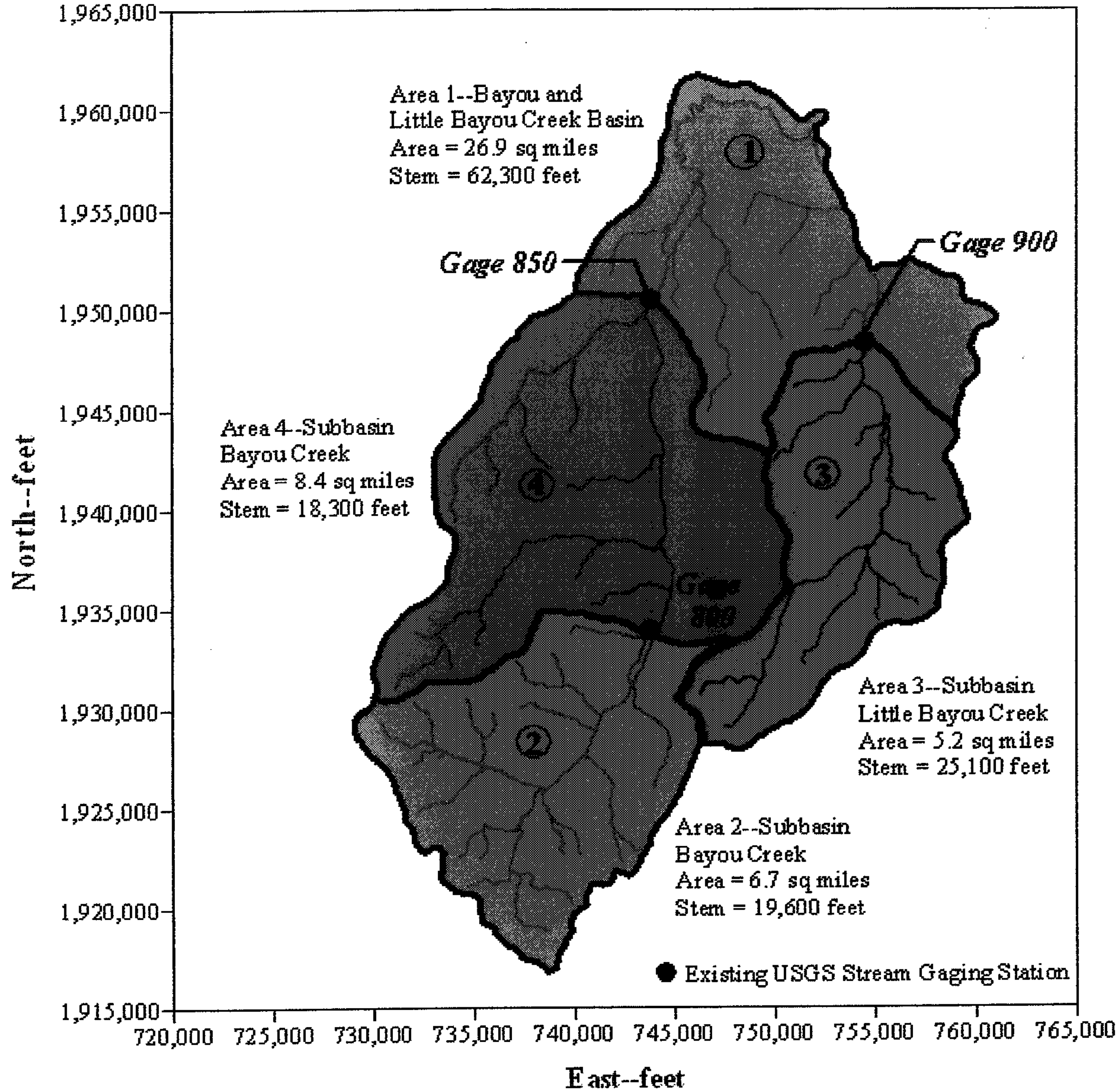


Figure 3. Reach and watershed delineation for Bayou and Little Bayou Creeks, McCracken County, Kentucky. Coordinates shown refer to Kentucky State Plane Coordinate System, South zone.

Table 1 summarizes area, main stem and channel system lengths, and drainage density for both the Bayou Creek and the Little Bayou Creek watersheds. The drainage density for the two watersheds averages approximately 2.4 miles of drainage per square mile of watershed. This is a relatively coarse drainage network indicative of soils with high infiltration capacity and is of interest in this research because of its hydrologic significance.

Table 1. Basin and subbasin area, main stem length, channel system length, and drainage density for Bayou Creek and Little Bayou Creek.

Area or Subarea[1]	Area (mi^2)	Main Stem (ft)	Channel System (ft)	Density (mi/mi^2)
1 Main Basin	26.9	62,300	240,300	2.4
2 Subbasin	6.7	19,600	99,100	2.8
3 Subbasin	5.2	25,100	68,100	2.5
4 Subbasin	8.4	18,300	85,500	1.9

[1]Area and subarea locations are shown in figure 3.

Table 2. Basin and subbasin elevations and channel slopes for Bayou and Little Bayou Creek watersheds and subwatersheds.

Area or Subarea[1]	Maximum[2] Elevation (ft)	Headwater Elevation (ft)	Outlet Elevation (ft)	Channel Slope[3] (ft/ft)
1 Main Basin	474	450	290	0.003
2 Subbasin	474	450	375	0.004
3 Subbasin	425	410	325	0.003
4 Subbasin	474	375	335	0.002

[1]Area and subarea locations are shown in figure 3.
[2]Maximum value for basin or subbasin
[3]Based on blue line elevations at headwater and outlet and main stem length as shown on USGS Heath and Joppa quads

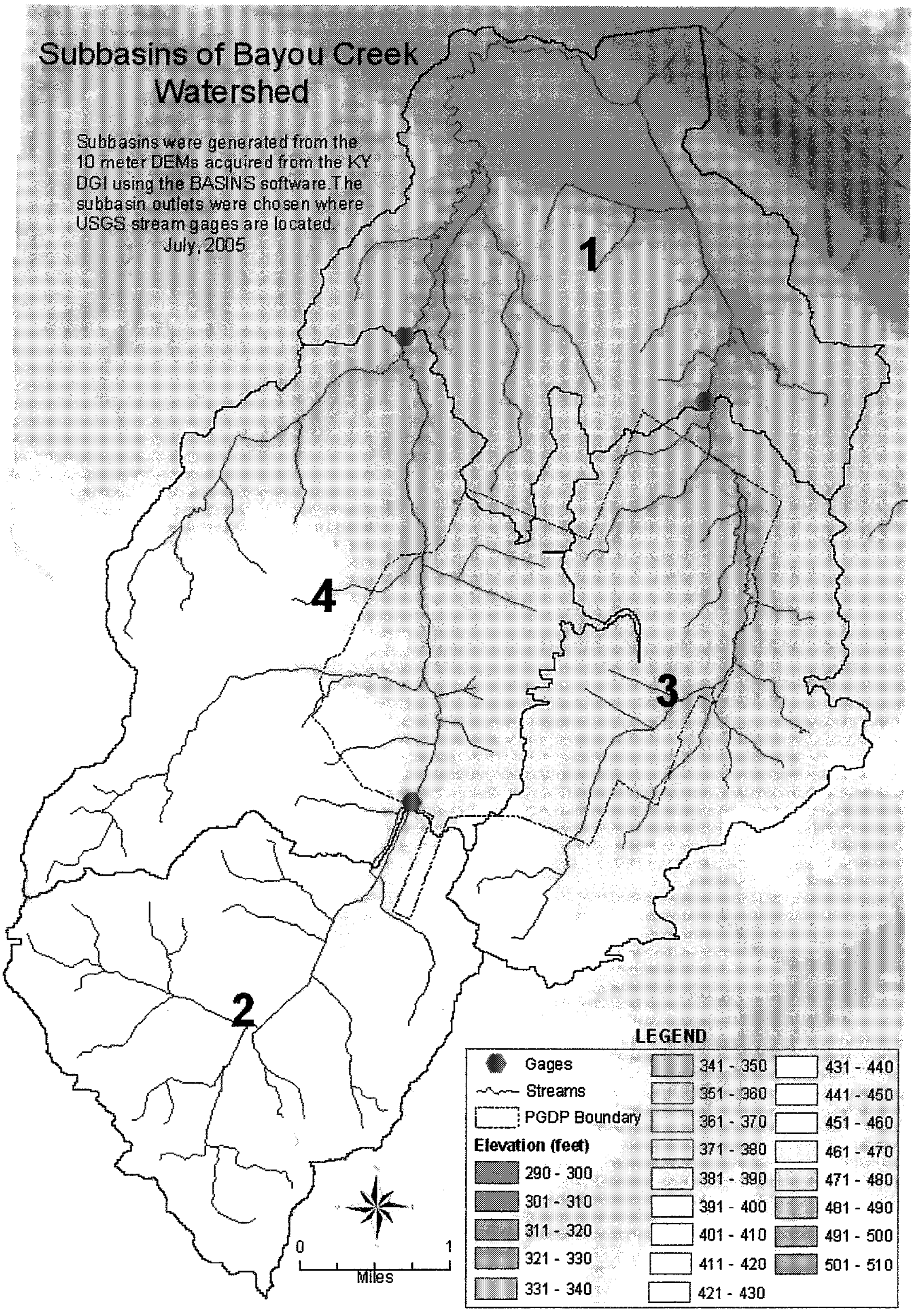
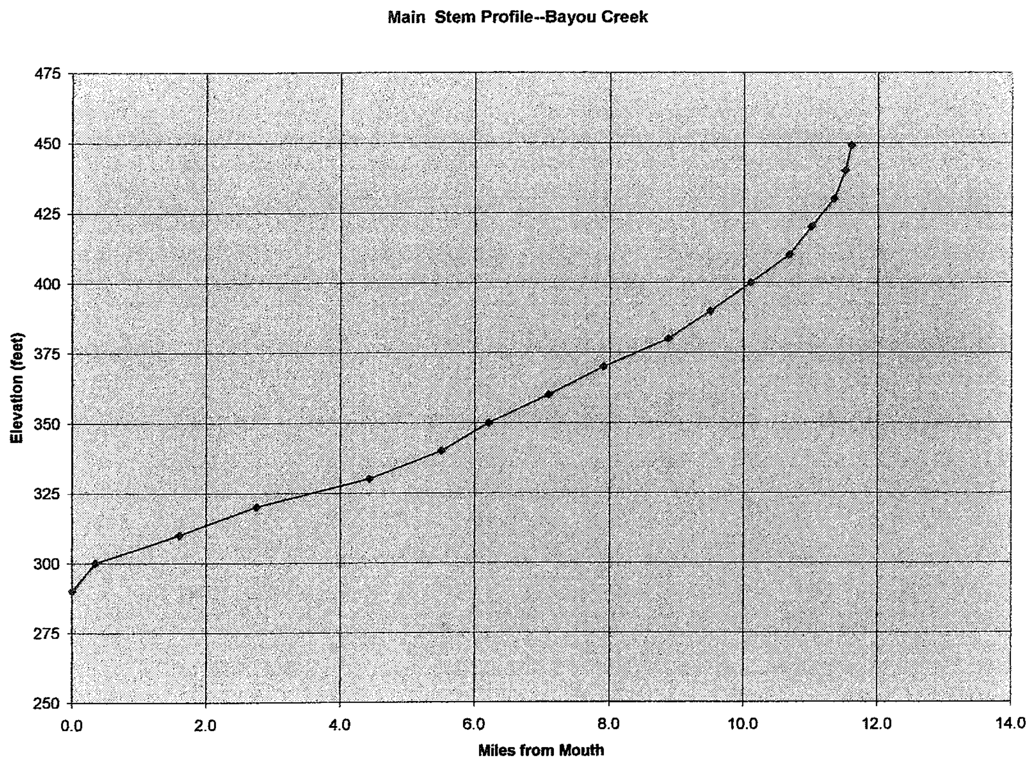


Figure 4. Bayou Creek and Little Bayou Creek subbasins.



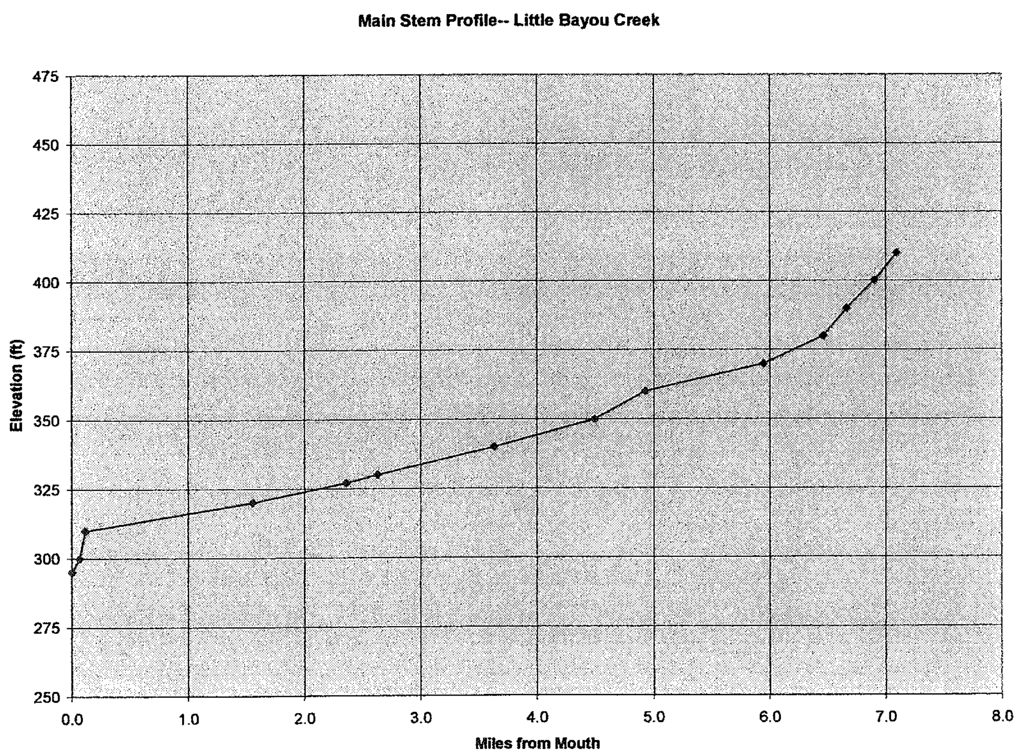


Figure 5. Main stem profiles for Bayou Creek and Little Bayou Creeks.

Elevations on the Bayou Creek watershed site range from 474 feet near the headwaters of the Ordinance Creek subwatershed to 290 feet at the Ohio River. On Little Bayou Creek, elevations range from 425 feet at the headwaters to 295 feet at the confluence of Little Bayou and Bayou Creeks. General topography, together with subbasin delineation is shown in figure 4.

Table 2 shows watershed elevations and channel slopes for the Bayou Creek and Little Bayou Creek subwatersheds. Channel slope naturally varies with the position in the watershed (headwaters versus outlet). Channel slopes are relatively flat, averaging approximately 0.003 ft/ft (0.3%). The drainage pattern of both Bayou and Little Bayou Creeks is dendritic.

Main stem profiles for Bayou Creek and Little Bayou Creek taken from the Heath (1978) and Joppa (1982) USGS 7 ½ minute quadrangles are shown in figure 5. Both profiles have a classic J-shape. There are no obvious nick points shown on either profile.

Mormophometric descriptors, describing general subwatershed shape, for both the Big Bayou and Little Bayou watersheds are shown in Table 3. In general, the computations appear to show no predominant shape for the subwatersheds included in this study. Equations used in morphometric computation are as follows:

$$F = \frac{A}{L^2} \qquad (1)$$

$$C = \frac{4\pi A}{p^2} \qquad (2)$$

$$E = \frac{2\left[\frac{A}{\pi}\right]^{\frac{1}{2}}}{L} \qquad (3)$$

$$K = \frac{L^2}{4A} \qquad (4)$$

$$S = \frac{L}{W} \qquad (5)$$

where F=Horton's form factor (Horton, 1932); A = basin area; L=basin length; C= Miller's circularity (Miller, 1953); p = basin perimeter; E=Schuum's basin elongation (Selby, 1985); K= Chorley's lemniscate ratio (Chorley, 1957); W = basin width; and S = Selby's basin shape (Selby, 1985).

Table 3. Morphometric descriptors for the Bayou Creek and Little Bayou Creek.

Watershed	Form Factor	Circularity Ratio	Basin Elongation	Lemniscate Ratio	Shape Factor
Bayou Creek	0.27	0.42	0.59	0.93	2.7
Little Bayou Creek[1]	0.23	0.35	0.54	1.09	3.5

[1]Watershed upstream of confluence with Bayou Creek.

The general hydrology of the study area has been discussed by Davis, Lambert, and Hansen (1971, 1987), Hansen (1966), Lambert (1966), and McGrain (1978). Fryar, Miller, and Brown (2000) reported specifically on groundwater conditions in the study area.

McGrain (1978) showed Bayou Creek and Little Bayou Creek watersheds to be primarily underlain by continental deposits of sand and gravel. The continental deposits are largely chert pebbles which have a coating of limonite (McGrain, 1978). Lambert (1966) and Hansen (1966) mapped shallow aquifers and water surface elevations on the study area. They showed water surface elevations to vary from 400 feet at Bethel Church Road south of the Kentucky Ordnance Works (Heath Quad) to less than 300 feet south at the Ohio River (Joppa Quad). The primary shallow aquifer shown consists of Pliocene (?) and Pleistocene gravel which is described as having a thickness of 3 to 40 feet (Lambert, 1966). Fryar, Wallin, and Brown (2000), based on detailed work on the Bayou Creek and Little Bayou Creek watersheds, described the aquifer as being 90 to 120 m thick. Lambert (1966) described this aquifer as:

> Continental terrace deposits lying on two irregular surfaces cut at different levels into sediments of Eocene, Paleocene, and Cretaceous ages. The pre-Pliocene surface consists of channels and terraces cut by an intricate drainage system at an altitude of about 400 feet above sea level. At least one such channel occurs north of Grahamville...In the Pliocene(?) and Pleistocene water-availability area, the gravel rests on an eroded surface that is below 330 feet in altitude.

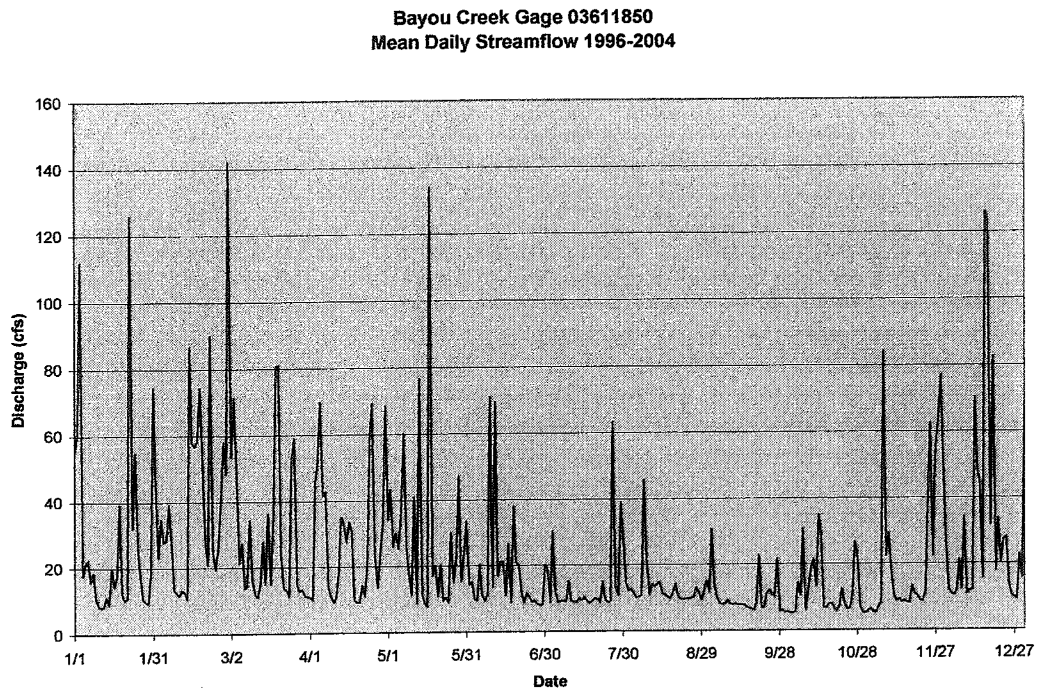
Davis, Lambert, and Hansen (1971) showed shallow ground water movement on Bayou Creek and little Bayou Creek watersheds to be northward toward the Ohio River. They stated further that the gravel aquifer west of Paducah (that lying on the study area) has the largest potential yields from a continental terrace aquifer in the Jackson Purchase. This yield is possible because the aquifer is both thick and heavily saturated (Davis, Lambert, & Hansen, 1971).

Davis, Lambert, and Hansen (1987) stated that recharge of the Pliocene(?)-Pleistocene gravel aquifer occurs through overlying loess. Pree, Walker, and MacCary (1957) (cited by Davis, Lambert, and Hansen, 1987) saw this recharge as taking place when the overlying loess becomes saturated. Prill (1968) (cited as personal communication d by Davis, Lambert, and Hansen, 1987) favored unsaturated flow during recharge. McGrain (1978) noted that "springs and seeps are common along the base of porous sand and gravel formations where they are in contact with underlying impervious clay deposits".

Fryar, Miller, and Brown (2000) investigated gaining and losing portions of Bayou and Little Bayou Creeks. They concluded that Bayou Creek was a losing stream between gages 800 and 850, while Little Bayou Creek was a losing stream above gage 900. Additional work concerning losing and gaining sections of the creeks was reported by Evaldi and McClain (1989).

Davis, Lambert, and Hansen (1971) described water quality as being moderately hard, slightly acidic, and high in iron content. Lambert (1966) and Hansen (1966) showed seven water quality samples obtained on the Bayou Creek and Little Bayou Creek watershed. For these samples, hardness averaged 140 ppm $CaCO_3$ equivalent (range 33-338 ppm). Iron content averaged 0.43 ppm and varied from 0.03 to 1.2 ppm (Lambert, 1966; Hansen, 1966).

Daily stream flow data used in this research were recorded by the three gaging stations located on the Bayou and Little Bayou Creek watersheds. Hydrographs for gaging stations 03611850 and 036900 for the period October 1, 1996 to August 31, 2003 (the period of data available at the beginning of this project) are shown in figure 6.



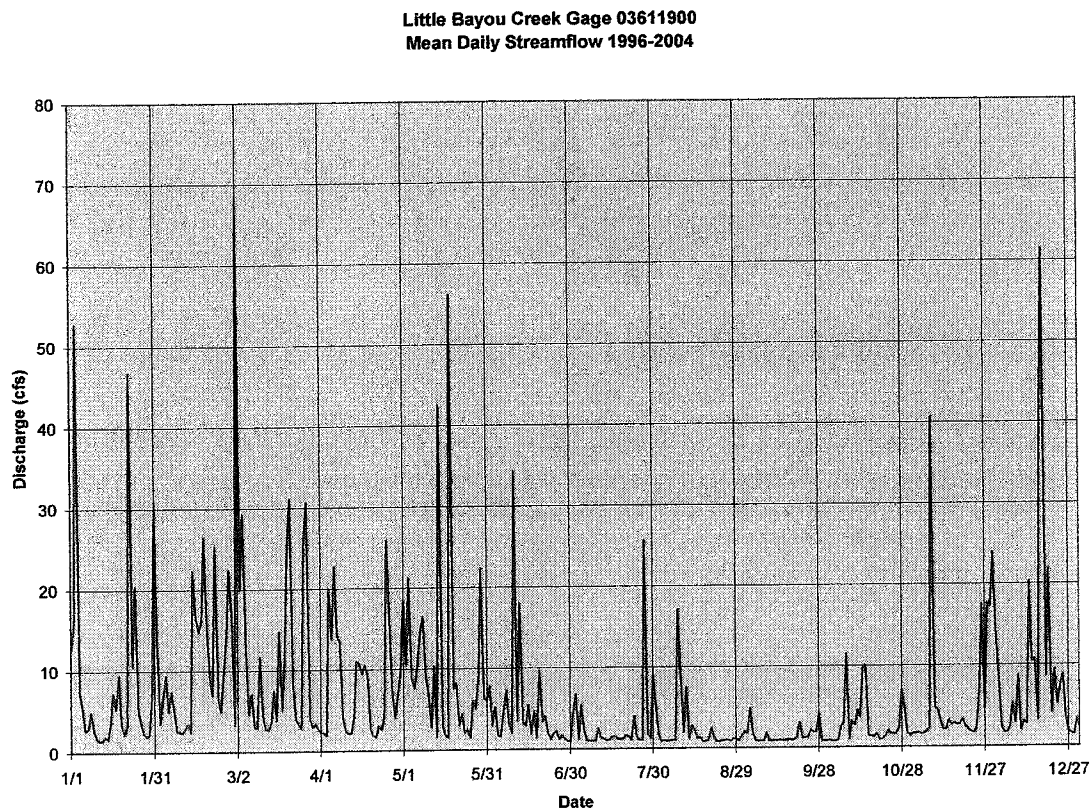


Figure 6. Mean daily streamflow 1996-2004 Bayou Creek gage 03611850 and Little Bayou Creek gage 03611900.

HYDROLOGIC MODELING

Hydrologic modeling for this project was done using the Hydrologic Simulation Program FORTRAN (HSPF) (EPA, 2000). HSPF is a continuous simulation, lumped parameter model based on the Stanford Watershed Model (SWM) originally developed by Crawford and Linsley (1966).

In addition to HSPF, three other programs were used in this research. WDMUtil (EPA, 2001) was used to input, store, edit, summarize, compute, and export meterological data needed for use in HSPF. BASINS software (EPA, 2004) was employed for watershed, subwatershed, and main stem delineation. Finally, Watershed Management Software (DOT, 2004), which is designed as a data formatting and extraction program for several hydrologic modeling programs (including HSPF) was used for initial watershed, subwatershed, and stream network delineation and analysis.

BASINS watershed, subwatershed, and main stem delineations were based on a 10-meter resolution digital elevation model (DEM) obtained from the Kentucky Office of Geographic Information, and stream vector data from the USGS National Hydrography Dataset (NHD). Subwatersheds outlets were arbitrarily defined at USGS stream gaging sites (gages 03611800 and 03611850 on Bayou Creek and 03611900 on Little Bayou Creek). Basin and subbasin designations are shown in figures 3 and 4. These may be further described as follows:

a. **Area 1** aggregates the Bayou Creek and Little Bayou Creek drainage basins.
b. **Area 2** includes the Bayou Creek subbasin upstream of gage 03611850. All outfalls from the PGDP that discharge into Bayou Creek do so upstream of gage 03611850. Subbasin area at the outlet is approximately 6.7 square miles.
c. **Area 3** includes the Little Bayou Creek subbasin upstream of gage 03611900. This subbasin drains an area of 5.2 square miles. Gage 03611900 is located downstream of all outfalls from the PGDP that discharge into Little Bayou Creek.
d. **Area 4** includes the Bayou Creek subwatershed located upstream of gage 03611800. Gage 03611800 is located upstream of all outfalls from the PGDP that discharge into Bayou Creek. Subbasin area is 15.1 square miles.

After being generated by BASINS, these data were exported to HSPF.

Additional input for the HSPF model included hourly precipitation and daily maximum and minimum temperature recorded by the U.S. Weather Bureau for Barkley Regional Airport in Paducah. This was formatted and exported to HSPF using WDMUtil as noted previously.

Maximum and minimum temperatures are used by HSPF in estimating evapotranspiration losses using the Hamon method. Mathematically,

$$PET_{Hamon} = C_m D^2 W_t \qquad (6)$$

where PET_{Hamon} = daily potential evapotranspiration; C_m = monthly variable coefficient; D = possible hours of sunshine (units of 12 hours) as a function of latitude and time of year; and

W_t = saturation vapor density (absolute humidity) at the daily mean air temperature. HSPF assumes PET = 0 when T = 0°C or less (Hamon, R.W., 1961; Bicknell, et al., 2001) Further, HSPF uses the potential evapotranspiration computed through equation (6) to compute estimated actual evapotranspiration.

Precipitation data are used in HSPF to generate runoff quantities following partitioning of land use designations into pervious and impervious surface areas. Data provided in the land use and land cover input file form the basis for this partition. Land use and land cover data for the Bayou Creek area is shown in figure 7. This shows the predominant land use on the study area to be agricultural. This is highly generalized land use and does not include the transportation network (roads, railroads). Landuse and land cover data were acquired using the BASINS Download Data tool and were created by the EPA from data collected by the USGS for the Geographic Information Retrieval and Analysis System (GIRAS) project. According to the metadata provided by EPA, the land cover types were mapped at 1:250,000 scale using the Anderson classification system (Anderson, et al, 1976) for coding land use and land cover at level 2 of the hierarchical system. The aerial photography used for the land cover interpretation range in dates from mid 1970s to early 1980s. A more detailed land use and land cover data set was created using data from the Kentucky Gap Analysis Project (GAP) that was generated from 1990s Landsat Thematic Mapper data and the USGS Impervious Surfaces data, but it has not yet been successfully incorporated into the BASINS model.

Soils on the study area were taken from *Soil Survey of Ballard and McCracken Counties, Kentucky,* (USDA, 1976). The predominant soil association in the watershed is the Calloway-Henry association. This is described as "Nearly level, somewhat poorly drained and poorly drained, medium-textured soils on uplands" (USDA, 1976). The other associations include a small area of the Rosebloom-Wheeling-Dubbs association along the lower reaches of the streams. The Rosebloom-Wheeling-Dubbs is described as "Nearly level to sloping, poorly drained and well drained, medium textured and moderately fine textured soils on flood plains and stream terraces". In addition, there is a small area of the Nolin-Newark association along the Ohio River. This association is described as "Nearly level, well drained and somewhat poorly drained, medium textured and moderately fine textured soils on flood plains". Finally, the Grenada-Calloway association in the upland areas described as "Nearly level to sloping, moderately well drained and somewhat poorly drained, medium-textured soils on uplands" (USDA, 1976). Soils distributions on the study area are shown in figure 8.

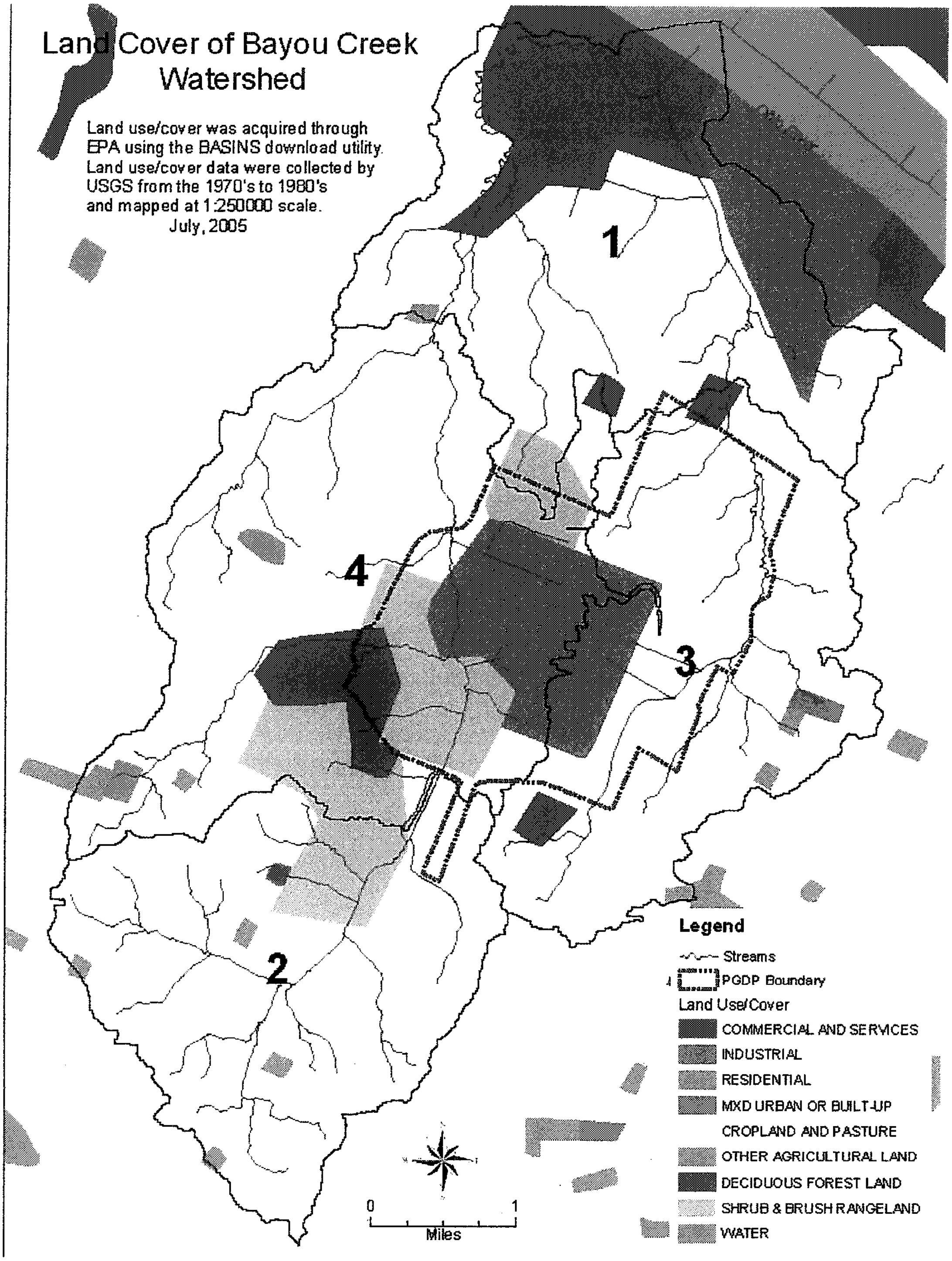


Figure 7. Land Cover of Bayou Creek Watershed, July 2005.

Several gravel pits exist on the watershed. According to the USGS Geologic Map of Heath Quadrangle (Olive, 1966), these consist mostly of chert with a reddish color indicating high iron content. Also within the watershed is the historic Kentucky Ordnance Works (KOW) which could potentially be a source for metals contamination in the water (U.S.Department of Health and Human Services, 2005). Although, anecdotal information indicates that only explosives were produced.

The Soil Survey data sheets were scanned and then georeferenced to the corresponding Digital Orthophoto Quarter Quad (DOQQ) using ArcInfo 8.3 (ESRI, 2002). The DOQQs were downloaded from the Kentucky Office of Geographic Information (2005). Soil boundaries were digitized, edited, and formed into polygons which were then assigned the soil symbol, name, and hydrologic group in the attribute table. The soil layer was imported into BASINS and then reclassified using the USDA-NRCS Soil-5 database information in BASINS for the HSPF model. HSPF uses a look-up table based on the Soil-5 code to assign values for soil texture, erodibility, permeability, and other parameters. Landuse and soils data are necessary for in-model partitioning of interception, surface runoff, interflow, and groundwater storage.

USGS stream gaging data for gages 03611800, 03611850, and 03611900 were used for calibration of the HSPF model. Data used in calibration were those available at the start of this project and covered the period from October 1, 1996 to August 31, 2003. These data were imported to a second WDMUtil file which stores input time-series tables for each gage. This WDMUtil file also stores input point source data for pollutants (concentrations and flow) as well as the predicted flow calculated by the HSPF model.

Because this project was in part concerned with pollutant concentration in Bayou and Little Bayou Creeks, there was interest in determining minimum streamflows for both streams. To do this, it was necessary to investigate stream discharge, hydrology, precipitation records, and predevelopment mapping of the PGDP site. Fryar, Miller, and Brown (2000), as explained previously, describe the reach from gage 036800 to gage 036850 on Bayou Creek and that reach upstream of gage 03611900 on Little Bayou Creek as losing streams based on their fieldwork. In addition, the same authors note that a predevelopment (1932) USGS topographic map shows Little Bayou Creek downstream of gage 03611900 as perennial (Fryar, Miller, & Brown, 2000).

Field examination conducted in summer of 2005 of Little Bayou Creek at and downstream of gage 03611900 verified the gaining/losing conclusions by Fryar, Miller, and Brown (2000). Specifically, downstream of gage 03611900 sand boils and springs were observed in the bed and banks of Little Bayou Creek. Further, the streambed downstream of the gage 03611900 appears to be dense clay. At that gage, the streambed is light gravel and no springs or boils were observed.

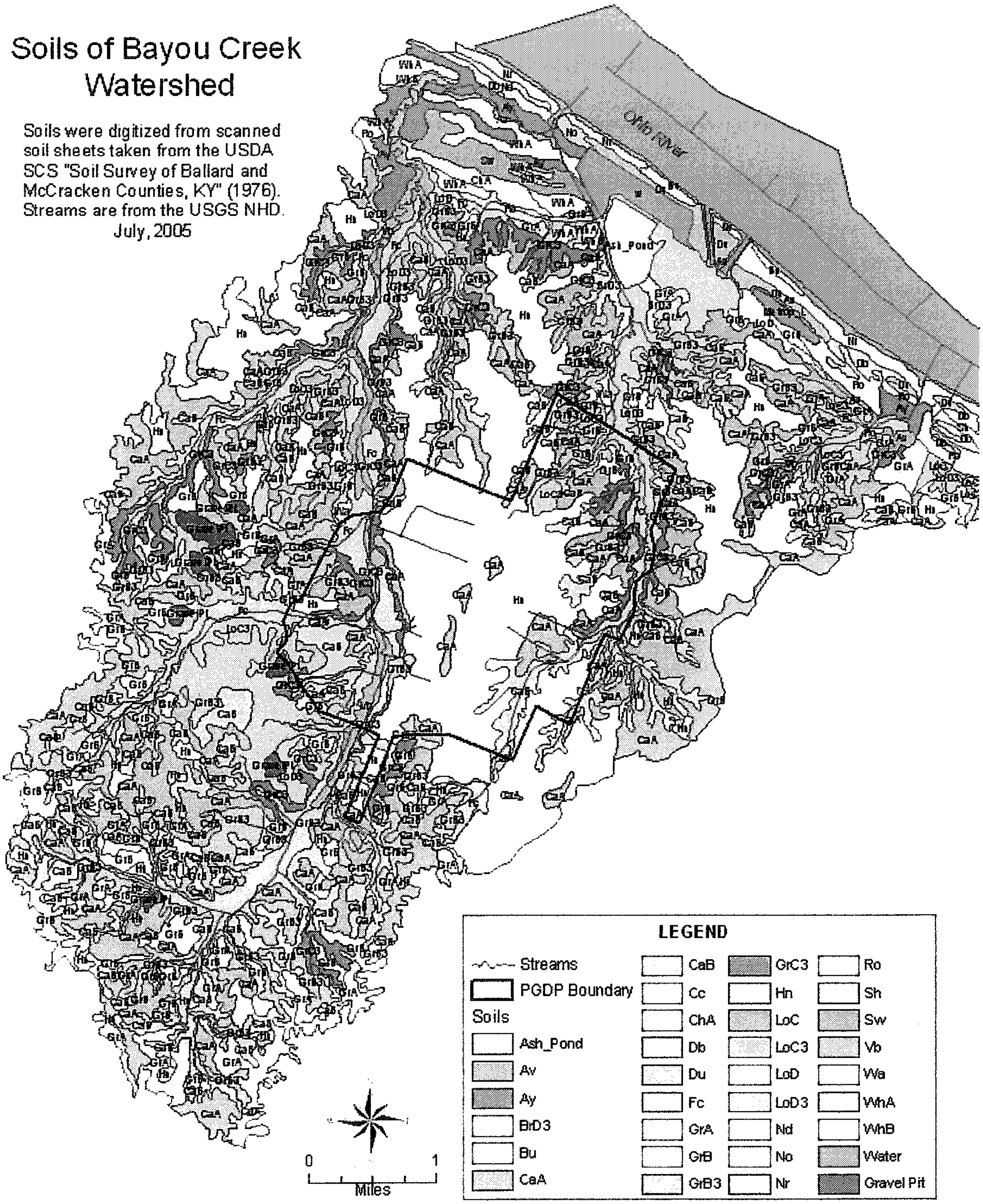


Figure 8. Soils of Bayou Creek Watershed, July 2005.

The 1932 map cited by Fryar, Miller, and Brown (2000) could not be located; it was possible, however, to find a 1928 USGS topographic quad (1:62,500 scale). The 1928 map showed Bayou Creek to be intermittent throughout its length. Little Bayou Creek was shown as perennial downstream of route 358.

To evaluate streamflows, the average annual discharge from the plant outfalls was subtracted from measured discharge at gages 03611850 and 03611900. At gage 03611850 average plant discharge of 8.5 cubic feet per second (cfs) was subtracted from gaged flows for water year 1997 (October 1, 1996 to September 30, 1997), which was the wettest of the seven years for which stream gaging data were available. The result was 98 days with no flow. At gage 03611900, an average point source discharge of 2.2 cfs was subtracted. The result was 206 days with no flow. Historical flow measurement variability is discussed more fully later in this report.

Model calibration

To calibrate the model, stream flows predicted by HSPF were compared against gaged discharges. The initial attempt at calibration produced wide differences between HSPF predicted annual runoff volumes and gaged runoff volumes used for model calibration. Despite this, there was good correlation ($R^2 = 0.76$) between the data sets.

Following the initial model run, model calibration parameters were adjusted to conform with suggested values from HSPF Technical Publication 6 (EPA, 2000). This resulted in much improved agreement between predicted and total runoff volumes. For example, using the calibrated model for Reach 4 on Bayou Creek, total predicted runoff volume computed for water year 1997 (October 1, 1996 to September 30, 1997) differed from the gaged runoff volume at gage 03611850 by 0.2 percent. For the same year, the correlation coefficient (R^2) for the predicted and gaged data was 0.78. Hydrographs showing the predicted and the gaged runoff values are shown in figure 9.

The most sensitive parameter encountered in model calibration was lower zone nominal storage (LZSN). In addition, the infiltration parameter (INFILT) appeared quite sensitive as well.

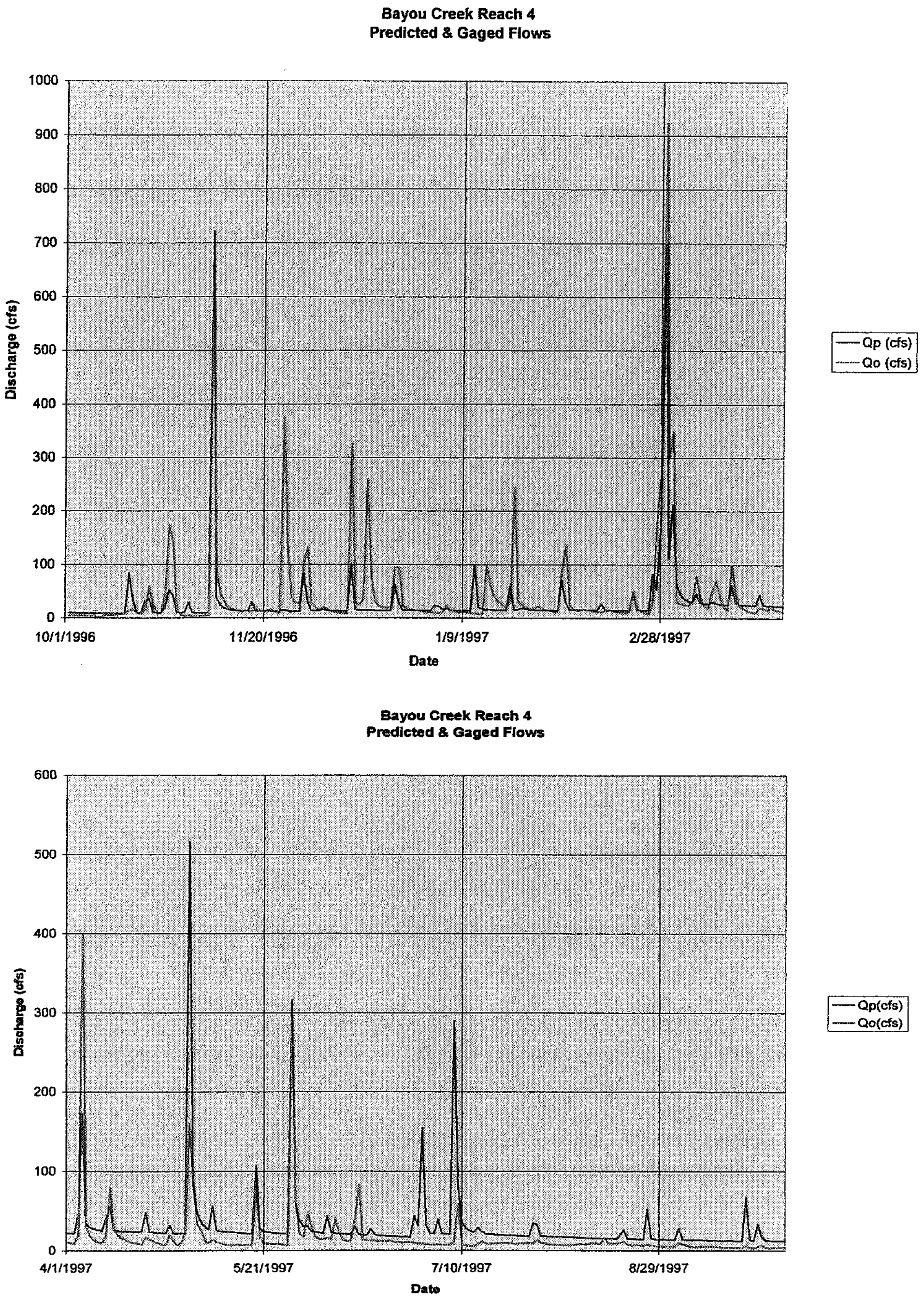
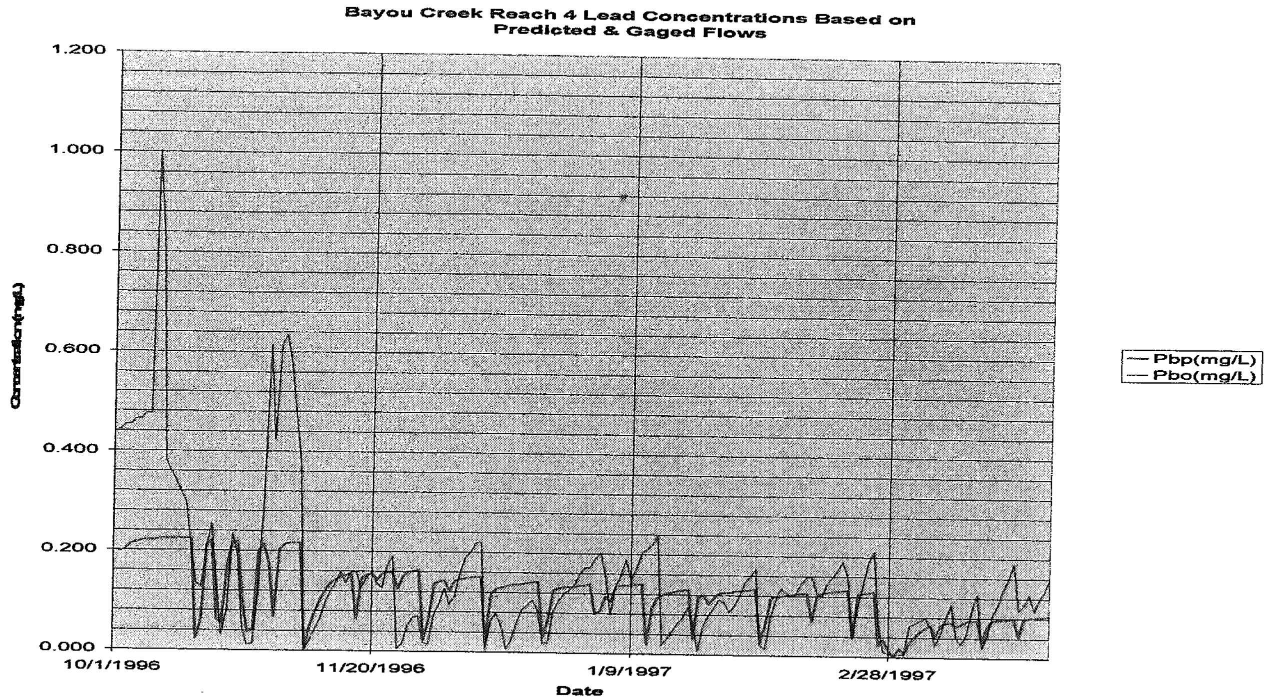


Figure 9. Bayou Creek subbasin 4 predicted and gaged flows.

One of the factors making model calibration difficult was obtaining reliable estimates for point source inputs. The point source flow used during calibration was the total average point source input for the seven year period for which stream gaging data was available. Examination of hydrographs of annual predicted and gaged flows together with a graph of annual precipitation sometimes showed the predicted base flows to be obviously incorrect. It is strongly suspected that this was due to input of average point source flows which did not match the actual flows for the year under examination.

Despite the work done on the HSPF model, the calibration is not considered by any means to be complete. Additional work should be done if reliable results are to be obtained on the range of meterological and hydrological conditions which occur with time on the watersheds. In particular, the HSPF daily predicted flows need to be disaggregated and hourly hydrographs generated. This will allow examination and calibration to storm runoff hydrographs. Further, calibration to date has concentrated on matching annual runoff volume. Examination of 90% and 50% exceedences also is necessary.

Figures 10 and 11 show lead and copper concentrations for reach 4 on Bayou Creek. These concentrations were based on average daily masses of lead and copper for the period 1997-2003; the concentrations shown differ due to differences in predicted and gaged flows. As was the case with the point source volumetric flow rates, pollutant concentrations are based on limited sampling data.



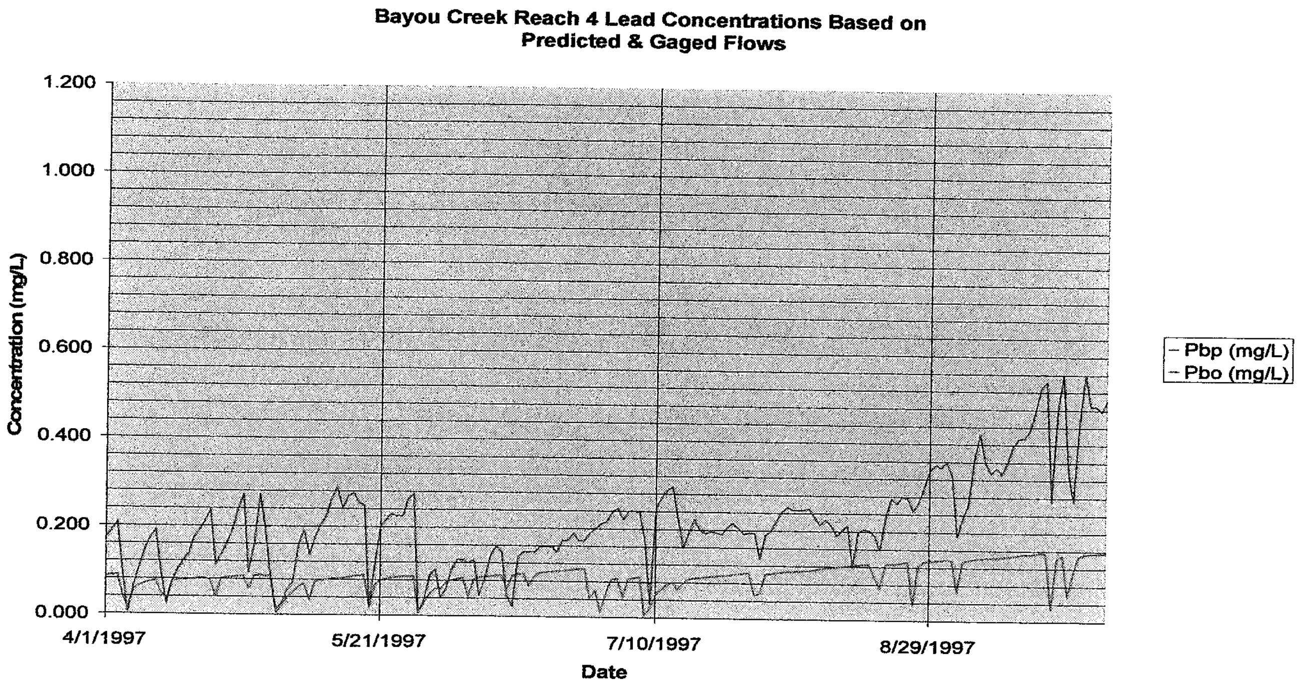
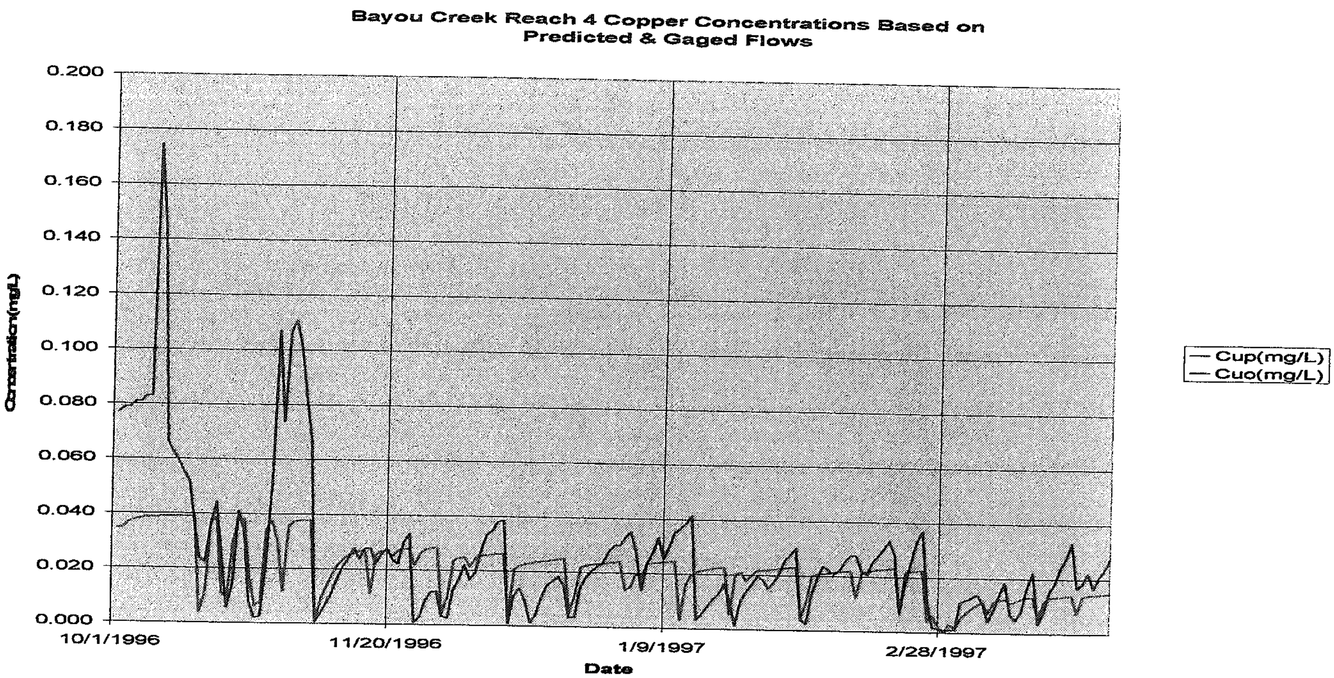


Figure 10. Bayou Creek subbasin 4 lead concentrations based on predicted and gaged flows.



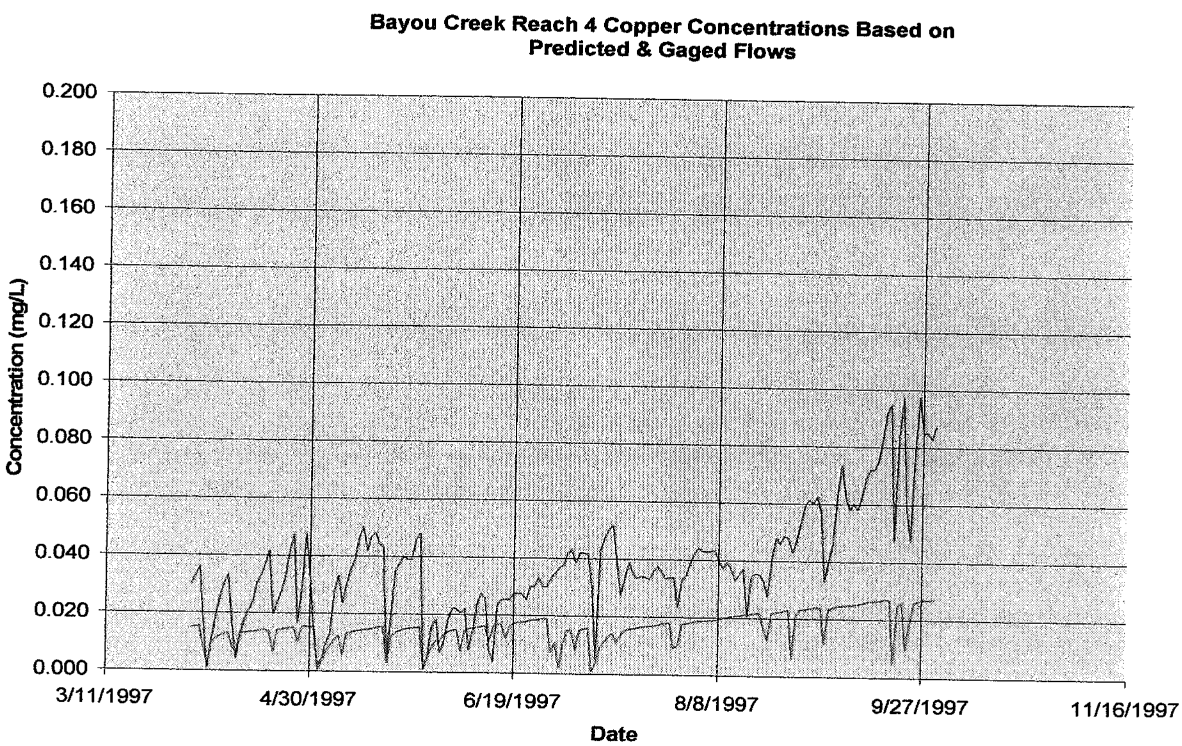


Figure 11. Bayou Creek subbasin 4 copper concentrations based on predicted and gaged flows.

CONCLUSIONS AND RECOMENDATIONS

The hydrologic model of Bayou and Little Creeks that was developed as part of this research has application in providing a continuous simulation model of both streamflow and pollutant concentrations. Usefulness of the model is limited by uncertainties in both point source inputs and non-point source inputs within the watershed. These uncertainties are attributable to mixed process water and storm water flows from the PDGP, problems inherent in defining exactly the subbasin limits in any industrialized area, and background pollutant levels. Further refinement of the model is required so that modeled flows more accurately match actual flows.

Low flow modeling performed in this research, together with historical mapping, indicate that both Bayou and Little Bayou Creeks in those sections adjacent to the Paducah Gaseous Diffusion Plant are in all probability no-flow streams. During dry weather periods, essentially all of the flow in Bayou and Little Bayou Creeks above gages 850 and 900 is due to plant process discharge. Consequently, the 7Q10 flow used for TMDL development is zero in both streams. Other scenarios related to exceedence frequencies may be useful in waste load allocation (WLA), but additional flow and chemical data are needed to assess those situations.

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