SPATIAL ASSESSMENT OF NONPOINT PHOSPHORUS SOURCES USING STREAMBED SEDIMENT MONITORING IN THE KINGS RIVER BASIN, NW ARKANSAS

A Thesis

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Master of Science in Resource Planning

by

Jason W. White

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ABSTRACT

This study of the Kings River Basin provides a watershed-scale assessment of streambed sediment-Phosphorus (P) and its sources on the landscape. The Kings River drains into Table Rock Lake where surface algal blooms have concerned water scientists and disrupted summer tourism. There are questions about how sediment loads, widespread poultry and cattle operations, and sewage treatment plants are affecting water quality. Previous water quality studies across the U.S. have generally evaluated water-column P. In contrast, few studies have used streambed sediment monitoring to detect P levels at a watershed-scale, and none have been attempted in the Kings River Basin. Sediment samples may be preferred over water column samples for their ability to concentrate a range of pollutants, be less affected by fieldwork error, and incur fewer processing costs. Land cover/use in the watershed consists of forest (68%), pasturelands (32%), and one urban area, Berryville. Eighty-nine streambed sediment samples and six reference samples were collected from 100 river miles of the Kings River and its seven major tributaries. Variables included for analysis were sediment geochemistry, upstream drainage area, land use, geology, quantity of chicken houses, and sediment particle size. Values were quantified and entered into a Geographical Information System (GIS) to create a nonpoint source P risk model. The mean sediment-P concentration was 209 micrograms per gram (*u*g/g), ranging from 40 *u*g/g near a pristine forested area to 1,280 *u*g/g downstream from the only sewage treatment plant in the watershed, below the city of Berryville. Regression analysis revealed that sediment composition and land use were the dominant factors affecting sediment-P variability in the watershed. A "best-fit" regression equation ($r^2 = 0.83$) was developed to estimate sediment-P concentrations using organic matter content, sand content, poultry index, Fe and Al. This equation suggests that poultry operations and other nonpoint sources account for 11% of the sediment-P, on average, with a range of 0.5% to 50%. Piney Creek and Sweden Creek sub-watersheds proved to be the most and least affected by nonpoint sources, respectively. This study gives credibility to the integration of streambed sediment monitoring and GIS analysis in Ozarks watersheds. The quantitative results will aid scientists and natural resource managers in their ongoing attempts to compile baseline nutrient concentrations for Ozarks watersheds.

This abstract is approved as to form and content

Chairperson, Advisory Committee

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CHAPTER 1

INTRODUCTION TO WATERSHED ASSESSMENT

Introduction

Human population growth has taken its toll on waterways throughout the United States. River degradation spans the range from declining water quality and extinction of aquatic species to reduced recreational value and aesthetic appeal, declining productivity of sport and community fisheries, and threats to human health (Dopplet et. al., 1993). Of these negative results, declining water quality has been in the forefront of most scientific studies. Considerable research interest has been generated in attempting to assess the impact of anthropogenic land use on stream hydrology and erosion (Olive and Rieger, 1991). Shifts from forested conditions to more intense urban or agricultural land uses often contribute pollutants to streams. Of particular concern are cases in which stream disturbance is the result of land use changes at the watershed-scale where the source of disturbance is broadly disseminated over the landscape, rather than occurring at a specific location (Jacobson, 1995).

Terrestrial and aquatic sources on the landscape can be classified as either point or nonpoint sources. Point sources are easily located and may include wastewater treatment plants, industrial operations, or confined animal operations. Nonpoint sources (NPS) are more diffuse and may include storm water runoff, geology and soils, or animal feeding operations that re-apply dry litter as crop fertilizer. Both source categories inadvertently release nutrients.

Nutrients are essential to plant life, however when introduced at excessive levels, they can disturb the natural ecosystem balance. Plant nutrients, such as nitrogen (N) and phosphorus (P), are common constituents of NPS runoff (Harper, 1995). Phosphorus is essential to all forms of life on earth and has no known toxic effects. However, environmental concerns associated with P center on its stimulation of biological productivity in aquatic ecosystems (Pierzynski et al., 1994). Phosphorus can stimulate eutrophication and cause nutrient competition between non-resident algal blooms and resident fish species. This situation can cause far-reaching fish kills and decreased recreational opportunities.

Sediment is the largest contributor by volume to NPS runoff in the United States (Harper, 1995). This contribution is due to the composition of sediment that allows it to adsorb P during transport processes from the terrestrial to the aquatic environment (Statham, 1977). Approximately 95 percent of the P in streams tends to adhere to sediment particles (Hem, 1985). Furthermore, the adsorption of P onto bottom and suspended sediments is considered the main factor affecting the mobility of P in aquatic systems (Stone and Murdoch, 1989). Adsorption can be stimulated in areas of P-rich sediment storage such as low energy reaches (Meade, 1982), wetlands (Gale et al., 1994), or lakes (Garman et al., 1986).

Accelerated soil and sediment erosion sources, excessive nutrient inputs, and downstream transport and deposition patterns are key factors in the degradation of rivers. As a consequence of the unidirectional and dynamic nature of flow in rivers, temporal and spatial separations between the source of P and the point of potential impact are introduced when considering an entire watershed (Edwards et al., 2000). It is possible for a particular land use to contribute P in the upper reaches of a watershed and its effects be detected several miles downstream (Moreau et al., 1998). Several geomorphic and hydrologic factors directly affect downstream nutrient transport such as drainage area, sediment composition, land cover and land use, topographic slope or parent material. Any one of these variables may cause varying results at a particular survey site. By quantifying the characteristics of the drainage area above each sampling location, it is possible to create a spatial model of the source locations and transport patterns of P in the watershed (Chalmers, 1998). This watershed approach is important to detect the furthest possible extent of nutrient loading to a stream and provides the basis for sediment guidelines and water quality-based controls (USEPA, 1999).

Local Interest

This study is the first to scientifically evaluate the spatial distribution of nonpoint P sources in Kings River streambed sediment. Evidence can be found that supports the need for such a study. Water column data from the 1999 Lakes of Missouri Volunteer Program annual report revealed that among 13 sampling sites, the site on the Kings River arm showed P values seven times higher than regional averages (Obrecht et al., 1999). Although these numbers describe total P values in the water column, sediments reflect on the water quality because they are capable of adsorbing nutrients to high levels. In particular, sediment in an agricultural setting is at high risk of adsorbing excess fertilizer P and eroding from the fields into nearby streams. Studies in Arkansas have found excess P loadings entering watersheds that have naturally high soil P levels and are also continuously fertilized with dry poultry waste (AWRC, 1993; Edwards and Daniel, 1992; Eghball et al., 1996.).

Missouri and Arkansas have an interest in the water quality of the Kings River, since it begins in the Boston Mountains, flows north for 100 miles through the Ozark Highlands in Arkansas, and finally discharges into Table Rock Lake on the Missouri-Arkansas border (MODNR, 1998). In particular, the states of Missouri and Arkansas are currently expressing great concern about the release of nutrients in upstream tributaries that eventually discharges directly into the lake. Local news stories have reported recent fish kills and continuous algal blooms. These reports magnify the serious environmental issue of nutrient loading in Ozarks lakes and streams and the economic decline in the recreational businesses of fishing, boat rental, and sailing.

During the First Annual White River Basin Forum on October 27, 1999 in Branson, MO, governmental agencies from both states signed a memorandum of agreement. Included in this document, "the Arkansas Soil and Water Conservation Commission (AS&WCC) has jurisdiction over water conservation in the state of Arkansas and is authorized to enter into negotiations relating to the protection and use of interstate waters" (WRBF, 1999). Besides defining operational duties and areas of study, this annual conference is expected to open future lines of communication between Missouri and Arkansas by integrating databases and scientific results for the purpose of improving water quality management in the Ozarks region.

Research Questions

This study will address some lingering questions among environmental agencies and academic researchers in the Ozarks. Firstly, it is uncertain how the spatial distribution of streambed sediment-P is represented throughout local watersheds. In particular, what is the sensitivity of sediment-P concentrations to land use effects and can sediment analysis be used to isolate the effects of one land use from others? By definition, nonpoint sources are largely controlled by humankind's activities on the land, which differentiates it from natural erosion and sediment movement (Krenkel and Novotny, 1980). Although predominately forested areas, such as the Kings River Basin, can release natural background levels of P, water quality in natural environments may also be influenced by anthropogenic factors that cross basin and regional boundaries (Clark et al., 2000). Sediment erosion can be pervasive in both natural land cover areas and intense human land use areas, physically causing turbidity and geochemically adsorbing trace elements and nutrients from nearby land uses (Schumm, 1977). Therefore, sediment is an efficient method of assessing the diversity of land use and varying nutrient levels at a watershed-scale.

Secondly, Missouri and Arkansas officials are quick to debate the source geography of nonpoint sources, such as P, into tributary streams of Table Rock Lake. On a national and local scale, recent successes in muzzling excess P loading from point sources has magnified the continuous and cumulative effects of nonpoint source loadings (Garman et al., 1986). Only after problem areas are targeted will water resource management and watershed restoration activities be efficiently stimulated from either side of the state border.

Thirdly, there is the possibility that less emphasis needs to be placed on anthropogenic activities and more attention given to natural background levels of P. An understanding of regional patterns in natural water quality provides for a more valid baseline for setting objective, attainable water-quality goals and ultimately will provide a more rigorous tool for separating natural and anthropogenic factors affecting water quality in streams across the nation (Clark et al., 2000). Background P sources can make NPS assessment difficult because of their diffuse transport patterns throughout subsurface geology, atmospheric deposition, the soil column, or forest organic matter. The Kings River Basin consists of large forested tracts with dispersed agricultural strips of poultry operations. These operations do not require much real estate and are often found within or near natural vegetated areas making land cover and land use classification difficult. It is important to carefully analyze the watershed variables upstream of each sample location in an attempt to distinguish between background and anthropogenic sources that may be represented in a natural area.

Purpose and Objectives

The purpose of this study is to determine the spatial distribution of P in streambed sediments in the Kings River watershed. The land use categories of forest, agriculture, and the urban area of Berryville will be used to describe the source geography of nonpoint P sources The results will help in the establishment of baseline sediment-P guidelines and will reveal the need for the continuation of nutrient management plans (NMPs), which are currently being implemented in the watershed. The three main objectives of this thesis are to:

1. Quantify sediment-P concentrations in fine-grained streambed sediment in the Kings River and seven major tributaries.
2. Assess the implications of NPS pollution in an Ozarks watershed dominated by poultry houses with nearby land-applied chicken waste.
3. Construct a GIS-based spatial model that best explains the relation(s) between sediment-P concentrations and watershed features such as sediment composition, sediment geochemistry, and land use sources.

This study will address relationships among watershed land use practices and their effects on the spatial distribution of P occurring in streambed sediment surveys. The results of this study are focused on four primary hypotheses:

1. Land use will be a good predictor of the source geography of nonpoint P sources.
2. It will be possible to differentiate between background and anthropogenic sources of sediment-P.
3. The locations of broiler operations in the basin will be spatially linked to higher downstream sediment-P concentrations.
4. Sediment surveys collected below the confluence of Osage Creek will reveal extremely high P levels due to contributions by the city of Berryville wastewater

treatment plant.

Traditional sampling techniques have used water column samples to detect chemically dissolved nutrients and attached nutrients on the suspended sediment. This sampling process includes a combination of fixed-station sampling (i.e. USGS surface water gauging stations), grab samples throughout different basin conditions, and stream flow-load duration estimates (Price and Schaefer, 1995; Boyd, 1996).

More recently, streambed sediment sampling has been used to detect nutrient levels instead of the waterborne sediment samples that tend to be more cumbersome to work with (Feltz, 1980). Bed sediments tend to be preferable to suspended sediments because they are easier to collect sufficient amounts to meet all requisite physical and chemical analyses, and suspended sediments tend to show more variability than do bed sediments (Horowitz, 1991). In comparison to water column samples, streambed samples are not completely dependent upon optimum water temperature, container material, or temporal variation. Furthermore, streambed samples serve a dual purpose of quantifying nutrient levels and targeting source geography throughout a watershed.

Sediment-based techniques have thesis roots in the fields of explorative geochemistry, geomorphology, and soil science. These methods have been improved and extended more recently with applications in environmental sciences and assessments. Thus, this thesis not only addresses regional environmental problems, but also enhances scientific understanding of surface processes on the Earth's surface and the intricate nutrient transport mechanisms that occur in catchments, rivers, lakes, and oceans.

CHAPTER 2

LITERATURE REVIEW

River System Approach

Watercourses ranging from tiny drainage catchments to wide meandering rivers to expansive ocean bodies flow throughout our nation. Of these water bodies, rivers are the only systems that continuously drain both natural and developed lands. These lands are covered and manipulated by different land use practices such as forest, agriculture, and urbanization. Inorganic and organic nutrient constituents such as fertilizers and geologic leaching, respectively, can be attributed to these different land use areas. Human population and settlement intensify inorganic nutrient contributions, which can lead to eutrophication, nutrification, and biotic degradation if introduced at prolonged intervals. Once the contamination enters the river system it disperses through the water column and attaches to sediment particles as it moves downstream at the mercy of hydrologic processes.

For years scientists and researchers have studied these complex fluvial processes for the benefits of targeting, monitoring, collecting, and restoring river environments to a manageable level. Most studies have focused on a particular component of the larger drainage network. However, rarely is thought given to the entire fluvial system, which consists of the sediment-source area, the transportation network, and the deposition sites (Schumm, 1977). More recently, researchers have taken advantage of subsidized research projects, enhanced sampling techniques and modified spatial and temporal technology to aid in pollution monitoring at a watershed-scale. Studies must be targeted at a watershed-scale in order to encompass the multitude of factors and geographic areas that fall within a river's drainage area. Results from such studies can be used to implement management and conservation plans that will protect our natural aquatic environments for the future.

Land Use And Sources

Natural and human factors directly affect land areas on Earth's surface. Natural factors have existed for thousands of years and continue to affect today's streams. In contrast, human factors have grown exponentially over the years and humans are demanding more from existing water resources. Scientists must connect land use with water quality issues, because water flows through all of the different land uses and picks up contaminants and substances along the way. Such land uses may include agriculture, urban, or forest. These land uses are known to carry pollution to streams either above ground or underground. Most researchers and scientists agree that pollutants can be categorized as originating from either point or nonpoint sources (USC, 1994). A 1994 U.S. Code extract of the Clean Water Act officially states that:

> The term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture. (USC, 1994).

In contrast, nonpoint pollution sources are both diffuse in nature and more difficult to define. Such a precise definition is not clearly stated in the Clean Water Act or its amendments, however the act casually refers to NPS pollution as any type of source not included in the above definition of point sources. The 1984 EPA Report to Congress about NPS pollution in the U.S. expanded this vague reference:

> NPS pollution is generally carried over and through soil and ground cover via rainfall and snowmelt. Unlike 'point' sources of pollution (mainly industrial and municipal effluent discharge pipes), nonpoint sources are extremely diffuse and can come from any land area. It must be kept in mind that these definitions are very general; legal and regulatory decisions have sometimes resulted in certain

> sources being assigned to either the point or nonpoint source categories because of considerations other than their manner of discharge. (USEPA, 1984).

Studies have documented findings of direct correlations between land use sources and their adverse effects on nearby streams. Rice (1999) reported a thorough analysis of common metals that can originate in urban settings versus more pristine rural settings. Robinson et al. (1998) concluded that land use has a strong effect on water-quality trends in New Jersey. Spahr and Wynn (1997) linked land use to water quality in the Colorado study unit of the USGS National Water Quality Assessment (NAWQA) program, where they found that spatial distributions of nutrients indicated elevated concentrations in areas of increasing urbanization and in areas of agricultural land use. Similarly, the 1994 EPA National Water Quality Inventory identified agriculture as the leading cause of water quality impairments. Two studies (Dillon and Kirchner, 1975; Grobler and Silberbauer, 1985) assessed the combination of anthropogenic sources, varying land uses, background sources, parent material, and atmospheric phosphate. Both studies found a higher degree of uncertainty in predicting NPS pollution from watersheds that were dominated by phosphate-rich geologic strata and abnormal runoff events.

Phosphorus

It is known that nutrients are necessary for growth and maintenance of all life forms, however nutrients can cause problems in aquatic systems when they are present in quantities that greatly exceed the amounts normally needed to sustain organisms in the system (Payne, 1994). Eutrophication, or accelerated nutrient levels, includes an over-abundance of algae that competes with fish for oxygen and poor water clarity that decreases recreational demands (Rosensteel and Strom, 1991). These abnormal aquatic processes are slightly affected by the naturally occurring nutrients and more affected by the unnatural nutrients that leak into the intricate drainage network. Decreased oxygenation is the primary negative effect of eutrophication because low dissolved oxygen levels seriously limit the growth and diversity of aquatic biota and, under extreme conditions, cause fish kills (Pierzynski et al., 1994).

The nutrient P has gained primary attention of researchers and environmental managers in recent years for its potential of damaging natural aquatic processes. The chemical element P can be found in the environment in several different forms and moves between these forms in complex processes (Figure 2.1.). Stumm and Morgan (1981) point out that almost all of the P in nature is in the form of orthophosphate, a positively charged ion consisting of four oxygen atoms bound to one P atom (PO_4^{-3}) that may be free or bonded with positively charged atoms or particles. Although the chemical makeup of this element is not important for the present study, the particle charges become somewhat important when discussing geochemical interactions in aquatic environments. Water quality researchers most often report findings as elemental phosphorus (P), while soil scientists and chemists may give attention to other chemical bonding forms beyond the context of this study. Sediment-P concentrations will be reported in the findings for the present study.

Phosphate deposits and phosphate-rich rocks release P during weathering, erosion, and leaching, and P also enters fluvial systems where the discharge of sewage or runoff from fertilized fields has disturbed the natural equilibrium (NCSU, 1998; Kramer et al., 1972; Hearn, 1985). These latter contaminants are the primary anthropogenic nonpoint sources of P (USEPA, 1995). Litke (1999) describes that P sources to the environment will continue to be important because almost all elevated levels of P in water bodies are due to unnatural sources. In contrast, background sources of geologic P may be completely natural and relatively high, which may be difficult to detect because of their sometimes subsurface and inaccessible locations. Literature suggests that

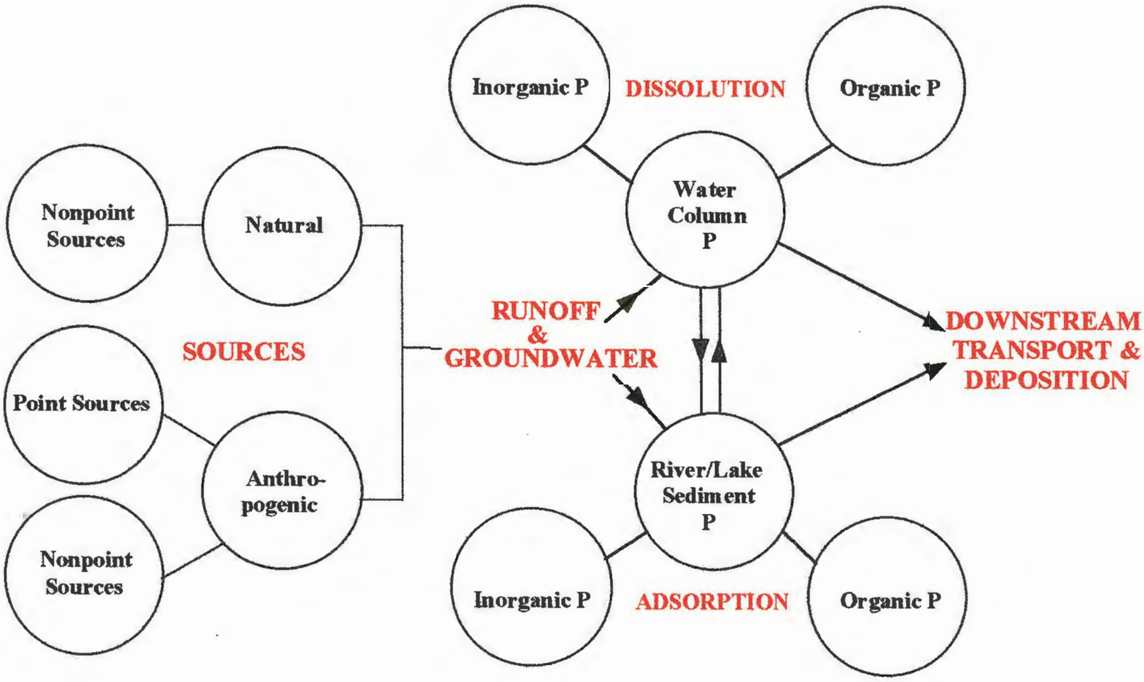


Figure 2.1. Natural aquatic phosphorus cycle. Adapted from Garman, 1986.

concentration of geologic P may be controlled by geochemical substrates (rock types) and compositional controls (oxide coatings around clay minerals) (Horowitz, 1991; Forstner and Witman, 1981; Horowitz and Elrick, 1987). Furthermore, elemental concentrations may vary among rock types (Table 2.1). An understanding of the background, or reference, source conditions can assist with a more efficient assessment of diffuse anthropogenic P (Dillon and Kirchner, 1975; Grobler and Silberbauer, 1985; Clark et al., 2000).

Upon entrance into a fluvial system, P can move through several watershed processes as it makes its way downstream. A few of these processes include transport by geomorphic and hydrologic processes, deposition in low-energy side-pools and/or gravel bars, deposition in floodplains during overbank storm events, uptake by aquatic flora and fauna, dissolution into the water column, or adsorption by suspended and streambed sediments (Figure 2.1). Eventually, P is flushed through the system towards a lake or ocean confluence where it is then less affected by river processes and becomes more susceptible to factors such as depth, storage, and circulation. Juracek (1998) describes that such factors can cause the release of P from lake-bottom sediment involving a mobilization from particulate to dissolved form followed by transportation into the water column.

There is an abundance of animal operations that are in the Kings River Basin. In particular, poultry operations dominate the landscape. More recently focus has been placed on quantifying agricultural P loading. This shift in emphasis is of enormous significance because it presents farmers, researchers, and government agencies with the challenge of addressing P control in agricultural systems that have proven to be more complex than the typical P point-source input (Tunney et. al., 1997).

Table 2.1. Elemental concentrations in different rock types. Adapted from Horn and Adams, 1966.

	SHALE	SANDSTONE	LIMESTONE/ DOLOMITE
P (ppm)	733	539	281
Al %	8.0	3.2	0.9
Ca %	2.3	2.2	27.2
Fe %	3.9	1.9	0.8
Mn (ppm)	575	392	842

For centuries farmers have recycled their animal waste as crop fertilizer for nearby farm fields. This practice was sufficient up until the introduction of mass-produced commercial fertilizers that consist of synthetic chemical elements. Also, nutrients in livestock manure are not balanced with respect to crop requirements. Some field soils may have a sufficient level of natural soil-P for crop success, without having to add either animal manure or commercial fertilizers. Unless tested properly, agricultural soils may be super-saturated with P, which will be lost during runoff, erosion, or sedimentation into nearby aquatic environments (Sharpley et al., 1999).

The threat of sediment-P entering watersheds from areas with land application of dry waste has been studied thoroughly (Beauchemin et al., 1996; Mozaffari and Sims, 1994; Campbell and Racz, 1975; Reddy et al., 1980, Daniel et al., 1998). Spatial and temporal scale varied throughout the studies, however general findings were that, upon displacement from its original source area, agricultural-P can attach to sediment particles of varying size and be transported to the stream environment via runoff storm events. Two publications (Sharpley et al., 1999; Edward and Daniels, 1992) compiled previous findings and current trends to present generalized statistics about the possible threat of nutrients issuing from areas with dense animal operations. Results revealed that an intensification of crop and animal farming in many areas has created regional and local imbalances in P inputs and outputs. On average, only 30 percent of the fertilizer and feed P input to farming systems is output in crop and animal produce. Therefore, when averaged over the total utilizable agricultural land areas in the U.S., an annual P surplus of 30 lb/acre exists. Since most riparian soils cannot efficiently handle such a cumulative surplus, the excess P is susceptible to runoff and erosion into nearby streams and lakes. "Generally from 70 to 90 percent of the agricultural total P load to lakes is sediment-associated while 10 to 30 percent is found in the dissolved form (Garman et al., 1986).

Sediment-P Transport and Storage

Rivers are unique watercourses in that they both erode and deposit sediment within watersheds. Floodplains are natural sinks for historic deposition of sediment, while banks and streambeds tend to be erosive areas of more recent, or active, sediment activity (Leopold et al., 1992). Sediment in both depositional and erosional areas is susceptible to river transport. Floodplain sediment can be re-introduced to the fluvial system during overbank storm events, while fine-grained, in-channel sediment can be entrained in the continuous flow of the water column and coarse-grained particles can be tumbled along the streambed. Over much of the world the products of weathering carried toward the ocean by running water in creeks and rivers are composed principally of solid material or sediment (Leopold, 1994). Sediment can range in size and shape depending on the primary rock type that has been fractured into smaller pieces. All sediment is classified somewhere in the range from very fine clay particles to coarser sand or gravel particles.

The transport of eroded material is particle-size-selective and hence effective at transporting P adsorbed on to organic-rich clay and silt-sized soil fractions. Hem (1985) studied P attachment and concluded that approximately 95% of P in streams tends to adhere to sediment particles. Depending on the factors of slope, runoff, vegetation, and soil infiltration the P-rich sediment can then be deposited or transported throughout the fluvial system. Data suggest that, in general, silt and clay are transported in suspension and that sand and coarser sediment are transported on or near the streambed (Schumm, 1977).

Transported fine-grained sediment is eventually deposited in low energy areas of a streambed such as the terminus of a point bar. These areas are transition zones where the grains are regularly picked up and moved during storm flushes. This temporary storage is most likely the result of sediment that has been introduced into the system from nearby land use activities. Therefore, the nutrients that may be attached to this sediment are referred to as external loading. In contrast, sediment in floodplains and areas of long-term storage may still be a desorption threat; this is referred to as internal loading (Garman et al., 1986).

Depending on the chemical form of P in the streambed sediment it may be released with no help from a storm event. This form of P is usually bio-available for aquatic uptake in the water column and is a primary factor in algal bloom production. Meade (1982) suggested that any given sediment particle that has been entrained by a river is likely to spend very little time in actual transport and a great deal of time in storage. He adds that perhaps watershed studies should place more emphasis on storage and less on transport-especially those models that are designed to predict the fate of the contaminants adsorbed onto the sediment particles.

Numerous studies have measured water column samples for TP and orthophosphate levels (Boyd, 1996; Emmereth and Bayne, 1996; Hearn, 1985; Meals and Budd, 1998; Spahr and Wynn, 1997; Litke, 1999). These studies have added to our knowledge of suspended and dissolved P movement trends at sub-watershed and watershed scales. A majority of historical TP studies have used water column methodologies similar to these particular studies. However, the alternative sampling methodology of using streambed surveys to detect sediment-P has been less popular.

Fine-grained sediment naturally attracts, or adsorbs, P due to its chemical composition (Horowitz, 1991). This polluted sediment is then susceptible to downstream mobility during storm events. Sediment movement within a stream is directly affected by complex hydraulics, which leads to spatial variability between initial source areas and end deposition of the particles and their attached nutrients (Leopold, 1994).

The body of literature pertaining to bed sampling is much smaller than for water sampling, however documented studies have revealed successful accounts of using streambed-sampling methodologies. For most of the past century, streambed sediment was collected to primarily look for ore bodies that could be of economic interest to mine (Rice, 1999). More recently, the primary interest has shifted to assessing whether trace elements are present in the environment at concentrations that are detrimental to aquatic biota or human health (Horowitz, 1991; Salminen and Sipila, 1996; O'Brien, 1997; Lecce and Pavlowsky, 1997; Rice, 1999). Depending on the study, either bulk-sediment or sieved-sediment samples were used. Bulk samples reflect a more general concentration of constituents, while sieved samples divide the bulk into size categories. The smallest sieved sample, < 0.63 *u*m-category (fine-grained) has been the most popular because trace-element concentrations commonly increase with decreasing grain size (Horowitz, 1991).

GIS and Spatial Assessment

Diffuse nutrient analysis at a watershed-scale is facilitated through quantitative methods in which sediment-P concentrations are targeted. These methods are based on a sound knowledge of an area's lithology, land use, soil infiltration, slope, drainage area, and drainage network. Land use, slope, drainage area and network are responsible for controlling overland flow of polluted sediment, while soil infiltration and lithology are all responsible for subsurface activity. Surface activity can be quantified on a regular basis, while subsurface activity is very complex and beyond the scope of this study. All of these factors have different effects on P concentrations depending on the particular stream reach. When quantifying P concentrations at a watershed-scale it is important to delineate sub-watersheds directly upstream from each survey location (Chalmers, 1998). All of the landscape factors can then be calculated in each minor watershed and pieced together to reveal a patchwork of possible sediment-P contamination areas.

What is geographical information system (GIS)? In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations (Borden, 1999). They also provide both database management (creation, update, query, control) and graphical display (essentially mapping) of spatially distributed data (Paniconi et al., 1999). The theoretical framework for this integration science is anything but modern. On the walls of caves near Lascaux, France, Cro-Magnon hunters drew pictures of the animals they hunted 35,000 years ago. Associated with the animal drawings are track lines and tallies thought to depict migration routes (USGS, 1997). These early records followed the two-element structure of modern geographic information systems: a graphic file linked to an attribute database.

Since its mainstream introduction during the late 1970's, GIS's have facilitated large project organization and have been applied to varying academic and scientific career fields. Basically, there are three areas of interest when dealing with GIS: specific interest in GIS (both theory and applications), interest in applied spatial data analysis, and interest in the theory and methods of spatial data analysis (Goodchild, 1992). The environmental science and resource management fields have been more concerned with the applications of GIS, which include the capabilities of storing complex field data, expressing spatial and temporal trends among study sites, and portraying these findings to colleagues of varying mapping savvy.

A few examples of the marriage between GIS and water resource management are the storage of information about a location, topology, and attributes of spatially referenced objects (such as rivers, wetlands, political boundaries, and roads). GIS's can also provide analysis of the spatial properties (such as length, area, and perimeter) of these geographic objects (Leipnik et al., 1993). Furthermore, (Downs and Priestnall, 1999) designed a GIS system for the purpose of understanding the sensitivity of a river reach to cumulated drainage basin factors and (Paniconi et al., 1999) attempted to understand the spatio-temporal behavior of hydrologic processes at a drainage basin scale.

Another group of researchers has focused less on the existing hydrologic implications and more on the ability to predict outcomes using modeling capabilities (Mankin et al., 1999; Ahl, 1994; Milne and Sear, 1997; Middelkoop and Van Der Perk, 1998). Prediction of outcomes is the core element of spatial modeling at a watershed-scale. Paralleling the recent national interest in targeting nonpoint sources throughout watersheds, GIS researchers have been giving more attention to modifying existing systems and using imagination for the purpose of monitoring such diffuse sources. In particular, when dealing with agricultural watersheds, “advances in combining GIS with modeling capabilities offer a powerful, efficient opportunity to target regions creating the most nonpoint loadings" (Mertz, 1993). With such studies it is often found that multiple layers of watershed data are the most efficient and artistic approach to analysis. Layers of varying data can all be laid on top of one another to portray a strong spatial geography of the particular study area. USGS conducted such a study on the Winooski River Watershed, Vermont (Chalmers, 1998) where they characterized land use, soil type, basin slope, and flow regime directly upstream from each sampling point. Mckimmey and Scott, 1993 also used a GIS to investigate the spatio-temporal distribution of areas in the Beaver Reservoir Watershed, AR susceptible to P runoff.

Research Needed In The Ozarks

All of the mentioned studies have focused on one particular element of the entire fluvial system, however it is nearly impossible to find one particular study that has assessed an entire fluvial system for the very dependent processes of source contribution, nutrient transportation, and sediment deposition. Studies have focused on these processes individually, however few have attempted a unified assessment.

Questions arise when trying to connect downstream bed sediment-P levels to upstream land uses, targeting source areas, and how P behaves once it enters the fluvial system. Answers to these questions will help when spatially analyzing how tributaries and different areas of a stream are susceptible to the entrance of P attached to sediment that has been affected by upstream land use.

Few studies have created a spatial model that describes bed sediment nutrient levels and correlated source geography. Researchers have a grasp of site-specific dynamics, however perspectives at a watershed-scale are more difficult to find. Knowing how P moves in the system will aid geomorphologists in studying impacted fluvial processes and knowing where the sediment is deposited throughout the system will aid environmental managers in implementing NMPs to suggest efficient application of nutrients throughout a basin.

In the Ozarks, only a few studies have used sediment as a tracer for watershed source analysis and these few studies have revealed the need for further exploration of sediment survey methodologies, nationally and here in the Ozarks.

Firstly, (Steele and Wagner, 1975) studied trace metal relationships in bottom sediments of the Buffalo River Watershed, AR and found that Ca and Mg coatings had an affinity for trace metals in areas of dolomitic parent material. Secondly, (Youngsteadt et al., 1984) studied the sediment equilibrium dynamics of Fellows and McDaniel Lakes near Springfield, MO and found that P equilibrium values were highest for McDaniel Lake and settled sediments had higher P levels due to decomposing cattle manure. Thirdly, (Carlson, 1999) used overbank sediment as an indicator of historic lead mining locations and found that there was a positive relationship between floodplain soil depth and metal concentration. Fourthly, a study is currently (2001) in progress on the James River near Springfield, MO with very similar methodologies to this study. Brian Fredrick is a graduate student in the Resource Planning program and he is assessing the extent of nonpoint P sources using streambed sediment surveys and a spatial GIS model. The James River Watershed, SW MO contains several urbanizing towns and wastewater treatment plants. In contrast, the Kings River Watershed, NW AR contains hundreds of poultry operations. Fredrick's sediment–P data will be compared with sediment-P data from the current study for the purpose of targeting initial nonpoint P sources from either side of Table Rock Lake on the Missouri-Arkansas line.

Summary

Watershed studies are very complex and comprehensive because of the many related variables that must be assessed during the research process. Rivers are vehicles for downstream sediment transport that has been affected by nutrient runoff and erosion from varying upstream land uses. Sediment erosion has been found to be the largest contributor to nonpoint loadings in U.S. watersheds. Sediment serves as a dual mechanism by physically clogging waterways and choking aquatic habitat, while at the same time chemically adsorbing trace elements and nutrients. Nutrients are essential for the function of all watershed processes, however too many nutrients in areas that are not capable of facilitating excess supply are susceptible to algae growth . Phosphorus is also essential to all life forms, however it is the limiting nutrient in rivers and lakes when other variables such as light, oxygen etc. are not present, resulting in nuisance algal blooms that destroy aquatic habitat and dampen aesthetic recreation desires. Phosphorus-laden sediment is either suspended in the water column or transported along the streambed during storm evens and deposited in floodplains and low-energy areas during its downstream migration towards lakes, or natural sediment sinks. The upstream cumulative loads result in thick and far-reaching algal blooms that cause large-scale fish kills and media attention. Such an algal bloom in Table Rock Lake stimulated this study to assess how nonpoint P sources could be attributed to Kings River sediment loadings on the Arkansas side of the lake. Sediment sampling has been performed nationally for decades, however it has been slow to catch on in the Ozarks. The easy and cost-effective streambed sediment methodologies, coupled with modern GIS spatial analysis techniques and database organization, can be powerful research tools.

This study of the Kings River Watershed provides sediment sampling and spatial analysis credibility to the larger fields of fluvial geomorphology and watershed management, as well as fills the local knowledge gap by establishing baseline nutrient concentrations for the Kings River, which has not been studied at a watershed-scale. The quantitative results will also help piece together lingering questions about nonpoint P sources in Ozarks watersheds and how fragmented land use affects downstream nutrient transport. Streambed sediment samples were collected from the main stem of the river, seven major tributaries, and six source reference areas, analyzed geochemically, and the results were statistically quantified and entered into a GIS for spatial analysis of watershed trends.

CHAPTER 3

STUDY AREA

The Ozarks Region

A review of Ozarks geography literature reveals slightly different regional classifications for the boundary of the Ozarks region. This study adopts the region defined by Rafferty (1980), which is approximately 60,000 mi^2, larger than the state of Arkansas. The Ozarks are bound in a general way by rivers (Figure 3.1). The northern boundary lies just north of the Missouri River valley along a strip of ridges that follow its northern bluffs. The eastern boundary is defined by the Mississippi River, which also forms the border between Missouri and Illinois. The southeastern flatlands are drained by the Black River, while the southern boundary lies along the northern hills of the fertile Arkansas River valley. The western boundary is less defined and consists of the Grand, or Neosho, River in northwestern Oklahoma and follows the Spring River across the Springfield Plain in southwestern Missouri diagonally northeast back to the Missouri River. Adamski et al. (1995) further subdivides the Ozarks region into four smaller sub-regions: the Ozarks Plateaus Province, the Salem Plateau, the Springfield Plateau, and the Boston Mountains (Figure 3.2).

Kings River Basin

The Kings River Basin drains approximately 1457 km^2 (564 mi^2) of land in northwestern Arkansas, which is in the southwestern Ozarks (Figure 3.2). The Kings River, the largest perennial flowing stream in the watershed, starts high in the Boston Mountains of Madison County, Arkansas and flows due north for approximately 90 miles through the toe of the Springfield Plateau in Carroll County, Arkansas until its confluence with the White River Arm of Table Rock on the Missouri-Arkansas border (Figure 3.2).

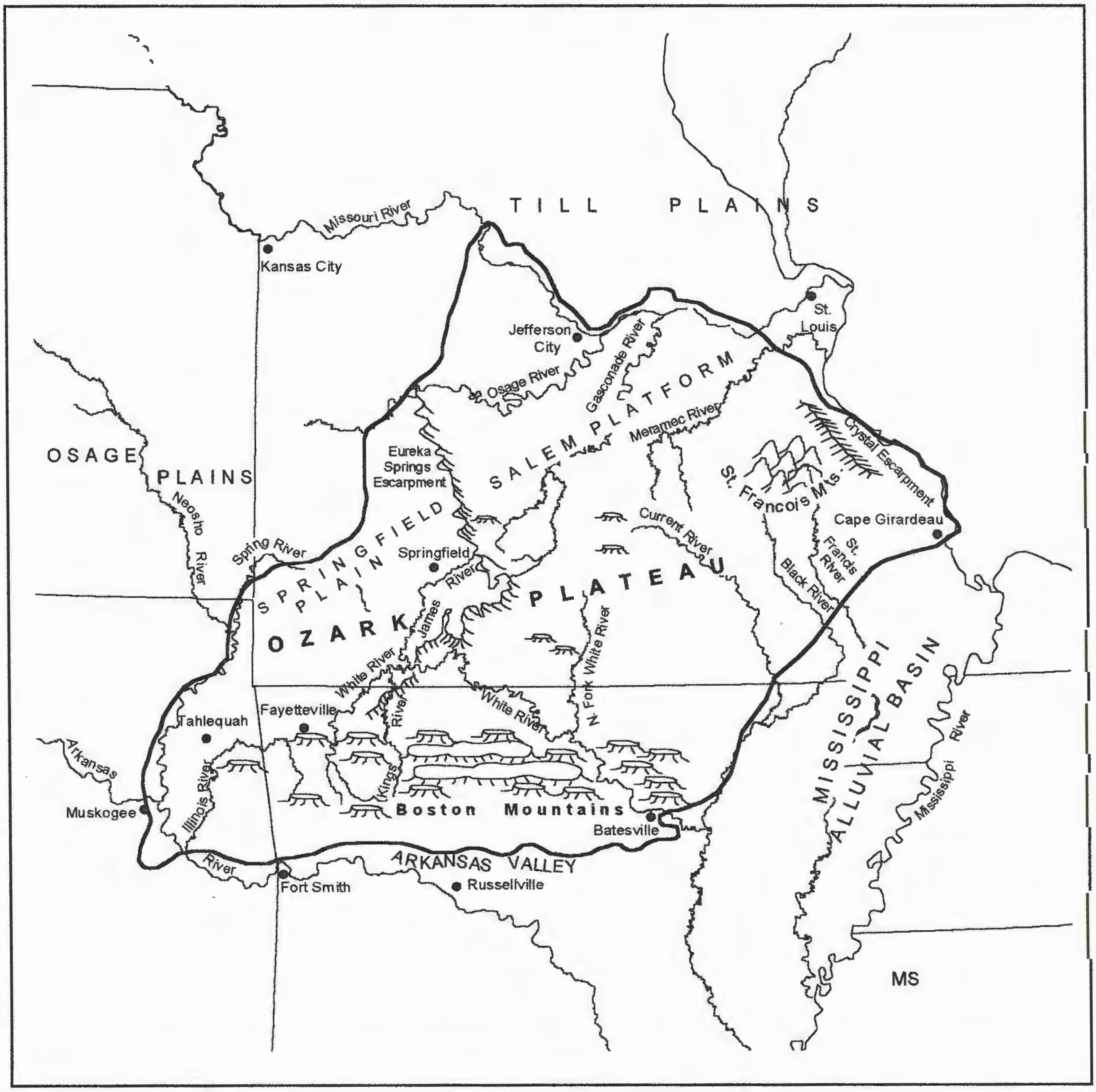


Figure 3.1. Ozarks physiography and bordering rivers. Adapted from Rafferty, 1980 and Adamaski et al., 1995.

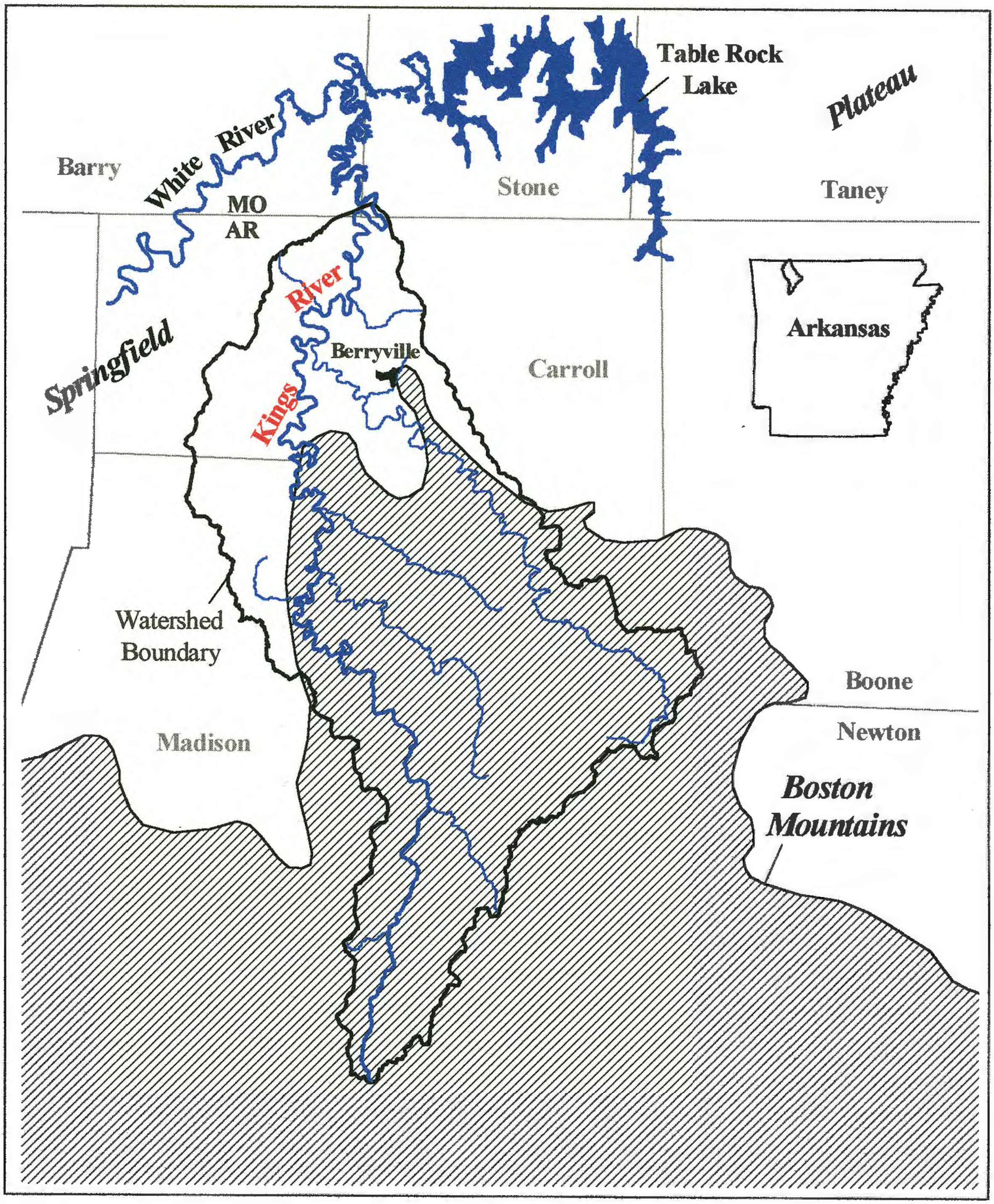


Figure 3.2. General location of the Kings River.

The Kings River Basin is contained within the White River Basin that flows into the Arkansas River Basin, which is a sub-basin of the larger Lower Mississippi River Basin. The Kings River Basin is unique in that it drains two different physiographic units. The Boston Mountain unit forms the headwaters region of the Kings River and contains steep, narrow tributaries that carry a high velocity of water during storms. The Springfield Plateau is more level and contains larger tributaries with wider floodplains in the lower reaches of the watershed. The topographic elevations range from 750 meters in the headwaters to 280 meters near the lake arm, yielding a basin relief of 470 meters and an average basin slope of 15 feet per mile (Figure 3.3). Because of the rugged terrain and steep slopes in the Boston Mts., streams have average gradients of 20 feet per mile, whereas streams in shallower relief areas of the Springfield Plateau may only have average gradients of 3-5 feet per mile (Adamski et al., 1995).

Geology

The geology of the Kings River Basin is diverse in lithology, mineralogy, and structure. Secondary mineralization has occurred in many of the rock units, and uplifting has resulted in fracturing and faulting of the rock units yielding young valleys drained by steep, dissected ravines and draws (Adamski et al, 1995). All of the basement rock is crystalline and is overlain by interbedded sedimentary layers with consolidated rock in the higher elevations and unconsolidated rock in the alluvial environment.

As mentioned previously, two different physiographic regions dissect the watershed. These regions are different in age and geology, or parent material. The Boston Mountains, in the southern portion of the watershed, are the younger of the two and are primarily composed of Upper Mississippian and Pennsylvanian age sandstones, shales, and limestones. The toe of the Springfield Plateau, in the northern half of the

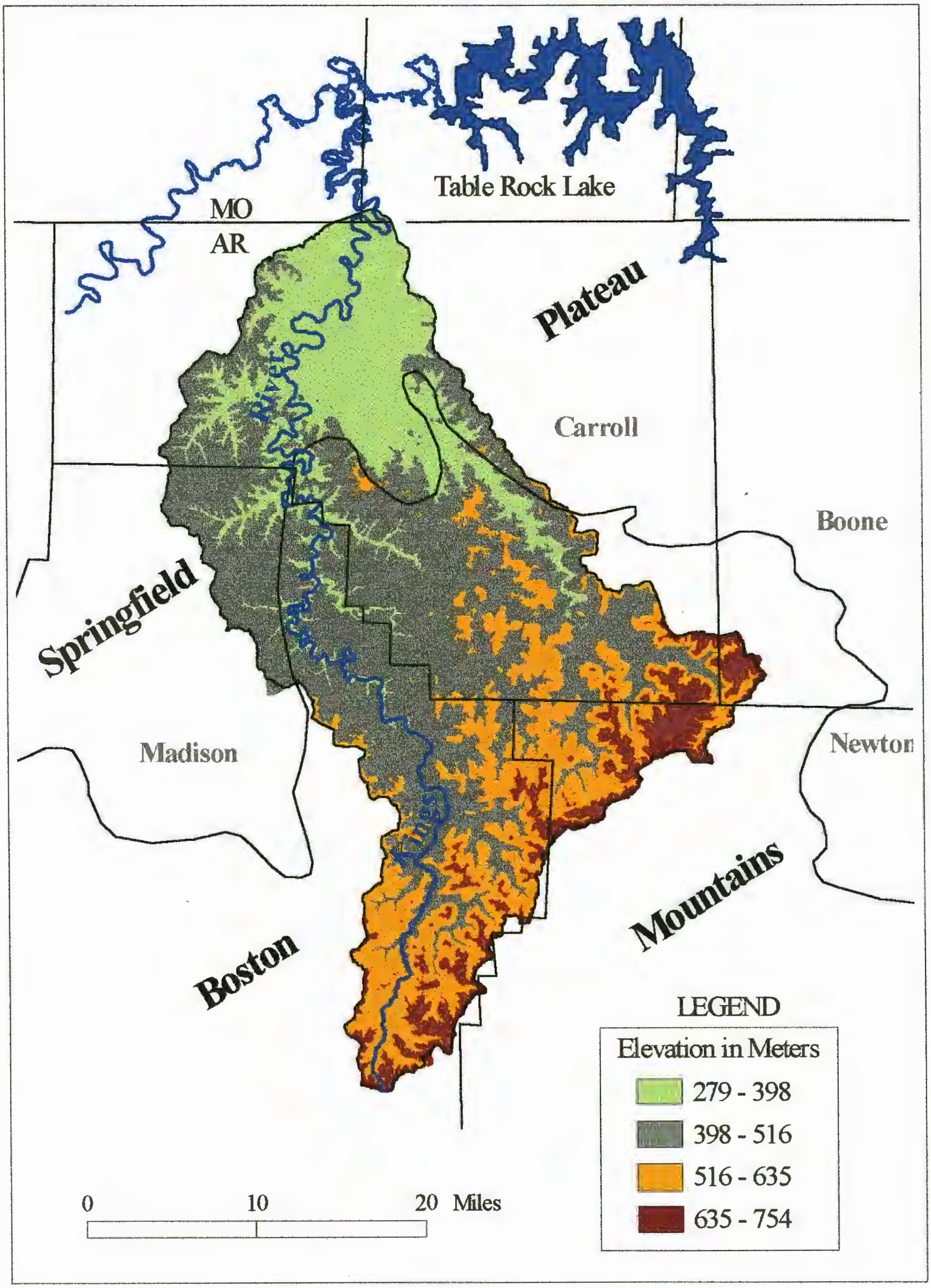


Figure 3.3. Topographic elevations in the Kings River Basin.

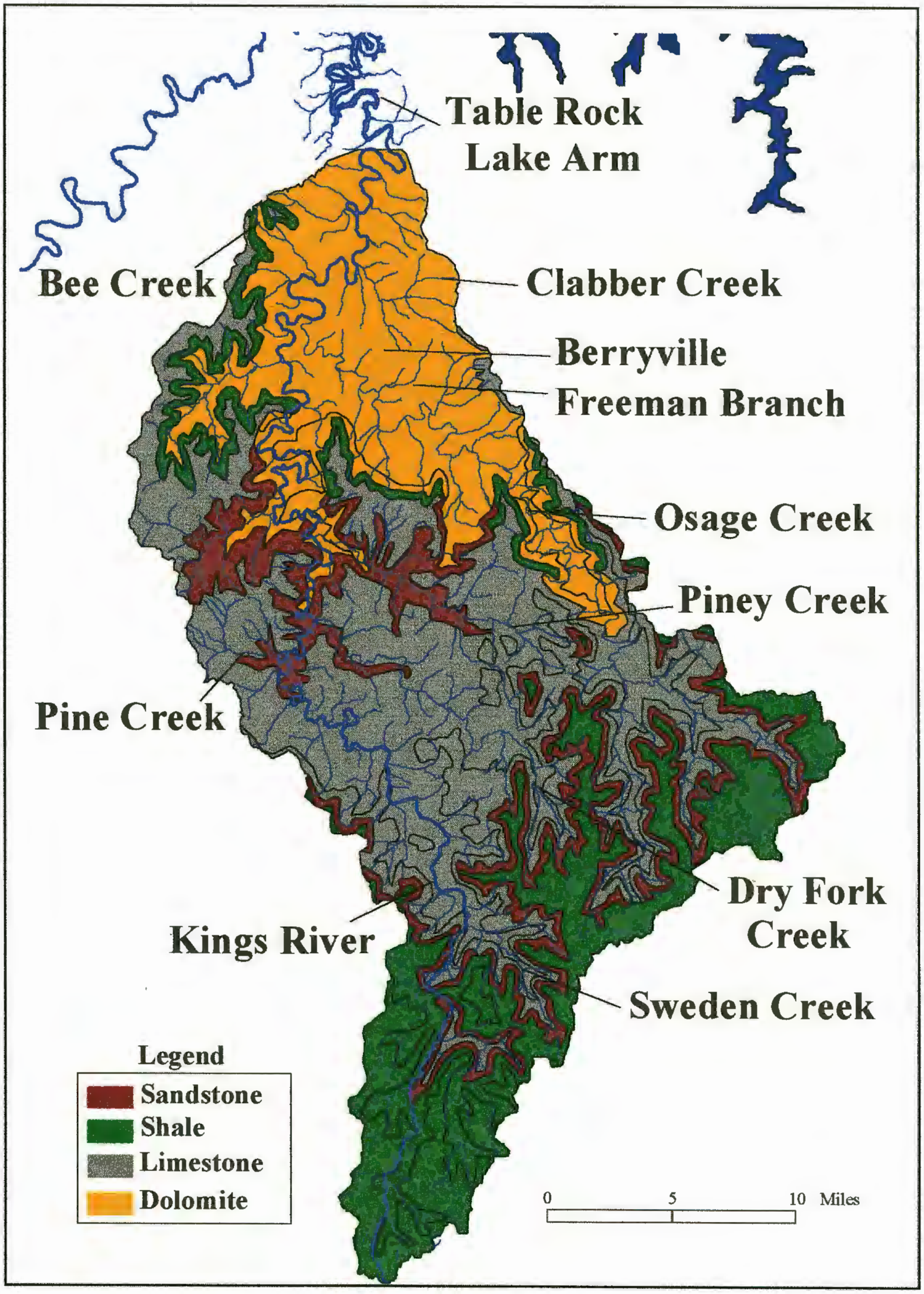


Figure 3.4. Generalized geology in the Kings River Basin.

watershed, is primarily composed of Mississippian age limestone and dolomite with random sandstone bluff caps and outcrops. A generalized geology map (Figure 3.4) shows the spatial distribution of the geology in the watershed with the dominant rock types noted. The watershed consists of four major lithology types: sandstone (14%), shale (23%), limestone (39%), and dolomite (24%). The areas with the most relief are composed mostly of the Pennsylvanian age Atoka Formation (McKimmey and Scott, 1993). This formation consists of sandstone parent material with alternating sandy shale and clay shale layers that cap the Boston Mountain bluff lines high above narrow stream valleys (McFarland, 1998). The clean and very friable sands found in streambed outcroppings, such as the Everton Formation, are thought to be the source of the sandy river sediments that are found throughout the entire watershed (Braden, 2000).

Found in the middle reaches of the watershed, the Boone Formation consists primarily of limestone/chert parent material and can be found in the valley bottoms as the base on which most other formations sit. This formation makes up the largest percentage of geology in the watershed (Figure 3.4). Nearer Table Rock Lake, on the Springfield Plateau, the Cotter and Jefferson City formations are abundant and are composed of dolomitic parent material. Limestone and dolomite are very similar in composition and are subject to solution by groundwater. Over millions of years the movement of rainwater through cracks and crevices in the rock has caused large amounts of the rock to dissolve, resulting in solution channels, caves, springs, and the development of sinkholes at the surface (Rafferty, 1980). These features are collectively known as karst rock units and are responsible for high velocity sub-surface flow that can harbor contamination.

Climate

The Kings River Basin has a temperate climate because of its mid-latitude, interior-climate location (Adamski et al., 1995). Thunderstorms are the primary source of water quantity and these storms can produce large amounts of runoff and flooding. Most rainfall usually occurs during the months of March through June and average annual precipitation amounts generally range from 38-44 inches per year. Most rainfall events of greater than 0.5 inches usually produce ample amounts of runoff depending on site-specific soil and vegetation characteristics.

Mean annual air temperature remains around 60° F with an average high temperature of 80° F in July and an average low temperature of 34° F in January. The seasonal variation in mean temperatures is closely related to seasonal solar radiation with greater regional contrasts in winter than in summer. Also, the polar front and jet stream normally pass through the study unit in winter causing increased temperature contrasts within the study unit (Adamski et al., 1995).

Climate and precipitation have a direct effect on runoff and stream discharge within watersheds. Runoff can be defined as the water that drains from the land into stream or river channels after precipitation and is a function of precipitation amounts, topography, geology, soil moisture, and other factors (Adamski et al., 1995). Mean annual runoff for a watershed is calculated by dividing the mean annual volume of water leaving the basin by the drainage area. Annual runoff for the Springfield Plateau physiographic unit ranges from 10-15 inches and slightly higher (14-20 inches) for the

Boston Mountain unit.

Duration of high streamflow, or discharge, and the time lag between onset of precipitation and the peak flow, generally will be shortest in small, steep watersheds. Therefore, the Boston Mountain tributaries remain at flood stage for shorter time intervals than the shallower Springfield Plateau tributaries. Streamflow can vary yearly and seasonally dependent upon the amount of precipitation. Minimum monthly streamflows typically occur in summer and fall, July through October and maximum monthly streamflows typically occur in spring, March through May. The only USGS fixed stream gauge on the Kings River is just downstream of Berryville and the mean daily flow for the last 38 years as this station ranges from 242-6,390 cubic feet per second (cfs) with an average of 1,250 cfs.

Soils

There is a diversity of soil series ranging from very thick and fertile alluvial soils in the lower reaches of the watershed to thin and compacted soils on Boston Mountain slopes in the upper reaches of the watershed. In general, most of the soils have a high potential for nutrients and other dissolved constituents to be leached to the ground water and have a high potential for runoff to surface water systems (Adamski et al., 1995). The majority of the soils within the Kings River Basin are categorized in the Ozark Highlands category, which consists of a mixture of alfisols and ultisols. Soil data is very site-specific and the series can blend together making detailed classification difficult. Figure 3.5 is a generalized soils map that was compiled from the more specific

SSURGO soils database distributed by the National Soils Survey Center (NSSC). Detailed soil series classification is beyond the scope of this watershed-scale study, however several series will be referred to because of their consistent spatial geography and intimacy with the underlying parent material in which the soils have formed (Fowlkes et al., 1984). Soil formation can be grouped into one of three general processes: alluvium, colluvium, and residuum. Alluvium is material that has been deposited by water, colluvium is material moved by creep or slide and deposited on slopes, and residuum is unconsolidated material that has been formed from rock mineral in its current location (Phillips, 1986). The breakdown of parent material into the soil column results in eroding sediments with varying sizes that reflect the bedrock composition of the area. For example, a soil formed in residuum of the Atoka Formation is going to yield a higher percentage of sand than a soil formed in residuum of the Boone Formation, which would yield a higher percentage of cherty sediment.

The upper reaches of the watershed are predominately made up of the Enders, Mountainburg, Leesburg, and Linker soil series. These series contain very stony, sandy and gravelly soil particles that are characteristic of moderately sloping terrain and are well drained. Downstream in the middle reaches Clarksville, Nixa, Noark, and Captina soil series predominate. This categorization includes series that consist of more cherty soils with some stony mixture. These soils are deep, fertile, and found in a range of topography. Closer to Table Rock Lake in the lower reaches of the Kings River Watershed, the soil series are a combination of Arkana, Eldon, and Moko. These series

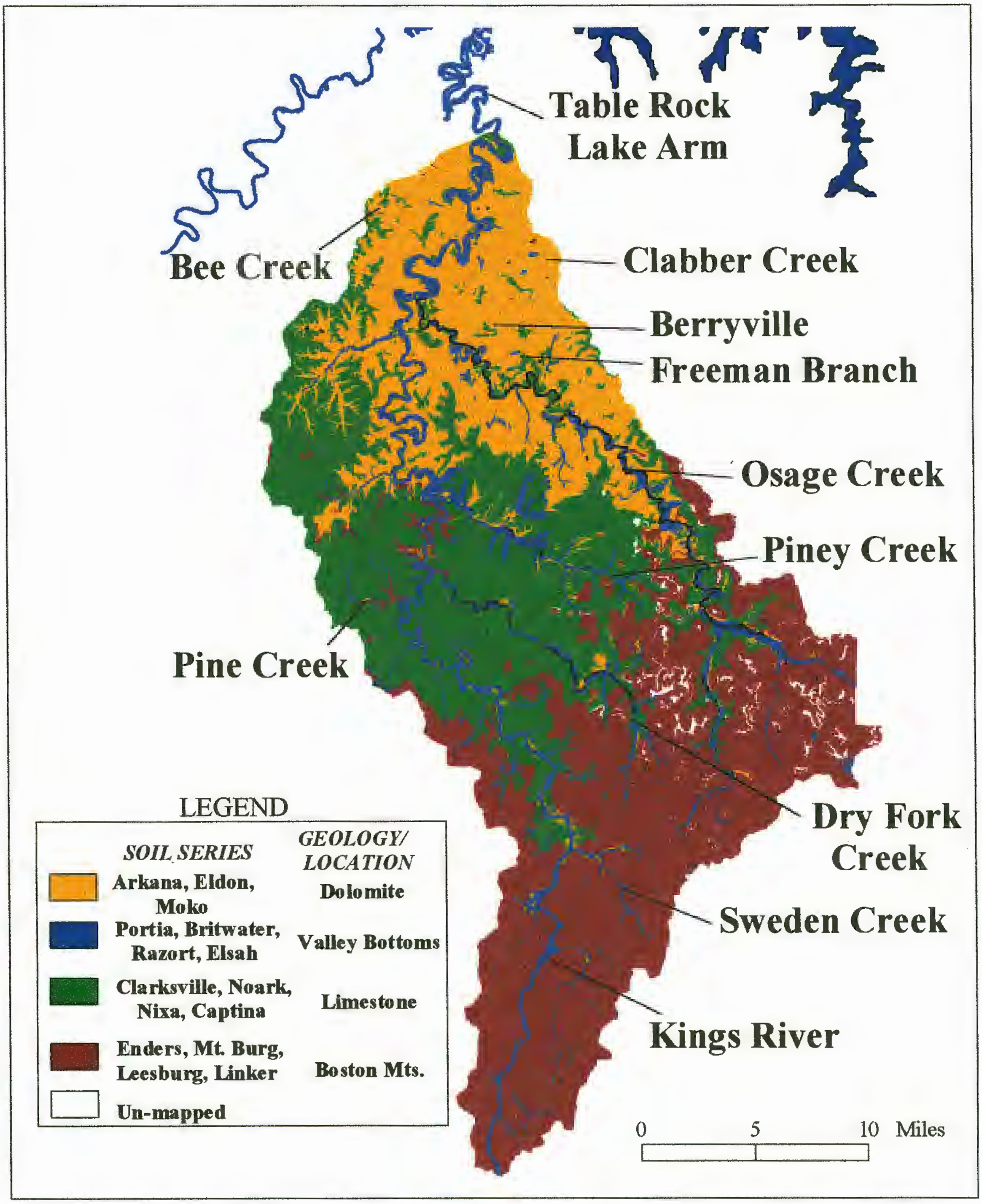


Figure 3.5. Generalized soil series in the Kings River Basin.

are chert-loam mixtures that were formed from dolomite or limestone residuum. These series are shallower and are characteristic of larger floodplain areas adjacent to lake confluences. The last group of soils is found on floodplains and lower stream terraces throughout the entire Kings River Basin. Portia, Britwater, Razort, and Elsah soils are much younger than the other groups and they are very well drained because of their historical formation in old alluvial sediment. This group of soils is represented in local erosion from adjacent fields and stream banks that have been affected by stream processes for many years.

As a geomorphic agent, soil is a component of runoff processes and a source of erodible sediment from the landscape. Variables including topsoil and subsoil texture, organic matter content, and depth to bedrock are important when assessing the susceptibility of soil movement in a fluvial system. There are four general geologic units in the Kings River Basin (Figure 3.4) and each unit possesses varying characteristics that can play a factor in soil movement from the terrestrial to the aquatic environment (Table 3.1). The table shows that the Boston Mts. unit contains very shallow soils, low organic matter content and the soil texture is hard gravel and stone. In contrast, the dolomite and limestone units have deeper soils, they have moderate organic matter content and soil texture consists of silt, loam, and clay particles. According to these characteristics, the Boston Mts. unit would be less susceptible to organic soil matter eroding into nearby streams than the dolomite and limestone units, which would be a factor when assessing source areas of P-laden sediment erosion.

Table 3.1. Soil characteristics of different geologic units.

	TEXTURE		BEDROCK DEPTH	OM CONTENT
UNIT	TOPSOIL	SUBSOIL		
Boston Mts.	stony,gravel	silty clay	20	LOW
Limestone	cherty	cherty, silt loam	75	MEDIUM
Dolomite	cherty, silt loam	cherty, clay	50	MEDIUM
Alluvial	gravelly, silt loam	silty, clay loam	70	MEDIUM

Land Use

Land use in the Ozarks region and adjacent areas prior to European settlements was primarily oak-hickory forests on the hilly regions and bluestem prairie on the un-dissected plateaus (Adamski et al., 1995). Land-use changes with the potential to create landscape disturbance at the drainage-basin scale began in the Ozarks in the 1830's. Disturbance included clear-cutting for silviculture from 1880 to 1920, mining up until the 1960s, and gravel mining and grazing that still exists today (Jacobson, 1995). Today's forests are predominately second-growth hardwood trees with intermixed riparian species. Prairies are almost non-existent and their legacy can be found in local glade areas with outcropping limestone and dispersed cedar trees. Historical settlements were strategically established near springs and rivers without much effect on natural resources, however today's towns and urban areas are expected to facilitate more people, which results in more strain on surrounding rivers and lakes.

Modern land cover classification can include several categories, however, only three general categories will be used for this study: forested, agriculture, and urban. These percentages are 67.8%, 32.1%, and 0.1%, respectively (Figure 3.6). These percentages were calculated from a land use file that was provided by the Center for Advanced Spatial Technologies (CAST). The Upper, Middle, and Lower Kings sections are similar with predominate forest and secondary agricultural land (Figure 3.7). Pine Creek has the highest percentage of forested land, Clabber Creek has the highest percentage of agricultural land, and Osage is the only creek with urban influences (Figure 3.7). Most of the forested land is continuous along tributaries and stretches of the main stem where urbanization has not taken over. Most of the agricultural land is utilized for the purposes of cattle grazing, broiler (chicken) houses, turkey houses, and minimal dairy production. Of these practices, broiler operations are the primary structures found in the Kings River Basin.

Traditional plow farming has given way to technology and chicken houses. Large corporations such as Tyson bring birds to the farmers and then pick them up after a period of contracted time of care and services. According to an aerial photo count by the Arkansas Department of Environmental Quality (ADEQ), there are approximately 472 poultry houses in the Kings River Basin (Figure 7). Steve Ford and Larry Cash, district conservationists for the Madison and Carroll counties soil and water conservation offices, respectively, estimate there are currently 377 houses in operation within the watershed boundaries. One house may facilitate an average of 90,000 chickens per year and one bird can produce approximately 0.64 lbs. of waste per day for a total of 57,600

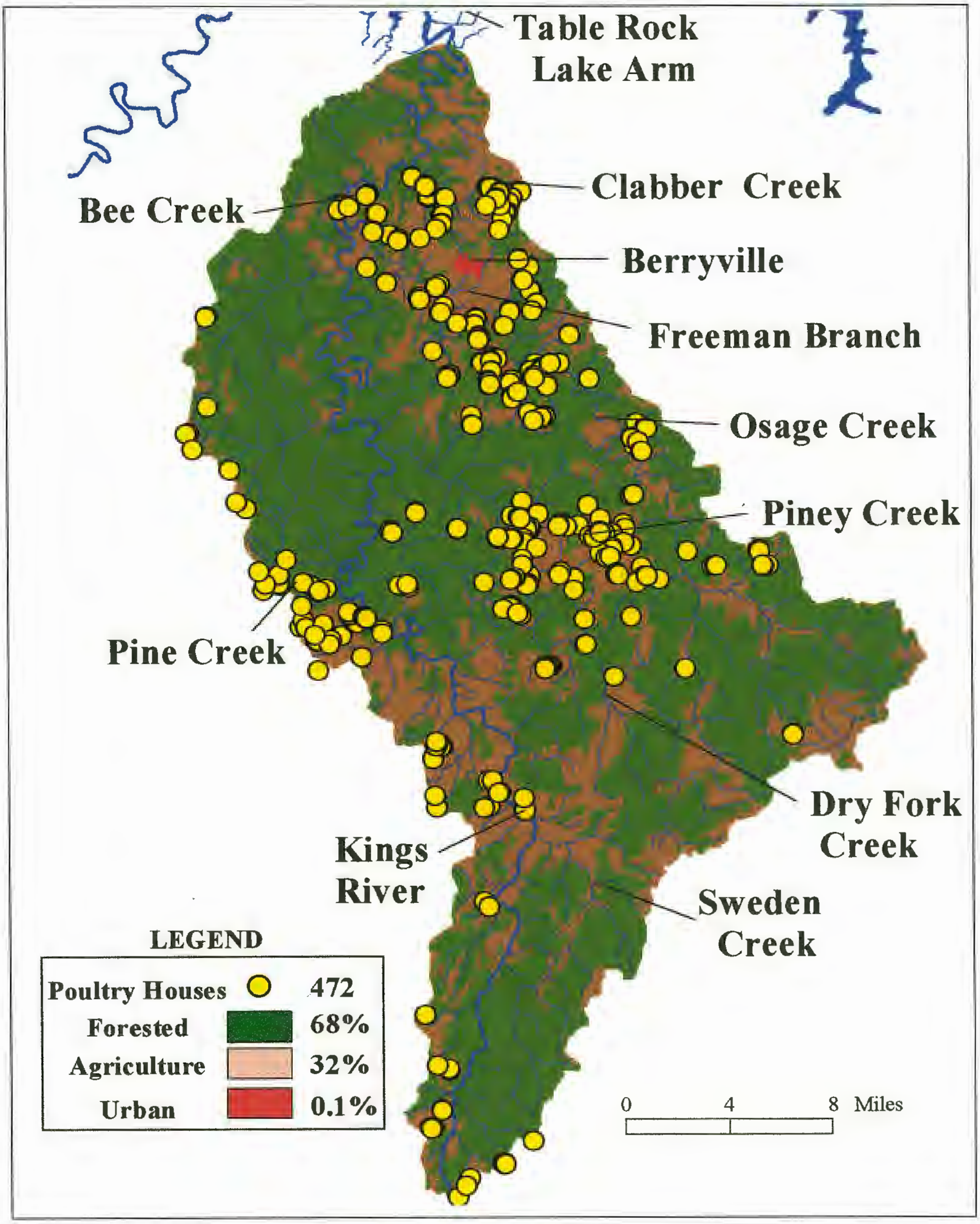


Figure 3.6. Generalized land use and poultry house locations.

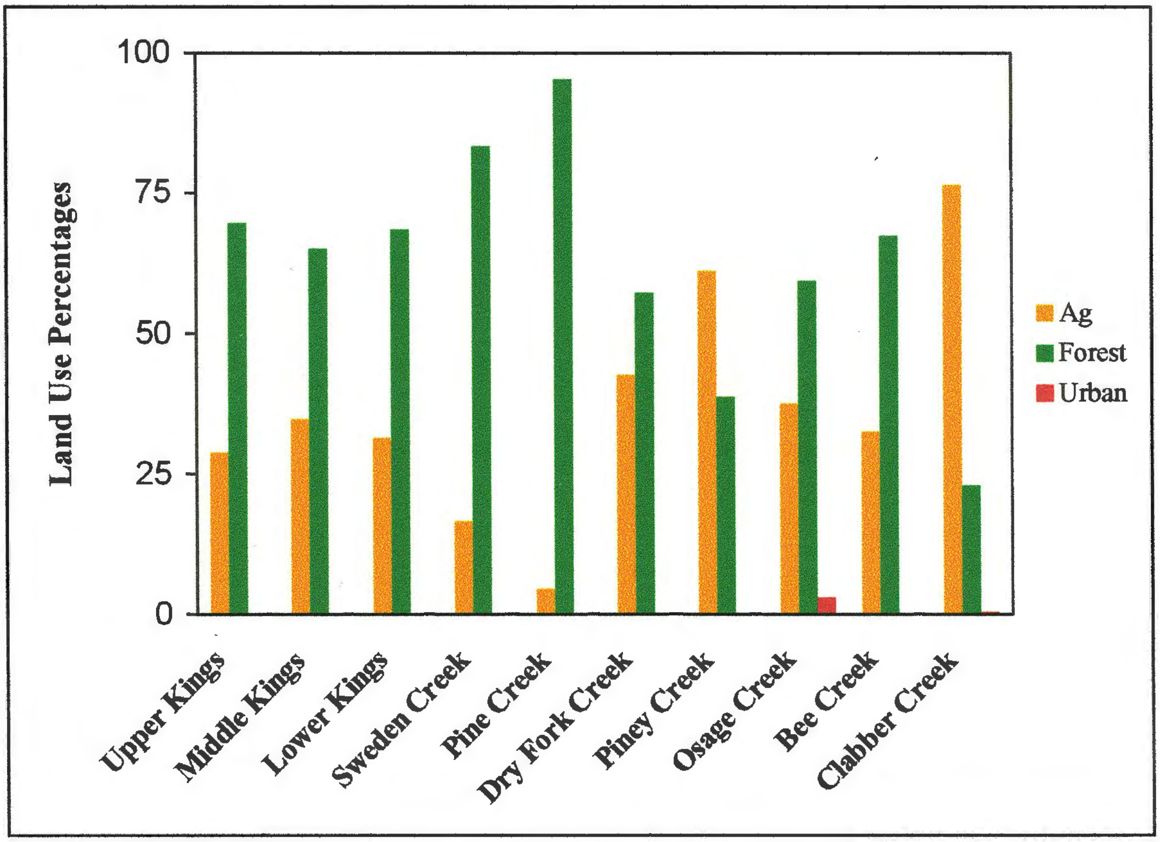


Figure 3.7. Land use percentages by reach and tributary.

lbs. of dry waste per year (USDA, 1992). Nutrient management plans recommend spreading approximately 4,000 lbs. per acre for fertilizer, which leaves an excess of 53,600 lbs. of waste for storage. Efficient soil tests, routine litter samplings, litter storage, and litter composting help prevent farmers from spreading more nutrients than their fields need.

All of the poultry operations in the Kings River Basin escape the management classification of "confined animal feeding operation (CAFO)" because their inventories fall below the minimal animal unit requirement for a point source discharge. The poultry waste management parameters (USDA, 1992) state that one animal unit equals 1,000 lbs. and it takes 1,000 units to be considered a point source discharge. In contrast to dairy operations, which are supervised under the National Pollutant Discharge Elimination System (NPDES), poultry operations have dry waste to discard. Therefore, land application of dry chicken waste is not only good for the crops, but is also legal. This is the reason why these operations are a potential risk for diffuse and candid agricultural NPS pollution. Even operations that are no longer housing birds are still a possible NPS threat because of historic land application of chicken waste that may still be active in nearby fields. Once excess P is tied up in a field, it must be removed by either vegetation uptake or surface erosion.

There are very low amounts of urban land in the Kings River Basin (0.1%), however Osage Creek sub-watershed is the largest creek in the basin, one-fifth the drainage area of the Kings, so the urban influence has a slightly greater effect in this creek (Figure 3.7). The largest city is Berryville, which had a 1990 population of 3,212

(US Census Bureau, 1990). Several other smaller townships exist, but their populations average about 600 persons per town. Berryville was the only area that was detected by the initial land cover classification system used in this study. Berryville has one chicken processing plant and one wastewater treatment plant. Both operations are supervised under the NPDES system, however the wastewater treatment plant is not required by law to test for its P effluent.

CHAPTER 4

METHODOLOGY

Introduction

This chapter discusses the research design and methodology used for this study. Ninety-five streambed sediment surveys were collected from the Kings River, seven large tributaries, and six background reference locations, and all site locations were measured using a Global Positioning System (GPS). All of the samples were further processed and quantified, however the six reference samples were not included in regression analysis for the study. Ninety-five sediment samples were analyzed in the SMSU geomorphology lab for grain-size variability and organic matter content. An outside chemical lab did further geochemcial analysis including sediment-P and other trace element concentrations. Results were analyzed with standard statistical software and graphing procedures. This data was then used to create a spatial regression model using supplementary databases collected from various environmental agencies and a GIS for manipulation and presentation of the information.

Sediment Surveys

Eighty-nine streambed sediment samples and six reference samples (95 total) were collected during a three-week period from August 15 to September 5, 2000. The survey locations represented typical, low-energy stream reaches where fine-grained sediment has been most recently deposited by fluvial processes. Most of the samples were collected from side-pools and eddies, but some were collected at the apex of gravel bars on stream bends (Figure 4.1). The author chose sampling locations based on past fieldwork experience and ease of access at each site. Middle and Lower Kings samples were taken by water access from a kayak, while the Upper Kings and tributary samples were collected on foot with permission from landowners. Upper Kings samples (1-7) were taken from a totally dry streambed and the river was not navigable until site 8 (Figure 4.2). A composite sample was collected at each location to represent sediment characteristics in the immediate vicinity. Collecting sediment from three different areas, one just upstream, one just downstream, and one right at the chosen site made the composite sample. Each composite sample was collected in a Ziploc™ bag and chronologically numbered. Except for several samples taken in the un-navigable headwater reaches, samples were spaced approximately 1 km (Figure 4.2). Sample sites were not pre-meditated, instead they were chosen based on proximity to stream confluences, varying land uses, easy access, and sufficient fine-grained deposits. See Appendix A and B for a complete listing of each site, its characteristics, and the geochemical constituents that were quantified.

The six reference samples that were omitted from analysis were samples sixty-three and sixty-four, which were collected from the lake arm outside of the actual Kings River Basin; a background forest soil sample that was collected from a soil bank deep in the woods of the headwaters; a sample that was collected at the mouth of a pristine spring in the forested headwaters for baseline soil conditions; a scoop of dry chicken waste that was collected for baseline poultry P; and a subsidiary sample that was collected just above sample thirty-one from the same gravel bar to compare the variability of dry and

Arrow points to gravel point bar terminus

Arrow points to a deep, shaded side-pool

Figure 4.1. Typical low-energy sediment sampling sites.

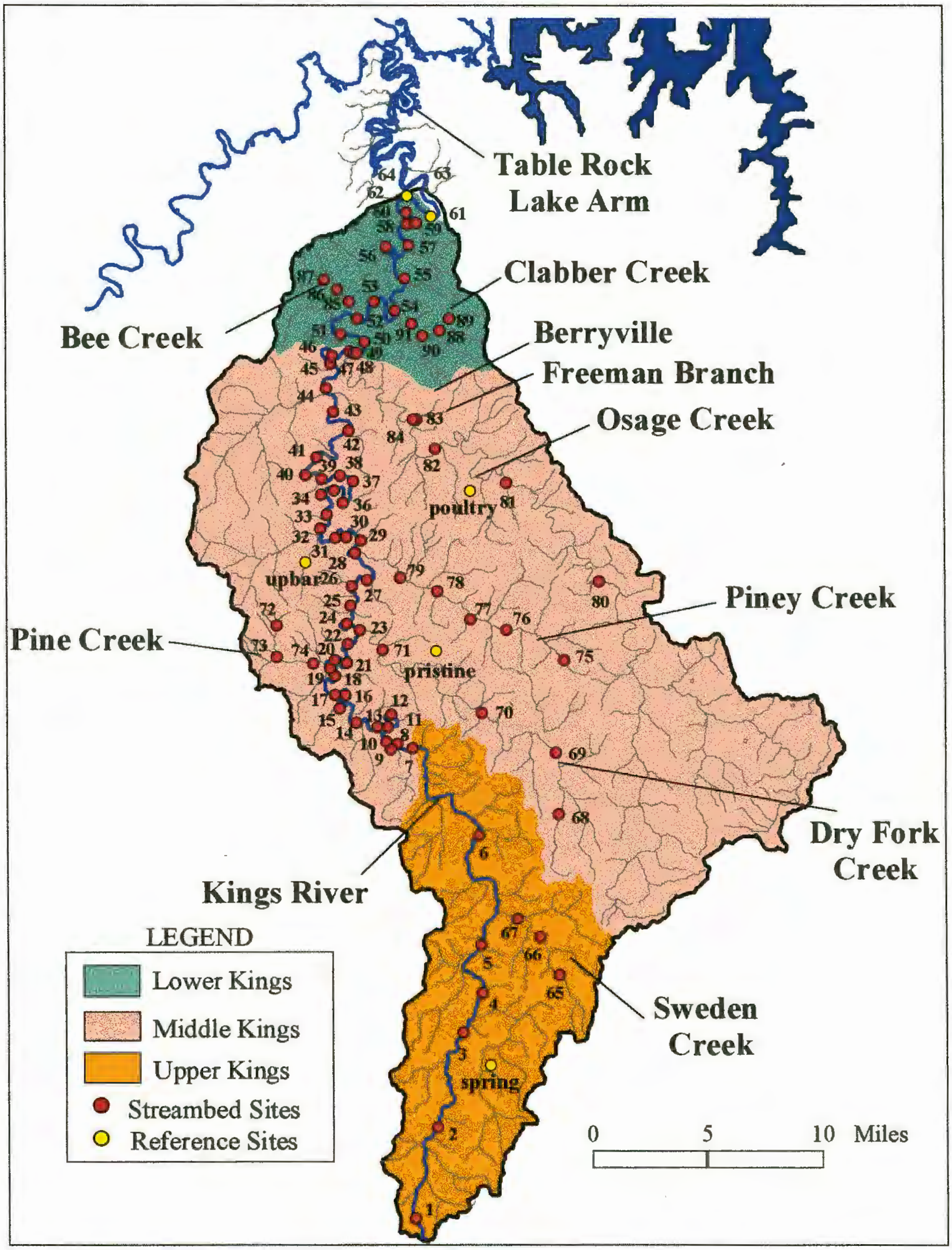


Figure 4.2. Sediment monitoring locations in the Kings River Basin.

wet fine-grained sediment in that area. The results from these six sample locations are important baseline information for this study and are referred to in discussion, however they are not included in the spatial model because their values serve as controls.

A Garmin™ 12XL GPS unit was used to store the geographic locations of the samples for later GIS facilitation and for possible re-sampling at a particular site. Prior to fieldwork, a line file showing the Kings River was uploaded into the GPS unit using Waypoint + ™ software to make navigation easier once on the river. Each location was numbered to coincide with its sample bag and other major landmarks were marked for reference. In addition to the sediment samples, pictures and detailed journal notes were compiled for supporting information.

Sediment Processing

The partially dried samples were returned to SMSU for three different steps of sediment processing techniques.

First, the samples were put through pre-processing to prepare them for further analysis. Samples were dried in industrial ovens at a steady temperature of 60 degrees to evaporate any possible moisture content that was still present. The dried samples were then ground and sieved through a 2 mm sieve to separate out the bulk of the fine-grain fraction. The 2 mm portion of each sample was then put back into its original bag and used for the remaining lab procedures.

Second, all of the samples were analyzed in the SMSU geomorphology lab for percent organic matter content and percent sand fraction. For the organic matter (OM) procedure, laboratory crucibles were weighed for their empty weights. The scale was then zeroed and five grams of sediment was placed into a crucible and weighed for a pre-burn sediment weight. This process was systematically repeated for all ninety-five sediment samples. After the weights were recorded, the samples were placed in a large oven at 105 degrees for two hours to remove atmospheric moisture, which could disrupt the true sediment weight. The samples were placed in a dessicator and allowed to cool for one hour to equilibrate relative humidity in the air. After total cooling, the crucibles were weighed once again for a pre-burn sediment and crucible weight. Once all of the samples were completely dry and weighed, they were then ready to be placed in a furnace to burn off the actual organic matter, which can consist of tiny twigs, grass clippings, humus and other organic debris that is often found on the top layer of soil or sediment in riparian areas. The samples were placed in a muffle furnace set at 500 degress for 6 hours in order to burn off all of the available organic matter. After ample cooling time, the samples were weighed one last time to obtain the organic matter percent loss on ignition. This final percentage was found by subtracting the post-burn sediment weight from the pre-burn sediment and crucible weight.

For the sand fraction procedure, the mechanics are similar to calculating the organic matter in that the whole sample is used to extract a desired outcome. A 200 mL glass beaker was first weighed to find its empty weight before adding sediment. Thirty grams of sediment was then added to the empty beaker and weighed again for its total dry beaker and sediment weight. Next, 50 mL of liquid dispersant (a mixture of water and sodium hexametaphosphate) and 100 mL of deionized, or sterile, water was added to the beaker and vigorously stirred with a glass stir rod. This mixing procedure was repeated for all ninety-five samples in groups of twenty samples. The beakers were then left to sit overnight for the natural coagulation of the sand particles at the bottom of the beaker and collection of fine-grain particles near the top of the beaker. The next day, each beaker was decanted, or carefully poured, to leave only the sand particles settled in the beaker. This sand was then directly put into a 0.63 *u*m sieve and oscillated under running water, which is known in geomorphology as wet sieving. In general, this process is cleaning the sand and making sure any un-wanted debris or fine-grain particles are not stuck to the sand particles. After wet sieving each sample and placing them back into the same beaker, they were placed in an oven at 110 degrees for two hours to evaporate any water still in the sample. The samples were weighed one last time with only the sand fraction present and this number was subtracted from the pre-burn beaker and sediment weight to obtain the final sand fraction percentage. The final number was recorded as the total sand fraction percentage for each of the ninety-five sediment samples.

The third and final step during the sediment processing procedures involved separating out five grams of each sediment sample, putting them in numbered bags, and sending them to Chemex geochemical lab in Sparks, Nevada. One gram of sediment was extracted with aqua region, hot 3:1 ratio Hcl:HNO_3. Geochemical ring and Inductively-Coupled Plasma (ICP) spectroscopy were then used to read the actual constituent concentrations. The 32-constituent ICP analysis was the primary analytical technique and the numbers from this process are the numbers that were used in various statistical analysis routines for this study. Although results from Chemex included thirty-two different geochemical elements inlcuding nutrients and trace metals, only five trace elements were analyzed in this study: sediment-P, Al, Fe, Mn, and Ca. For reference, 10,000 ppm = 10,000 *ug*/g = 10,000 mg/kg = 1%.

GIS Database

There were two stages involved in this study's GIS procedures: initial database integration to prepare for modeling, and spatial modeling for the assessment and prediction of geochemical concentrations and sub-watershed conditions directly upstream of each sampling location.

The first step was to create a vector line file depicting the Kings River Basin boundary. Little Rock, Arkansas USGS provided a file that was then slightly altered to coincide with this study's sampling locations. The final watershed boundary was approximated at 561 mi^2 and this file was then used to clip each of the subsequent geographic files for use in a GIS. The GIS files were collected from five supplementary datasets provided by local environmental agencies and public access via Internet sites (Table 4.1).

The land cover dataset was downloaded from the Center for Advanced Spatial Technologies (CAST) website on the University of Arkansas, Fayetteville campus. The land cover information is a component of a larger Arkansas Gap Analysis Project (GAP) that brings together the problem-solving capabilities of federal, state, and private scientists to assess the difficult issues of landcover mapping, vertebrate habitat characterization, assessment, and biodiversity conservation at the state, regional, and national levels (Jennings, 1993). AR-GAP mapped these patterns at a 1:100,000 scale

Table 4.1. GIS databases and agency sources.

DATABASE	AGENCY	DATA SOURCE
Poultry Houses	ADEQ	http://www.adeq.state.ar.us/
Land Cover	CAST - AR GAP	http://www.cast.uark.edu/gap/
Geology	CAST	http://www.cast.uark.edu/
Soils	USDA-NRCS	http://www.statlab.iastate.edu/soils/nsdaf/
Roads, Counties etc.	US Census Bureau TIGER Files	http://www.esri.com/data/online/tiger/

using combinations of remotely sensed data (e.g., air photos, air videography, and various transformations of satellite imagery) along with field data and previous surveys. Each scene was geocoded to a UTM (NAD 27) coordinate system based on ground control points (GCP) collected from 1:100,000 scale U.S. Geological Survey (USGS) Digital Line Graph (DLG) roads (Jennings, 1993; Scott et al., 1993). The initial land cover categorization included urban, agriculture, and approximately fifty-seven different tree species. For generalization, this study concentrated on urban, agriculture, forested land cover, and water (Figure 3.6). Only four categories were chosen because the goal was to perform a watershed-scale analysis, not a segmented sub-watershed assessment.

The geology dataset was accessed from CAST and the original collaborators were the Arkansas Geological Commission, the Arkansas Archeological Commission and Arkansas USGS. The file delineates sixty-one statewide geologic units at a 1:500,000 scale with a raster projection of UTM coordinate system zone 15 and a North American Datum of 1927 Clarke 1866 spheroid datum. The digital dataset was digitized in 1976 and no unknown updates have been attempted. Because of the very detailed mapping scale that was involved with the original file, only the major geology units of sandstone, shale, dolomite, and limestone were used for this study (Figure 3.4). The percentage of each of these four units was calculated for each sub-watershed above the sampling sites to explain possible geochemical relationships. Subsidiary references included spoken communication with the Arkansas Geological Commission (Braden, 2000) and field pictures of streambed rock units at several sampling locations.

The soils information was adapted from the USDA-NRCS National Soil Survey Center's Soil Survey Geographic (SSURGO) database. This database is a collection of digitized map units from the original county soil surveys provided by extension offices throughout the nation. A total of nineteen soil attributes are available in table and file format, however, only the series names were used for this study. The soil geographic layer was not part of the statistical analysis, however, it was useful during discussion of geologic weathering and resulting soil formation.

Poultry house locations were first interpreted from aerial photos and later updated when the Arkansas Department of Environmental Quality provided a point file of individual houses. Houses that are no longer in operation were deleted. A poultry index was created to account for the quantity of poultry houses in sub-watersheds above each sample site. To account for varying drainage areas, the number of poultry houses was divided by the drainage area in each sub-watershed to obtain an index number that reveals the intensity of houses per square mile. This index number was then used for statistical and graphing purposes.

Some miscellaneous watershed files were also needed to facilitate map production that included roads, county boundaries, city boundaries, and streams. These files were downloaded from the U.S. Census Bureau's 1995 Topologically Integrated Geographic Encoding and Referencing (TIGER) files database. This is a comprehensive GIS depository for geographic information that was originally compiled from the 1990 Census and later updated in 1995. In addition to these subsidiary files, water column Total P data was obtained from two ADEQ fixed sampling gauges to create a point source loading index (PSLI) that accounted for the amount of P being released from the

Berryville wastewater treatment plant in any given year. This information was used as secondary explanation of possible high sediment-P values in the Kings River below the Osage Creek confluence.

Statistical Analysis

The two types of statistics used for this study were single and multivariate regression. Single-variate regression was performed using Microsoft Excel graphing and calculating procedures and multivariate regression was performed with SPSS statistical software. Linear regression estimates the coefficients of the linear equation, involving one or more independent variables, that best predict the value of the dependent variable. A trend line with an "r^2" value reveals either a positive or inverse relationship between the two variables. An "r^2" value of 1.0 is a perfect positive relationship and a value of -1.0 is a perfect negative relationship. Values within this range represent the strength of the relationship with values closer to either 1.0 or -1.0 being the strongest.

The primary benefit of multivariate regression is the ability to assess several relationships in one large data matrix. Independent and dependent variables are still used, however several chosen independent variables can be compared simultaneously. SPSS statistics software allows the user to form a data matrix from an existing Microsoft Excel file and cross-referencing columns can reveal quick results. The goal is to find the independent variables that predict the variance among dependent variables. Variables can be added and deleted in order to come up with proper statistical validity. For example, the independent variables agriculture, forested, and urban land use; poultry index values; organic matter percentages; sand content; Fe, Mn, Al and Ca percentages; P:Al ratio values; sandstone, shale, dolomite, and limestone bedrock percentages; and a point source loading index were used to most efficiently explain the dependent variable sediment-P. Final statistical analysis used only significant independent variables.

Spatial Database and Attributes

GPS technology was used to measure the geographic location of each sample location for the 89 in-channel and 6 reference locations. The geographic location was stored on the unit until returning to the lab. The GPS was then connected to a computer and the site information was transferred from the GPS with the Waypoint + software.

The first step in creating the spatial model was to delineate a sub-watershed upstream from each sediment sampling location. A digital elevation model (DEM) was downloaded from USGS and processed with the Watershed Delineator™ Extension that can be integrated with the ArcView mapping software. After the watershed was pre-processed, the flow direction of each pixel was calculated and delineating at each point location created eighty-nine sub-watersheds. Each sub-watershed number corresponds with the sample site number at its mouth. These sub-watersheds were then used as outlines for clipping the land cover and broiler house files.

The second step was to enter sediment-P concentrations, land use percentages, OM percentages, sand percentages, and poultry index values into an SPSS software data matrix and calculate regression and correlation statistics. Several stepwise regression queries were used including all variables, except urban influence. A best-fit line equation was then developed using the most statistically significant variables.

The primary use of the spatial model was to have the capability of predicting outcomes based on entered parameters. This was accomplished by using the best-fit line equation from the regression methodologies. By knowing the y-intercept, constant variable, and slope of the line, the b values, or independent variables, can then be entered into the equation to come up with possible explanations. Using the equation to predict the quantitative data and watershed GIS file layers to portray the data, the spatial model can be a powerful tool for watershed resource managers. Identifying and considering the modifying influence of watershed factors should improve the predictability of the relationship between river P concentration or load and an increase in algal growth (Edwards et. al, 2000).

CHAPTER 5

RESULTS & DISCUSSION

Introduction

This chapter presents four main sections of results describing the relationships between sediment-P concentrations and the spatial patterns of land use and sediment properties in the Kings Basin. First, the overall sediment-P pattern is assessed throughout the watershed and the mean concentrations are compared to previous sediment studies. Second, sediment composition effects are isolated in order to better quantify the actual land use influences on sediment-P variability. Sediment composition variables include sand %, organic matter %, Fe %, Al %, Mn (*u*g/g), and Ca %. Third, the effects of agriculture, forested, and urban land use characteristics are presented and their effects on sediment-P values are evaluated at the sub-watershed level. Fourth, multivariate regression is used to quantify the relationships among watershed variables to create a spatial model that predicts P concentrations from various nonpoint sources.

Results are stratified by reach and tributary location into ten watershed units: Upper Kings (sites 1-7; n=7), middle Kings (8-48; n=40), lower Kings (49-62; n=13); and Sweden Creek (65-67; n=3), Pine Creek (72-74; n=3), Dry Fork Creek (68-71; n=4), Piney Creek (75-77; n=3), Osage Creek (80-84; n=5), Bee Creek (85-87; n=3), and Clabber Creek (88-91; n=4). The overall characteristics of the watershed units vary substantially. The upper reaches of the watershed are narrow, sandy, and forested, while the middle and lower reaches have wider channels, finer grained sediments, and more agricultural land use. Tributaries are a mix of sediment composition and land use including high densities of poultry operations that reapply chicken waste as crop fertilizer.

As is often the case in field studies, data collected from a few sites often reflect extreme values, or "outliers", from the normal range of observed values. These values often complicate regression analysis and need to be accounted for in statistical models. Sites 17 (Middle Kings) and 83 (Osage Creek) were always omitted from regression analysis because of outlying values, but were included in general trend maps. Sites 63 and 64, both lake arm samples, were removed from regression analysis and treated as reference samples for future research. Therefore, of the 91 original sediment samples that were collected, 87 were used for nonpoint source monitoring.

The complete dataset showing each site and all necessary concentrations and percentages is in Appendix B and will be referred to throughout this chapter.

Sediment-P Concentrations

Sediment-P concentrations for the 87 samples ranged from 7 to 1,280 micrograms per gram (*ug*/g), with a median concentration of 130 *ug*/g and a mean concentration of 209 *ug*/g. (Figure 5.1). The highest value (1,280 *ug*/g) was detected at site 83 on the Freeman Branch of Osage Creek, which drains the city of Berryville and the only wastewater treatment plant in the basin. The next highest P values were detected in a cluster around Bee and Clabber creeks, which drain into the lower reaches of the basin near a high density of poultry houses (Figure 3.6). Sites 85-91 in Clabber and Bee creeks

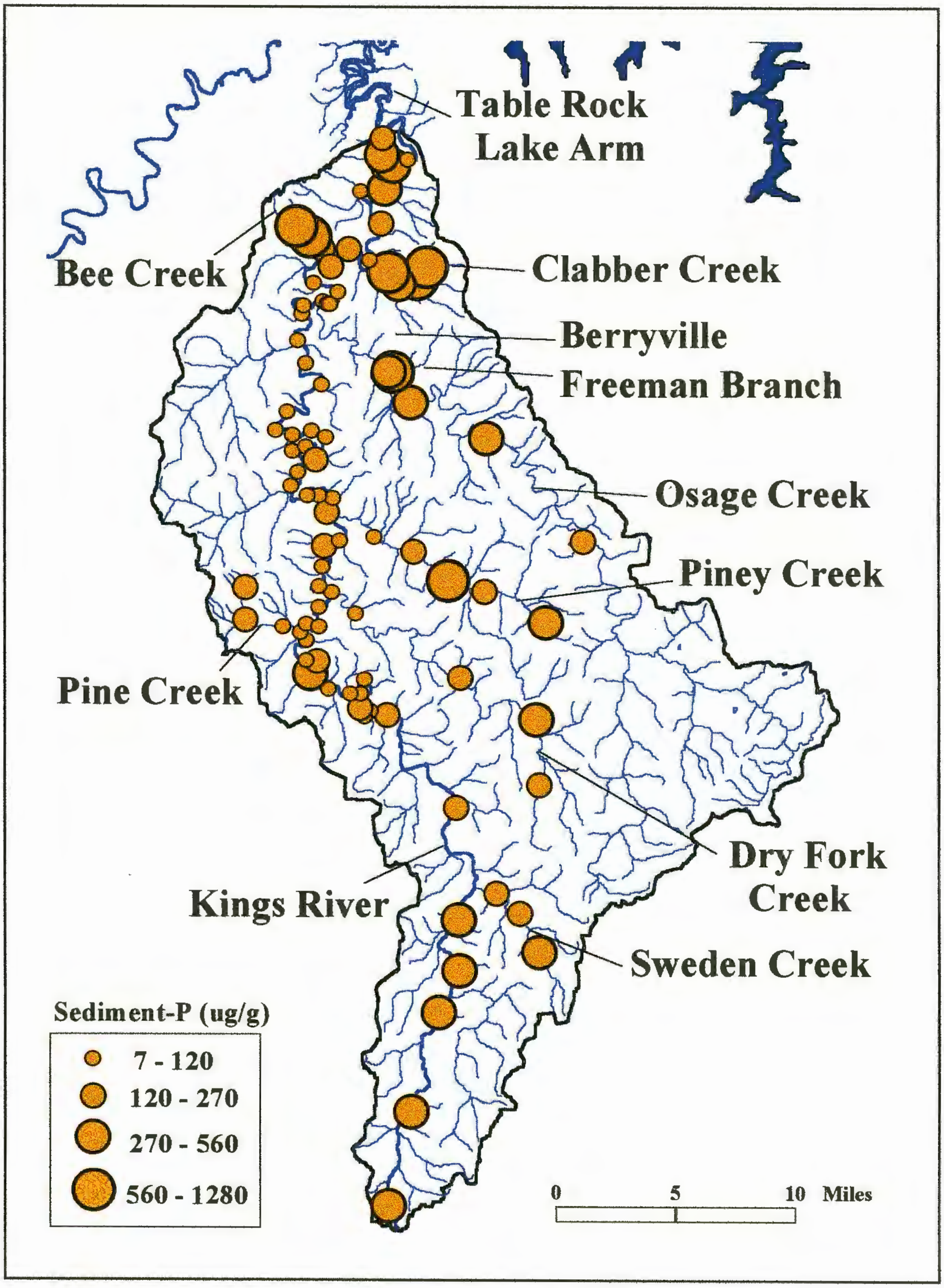


Figure 5.1. Sediment-P variability in the Kings River Basin.

had a mean sediment-P concentration of 630 *ug*/g and the other 80 sites in the watershed only had a mean concentration of 170 *ug*/g. The lowest P concentrations were detected along the Middle Kings reach with concentrations ranging from 4-270 *ug*/g. In general, the P levels tended to be above median in the Upper Kings, lower than median in the Middle Kings and above median in the Lower Kings. Osage, Bee, and Clabber creeks had higher mean P levels than any other sites in the basin. Mean P levels in Piney Creek seem to be affecting the mean P levels in the Middle Kings as shown by the data spike at the Piney Creek confluence (Figure 5.2). Data also reveal a gradual increase in sediment-P values below the Osage Creek confluence. This increase may be due to effluents from the Berryville wastewater plant approximately seven miles upstream on Freeman Branch, along with the abundance of agricultural land use and poultry houses in the upstream drainage area (Figure 3.6).

Ranges of mean sediment-P values varied among the sub-watersheds (Figure 5.3). Pine Creek had the narrowest range of values and Osage Creek had the broadest range of values. While sampling limitations may be a factor, this pattern may be explained by Pine Creek's small drainage area (10 km^2) with consistent forested land use (Appendix A), and Osage Creek's larger drainage area (420 km^2) with varied land use (Appendix A). For the main stem, the ranges for Upper, Middle, and Lower Kings are similar. This may be explained by noting that more samples were used to calculate mean P values in these areas than the tributaries, causing an equalizing effect on the data.

The six reference samples were collected throughout the watershed (Figure 3.6) to

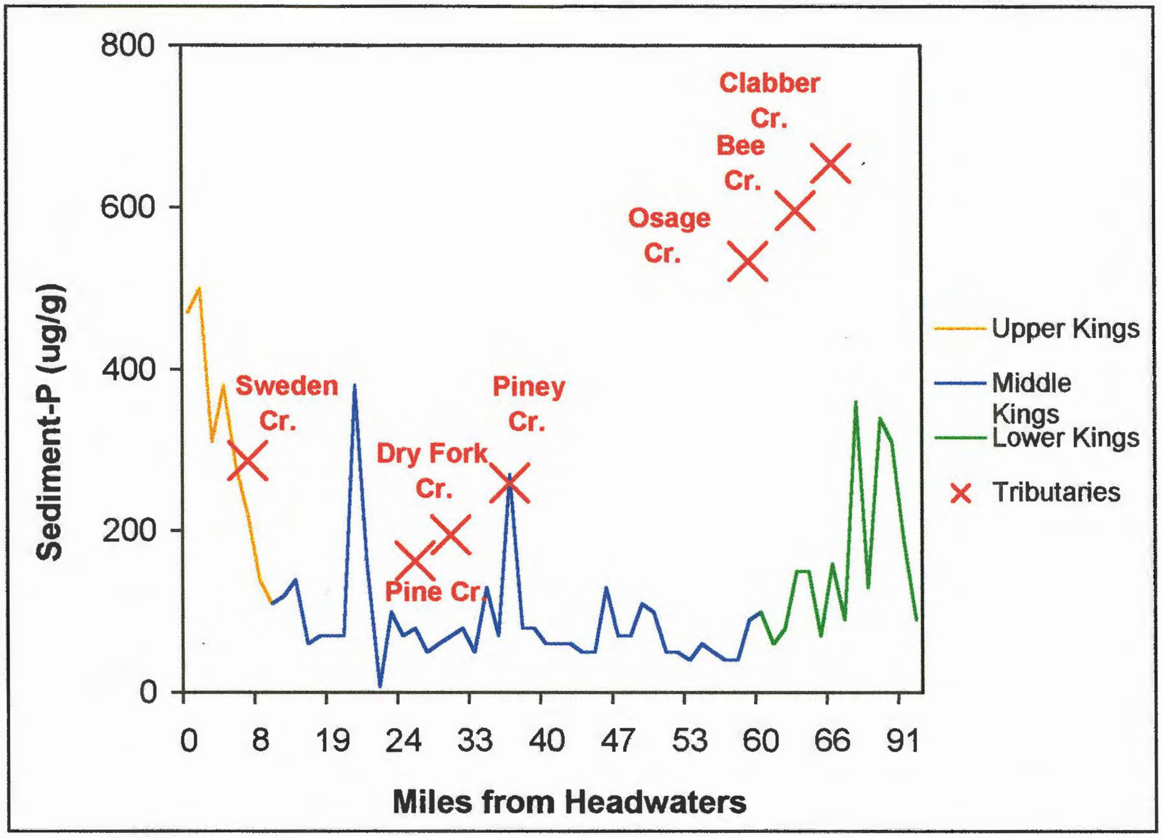


Figure 5.2. Downstream trend of sediment-P concentrations.

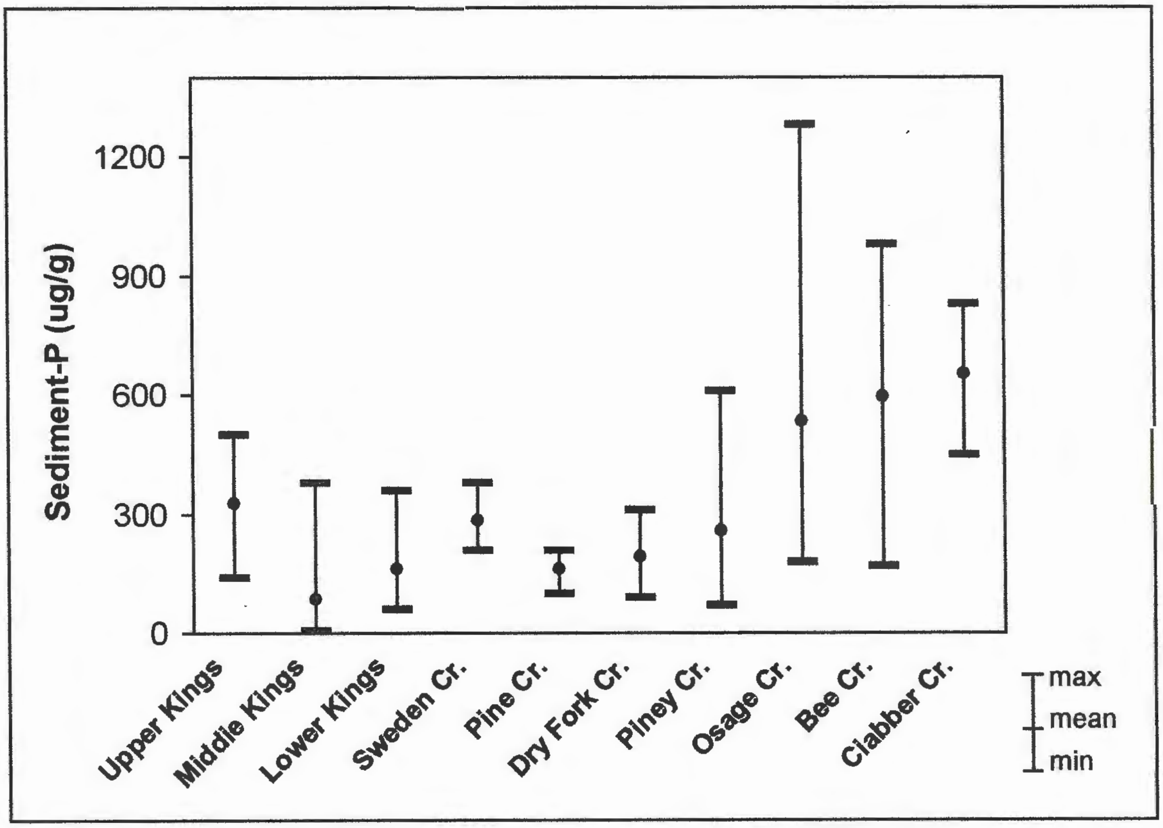


Figure 5.3. Range of sediment-P concentrations.

assess the background concentrations in varying land use areas and compare these values to sample concentrations collected from similar areas affected by nonpoint sources (Table 5.1). High sediment-P concentrations were detected at the spring and forest sites in the Upper Kings, which coincides with high sediment-P values near sites 1-6 (Figure 5.1). As expected, the chicken waste sample had an extremely high sediment-P value, one to two orders of magnitude higher than those in surface soils, which shows that this P-enriched waste may be at risk of offering too many nutrients to the soils and sediments when re-applied on the landscape as fertilizer. Secondly, high Fe and Mn concentrations were detected at the forest and spring site, which also coincides with high Fe and Mn levels at sites 1-6 (Appendix). This shows that there are high levels of oxidation and mineralization of P in the headwater soils, which could be detected with further soil analysis. Thirdly, the two lake arm samples had low concentrations relative to the other source areas.

The mean sediment-P value for the Kings River Watershed (209 *u*g/g) was well below mean values compiled in previous watershed sediment studies across the United States (Table 5.2). The highest mean values in the table (3,100 and 2,250 *u*g/g) were found in watersheds with predominate agricultural land use and few continuous reaches of forested land, similar to the Kings River (Figure 3.6). Although the Kings River contains 472 chicken houses, which are traditionally categorized with agricultural land use, a high percentage of forested land use (68%) masks the effects and the mean sediment value remains low.

The current study collected the second most number of samples (91), behind the

Table 5.1. Source reference samples and concentrations.

Type	Location	Sed-P *ug/g*	Al %	Fe %	Mn ppm	Sand %	OM %
Spring Sediment	Upper	**320**	0.6	1.6	665	55	4.4
Forest Soil	Upper	**390**	0.8	4.0	1180	88	2.3
Sandbar	Middle	**60**	0.1	0.5	110	99	0.3
Chicken Waste	Osage Trib	**> 10,000**	0.2	0.3	785	---	63
Lake Arm Site 63	Lower	**220**	0.4	0.9	190	83	2.0
Lake Arm Site 64	Lower	**200**	0.3	0.9	195	82	1.9

Table 5.2. Mean sediment-P concentrations from previous sediment studies.

Watershed	Location	N	sed-P (*ug/g*) mean (min,max)	Reference
*Kings River	AR	91	**209** (7-1,280)	White, 2001
*James River	MO	80	**366** (100-1,960)	Fredrick, 2001
Chat Creek	MO	67	**1,188** (220-3,080)	Trimble, 2001
Tualatin River	OR	15	**1,410** (600-2,000)	Bonn, 1999
Winooski River	VT	59	**957** (652-1,180)	Chalmers, 1998
Cheney Lake Arm	KS	10	**410** (94-674)	Pope, 1997
Thames River	MA, CT	6	**3,100** (1,800-4,100)	Harris, 1997
Connecticut River	MA, CT, NH, VT	26	**2,250** (1,100-5,100)	Harris, 1997
Housatonic River	NY, MA, CT	7	**1,700** (1,300-2,800)	Harris, 1997
Puget Sound	WA	17	**1,540** (900-2,800)	Tarver, 1995
Illinois River	IL, IN, WI	372	**1,502** (400-4,000)	Colman, 1991

* < 2mm sieve for sediment-P analysis; all other studies used < 0.63 *um* sieve.

Illinois River study, giving credibility to data accuracy. However, such statistical accuracy is also dependent upon site-specific watershed variables that can vary greatly from one watershed to the next.

Sediment Composition Influences

Sediment composition can largely influence the variability of sediment-P throughout a watershed and it must be isolated so other effects, such as land use, can be detected. Sand and OM percentages were used to assess the depositional environment and adsorption capacities; Fe and Mn were used to assess secondary oxidation of soil-P; Al was used as a clay indicator; and Ca was used to detect apatite mineral-P.

Sand Content

The channel sediments of the Kings Basin are relatively sandy with the exception of a few tributaries (Figures 5.4 and 5.5). Sand content ranged from 21-99 % with a median of 85 % and a mean of 95 %. Streambed sample sites 1-84 were predominately sandy with 90% average sand content, but sites 85-91 on Bee and Clabber creeks were considerably less sandy with 22 % mean sand content. In general, Dry Fork, Piney, and Sweden creek sites had high sand percentages, while Bee, Clabber, Osage, and Pine creek sites had low sand percentages. The majority of the main stem sample sites fell in the highest category 96-99 % and the tributary sites contained slightly less sand content (Figures 5.4 and 5.5). Many areas surrounding the main stem sampling sites were underlain by sandstone bedrock units, which provide a major supply of sand to the Kings River (Figure 5.6).

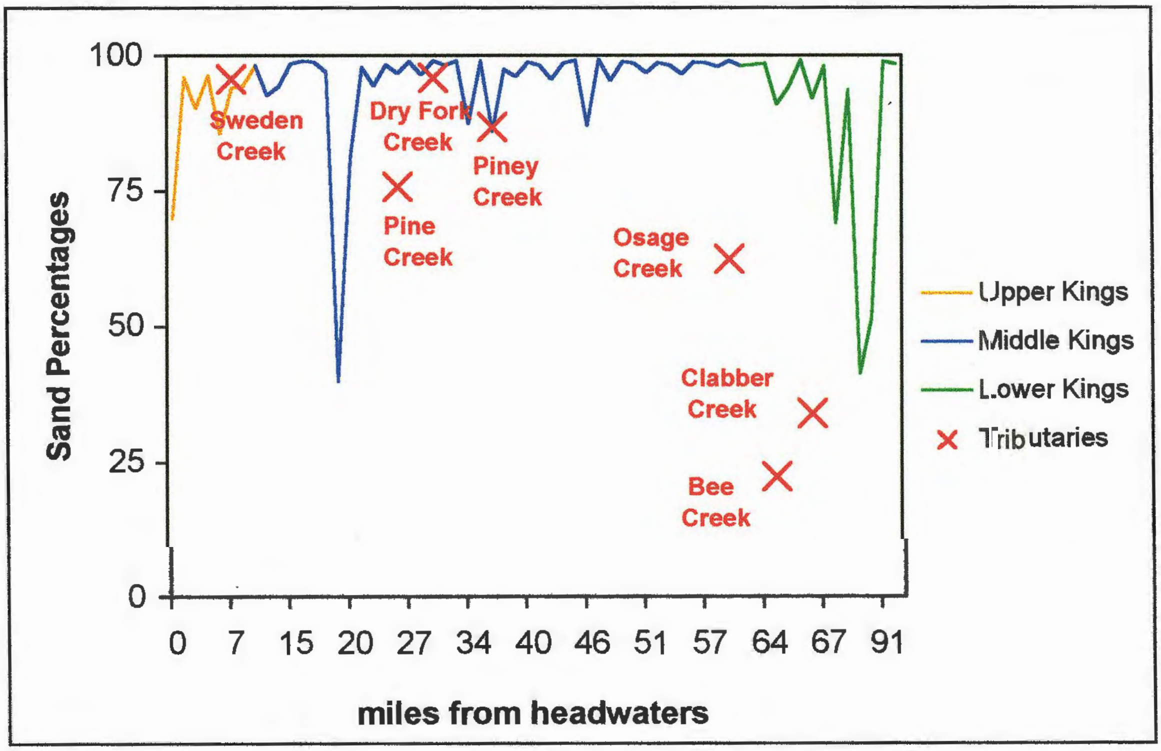


Figure 5.4. Downstream trend of sediment-sand percentages.

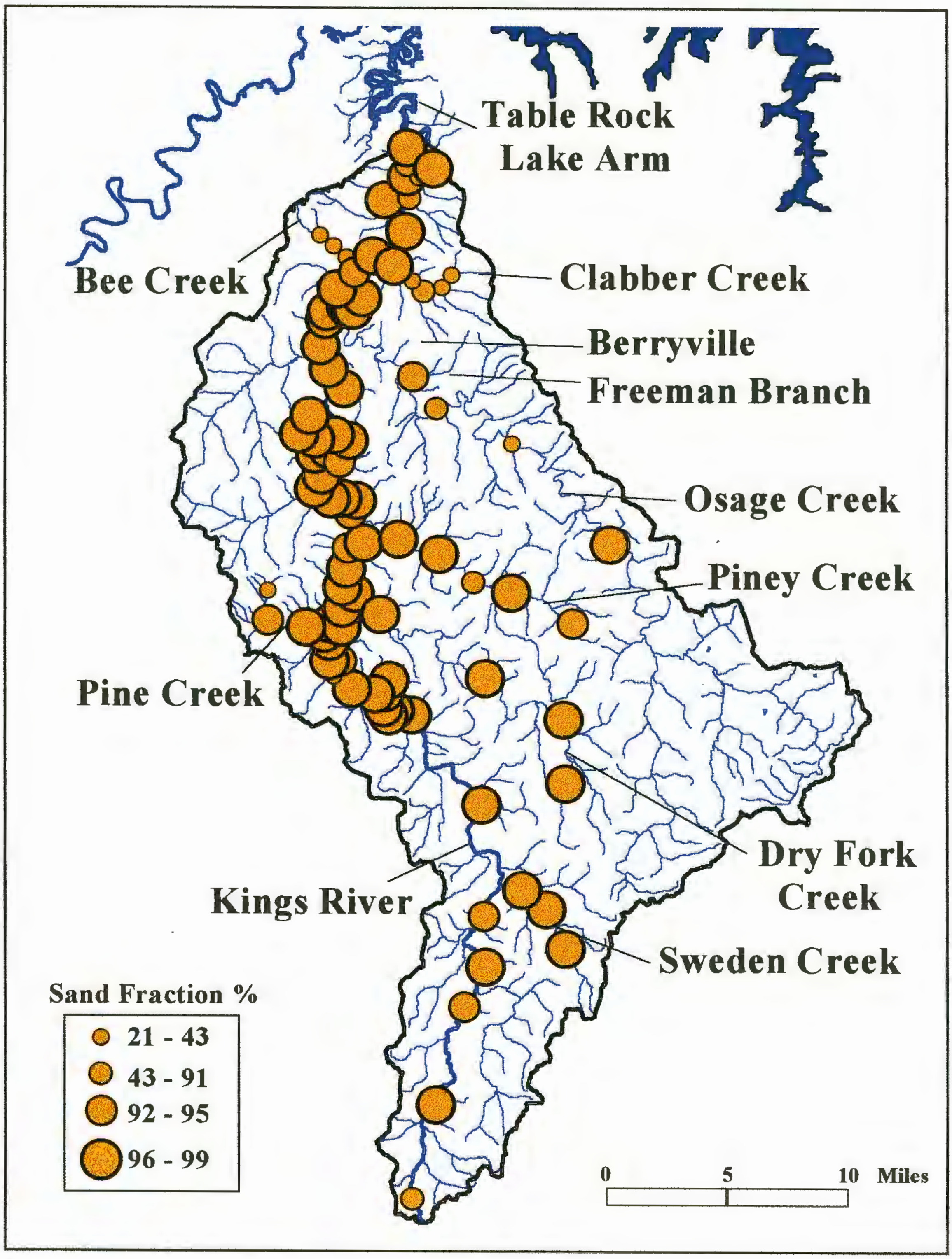


Figure 5.5. Sediment sand variability in the Kings River Basin.

Figure 5.6. Picture of typical sandstone bedrock reach. Taken downstream of site 5 in the Upper Kings.

The effect of geology on sediment texture is more clearly shown by comparisons among the sub-watersheds (Figure 5.7). In the main stem sections, the Middle and Lower Kings had the broadest ranges of variability. Both of these sections are underlain by intermittent sandstone bedrock. In the tributaries, Bee and Sweden creeks had the narrowest variability, but Bee had overall low sand content and Sweden had overall high sand content. Sweden Creek is located in the southern part of the watershed near the sandy Boston Mountain outcrops, while Bee Creek is in the northern part of the watershed near limestone/dolomite outcrops (Figure 3.4).

It was expected that there would be a strong negative relationship between the sand and sediment-P because sand is less likely to adsorb P than finer-grained particles. Indeed, there was a fairly strong negative relationship ($r^2 = 0.63$) and the majority of the samples were clustered in the lower right corner of the graph indicating consistently high sand values and low sediment-P values (Figure 5.8).

Organic Matter Content

Research has shown that nutrients have an affinity for the OM component of sediment (Li et al., 1998; Fox and Kamprath, 1971; Campbell and Racz, 1975), therefore it was expected that there would be a positive relationship between these two variables. It was also expected that the values would be high because of the high percentage of forested land use with organic-rich surface debris in the basin (Figure 3.7). The range was from 0.2-16 % with a mean of 2 % and median of 0.76 %. There are three areas in the Middle Kings where the OM% rose drastically (Figure 5.9) because of high sinuosity

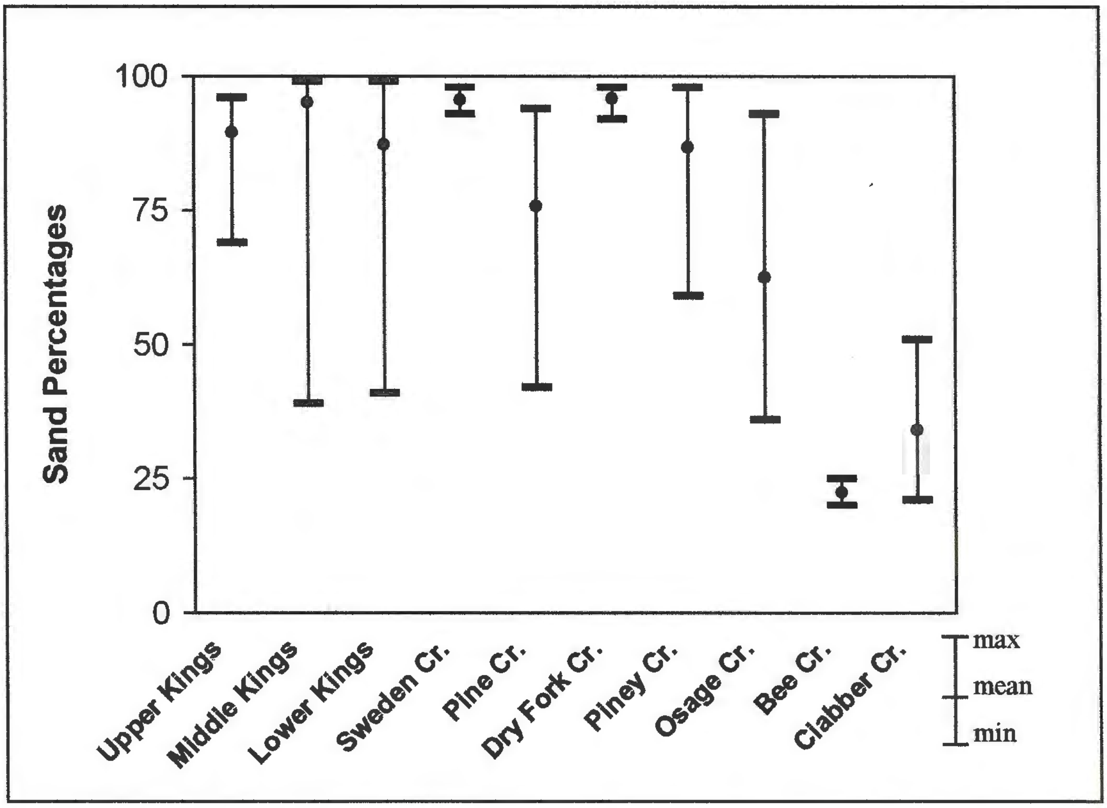


Figure 5.7. Range of sediment-sand percentages.

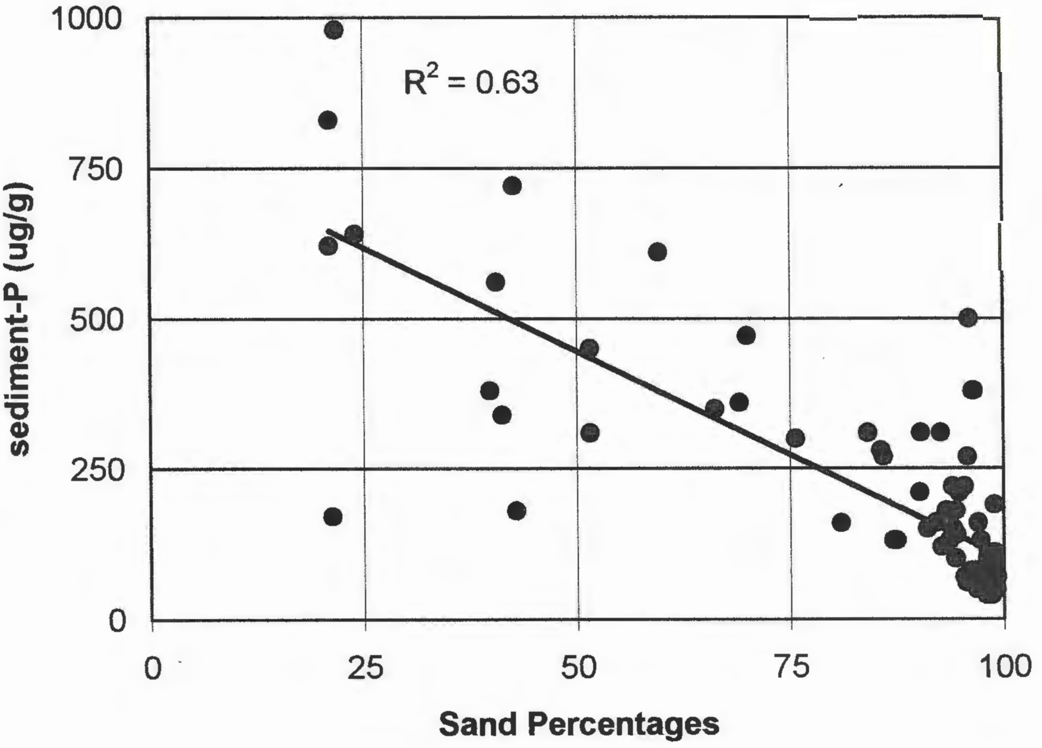


Figure 5.8. Relationship between sediment-P and sediment-sand.

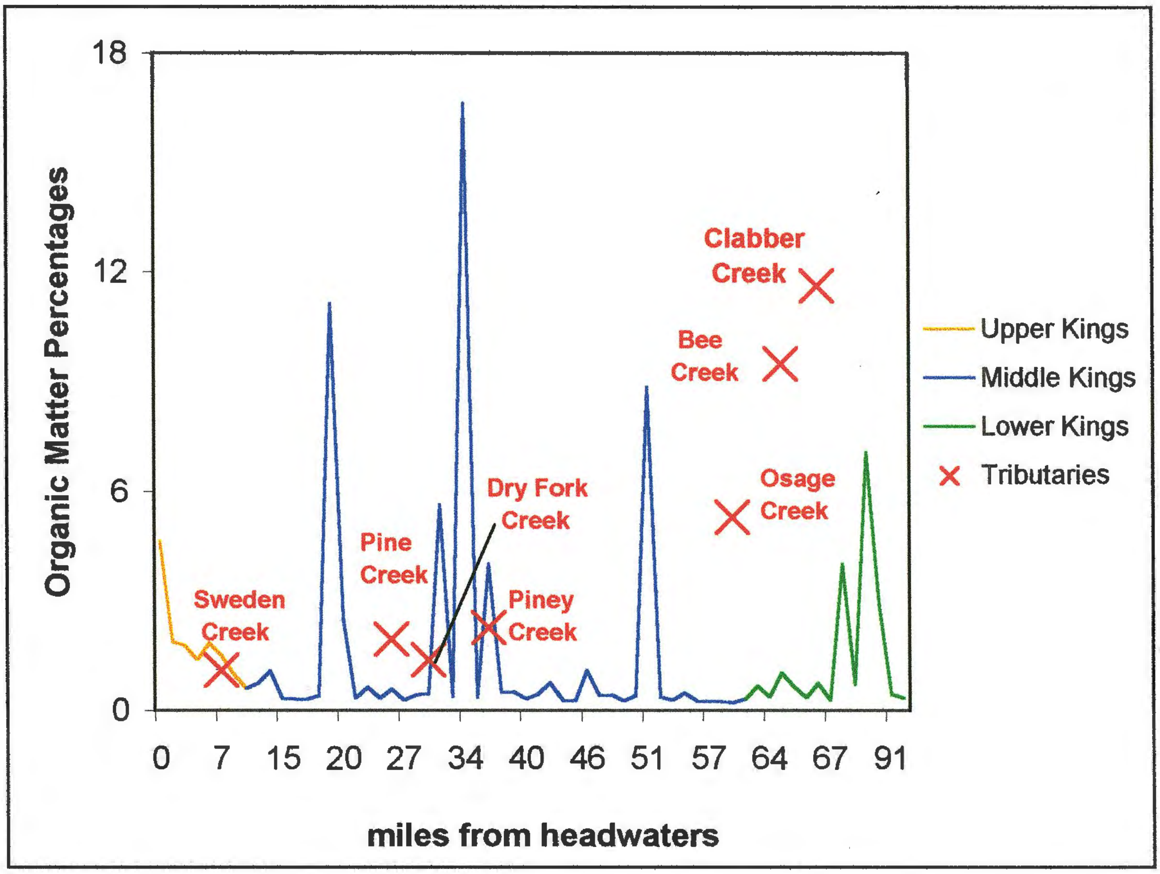


Figure 5.9. Downstream trend of sediment-organic matter percentages.

and low-energy accumulation of organic matter and surface debris. Overall, the values remained fairly low and continuous throughout the entire main stem. At tributary confluences, Clabber, Bee, and Osage creeks revealed the highest mean OM values. These three sub-watersheds have predominate silt/clay sediments (Figure 5.7) and high forested land cover (Figure 3.7), yielding natural organic matter supply. The majority of the sample sites fell in the lowest category 21-43 and the only sites that were in the highest category 96-99 % are the three in the Middle Kings, that were previously mentioned, and a few sites in Bee and Clabber creeks (Figure 5.10). The Middle Kings had the broadest range of mean OM values, which may be explained by the large quantity of samples that were taken in this section (Figure 5.11). Osage Creek had the next broadest range of values, which may be explained by the varying land use in the sub-watershed (Figure 3.7). Also, there is a gradual decrease in OM percentages from the tributaries to the main stem of the Kings. This parallels the increasing fined-grained sediment trend in the same sub-watersheds (Figure 5.7).

As expected, there was a strong relationship between OM and sediment-P in the Kings River (Figure 5.12). There was a positive relationship ($r^2 = 0.74$) between OM and P and a cluster of values in the lower left corner of the graph indicating overall low OM percentages and sediment-P values. Data suggest that the sediment composition variable OM is a good tracer of sediment-P variability throughout the watershed. This is because P is found in high concentrations in OM and can chemically adsorb to high levels on its surfaces.

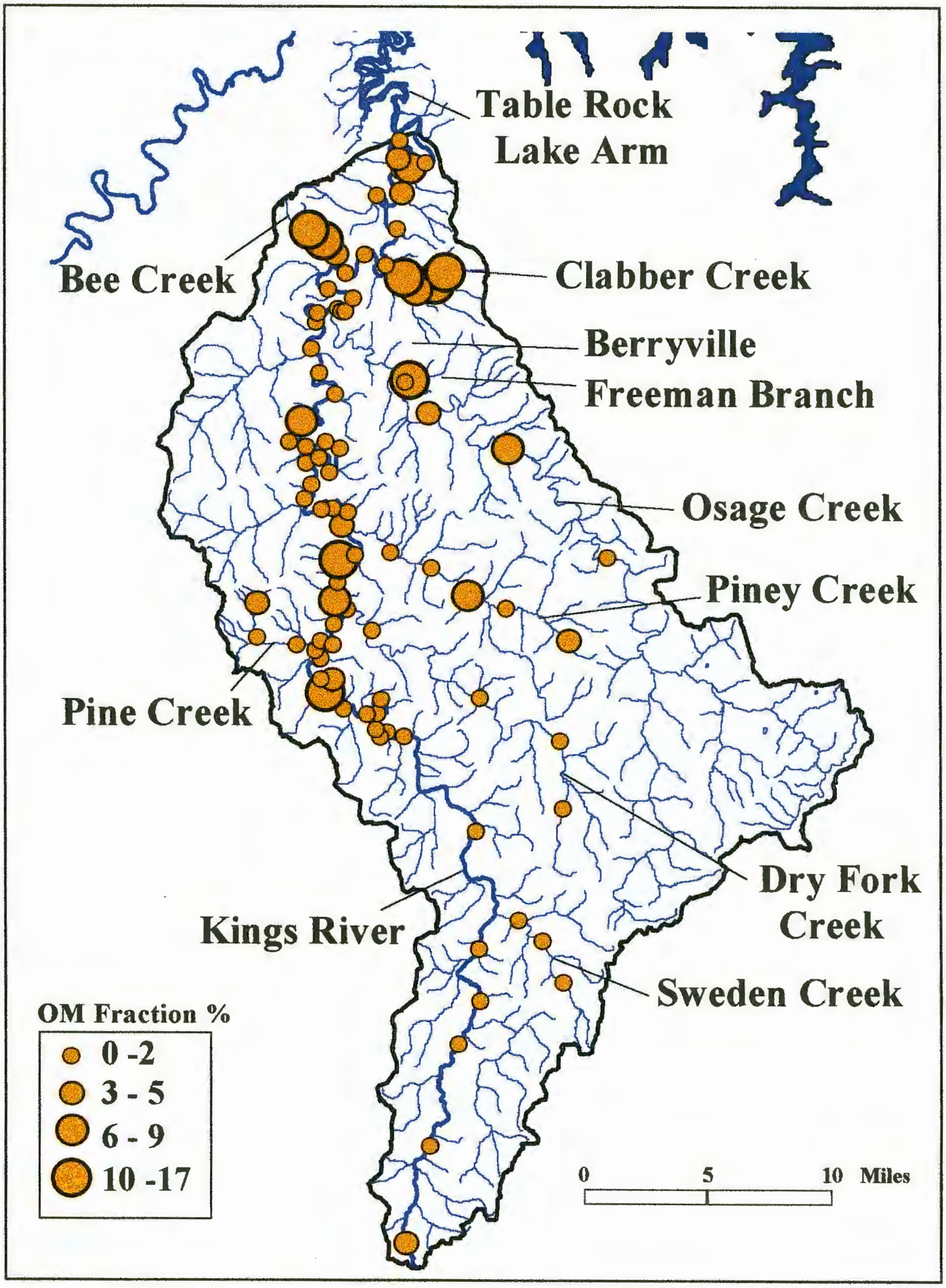


Figure 5.10. Sediment-organic matter variability in the Kings River Basin.

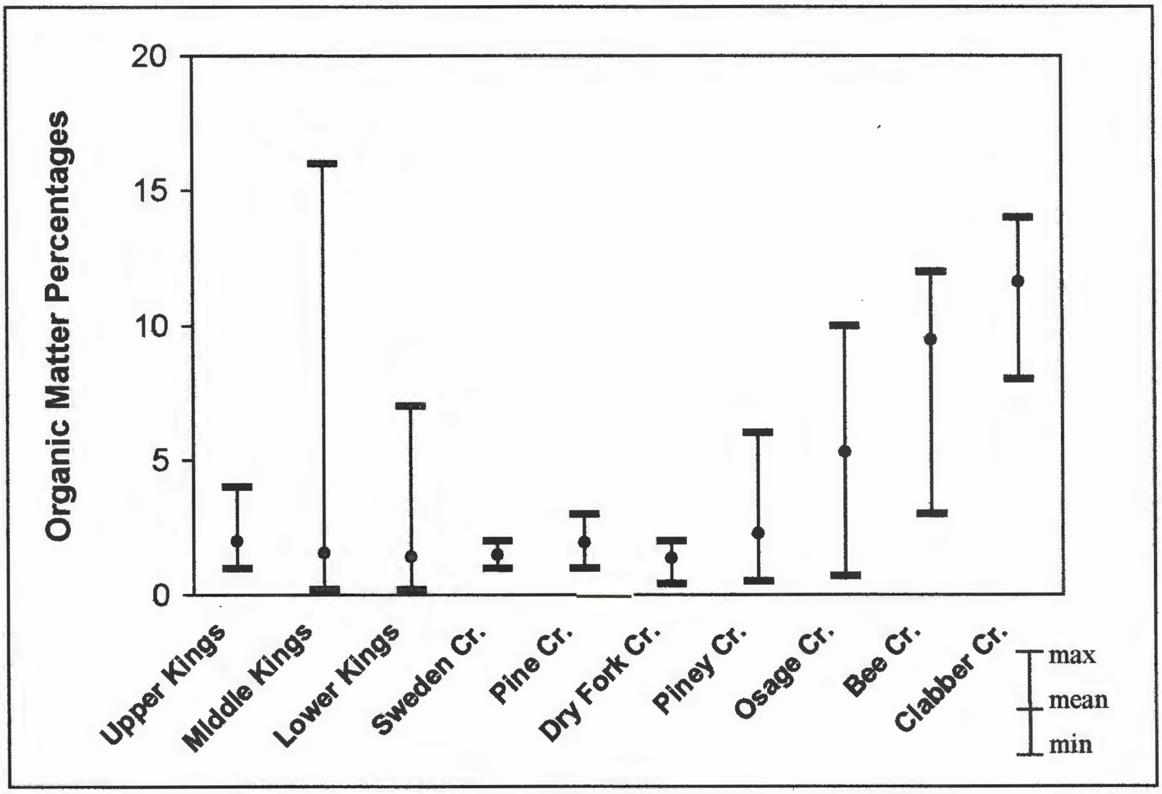


Figure 5.11. Range of sediment-organic matter percentages.

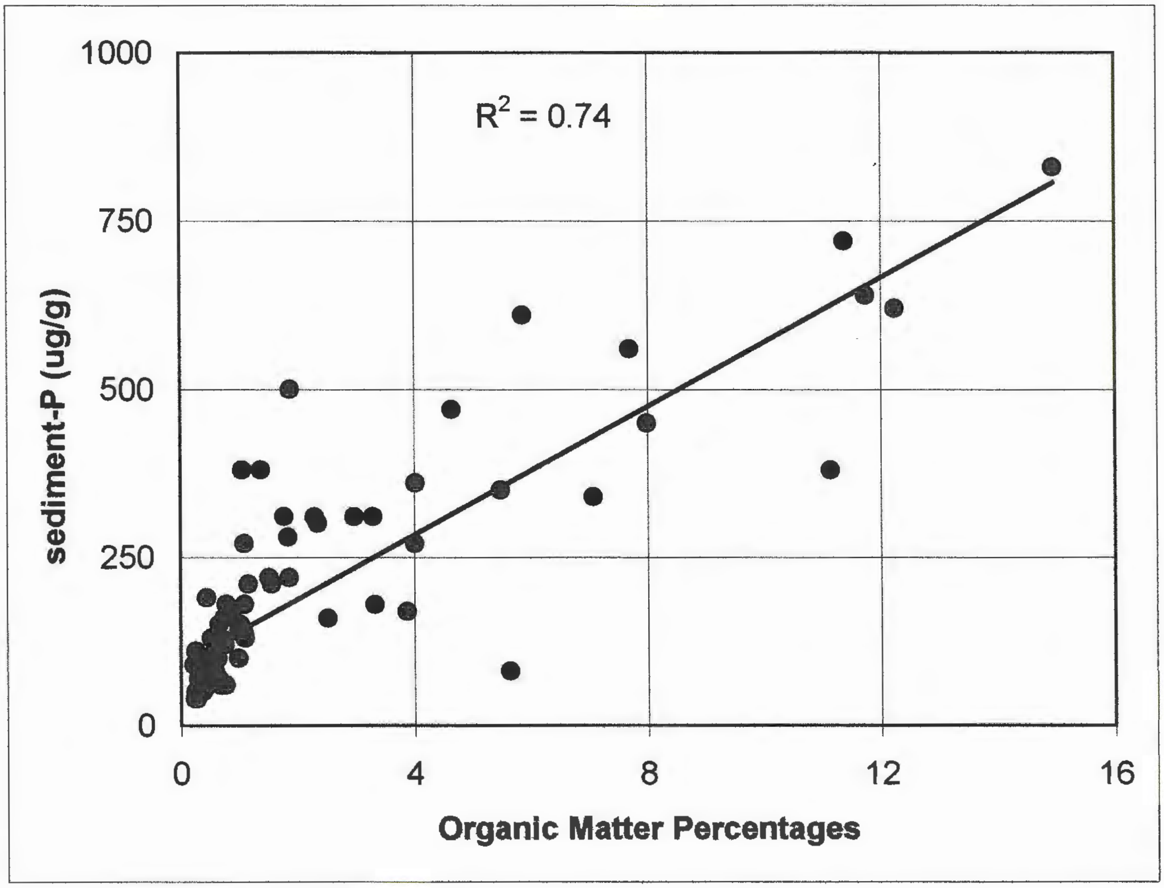


Figure 5.12. Relationship between sediment-P and sediment-organic matter.

Geochemcial Influences

Minerals and trace elements that occur at much smaller concentrations in the environment can also control sediment composition and varying sediment-P concentrations. These are usually referred to as either major or minor trace elements, depending on the reporting level decided upon by researchers. Sediment adsorption is most strongly associated with amorphous or at most short-range ordered secondary hydroxy Fe and Mn coatings (McCallister and Logan, 1978). Elements from the Earth's crust, such as Ca, Al, and P, can occur geologically in parent material that eventually erodes into sediments and overlying soils causing background source mineralization (Dillon and Kirchner, 1975; Grobler and Silberbauer, 1985). Fe, Mn, Al, and Ca were compared with sediment-P concentrations to assess possible background nonpoint source correlations.

Aluminum

Aluminum is an element that is most often found concentrated in finer-grained particles and is used as a tracer when detailed particle size analysis is not performed on a sample set (Horowitz, 1991; Forstner and Witman, 1981). The highest Al concentrations were found at sites 85-91, which also had the lowest sand % (Appendix). As expected, there was a strong negative relationship ($r^2 = 0.82$) between Al and sand, which is characteristic of the sandy sediments (Figure 5.13). Accordingly, sediment-P and Al concentrations exhibited a strong positive relationship ($r^2 = .82$) because of the affinity sediment-P has for fine-grained trace elements such as Al (Figure 5.14).

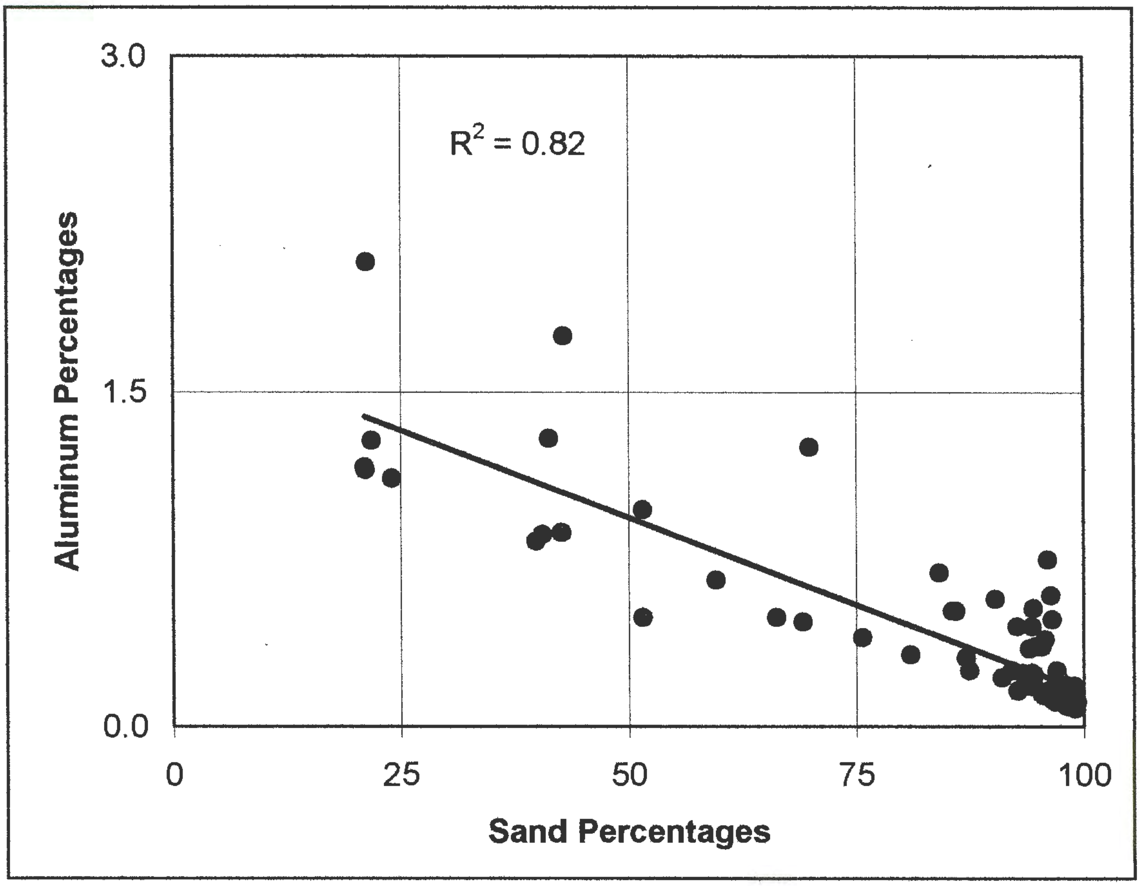


Figure 5.13. Relationship between sediment- sand and sediment-aluminum.

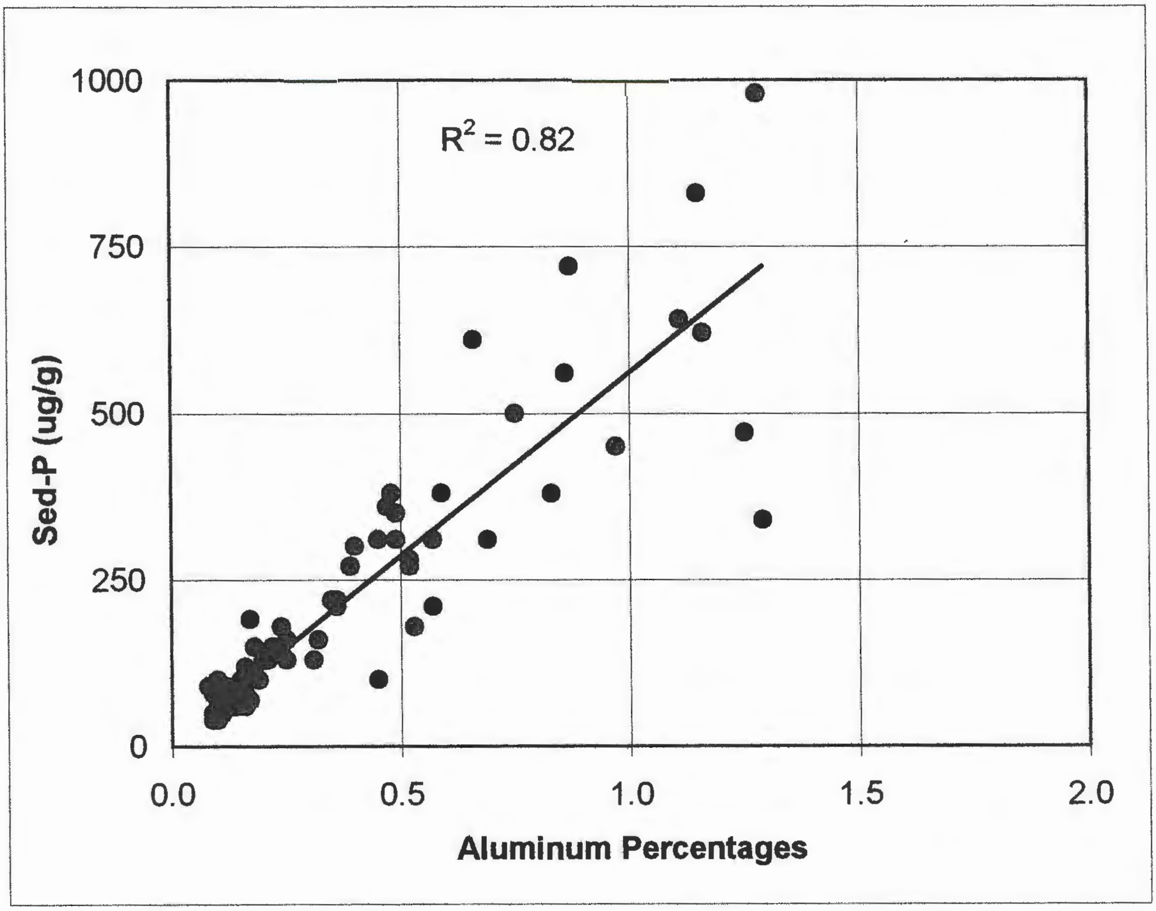


Figure 5.14. Relationship between sediment-P and sediment-aluminum.

Since the sediment composition variables of sand and OM proved to be strong indicators of sediment-P variability, it was apparent that these influences must be isolated in order to see how much sediment-P was actually related to the finer-grained particles detected by Al. Therefore, a P:Al ratio was used to look for this relationship (Figure 5.15). A high ratio indicates that excess P is present in relation to the abundance of Al and this enrichment is due to factors other than sorption capacity, such as mineralology and anthropogenic sources. Al (reported in percentages) was divided by P (reported in *ug*/g), so the Al:P ratio is not an exact ratio with even units, but rather a representation of the Al fraction of the total sediment sample. Phosphorus:Aluminum ratios served as good indicators of nonpoint sources by distinguishing between geology sources and pollution intensity (Figure 5.15). The Upper Kings exhibited high P:Al ratios because of the shale rock units (similarity with Table 2.1); the Middle Kings exhibited decreasing medium to low P:Al ratios as a function of sample quantity, dilution, and dolomite rock units; and the Lower Kings exhibited the highest P:Al ratios due to the wastewater treatment plant's loading into Osage Creek.

Iron and Manganese

The next elements used to further describe possible background sources were Fe and Mn. In the literature, Mn and Fe are usually discussed together as functions of soil redox potential, which is beyond the scope of this study. It is interesting to note that high concentrations of Mn and Fe are often in the black and orange stains, respectively, that are seen coating bedrock bluff faces along Ozarks streams. Therefore, these two

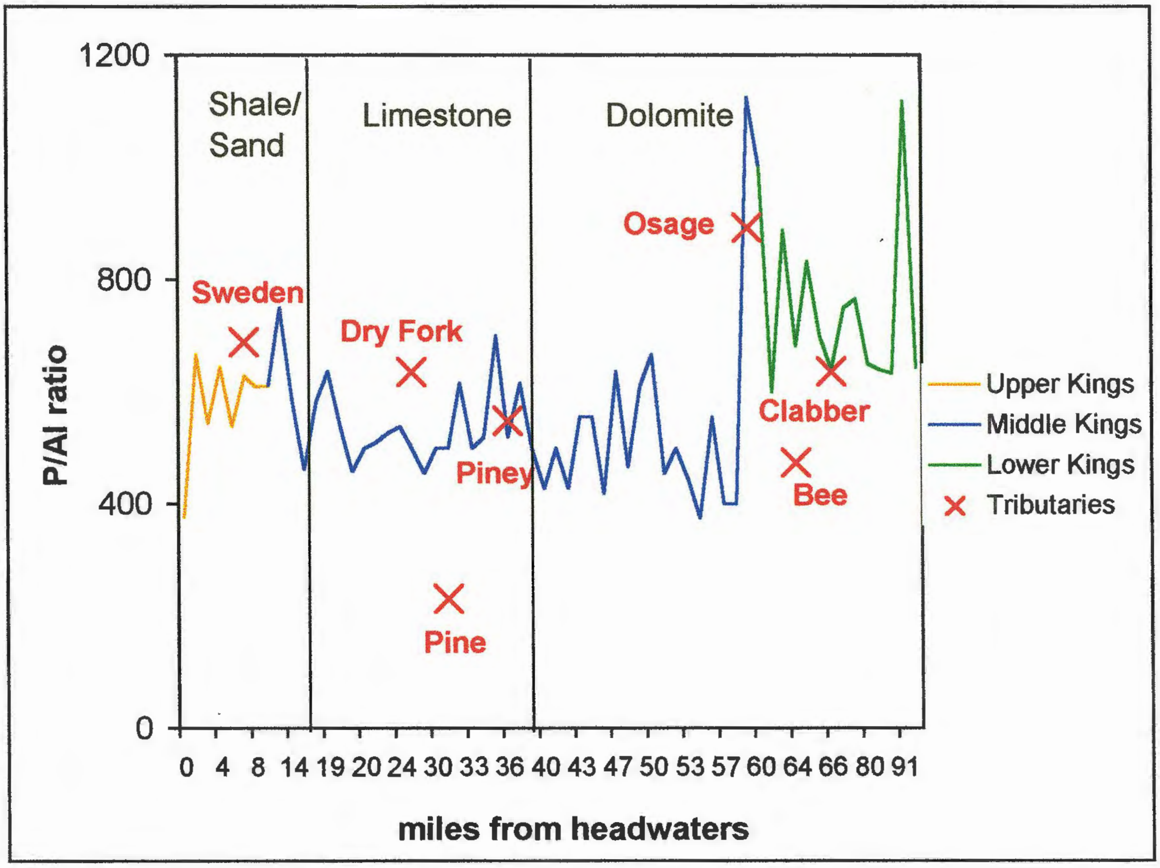


Figure 5.15. Downstream trend of Phosphorus:Aluminum ratios.

elements are directly associated with geology and groundwater processes in the basin and their trends may help explain sediment-P concentration trends. The highest Fe percentages were found at sites 1-5 (2-6%) surrounded by high shale content, forested land cover and little anthropogenic activity. The reference soil sample collected near these sites had a similar Fe concentration (Table 5.1), revealing high background Fe, as a component of shale, in this part of the river system. The highest Mn concentrations were also found at sites 1-5 (440-2,240 ppm) surrounded by shale, forested land cover, and minimal anthropogenic activity. Also, high levels were detected at sites in Osage, Bee, and Clabber creeks (Appendix B).

Sediment-P and Fe concentrations had an overall weak positive relationship (Figure 5.16). However, the data values flare from the trend line in separate linear patterns indicating better relationships in the Upper Kings and the tributaries. Because Fe was poorly correlated with sediment-P, it was expected that Mn would be as well. There was a moderately strong positive relationship between Mn and P (r^2 value 0.65), suggesting that Mn may be a better tracer for sediment-P than Fe (Figure 5.17). There was a moderately strong positive relationship (r^2 value 0.58) between Mn and Fe, suggesting their geochemical similarities in background sources within the watershed (Figure 5.18). Furthermore, the downstream trends of Fe and Mn show high concentrations in the shale/sandtone units confirming the background sources of geochemical constituents (Figures 5.19 and 5.20).

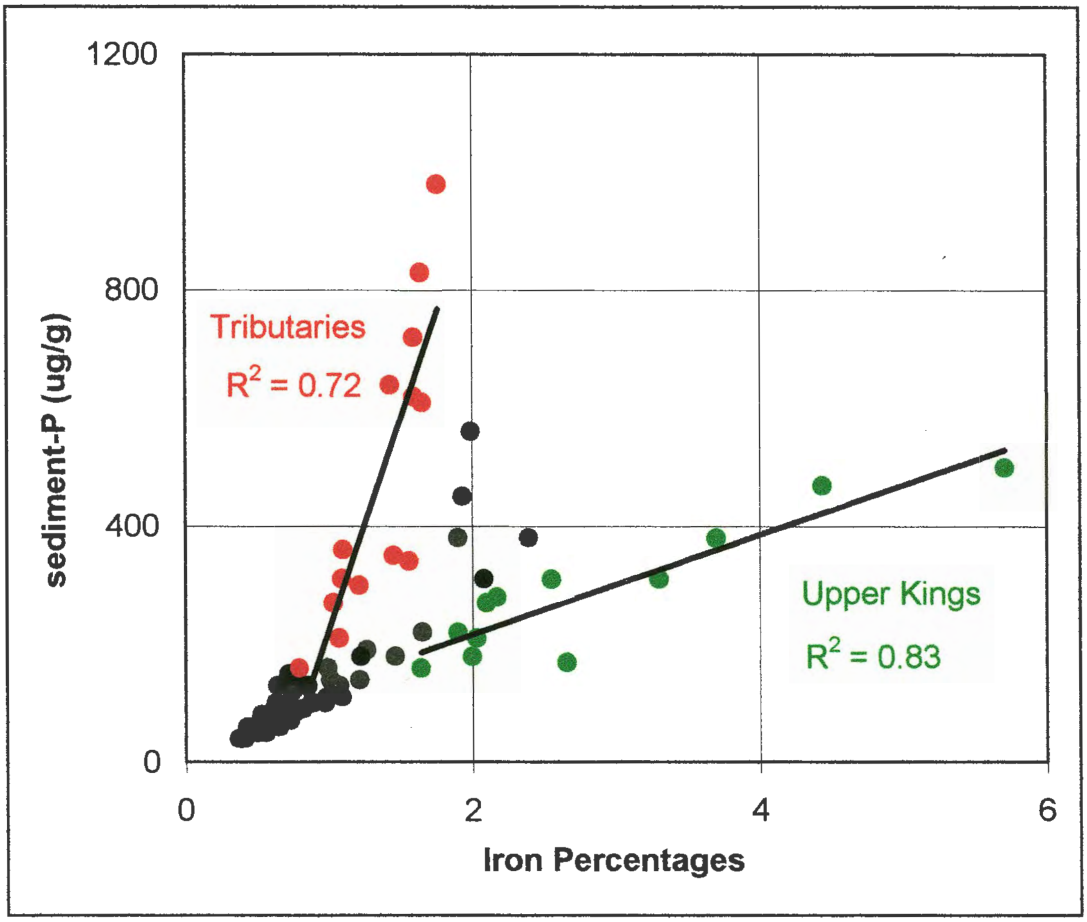


Figure 5.16. Relationship between sediment-P and sediment-iron.

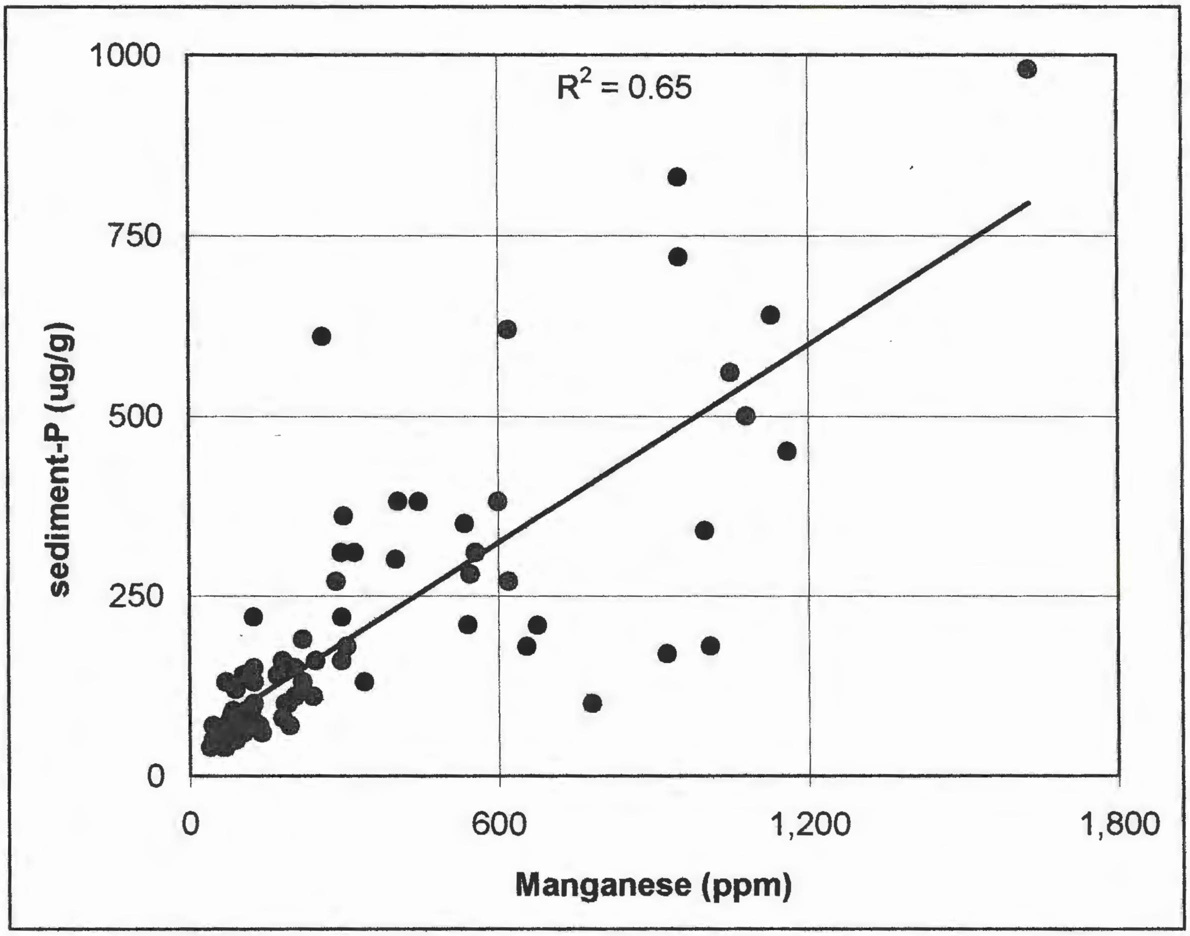


Figure 5.17. Relationship between sediment-P and sediment-manganese.

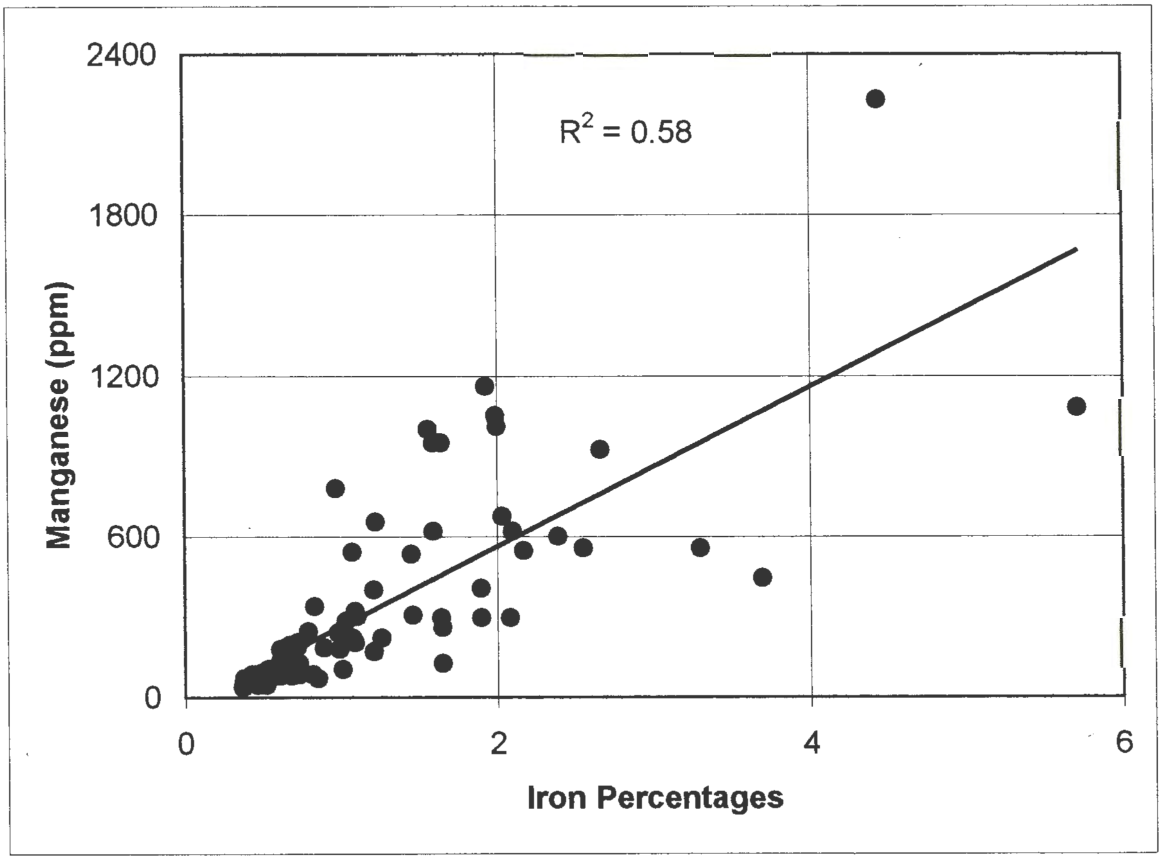


Figure 5.18. Relationship between sediment-iron and sediment-manganese.

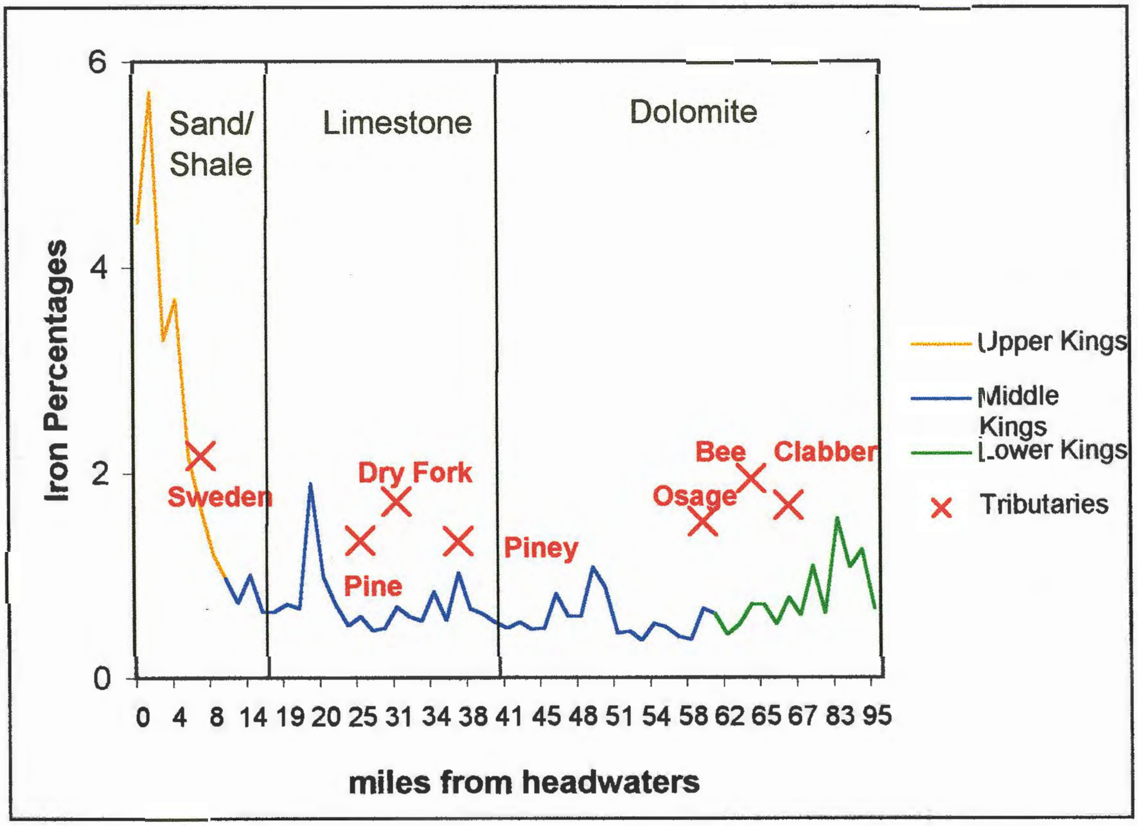


Figure 5.19. Downstream trend of sediment-iron.

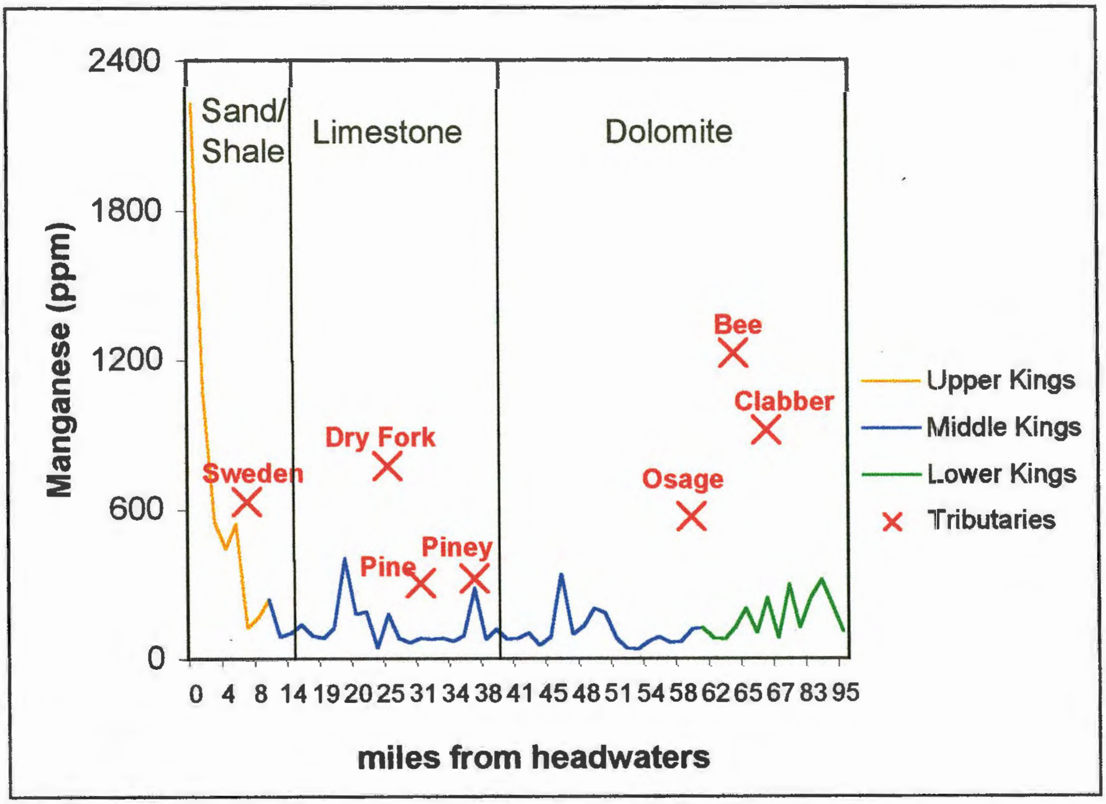


Figure 5.20. Downstream trend of sediment-manganese.

Calcium

The last background element, Ca, was used to further assess downstream geochemical and sediment-P trends. It was expected that the Ca concentrations would be higher in the Lower Kings reach because of the underlying limestone/dolomite geology that can harbor high levels of natural calcium carbonate (Tarbuck and Lutgens, 1993) (Figure 3.4). This is important to know because calcium carbonate is very soft and susceptible to karst formation, which stimulates the rapid loss of polluted surface water into sub-surface groundwater channels (Tarbuck and Lutgens, 1993). With respect to the larger water cycle, this polluted groundwater will eventually resurface in streams and rivers adding to the already extensive number of nonpoint sources in the Kings River. The lowest Ca percentages were in the sand/shale section and the highest percentages were found in the dolomite section (Figure 5.21). This finding parallels an Ozarks study that found elevated Ca concentrations in dolomite tailings from historical mining practices (Steele, 1985). There is a definite increase at the Bee Creek confluence and the trend increases at an increasing rate below Bee. Without further rock and soil analysis in that area, assumptions cannot be made about whether or not the increasing trend is a result of geology or even the land use from Osage Creek. When Ca was compared with sediment-P concentrations (Figure 5.22) there was a moderately strong positive relationship (r^2value 0.65) between the two variables, suggesting that with further analysis of watershed geology, Ca could be used as a tracer for areas with elevated sediment-P concentrations.

In summary, it was found that geochemical constituents, such as Al, Fe, Mn, and

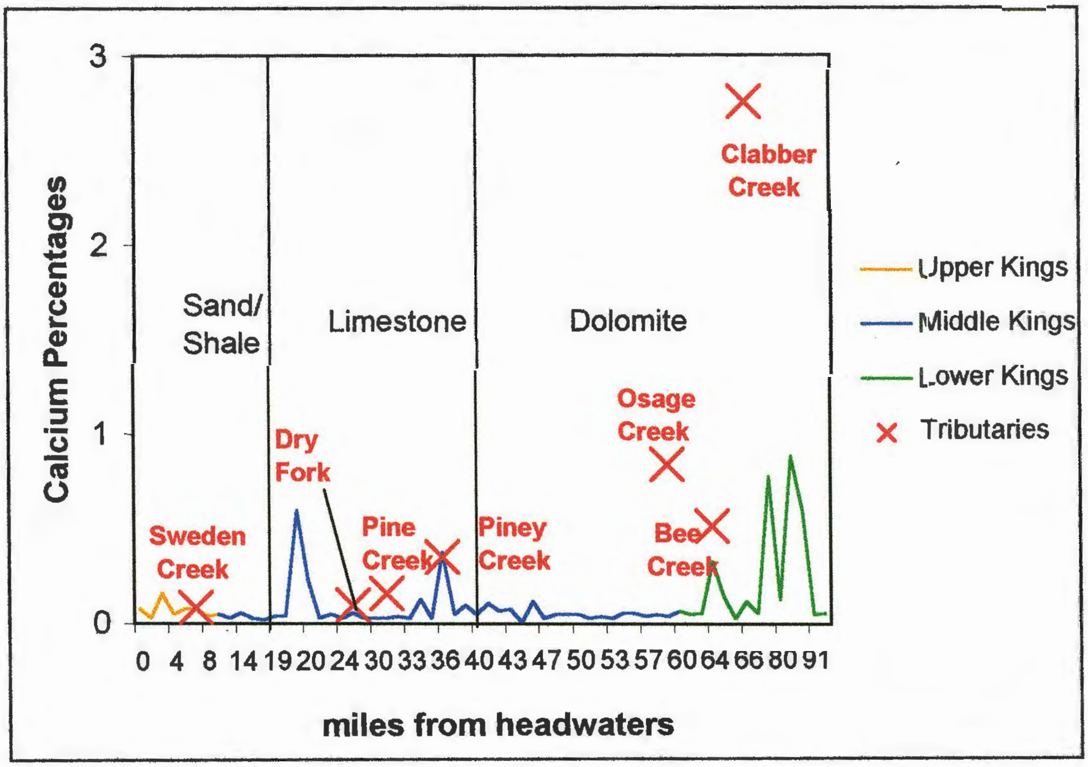


Figure 5.21. Downstream trend of sediment-calcium.

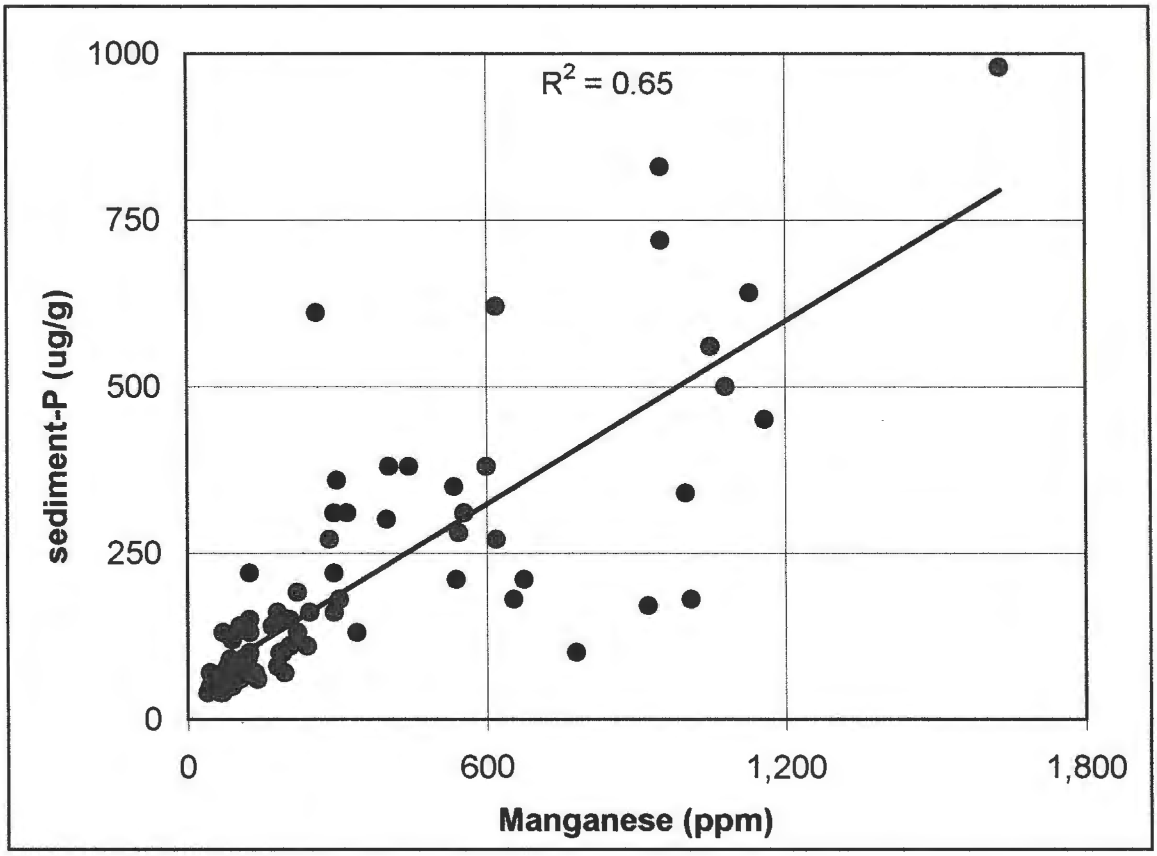


Figure 5.22. Relationship between sediment-P and sediment-calcium.

Ca, could be used to assess sediment-P trends. A P:Al ratio detected high P levels in relation to Al in the Upper and Lower Kings. High Fe and Mn concentrations were detected in the shale/sandstone rock units of the Upper Kings and both minerals were correlated with sediment-P concentrations. High Ca percentages were detected in the Lower Kings where limestone/dolomite bedrock may be producing carbonate-rich sediment. Therefore, data suggest that background sources of P do exist in the Kings Basin and geochemical minerals do affect the intensity and geography of NPS pollution.

Land Use Influences

Once sediment composition variables and their effects were isolated, it was easier to assess relationships between nonpoint sources and land uses. The three main land uses assessed in this study (% forested, % agriculture, and % urban) were compared with sediment-P concentrations to assess watershed-scale trends. In addition to agricultural assessment, the poultry index was evaluated to find the actual influence from poultry land use.

Agriculture

First, sediment-P was plotted against the percentage of agriculture upstream from each sampling location (Figure 5.23). As expected, there existed a positive relationship between P and % agriculture. The relationship was not too strong, which may be explained by the fact that background sources and sediment composition can mask relationships at the sub-watershed-scale.

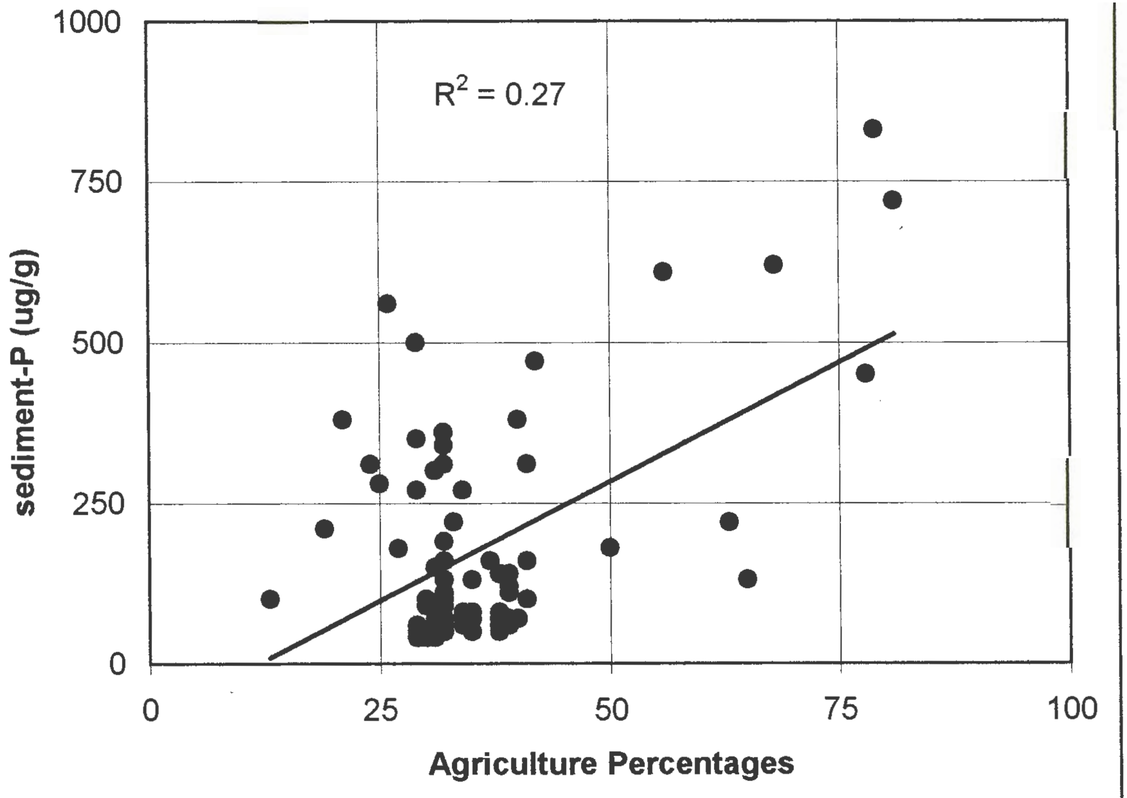


Figure 5.23. Relationship between sediment-P and agricultural land use.

It may appear odd that a watershed with 472 chicken houses has so much forested land. However, chicken houses on relatively small tracts can be placed just about anywhere with little land or maintenance required. For the most part, however, chicken houses are found on large, open tracts of agricultural land that has been previously used for open grazing or row crop production. The houses serve as sound structures that represent possible re-application of chicken fertilizer on nearby fields.

Taking the above comments into consideration, it was necessary to assess just how much the chicken houses were affecting NPS loadings in the watershed. The poultry index (# of upstream poultry houses/drainage area), which was described earlier in the study, was compared with sediment-P concentrations. The raw PI index value was multiplied by ten and the resulting score was placed into one of three risk categories: low risk (0-5), medium risk (6-20), high risk (21-48). Piney and Clabber creeks had the highest risk values because of the high density of poultry houses in relatively small drainage areas (Figure 5.24). Both creeks had the highest mean agriculture percentages in the watershed, which indicates the close association between poultry houses and other forms of agriculture, mainly cattle pasture in the Kings Basin. The highest index value (9.8) was at site 75 in the Piney Creek sub-watershed. This value suggests that, relative to its drainage area, the sub-watershed directly above site 75 is at most risk of nonpoint P from broiler houses. However, its sediment-P concentration was 310 *ug*/g, which is relatively low compared to other sediment-P values (Appendix B).

This is a good example that the PI is only a risk assessment and connecting

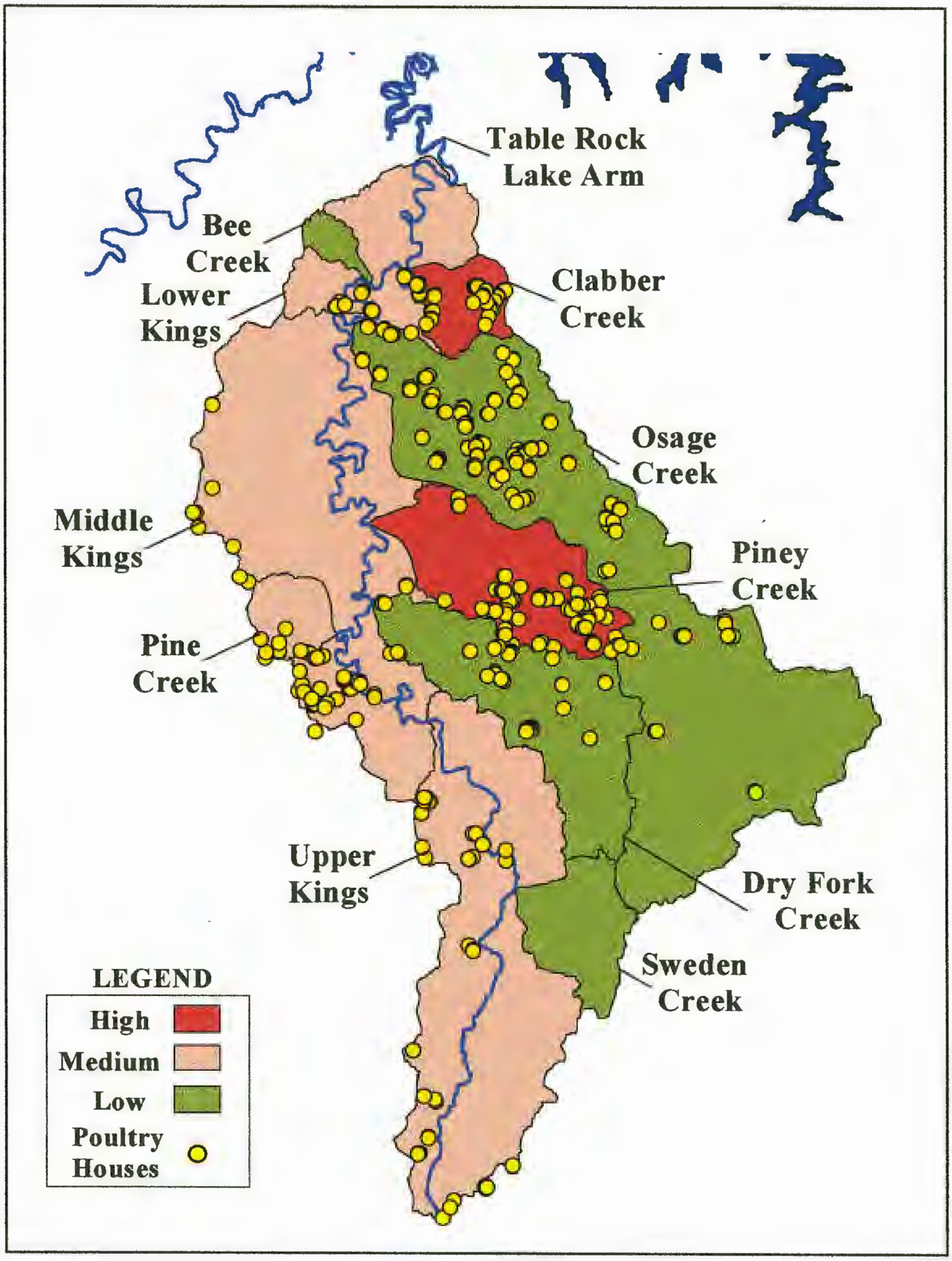


Figure 5.24. Poultry index risk categorization.

nonpoint sources with one particular area of chicken houses is impossible to do without further field-scale analysis. There are other factors that could have caused the value at site 75 to be somewhat low, including background sources of P, low chicken occupancy in the houses, or variations in P-rich broiler waste application on upstream fields. The highest P concentration (1280 ug/g) was associated with the lowest index value (0.0) because this

site's drainage area was void of broiler houses and dominated by Berryville's wastewater treatment plant.

Forested

It was expected that there would be a strong negative relationship between sediment-P and percent forested land use because of the high percentage of forested land use in the Kings River Basin (Figure 3.6) and the pristine conditions that are most often found in these areas. As expected, there existed a weak negative relationship between forested % and P (Figure 5.25). Although weak, the relationship reveals that forested areas are at less risk of elevated sediment-P concentrations than agricultural areas, and variability can be affected by background sources and sediment composition.

Urban

The plot comparing urban land use percentages and sediment-P concentrations was removed because the 0.1 % overall urban land use was not enough to see spatial relationships. Instead, the five sites on Osage Creek and the sites immediately above and below the Kings River confluence were graphed with their corresponding sediment-P

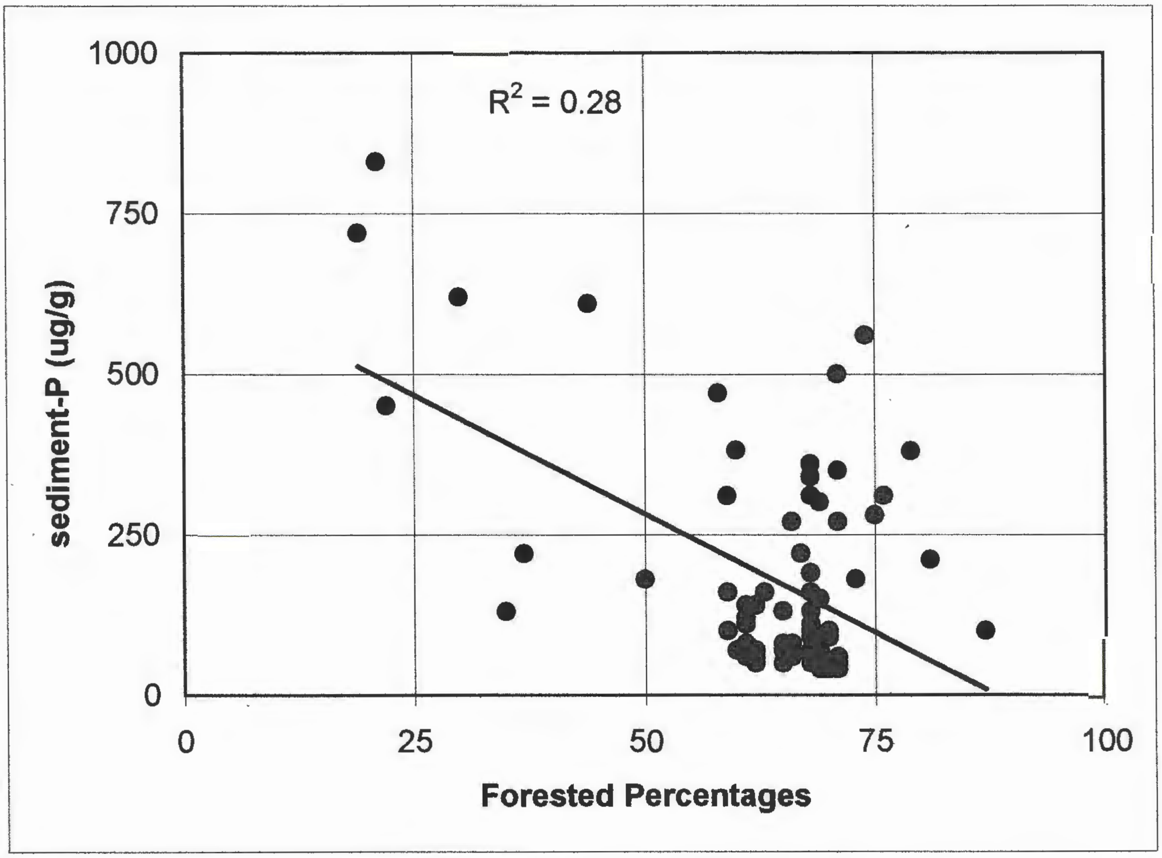


Figure 5.25. Relationship between sediment-P and forested land use.

concentrations (Figure 5.26). The highest sediment-P concentration in the watershed (1,280 *ug*/g) was detected nine miles upstream of the Kings River where Freeman Branch drains the Berryville wastewater treatment plant. The concentration at site 84 just downstream of Freeman Branch on Osage Creek is considerably lower suggesting the P is moved rapidly downstream to lower-energy areas. However, the continuous loading from this treatment plant is apparent further downstream of Osage Creek on the Kings River where the P levels are higher than they are above the Osage confluence (Figure 5.2). Data suggest that there is not enough urban land use in the watershed to make assumptions about relationships with sediment-P, however the only wastewater treatment plant at the City of Berryville did to prove to be the largest and most continuous source of sediment-P pollution in the watershed (Figure 5.26).

Relationship with Sediment-P

Land use percentages had good relationships with P concentrations (Figure 5.27). The P:Al ratio was used instead of the raw sediment-P values because the ratio is a better representation of possible nonpoint P sources by minimizing other sediment composition variables. The Upper and Middle Kings had four similar trends: predominate forested land use, some of the lowest agricultural land use in the watershed, a low to moderate potential for fine-grained sediment-P, and a low risk of being affected by broiler waste fertilization. The Lower Kings was slightly different with the second highest risk of fine-grained sediment-P, an average percentage of forested land use, and a low risk broiler waste fertilization.

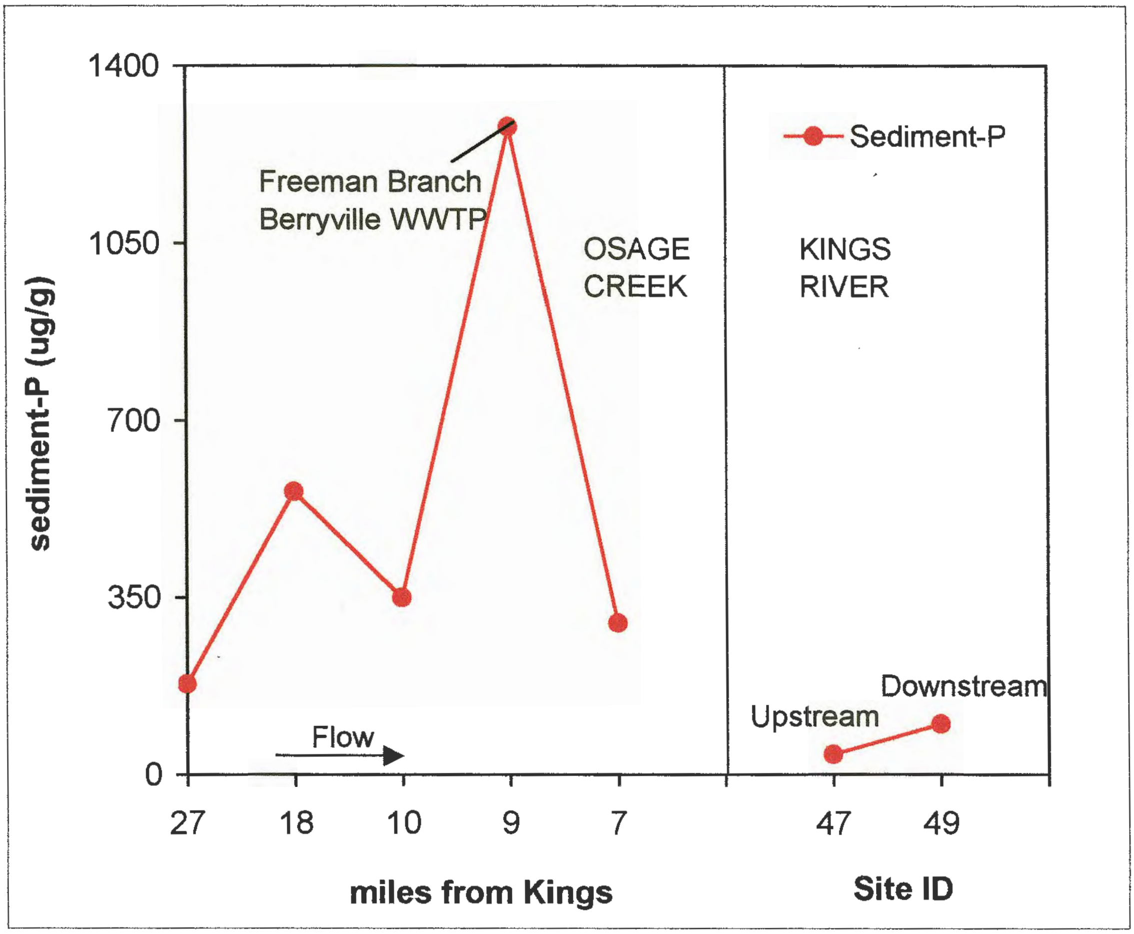


Figure 5.26. Sediment-P concentrations below Berryville wastewater plant.

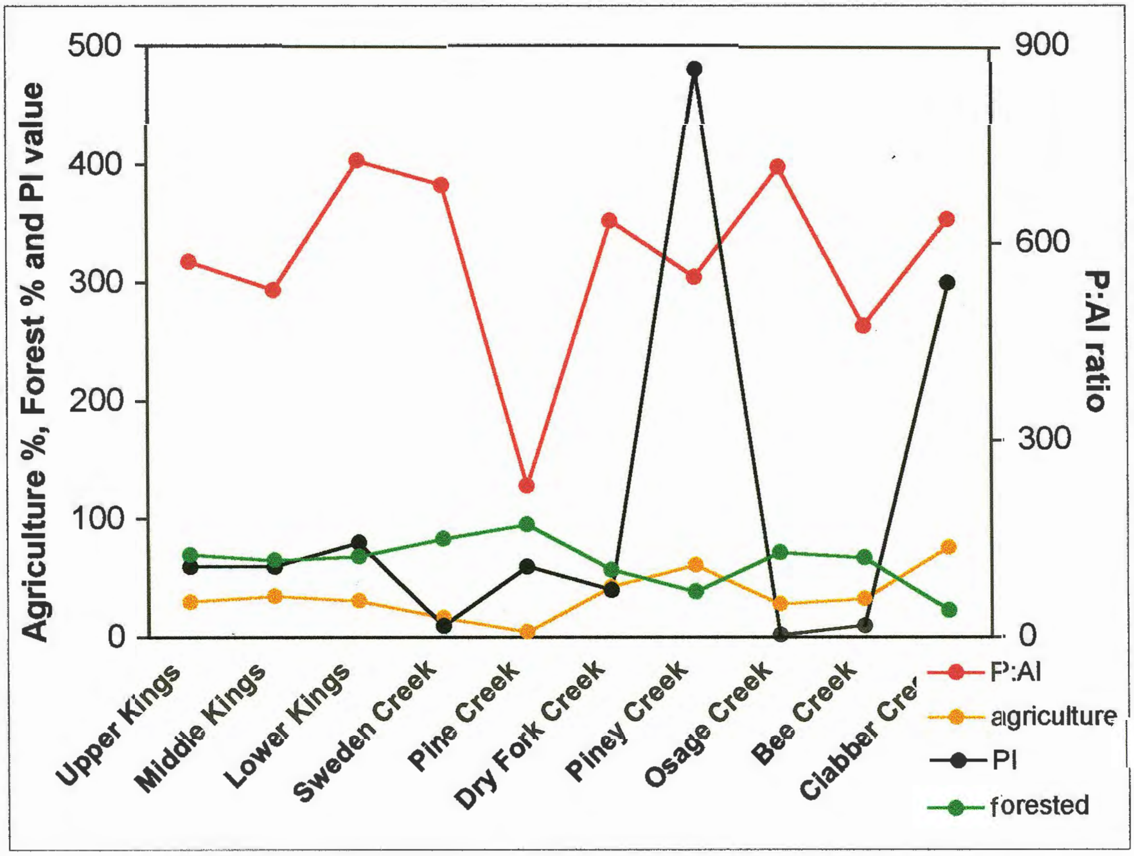


Figure 5.27. Relationship between P:Al ratios and varying land use.

The downstream trends of P:Al for all seven tributaries were "flashy," rising and falling abruptly. Sweden Creek had some of the most forested land use, the lowest risk of broiler waste fertilization, and a moderately high risk of sediment-P. Pine Creek showed to be the most pristine tributary sub-watershed in the basin with the lowest percentages of agricultural land use, the highest amount of forested land use, and the lowest risk of fine-grained sediment-P. Dry Fork Creek had fairly moderate values for all four variables and Piney Creek showed to be the most at risk sub-watershed in the basin with the second highest percentage of agriculture, a moderate risk of fine-grained sediment-P, and the highest poultry index risk. Bee and Clabber creeks were both at high risk of fine-grained sediment-P and Clabber Creek has the second highest PI value, as shown by the density of poultry houses in the drainage area (Figure 5.24).

In summary, connecting land use characteristics with sediment-P trends at the watershed and sub-watershed scale is difficult because of the scale of measurement, problems and lags in source effects and sediment transport/deposition. As expected, forested areas were found to have the lowest sediment-P values, while agricultural areas with high densities of broiler houses were found to have the highest sediment-P values and at greatest risk of NPS sediment-P release due to re-application of broiler waste as fertilizer.

Spatial Model

Spatial modeling is an important step in watershed data analysis because rankings and combinations of influences can be orderly assessed. Secondly, background sources and sediment composition effects can be differentiated from land use sources to gain a better understanding of overall nonpoint P sources. Regression analysis, a component of spatial modeling, allows for the determination of relationships among specific variables. By eliminating variables with weak correlation, the variables that best describe the dataset can be detected and used to develop a "best-fit" regression model.

Pearson Correlation

Several variables were entered into a data matrix for comparative statistical analysis (Table 5.3). The top value in each box is the r^2 value, the middle value is the significance value that reveals the possibility of exceeding that particular value at the 0.01 or 0.05 significance levels, and the bottom value represents the number of samples used in the data matrix (87 samples remained after removing extreme outliers that were discussed previously). Overall, there was good autocorrelation among the variables. Some key findings include the good relationship between sediment-P and OM, Sand, Fe, Mn, Al, and Ca. Second, PI was positively correlated with % agriculture and negatively correlated with % forested. Third, OM was weakly correlated with % agriculture and negatively correlated with % sand. Fourth, Mn was strongly correlated with Fe and Al (Table 5.3). These findings parallel single variable regression results that showed strong influences from sediment composition (Figures 14-22), sediment geochemistry (Figures 23-32), and varying land use (Figures 33-37).

Table 5.3. Pearson mulitvariate correlation matrix.

Correlations

		SED_P	AG	PI	FOREST	URBAN	PSLI	S_STONE	SHALE	LIME	DOLO	SAND	OM	FE	MN	CA	AL	P:Al
SED_P	Pearson Correlation	1.000	.143	.23*	-.145	.237*	.012	.037	-.538**	.221*	.631**	-.795**	.745**	.596**	.759**	.723**	.718**	.216*
	Sig. (2-tailed)	.	.187	.03	.180	.027	.914	.737	.000	.040	.000	.000	.000	.000	.000	.000	.000	.045
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
AG	Pearson Correlation	.143	1.000	.63**	-1.000**	.205	-.067	-.240*	-.315**	.047	.527**	-.243*	.218*	.088	.022	.474**	.216*	-.06
	Sig. (2-tailed)	.187	.	.00	.000	.056	.539	.025	.003	.668	.000	.024	.042	.417	.840	.000	.044	.557
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
PI	Pearson Correlation	.230*	.634**	1.0	-.634**	.181	-.019	.097	-.552**	.467**	.358**	-.147	.186	.088	.076	.361**	.145	-.02
	Sig. (2-tailed)	.032	.000	.	.000	.094	.864	.374	.000	.000	.001	.174	.085	.420	.484	.001	.181	.850
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
FOREST	Pearson Correlation	-.145	-1.00**	-.6**	1.000	-.217*	.067	.240*	.316**	-.045	-.531**	.246*	-.221*	-.088	-.02	-.48**	-.218*	.064
	Sig. (2-tailed)	.180	.000	.00	.	.043	.537	.025	.003	.677	.000	.022	.040	.417	.836	.000	.042	.554
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
URBAN	Pearson Correlation	.237*	.205	.18	-.217*	1.000	-.027	-.045	-.231*	-.064	.467**	-.317**	.285**	.048	.076	.420**	.217*	-.03
	Sig. (2-tailed)	.027	.056	.09	.043	.	.804	.676	.031	.556	.000	.003	.007	.658	.482	.000	.044	.786
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
PSLI	Pearson Correlation	.012	-.067	.0	.067	-.027	1.000	.029	-.010	.066	-.065	-.017	-.059	-.070	-.04	.000	-.052	.281**
	Sig. (2-tailed)	.914	.539	.86	.537	.804	.	.787	.924	.545	.549	.874	.588	.518	.707	1.0	.634	.008
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
S_STONE	Pearson Correlation	.037	-.240*	.10	.240*	-.045	.029	1.000	-.517**	.601**	-.073	-.070	-.027	.045	.154	-.02	.208	-.21*
	Sig. (2-tailed)	.737	.025	.37	.025	.676	.787	.	.000	.000	.502	.522	.807	.677	.153	.869	.054	.048
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
SHALE	Pearson Correlation	-.538**	-.315**	-.6**	.316**	-.231*	-.010	-.517**	1.000	-.800**	-.618**	.605**	-.459**	-.176	-.48**	-.55**	-.611**	.146
	Sig. (2-tailed)	.000	.003	.00	.003	.031	.924	.000	.	.000	.000	.000	.000	.103	.000	.000	.000	.178
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
LIME	Pearson Correlation	.221*	.047	.47**	-.045	-.064	.066	.601**	-.800**	1.000	.037	-.295**	.118	.115	.293**	.013	.402**	-.20
	Sig. (2-tailed)	.040	.668	.00	.677	.556	.545	.000	.000	.	.735	.006	.275	.290	.006	.905	.000	.058
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
DOLO	Pearson Correlation	.631**	.527**	.36**	-.531**	.467**	-.065	-.073	-.618**	.037	1.000	-.650**	.631**	.149	.426**	.903**	.503**	.044
	Sig. (2-tailed)	.000	.000	.00	.000	.000	.549	.502	.000	.735	.	.000	.000	.168	.000	.000	.000	.689
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
SAND	Pearson Correlation	-.795**	-.243*	-.1	.246*	-.317**	-.017	-.070	.605**	-.295**	-.650**	1.000	-.789**	-.349**	-.68**	-.72**	-.866**	.125
	Sig. (2-tailed)	.000	.024	.17	.022	.003	.874	.522	.000	.006	.000	.	.000	.001	.000	.000	.000	.247
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
OM	Pearson Correlation	.745**	.218*	.19	-.221*	.285**	-.059	-.027	-.459**	.118	.631**	-.789**	1.00	.266*	.531**	.701**	.613**	-.01
	Sig. (2-tailed)	.000	.042	.08	.040	.007	.588	.807	.000	.275	.000	.000	.	.013	.000	.000	.000	.925
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
FE	Pearson Correlation	.596**	.088	.09	-.088	.048	-.070	.045	-.176	.115	.149	-.349**	.266*	1.00	.717**	.169	.636**	-.02
	Sig. (2-tailed)	.000	.417	.42	.417	.658	.518	.677	.103	.290	.168	.001	.013	.	.000	.117	.000	.844
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
MN	Pearson Correlation	.759**	.022	.08	-.023	.076	-.041	.154	-.482**	.293**	.426**	-.684**	.531**	.717**	1.0	.416**	.833**	-.16
	Sig. (2-tailed)	.000	.840	.48	.836	.482	.707	.153	.000	.006	.000	.000	.000	.000	.	.000	.000	.134
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
CA	Pearson Correlation	.723**	.474**	.36**	-.478**	.420**	.000	-.018	-.551**	.013	.903**	-.716**	.701**	.169	.416**	1.0	.518**	.129
	Sig. (2-tailed)	.000	.000	.00	.000	.000	1.000	.869	.000	.905	.000	.000	.000	.117	.000	.	.000	.233
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
AL	Pearson Correlation	.718**	.216*	.14	-.218*	.217*	-.052	.208	-.611**	.402**	.503**	-.866**	.613**	.636**	.833**	.518**	1.000	-.30**
	Sig. (2-tailed)	.000	.044	.18	.042	.044	.634	.054	.000	.000	.000	.000	.000	.000	.000	.000	.	.005
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
P:Al	Pearson Correlation	.216*	-.064	.0	.064	-.030	.281**	-.213*	.146	-.204	.044	.125	-.010	-.021	-.16	.129	-.297**	1.0
	Sig. (2-tailed)	.045	.557	.85	.554	.786	.008	.048	.178	.058	.689	.247	.925	.844	.134	.233	.005	.
	N	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87

*. Correlation is significant at the 0.05 level (2-tailed).

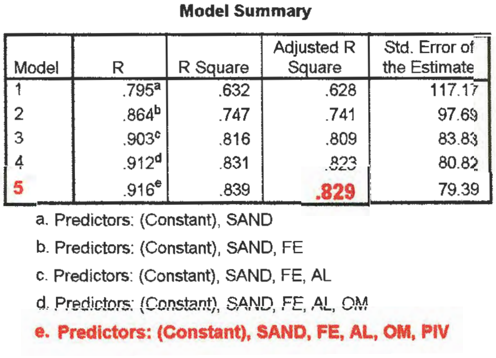
**. Correlation is significant at the 0.01 level (2-tailed).

Regression Analysis

From the data matrix, stepwise regression was used to exclude weakly correlated and include strongly correlated variables. It was found that PI, sand, OM, Fe, and Al best explained sediment-P variability (Table 5.4). PI was included in the model because the other four variables were related to sediment composition and geochemistry, whereas PI was the only land use tracer that best accounted for the most dominant land use in the watershed: chicken houses. Stepwise regression chose the fifth model as the most efficient explanation of sediment-P variability (r^2 value 0.83). It is also important to note that the B values served as the variables used for the "best fit" regression line predicting sediment-P values (Figure 5.28).

By processing the regression line with PI = 0, predicted background P values were calculated (reported as back_P), and by putting in PI values for each sample, predicted anthropogenic values were calculated (reported as anthro_P). The sum of back_P and anthro_P served as the total predicted P values (reported as pred_P). There was a strong relationship (r^2 value 0.85) between the original sed-P values and the pred_P values giving credibility to the prediction qualities of the regression model (Figure 5.29). The residuals, or percent increase above predicted back_p values, fluctuated according to the magnitude of poultry-associated nonpoint P risk. Therefore, Piney Creek is affected the most by nonpoint P attributed to chicken house locations (Figures 5.30 and 5.24).

Table 5.4. Linear regression output of multivariate regression.



Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.795^a	.632	.628	117.17
2	.864^b	.747	.741	97.69
3	.903^c	.816	.809	83.83
4	.912^d	.831	.823	80.82
5	.916^e	.839	.829	79.39

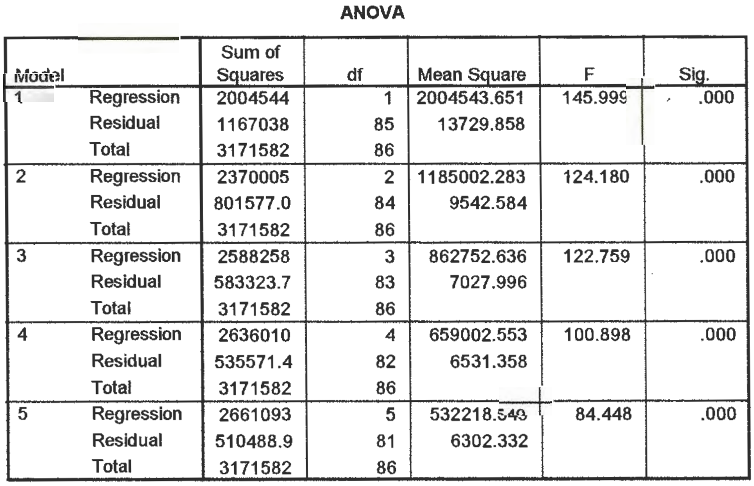
a. Predictors: (Constant), SAND

b. Predictors: (Constant), SAND, FE

c. Predictors: (Constant), SAND, FE, AL

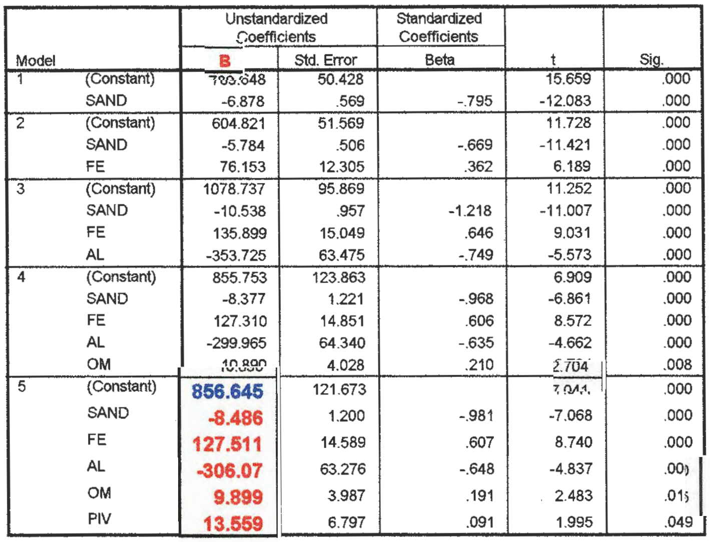
d. Predictors: (Constant), SAND, FE, AL, OM

e. Predictors: (Constant), SAND, FE, AL, OM, PIV



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2004544	1	2004543.651	145.999	.000
	Residual	1167038	85	13729.858		
	Total	3171582	86			
2	Regression	2370005	2	1185002.283	124.180	.000
	Residual	801577.0	84	9542.584		
	Total	3171582	86			
3	Regression	2588258	3	862752.636	122.759	.000
	Residual	583323.7	83	7027.996		
	Total	3171582	86			
4	Regression	2636010	4	659002.553	100.898	.000
	Residual	535571.4	82	6531.358		
	Total	3171582	86			
5	Regression	2661093	5	532218.540	84.448	.000
	Residual	510488.9	81	6302.332		
	Total	3171582	86			



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	789.648	50.428		15.659	.000
	SAND	-6.878	.569	-.795	-12.083	.000
2	(Constant)	604.821	51.569		11.728	.000
	SAND	-5.784	.506	-.669	-11.421	.000
	FE	76.153	12.305	.362	6.189	.000
3	(Constant)	1078.737	95.869		11.252	.000
	SAND	-10.538	.957	-1.218	-11.007	.000
	FE	135.899	15.049	.646	9.031	.000
	AL	-353.725	63.475	-.749	-5.573	.000
4	(Constant)	855.753	123.863		6.909	.000
	SAND	-8.377	1.221	-.968	-6.861	.000
	FE	127.310	14.851	.606	8.572	.000
	AL	-299.965	64.340	-.635	-4.662	.000
	OM	10.890	4.028	.210	2.704	.008
5	(Constant)	**856.645**	121.673		7.041	.000
	SAND	**-8.486**	1.200	-.981	-7.068	.000
	FE	**127.511**	14.589	.607	8.740	.000
	AL	**-306.07**	63.276	-.648	-4.837	.000
	OM	**9.899**	3.987	.191	2.483	.015
	PIV	**13.559**	6.797	.091	1.995	.049

KINGS RIVER NONPOINT SOURCE PREDICTION MODEL

Sediment-P = Sand + Fe + Al + OM + PI

$$\text{sed-P} = b_0 + (b_1 * x_1) \ldots$$

where:

b_0 = constant or y-intercept
790

$b_{1\text{-}5}$ = slope values or regression coefficients (Table 7)
-8.9, 1.3, -3.3, 9.1, 13.8

$x_{1\text{-}5}$ = values of each sample
sand, Fe, Al, OM, PI

Figure 5.28. Kings River Basin nonpoint source prediction model.

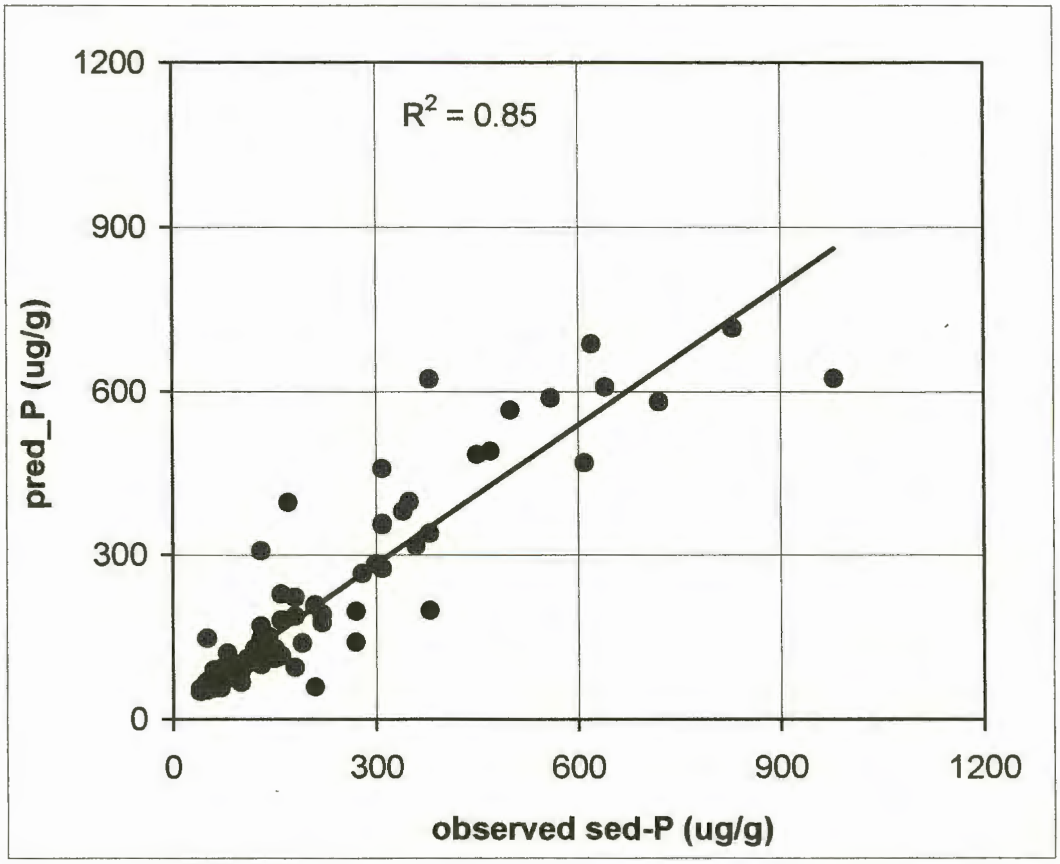


Figure 5.29. Relationship between observed and predicted sediment-P.

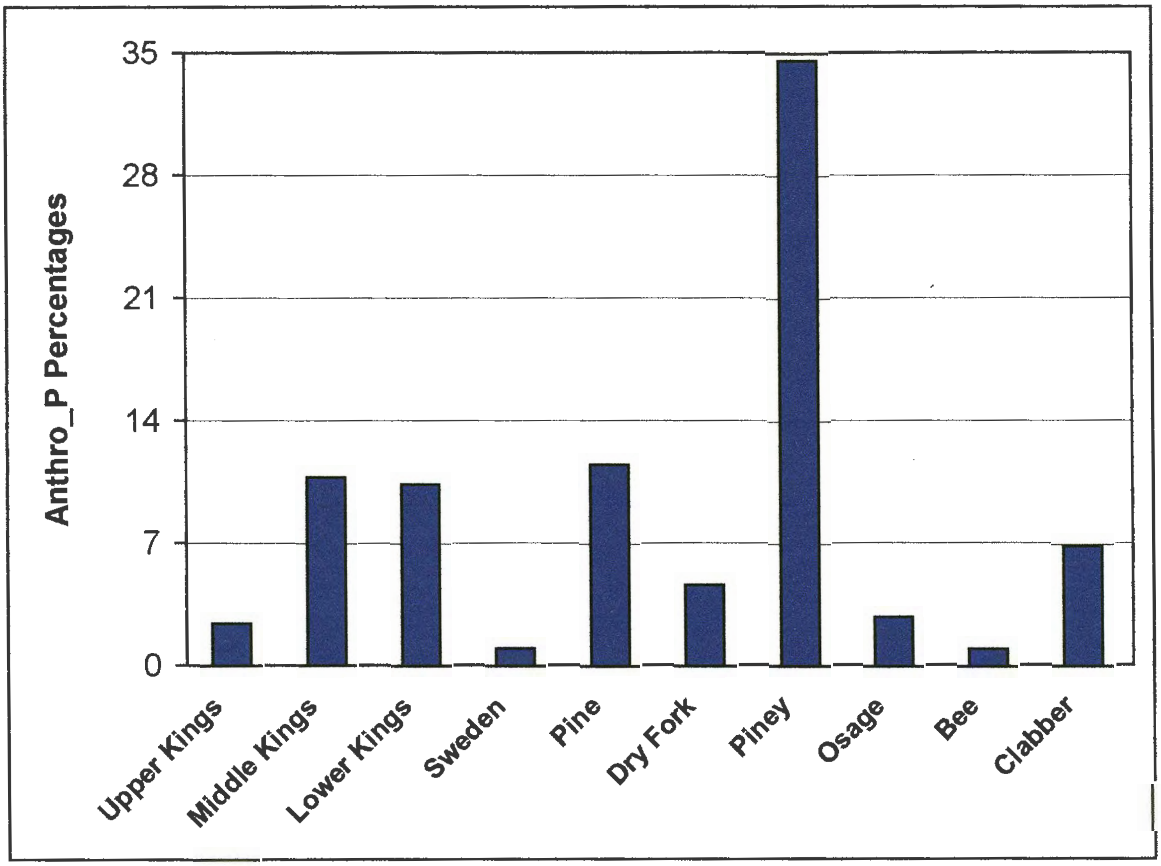


Figure 5.30. Percentage of predicted anthropogenic-P over background-P.

Application of Regression Model

Efficient nonpoint source assessment depends upon the ability to predict nutrient levels as close to the actual values as possible. The margin of error between actual P values and total predicted P values was minimal for all reaches (Figure 5.31). The slight under-estimation in most reaches may be due to the fact that the prediction model isolated the dominant sediment composition and land use variables, whereas the original sediment-P values were masked by these variables and represented a more general range of concentrations (Figure 5.3).

It is more important, however, to concentrate on efficient prediction of the anthropogenic nonpoint P sources, since less is known about their extent. There was a gradual increase in Middle Kings anthro_P values, which may be explained by the very high Piney Creek values (Figures 5.32 and 5.33). A second increase occurred downstream of the Osage Creek. Although the wastewater treatment plant sample site (83) was removed from analysis, this trend may still be affected by the continuous point source loadings that are affecting all downstream sediments. This assumption is verified by total P water column data taken from ADEQ fixed sampling gauges above and below the Berryville wastewater plant and a gauge below the Osage Creek confluence on the Kings River. Data reveal higher mean TP values in Osage Creek below the treatment plant than above, as well as moderately high values at the Kings gauge (Table 5.5).

A different perspective shows less threat from Osage Creek and a more realistic threat from Piney and Clabber creeks, which were previously targeted for nonpoint P source risk due to chicken house densities (Figures 5.34 and 5.35). Further analysis using

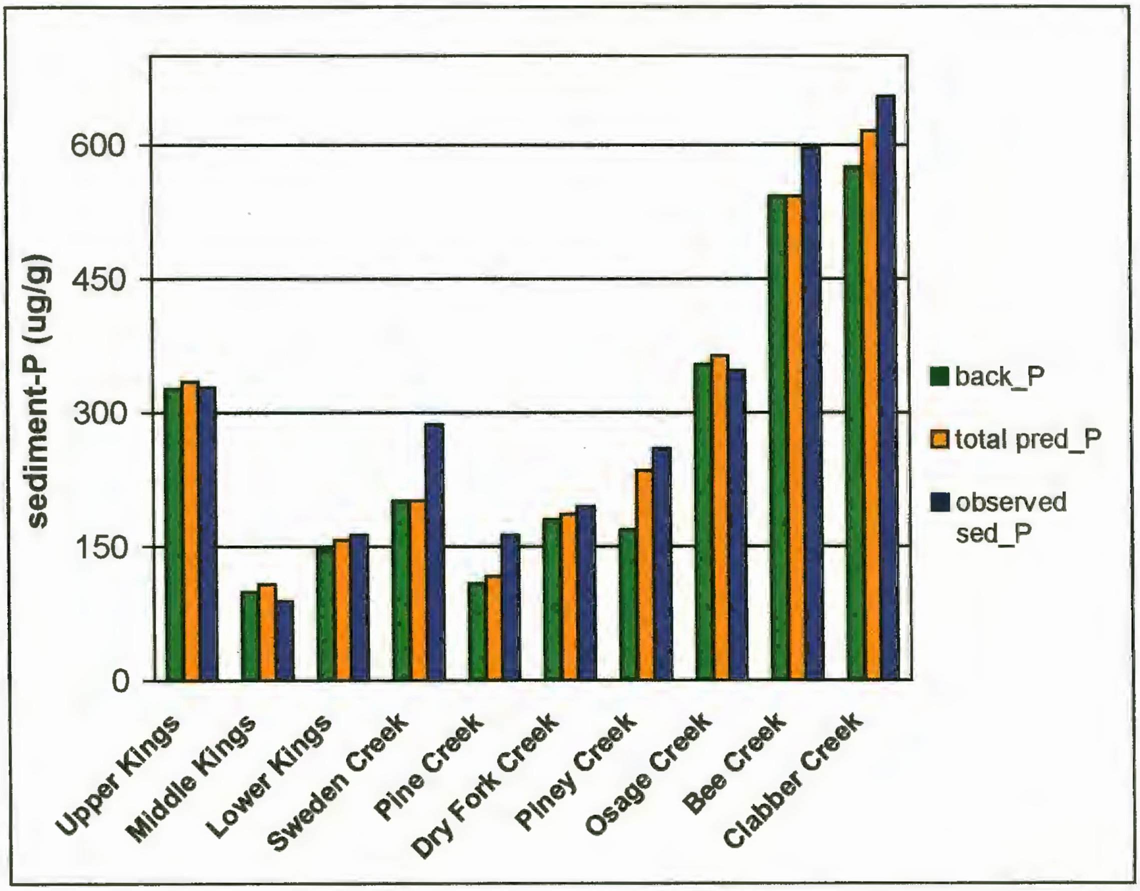


Figure 5.31. Observed, background, and predicted sediment-P values.

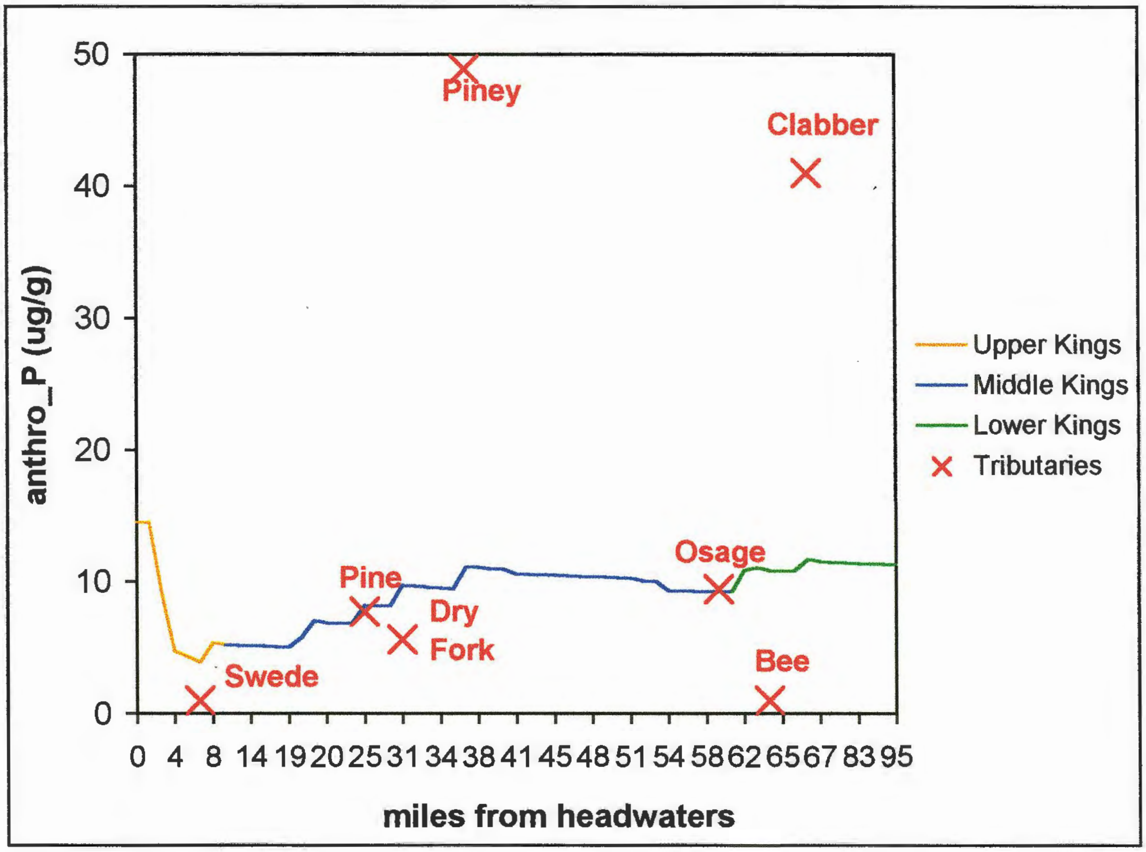


Figure 5.32. Downstream trend of anthropogenic-P values.

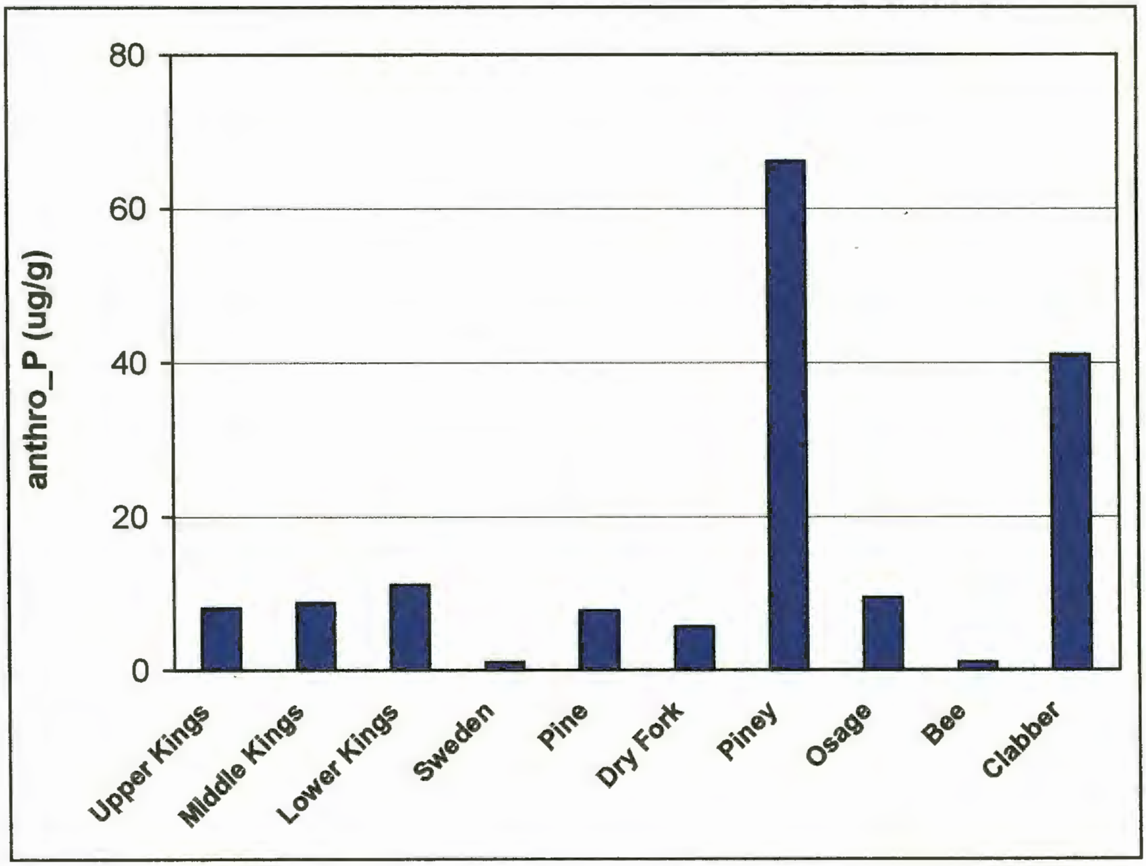


Figure 5.33. Mean anthropogenic-P values in the Kings River Basin.

Table 5.5. Water Column Total P data from ADEQ fixed gauges.

Gauge	Location	# samples	Mean (mg/l)	Min. (mg/l)	Max. (mg/l)
168	Above WWTP on Osage	29	0.07	0.02	0.21
169	Below WWTP on Osage	38	1.88	0.04	24.62
109 A	Below Osage on Kings	40	0.38	0.04	1.33

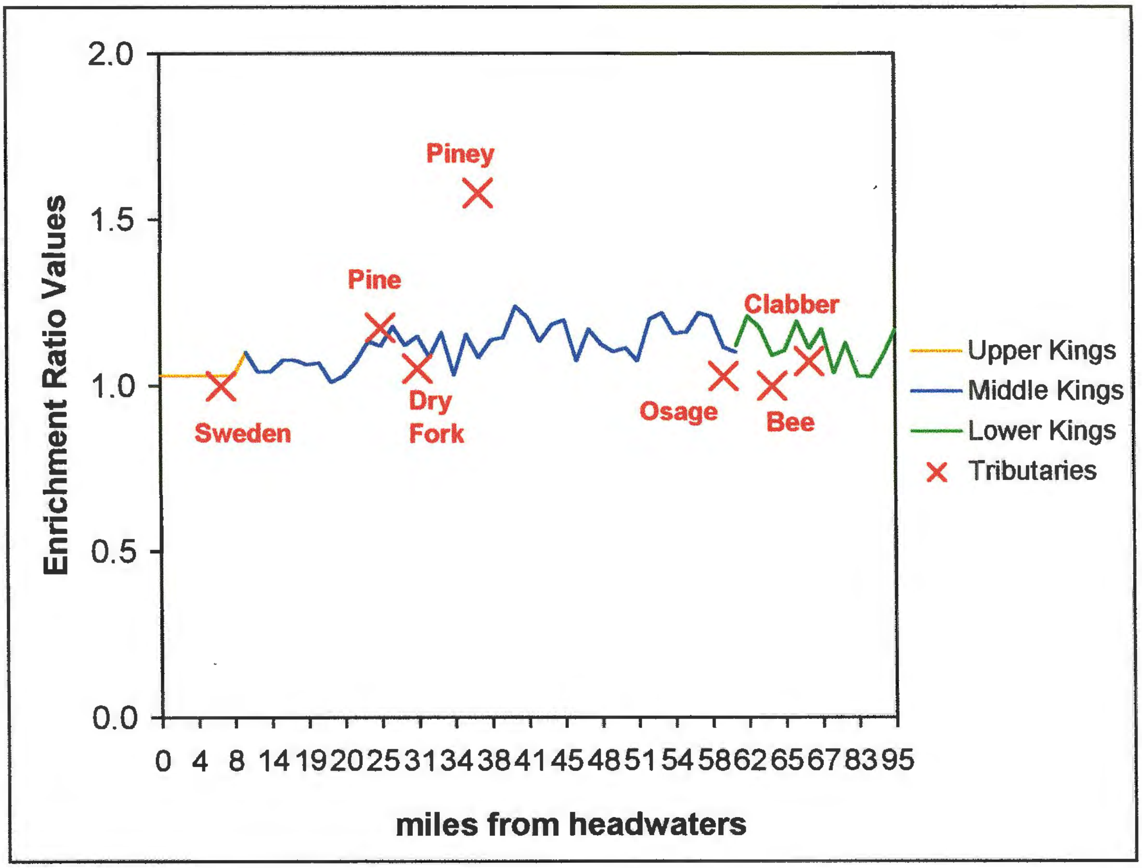


Figure 5.34 Downstream trend of nonpoint source enrichment ratio.

an enrichment ratio (total pred_P / back_P) also showed Piney Creek with the highest ratio, which can be interpreted as the portion of the total pred_P values over background levels (Figure 5.34). The overall, relative effect of poultry operations can be most easily interpreted as a nonpoint percentage (NPS_P %) of the total observed sediment-P values. The downstream trend of NPS_P shows how the high PI risk in Piney Creek is pulling the Middle Kings data with it; and the Lower Kings, which was previously shown to be contributing the highest original sediment-P values (Figure 5.2), is actually more of a point source threat than a nonpoint source threat (Figure 5.35).

In summary, regression model applications revealed that high-density areas of chicken houses exhibited the highest risk and highest percentages of nonpoint P sources. Furthermore, specific anthropogenic values and general nonpoint P values were best portrayed as percentages of the total P values over background levels. Dominant sediment composition and land use effects, causing misinterpretation of actual nonpoint P, were masking original sediment-P values. Once these factors were isolated, a more realistic assessment could be made of areas contributing high percentages of NPS sediment-P via re-application of chicken waste or natural background levels of P.

Implications for NPS Management

The motive behind this study was to better understand, target, and eventually manage nonpoint P sources from a watershed perspective. Efficient and accurate management at the watershed-scale is facilitated with a sound knowledge of overall watershed trends including background source loadings, sediment composition, locations of wastewater treatment plants, and areas high in agricultural land use such as the continuous application of chicken waste as crop fertilizer. Knowing background levels, or establishing baseline concentrations, allows for a better assessment of the actual loadings from more prevalent nonpoint sources. These sources can then be targeted for careful monitoring or implementation of proactive best management practices. For example, initial watershed-scale assessment may magnify the risk of nonpoint P sources in poultry areas, however more concentrated field-scale research and nutrient management plans will serve as the most efficient controls. Furthermore, as point sources such as wastewater treatment plants continue to enhance their operations in compliance with federal law, nonpoint source loadings will be become more apparent.

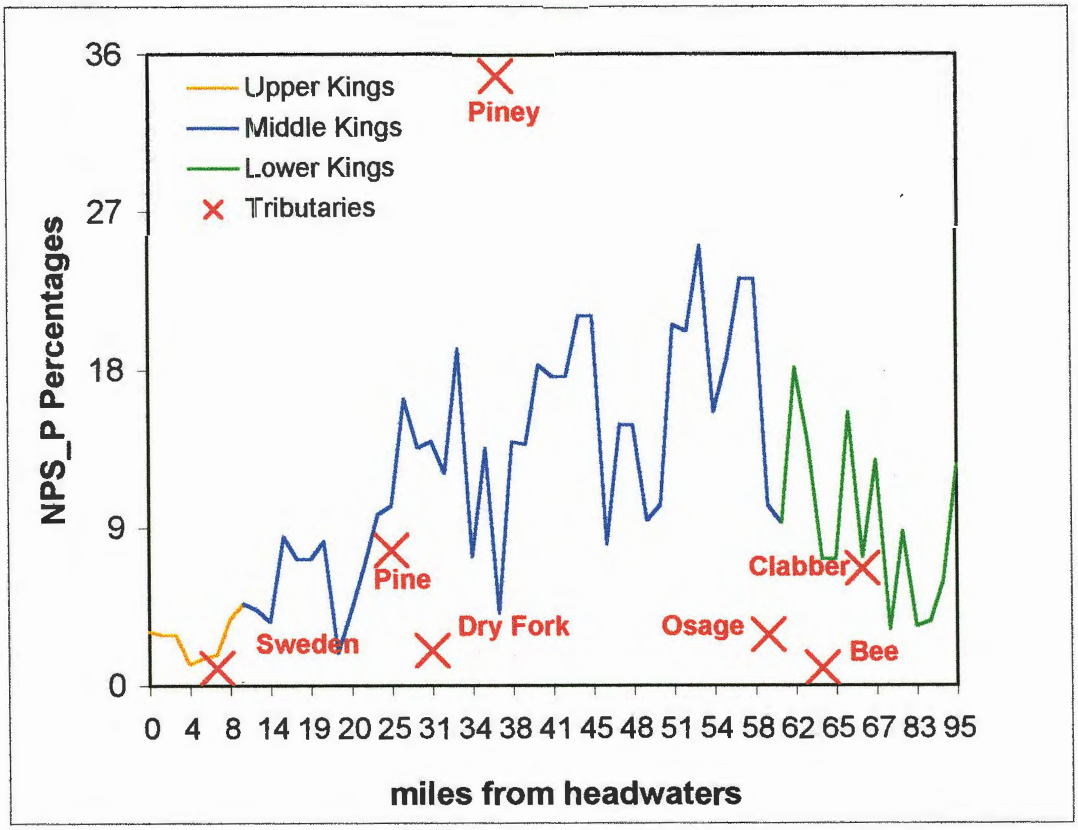


Figure 5.35. Downstream trend of overall nonpoint source percentages.

CHAPTER 6

SUMMARY AND CONCLUSIONS

In general, the Kings River Basin is a forested, steep watershed at the foothills of the Boston Mountains that contains diverse natural resources and the second largest production of chickens in the United States. This combination of pristine and anthropogenic sources results in a difficult task of controlling diffuse, nonpoint sediment erosion that adsorbs high concentrations of P as the sediment makes its way from the terrestrial to the aquatic environment. Streambed sediment monitoring indicates that the Kings River Basin has low sediment-P concentrations compared to similar studies across the United States. Berryville's wastewater treatment plant is the only major point source in the watershed and is responsible for the highest sediment-P values in the Kings Basin. This suggests that any elevated P levels upstream can be attributed to some facet of nonpoint source P runoff.

The results provide evidence that elevated sediment-P concentrations can be attributed to nonpoint sediment adsorption. The main findings of the watershed analysis include:

1. **Streambed sediment-P concentrations were quantified at the watershed-scale and varied with watershed variables such as sediment composition, sediment geochemistry, and land use variability.**

Sediment-P concentrations (n=87) ranged from 7 to 1,280 micrograms per gram (*u*g/g), with a median concentration of 130 *u*g/g and a mean concentration of 209 *u*g/g. (Figure 13). The highest level (1,280 *u*g/g) was detected at site 83 on the Freeman Branch of

Osage Creek, which drains the city of Berryville and the only wastewater treatment plant in the watershed. This point source loading is also noticeable downstream of the Osage Creek confluence on the Kings River where sediment-P levels remain consistently high (Figure 12 and Table 5.5). The next highest P levels were detected in a cluster around Bee and Clabber creeks, which drain into the lower reaches of the basin near a high density of poultry houses (Figure 3.6 and 5.1). Sediment-P concentrations were negatively correlated (r^2 value 0.63) with the predominately sandy sediments (mean 85%) and positively correlated (r^2 value 0.74) with sediment-OM. Land use was divided among forested (68%), agriculture (32%), and urban (0.1%). As expected, sediment-P concentrations were positively correlated with agriculture use, negatively correlated with forested land cover, and there was not enough urban land use to assess relationships. There are 472 broiler houses in the 564 mi^2 watershed that inconsistently spread P-rich chicken waste as crop fertilizer. High-density areas of poultry houses in Piney and Clabber creeks were found to be at high risk of nonpoint sediment-P as was detected by a poultry index (# of broiler houses/upstream drainage area); more field-scale research is needed to make further assumptions. Sediment composition (very sandy sediments) and land use variability (large forested tracts with organic-P surface matter) were found to be the most dominating variables masking connections between nonpoint P sources and downstream trends.

2. Bedrock units were found concentrating high levels of background-P and significant geochemical concentrations of Fe, Mn, Al, and Ca.

Literature suggests that sandstone/shale rock units can harbor high levels of mineral P

(Table 2.1) and geochemical sediment coatings are responsible for P adsorption (Horowitz, 1991). The shale/sandstone rock units in the Boston Mountain region of the Upper Kings contributed high levels of Mn, Fe, and Al, while the limestone/dolomite rock units of the Springfield Plateau region of the Lower Kings contributed high levels of Ca, suggesting karst formations. Source reference samples also showed high levels of background mineral constituents, suggesting the headwaters have higher background-P levels than the lower reaches. Sediment-P concentrations were strongly correlated with Fe, Mn, Al, and Ca, indicating these minerals can be used as P tracers, however the bedrock percentages were not strongly correlated enough with sediment-P values to be included in the prediction model.

3. **The nonpoint source prediction model for the Kings River Watershed was developed with five statistically relevant variables: OM content, sand content, Al, Fe, and poultry index (PI).**

Ten independent watershed variables: OM%, sand %, forest %, ag %, poultry index, P:Al ratio, Fe, Mn, Al, and Ca were used to describe the activity of the dependent variable sediment-P. A Pearson multivariate matrix was first used to assess autocorrelation among the variables. Stepwise regression was then used to systematically remove non-significant variables and keep five significant variables (r^2 value 0.83) (Table 7) and develop a regression prediction model (Figure 38). Isolation of overbearing sediment composition and land use allowed for a more efficient assessment of anthropogenic nonpoint sources as percentages over background levels. Original sediment-P values were misrepresenting Lower Kings loadings, influenced heavily by Osage Creek and the Berryville wastewater treatment plant, whereas more realistic NPS_P percentages put less threat on the Lower Kings and more threat on the Middle Kings and Piney Creek where the most broiler houses are found. An enrichment ratio (total predicted P / background P) showed Piney and Clabber creeks to have the highest predicted NPS values, as was similar to the original, observed sediment-P values. Credibility was given to the prediction capabilities of the regression model, which will aid resource managers in future Kings River watershed-scale studies.

4. This study gives credibility to the integration of streambed sediment surveying and GIS analysis in Ozarks watersheds.

This study used a less-popular medium for fluvial assessment (sediment surveying) and coupled it with modern technology (GIS technologies) to spatially analyze the variability of NPS sediment-P at a watershed-scale. Sediment monitoring has advantages over water column monitoring in that samples are cheaper to process, sediment can concentrate a greater range of elements, and sediment reflects fluvial processes over a longer period of time. The Kings River has never been studied at the basin-scale, therefore this study not only established useful nutrient references and baseline data, but also added to the minimal knowledge of NPS dynamics throughout Ozarks watersheds where tourism is needy of good water quality. Future streambed monitoring studies can use this study as a guide or literature reference to enhance such methodologies and specific sampling sites could be re-visited for a follow-up study by using the compiled GPS coordinates (Appendix A). Also, since some areas were targeted more for nonpoint sediment-P than others, such as chicken house locations, resource managers or academic researchers can better control these areas from further water eutrophication and sediment erosion.

5. Future work in this area will need to focus on agricultural NPS sediment-P at the watershed and sub-watershed-scale, and assessment of Osage Creek loadings.

The highest sediment-P values were connected with Osage Creek loadings and the second highest range of sediment-P values were connected with densities of broiler houses in small sub-watershed drainage areas. Therefore, future research must be oriented in the same manner. The Berryville wastewater treatment plant does not currently have to report its effluent P levels, therefore that plant could be contributing an enormous amount of continuous point source-P. A review of local and federal water policy may assist in the inclusion of Berryville's wastewater plant as a P-testing facility. Furthermore, a detailed study needs to be conducted only on Osage Creek, the Lower Kings below Osage Creek confluence, and the Table Rock Lake arm. This study's results indicate that Osage Creek is contributing the majority of elevated sediment-P levels and since very few silt-clay particles were found further up in the Kings River Watershed, it is suspected that they have been transported and deposited in the bottom of the lake arm where sediment-P is susceptible to the active nutrient exchange processes. Revisiting some of the sites used for this study would also assist in gaining background information. Secondly, the majority of agricultural NPS sediment-P originates from sediment erosion and runoff from barren pastureland. Initial source controls must be implemented to reduce initial sediments that will eventually adsorb nutrients during transport from the terrestrial to the aquatic environment. Furthermore, best management practices and nutrient management plans (NMPs) must be implemented more often through cost-sharing and communication with soil and water conservation districts. It is important to note that these best management practices are crucial in detouring future agricultural NPS sediment-P degradation and they are the only ally most remote farmers have. Administers of these plans are diligent about collecting a soil sample, balancing fertilizer application with natural nutrient levels, and continuously monitoring farmer progress. Our market-driven economy has deflated traditional crop agriculture resulting in secondary, easily managed farm occupations, such as contract poultry production, that will allow the farmers to remain on their family property. Since the Kings River Basin is a relatively large and economically poor watershed, modern and expensive best management practices are not going to be implemented with enthusiasm. Therefore, it will be important for environmental resource managers to maintain good landowner relations and consistently provide updates to conservation practices.

LITERATURE CITED

Adamski, James C., James C. Peterson, David A. Friewald, and Jerri V. Davis. 1995. *Environmental and Hydrologic Setting of the Ozark Plateaus Study Unit, Arkansas,Kansas, Missouri, and Oklahoma.* National Water Quality Assessment Program. Little Rock: Government Printing Office.

Ahl, Thorsten. 1994. Regression Statistics as a Tool to Evaluate Excess (Anthropogenic) Phosphorus, Nitrogen, and Organic Matter in Classification of Swedish Fresh Water Quality. *Water, Air, and Soil Pollution* 74: 169-187.

Arkansas Water Resources Center (AWRC). 1993. Phosphorus Management for Agriculture and Water Quality. *Focus on Phosphorus: Proceedings of the 1993 Research Conference* held in Fayetteville, AR 6-7 April, 1993, by the Arkansas Water Resources Center, 36p. Fayetteville: Water Resources Center.

Beauchemin, Suzanne, R.R. Simard, and D. Cluis. 1996. Phosphorus Sorption-Desorption Kinetics of Soil Under Contrasting Land Uses. *Journal of Environmental Quality* 25: 131-1325.

Bonn, Bernadine A. 1999. Selected Elements and Organic Chemicals in Bed Sediment and Fish Tissue of the Tualatin River Basin, Oregon, 1992-96. Water Resources Investigations Report 99-4107, 61p.

Boyd, Robert A. 1996. Distribution of Nitrate and Orthophosphate in Selected Streams in Central Nebraska. *Water Resources Bulletin* 32: 817-829.

Braden, Angela. Arkansas Geological Commission. Personal communication. December, 11, 2000.

Carlson, Jason. 1999. *Zinc Mining Contamination and Sedimentation Rates of Historical Overbank Deposits, Honey Creek Watershed, Southwest Missouri.* MS thesis, Southwest Missouri State University; Springfield, MO:

Campbell, L.B. and G.J. Racz. 1975. Organic and Inorganic P Content, Movement and Mineralization of P in Soil Beneath a Feedlot. *Canadian Journal of Soil Science* 55: 457-466.

Chalmers, Ann T. 1998. Distribution of Phosphorus in Bed Sediments of the Winooski River Watershed, Vermont, 1997. U.S. Geological Survey Fact Sheet FS-108-98. Virginia: Government Printing Office, 6pp.

Clark, Gregory M., David K. Mueller, and M. Alisa Mast. 2000. Nutrient Concentrations and Yields in Undeveloped Stream Basins of the United States. *Journal of the American Water Resources Association* 4: 849-860.

Colman, J.A., and Sanzolone, R.F. 1991. Surface-Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin: Geochemical Data for Fine-fraction Streambed Sediment from High- and Low-order Streams, 1987. USGS Open-File Report 90-571, 108 p.

Daniel, T.C., A.N. Sharpley, and J.L. Lemunyon. 1998. Agricultural Phosphorus and Eutrophication: A Symposium Overview. *Journal of Environmental Quality* 27: 251-257.

Dent, Borden D. 1999. *Cartography: Thematic Map Design.* Boston: McGraw Hill Company.

Dillon, P.J. and W. B. Kirchner. 1975. The Effects of Geology and Land Use on the Export of Phosphorus From Watersheds. *Water Research* 9: 135-148.

Dopplet, Bob, Mary Scurlock, Chris Frissell, and James Karr. 1993. *Entering the Watershed: A New Approach to Save America's River Ecosystems.* Washington, D.C.: Island Press.

Downs, Peter W. and Gary Priestnall. 1999. System Design for Catchment-Scale Approaches to Studying River Channel Adjustments Using a GIS. *International Journal of Geographical Information Science* 13: 247-266.

Edwards, A.C., H. Twist, and G.A. Codd. 2000. Assessing the Impact of Terrestrially Derived Phosphorus in Flowing Water Systems. *Journal of Environmental Quality* 29: 117-124.

Edwards, D.R., and T.C. Daniel. 1992. Potential Runoff Quality Effects of Poultry Manure Slurry Applied to Fescue Plots. *Journal of the American Society of Agricultural Engineers* 35: 1827-1832.

Eghball, B., G.D. Binford, and D.D. Baltensperger. 1996. Phosphorus Movement and Adsorption in a Soil Receiving Long-Term Manure and Fertilizer Application. *Journal of Environmental Quality* 25: 1339-1343.

Emmereth, P. and David R. Bayne. 1996. Urban Influence of Phosphorus and Sediment Loading of West Point Lake, Georgia. *Water Resources Bulletin* 32: 45-154.

Feltz, H.R. 1980. Significance of Bottom Material Data in Evaluating Water Quality, in Baker, R., ed., Contaminants and Sediments, v.1. Ann Arbor: Ann Arbor Science Publishers, Inc., 271-287.

Forstner, U. and G.T.W. Wittman. 1981. *Metal Pollution in the Aquatic Environment.* New York: Springer-Verlag.

Fowlkes, David H., M. Dean Harper, and Richard T. McCright. 1984. *Soil Survey of Carroll County Arkansas.* Little Rock: Government Printing Office.

Fox, R.L. and E.J. Kamprath. 1971. Adsorption and Leaching of P in Acid Organic Soils and High Organic Matter Sand. *Soil Science Society America Proceedings* 35: 154-156.

Gale, P.M., K.R. Reddy, and D.A. Graetz. 1994. Phosphorus Retention by Wetland Soils Used for Treated Wastewater Disposal. *Journal of Environmental Quality* 23: 370-377.

Garman, Gayle D., Gregory B. Good, and Linda M. Hinsman. 1986. *Phosphorus: A Summary of Information Regarding Lake Water Quality.* Springfield: Division of Water Pollution Control Illinois Environmental Protection Agency, 63p.

Goodchild, Michael. 1992. Integrating GIS and Spatial Data Analysis: Problems and Possibilities. *International Journal of Geographic Information Systems* 6: 407-423.

Grobler, D.C., and M.J. Silberbauer. 1985. The Combined Effect of Geology, Phosphate Sources and Runoff on Phosphate Export From Drainage Basins. *Water Resources* 19: 975-981.

Harper, Harvey H. 1995. *Stormwater Chemistry and Water Quality.* Orlando: Environmental Research and Design Press.

Hearn, Paul P. 1985. Controls on Phosphorus Mobility in the Potomac River Near the Blue Plains Wastewater Treatment Plant. U.S. Geological Survey Water-Supply Paper 2231, U.S. Government Printing Office, Washington, D.C., 46p.

Hem, J.D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water (Third Edition). U.S. Geological Survey Water-Supply Paper 2254, U.S. Government Printing Office, Washington, D.C., 263pp.

Hinkle, Stephen J. 1999. Inorganic Chemistry of Water and Bed Sediments in Selected Tributaries of the South Umpqua River, Oregon, 1998. USGS Water Resources Investigations Report 99-4196, 20p.

Horn, M.K. and J.A.S. Adams. 1966. Computer-derived Geochemical Balances and Element Abundances. *Geochimica et Cosmochimica Acta* 30: 279-297.

Horowitz, Arthur J. 1991. *Sediment-Trace Element Chemistry (Second Edition)*. Michigan: Lewis Publishers.

Horowitz, A. and Elrick, K. 1987. The Relation of Stream Sediment Surface Area, Grain Size, and Composition to Trace Element Chemistry. *Applied Geochemistry* 2: 437-451.

Jacobson, Robert J. 1995. Spatial Controls on Patterns of Land-use Induced Stream Disturbance at the Drainage-basin Scale: An Example from Gravel-bed Streams of the Ozark Plateaus, Missouri. *Geophysical Monograph* 89: 219-239.

Jennings, M.D. 1993. *Natural terrestrial cover classification: Assumptions and Definitions*. Gap Analysis Technical Bulletin 2. Moscow, Idaho: Idaho Cooperative Fish and Wildlife Research Unit.

Juracek, Kyle E. 1998. Analysis of Lake-Bottom Sediments to Estimate Historical Nonpoint-Source Phosphorus Loads. *Journal of the American Water Resources Association* 34: 1449-1463.

Kramer, J.R., S.E. Herbes, and H.E. Allen. 1972. Phosphorus: Analysis of Water, Biomass, and Sediment. Pages 51-100 in H.E. Allen, Jr. Kramer (eds.) *Nutrients in Natural Waters*. New York: Wiley Interscience.

Krenkel, P. and V. Novotny. 1980. *Water Quality Management*. New York: Academic Press.

Lecce, Scott A. and Robert T. Pavlowsky. 1997. Storage of Mining-Related Zinc in Floodplain Sediments, Blue River, Wisconsin. *Phyiscal Geography* 18: 424-439.

Leipnik, Mark R., Karen K. Kemp, and Hugo A. Loaiciga. 1993. Implementation of GIS for Water Resources Planning and Managment. *Journal of Water Resources Planning and Management* 119: 184-205.

Li, Feng-Min, Tong-Chao Wang, and Jing Cao. 1998. Effect of Organic Matter on Total Amount and Availability of Nitrogen and Phosphorus in Loess Soil of Northwest China. *Community of Soil Scientists Plant Anals* 29: 947-953.

Leopold, Luna B., M. Gordon Wolman, and John P. Miller. 1992. *Fluvial Processes in Geomorphology*. New York: Dover Publications Inc.

Leopold, Luna B. 1994. *A View of The River*. Massachusetts: Harvard University Press.

Litke, David W. 1999. Review of Phosphorus Control Measures in the United States and Their Effects on Water Quality. U.S. Geological Survey, Water-Resources Investigations Report 99-4007, U.S. Government Printing Office, Washington, D.C., 38pp.

Mankin, K.R., J.K. Koelliker, and P.K. Kalita. 1999. Watershed and Lake Water Quality Assessment: An Integrated Modeling Approach. *Journal of the American Water Resources Association* 35:1069-1080.

McCallister, Dennis L. and Terry J. Logan. 1978. Phosphate Adsorption-Desorption Characteristics of Soils and Bottom Sediments in the Maumee River Basin of Ohio. *Journal of Environmental Quality*: 7: 87-92.

McFarland, John David. 1998. Stratigraphic Summary of Arkansas. Arkansas Geological Commission, Information Circular 36, Little Rock, Arkansas 39p.

McKimmey, J.M. and H.D. Scott. 1993. *Prediction and Management of Sediment Load and Phosphorus in the Beaver Reservoir Watershed Using a Geographic Information System.* Arkansas Water Resources Center Publication 165. Fayetteville: AWRC Press.

Meade, Robert H. 1982. Sources, Sinks, and Storage of River Sediments in the Atlantic Drainage of the United States. *The Journal of Geology* 90: 235-252.

Meals, Donald W. and Lenore F. Budd. 1998. Lake Champlain Basin Nonpoint Source Phosphorus Assessment. *Journal of the American Water Resources Association* 34: 251-265.

Mertz, Tawna. 1993. GIS Targets Agricultural Nonpoint Pollution. *GIS World* 6: 41-46.

Milne, J.A. and D.A. Sear. 1997. Modelling River Channel Topography Using GIS. *International Journal of Geographic Information Science* 11: 499-519.

Middlekoop, Hans and Marcel Van Der Perk. 1998. Modeling Spatial Patterns of Overbank Sedimentation on Embanked Floodplains. *Geografiska Annaler* 80 A: 95-109.

Missouri Department of Natural Resources (MODNR). 1998. *Determination of the Pollutant Loads in the Kings River Near Beryville*. Springfield, MO: Division of Environmental Quality, Southwest Regional Office. Photocopied.

Moreau, Samuel, Georges Betru, and Christian Buson. 1998. Sesonal and Spatial trends of Nitrogen and Phosphorus Loads to the upper Catchment of the River Vilaine (Brittany): Relationships With Land Use. *Hydrobiologia* 373/374: 247-258.

Mozaffari, M. and J.T. Sims. 1994. Phosphorus Availability and Sorption in an Atlantic Coastal Plain Watershed Dominated by Animal-Based Agriculture. *Soil Science* 157: 97-107.

North Carolina State University. 1998. *Watersheds Web Site: Phosphorus.* http://h2osparc.wq.ncsu.edu/info/phos.html.

Obrecht, D., F. Pope, and J.R. Jones. 1999. *Lakes of Missouri Volunteer Program Data Report*. Missouri: University of Missouri Columbia and Department of Natural Resources.

O'Brien, Anne K. 1997. Presence and Distribution of Trace Elements in New Jersey Streambed Sediments. *Journal of the American Water Resources Association* 33: 387- 403.

Olive, L.J. and W.A. Rieger. 1991. Assessing the Impact of Land Use Change on Stream Sediment Transport in a Variable Environment. In *Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation: Proceedings of the Vienna Symposium in Vienna, Austria*, August 11-24, 1991, by the International Commissions on Continental Erosion and on Water Quality of the International Association of Hydrological Sciences (IAHS), 63-71. United Kingdom: IAHS Press, Institute of Hydrology.

Paniconi, Claudio, Sally Kleinfeldt, Jonathan Deckmyn, and Andrea Giacomelli. 1999. Integrating GIS and Data Visualization Tools for Distributed Hydrologic Modeling. *Transactions in GIS* 3: 97-118.

Payne, Gregory A. 1994. Sources and Transport of Sediment, Nutrients, and Oxygen-Demanding Substances in the Minnesota River Basin, 1989-1992. U.S. Geological Survey Water-Resources Investigations Report 93-4232, U.S. Government Printing Office, Washington, D.C., 71pp.

Phillips, Wallace. 1986. *Soil Survey of Madison County Arkansas.* Little Rock: Government Printing Office.

Pierzynski, Gary M., J.Thomas Sims and George F. Vance. 1994. *Soils and Environmental Quality*. Ann Arbor: Lewis Publishers.

Pope, Larry M. 1997. Watershed Trend Analyses and Water-Quality Assessment Using Bottom-Sediment Cores From Cheney Reservoir, South-Central Kansas. USGS Water-Resources Investigations Report 98-4227, Lawrence, KS.

Price, C.V. and F.L. Schaefer. 1995. Estimated Loads of Selected Constituents From Permitted and Non-Permitted Sources at Selected Surface-Water-Quality Stations in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-90. U.S. Geological Survey Water-Resources Investigations Report 95-4040, U.S. Government Printing Office, Washington, D.C., 28p.

Pye, Kenneth. 1994. *Sediment Transport and Depositional Processes.* Oxford: Blackwell Scientific Publications.

Rafferty, Milton D. 1980. *Ozarks Land & Life.* Norman: University of Oklahoma Press.

Reddy, K.R., M.R. Overcash, R. Khaleel, and P.W. Westerman. Phosphorus Adsorption-Desorption Characteristics of Two Soils Utilized for Disposal of Animal Wastes. *Journal of Environmental Quality* 9: 86-92.

Rice, Karen C. 1999. Trace-Element Concentrations in Streambed Sediment Across the Conterminous United States. *Environmental Science and Technology* 33: 2499-250.

Robinson, Keith W., Timothy R. Lazarro, and Connie Pak 1996. Associations Between Water-Quality Trends in New Jersey Streams and Drainage-Basin Characteristics, 1975-86. U.S. Geological Survey Water-Resources Investigations Report 96-4119, U.S. Government Printing Office, Washington, D.C., 148pp.

Rosensteel, Barbara A. and Peter F. Strom. 1991. River Phosphorus Dynamics and Reservoir Eutrophication Potential. *Water Resources Bulletin* 27: 957-966.

Salminen, Reijo and Pekka Sipila. 1996. The Environmental Impact of Sulphide Mines With Organogenic Sampling Media. *Applied Geochemistry* 11: 277-283.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens and R. Parry. 1999. Agricultural Phosphorus and Eutrophication. Agricultural Research Service ARS-149 reference. Washington, D.C.: Government Printing Office.

Schumm, Stanley A. 1977. *The Fluvial System.* New York: Wiley-Interscience Publications.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, Jr., J. Ulliman, and G. Wright. 1993. *Gap Analysis: A Geographic Approach.* Moscow, Idaho: Idaho Cooperative Fish and Wildlife Research Unit.

Spahr, N.E. and K.H. Wynn. 1997. Nitrogen and Phosphorus in Surface Waters of the Upper Colorado River Basin. *Journal of the American Water Resources Association* 33: 547-560.

Statham, Ian. 1977. *Earth Surface Sediment Transport*. Oxford: Clarendon Press.

Steele, Kenneth F. and George H. Wagner. 1975. Trace Metal Relationships in Bottom Sediments of a Fresh Water Stream-The Buffalo River, Arkansas. *Journal of Sedimentary Petrology* 45: 310-319.

Stone, M. and A. Murdoch. 1989. The Effect of Particle Size, Chemistry and Mineralogy of River Sediments on Phosphate Adsorption. *Environmental Technology Letters* 10: 501-510.

Stumm, W. and J.J. Morgan. 1981. Case Studies: Phosphorus, Iron and Manganese. Chapter 10 in *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters.* New York: Wiley Interscience.

Tarbuck, Edward J. and Frederick K. Lutgens. 1993. *The Earth: An Introduction to Physical Geology.* New York: Macmillan Publishing Company.

Tunney, H., O.T. Carton, P.C. Brookes and A.E. Johnston. 1997. *Phosphorus Loss From Soil To Water*. UK: CAB International.

United States Bureau of Census. 1992. *1990 United States Census.* Washington, D.C.: Government Printing Office.

United States Code (USC). 1994 ed. *Navigation and Navigable Waters*. Washington: Government Printing Office.

United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). 1992. *Agricultural Waste Management Field Handbook.* Washington, D.C.: Government Printing Office.

United States Environmental Protection Agency. 1984. Report to Congress: Nonpoint Source Pollution in the U.S. Office of Water Program Operations, Water Planning Division, variously paged.

United States Environmental Protection Agency. 1992. Managing NPS Pollution: Final Report to Congress on Section 319 of the Clean Water Act (1989): U.S. Environmental Protection Agency Office of Water, EPA-506/9-90, 120 p.

United States Environmental Protection Agency. 1995. National Water Quality Inventory, 1994, Report to Congress. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency. 1999. Protocol for Developing Nutrient TMDLs. EPA 841-B-99-007. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 135 pp.

United States Geological Survey (USGS). *Geographic Information Systems.* Washington, D.C.: USGS, 1997. Available from http://www.usgs.gov/research/gis/title.html. Accessed 8 February 2001.

White River Basin Forum (WRBF). 1999. *Memorandum of Agreement Between the Arkansas Department of Environmental Quality, the Missouri Department of Natural Resources, and the Arkansas Soil and Water Conservation Commission*: Proceedings of the first White River Basin Forum held in Branson, Missouri 27 October 1999.

Youngsteadt, Norman W., Reynaldo J. Gumucio and John T. Witherspoon. 1984. *Fellows Lake-McDaniel Lake Watershed Study: Eutrophication and Modeling Strategies Based on Lake Dynamics, Sediment Equilibria, Water Quality and Phytoplankton Relationships.* Springfield, MO: City Utilities Central Laboratory Engineering and Planning Department.

APPENDIX A

"Sampling Site Characteristics"

Sampling Site Characteristics - page 1

Site	Latitude	Longitude	Location	Area(mi^2)	River Miles	% AG	% Forest	% Urban	S_stone%	Shale %	Dolo %	Lime %
1	35.8586	-93.5964	Kings	0.95	0	42	58	0.0	0.00	100.00	0.00	0.00
2	35.9042	-93.5716	Kings	15.17	1.5	29	71	0.0	0.00	100.00	0.00	0.00
3	35.9641	-93.5514	Kings	26.03	3.4	24	76	0.0	0.04	99.94	0.02	0.00
4	35.9897	-93.5361	Kings	49.61	3.9	21	79	0.0	0.05	99.94	0.01	0.00
5	36.0204	-93.5371	Kings	63.69	5.2	25	75	0.0	0.28	97.52	2.20	0.00
6	36.0893	-93.5393	Kings	99.17	6.6	33	67	0.0	13.34	67.25	19.41	0.00
7	36.1444	-93.5910	Kings	126.10	8.1	38	62	0.0	0.11	96.20	3.69	0.00
8	36.1470	-93.6032	Kings	130.81	10	39	61	0.0	0.11	97.35	2.54	0.00
9	36.1442	-93.6082	Kings	131.04	11.8	39	61	0.0	0.11	97.35	2.54	0.00
10	36.1488	-93.6114	Kings	131.87	14	39	61	0.0	0.11	97.35	2.54	0.00
11	36.1579	-93.6104	Kings	132.29	15.4	39	61	0.0	0.11	97.35	2.54	0.00
12	36.1662	-93.6078	Kings	133.62	17.6	39	61	0.0	0.11	97.35	2.54	0.00
13	36.1576	-93.6182	Kings	134.06	18.8	39	61	0.0	0.11	97.35	2.54	0.00
14	36.1603	-93.6348	Kings	136.36	19.5	39	61	0.0	0.11	97.35	2.54	0.00
15	36.1693	-93.6484	Kings	143.08	19.6	40	60	0.0	0.23	97.23	2.54	0.00
16	36.1775	-93.6434	Kings	146.59	19.8	41	59	0.0	0.23	97.23	2.54	0.00
17	36.1780	-93.6515	Kings	147.04	20.8	41	59	0.0	0.23	97.23	2.54	0.00
18	36.1898	-93.6516	Kings	147.62	22.3	41	59	0.0	0.23	96.09	3.69	0.00
19	36.1947	-93.6558	Kings	149.30	24.1	40	60	0.0	0.23	96.09	3.69	0.00
20	36.2002	-93.6518	Kings	163.13	25.4	38	61	0.0	0.74	96.73	2.53	0.00
21	36.1961	-93.6471	Kings	163.53	27.4	38	62	0.0	0.85	96.63	2.52	0.00
22	36.2102	-93.6422	Kings	164.20	30.3	38	62	0.0	0.74	95.60	3.67	0.00
23	36.2191	-93.6329	Kings	219.46	31.3	35	65	0.0	0.96	97.68	1.36	0.00
24	36.2231	-93.6425	Kings	220.34	32.2	35	65	0.0	0.85	96.60	1.34	1.21
25	36.2345	-93.6400	Kings	222.64	33.3	35	65	0.0	0.96	97.08	1.35	0.61
26	36.2469	-93.6387	Kings	223.63	34	35	65	0.0	0.96	97.08	1.35	0.61
27	36.2507	-93.6270	Kings	225.83	35.2	34	66	0.0	1.16	96.88	1.35	0.61
28	36.2678	-93.6368	Kings	271.03	36.4	34	66	0.0	1.26	95.82	1.66	1.26
29	36.2763	-93.6322	Kings	271.66	37.6	34	66	0.0	1.15	95.92	1.66	1.27
30	36.2780	-93.6432	Kings	274.83	38.5	34	66	0.0	0.85	96.22	1.66	1.27
31	36.2777	-93.6517	Kings	275.30	39.8	34	66	0.0	0.85	96.22	1.66	1.27
32	36.2836	-93.6639	Kings	295.35	41.2	32	68	0.0	0.33	95.58	2.82	1.26
33	36.2919	-93.6586	Kings	296.38	42.1	32	68	0.0	0.33	95.58	2.82	1.26
34	36.3047	-93.6631	Kings	297.05	43.3	32	68	0.0	0.23	95.11	2.81	1.85
35	36.3077	-93.6531	Kings	297.48	44.5	32	68	0.0	0.23	95.68	2.83	1.26
36	36.2994	-93.6461	Kings	298.19	46.2	32	68	0.0	0.23	95.68	2.83	1.26
37	36.3134	-93.6383	Kings	300.47	46.8	32	68	0.0	0.23	95.68	2.83	1.26
38	36.3180	-93.6485	Kings	300.98	48	32	68	0.0	0.23	95.68	2.83	1.26
39	36.3150	-93.6634	Kings	301.44	48.9	32	68	0.0	0.23	95.68	2.83	1.26
40	36.3171	-93.6752	Kings	303.41	50.3	32	68	0.0	0.23	95.68	2.83	1.26
41	36.3284	-93.6671	Kings	304.21	51.2	32	68	0.0	0.23	95.68	2.83	1.26
42	36.3453	-93.6419	Kings	310.06	52.4	31	69	0.0	0.23	95.69	2.82	1.26
43	36.3576	-93.6536	Kings	312.16	53.4	31	69	0.0	0.23	95.69	2.82	1.26
44	36.3718	-93.6595	Kings	343.04	54.3	29	71	0.0	0.23	95.70	2.81	1.26
45	36.3877	-93.6563	Kings	345.41	55.2	29	71	0.0	0.23	95.70	2.81	1.26

Sampling Site Characteristics - page 2

Site	Latitude	Longitude	Location	Area(mi^2)	River Miles	% AG	% Forest	% Urban	S_stone%	Shale %	Dolo %	Lime %
46	36.3928	-93.6549	Kings	346.12	56.8	29	71	0.0	0.23	95.70	2.81	1.26
47	36.3957	-93.6408	Kings	346.45	57.8	30	70	0.0	0.23	95.70	2.81	1.26
48	36.3937	-93.6375	Kings	346.51	58.7	30	70	0.0	0.23	95.70	2.81	1.26
49	36.3941	-93.6366	Kings	346.54	60.4	30	70	0.0	0.23	95.70	2.81	1.26
50	36.4016	-93.6294	Kings	510.78	61.8	31	69	0.1	1.29	87.84	10.24	0.62
51	36.4068	-93.6479	Kings	512.28	63.9	31	69	0.1	1.29	87.84	10.25	0.62
52	36.4164	-93.6351	Kings	523.62	64	31	69	0.1	1.29	87.84	10.25	0.62
53	36.4273	-93.6218	Kings	525.01	64.9	31	69	0.1	1.29	43.68	54.41	0.62
54	36.4210	-93.6059	Kings	527.03	65.6	31	69	0.1	1.29	87.84	10.25	0.62
55	36.4424	-93.5978	Kings	543.83	66	32	68	0.1	1.29	87.84	10.25	0.62
56	36.4621	-93.6128	Kings	549.62	66.8	32	68	0.1	1.29	87.84	10.25	0.62
57	36.4633	-93.5951	Kings	554.93	73.3	32	68	0.1	1.29	87.84	10.25	0.62
58	36.4768	-93.5962	Kings	555.59	79.7	32	68	0.1	1.29	87.84	10.25	0.62
59	36.4773	-93.5888	Kings	555.93	82.8	32	68	0.1	1.29	87.84	10.25	0.62
60	36.4835	-93.5972	Kings	558.23	85.1	32	68	0.1	1.29	87.84	10.25	0.62
61	36.4942	-93.5965	Kings	559.98	90.5	32	68	0.1	1.29	87.84	10.25	0.62
62	36.4814	-93.5775	Kings	560.80	95.1	32	68	0.1	1.29	87.84	10.25	0.62
65	36.0010	-93.4766	Sweden	4.15	5	2	98	0.0	0.48	91.31	8.21	0.00
66	36.0252	-93.4912	Sweden	9.60	3	19	81	0.0	0.70	93.22	6.08	0.00
67	36.0371	-93.5087	Sweden	19.97	1.1	29	71	0.0	0.35	93.55	6.10	0.00
68	36.1031	-93.4773	Dry Fork	4.35	18.3	63	37	0.0	1.67	91.12	7.21	0.00
69	36.1423	-93.4792	Dry Fork	17.33	15.4	41	59	0.0	1.54	93.52	4.94	0.00
70	36.1675	-93.5367	Dry Fork	34.19	9.8	37	63	0.0	1.29	93.17	5.54	0.00
71	36.2066	-93.6147	Dry Fork	50.09	2	30	70	0.0	2.12	91.81	6.07	0.00
72	36.2013	-93.7080	Pine	0.80	3.8	0	100	0.0	20.74	0.00	79.26	0.00
73	36.1967	-93.6905	Pine	3.32	2.3	1	99	0.0	25.86	0.00	74.14	0.00
74	36.2184	-93.7095	Pine	7.74	0.6	13	87	0.0	30.36	0.00	69.64	0.00
75	36.2012	-93.4729	Piney	2.04	11.8	97	3	0.0	0.19	0.00	99.78	0.00
76	36.2203	-93.5183	Piney	12.53	8.5	65	35	0.0	11.23	0.41	86.18	2.19
77	36.2267	-93.5463	Piney	22.35	6.7	56	44	0.0	15.46	0.28	60.41	23.85
78	36.2262	-93.5770	Piney	25.87	4.6	50	50	0.0	6.02	0.21	75.48	18.28
79	36.2527	-93.6015	Piney	39.70	2.8	38	62	0.0	2.27	0.75	83.16	13.82
80	36.2508	-93.4453	Osage	96.20	26.9	27	73	0.0	6.47	77.94	12.69	2.89
81	36.3130	-93.5178	Osage	117.00	17.6	26	74	0.0	5.43	56.52	35.96	2.09
82	36.3341	-93.5747	Osage	141.80	9.8	29	71	0.0	5.41	56.37	36.05	2.16
83	36.3528	-93.5898	Freeman	3.44	0.1	75	10	15.0	0.00	0.00	0.00	100.00
84	36.3529	-93.5913	Osage	153.65	7	31	69	0.3	5.41	56.28	36.16	2.15
85	36.4305	-93.6402	Bee	3.98	0.9	97	3	0.0	0.00	6.27	62.01	31.73
86	36.4341	-93.6424	Bee	3.56	1.6	1	99	0.0	0.00	6.27	62.01	31.73
87	36.4345	-93.6419	Bee	1.71	2.4	0	100	0.0	0.00	6.27	62.01	31.73
88	36.4091	-93.5705	Clabber	2.69	3	79	21	0.0	0.00	0.00	0.00	100.00
89	36.4125	-93.5675	Clabber	2.36	3.6	81	19	0.0	0.00	0.00	0.00	100.00
90	36.4080	-93.5720	Clabber	7.37	2.3	78	22	0.0	0.00	0.00	0.26	99.74
91	36.4070	-93.5753	Clabber	10.75	1.3	68	30	2.0	0.00	0.00	0.26	99.74

APPENDIX B

"Sample Concentrations and Percentages"

Sample Concentrations and Percentages - page 1

Site	Location	PIV	Broilers	OM%	SAND%	Sed-P	Al%	Fe%	Ca%	Mn(ppm)
1	Kings	1.1	1	4.6	69.9	470	1.3	4.4	0.08	2230
2	Kings	1.1	16	1.9	96.0	500	0.8	5.7	0.03	1080
3	Kings	0.7	17	1.8	90.3	310	0.6	3.3	0.16	555
4	Kings	0.3	17	1.4	96.4	380	0.6	3.7	0.05	445
5	Kings	0.3	20	1.8	85.6	280	0.5	2.2	0.08	545
6	Kings	0.3	28	1.5	94.0	220	0.4	1.7	0.08	125
7	Kings	0.4	49	1.0	94.5	140	0.2	1.2	0.04	170
8	Kings	0.4	49	0.6	98.2	110	0.2	1.0	0.05	240
9	Kings	0.4	49	0.8	92.7	120	0.2	0.7	0.03	90
10	Kings	0.4	49	1.1	94.4	140	0.2	1.0	0.06	105
11	Kings	0.4	49	0.3	98.5	60	0.1	0.7	0.03	140
12	Kings	0.4	49	0.3	99.1	70	0.1	0.7	0.02	95
13	Kings	0.4	49	0.3	98.8	70	0.1	0.7	0.04	85
14	Kings	0.4	57	0.4	97.0	70	0.1	0.7	0.04	125
15	Kings	0.5	73	11.1	39.9	380	0.8	1.9	0.6	405
16	Kings	0.5	73	2.5	81.1	160	0.3	1.0	0.23	180
17	Kings	0.5	73	0.3	97.9	7	0.1	0.6	0.03	140
18	Kings	0.5	73	0.6	94.5	100	0.2	0.7	0.05	190
19	Kings	0.5	74	0.3	98.3	70	0.1	0.5	0.03	45
20	Kings	0.6	97	0.6	96.8	80	0.2	0.6	0.06	180
21	Kings	0.6	97	0.3	98.9	50	0.1	0.5	0.03	85
22	Kings	0.6	97	0.4	96.6	60	0.1	0.5	0.03	65
23	Kings	0.7	155	0.5	99.1	70	0.1	0.7	0.03	85
24	Kings	0.7	155	5.6	98.2	80	0.1	0.6	0.04	80
25	Kings	0.7	155	0.4	99.1	50	0.1	0.6	0.03	85
26	Kings	0.7	155	16.6	87.5	130	0.3	0.9	0.13	71
27	Kings	0.7	155	0.4	99.1	70	0.1	0.6	0.03	95
28	Kings	0.8	219	4.0	86.0	270	0.5	1.0	0.38	285
29	Kings	0.8	219	0.5	97.5	80	0.1	0.7	0.05	80
30	Kings	0.8	219	0.5	96.2	80	0.2	0.6	0.1	120
31	Kings	0.8	219	0.3	98.9	60	0.1	0.6	0.05	80
32	Kings	0.8	227	0.4	98.3	60	0.1	0.5	0.11	85
33	Kings	0.8	227	0.8	95.7	60	0.1	0.6	0.07	105
34	Kings	0.8	227	0.3	98.5	50	0.1	0.5	0.08	55
35	Kings	0.8	227	0.3	99.1	50	0.1	0.5	0.01	90
36	Kings	0.8	227	1.1	87.1	130	0.3	0.8	0.12	340
37	Kings	0.8	227	0.4	99.3	70	0.1	0.6	0.03	100
38	Kings	0.8	227	0.4	95.4	70	0.2	0.6	0.05	135
39	Kings	0.8	227	0.3	99.0	110	0.2	1.1	0.05	205
40	Kings	0.7	227	0.4	98.6	100	0.2	0.9	0.05	185
41	Kings	0.7	227	8.9	96.9	50	0.1	0.4	0.03	85
42	Kings	0.7	227	0.4	98.7	50	0.1	0.5	0.04	45
43	Kings	0.7	227	0.3	98.2	40	0.1	0.4	0.03	40
44	Kings	0.7	233	0.5	96.7	60	0.2	0.5	0.06	70
45	Kings	0.7	233	0.3	98.8	50	0.1	0.5	0.06	90

Sample Concentrations and Percentages - page 2

Site	Location	PIV	Houses	OM%	SAND%	Sed-P	Al	Fe%	Ca(%)	Mn(ppm)
46	Kings	0.7	233	0.2	98.7	40	0.1	0.4	0.04	65
47	Kings	0.7	233	0.2	98.0	40	0.1	0.4	0.05	70
48	Kings	0.7	233	0.2	99.1	90	0.1	0.7	0.04	120
49	Kings	0.7	233	0.3	98.1	100	0.1	0.6	0.07	125
50	Kings	0.8	403	0.7	98.4	60	0.1	0.4	0.05	85
51	Kings	0.8	412	0.4	98.6	80	0.1	0.5	0.06	80
52	Kings	0.8	412	1.0	91.1	150	0.2	0.7	0.33	125
53	Kings	0.8	412	0.7	94.1	150	0.2	0.7	0.14	205
54	Kings	0.8	416	0.4	99.1	70	0.1	0.5	0.03	105
55	Kings	0.8	461	0.7	92.1	160	0.3	0.8	0.12	245
56	Kings	0.8	461	0.3	98.2	90	0.1	0.6	0.06	85
57	Kings	0.8	461	4.0	69.2	360	0.5	1.1	0.78	300
58	Kings	0.8	461	0.7	93.7	130	0.2	0.6	0.13	125
59	Kings	0.8	461	7.1	41.3	340	1.3	1.6	0.89	1000
60	Kings	0.8	461	3.0	51.6	310	0.5	1.1	0.6	320
61	Kings	0.8	461	0.4	98.9	190	0.2	1.3	0.05	220
62	Kings	0.8	461	0.3	98.4	90	0.1	0.7	0.06	110
65	Sweden	0.0	0	1.1	96.5	380	0.5	2.4	0.1	600
66	Sweden	0.0	0	1.2	94.8	210	0.4	2.0	0.07	675
67	Sweden	0.0	0	1.1	95.8	270	0.4	2.1	0.09	620
68	Dry Fork	0.0	0	1.9	95.4	220	0.4	1.9	0.09	295
69	Dry Fork	0.1	1	2.3	92.7	310	0.5	2.6	0.16	555
70	Dry Fork	0.7	23	0.9	97.0	160	0.3	1.6	0.09	295
71	Dry Fork	0.9	45	0.5	98.6	90	0.2	0.8	0.06	85
72	Pine	0.0	0	3.3	42.9	180	1.8	2.0	0.27	1010
73	Pine	0.0	0	1.6	90.2	210	0.6	1.1	0.16	540
74	Pine	1.7	13	1.0	94.3	100	0.5	1.0	0.05	780
75	Piney	9.8	20	3.3	84.1	310	0.7	2.1	0.31	295
76	Piney	4.7	59	0.5	97.3	130	0.2	1.1	0.12	220
77	Piney	3.8	84	5.9	59.6	610	0.7	1.7	1.12	260
78	Piney	3.4	87	1.1	94.5	180	0.5	1.2	0.17	655
79	Piney	2.3	93	0.6	98.8	70	0.2	0.7	0.06	195
80	Osage	0.3	25	0.8	93.3	180	0.2	1.5	0.1	305
81	Osage	0.6	66	7.7	40.6	560	0.9	2.0	0.68	1050
82	Osage	1.0	135	5.5	66.3	350	0.5	1.5	0.54	535
83	Freeman	0.0	0	10.2	36.8	1280	0.8	1.7	2.51	1190
84	Osage	1.0	148	2.3	75.7	300	0.4	1.2	0.4	400
85	Bee	0.0	0	3.9	21.3	170	2.1	2.7	0.26	925
86	Bee	0.0	0	11.7	24.1	640	1.1	1.4	0.59	1130
87	Bee	0.0	0	12.8	21.9	980	1.3	1.8	0.71	1630
88	Clabber	2.6	7	15.0	21.1	830	1.2	1.6	3.36	950
89	Clabber	3.0	7	11.4	42.7	720	0.9	1.6	3.5	950
90	Clabber	3.3	24	8.0	51.6	450	1.0	1.9	1.55	1160
91	Clabber	3.1	33	12.2	21.0	620	1.2	1.6	2.65	620

APPENDIX C

"Units Guide"

Units Guide

UNIT	DESCRIPTION
Latitude, Longitude	UTM Zone 15 Coordinate System
Area	Drainage area above each sample location in sq. miles
Riv. Mi.	Distance from headwaters to each sample location in miles
AG, Forest, Urban	Percent of each use in drainage area above sample locations
PIV	# of chicken houses divided by each sample's upstream drainage area
Broilers	Total # of chicken houses above each sample location
OM, Sand	Percentage of each sediment sample
Sed-P	P concentration of each sample as measured in *u*g/g
Fe, Al, Ca	Percentage of each sediment sample
Mn	Mn concentration of each sample as measured in ppm
s_stone, shale, dolo, lime	Percentage of each bedrock unit in the drainage area above each monitoring location

10,000 ppm = 10,000 *u*g/g = 10,000 mg/kg = 1%