ROADWAY EFFECTS ON THE HYDROLOGIC REGIME OF TEMPORARY WETLANDS IN THE MISSOURI RIVER FLOODPLAIN IN MISSOURI

In Partial Fulfillment

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Masters of Science

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by

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ABSTRACT

The effects of roadways on wetland ecosystems are not clearly understood, although alterations of wetland hydrologic regimes have been frequently observed (Nunnery and Richardson 1997). The goal of this research was to assess the effects of roadways on the hydrologic regime of temporary wetland basins within the agricultural landscape of the Missouri River floodplain from Hartsburg to Independence, Missouri. This study is part of a larger existing research project designed by the Missouri Department of Conservation to evaluate habitat use by various waterfowl and shorebirds in the Missouri River floodplain (Raedeke et al. 2003). Aerial surveys were conducted for sixteen 1.6 km wide survey transects, bluff-to-bluff and perpendicular to the Missouri River from fall 2000 through fall 2002 to record the extent of surface water for individual wetland basins. A Geographic Information System (GIS) was used to determine the inundation and shape characteristics for selected wetland basins within the transects. Roads and other anthropogenic alterations of wetlands within the study area were inventoried using GIS and Global Positioning System (GPS).

When unaltered basins were compared to basins affected by roads, agricultural ditches and levees, those basins affected by roads were most similar to unaltered basins, indicating that incidental effects from roads may not be as severe as effects from other anthropogenic alterations. Findings from these analyses indicate that roads, especially state roads, tend to impound water, resulting in basins being inundated for longer periods of time with less fluctuation in the amount of surface water area than unaltered basins and basins affected by local and private roads. This research provides information for agencies tasked with protecting or enhancing wetland systems and can be used to aid in

the development of future goals and objectives for conservation or restoration of wetlands. Continued research is required to define roadway impacts on the hydrologic regime of wetlands and explore methods to minimize these impacts.

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CHAPTER 1.

INTRODUCTION

Roads are the most ubiquitous structures created by humans (Hunter 1996). In the United States, there are approximately 6.2 million km in the public road system (Transportation Research Board 2001) used by approximately 200 million vehicles (Forman and Alexander 1998). With a mean density of 1.2 km/km^2 (Forman 2000), public roads and their associated right-of-ways cover approximately 1.5% of the land area in the United States (Turrentine et al. 2002), which directly or indirectly affects an estimated 18 – 22% of U.S. land area (Forman 2000). In Missouri, the Department of Transportation (MoDOT) directly owns roughly 1560 km^2 and maintains in excess of 51,500 km of primary roadways (Missouri Department of Transportation 2001a). The mean density of all public roads in Missouri is approximately 2.91 km/km^2. Public roadways traverse varied landscape settings by utilizing features including fill, bridges and culverts. The impact of these structures on wetlands is not clearly understood, although alteration of hydrologic conditions has been observed (Nunnery and Richardson 1997). As the human population continues to expand and transportation needs increase, road construction will have an increasing influence on the quantity, quality and functionality of remaining wetland systems (Nunnery and Richardson 1997). As transportation networks expand with the advent of modern construction methods and equipment, impacts on wetlands have become increasingly severe (Zeedyk 1996). Both federal and state transportation agencies have the broad responsibilities of planning, construction, and operation of an environmentally sound, effective, safe and economical transportation infrastructure (Garrett and Bank 1995).

Roadways can affect wetlands in a number of ways. In addition to the obvious physical alterations attributable to the initial construction activities, there are often physical and biological effects that extend well beyond the construction zone and right-of-way corridor (Winter 2002). Roads and their associated drainage systems transform the physical conditions and alter the water flow under and adjacent to it by altering several characteristics of the site: soil density, soil moisture content, surface and subsurface -water flow, and patterns of runoff and sedimentation. Long-term use of roads leads to soil compaction. During dry periods, the moisture content of the soil declines, probably in response to the changes in the soil porosity (Trombulak and Frissell 2000). Highway fills, ditches, culverts, and bridges can intercept, inhibit, enhance or redirect surface and shallow subsurface water, efficiently rerouting the flow and causing changes in the timing and routing of natural runoff among streams, wetlands and their riparian ecosystems (Thibodeau and Nickerson 1985, Winter 2002). These effects cascade beyond the immediate site, because wetlands are, by definition (Shuldiner et al. 1979a), “those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions” (Environmental Laboratory 1987). As such, each wetland reflects even the smallest changes in the waters that supply it and, in turn, transmit these changes to downstream wetlands (Shuldiner et al. 1979a).

Ecological patterns and processes form broad patterns across the landscape, whereas the traditional transportation planning process is meticulously focused on a narrow strip of land close to an existing or proposed roadway (Forman and Deblinger 2000). Today, however, that view is changing. It has become not only feasible, but also desirable to accommodate ecosystem value in the construction and maintenance of a transportation infrastructure (Zeedyk 1996). Although wetland sites have always posed a challenge to engineers who design and construct highways, there are now additional legal and environmental concerns that must be considered prior to construction (Shuldiner et al. 1979a). Consequently, a need exists to understand the impacts of roadways on wetlands and provide guidance in making decisions when wetlands are involved. Determining these effects is a complex problem involving many aspects of site biology and hydrologic conditions (Shuldiner et al. 1979b). Assessing the potential ecological impacts of a proposed activity first requires the determination of physical changes in the water regime (Shuldiner et al. 1979a). Deliberate and methodical monitoring has been proposed to ensure that projects minimize adverse effects, as short-term environmental assessments of plant and animal communities are likely to underestimate effects due to a lag in species response time to perturbations (Findlay and Bourdages 2000).

Study Objectives

The primary goals of this research are to assess the general impacts of roadways on wetland surface hydrologic regime by characterizing the nature of the alteration and to increase the understanding of the relationship between roads and wetlands and the indirect and undocumented changes in wetland hydrologic regime. The hydrologic regime of a wetland refers to the annual and seasonal patterns of water levels, as well as the flow, frequency, duration and timing of flooding. Frequency refers to the number of times a wetland is flooded within a given period. Duration refers to the amount of time that a wetland has standing water. The hydrologic regime of wetlands affects many abiotic factors, including soil and water chemistry, nutrient availability and sediments. These, in turn, influence the species composition and richness that develop in a wetland. Hydrology is likely the single most important factor in establishing and maintaining wetland types and processes. As such, seemingly minor changes in the hydrologic regime of a wetland can result in significant biotic alteration (Mitsch and Gosselink 2000).

The landscape of the Missouri River floodplain from Hartsburg to Independence, Missouri is complex, including many anthropogenic alterations, such as roads, road ditches, culverts, agricultural ditches and levees (Figure 1.1). The purpose and placement of agricultural ditches is to drain excess water from cropland as efficiently as possible. Occasionally, due to the topography of the landscape, complete drainage is not possible. Sometimes, agricultural ditches drain portions of a field into low-lying areas of the field, thus impacting as little highly productive cropland as possible. These areas are described as ‘agricultural ditch wetland complexes’ and may have a semi-permanent flooding regime because they are inundated except during the driest conditions. Levees are designed to provide a measure of protection from flooding by the Missouri River and other tributary streams. For this study roads were classified into three groups; private, local, and state. Private roads are generally constructed at the level of the surrounding landscape and were unimproved dirt surfaced. Local roads within the study area are largely constructed at the level of the surrounding landscape and are generally surfaced with gravel or may be unimproved dirt roads. State roads, or highways, have more advanced and exacting design standards, referring to many aspects of road construction, including lane widths, shoulder widths, pavement materials, roadside slopes, fill materials, compaction techniques and many additional aspects. Road ditches are designed to efficiently drain water away from the road surface and subsurface. Culverts and box culverts are designed and placed to aid in the transport of water away from the road. Temporary wetland basins are depressions in agricultural fields that were periodically inundated for short periods during this study. The Natural Resource Conservation Service classifies this type of wetland in agricultural landscapes as farmed temporary wetlands. Hereafter, I use basin to describe this wetland type.

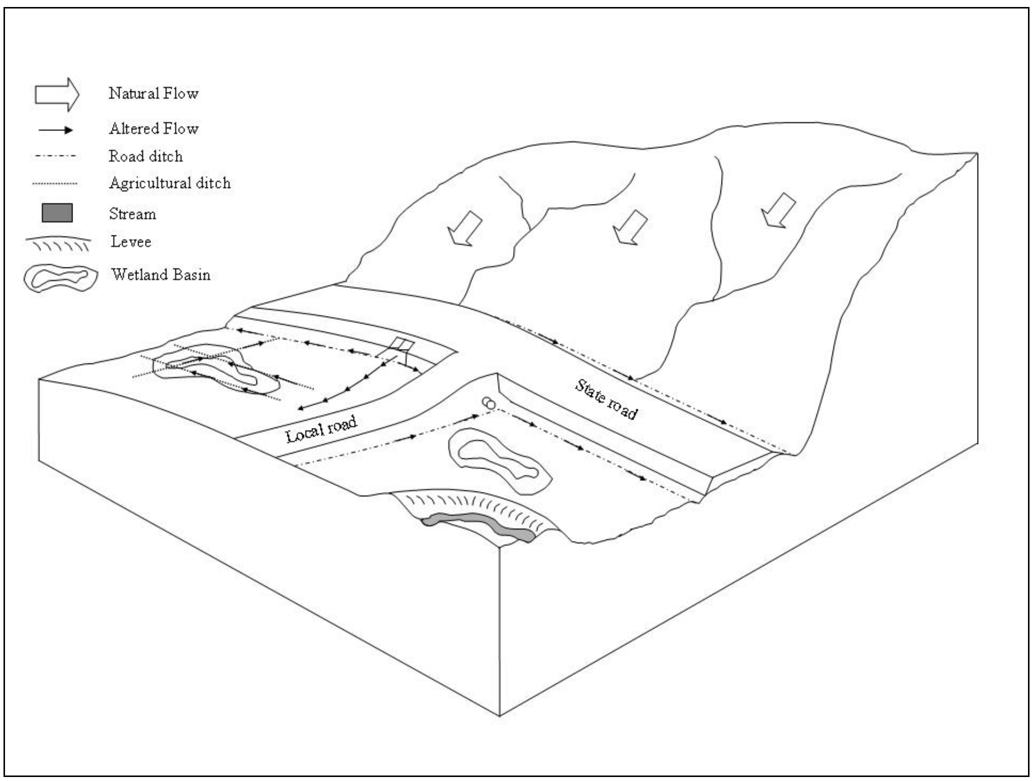


Figure 1.1: Anthropogenic alterations of the Missouri River floodplain. The outer polygon of a wetland basin represents the maximum area and the inner polygon represents the minimum area of flooding inundation for the wetland basins.

My first objective was to characterize and evaluate the effects of levees, agricultural ditches and state, local, and private roads on the inundation and shape characteristics of temporary wetland basins within a selected reach of the Missouri River floodplain. Few studies have been able to document the alteration of water flow and wetland hydrologic regime caused by roads. Although, the alteration of wetland hydrologic regime has been observed, the impact of roadways on wetland ecosystems is not clearly understood (Nunnery and Richardson 1997). In support of the first objective, my second objective was to characterize and document differences between roadway characteristics, such as use of fill material, roadside ditching, culverts, box culverts, and bridges and determine the distribution of roads, in the Missouri River floodplain from Hartsburg to Independence, Missouri. A third, supplementary, objective of my research was to document and examine the distribution of agricultural ditches within a selected reach of the Missouri River floodplain and evaluate the influence of road placement on the distribution of agricultural ditches.

CHAPTER 2.

BACKGROUND

Wetland Loss and Regulation

Wetlands have been steadily and rapidly disappearing across the country since the beginning of European settlement. Over the past two hundred years, the conterminous United States has lost more than half the original presettlement wetland acreage. This loss is primarily due to conversion to agriculture and human development. Missouri has lost approximately 87% of its original wetlands between the 1780's and 1980's (Dahl 1990).

There is no single wetland protection law, rather there is a collection of legislation combined to monitor and regulate human development within the wetland environment (Nunnery and Richardson 1997). Environmental analysis as related to transportation has been largely shaped by the National Environmental Policy Act of 1969 (NEPA) and the implementation of regulations established by the President's Council on Environmental Quality. NEPA was enacted to balance the effects of a wide range of environmental issues. It's enactment marked the beginning of the environmental review process for all federal actions (Laymon et al. 2001). Several single-focus regulations, such as Section 404 of the Federal Water Pollution Control Act of 1972 and subsequent amendments, known as the Clean Water Act, must also be addressed. Section 404 gives the U.S. Army Corps of Engineers regulatory authority over all dredge and fill activities in "waters of the U.S.", effectively including all wetlands. Under the Clean Water Act, any unavoidable destruction of wetlands for development generally requires that the lost wetland area, functions and values be replaced or mitigated by the developer. The Federal Highway Act of 1970 placed responsibility on the U.S. Department of Transportation Federal Highway Administration (FHWA) to fully consider adverse effects of transportation. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21) included measures and policies encouraging or requiring an approach to transportation development, which integrates management considerations for both natural and constructed environments (Garrett and Bank 1995). FHWA responded to the ISTEA by broadening its mission to reflect increasing national interest in developing an environmentally sensitive transportation system (Laymon et al. 2001). In the Strategic Plan for Environmental Research, the FHWA (1998) developed the strategic goal to "Protect and enhance the natural environment and communities affected by highway transportation." One of the wetland-specific objectives aims to "Develop approaches to analyze and minimize indirect and cumulative impacts of highway development, reconstruction, and maintenance on wetlands" (Federal Highway Administration 1998). The FHWA stated that, while methods to assess direct impacts of highways on wetland function are currently being advanced, there is little understanding of the indirect and cumulative effects of highways on wetlands. These impacts are currently unaccounted for under the Section 404 permit process. A better understanding of the indirect and cumulative impacts are essential for decision-makers to account fully for effects in transportation planning (Transportation Research Board 2002). The Missouri Department of Transportation also has developed a goal to "protect Missouri's environment and natural resources by making investments that are not only sensitive to the environment but also provide and encourage environmentally beneficial transportation choices" (Missouri Department of Transportation 2001b). This new emphasis on the environmental impacts of transportation is changing the framework of transportation planning.

The Missouri River and Its Floodplain

The Missouri River drains approximately one-sixth of the continental United States, encompassing 1.36 million km^2 in ten states (Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wyoming) (Figure 2.1). The river flows a total of 3,768 km from its headwaters near Three Forks, Montana, to its confluence with the Mississippi River in St. Louis, Missouri (Galat et al. 1998). The river drains four physiographic provinces: the Rocky Mountains (10.7 % of total area), the Great Plains (70.2% of total area), the Central Lowlands (17.2% of total area), and the Interior Highlands (1.9% of total area) (Galat et al. 1998). The westernmost tributaries of the Missouri River begin in the Rocky Mountains at elevations near 3350 m mean sea level and decrease to 120 m at the confluence with the Mississippi River (National Research Council 2002). Precipitation in the basin varies from an annual mean of 1000 mm in the Interior Highlands of the Missouri Ozarks to 300 mm in the dry upland plains of Wyoming, Montana, North and South Dakota (Kelmelis 1994). However, precipitation varies greatly within each of the physiographic provinces of the basin.

Figure 2.1: Missouri River basin.

Until channel modifications began in the 1800's, the Missouri River was composed of abundant braided channels, riparian lands, chutes, sloughs, backwater areas, side channels, migrating islands and sandbars. These riverine and floodplain habitats were created and maintained by a dynamic equilibrium of continuous erosion and deposition, brought about by flooding events that constantly reshaped the river channel and floodplain (Schmudde 1963). The river's course through highly erodible glacial soils of the Great Plains, coupled with recurrent flooding in the lower basin, resulted in major channel migrations and reconfigurations (Galat et al. 1998). Over time, especially during flood events, the physical features of a stream and its floodplain are created and modified by interactions among water, debris, erosion and sediment deposition (Jones et al. 2000). Erosion within the Missouri River floodplain tends to be greatest as floodwaters are rising, and substantial deposition of sediments occurs as floodwaters recede (National Research Council 2002).

In 1832, Congress endorsed an act approving the removal of snags from the river (Ferrell 1996). In 1884 the Missouri River Commission was formed (Ferrell 1996), having the mission to improve navigation on the river, by "contracting the width of the stream to comparative uniformity and fixing the location and direction of the channel by protecting all banks exposed to the erosive action of the current" (Funk and Robinson 1974). During its 18 years of development and maintenance of the Missouri River, the Commission employed revetments of woven willow and rock to stabilize banks and pile dikes to narrow the channel and close off chutes. However, with the expansion of railroad networks, the need for barge traffic declined and in 1902 the Missouri River Commission was dissolved and responsibility for the Missouri River was given directly to the U.S. Army Corps of Engineers (Funk and Robinson 1974). In 1912, Congress approved a navigation channel 1.8 m in depth and 61 m wide (Ferrell 1996), extending from Kansas City to the mouth, which was not completed until after 1933 (Funk and Robinson 1974). The Rivers and Harbors Act of 1945 authorized increasing the channel depth to 2.7 m and width to 91.4 m, extending from Sioux City, Iowa to the mouth (Galat et al. 1996). This task was largely completed by 1967 (Funk and Robinson 1974). During this time, an extensive network of levees and drainage ditches was developed to reduce the frequency and intensity of flooding on agricultural lands within the floodplain (Funk and Robinson 1974).

Today the lower Missouri River has been made narrower, deeper and swifter, constrained to a 2.7 m navigation channel by levees, rock dikes and revetments. Theses structures served to narrow and focus the current to maintain a self-scouring channel for 1,170 km from St. Louis, Missouri to Sioux City, Iowa (Jacobson et al. 2001; Figure 2.2). These dikes serve to deflect water toward the center of the channel. Silt then accumulates behind the dikes, creating new land and a narrower river. Between 1879 and 1972 the river has been shortened by 73.4 km from Rulo, Nebraska to the confluence (Funk and Robinson 1974). Approximately 50% of the original surface area has been lost and unconnected islands were practically eliminated, being reduced by about 98% (Funk and Robinson 1974).

In addition to the alteration resulting from the channelization of the river and the development of levee and drainage systems, the Pick and Sloan Plan was authorized by the Flood Control Act of 1944 to construct six dams on the mainstem of the Missouri River (Galat et al. 1996); Gavins Point (near Yankton, South Dakota), Fort Randall (near Wagner, South Dakota), Big Bend (Fort Thompson, South Dakota), Oahe (Pierre, South Dakota), Garrison (Riverdale, North Dakota) and Fort Peck (near Glasgow, Montana) (Figure 2.2). Prior to impoundment, the river's hydrograph was characterized by a bimodal flood pulse (Hesse and Mestl 1993; Figure 2.3). The first pulse, or "April rise" (Galat and Lipkin 2000), was a result of snow melt in the Great Plains and breakup of ice in the river and its tributaries. The second pulse, or "June rise", was a result of snow melt in the Rocky Mountains and rainfall in the Great Plains and lower basin (Hesse et. al.

1989). Regulation of the river has served to truncate the two flood pulses and augment summer and autumn flows in order to facilitate navigation (Hesse and Mestl 1993). The six large mainstem reservoirs also have severely reduced the sediment load carried downstream by the river (Hesse et. al. 1988). Prior to impoundment the Missouri River's contribution of sediment load to the Mississippi was so great that turbidity was increased by six-fold downstream from the confluence in St. Louis, Missouri (Galat et al. 1996). Today the sediment load of the Missouri River has been greatly reduced. The majority of the sediments once carried through the system are being deposited within the reservoir system (National Research Council 2002).

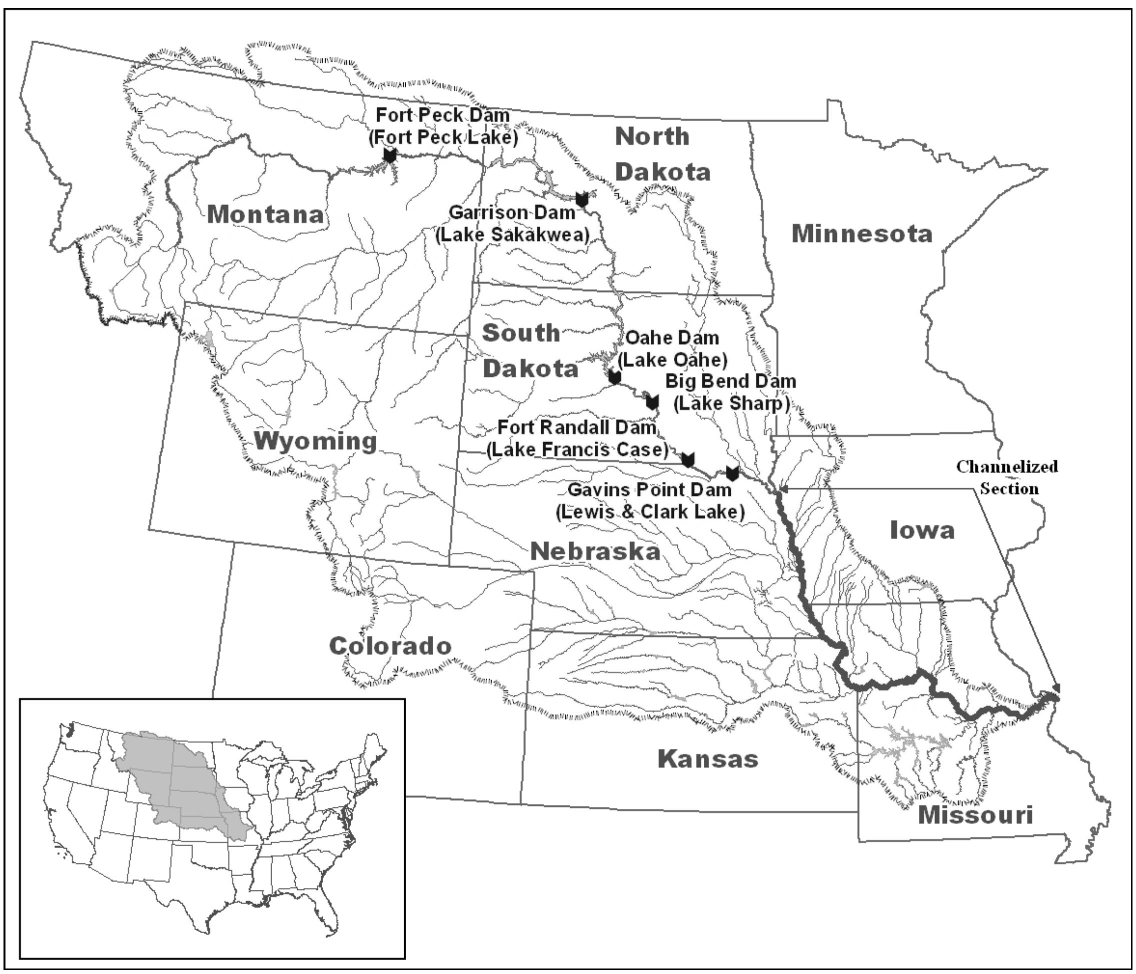


Figure 2.2: Locations of mainstem dams on the upper Missouri River and channelization extent of the lower Missouri River.

With the westward expansion of the 1800's, cultivation of the fertile floodplain soils began in earnest, clearing thousands of hectares of floodplain forest for cropland. The establishment of dikes and levees along the lower reaches of the river and construction of dams on the upper reaches of the river provided some control of the river and furthered the conversion of native vegetation to cropland (Hesse et al. 1988). It was estimated that cultivated land in the floodplain increased 43-fold over a 90-year period (1892 – 1982) from the mouth of the Missouri River to Ponca, Nebraska. During this period deciduous vegetation, wetlands, sandbars and grasslands were reduced by 41%, 39%, 97% and 12% respectively (Hesse et al. 1988).

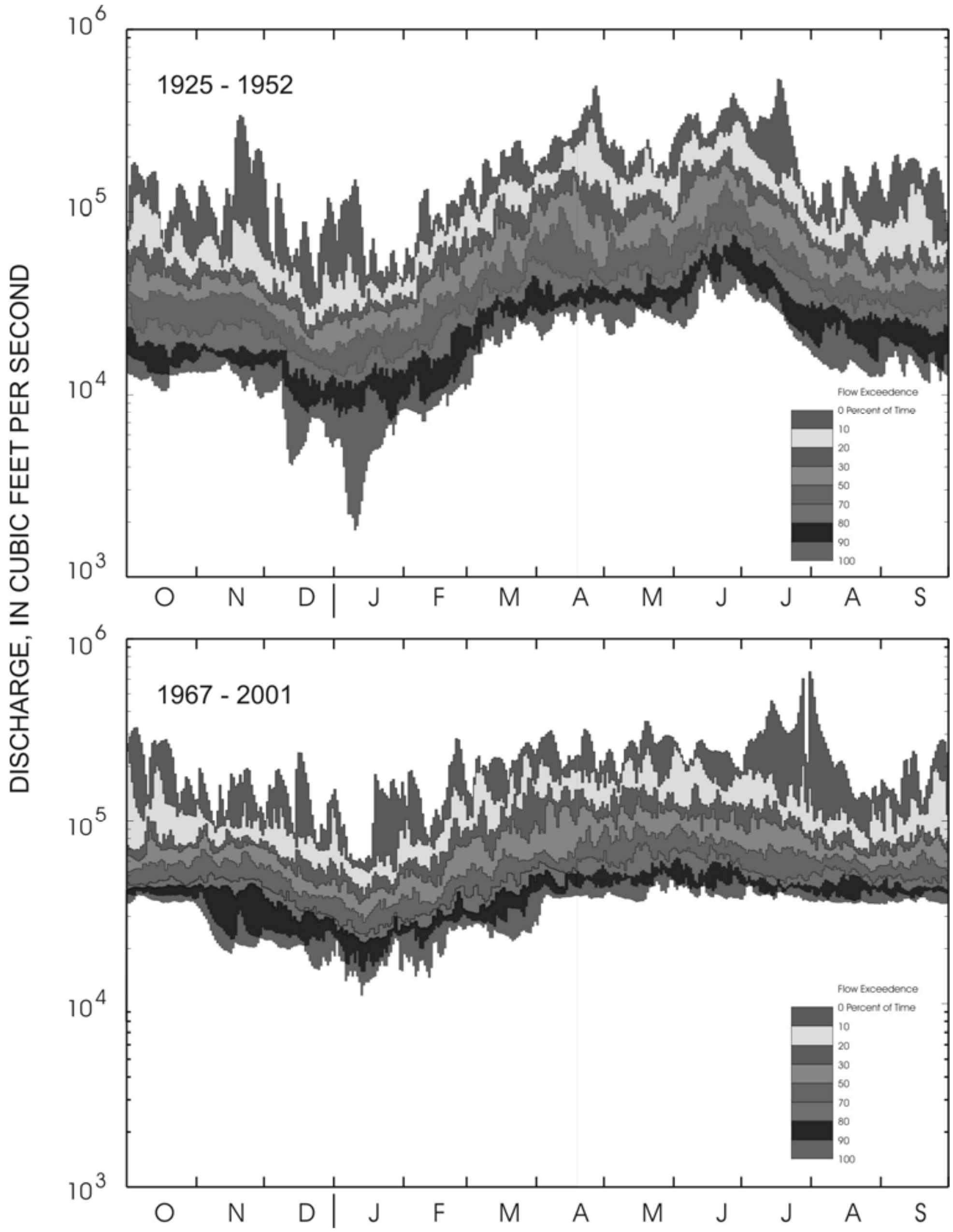


Figure 2.3: Pre-regulation (top) and post-regulation (bottom) duration hydrographs of the Missouri River at Boonville, Missouri, showing discharges and percentages of time the discharge indicated is equaled or exceeded. The data are graphed separately for each day of the year. Source: Jacobson et al. 1999.

CHAPTER 3.

STUDY AREA

General Description

The study area spanned 217 river km in the lower Missouri River floodplain between Hartsburg and Independence Missouri, USA (Figure 3.1). The Missouri River effectively horizontally bisects the state of Missouri, flowing southward to Kansas City and then turning generally eastward toward its mouth in St. Louis, Missouri. The glaciated Dissected Till Plains physiographic province lies to the north of the Missouri River and the Ozark Highlands and Western or Osage Plains lie to the south and southwest respectively (Thom and Wilson 1980). Throughout the study area, the river is bordered by flat bottomland areas, which are incised 70 to 120 m below the adjacent upland surface (Kelmelis 1994). Relief in this section of the floodplain is very low, usually not more than 2 m within a kilometer, including low escarpments of alluvial terrace resulting from shifts of the river channel (Nigh and Schroeder 2002).

From Independence to Glasgow, Missouri the floodplain is quite broad, widening to as much as 16 km (Figure 3.1; Figure 3.2), bounded by the conspicuous bluffs of the adjacent loess hills (Unklesbay and Vineyard 1992). Bedrock within this region is generally more than 9 m below the surface (Nigh and Schroeder 2002). The alluvial material consists primarily of Pleistocene and Holocene gravel, sand and silt transported from glaciated areas to the north overlaid by recent alluvium (Nigh and Schroeder 2002). Streams within this portion of the study area flow south into the Missouri River. The valley bottom in this section is described as broad and having a higher proportion of finetextured and poorly drained soils than the alluvial plain within the Ozark Highlands (Nigh and Schroeder 2002).

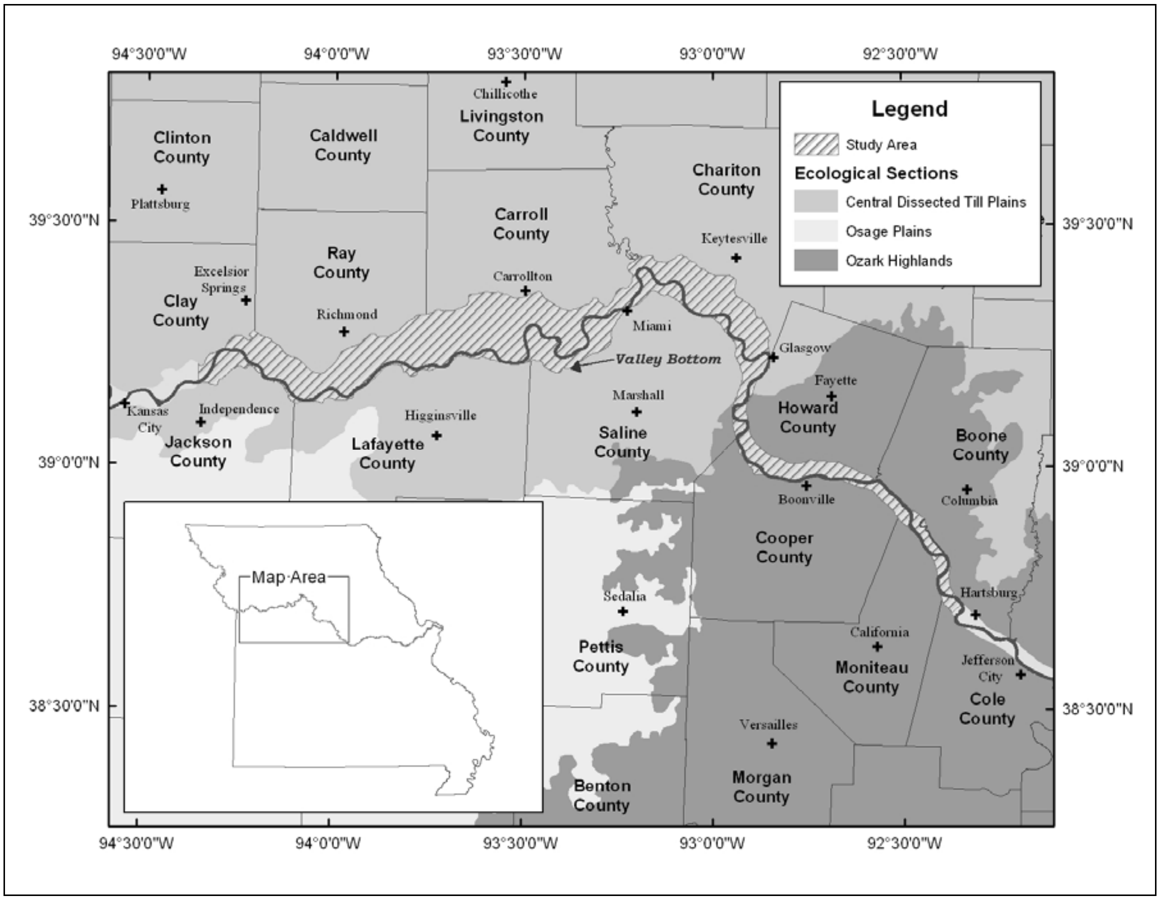


Figure 3.1: Study area within the Missouri River floodplain from Hartsburg to Independence, Missouri.

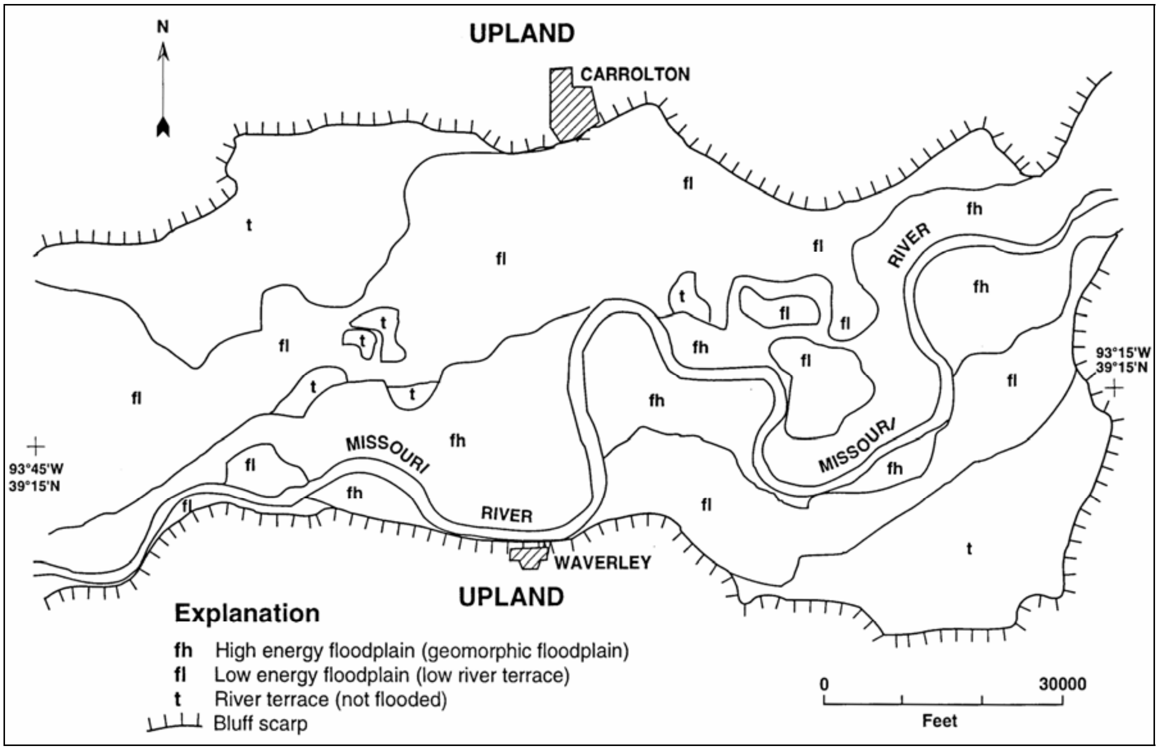


Figure 3.2: Missouri River floodplain in the area of Carrolton and Waverly, Missouri, which is typical of the floodplain between Independence and Glasgow, Missouri. Source: Kelmelis 1994.

From Glasgow, Missouri downstream, limestone of the Ozark foothills confines the floodplain to a narrower width, averaging about 3.4 km (Kelmelis 1994; Figure 3.1; Figure 3.3). The surrounding upland is underlain by almost horizontally stratified carbonate bedrock (limestones and dolomites) (Kelmelis 1994). This bedrock outcrops virtually continuously, bounding the river valley with intermittent limestone and sandstone bluffs of the Ozark Highlands (Nigh and Schroeder 2002). The numerous small streams within the Ozarks flow east or northeast to empty into the river.

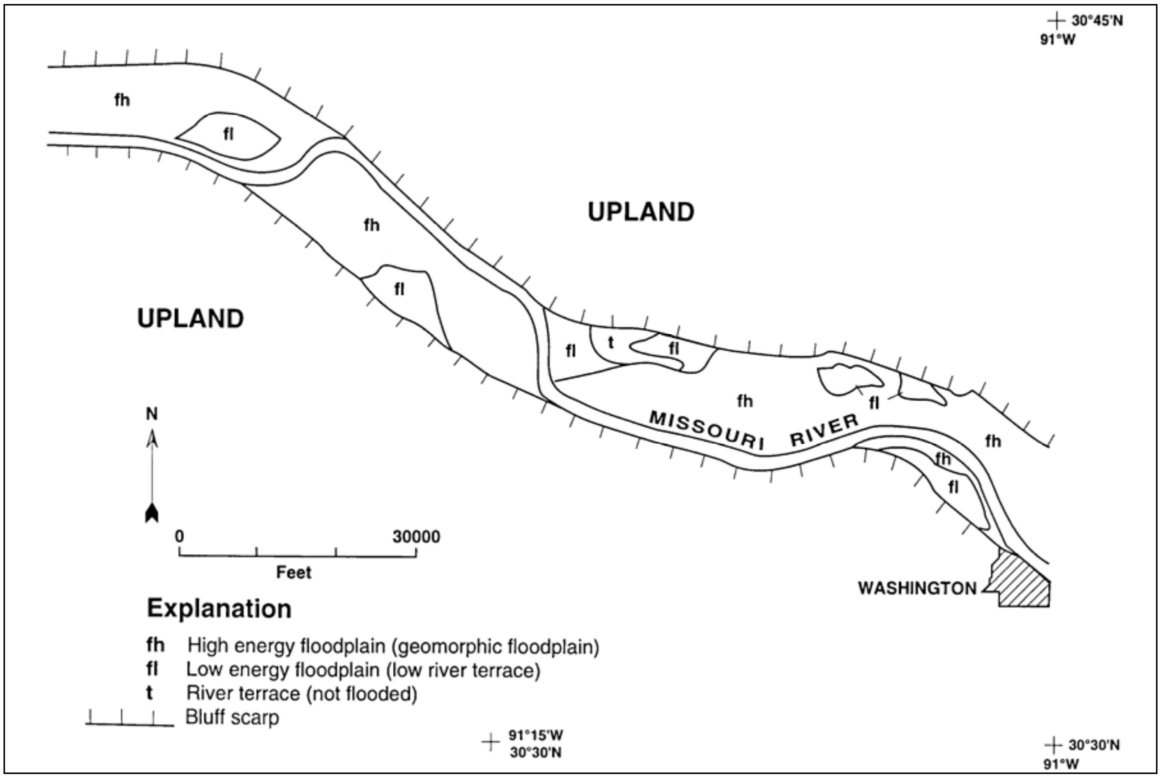


Figure 3.3: Missouri River floodplain in the Washington, Missouri area, which is typical of the floodplain between Glasgow and St. Charles, Missouri. Source: Kelmelis 1994.

Soils within the study area are largely alluvial, deep and highly productive (Thom and Wilson 1980), with little subsoil development (Nigh and Schroeder 2002). Texture and drainage of the soils vary depending on the position within the floodplain. Splay deposits near the river are often composed of sandy soils, such as the excessively drained Sarpy series. Back swamp or slack water areas further from the river often consist of clayey soils, such as the poorly drained Albaton and Waldron series. Natural levees are often composed of sandy-silty soils, such as the well-drained Haynie series. Due to the historical meandering river channel some soils have contrasting textures within their profile, reflecting changes in river locations over time (Nigh and Schroeder 2002).

Today the Missouri River floodplain is predominantly rowcrop agricultural land, taking advantage of these rich deep soils (United States Fish and Wildlife Service 1999). It was estimated that the amount of cultivated land in the Missouri River floodplain within the state of Missouri increased 65% in less than 150 years, from 18% in 1826 to 83% in 1972 (Bragg and Tatschl 1977). Corn and soybeans are the most common crops, but milo and winter wheat also are grown. Private and chartered levee and drainage districts are prevalent throughout the study area to help protect the private land within the floodplain from excessive water levels (United States Fish and Wildlife Service 1999).

The region is characterized by a mid-continental temperate climate marked by strong seasonality. Mean annual temperature from 1961 to1990 was about 12°C. Mean temperature was approximately -8° to -7°C in January and 31° to 32°C in July. Mean annual precipitation from 1961 to 1990 was approximately 1000 mm. Mean annual snowfall within the region is approximately 480 to 500 mm. The mean precipitation was less than 50 mm in January and about 100 mm in July. The growing season within the region averages 200 to 210 days (Nigh and Schroeder 2002).

CHAPTER 4.

METHODS

Landscape Sampling

This study is an enhancement and expansion of an existing research project designed by Missouri Department of Conservation (MDC) staff to evaluate the role of intensively managed wetlands, passively managed wetlands, and unmanaged temporary wetlands within the agricultural landscape of the Lower Missouri River floodplain for migratory waterfowl and shorebirds. Intensively managed wetlands included wetland pools on publicly owned and managed areas that are manipulated specifically for fall seed production (Raedeke et al. 2003). Passively managed areas included seasonal wetland basins on publicly owned areas that are minimally manipulated, having no water pumping capabilities, few internal levees and water control structures and little active soil manipulation. Unmanaged agricultural areas include temporary wetlands on privately owned lands that are frequently mechanically disturbed and tend to support annual rather than perennial plants (McColpin 2003). My research focuses on roadway effects on temporary wetlands in the agricultural landscape of the Missouri River floodplain.
MDC staff divided the agricultural landscape of the Missouri River into three sections based on different river and floodplain characteristics and defined 16 survey transects covering approximately 10 percent of each section (Raedeke et al. 2003). The first river section (RS1) extended westward from near Hartsburg, Missouri to Highway 240 north of Glasgow, Missouri (Raedeke et al. 2003; Figure 4.1). This section of the floodplain is described as being relatively narrow, averaging approximately 3.4 km in width (Kelmelis

1994), bound by limestone of the Ozark foothills. The second river section (RS2) extends from Highway 240 to Highway 41 in Miami, Missouri (Raedeke et al. 2003; Figure 4.1). The floodplain within this segment is broader than the first and is influenced by two tributaries, the Grand River and the Chariton River. The third river section (RS3) continues upstream from Highway 41 to US Highway 24 in Independence, Missouri and is characterized by an expansive floodplain (Raedeke et al. 2003; Figure 4.1). Sixteen US Army Corps of Engineers river miles were randomly selected and the transect was defined up stream as a 1.6 km wide, bluff-to-bluff section of the floodplain, perpendicular to the flow of the Missouri River (Figure 4.1). Five, 1.6 km wide bluff-to-bluff transects were selected in the first section of river floodplain (T01-T05), five transects were selected in the second section (T06-T10) and six transects in the third section of the river floodplain (T11-T16).

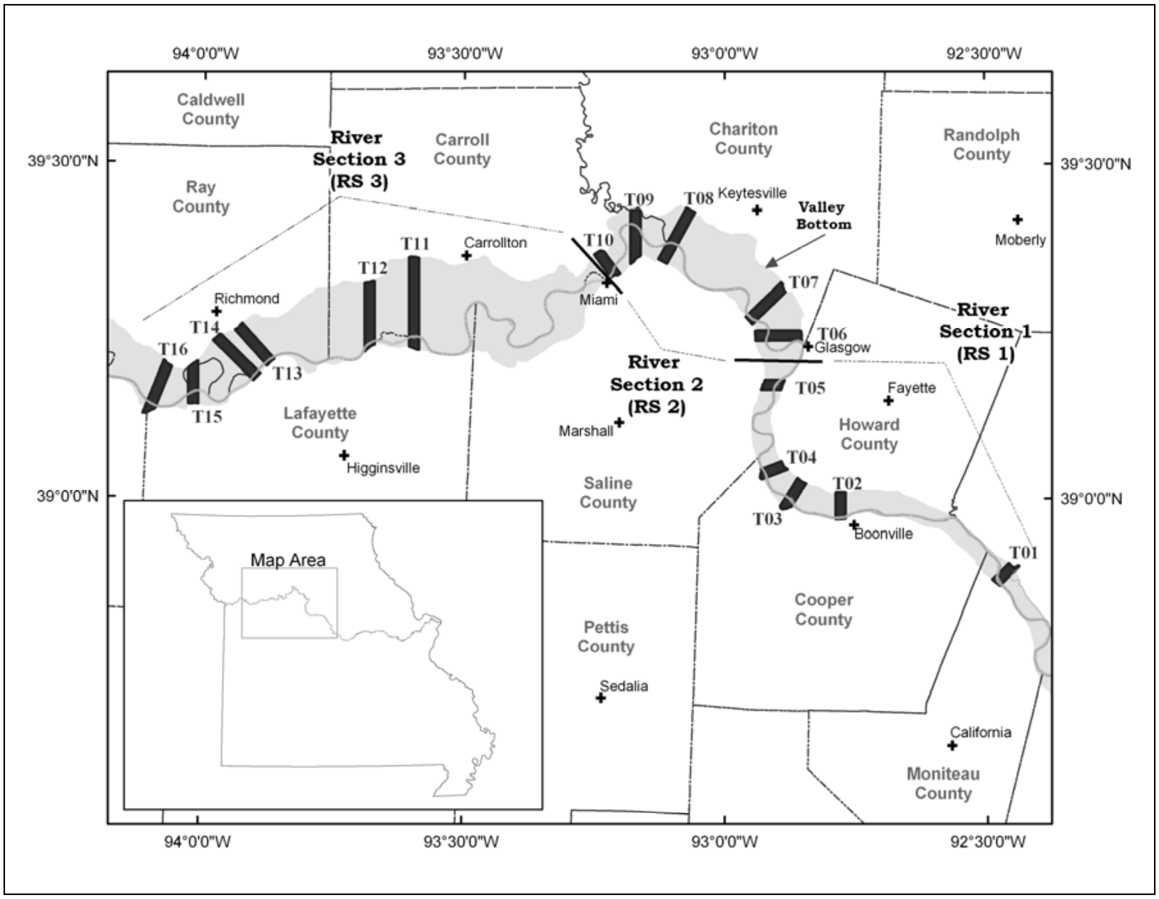


Figure 4.1: Locations of the sixteen transects within the three river sections of the Missouri River floodplain study area from Hartsburg to Independence, Missouri.

Wetland Basin Inundation and Shape Characteristics

To evaluate the effects of roadways on inundation and shape characteristics of selected wetland basins within the Missouri River floodplain the 16 transects were surveyed by helicopter to record the extent of wetland basin inundation, the spatial accuracy of the aerial surveys was validated, basin inundation and shape characteristics were summarized, an Analysis of Variance was preformed, and finally precipitation and river discharge data were obtained.

Wetland Basin Aerial Surveys

A combination of Digital Orthophoto Quarter-Quad (DOQQ, georectified digital image of an aerial photograph), Digital Raster Graphic (DRG, digital topographic maps) and National Wetlands Inventory data were used by Missouri Department of Conservation personnel to digitize and attribute the initial wetland basins within the sample transects. Beginning in September 2000, Missouri Department of Conservation personnel conducted aerial surveys over the 16 1.6 km wide survey transects, bluff-to-bluff and perpendicular to the Missouri River to determine the amount and distribution of surface water within each wetland basin. The aerial surface water surveys were conducted from fall 2000 through fall 2002 using a Bell Jet Ranger Helicopter (operated by MDC pilots) at approximately 150 m altitude (Raedeke et al. 2003). These flights were attempted bi-weekly during the spring and fall (Table 4.1), but due to weather and other unforeseeable events were actually collected somewhat less frequently. Spring surveys were conducted from late January or early February, when ice began to thaw and continued through May. Fall surveys were conducted from August or September and continued until surface water began to freeze. A total of 44 surveys were conducted; 9 in fall 2000, 10 in spring 2001, 11 in fall 2001, 9 in spring 2002 and 5 in fall 2002. A decision was made to end the surveys on 18 November 2002 due to dry conditions similar to the previous two falls (Raedeke et al. 2003).

Table 4.1: Survey dates from fall 2000 to fall 2002.

Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002
9/5	2/5	8/6	1/28	9/11
9/11	2/12	8/20	2/25	9/23
10/2	2/26	8/31	3/11	10/7
10/10	3/5	9/21	3/22	10/21
10/19	3/19	10/11	4/2	11/18
10/30	3/26	10/22	4/12	
11/6	4/2	10/29	4/29	
11/20	4/16	11/19	5/13	
12/4	4/30	12/10	5/29	
	5/15	12/19		
		12/28		

Wetland Basin Data Development

The extent of surface water for individual basins was assessed and recorded from low oblique aerial photography and videography taken as needed during each survey. For each portion of the floodplain surveyed, MDC staff estimated the extent of surface water from the aerial photography and/or videography. The extent of surface water was transferred (digitized) into a digital GIS coverage and database using ArcInfo 7.2.1 (Environmental Systems Research Institute, Inc. 1999), resulting in 44 separate coverages representing surface water area during each flight survey. ArcInfo was used to calculate the area and perimeter of each individual polygon for each flight survey, which was maintained in the individual INFO file of each ArcInfo coverage. MDC personnel were interested in these metrics at the landscape level; consequently each individual wetland was difficult to trace throughout the duration of the study. Therefore, a method was needed to extract the area and perimeter data for individual basins from all 44 surveys and compile that information into one dataset so that each basin could be tracked throughout the study. The 44 individual flight survey datasets were merged into a single dataset. This process combined all polygons with the area and perimeter attributes from the individual flight survey datasets into one single dataset with all polygons from all the flight survey datasets. A relational database schema was developed, whereby a numeric basin identifier was created and populated with a mutually exclusive identifier where the first two digits were the transect number followed by a three digit code for each individual basin within each transect (for example 01.001 was the first basin within transect one and 16.045 was the forty-fifth basin in transect sixteen). Patch Analyst 2.3 (Rempel and Carr 2003) for ArcView (Environmental Systems Research Institute, Inc. 2002) was then used to calculate the mean area, mean shape index (MSI), for each individual basin throughout the study. These metrics describe the size and summarize the shape complexity for each individual basin through time. Mean area describes the mean basin area over the duration of the study, during periods of inundation only (excluding periods with an area of zero or completely dry periods). MSI are measures of shape complexity. MSI equals the sum of the basin perimeter divided by the square root of basin area, adjusted by a constant for a circular standard; $MSI = \frac{\sum_{j=1}^{n}\left(\frac{p_{ij}}{2\sqrt{\pi \circ a_{ij}}}\right)}{n_i}$. MSI is greater than 1, increasing without limit as shape becomes more irregular (McGarigal and Marks 1994, Elkie et al. 1999).

Finally, ArcView (Environmental Systems Research Institute, Inc. 2002) was used to perform a ‘dissolve’ on the dataset based on the individual basin identifier, which allowed the summation of all area and perimeter attributes for each basin. The output of this operation contained one record for each basin with attributes for the area and perimeter of each flight survey during the study. In order to determine any type of alteration to wetland basins, several data layers, including roads, levees, railroads, waterways, and digital aerial photography were used to record Euclidean distance from each wetland basin to the nearest road, levee, and agricultural ditch. Three sets of digital aerial photography were used during this process; circa 1995-2000 black and white (1-m resolution) Digital Orthophoto Quarter-Quad (DOQQ) flown during leaf-off periods, 2002 true color (2-m resolution) National Agricultural Inventory Photography (NAIP) flown during the growing season and 2003 near infrared (1-m resolution) NAIP also flown during the growing season. Units were recorded in meters, and distances were estimated to the nearest ten meters, from the closest but most persistent portion of the individual wetland basins to other features of interest using. An effort was made to obtain distance measurement approximations at or less than a scale of 1:24,000. Approximate measurements were not recorded for stream channels or wetland basins that were only partially contained within the individual study transect boundary. The basins were placed within classes based on type of alteration; unaltered, affected by roads, agricultural ditch wetland complex, affected by levees, affected by other structures and those partially contained within the survey transect. Basins were placed in alteration categories if they were less than approximately 200 m from the structure (road, levee or agricultural ditch) and were not visibly influenced by any other alteration. Unaltered basins were defined as having no visible anthropogenic alterations, such as agricultural ditches, levees and roads. However, the Missouri River floodplain is a highly modified system and these basins may be affected to some degree by alterations which were not visible, such as soil compaction by heavy farm equipment or drainage tiles. Basins that were defined as being affected by roads were then subdivided based on road type (state, local and private roads). The dataset’s table was imported into Microsoft Excel to calculate the number of survey periods that were inundated, number of periods of stable inundation (basin area remained unchanged), and inundation duration index (number of periods of inundation divided by the frequency of inundation). The duration index describes the constancy of an individual basin. The duration index is greater than 1, approaching 44 as basin inundation becomes more constant. This index was calculated as a ratio of the number of periods of inundation to the frequency of inundation. The frequency of inundation was defined as the number of flooding events and a single flooding event was defined from dry period to dry period.

The inundation and shape characteristics data were imported into SAS 8.2 (SAS Institute 1999), and a one-way analysis of variance (ANOVA) was preformed to test differences between structure types (roads, agricultural ditches and levees) and road type (state, local and private). Tukey-Kramer's mean separation procedure was used to identify significant differences between factor level least squares means.

Validation of Spatial Accuracy for Wetland Basins

I preformed a test in order to validate the photo interpretation of wetland basins. Three test basins (NC3, F, and Z) were selected because they changed relatively little during the study and were located on publicly owned land. The minimum and maximum basin area and perimeter were determined for each test basin. Buffers of the range of the basin perimeter over time were developed at 1-m and 3-m intervals to test for spatial coincidence. The actual basin perimeter was then collected at a one-second interval using Trimble ProXR Global Positioning System (GPS) at sub-meter accuracy. The GPS data for all datasets were collected at a one-second interval using "Real-time differential GPS" by using a broadcast from a U.S. Coast Guard base station. The data were downloaded into Trimble GPS Pathfinder Office where a post-processing differential correction was preformed at the time of data download to increase positional accuracy of any data collected when the Coast Guard broadcast was unavailable. Differential correction (both "real-time" and post processing) is a procedure whereby a reference receiver or base station, at an accurately surveyed location, calculates the combined error within the satellite data. That correction factor can then be applied to other receivers within the area to reduce error within their measurements (Hurn 1989, Steede-Terry 2000). The data were then exported to ArcView (Environmental Systems Research Institute, Inc. 2002) where the basin area and perimeter length were calculated. The GPS data were intersected with the 1-m and 3-m buffer of the range of the photo interpreted basins to determine the length of the perimeter contained within each buffered range.

The GPS verified basin area and perimeter values were compared to those recorded during the aerial surveys (Table 4.2). Test basins NC3 and F had a GPS verified basin area within the range of areas values recorded during the aerial surveys. Basin Z had a GPS verified area approximately 5.15% larger than the maximum area recorded using aerial survey techniques. Basin NC3 had a GPS verified basin perimeter within the range of perimeter values estimated using aerial survey techniques. Basins F and Z had GPS verified perimeter values that were slightly higher than the ranges recorded during the aerial surveys, 0.02% and 1.03% respectively.

The test basins were largely spatially coincident with the expected spatial range of basin perimeters estimated during the aerial surveys. The spatial match rates for basins NC3, F, and Z were approximately 90.5%, 95.1% and 80.3%, respectively, within 1 m of the spatial range of perimeters estimated using aerial survey techniques. The match rate increased to approximately 97.6%, 100.0% and, 97.7% for basins NC3, F, and Z respectively, within 3 m of the spatial range of perimeters. It is important to note that basin Z, which is the smallest test basin also had the highest error rates. Overall, the error analysis indicates that the aerial basin delineation methods were sufficiently accurate for analysis of the location and amount of wetland surface area inundated.

Table 4.2: Minimum and maximum basin area and perimeter estimated using aerial surveys and basin area and perimeter verified using GPS.

BASIN	NC3	F	Z
Minimum survey area (ha)	6.0778	2.5908	0.1896
Maximum survey area (ha)	7.4658	2.6197	0.5805
GPS area (ha)	**7.2253**	**2.6041**	**0.6105**
Minimum survey perimeter (m)	1295.2	749.5	162.5
Maximum survey perimeter (m)	1468.6	752.9	314.3
GPS perimeter (m)	**1368.4**	**754.2**	**346.6**

Hydrologic Data

To facilitate a more complete understanding of the hydrologic conditions across the study area, time-series data on stream flow and climate were collected via the internet from the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) respectively. Daily climate data were downloaded from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC) website for weather stations in counties surrounding the study area. These data were then transformed from digital ASCII to Microsoft Excel spreadsheet, where the data were filtered to include only the daily precipitation information for each weather station. Discharge and stage data for the Missouri River at Kansas City, Glasgow, and Boonville, Missouri were obtained from USGS.

Characteristics of Roads and Agricultural Ditches

In order to document the distribution of roads and their associated features within the study transects, public roads and their associated water control structures were inventoried using a Global Positioning System (GPS), private roads were photo interpreted using several sets of aerial photography, and the distribution of roads within the landscape of the Missouri River floodplain was documented by stratifying the landscape. In order to determine the distribution of agricultural ditches and evaluate the relationship with roads, the agricultural ditch tie-in locations were recorded using GPS, the length of the ditch was then photo-interpreted and the distribution of agricultural ditches was documented by stratifying the landscape.

GPS Data Collection

Little or no information was readily available for several features or structures associated with roads and road maintenance (such as ditches, culverts, etc.), therefore much of these data were collected in the field. A Trimble ProXR GPS was used to inventory any wetland alterations associated with public roads including both state and local facilities, as well as alterations associated with agricultural practice (such as agricultural tie-in ditches that connect to road ditches). Data for private roads could not be collected via GPS due to access constraints. The features collected via GPS included the locations of roads, road ditches, bridges, box culverts, pipe culverts, agricultural ditch tie-in locations, levees, railroad crossings and other features of interest. A data dictionary was created to aid in the collection of feature attributes, using Trimble GPS Pathfinder Office version 2.90. A data dictionary includes a list of features captured in the field and, where applicable, a list of attributes describing the feature. A data dictionary prompts the user to enter information; it can also limit the entries from the user to ensure data integrity (Trimble Navigation Limited 2002). Public roads were divided and collected in two route classes; state roads were defined as those being owned and maintained by the Missouri Department of Transportation and local roads were defined as those maintained by a county or city. The precise road alignment was collected and stored in a linear vector dataset. Road name, route class, surface type and an approximation of road height above the surrounding landscape also were collected and stored as attributes. Surface types were defined as: hard surface materials (concrete or asphalt), gravel, or unimproved dirt. Height above the surrounding landscape was defined as: ground level, less than 0.3 m above the landscape, 0.3 to 0.9 m above the landscape, or greater than 0.9 m above the landscape. Ditch locations also were stored as linear vector data together with attributes describing the road it accompanied and an estimation of depth below the surrounding landscape. Ditch depth below the surrounding landscape was categorized into three classes: less than 0.3 m below the landscape, 0.3 to 0.9 m below the landscape and greater than 0.9 m below the landscape. Culvert locations were recorded as point locations along with attributes describing depth and diameter. Culvert diameter was recorded and culvert depth was recorded as one of three classes: less than 0.3 m below the landscape, 0.3 to 0.9 m below the landscape and greater than 0.9 m below the landscape. Box culvert locations were recorded as points in conjunction with attributes describing depth, height, width and presence or absence of erosion. Box culvert depth was recorded as one of three classes: less than 0.3 m below the landscape, 0.3 to 0.9 m below the landscape and greater than 0.9 m below the landscape. Bridge and low-water crossings also were recorded as point locations along with an attribute describing the presence or absence of erosion associated with the structure. Private road entrances were recorded as points with a single attribute classifying the private road as one of the four following height classes: ground level, less than 0.3 m above the landscape, 0.3 to 0.9 m above the landscape and greater than 0.9 m above the landscape. The alignment of the private road was not collected, only the connection to a public road was recorded. Agricultural ditch tie-ins were collected as point locations at the site where an agricultural ditch is directly connected to and utilizes a road ditch to drain water from fields. An attribute describing agricultural ditch depth was estimated visually and recorded as one of three classes: less than 0.3 m below the landscape, 0.3 to 0.9 m below the landscape and greater than 0.9 m below the landscape. Other features of interest within the transects, including levees and railroad crossings were collected in a generic point dataset in conjunction with a description and any comments.

The GPS data for all datasets was collected at a one-second interval using "Real-time differential GPS" by utilizing a broadcast from a U.S. Coast Guard base station. The data were downloaded into Trimble GPS Pathfinder Office where a post-processing differential correction was preformed at the time of data download to increase positional accuracy of any data collected when the Coast Guard broadcast was unavailable. A GIS dataset was created for each structure type (i.e., road ditches, agricultural ditches, culverts, etc.) by exporting an ArcView shapefile from GPS Pathfinder Office. Length of the individual line segments of the linear datasets collected via GPS (roads and ditches) were calculated within ArcView (Environmental Systems Research Institute, Inc. 2002) by using the "Theme.CalculateFeatureGeometry" Avenue script originally obtained from the ESRI samples and modified to calculate length in meters, kilometers and miles (Appendix A). Five fields were added to each of the GPS datasets to provide information on the transect number, river section, route class (state or local) and road name. The nine datasets collected via GPS were added to the existing MoDOT-TMS data to form a complete inventory of structures associated with roads.

Because all road and ditch classes were not equally sampled, a need existed to normalize feature occurrences by road or ditch class occurrence. Due to the fact that road ditches, agricultural ditch tie-ins, culverts, box culverts and bridges are found and recorded only along their associated roads, these measures were normalized by the amount of road distance in which a feature could have been detected and will hence forth be referred to as the "linear frequency" (LF). This statistic describes the frequency of some occurrence along a linear feature. For example, the study area contains approximately 145.9 km of roads with an associated 215.6 km of roadside ditches. When the length of ditch is normalized by the length of road, the linear frequency was 1.48. This index indicates that the total kilometers of road in a particular class had a ditch running the complete length on one side and about 48% of its length on the other side. A linear frequency of 2 would indicate that the complete length of road had full ditching on both sides. Similarly, when the 306 culverts located within the study area were normalized by the length of road, the linear frequency was 2.10 culverts/road km.

Characterizing roadway features in this manner can begin to provide a basis for understanding the complex nature of road related alterations within this landscape.

Photo Interpretation

In order to better understand the spatial distribution and density of other anthropogenic features of the landscape, ArcView (Environmental Systems Research Institute, Inc. 2002) was used to photo interpret the spatial extent of all the agricultural ditches and private roads within the study transects. Three sets of aerial photography were utilized in this process; circa 1995-2000 black and white (1-m resolution) Digital Orthophoto Quarter-Quad (DOQQ) flown during leaf-off periods, 2002 true color (2-m resolution) National Agricultural Inventory Photography (NAIP) flown during the growing season and 2003 near infrared (1-m resolution) NAIP also flown during the growing season. A linear feature dataset was created to capture each of the linear features; agricultural ditches and private roads. The GPS data representing agricultural tie-in ditches and private road entrances were used as a known verification points. The agricultural ditches were digitized in two sessions. The agricultural ditches along roads were digitized first, using the GPS agricultural ditch tie-in locations along roads as known control points or a “training” dataset in order to learn to recognize these features on aerial photography within the landscape. Then agricultural ditches that were not verified via GPS (those not connecting to a public road ditch) were digitized. The on-screen digitization was done in ArcView (Environmental Systems Research Institute, Inc. 2002) at a scale of approximately 1:10,000 to capture the location and length of the agricultural ditches. As a control of quality of photo-interpretation, if a GPS point indicated an agricultural ditch that was not visible on the three sets of aerial photography, no attempt was made to digitize a linear feature. The length of agricultural ditches was then calculated in ArcView (Environmental Systems Research Institute, Inc. 2002) using the "Theme.CalculateFeatureGeometry" script (Appendix A). When the extent of all visible agricultural ditches was recorded, an inventory of the match rate was preformed and found to be 292 of 397 or approximately 74%. This low match rate is due to the very shallow nature of many of these ditches resulting in their low visibility on the aerial photography. Match rates were not calculated for private roads, as these features are much larger and highly visible on the aerial photography.

Landscape Stratification

A method was needed to aid in determining the distribution and spatial relationship of anthropogenic alterations throughout the landscape. Therefore, the landscape was divided into several zones based on distances from features of the landscape, both natural and man-made. Buffers were developed at 500 m intervals from the valley wall to divide the landscape into manageable zones. The buffers were developed from the valley wall because it was a more stable feature in the landscape than the historically meandering Missouri River.

Forman and Deblinger (2000) found that wetlands were drained more than 100 m from a road construction project in Massachusetts. In order to ensure that any alteration be captured, this distance was extended to 200 m. Buffers were also developed at 200 m intervals (up to 4000 m) from state roads, local roads, private roads, combined public roads (state and local) and all combined roads (state, local and private). The newly developed distance zone datasets were “clipped” to the spatial extent of the study transects and the area and perimeter of the remaining polygons was recalculated using the “Theme.CalculateFeatureGeometry” script (Appendix A). Then the linear datasets were “intersected” with the distance zone polygons in a pair-wise fashion. This procedure served to create new breaks in the linear features where they crossed into a different distance zone. Finally, the newly created linear segments were re-measured using the “Theme.CalculateFeatureGeometry” script (Appendix A), revealing the length of each individual line segment within each distance zone.

The location quotient (LQ) for roads was calculated to determine levels of concentration within the distance zones. The LQ is an index for comparing the amount of a particular phenomenon to that of the area’s aggregate phenomenon (Burt and Barber 1996). For instance, the distribution of state roads may be more or less concentrated than the distribution of all roads within certain areas. The location quotient for an activity in an area *i* is the ratio of the percentage of the total regional activity in area *i* to the percentage of the total base in area *i*. If A_i is equal to the level of the activity in area *i* then B_i is the level of the base, then; $LQ = \frac{A_i / \sum A_i}{B_i / \sum B_i}$. Location quotients may be interpreted using the following conventions: 1) LQ > 1, indicates a relative concentration compared to the region as a whole. 2) LQ = 0, the area has an equal share compared to the region. 3) LQ < 1, indicates the area has less activity than the region as a whole (Burt and Barber 1996).

CHAPTER 5.

CHARACTERISTICS AND SPATIAL DISTRIBUTION OF ROADS AND AGRICULTURAL DITCHES

Roadway Characteristics

One objective of this research was to characterize and document differences between roadway characteristics, such as use of fill material, roadside ditching, culverts, box culverts, and bridges and determine the distribution of roads, within a selected reach of the Missouri River floodplain. Within the study area, 145.8 km of road centerline were recorded; of these 110.4 km (75.7%) were considered local roads. Local roads were largely surfaced with gravel (95.5 km or 86.5%), few were unimproved (11.8 km or 10.7%) and few were hard surfaced (3.2 km or 2.9%). All state roads were hard surfaced, constructed of concrete, asphalt or similar material. Generally, state roads were constructed higher above their relative landscape than were local roads, thus utilizing a greater amount of fill material in the road base. Approximately 89.9% of local roads within the study area were estimated to be at ground level (Table 5.1). Whereas, only 13.2% of state roads were estimated to be at ground level, and 17.1% were considered less than 0.3 m in height. Approximately 46.5% of state roads were estimated between 0.3 and 0.9 m in height and 23.2% were estimated to be greater than 0.9 m above the surrounding landscape (Table 5.1).

Table 5.1: Length and percent of road height classes by road class.

Road class	Height	Kilometers	Percent per road class
Local	At ground level	99.3	89.9
	Less than 0.3 meters	7.1	6.5
	0.3 to 0.9 meters	2.7	2.5
	Greater than 0.9 meters	1.3	1.2
State	At ground level	4.7	13.2
	Less than 0.3 meters	6.0	17.1
	0.3 to 0.9 meters	16.5	46.5
	Greater than 0.9 meters	8.2	23.2

State-maintained roads tended to have a greater number of water control and movement structures per km. I identified 215.6 km of roadside ditches were identified in the study area, of these 153 km (approximately 71%) accompanied local roads. When the length of road ditch was normalized by the length of road within a particular road class, local road ditches were more sparse than state road ditches, having a linear frequency of 1.4 km per local road km, whereas state road ditches had a linear frequency of 1.8 km per km of state road. The majority (84.8%) of local road ditches were classified as less than 0.3 m deep (Table 5.2). Approximately 60.5% of state road ditches were estimated to be less than 0.3 m deep. MoDOT created and maintained the 0.3 to 0.9 m ditch depth class more often than local agencies, accounting for 36% of state road ditches (Table 5.2).

Table 5.2: Length, percent and linear frequency (LF, km ditch/km road class) of the road ditch depth classes per road class.

Road class	Road ditch depth	Kilometers	Percent per road class	LF
Local	Less than 0.3 meters	129.8	84.8	1.18
	0.3 to 0.9 meters	13.2	8.6	0.12
	Greater than 0.9 meters	10.0	6.6	0.09
State	Less than 0.3 meters	37.9	60.5	1.07
	0.3 to 0.9 meters	22.5	36.0	0.64
	Greater than 0.9 meters	2.2	3.5	0.06

A total of 306 culverts was identified within the study area; 217 culverts were located on local roads and 89 were on state roads (Table 5.3). When normalized by the road class, the linear frequency was 1.96 culverts/km road class on local roads and 2.52 culverts/km road class on state roads. A total of 20 bridges was identified; 11 (55%) were on local roads and 9 were on state roads, with a linear frequency of 0.10 bridges/km road class on local roads and 0.25 bridges/km road class on state roads (Table 5.3). There were 15 box culverts identified within the study area; 8 (53.3%) were on local roads and 7 were on state roads. Linear frequency of box culverts was 0.07 box culverts/km road class and 0.20 box culverts/km road class on local and state roads respectively.

Table 5.3: Number and linear frequency (LF, number of structures/km road class) of water control structures associated with local and state roads within the study area.

Road class	Culverts	LF culverts	Box culverts	LF box culverts	Bridges	LF bridge
Local	217	1.96	8	0.07	11	0.10
State	89	2.52	7	0.20	9	0.25
TOTAL	306	2.10	15	0.10	20	0.14

Spatial Distribution of Roads between River Sections

Road distribution within the floodplain was examined using the three river sections defined by MDC staff (Table 5.4). Within RS1 the spatial density of state, local and private roads was 0.18, 0.42, and 0.39 km/km^2, respectively. The density of state, local and private roads within RS2 was 0.16, 0.49 and 0.30 km/km^2, respectively. In RS3 the density of state and local roads was 0.21 and 0.71, respectively, higher than in both

RS1 and RS2. The density of private roads was 0.26 km/km^2, lower than in both RS1 and RS2.

The linear frequency of road ditches also was examined between river sections (Table 5.4). State roads within the study area had higher linear frequency of roadside ditches than did local roads. Local roads within RS1 had very little associated roadside ditching, resulting in a linear frequency of only 0.19, while, the state road ditches in this section had a linear density of 1.44. The linear frequencies of local and state roadside ditches were much closer within RS3, 1.62 and 1.79, respectively (Table 5.4).

State roads also had higher LF of culverts than local roads throughout the study area. The lowest LF for culverts for both local and state roads was in RS1, 0.84 and 1.19 respectively. RS2 had the highest LF for culverts on local and state roads, 2.48 and 3.04 respectively. RS3 had the lowest LF for box culverts on local and state roads, 0.06 and 0.05, respectively. However, this area contained a high number of bridges on state and local roads, with an LF of 0.35 and 0.12 respectively (Table 5.4).

Table 5.4: Length and density of roads, length and linear frequency (LF, km ditch/km road class) of roadside ditches and number and linear frequency (LF, number of structures/km road class) of culverts, box culverts and bridges within the three sections of the Missouri River floodplain.

RS	Road class	Km roads	Road density	Km road ditch	LF road ditch	Culverts	LF culverts	Box culverts	LF box culverts	Bridge	LF bridge
	Private	13.1	0.39								
1	Local	14.2	0.42	2.8	0.19	12	0.84	1	0.07	1	0.07
	State	5.9	0.18	8.5	1.44	7	1.19	2	0.34		0.00
	Private	18.7	0.30								
2	Local	30.2	0.49	43.3	1.44	75	2.48	3	0.10	2	0.07
	State	9.6	0.16	18.5	1.94	29	3.04	4	0.42	2	0.21
	Private	24.7	0.26								
3	Local	66.1	0.71	107.0	1.62	130	1.97	4	0.06	8	0.12
	State	19.9	0.21	35.6	1.79	53	2.66	1	0.05	7	0.35

Spatial Distribution of Roads within River Sections

River Section 1:

Road distribution within the floodplain was examined using the three river sections defined by MDC staff and by dividing the landscape into discrete 500 m zones based on distance from the valley wall. Roads, especially state roads, within RS1 heavily utilized the toe-slope of the valley wall (Table 5.5). Within RS1 approximately 5.9 km of state roads were identified, 75.6% of which were within the first 500 m away from the valley wall, resulting in a spatial density of 0.5 km/km^2 and an LQ of 2.43. State roads within RS1 were not found farther than 2000 m away from the valley wall. Maximum distances from the valley wall in this section were from 2500 to 3000 m. Local roads were more evenly distributed throughout the floodplain, ranging from 1.8 road km (12.5%) within 500 to 1000 m to 4.7 km (33.2%) within 1500 to 2000 m of the valley wall. However, using the LQ local roads showed concentration within 1500 to 2000 m and 2000 to 2500 m of the valley wall, with an LQ of 1.45 and 1.93 respectively. Private roads also were fairly evenly distributed within the floodplain, ranging from 0.4 km (2.9%) within 2000 to 2500 m to 4.6 km (35.5%) within 1000 to 1500 m.

State road ditches within 500 m of the valley wall had a low LF of 1.3, while all other state road ditches within RS1 had a LF of 2.0 (Table 5.6). Local road ditching was very minimal within this section, having a LF of only 0.19. Of the 19 culverts recorded within RS1, 11 (57.9%) were within the first 500 m of the valley wall (Table 5.6). The single bridge structure and three box culverts recorded within RS1 were all within 500 m of the valley wall (Table 5.6).

Table 5.5: Length, percent and Location Quotient (LQ) of state, local and private roads within distance zones of the three sections of the Missouri River floodplain from Hartsburg to Independence, Missouri.

		State			Local			Private		
River section	Distance from valley wall (m)	Km	Percent	LQ	Km	Percent	LQ	Km	Percent	LQ
1	0 - 500	4.46	75.6	2.43	3.1	21.7	0.70	2.8	21.2	0.68
	500 - 1000	0.64	10.8	0.73	1.8	12.5	0.85	2.5	19.0	1.29
	1000 - 1500	0.70	11.9	0.49	2.8	19.7	0.80	4.6	35.5	1.45
	1500 - 2000	0.10	1.7	0.07	4.7	33.2	1.45	2.8	21.4	0.93
	2000 - 2500				1.8	12.9	1.93	0.4	2.9	0.44
	2500 - 3000									
		5.90			14.2			13.1		
2	0 - 500	1.99	20.8	1.84	3.2	10.5	0.93	1.4	7.6	0.67
	500 - 1000	1.02	10.7	1.21	2.6	8.6	0.97	1.5	8.3	0.93
	1000 - 1500	1.11	11.7	1.19	3.9	13.0	1.33	0.7	3.6	0.37
	1500 - 2000	2.32	24.3	1.06	7.7	25.6	1.12	3.3	17.8	0.78
	2000 - 2500	1.97	20.6	1.09	4.3	14.2	0.75	4.7	25.4	1.35
	2500 - 3000	1.15	12.0	1.13	2.2	7.4	0.70	2.8	15.0	1.41
	3000 - 3500				2.8	9.3	1.28	1.4	7.7	1.06
	3500 - 4000				2.1	7.1	0.95	2.2	11.8	1.59
	4000 - 4500				1.3	4.3	1.40	0.5	2.6	0.86
	4500 - 5000							0.0	0.2	3.13
		9.55			30.2			18.7		
3	0 - 500	1.85	9.3	1.06	6.3	9.6	1.09	1.5	6.2	0.71
	500 - 1000	1.01	5.1	0.67	5.1	7.8	1.03	2.2	8.9	1.19
	1000 - 1500	1.46	7.3	0.72	5.7	8.7	0.86	4.0	16.3	1.61
	1500 - 2000	4.04	20.3	1.49	6.9	10.4	0.77	4.1	16.7	1.23
	2000 - 2500	2.60	13.0	1.15	6.3	9.5	0.84	3.7	14.9	1.31
	2500 - 3000	0.73	3.6	0.42	6.4	9.7	1.11	2.5	10.3	1.18
	3000 - 3500	2.71	13.6	1.43	5.8	8.8	0.92	2.0	8.2	0.86
	3500 - 4000	0.84	4.2	0.42	9.7	14.7	1.45	0.7	2.6	0.26
	4000 - 4500	2.98	14.9	1.93	3.8	5.7	0.74	1.8	7.5	0.96
	4500 - 5000	1.34	6.7	1.29	3.7	5.6	1.06	0.8	3.1	0.60
	5000 - 5500	0.38	1.9	0.61	2.9	4.5	1.41	0.2	0.7	0.21
	5500 - 6000				0.5	0.8	1.43	0.1	0.4	0.67
	6000 - 6500				1.6	2.4	1.39	0.3	1.3	0.77
	6500 - 7000				1.2	1.9	1.68	0.0	0.0	0.00
	7000 - 7500				0.1	0.2	0.23	0.7	3.0	3.85
		19.93			66.1			24.7		

Table 5.6: Length and linear frequency (LF, km road ditch/km road class) of road ditches and number of water control structures associated with state and local roads within distance zones of the three sections of the Missouri River floodplain from Hartsburg to Independence, Missouri.

		State road ditch		Local road ditch				
River section	Distance from valley wall (m)	Km	LF	Km	LF	Culverts	Box culverts	Bridges
1	0 - 500	5.7	1.3	0.1	0.04	11	3	1
	500 - 1000	1.3	2.0			4		
	1000 - 1500	1.4	2.0					
	1500 - 2000	0.2	2.0	0.6	0.1	2		
	2000 - 2500			1.0	0.5	2		
	2500 - 3000							
	TOTAL	8.6	1.5	1.7	0.2	19	3	1
2	0 - 500	3.4	1.7	5.5	1.7	25	2	
	500 - 1000	2.0	2.0	3.2	1.2	7		2
	1000 - 1500	2.2	2.0	5.6	1.4	14	2	
	1500 - 2000	4.6	2.0	9.5	1.2	19	2	1
	2000 - 2500	3.9	2.0	5.6	1.3	11		1
	2500 - 3000	2.3	2.0	3.7	1.7	11	1	
	3000 - 3500			5.7	2.0	6		
	3500 - 4000			3.3	1.5	8		
	4000 - 4500			1.1	0.9	3		
	4500 - 5000							
	TOTAL	18.4	1.9	43.2	1.4	104	7	4
3	0 - 500	2.3	1.2	8.1	1.3	12		1
	500 - 1000	1.1	1.1	7.2	1.4	13		3
	1000 - 1500	2.8	1.9	9.1	1.6	15		1
	1500 - 2000	6.9	1.7	12.0	1.7	27		
	2000 - 2500	4.7	1.8	11.6	1.8	8	3	1
	2500 - 3000	1.5	2.0	11.8	1.8	19		2
	3000 - 3500	5.4	2.0	9.1	1.6	32	1	
	3500 - 4000	1.6	1.9	13.8	1.4	19		
	4000 - 4500	6.0	2.0	6.5	1.7	12		2
	4500 - 5000	2.5	1.8	6.5	1.8	12		3
	5000 - 5500	0.8	2.0	5.7	1.9	9	1	2
	5500 - 6000			1.0	2.0	1		
	6000 - 6500			3.2	2.0	1		
	6500 - 7000			2.5	2.0	2		
	7000 - 7500			0.2	2.0	1		
	TOTAL	35.6	1.8	108.3	1.6	183	5	15

River Section 2:

River Section 2 seems like a transition zone, exhibiting characteristics of both the narrow Ozark Boarder section (RS1) and the broad valley of RS3. The toe-slope of the valley was utilized for roads to some extent. Only 1.99 km (20.8%) of state roads in RS2 were within the first 500 m of the valley wall, but with an LQ of 1.84, did show a moderate level of concentration (Table 5.5). Another 2.3 km (24.3%) and 1.97 km (20.6%) were within 1500 to 2000 m and 2000 to 2500 m of the valley wall respectively. State roads within this section were not farther than 3000 m away from the valley wall. Local roads were more evenly distributed within the floodplain, but were concentrated within 1000 to 1500 m and 1500 to 2000 m from the valley wall, containing approximately 13% (LQ of 1.33) and 25.6% (LQ of 1.12) of local roads respectively. In general, private roads were concentrated past 2000 m from the valley wall.

State road ditches within 500 m of the valley wall had a LF of 1.7; while all state roads within other zones had a LF of 2.0 (Table 5.6). The lowest LF of local road ditches was within 4000-4500 m of the valley wall and the highest LF was from 3000-3500 m from the valley wall. Of the 104 culverts found within RS2, 25 (24%) were found within 500 m of the valley wall (Table 5.6). Other culverts within RS2 were largely distributed within the four zones from 1000 to 3000 m from the valley, accounting for 13.5%, 18.3%, 10.6% and 10.6% respectively. Box culverts and bridges were evenly distributed within the six distance zones extending out from the valley to 3000 m, with each zone containing one to three structures (Table 5.6).

<u>River Section 3:</u>

All road classes within RS3 were fairly evenly distributed (Table 5.5). The trend of increased state road activity within 500 m of the valley did not exist within this section. Instead, 4 km (20.3%, LQ of 1.49) of state roads were within 1500 to 2000 m and approximately 3 km (14.9%, LQ of 1.93) were within 4000 to 4500 m. State roads within this section were not found farther than 5500 m away from the valley wall. Maximum distances from the valley wall in this section were from 7000 to 7500 m. RS3 had slight concentration of local roads past 5000 m from the valley wall, in the area where no state roads existed. Private roads appeared to be somewhat concentrated within the five zones from 500 to 3000 m from the valley wall, ranging from 2.21 km (8.9%, LQ of 1.19) to over 4 km (over 16% and LQ of 1.61).

State road ditching was sparse within 200 m and 200 to 400 m of the valley wall with a LF of 1.2 and 1.1 respectively. The LF of state road ditching generally increased with distance away from the valley wall. Local road ditching exhibited the same pattern, with the lowest LF of 1.3 within 500 m of the valley wall and increasing with distance away from the valley wall (Table 5.6).

Culverts within RS3 were evenly distributed, with few localized concentrations. Of the 183 culverts recorded within this section, 32 (17.5%) were within 3000 to 3500 m and 27 (14.8%) were within 1500 to 2000 m of the valley wall (Table 5.6). Box culverts and bridges were evenly distributed within the six distance zones extending from the valley wall to 3000 m, with each zone containing one to three structures.

Spatial Distribution of Agricultural Ditches

A supplementary objective of my research was to document and examine the distribution of agricultural ditches within a selected reach of the Missouri River floodplain and evaluate the influence of road placement on the distribution of agricultural ditches. Within the sixteen transects, 397 agricultural ditch tie-ins were recorded via GPS, 336 (approximately 84.6%) were estimated at less than 0.3 m deep, 33 (about 8.3%)

were estimated to be 0.3 to 0.9 m deep and 28 (roughly 7.1%) were greater than 0.9 in depth. Approximately 66.5% of agricultural ditch tie-ins were associated with local roads. The number of agricultural ditch tie-ins was normalized by the length of road within a particular road class. Tie-in ditches were more sparse on local roads than state roads, having a linear frequency of 2.39 agricultural tie-in ditches per local road kilometer, whereas state roads had a linear frequency of 3.76 tie-in ditches per kilometer. Although the road ditch depth between 0.3 to 0.9 m and greater than 0.9 m represented only 16.6% and 5.7% of total ditches, these classes seemed to have a high degree of agricultural ditch tie-ins (Table 5.7).

The numbers of agricultural ditch tie-ins to road ditches (collected via GPS) increased from 26 recorded in RS1 to 282 in RS3. Approximately 38.5% of the agricultural ditch tie-ins within RS1 were recorded within 500 m of the valley wall. Approximately 30.8% of agricultural ditch tie-ins were recorded from 2000 to 2500 m away from the valley wall; these are all attributed to a single farm field.

The linear frequency of agricultural ditches also increased in a westerly fashion. Agricultural ditch tie-ins in RS1 had a linear frequency of 1.27 on local roads and 1.36 on state roads, when normalized by the length of road class. The linear frequency of agricultural ditch tie-in increased to 2.71 on local roads and 5.17 for state roads within RS3.

Table 5.7: Number, percent and linear frequency of agricultural tie-in ditches within the Missouri River floodplain from Hartsburg to Independence, Missouri.

Road ditch depth	Agricultural ditch frequency	Percent	Agricultural ditch tie-ins/road ditch class km
None	14	3.53	
Less than 0.3 m	278	70.03	1.66
0.3 - 0.9 m	74	18.64	2.07
Greater than 0.9 m	31	7.81	2.54

When the agricultural ditches were photo interpreted to determine their spatial extent and distribution, a total of 246.7 km of agricultural ditches were recorded within the study area, with an overall spatial density of 1.31 km/km^2. Approximately 39.1 km (15.9%) of agricultural ditches within the entire study area were within 500 m of the valley wall.

The density of agricultural ditches increases in a westerly direction from RS1 to RS3 (Table 5.8), as with the agricultural ditch tie-ins recorded via GPS. Agricultural ditches were found at a spatial density of 0.7 km/km^2 in RS1, the narrow Ozark Boarder section, 1.2 km/km^2 in RS2 and 1.6 km/km^2 in RS3. The highest concentration of agricultural ditches within RS1 was in the first 500 m from the valley wall, which contained 10.7 km (44.9%) of agricultural ditches, with a spatial density of 1.2 km/km^2. This trend was particularly evident when state roads also were located within this zone (T3 and T4), accounting for approximately 74.8% of the agricultural ditches within this zone. The use of the first 500 m from the valley wall was also apparent in RS2, although to a lesser degree. Approximately 21% of agricultural ditches were within 500 m of the valley wall, having a spatial density of 1.91 km/km^2. This trend was not repeated in RS3, where the highest percentages were within the five zones from 500 to 3000 m from the valley wall.

Table 5.8: Length, density and percent of agricultural ditches within distance zones of each of the three sections of the Missouri River floodplain from Hartsburg to Independence, Missouri.

River section	Distance from valley wall (m)	Km of agricultural ditches	Density	Percent
RS1	0 - 500	10.79	1.22	44.9
	500 - 1000	3.92	0.45	16.3
	1000 - 1500	4.91	0.58	20.4
	1500 - 2000	3.56	0.60	14.8
	2000 - 2500	0.88	0.49	3.6
	2500 - 3000		0.00	0.0
Total	TOTAL	24.06	0.71	
RS2	0 - 500	16.03	1.91	21.0
	500 - 1000	14.15	1.60	18.6
	1000 - 1500	11.57	1.32	15.2
	1500 - 2000	13.58	1.58	17.8
	2000 - 2500	5.47	0.71	7.2
	2500 - 3000	4.15	0.57	5.4
	3000 - 3500	5.44	0.76	7.1
	3500 - 4000	5.83	1.58	7.6
	4000 - 4500	0.04	0.04	0.1
	4500 - 5000		0.00	0.0
Total	TOTAL	76.27	1.24	
RS3	0 - 500	12.31	1.21	8.4
	500 - 1000	16.06	1.53	11.0
	1000 - 1500	15.41	1.50	10.5
	1500 - 2000	16.33	1.59	11.2
	2000 - 2500	13.40	1.31	9.2
	2500 - 3000	16.90	1.70	11.5
	3000 - 3500	11.20	1.32	7.7
	3500 - 4000	11.21	1.58	7.7
	4000 - 4500	11.08	2.28	7.6
	4500 - 5000	8.69	2.43	5.9
	5000 - 5500	6.17	2.44	4.2
	5500 - 6000	3.62	1.89	2.5
	6000 - 6500	3.09	1.61	2.1
	6500 - 7000	0.71	0.47	0.5
	7000 - 7500	0.20	0.68	0.1
Total		146.37	1.56	

The relationship between agricultural ditches and roads also was examined. When agricultural ditches were examined in relation to state roads, 22.7 km (9.2%) of agricultural ditches were within 200 m and 23.3 km (9.5%) were within 200 to 400 m (Table 5.9). These areas had the highest spatial densities of agricultural ditches, 1.7 km/km^2 and 1.9 km/km^2, respectively. When agricultural ditches were examined in relation to local roads, approximately 57 km (23.1%) of agricultural ditches were within 200 m and 53.1 km (21.5%) were within 200 to 400 m (Table 5.9). Agricultural ditches within these areas had spatial densities of 1.4 km/km^{2}and 1.5 km/km^2, respectively.

Approximately 31.1% of agricultural ditches were within 200 m of all public roads (combined state and local), and 63.9 km (25.9%) within 200 to 400 m of public roads (Table 5.10). These ditches had a spatial density of 1.5 km/km^{2}and 1.6 km/km^2, respectively. In all distance zones greater than 1000 m from public roads, there were a total of 30.6 km (12.4%) of agricultural ditches, with a density of 0.9 km/km^2.

When agricultural ditches were examined in relation to all road classes combined, approximately 92.4 km (37.5%) of agricultural ditches were within 200 m, and 71.3 km (28.9%) were within 200 to 400 m (Table 5.10). Agricultural ditches within these areas had spatial densities of 1.4 km/km^{2}and 1.5 km/km^2, respectively. In all distance zones greater than 1000 m from local roads, there were a total of 18.8 km (7.6%) of agricultural ditches, with a density of 1.1 km/km^2. The distance zones are not mutually exclusive, therefore there is some overlap when examining the influence of state or local roads individually and examining the trends for public roads and all roads.

Table 5.9: Length, percent and density of agricultural ditches within distance zones of state and local roads within the Missouri River floodplain from Hartsburg to Independence, Missouri.

	State roads			Local roads		
Distance to road	Km	Percent	Density	Km	Percent	Density
0 – 200 m	22.7	9.2	1.7	57.0	23.1	1.4
200 – 400 m	23.3	9.5	1.9	53.1	21.5	1.5
400 – 600 m	19.2	7.8	1.6	39.0	15.8	1.4
600 – 800 m	15.0	6.1	1.4	27.5	11.1	1.3
800 – 1000 m	11.1	4.5	1.1	21.8	8.9	1.6
>1000 m	155.4	63.0	1.2	52.3	21.2	0.9

Table 5.10: Length, percent and density of agricultural ditches within distance zones of public (state and local) and all (state, local and private) roads within the Missouri River floodplain from Hartsburg to Independence, Missouri.

	Public roads			All roads		
Distance to road	Km	Percent	Density	Km	Percent	Density
0 – 200 m	76.7	31.1	1.5	92.4	37.5	1.4
200 – 400 m	63.9	25.9	1.6	71.3	28.9	1.5
400 – 600 m	35.6	14.4	1.3	38.2	15.5	1.3
600 – 800 m	22.4	9.1	1.1	15.1	6.1	0.9
800 – 1000 m	17.5	7.1	1.3	10.9	4.4	1.2
>1000 m	30.6	12.4	0.9	18.8	7.6	1.1

Summary and Discussion

Design standards varied between road classes. State roads within the study area were constructed to more advanced design standards than local roads. State roads were constructed higher above the relative landscape, therefore using more fill material than local roads. State roads also had more complete roadside ditches and higher linear frequency of water control structures than local roads.

The spatial density of state roads varied only minimally among River Sections. It was lowest in RS2 and highest in RS3. Local road density increased and private road density decreased in a westward direction from RS1 to RS3.

Distribution of roads also varied within the River Sections. Within RS1, 75.6% of state roads were within the first 500 m of the valley wall. Historically, placing roads within the toe-slope of the valley wall within this narrow section of the floodplain may have served to minimize the risk of floodwaters overtopping the structure and maximize the amount of land for crop production. Local roads were slightly concentrated within 1500 to 2000 m and 2000 to 2500 m from the valley wall, containing 33.2% and 19.2% respectively. Private roads within RS1 were slightly concentrated within 1000 to 1500 m of the valley wall. RS2 also had a concentration of state roads within 500 m of the valley wall, however to a lesser degree than RS1. Local roads had a slight concentration within the three distance zones from 1000 to 2500 m of the valley wall. In general private roads were concentrated past 2000 m from the valley wall. Within RS3, the three road classes were more evenly distributed. The trend of increased state road activity within 500 m of the valley did not exist within this section. Instead state roads were somewhat concentrated within 1500 to 2000 m and 4000 to 4500 m of the valley wall. The distribution of soils and topography within the floodplain may also influence the placement of roads. Terraces of the floodplain may be an influence where state roads were concentrated away from the valley wall. RS3 had a slight concentration of local roads past 5000 m from the valley wall, in the area where no state roads existed. Private roads were slightly concentrated within the five zones from 500 to 3000 m from the valley wall.

Distribution of agricultural ditches varied between road classes and road ditch depth classes. State roads had a higher LF of agricultural ditch tie-in than local roads. Further, even though road ditches between 0.3 to 0.9 m and greater than 0.9 m represented only 16.6% and 5.7% of total ditches, these classes had a higher degree of agricultural ditch tie-ins.

The distribution of agricultural ditches also varied among River Sections. The density of agricultural ditches increased in a westerly fashion from RS1 to RS3. The distribution of agricultural ditches also varied within River Sections. Within RS1 a large percentage of agricultural ditches were found within 500 m of the valley wall. Within RS2 agricultural ditches had the highest density within 500 m from the valley wall, however this trend was not as pronounced as in RS1. This trend was not repeated in RS3, where the highest percentages and densities were within the five zones from 500 to 3000 m from the valley wall.

The spatial distribution of agricultural ditches seemed to be influenced by the distribution of public roads. Within the study area approximately 31% and 26% of agricultural ditches were within 200 m and 200 to 400 m of public roads, respectively. The relationship between roads and agricultural ditches may be somewhat over exaggerated due to the photo interpretation methods used. Many of the agricultural ditches within the study area were very shallow, often less than 0.3 m in depth, making remote detection of these features very difficult. However, this was accounted for by using the training dataset collected via GPS and offset by not attempting to digitize features that were verified via GPS, but not clearly visible on any of the three sets of aerial photography.

When the spatial distribution of the agricultural ditches throughout the study area was reviewed, it became apparent that these structures were very unequally distributed throughout the landscape, being heavily concentrated in some locations and very sparse to nonexistent in others. For example, one field partially contained within the northwestern portion of T8 contained over 1.5 km of agricultural ditches, spaced approximately 35 m apart along County Road 211. Agricultural ditches in this field had a spatial density of 21.2 km/km^2 within the area surveyed, while the field directly across the road had no visible ditching. This trend may be attributed to the drainage patterns of the soils, attitudes of the landowners, ownership status of the land or other financial, social or environmental factors.

In RS1, it became apparent that many of the agricultural ditches associated with state roads located within the toe slope of the valley wall are a response to surface water being channeled and funneled from the upslope side of the road, under the road via culverts. The linear frequency of state road ditches was only 1.3 within the first 200 m of the valley wall within RS1. This indicates that these roads do not have complete ditching on both sides of the road. Roads within the toe-slope of the valley often had complete ditches on the upslope side of the road and incomplete ditching on the downslope side of the road. Water is collected into the upslope road ditches and funneled under the roadbed via culverts, which converts dispersed surface water flow to concentrated point source flow.

CHAPTER 6.

TEMPORAL AND SPATIAL DISTRIBUTION OF SURFACE WATER AND EFFECTS OF ANTHROPOGENIC ALTERATIONS ON SELECTED WETLAND BASINS

Temporal Distribution of Surface Water

My first objective was to characterize and evaluate the effects of levees, agricultural ditches and state, local, and private roads on the inundation and shape characteristics of temporary wetland basins in the Missouri River floodplain from Hartsburg to Independence, Missouri. Wetland basins within the floodplain may have one or more mechanisms for delivery of water. Water may be delivered in the form of precipitation, ground water flow, flooding from the Missouri River, or flooding from other tributaries within the area. Precipitation data and discharge data for the Missouri River were obtained to gain a better understanding of the hydrologic conditions during the study. Data were not available for the ground water or smaller tributaries within the study area.

The influence of the Missouri River discharge and local precipitation on surface water extent in the floodplain is evident by examining river data from three proximate weather stations (obtained from the National Climatic Data Center) and three river monitoring stations (obtained from the United States Geological Survey). Precipitation and river discharge data from Kansas City, Missouri, which is located just upstream from the study area, provide perspective for RS1. River discharge data were obtained from Glasgow, Missouri and precipitation was obtained from Brunswick, Missouri, slightly northwest of Glasgow, to provide data near the center of the study area. Precipitation data obtained from Jefferson City and river discharge data from Boonville, Missouri provided information for RS3. The study was conducted during three relatively dry years as compared to the normal precipitation levels. The US Army Corps of Engineers maintained the Missouri River at minimum levels required to support navigation during much of the study (Raedeke et al. 2003).

Fall 2000 was relatively dry. From 1 August to 31 December Kansas City received only 288.29 mm of precipitation, Brunswick 248.67 mm and Jefferson City received 403.86 mm (Figure 6.1). Discharge of the Missouri River fluctuated slightly above 1000 m^3 per second (CMS) at the three selected stations (Figure 6.2). Around the first of December (end of the navigation season) the discharge of the river decreased below 1000 CMS. Because of the dry conditions, the extent of surface water remained essentially unchanged (Figure 6.3). The total area of surface water on the floodplain during fall 2000 ranged from a low of 189.3 ha (1.00% of total transect area surveyed) on 2 October to a high of 253.3 ha (1.34%) on 6 November.

During spring of 2001 conditions were wetter and more variable. From 1 January to 31 May Kansas City, Brunswick and Jefferson City received 615.4 mm, 479.0 mm and 537.2 mm respectively (Figure 6.4). The largest precipitation events were in late January and February. Discharge of the Missouri River varied greatly during the spring of 2001, repeating the variability in precipitation patterns, although the largest discharges occurred in March (Figure 6.5). Surface water distribution in the spring of 2001 was more variable over time (Figure 6.6). Surface water area on the floodplain during spring 2001 ranged from a high of 492.2 ha (2.61%) on 26 February, gradually fell to a low of 290.1 ha (1.54%) on 2 April and finally began to increase to 434.3 ha (2.30%) on 15 May.

Conditions also were dry during the fall of 2001. Precipitation patterns were similar to those encountered in the fall of 2000. Kansas City received 354.3 mm, Brunswick received 326.6 mm and Jefferson City received 416.1 mm of precipitation from 1 August to 31 December (Figure 6.7). Discharge of the Missouri River reached a high of approximately 3000 CMS on 19 September, and then continued to decline throughout the season (Figure 6.8). The greatest amount of surface water during fall 2001 was present during early fall and gradually declined throughout the season (Figure 6.9). The area of surface water ranged from a high of 321.8 ha (1.7%) on 6 August to a low of 186.7 ha (0.99%) on 28 December.

During spring 2002 conditions were relatively dry until late April, when several large precipitation events occurred throughout the study area. From 1 January to 31 May Kansas City, Brunswick and Jefferson City received 405.4 mm, 519.4 mm and 507.2 mm respectively (Figure 6.10). The month of May alone accounted for approximately half of the precipitation in Kansas City, Brunswick and Jefferson City, receiving 190.8 mm, 319.5 mm and 228.6 mm respectively. The river remained above flood stage in Glasgow from 12 May through 15 May and in Jefferson City, Missouri from 10 May through 17 May (Raedeke et al. 2003). The difference in the amounts of precipitation between the upper reaches and lower reaches of the study area were evident in the discharge of the Missouri River at Kansas City and Boonville (Figure 6.11). Surface water distribution in the spring of 2002 showed little change until late April. The greatest amount of surface water was available during late spring, ranging from a low of 174.6 ha (0.92%) on 28 January to a high of 854.4 ha (4.50%) on 13 May (Figure 6.12).

Precipitation patterns during fall 2002 again were similar to those encountered during the fall of 2000 and 2001. From 1 August to 31 December Kansas City, Brunswick and Jefferson City received 213.1 mm, 231.7 mm and 315.2 mm respectively (Figure 6.13). After a peak discharge of approximately 1650 CMS the discharge of the Missouri River fluctuated below 1400 CMS, until December when discharge fell sharply to below 1000 CMS (Figure 6.14). Fall 2002 was again relatively dry and the area of surface water remained essentially unchanged fluctuating slightly from 121.2 ha (0.64%) on 23 September to 133.3 ha (0.71%) on 21 October and then falling back to 120 ha (0.64%) on 18 November (Figure 6.15).

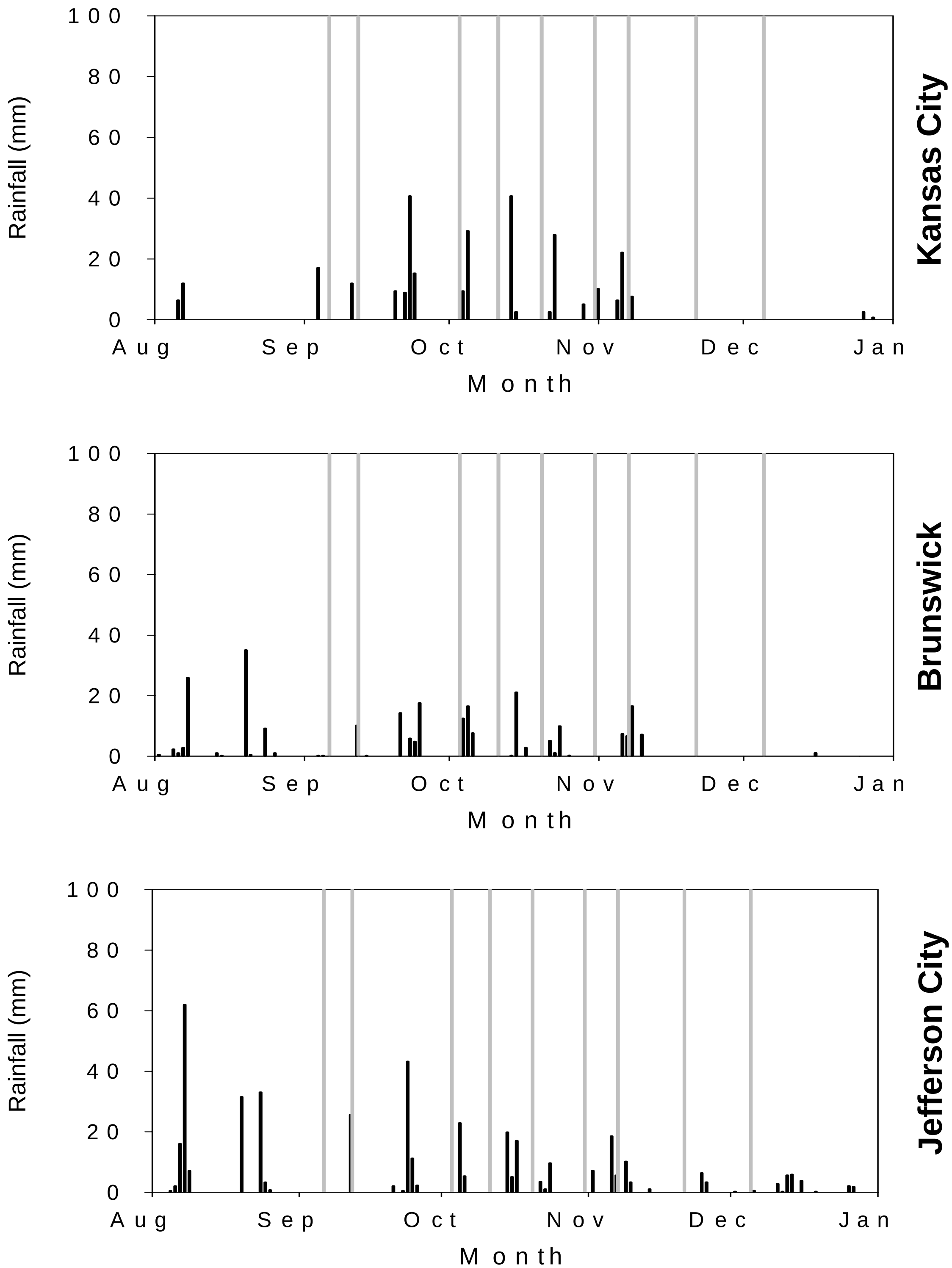


Figure 6.1: Precipitation at the Kansas City, Brunswick and Jefferson City weather stations during fall 2000. Vertical bars represent flight survey dates.

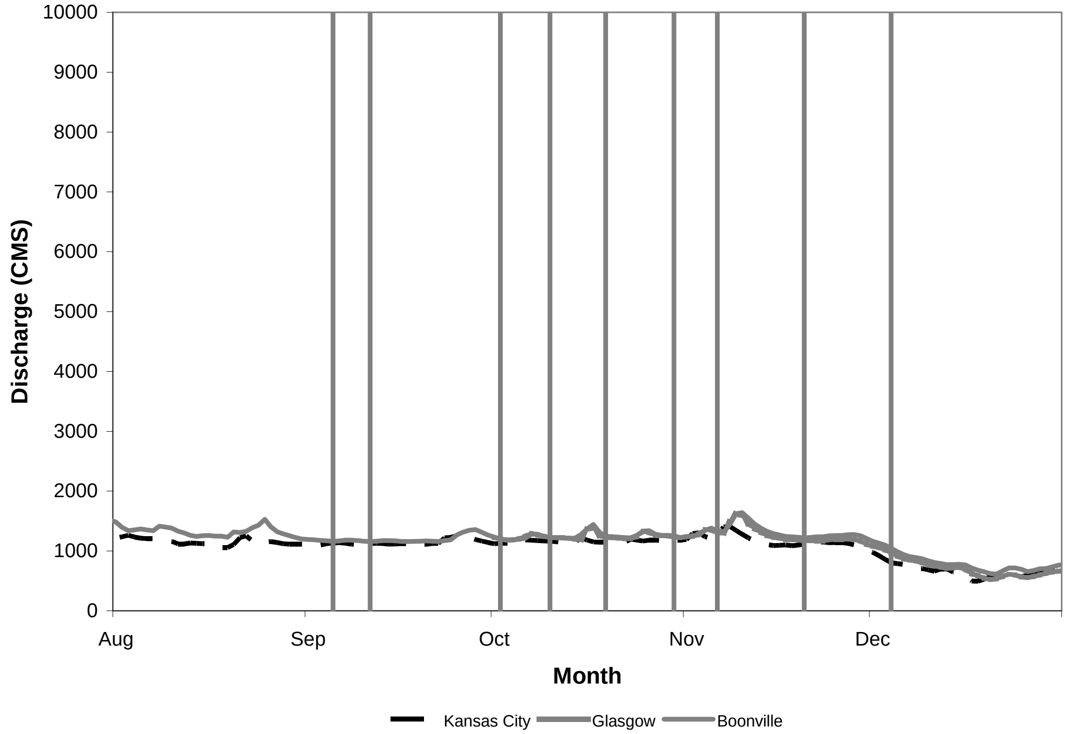


Figure 6.3: Discharge of the Missouri River at Kansas City, Glasgow and Boonville, Missouri during fall 2000. Vertical bars represent flight survey dates.

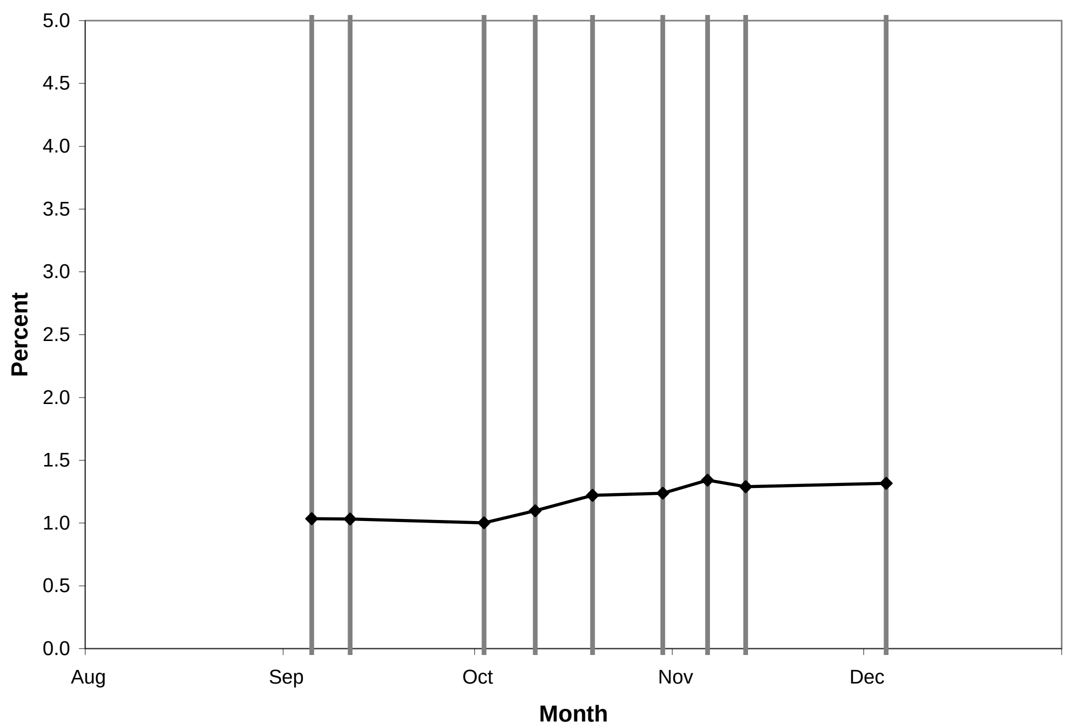


Figure 6.4: Percent surface water within the study area per survey date during fall 2000. Vertical bars represent flight survey dates.

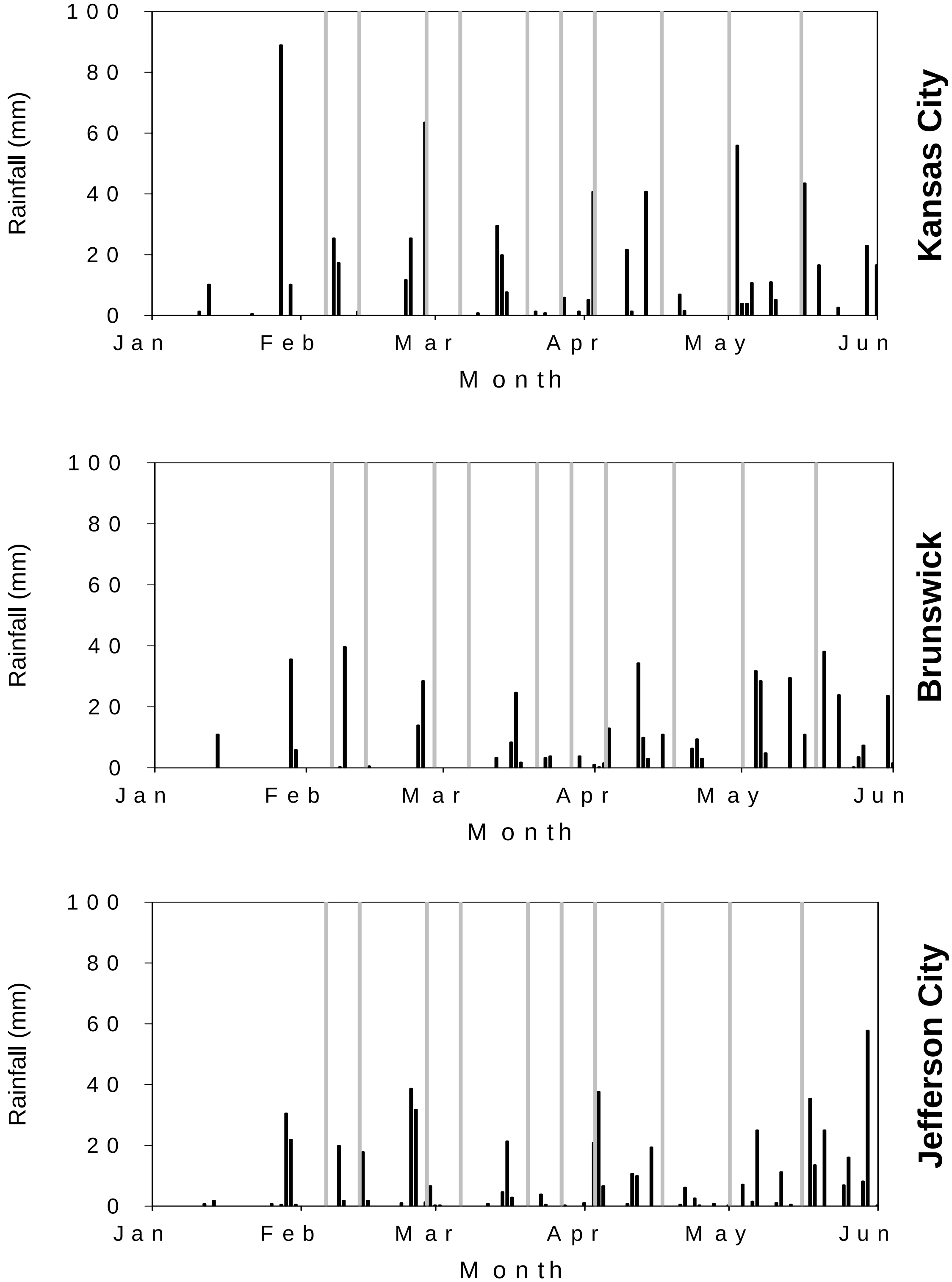


Figure 6.4: Precipitation at the Kansas City, Brunswick and Jefferson City, Missouri weather stations during spring 2001. Vertical bars represent flight survey dates.

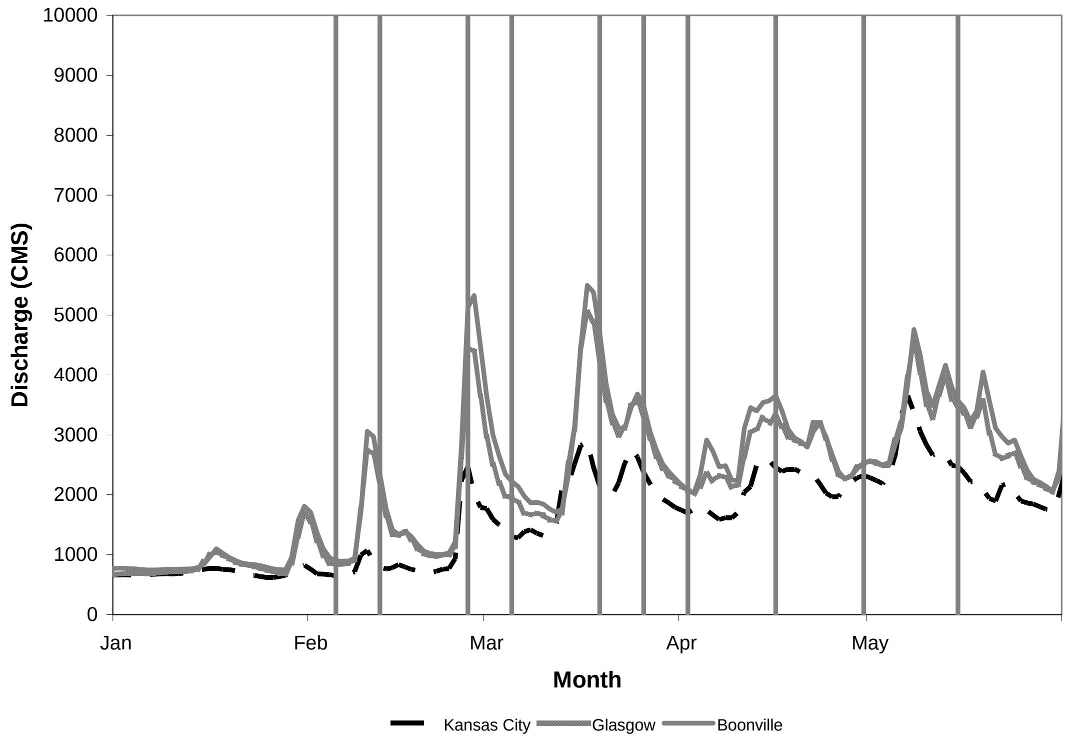


Figure 6.5: Discharge of the Missouri River at Kansas City, Glasgow and Boonville, Missouri during spring 2001. Vertical bars represent flight survey dates.

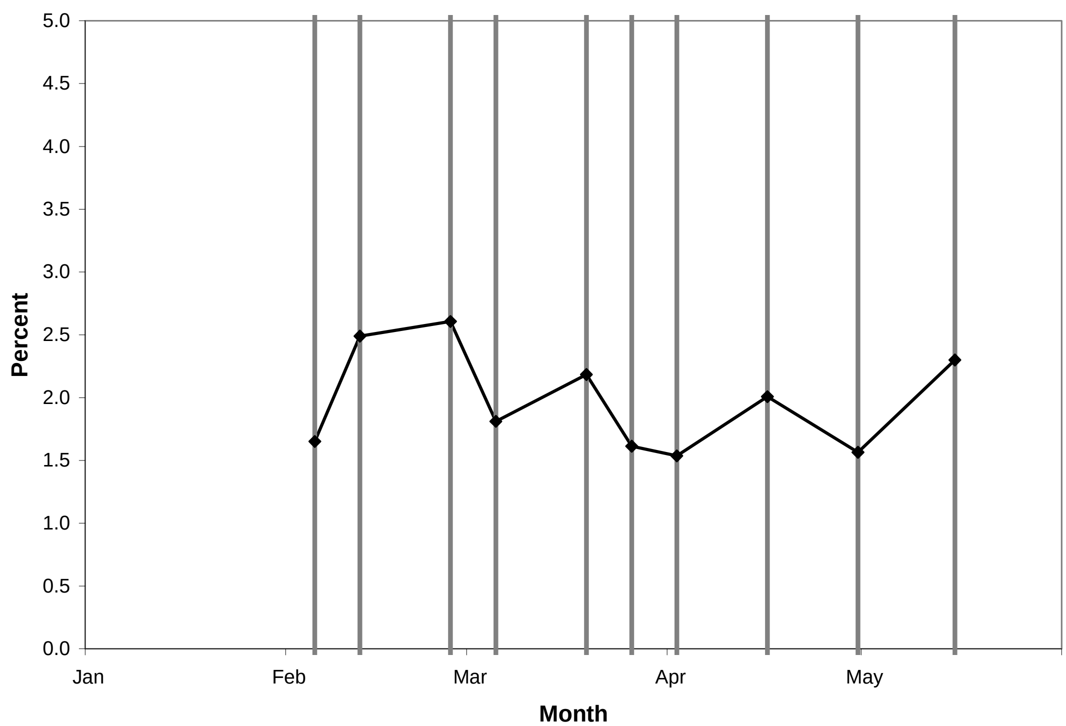


Figure 6.6: Percent surface water within the study area per survey date during spring 2001. Vertical bars represent flight survey dates.

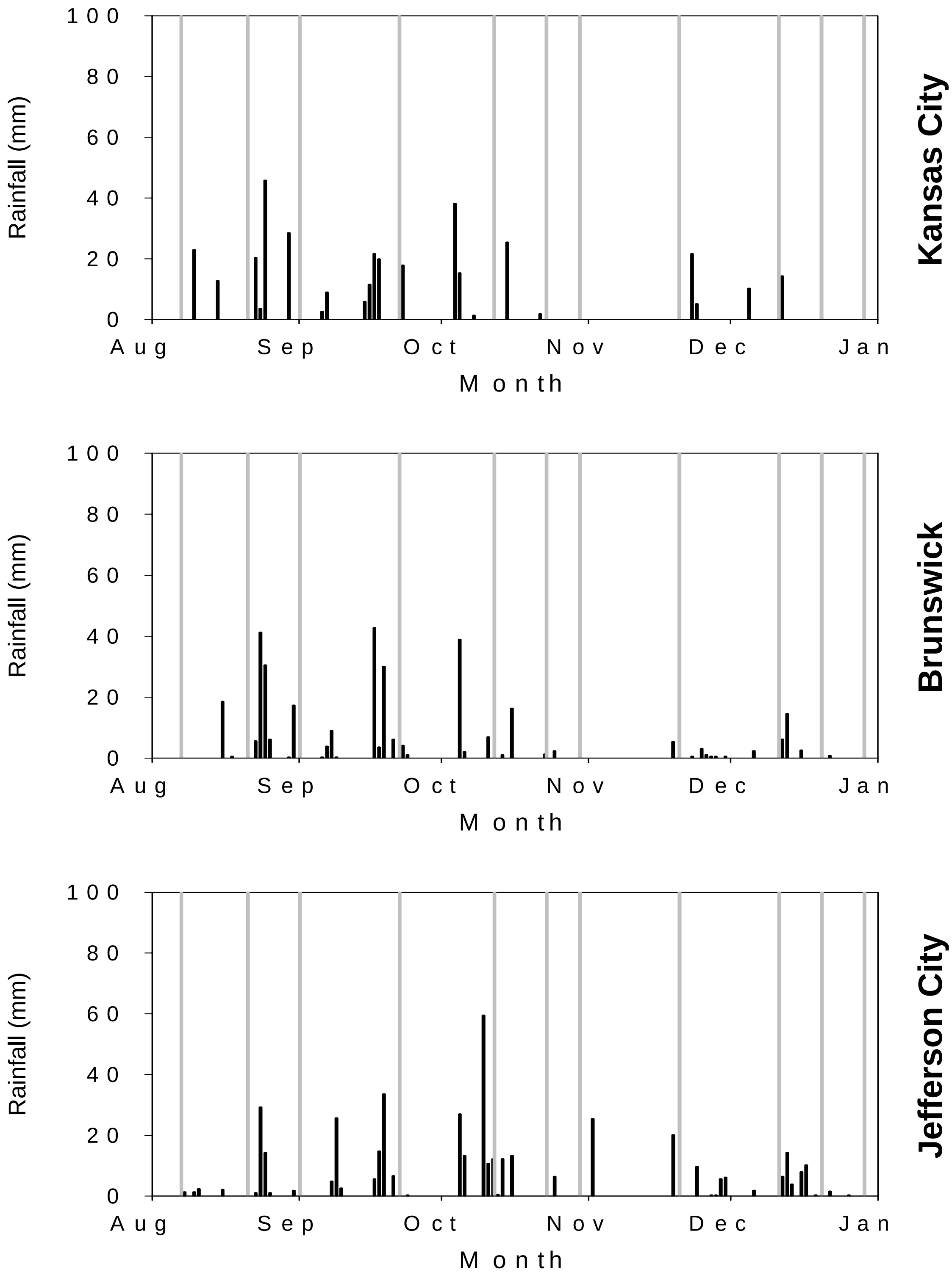


Figure 6.7: Precipitation at the Kansas City, Brunswick and Jefferson City, Missouri weather stations during fall 2001. Vertical bars represent flight survey dates.

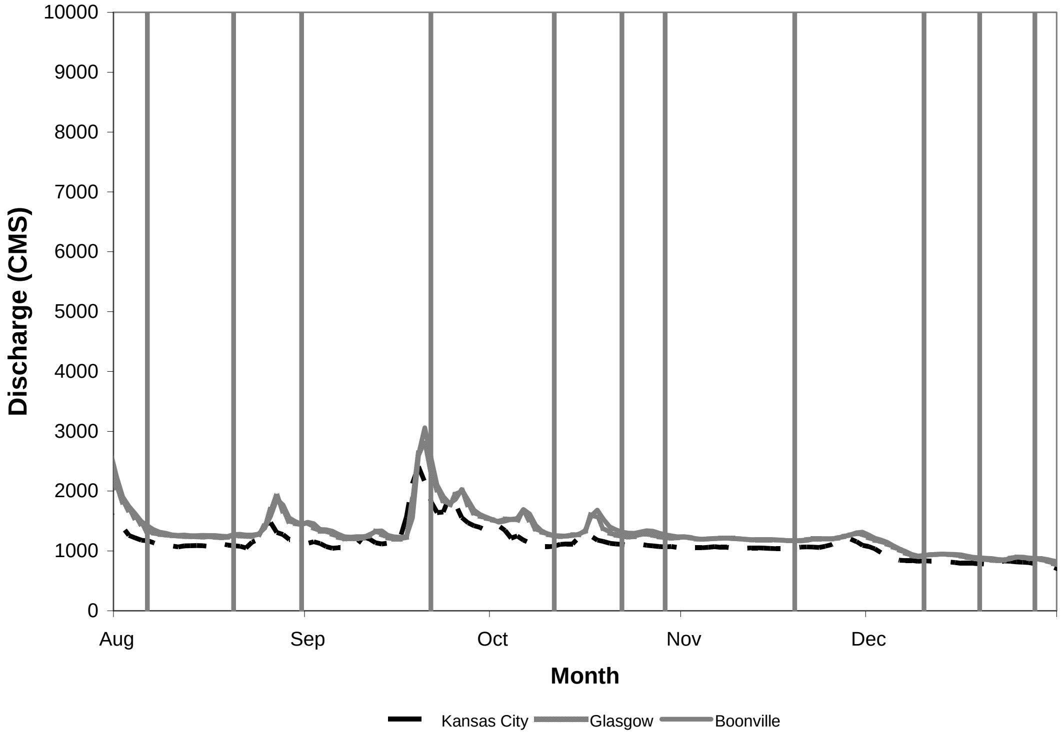


Figure 6.8: Discharge of the Missouri River at Kansas City, Glasgow and Boonville, Missouri during fall 2001. Vertical bars represent flight survey dates.

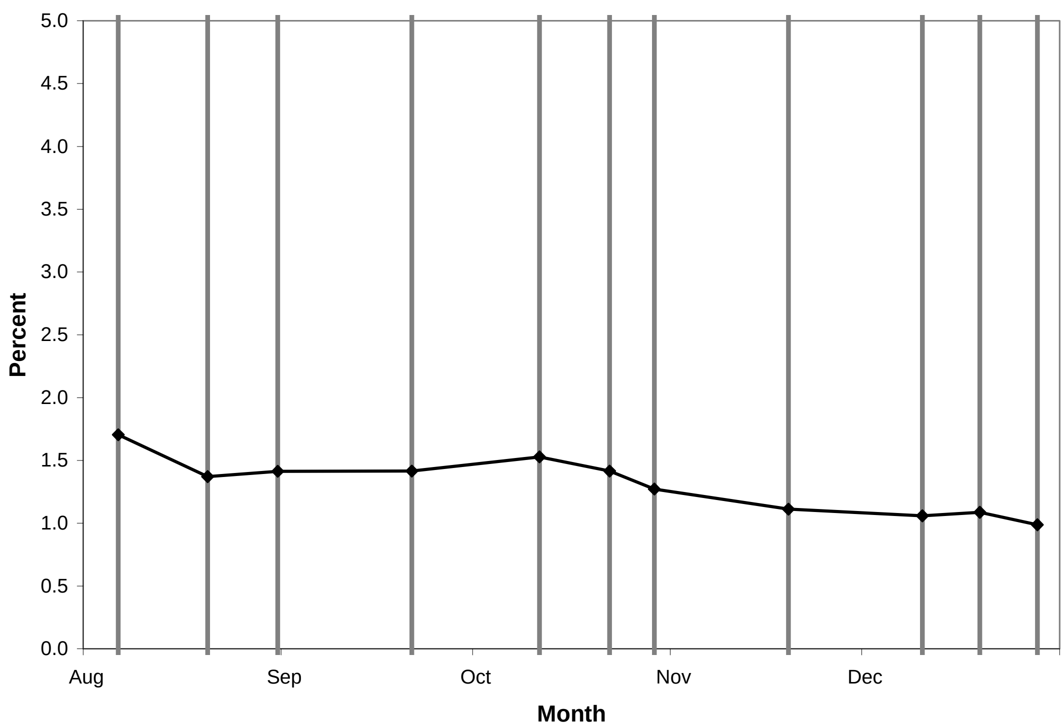


Figure 6.9: Percent surface water within the study area per survey date during fall 2001. Vertical bars represent flight survey dates.

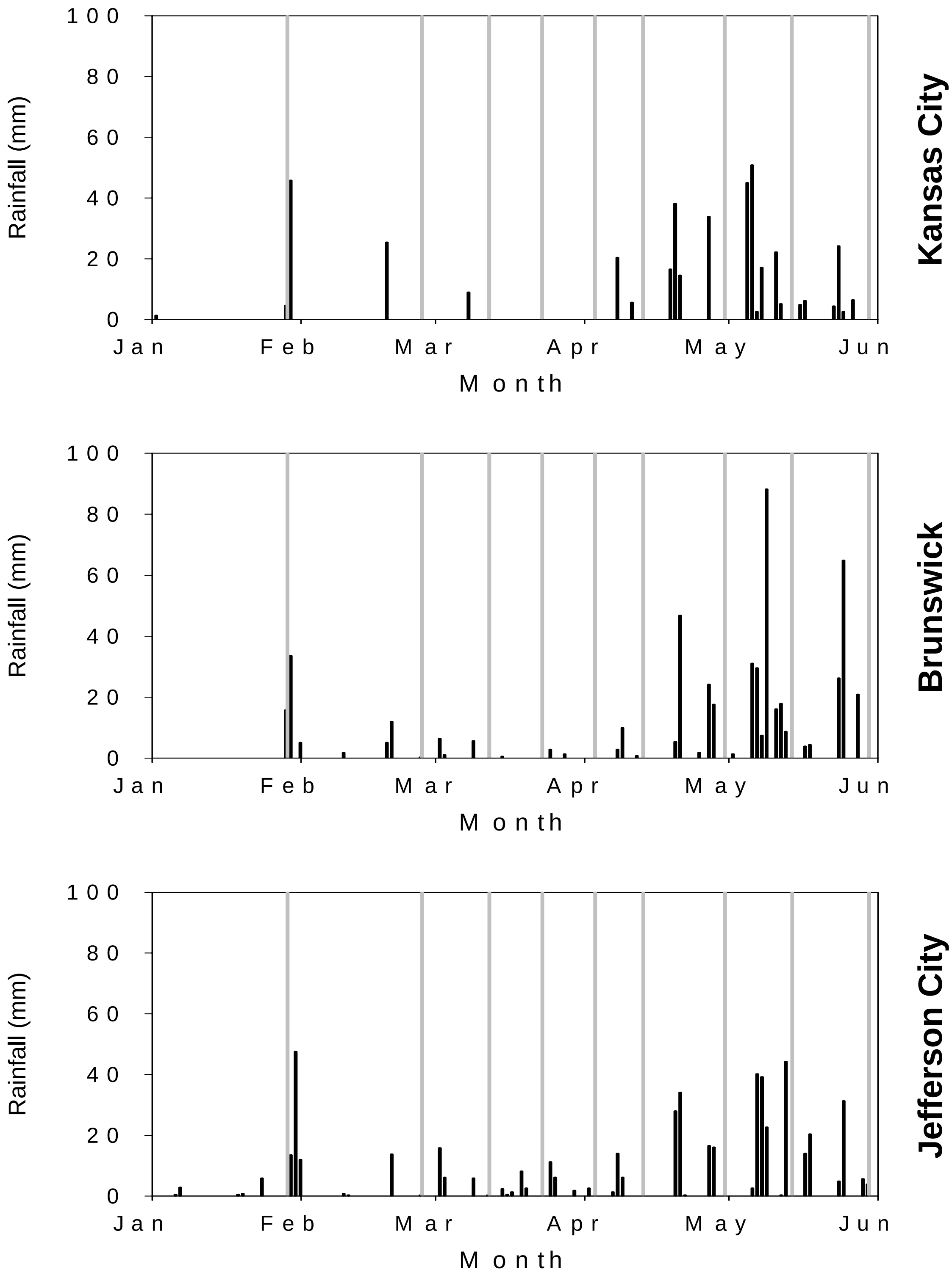


Figure 6.10: Precipitation at the Kansas City, Brunswick and Jefferson City, Missouri weather stations during spring 2002. Vertical bars represent flight survey dates.

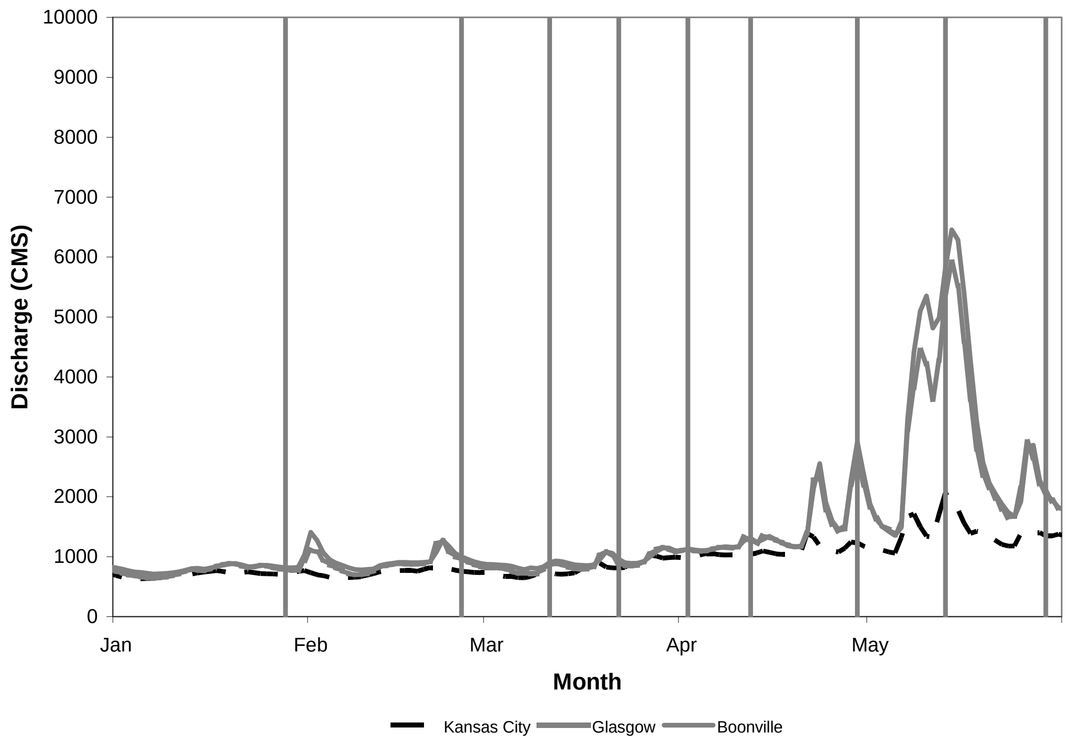


Figure 6.11: Discharge of the Missouri River at Kansas City, Glasgow and Boonville, Missouri during spring 2002. Vertical bars represent flight survey dates.

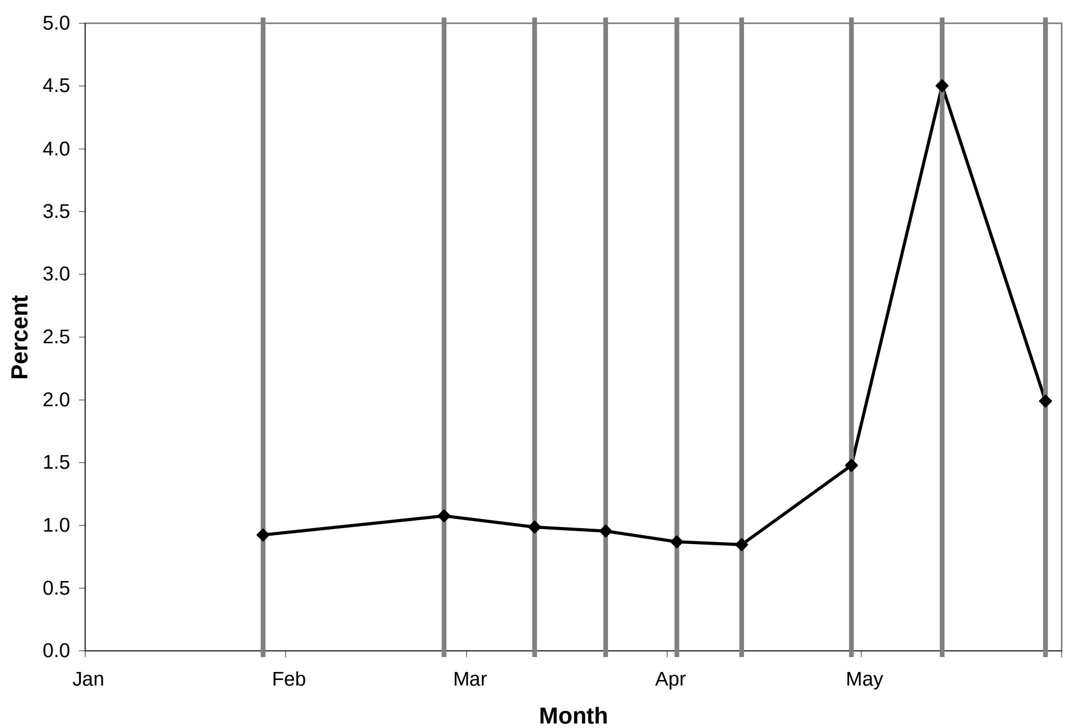


Figure 6.12: Percent surface water within the study area per survey date during spring 2002. Vertical bars represent flight survey dates.

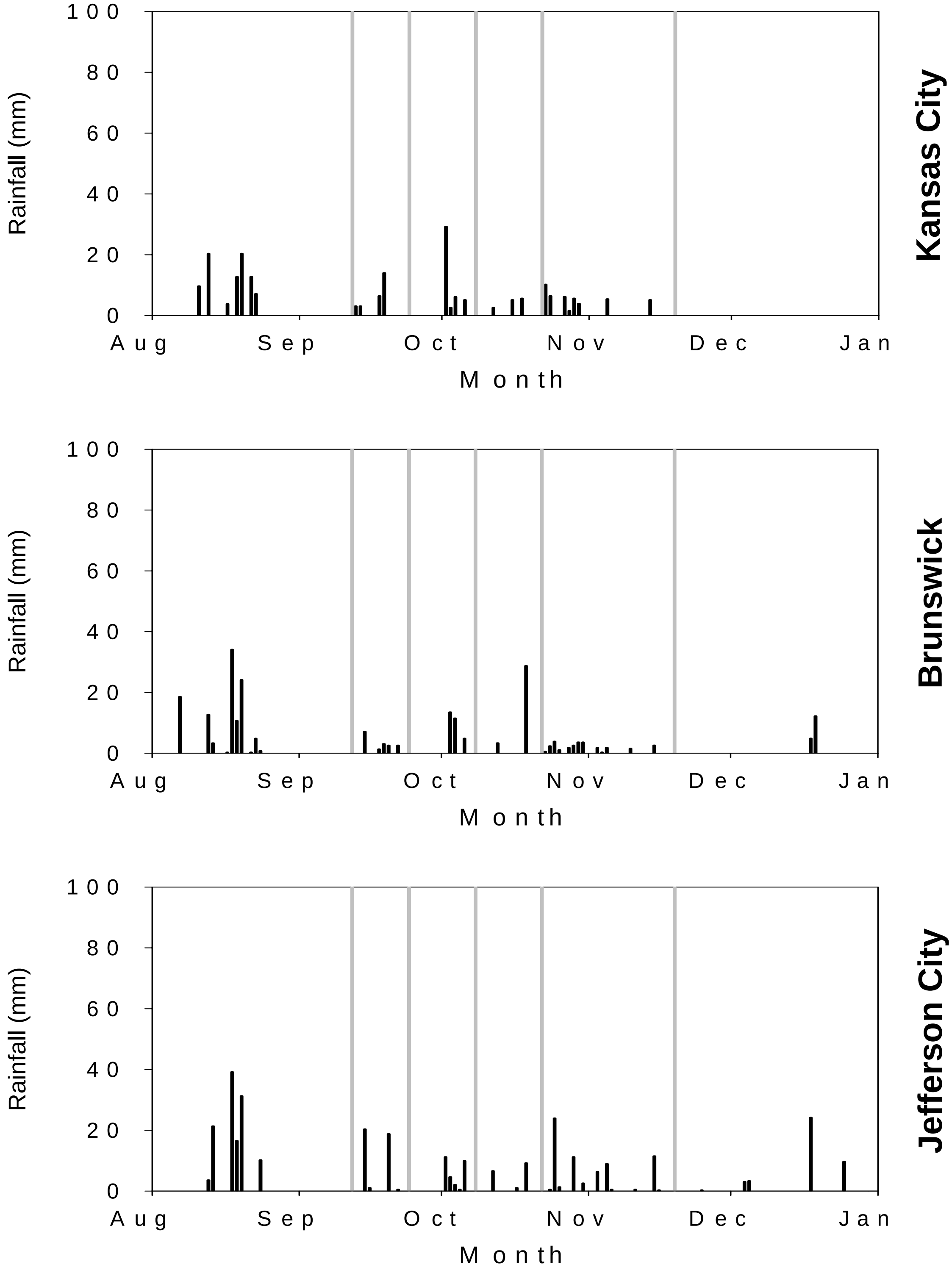


Figure 6.13: Precipitation at the Kansas City, Brunswick and Jefferson City, Missouri weather stations during fall 2002. Vertical bars represent flight survey dates.

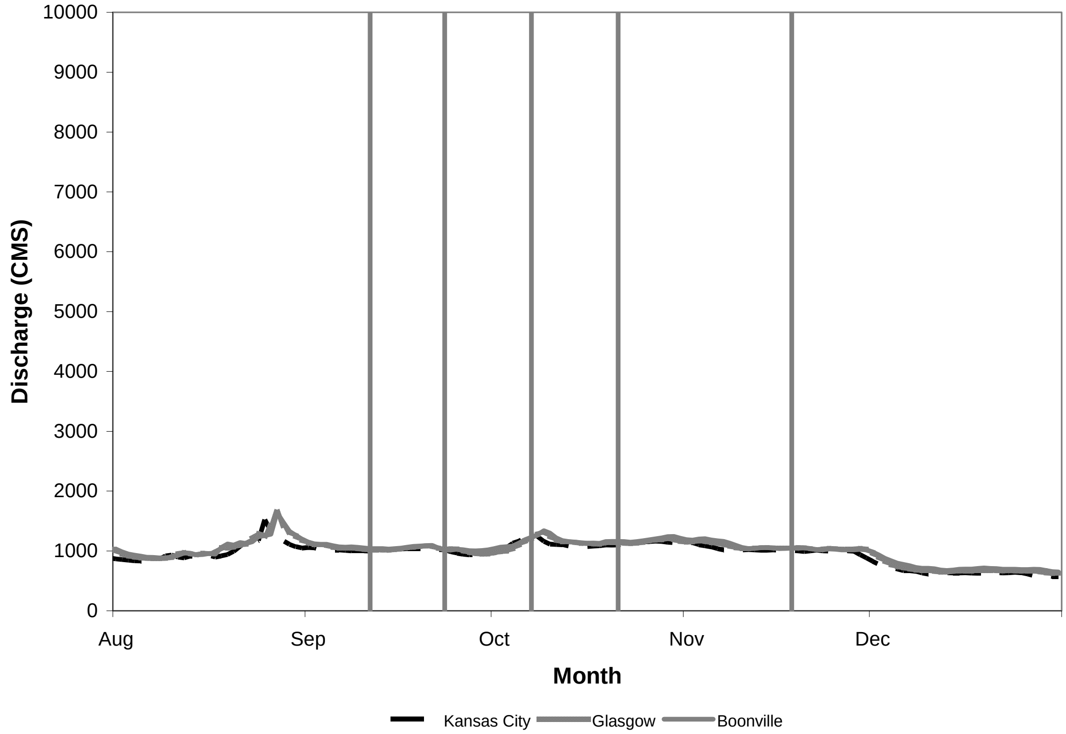


Figure 6.14: Discharge of the Missouri River at Kansas City, Glasgow and Boonville, Missouri during fall 2002. Vertical bars represent flight survey dates.

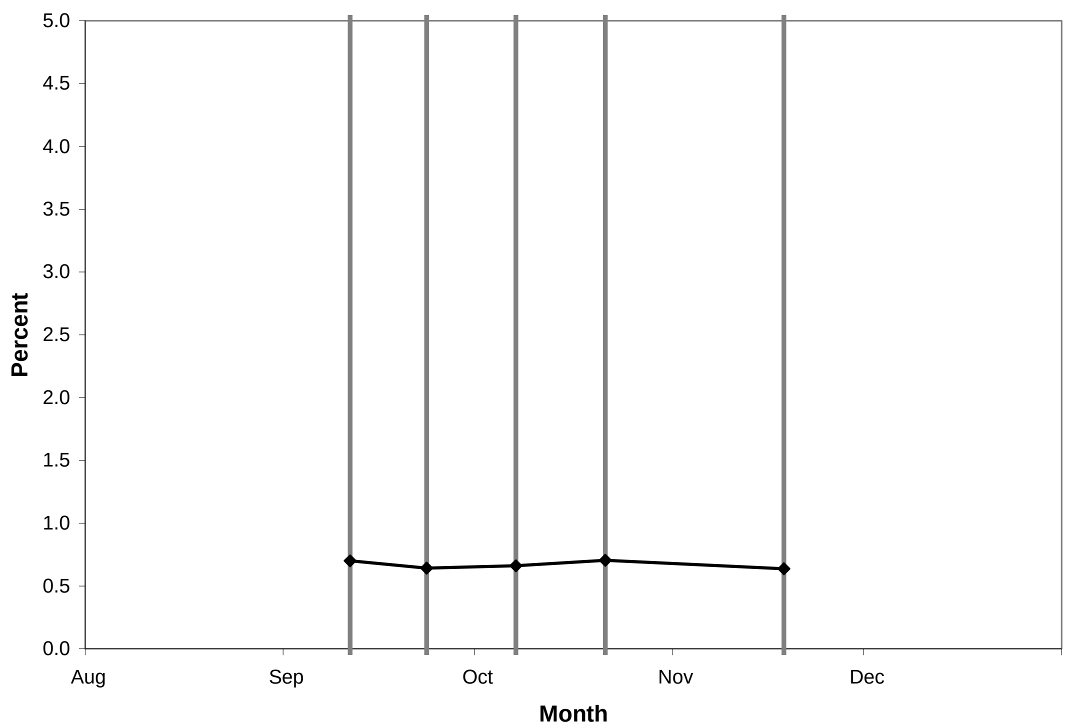


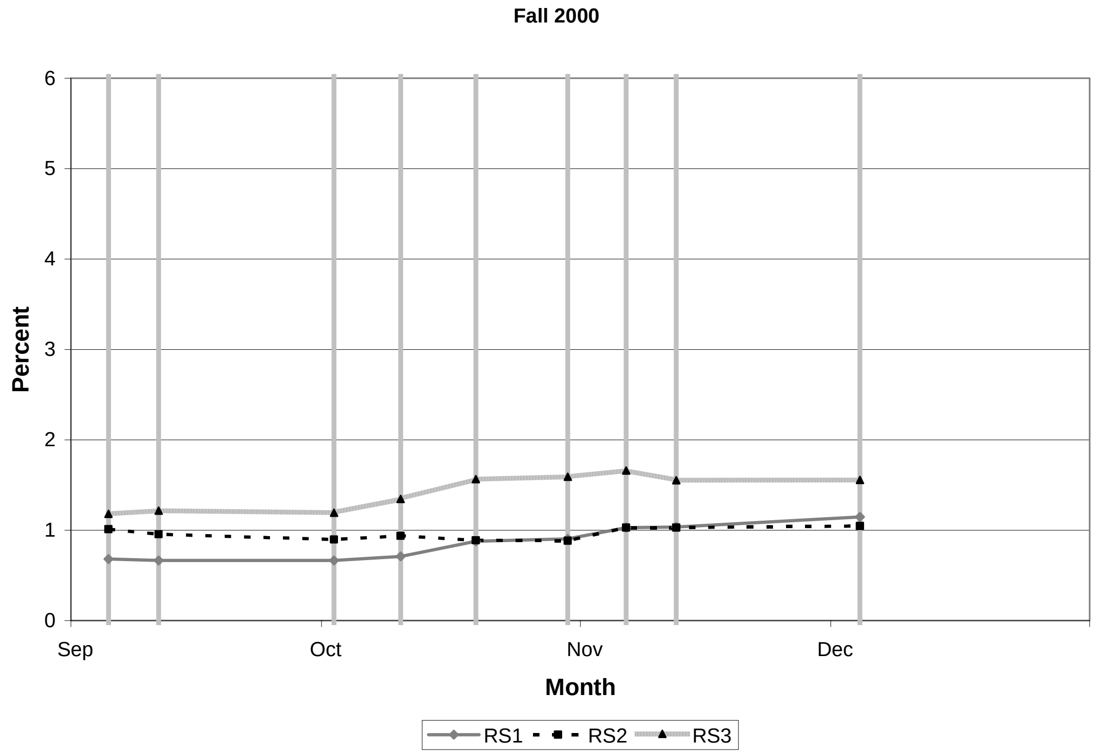
Figure 6.15: Percent surface water within the study area per survey date during fall 2002. Vertical bars represent flight survey dates.

Spatial Distribution of Surface Water by River Section and Transect

RS1 had the lowest mean percent of surface water, 1.03%, ranging from 17.0 ha (0.50%) to 139.2 ha (4.13%) averaged over all sampling times (Table 6.1; Figure 6.16). RS2 had the highest mean percent of surface water, 1.81%, ranging from 44.3 ha (0.72%) to 357.2 ha (5.80%). RS3 had a mean of 1.17% surface water during the study, ranging from 33.1 ha (0.35%) to 366.3 ha (3.91%). Wetland basin density (the number of basins per km^2) decreased westerly from RS1 to RS3 (Table 6.1).

Table 6.1: Minimum and maximum number of basins, basin density, area of surface water and percent of surface water and mean area of surface water and percent of surface water within the three sections of the Missouri River floodplain from fall 2000 to fall 2002.

	Minimum				Mean		Maximum			
RS	Number of basins	Basin density	Area (ha)	Percent	Area (ha)	Percent	Number of basins	Basin density	Area (ha)	Percent
1	17	0.50	17.0	0.50	37.3	1.03	124	3.68	139.2	4.13
2	14	0.23	44.3	0.72	107.3	1.81	207	3.36	357.2	5.80
3	20	0.21	33.1	0.35	120.2	1.17	221	2.36	366.3	3.91



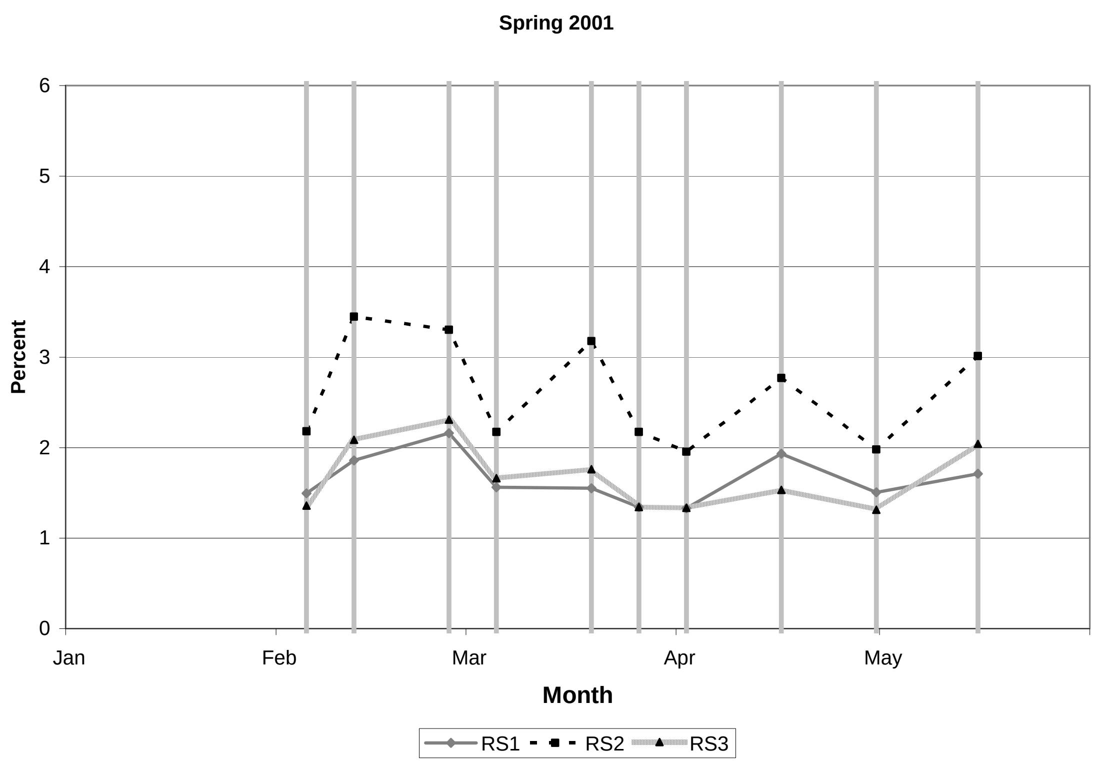
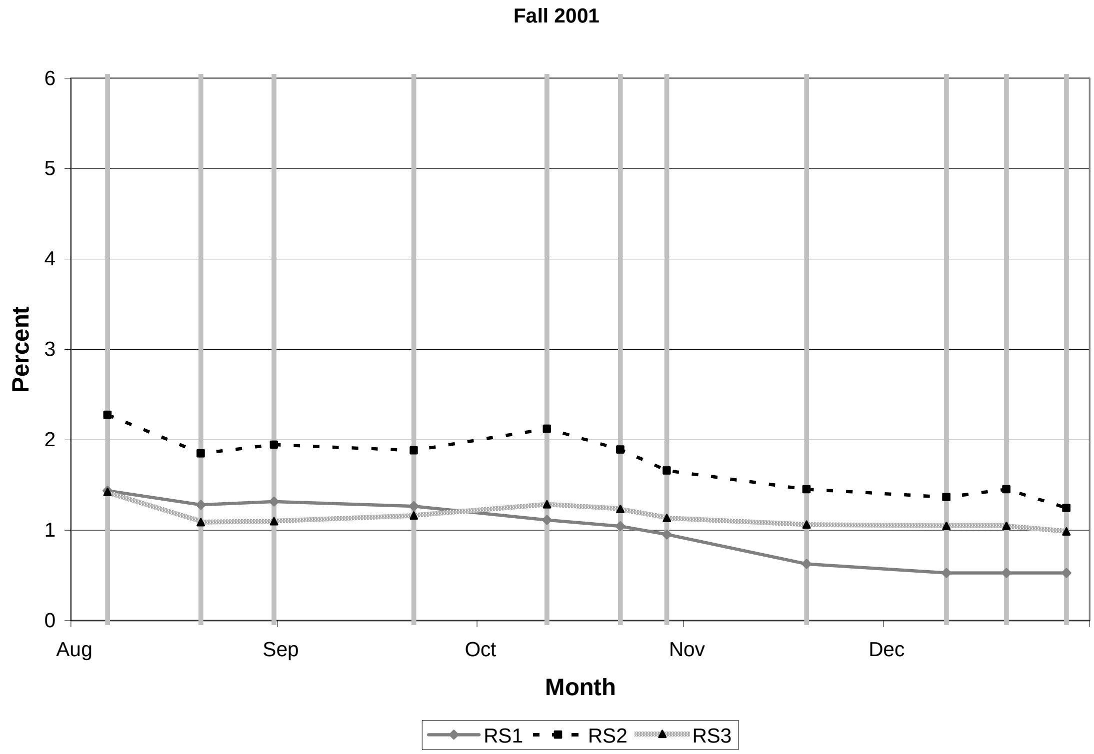


Figure 6.16: Percent surface water for 3 river sections between Hartsburg and Independence, Missouri from fall 2000 to fall 2002.



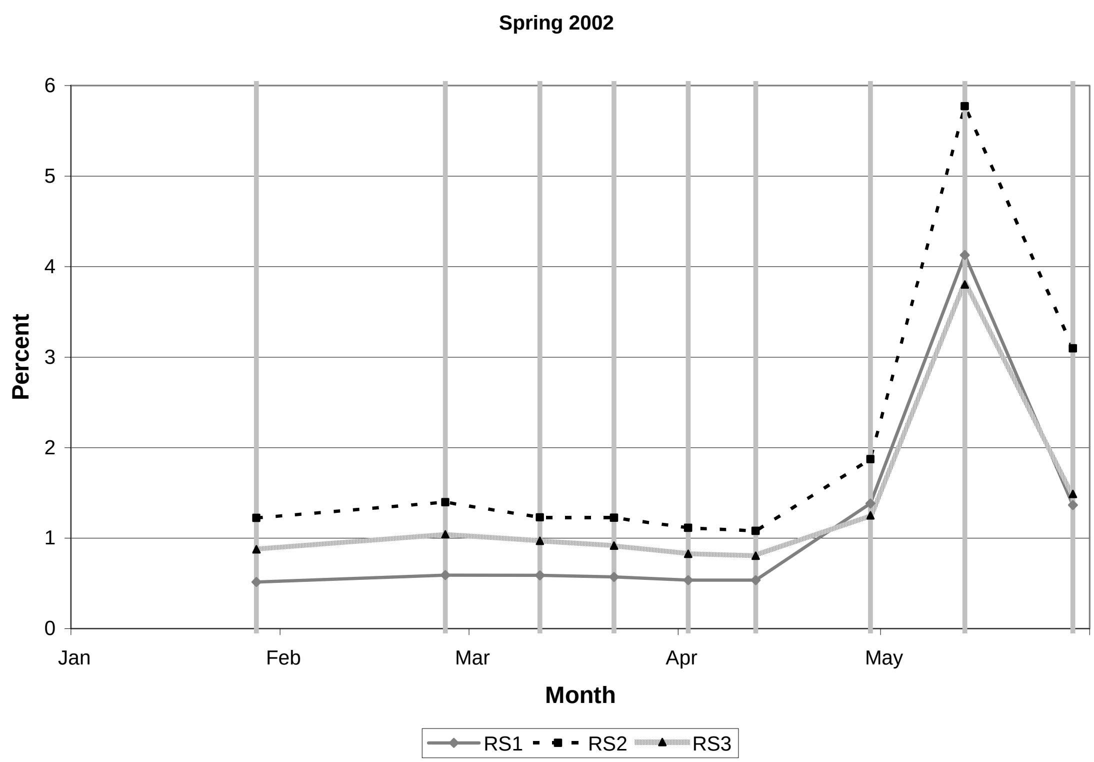


Figure 6.16: Continued.

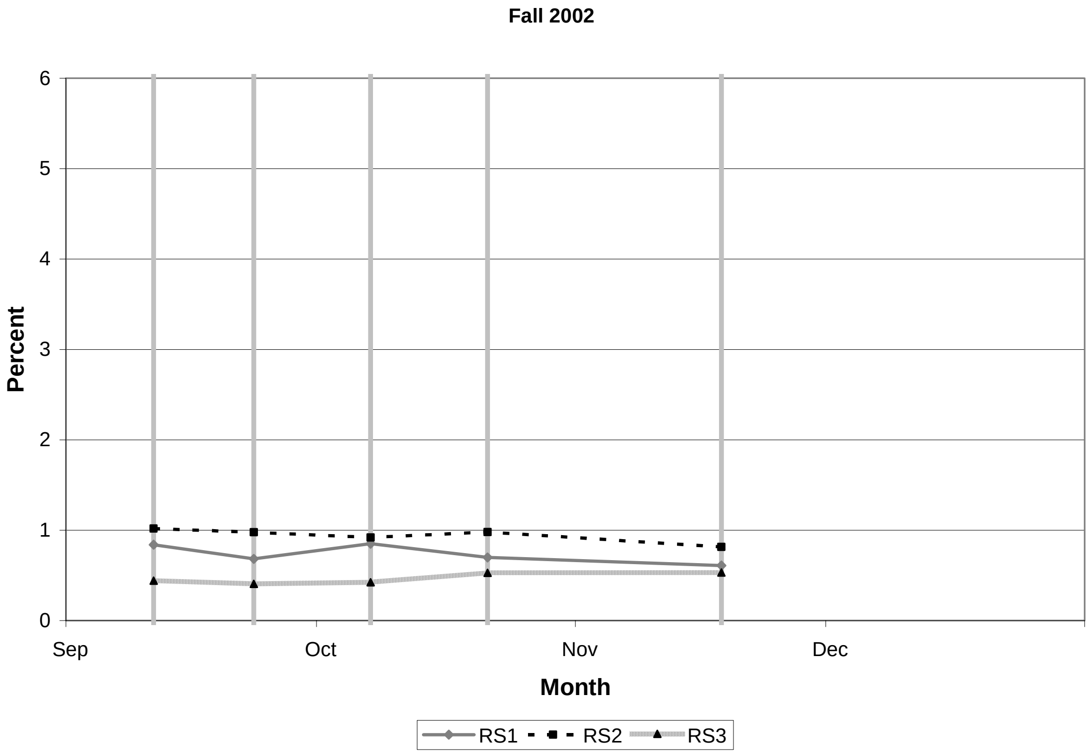


Figure 6.16: Continued.

<u>River Section 1:</u>

Transect 2, had the largest increase in surface water area from 3.5 ha (0.85%) on 29 April 2002 to 55.7 ha (7.86%) on 13 May 2002 (Table 6.2). Transect 3 had the largest average area of surface water within RS1, 15.3 ha or 1.78% of the area within the transect was flooded on average (Table 6.2; Figure 6.17). Transects 4 and 5 had the lowest mean area of surface water in RS1, 2.6 ha (0.41% of the total area) and 1.9 ha (0.37%), respectively (Table 6.2; Figure 6.17). Transect 5 also had the lowest minimum area of surface water ranging from 0.19 ha (0.04%) to 0.31 ha (0.06%). This very low area of surface water area generally occurred during the late fall and early spring (Table 6.2; Figure 6.17).

<u>River Section 2:</u>

Transect 6 had the lowest mean surface water area in RS2 (3.7 ha, 0.30%) and lowest minimum area (0.5 ha, 0.04%). This limited surface flooding generally occurred during the fall and early spring (Table 6.2; Figure 6.17). Transect 6 had one of the lowest minimum basin densities in the study area, containing a minimum of only 1 basin or a density of 0.08 basins/km^2 (Table 6.2). However, Transect 6 also had one of the higher maximum basin densities, containing a maximum of 50 basins or 4.09 basins/km^2 (Table 6.2). Transect 7 had a mean of 2.64% surface water that ranged from 2.08% to 4.38% (Table 6.2; Figure 6.17). The large minimum value in Transect 7 was largely due to a remnant oxbow. Transect 10 had the highest mean surface water area in RS2 (2.80%, 21.7 ha).

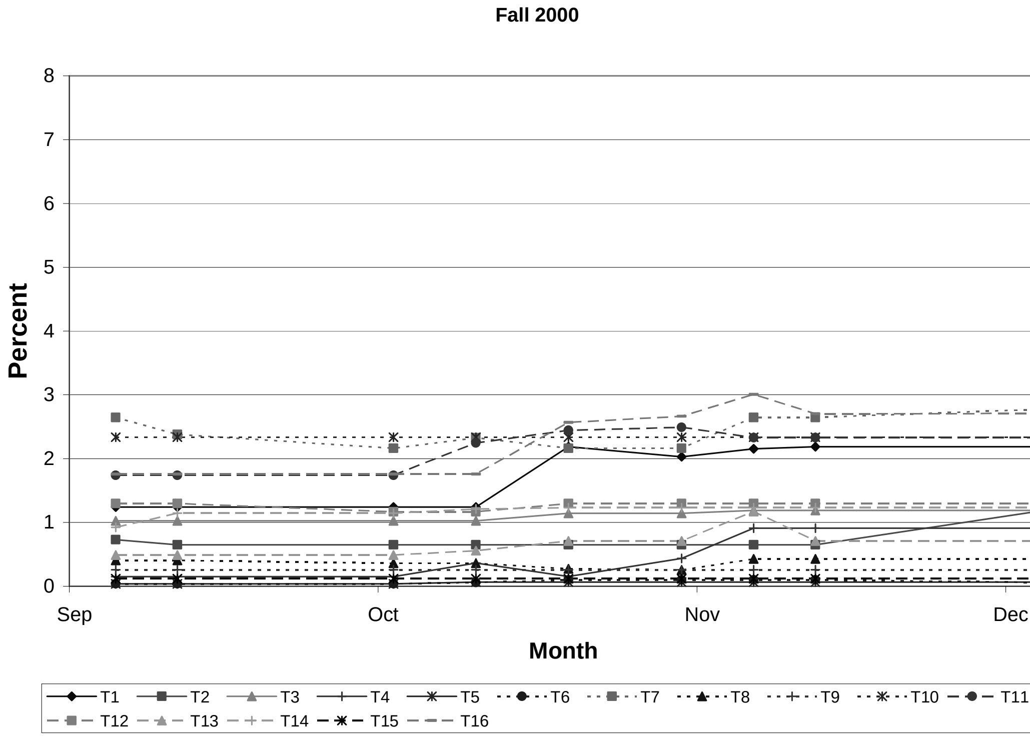
River Section 3:

Transect 11 had the highest mean surface water area in RS2 (1.91%, 47.1 ha), ranging from 15.9 ha (0.65%) to 155.1 ha (6.30%). Transect 11 also had the highest minimum and maximum basin density in RS3, with a minimum of 10 basins or a basin density of 0.41/km^2, a maximum of 90 basins or a basin density of 3.65/km^2 and a mean of 47.1 ha (1.91%) of surface water (Table 6.2). Transect 13 had the lowest minimum and maximum basin density in RS3, with a minimum of 1 basin or a basin density of 0.08/km^2, a maximum of 22 basins or a basin density of 1.75/km^2 and a mean of 7.1 ha (0.57%) of surface water. Transect 15 had the lowest mean surface water area in RS3 (3.53 ha, 0.34%) (Table 6.2; Figure 6.17). Transect 15 also had the lowest minimum basin densities in RS3, containing a minimum of only 1 basin or a density of 0.10/km^2 and a maximum of 14 basins or 1.34 basins/km^2 (Table 6.2; Figure 6.17).

Table 6.2: Minimum and maximum number of basins, basin density, area of surface water and percent of

surface water and mean area of surface water and percent of surface water within the sixteen study transects within the Missouri River floodplain from fall 2000 to fall 2002.

Site	Minimum				Mean		Maximum			
	Number of basins	Basin density	Area (ha)	Percent	Area (ha)	Percent	Number of basins	Basin density	Area (ha)	Percent
1	5	0.79	5.0	0.79	8.9	1.41	17	2.69	18.6	2.94
2	5	0.71	3.5	0.50	8.4	1.19	47	6.64	55.7	7.86
3	5	0.58	7.9	0.92	15.3	1.78	24	2.79	34.1	3.96
4	1	0.15	0.4	0.06	2.6	0.41	19	2.91	17.9	2.74
5	1	0.19	0.2	0.04	1.9	0.37	17	3.28	13.0	2.51
6	1	0.08	0.5	0.04	3.7	0.30	50	4.09	69.2	5.66
7	5	0.39	26.7	2.08	34.0	2.64	24	1.87	56.4	4.38
8	2	0.13	3.9	0.25	31.0	2.00	55	3.55	104.9	6.76
9	1	0.08	0.6	0.05	16.9	1.28	46	3.48	73.7	5.58
10	5	0.65	12.6	1.63	21.7	2.80	32	4.14	53.0	6.85
11	10	0.41	15.9	0.65	47.1	1.91	90	3.65	155.1	6.30
12	2	0.12	4.3	0.25	14.3	0.83	26	1.51	55.3	3.21
13	1	0.08	0.3	0.02	7.1	0.57	22	1.75	33.2	2.64
14	4	0.27	5.1	0.34	24.6	1.64	33	2.20	45.6	3.04
15	1	0.10	1.2	0.12	3.5	0.34	14	1.34	23.0	2.20
16	2	0.15	6.3	0.46	23.6	1.72	36	2.62	54.1	3.94



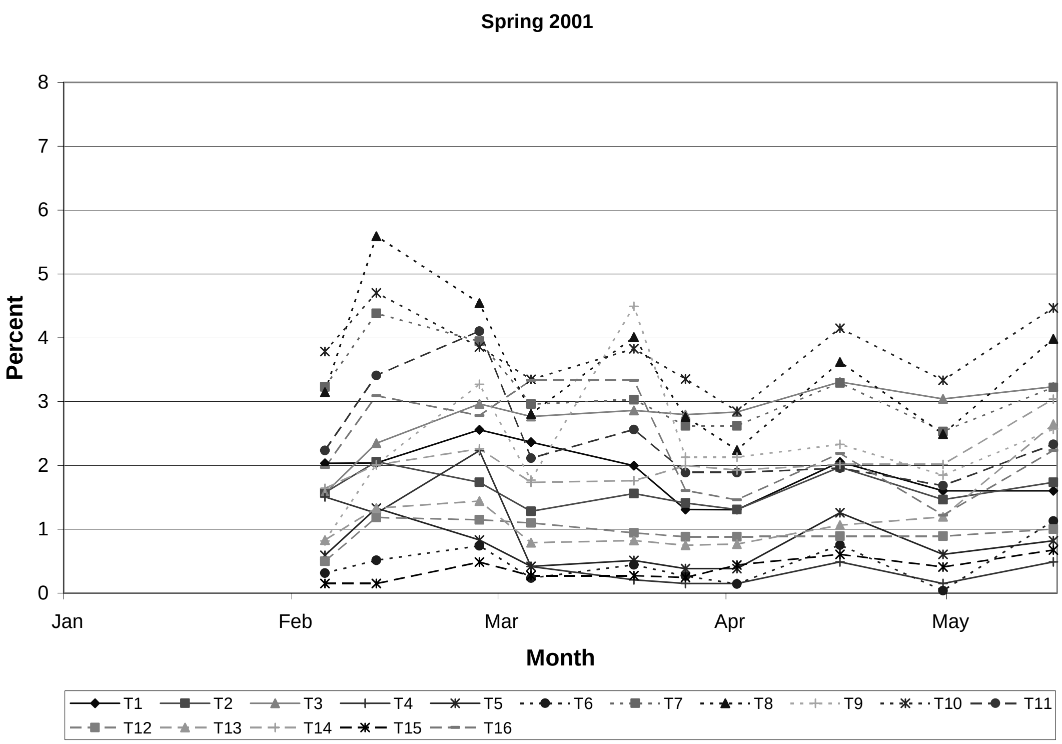
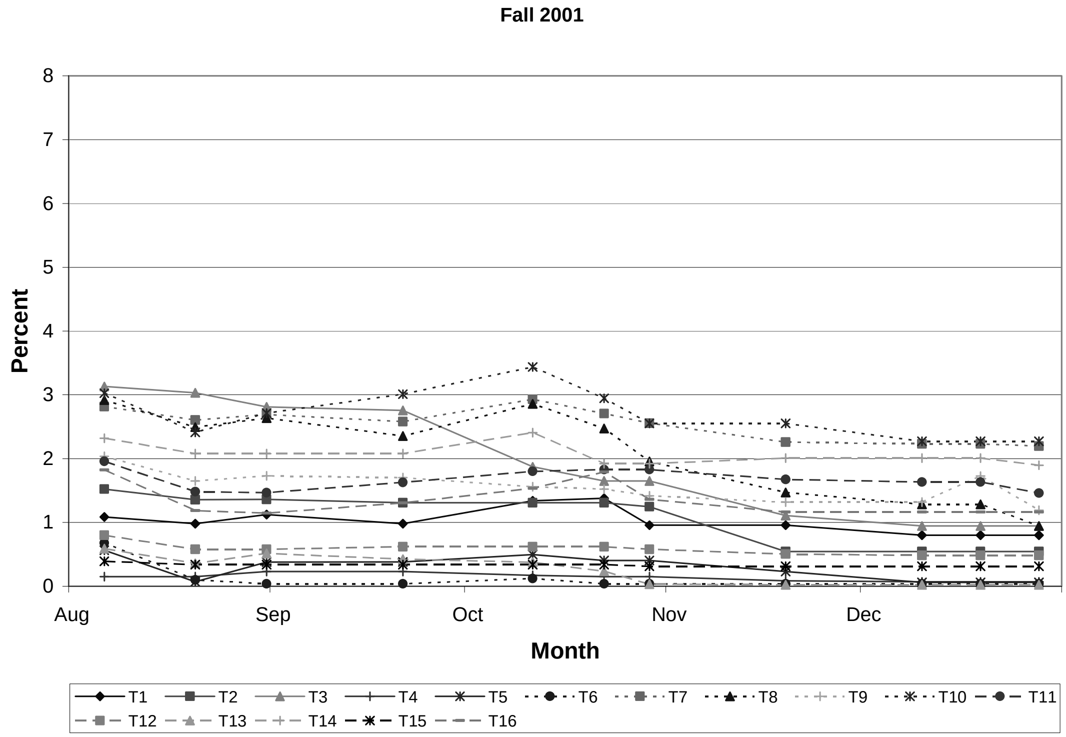


Figure 6.17: Percent surface water for 16 transects between Hartsburg and Independence, Missouri from fall 2000 to fall 2002. Solid lines represent transects within RS1, short dashed lines represent transects within RS2, and long dashed lines represent transects within RS3.



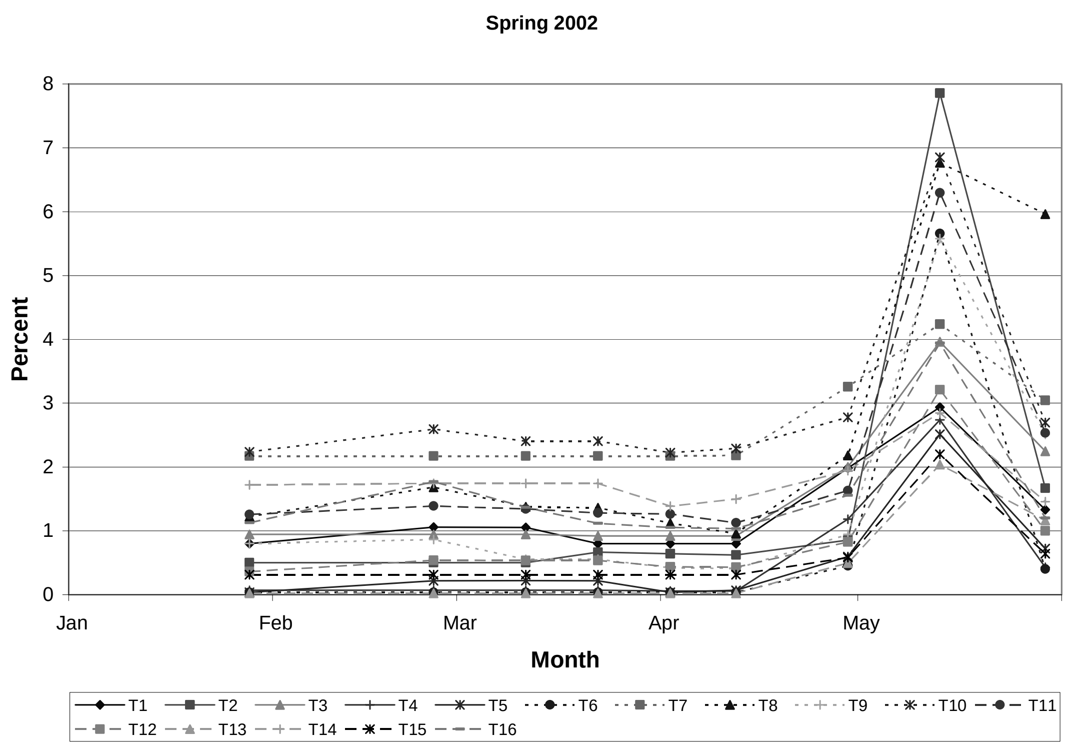


Figure 6.17: Continued.

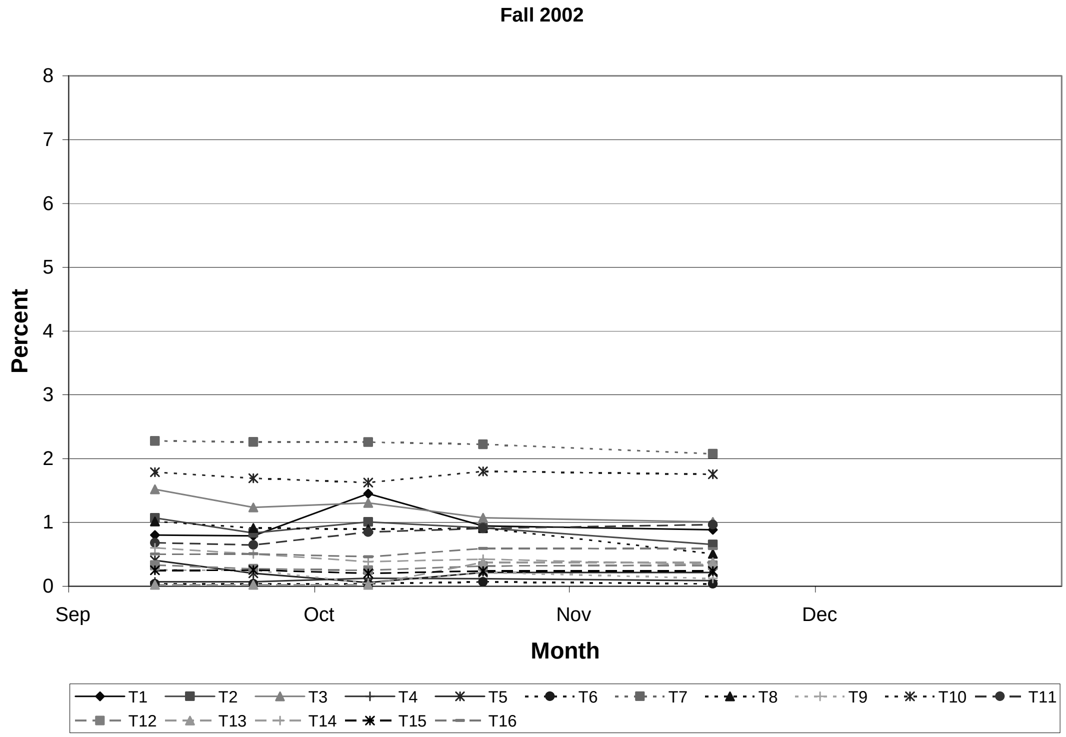


Figure 6.17: Continued.

Basin Inundation Responses by Class

A total of 520 wetland basins was identified within the selected portion of the Missouri River Floodplain. These wetlands were classified based on type of alteration: none visible, affected by roads, affected by agricultural ditches, affected by levees and affected by other structures. Of the 520 basins defined, 65 were classified as having no visible alterations, 109 were recorded as being affected by roads, 121 were considered agricultural ditch complexes, 104 were affected by levees, 12 were affected by other structures and 109 basins were neglected because they were partially contained with the transect. Wetland response variables were examined for four classes of wetlands: basins affected by roads, basins affected by levees, agricultural ditch wetland complexes and unaltered basins. Basins that were affected by other structures and basins partially contained within the study area were not included within this analysis, due to low sample size and incomplete data, respectively.

I classified basins with no discernable ditching or other alteration as unaltered in this study. However, the extent of anthropogenic alterations common within the Missouri River floodplain suggests that there likely is some degree of alteration for all wetland basins within the study area. Unaltered basins had a similar mean number of inundated periods during the study (mean 3.7 ± 6.1 SD), when compared to basins affected by roads (mean 5.6 ± 8.6 SD; $p = 0.2785$) (Table 6.3; Table 6.4; Figure 6.18). Unaltered basins had a lower number of inundated periods than basins affected by agricultural ditches ($p = 0.0058$) and levees ($p < 0.0001$), which had a mean of 8.4 (± 11.30 SD) and 11.5 (± 14.6 SD) periods of inundation respectively. Basins altered by roads had a lower mean number of inundated periods than those basins affected by levees ($p = 0.0001$), indicating that basins affected by roads were less frequently inundated than basins affected by levees.

The number of stable periods, those periods that showed no appreciable change in the amount of surface water area from one survey to the next, between wetland alteration classes was variable. The basins affected by levees had a significantly higher mean number of stable periods of inundation than basins affected by roads (mean 2.0 ± 6.0 SD; $p < 0.0001$), agricultural ditches (mean 4.4 ± 7.5 SD; $p = 0.0029$) and unaltered basins (mean 0.9 ± 2.8 SD; $p < 0.\ 0001$) (Table 6.3; Table 6.4; Figure 6.18). This indicates that basins affected by levees often experienced longer periods of time with no appreciable change in the amount of surface water within the basin. Basins affected by roads and unaltered basins had a similar mean number of stable periods ($p = 0.3903$), 2.0 and 0.9

respectively, indicating that the amount of surface water within these basins fluctuated frequently. Unaltered basins had fewer mean number of stable periods than those affected by levees ($p < 0.0001$) and agricultural ditches ($p = 0.0072$), indicating that unaltered basins fluctuated more frequently than those impacted levees or agricultural ditches.

Basins affected by roads had similar mean duration of inundation index (mean 3.1 ± 6.0 SD) compared to unaltered basins ($p = 0.5441$) and basins affected by agricultural ditches ($p = 0.1768$) (Table 6.3; Table 6.4; Figure 6.18). The duration of inundation index indicates that these basins were flooded a similar length of time per flooding event. Basins affected by levees had the highest mean duration of inundation index (mean 7.7 ± 12.6 SD), significantly higher than basins affected by roads (mean 3.1 ± 6.0 SD; $p < 0.0001$), and unaltered basins (mean 2.3 ± 4.2 SD; $p < 0.0001$). This finding indicates that basins affected by levees are inundated for longer periods than unaltered basins and basins affected by roads.

Unaltered basins had a lower mean area (0.54 ha $\pm$ 0.47 SD) than basins affected by agricultural ditches ($p = 0.0079$), with a mean area of 1.07 ha ($\pm$ 1.95 SD) (Table 6.3; Table 6.4; Figure 6.19). Basins affected by roads had a similar mean area when compared to basins altered by agricultural ditches ($p = 0.2695$) or levees ($p = 0.6083$). Basins altered by agricultural ditches or levees also were similar in size ($p = 0.1065$).

The mean shape index (MSI) indicates that basins affected by agricultural ditches (mean 2.08 ± 0.83 SD) had a more complex shape than that of unaltered basins (mean 1.52 ± 0.34 SD; $p < 0.0001$) and basins affected by roads (mean 1.73 ± 0.47 SD; $p < 0.0001$) or levees (mean 1.60 ± 0.53 SD; $p < 0.0001$) (Table 6.3; Table 6.4; Figure 6.19).

The mean shape index of basins affected by levees was similar to that of basins altered by roads (p = 0.1192) and unaltered basins (p = 0.4312).

Table 6.3: Mean and standard deviation of number of periods of inundation, periods of stable inundation, duration of inundation index, mean area, and mean shape index (MSI) of unaltered basins and basins affected by roads, agricultural ditches and levees within the Missouri River floodplain.

	Unaltered (n = 65)		Road (n = 109)		Ag ditch (n = 121)		Levee (n = 104)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Inundated	3.7	6.1	5.6	8.6	8.4	11.3	11.5	14.6
Stable inundation	0.9	2.8	2.0	6.0	4.4	7.5	7.8	12.7
Duration index	2.3	4.2	3.1	6.0	4.6	7.6	7.7	12.6
Mean area (ha)	0.54	0.47	0.88	1.06	1.07	1.95	0.79	0.80
MSI	1.52	0.34	1.73	0.47	2.08	0.83	1.60	0.53

Table 6.4: P-values of number of periods of inundation, periods of stable inundation, duration of inundation index, mean area, and mean shape index (MSI) of unaltered basins and basins affected by roads, agricultural ditches and levees within the Missouri River floodplain.

		Unaltered (n = 65)	Road (n = 109)	Ag ditch (n = 121)	Levee (n = 104)
Inundated	Unaltered		0.2785	0.0058	< 0.0001
	Road	0.2785		0.0530	0.0001
	Ag Ditch	0.0058	0.0530		0.0366
	Levee	< 0.0001	0.0001	0.0366	
Stable inundation	Unaltered		0.3903	0.0072	< 0.0001
	Road	0.3903		0.0341	< 0.0001
	Ag Ditch	0.0072	0.0341		0.0029
	Levee	< 0.0001	< 0.0001	0.0029	
Duration of inundation	Unaltered		0.5441	0.0757	< 0.0001
	Road	0.5441		0.1768	< 0.0001
	Ag Ditch	0.0757	0.1768		0.0063
	Levee	< 0.0001	< 0.0001	0.0063	
Mean area	Unaltered		0.0920	0.0079	0.2197
	Road	0.0920		0.2695	0.6083
	Ag Ditch	0.0079	0.2695		0.1065
	Levee	0.2197	0.6083	0.1065	
MSI	Unaltered		0.0313	< 0.0001	0.4312
	Road	0.0313		< 0.0001	0.1192
	Ag Ditch	< 0.0001	< 0.0001		< 0.0001
	Levee	0.4312	0.1192	< 0.0001	

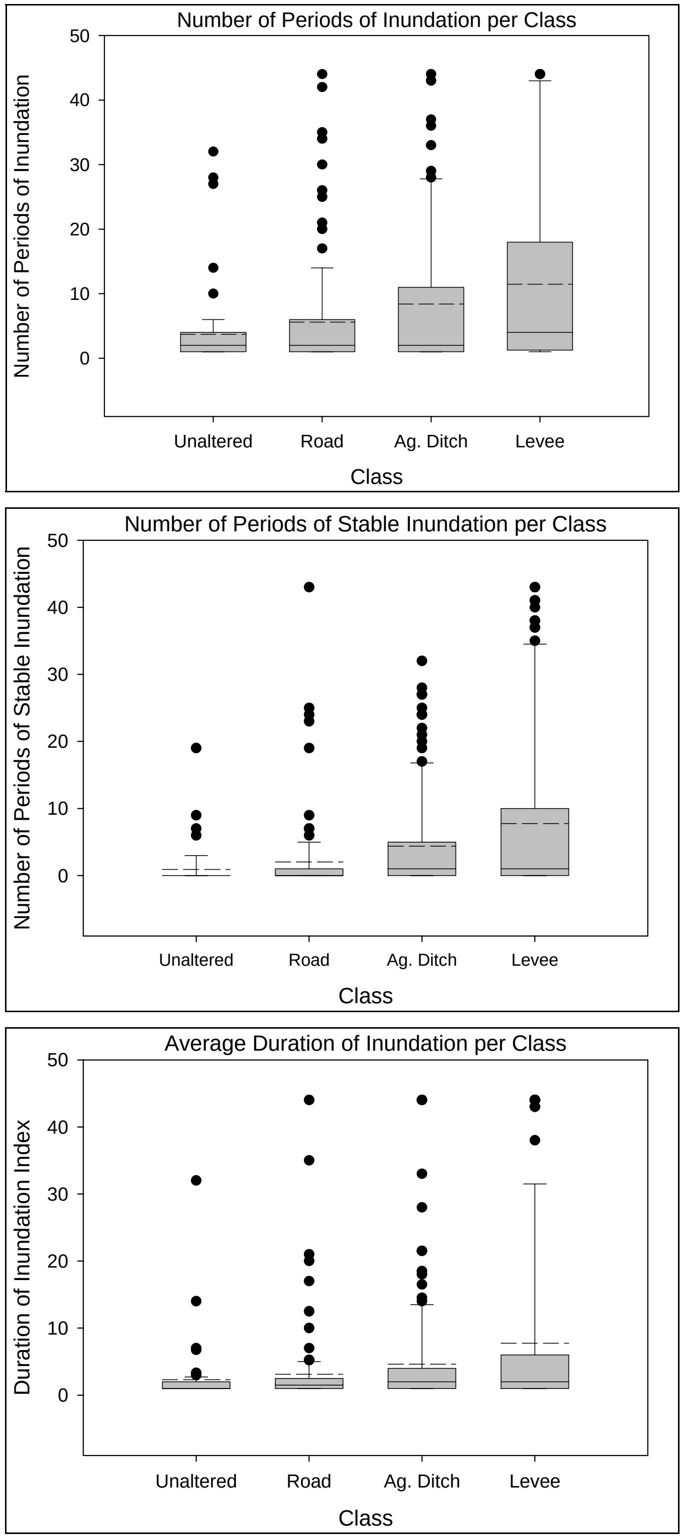


Figure 6.18: Number of periods of inundation, number of periods of stable inundation, and duration of inundation index for unaltered basins and basins impacted by roads, agricultural ditches and levees. The box extends from the 25th to the 75th percentile, error bars indicate the 90th percentile, outliers are represented by circles. The median is indicated by a solid line across the box and the mean is represented by a dashed line.

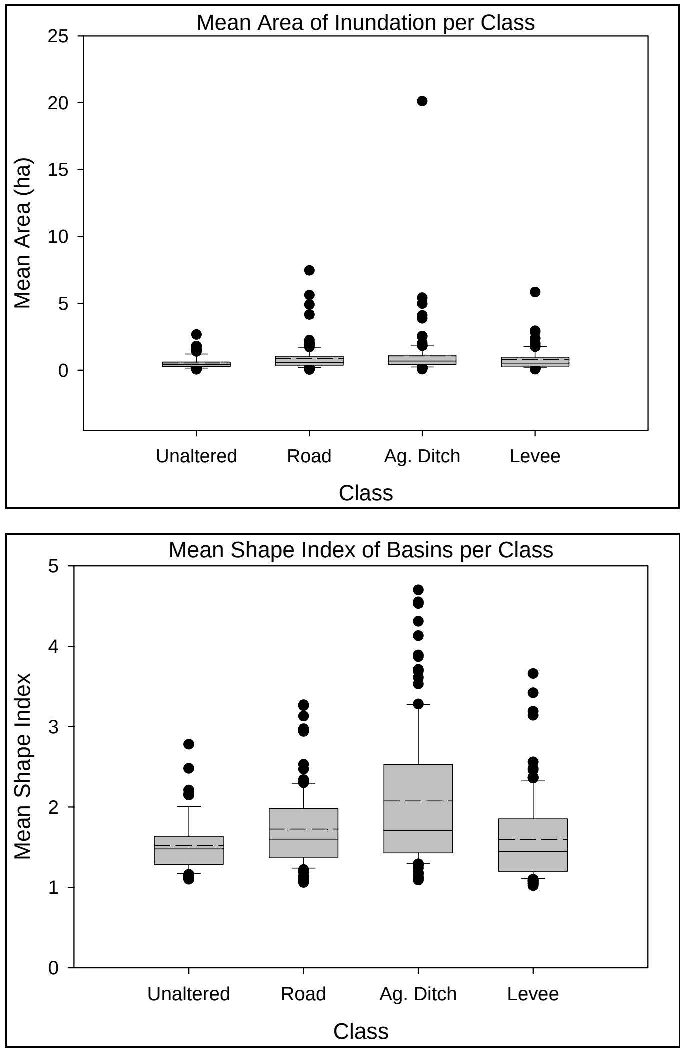


Figure 6.19: Mean area, and mean shape index (MSI) for unaltered basins and basins affected by roads, agricultural ditches, and levees. The box extends from the 25th to the 75th percentile, error bars indicate the 90th percentile, outliers are represented by circles. The median is indicated by a solid line across the box and the mean is represented by a dashed line.

Basin Inundation Responses by Road Class

Of the 520 basins defined, 65 were classified as having no visible impacts, 109 were recorded as being affected by roads, of these 14 were classified as being affected by state roads, 60 by local roads and 35 by private roads. When these basins were examined by road class, the responses were somewhat different among unaltered basins and basins affected by the three different road classes (state, local and private).

Basins affected by roads had a significantly higher mean number of periods of inundation (mean 16.0 ± 17.7 SD) than basins affected by local roads ($p < 0.001$), private roads ($p < 0. 001$) and unaltered basins ($p < 0.001$) (Table 6.5; Table 6.6; Figure 6.20). Unaltered basins and basins affected by local and private roads had a similar number of inundated periods recorded.

Basins affected by state roads had a mean of 9.4 stable periods (those that showed no appreciable change in the amount of surface water area from one survey to the next) and a standard deviation of 13.7 (Table 6.5; Table 6.6; Figure 6.20), higher than unaltered basins ($p < 0.0001$) and basins affected by local roads ($p < 0.0001$) and private roads ($p < 0.0001$). This indicates that basins affected by state roads experienced longer periods of time with no change in the amount of surface water within the basin. The number of stable periods was similar between unaltered basins and basins affected by local ($p = 0.9110$) and private roads ($p = 0.7593$).

The mean duration of inundation index for basins affected by state roads was 10.8 (±14.0 SD), significantly higher than unaltered basins ($p < 0.0001$) and basins affected by local ($p < 0.0001$) and private ($p < 0.0001$) roads (Table 6.5; Table 6.6; Figure 6.20). The higher duration of inundation index indicates that basins affected by state roads are inundated for longer periods of time. Unaltered basins and basins affected by local ($p = 0.7053$) or private roads ($p = 0.7660$) had a similar mean duration of inundation index, which had a mean of 2.32, 1.98 and 2.01 respectively.

Basins affected by state and local roads had a similar mean shape index of 1.82 and 1.83 respectively ($p = 0.9598$) (Table 6.5; Table 6.6; Figure 6.21). Unaltered basins and basins altered by private roads had similar mean shape index ($p = 0.9511$). The mean shape index of basins affected by state and local roads was higher than basins affected by private roads or unaltered basins indicating a more complex shape.

No significant differences were found in the average area between unaltered basins and basins affected by any of the three road classes (Table 6.5; Table 6.6; Figure 6.21).

Table 6.5: Mean and standard deviation of number of periods of inundation, periods of stable inundation, duration of inundation index, mean area, and mean shape index (MSI) of unaltered basins and basins affected by state, local and private roads within the Missouri River floodplain.

	Unaltered (n = 65)		Private (n = 35)		Local (n = 60)		State (n = 14)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Inundated	3.7	6.1	3.4	4.2	4.4	5.0	16	17.7
Stable inundation	0.9	2.8	1.2	3.5	0.8	1.5	9.4	13.7
Duration index	2.3	4.2	2	3.2	2.0	1.2	10.8	14
Mean area (ha)	0.54	0.47	0.55	0.45	1.08	1.33	0.82	0.55
MSI	1.52	0.34	1.52	0.35	1.83	0.51	1.82	0.46

Table 6.6: P-values of number of periods of inundation, periods of stable inundation, duration of inundation index, mean area, and mean shape index (MSI) of unaltered basins and basins affected by state, local and private roads within the Missouri River floodplain.

		Unaltered (n = 65)	Private (n = 35)	Local (n = 60)	State (n = 14)
Inundated	Unaltered		0.8431	0.5853	< 0.0001
	Private	0.8431		0.5130	< 0.0001
	Local	0.5853	0.5130		< 0.0001
	State	< 0.0001	< 0.0001	< 0.0001	
Stable inundation	Unaltered		0.7593	0.9110	< 0.0001
	Private	0.7593		0.6921	< 0.0001
	Local	0.9110	0.6921		< 0.0001
	State	< 0.0001	< 0.0001	< 0.0001	
Duration index	Unaltered		0.7660	0.7053	< 0.0001
	Private	0.7660		0.9800	< 0.0001
	Local	0.7053	0.9800		< 0.0001
	State	< 0.0001	< 0.0001	< 0.0001	
Mean area (ha)	Unaltered		0.9515	0.0006	0.2785
	Private	0.9515		0.0044	0.3322
	Local	0.0006	0.0044		0.3025
	State	0.2785	0.3322	0.3025	
MSI	Unaltered		0.9511	< 0.0001	0.0156
	Private	0.9511		0.0006	0.0217
	Local	< 0.0001	0.0006		0.9598
	State	0.0156	0.0217	0.9598	

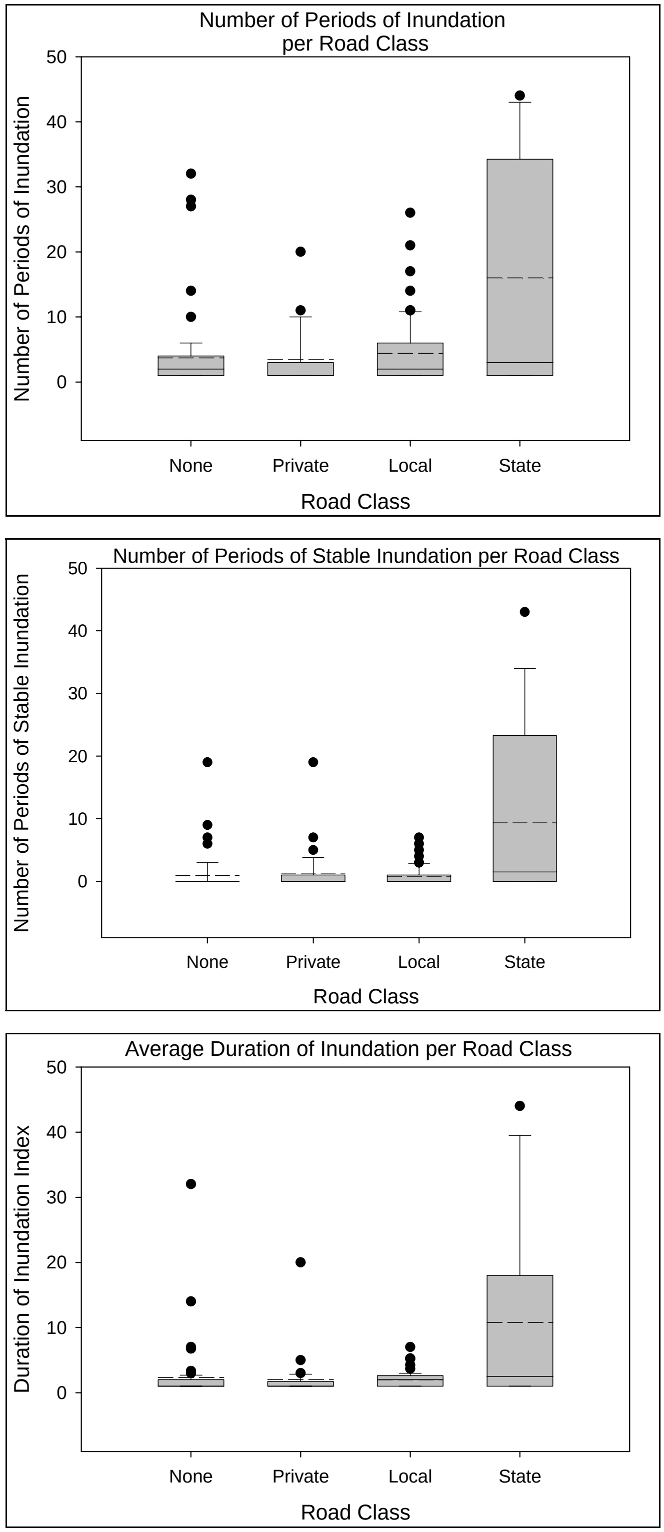


Figure 6.20: Number of periods of inundation, number of periods of stable inundation, and duration of inundation index for unaltered basins and basins affected by state, local and private roads. The box extends from the 25th to the 75th percentile, error bars indicate the 90th percentile, outliers are represented by circles. The median is indicated by a solid line across the box and the mean is represented by a dashed line.

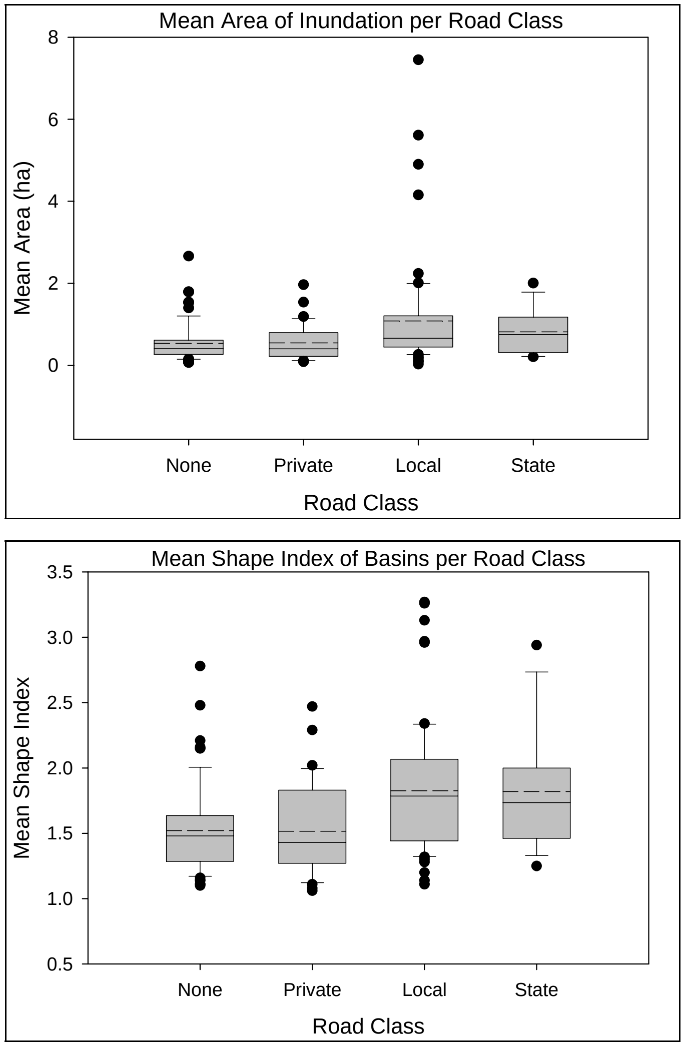


Figure 6.21: Mean area, and mean shape index (MSI) for unaltered basins and basins affected by state, local and private roads. The box extends from the 25th to the 75th percentile, error bars indicate the 90th percentile, outliers are represented by circles. The median is indicated by a solid line across the box and the mean is represented by a dashed line.

Summary and Discussion

The distribution of surface water area varied within and between seasons. The greatest amount of surface water during the study was generally available during spring. The three falls surveyed had relatively low amounts of precipitation and therefore provided little surface water. Fall 2000 was relatively dry and as a result the amount of surface water remained essentially unchanged. Surface water distribution in the spring of 2001 was more variable over time. The greatest amount of surface water during fall 2001 was available during early fall and gradually declined throughout the season. The distribution of surface water in the spring of 2002 showed little change until late April when precipitation increased. The greatest amount of surface water was available during late spring. Fall 2002 was relatively dry and the area of surface water remained essentially unchanged.

The distribution of surface water area varied among transects. Transects 4, 5, 6, 12, 13 and 15 had a mean of well below 1.0% of the total transect area being inundated with surface water. These transects contained largely temporary wetland basins, that were inundated only once or twice during the study. Transects 7 and 10 had a mean area of surface water of over 2.6% of the transect area being inundated, because these transects contained larger, more permanent wetland basins.

Unaltered basins had fewer mean periods of inundation, fewer stable periods and lower duration index than the basins affected by levees and agricultural ditches within the study area. This may be due to the high degree of alteration of the floodplain, that likely reduces surface and ground water flows. Many of the larger wetland basins within the study area were impounded by railroads or levees or an attempt was being made to drain the basin via agricultural ditches. The impacts from structures like railroads, levees and roads may concentrate and alter or completely block surface water flow. For example, roads located within the toe-slope of the valley appear to concentrate runoff into roadside ditches, which conduct the water under the road through culverts, into agricultural ditches and ultimately into stream networks, thus bypassing wetland basins within the floodplain.

Overall, basins affected by roads were most similar to unaltered basins, having a similar mean number of periods of inundation, periods of stable inundation, duration of inundation, mean area and MSI. This finding indicates that incidental impacts from roads may not be as detrimental as impacts from other anthropogenic alterations. However, basins affected by roads also had a similar number of periods of inundation, number of periods of stable inundation and duration of inundation index when compared to basins impacted by agricultural ditches. These findings suggest that basins altered by roads may have a hydrologic regime that is intermediate between that of unaltered basins and basins affected by agricultural ditches.

Agricultural ditches have a large effect on temporary wetlands within the Missouri River floodplain, directly affecting 23.3% of basins within the study area. Agricultural ditch wetland complexes had a significantly higher MSI than all other classes, due to the highly convoluted nature of the perimeter of these basins (Figure 6.22). Unaltered basins had a significantly lower number of periods of inundation and number of periods of stable inundation than basins affected by agricultural ditches. These findings indicated that despite efforts to drain these areas, agricultural ditch wetland complexes may sustain surface water more frequently and for longer periods of time than unaltered basins.

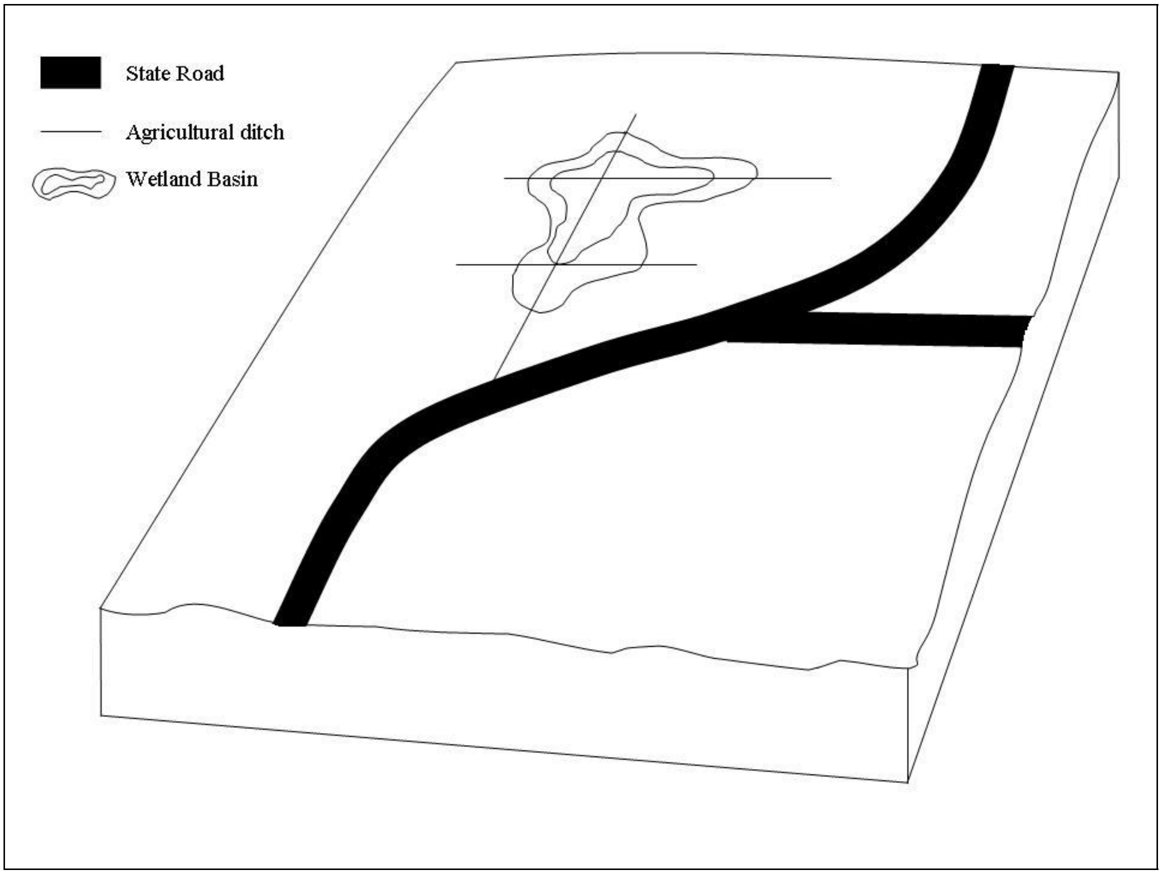


Figure 6.22: Effects of agricultural ditches on the shape characteristics of wetland basins within the Missouri River floodplain. The outer polygon represents the maximum area and the inner polygon represents the minimum area of flooding inundation for the wetland basins.

Levees also have a large impact on wetland basins, affecting approximately 20% of the basins within the study area. Basins affected by levees had a higher mean number of periods of inundation, periods of stable inundation and duration of inundation index than unaltered basins and basins affected by roads. This finding indicates that levees tend to act as dams, thus impounding surface water flow for long periods of time with a lower amount of fluctuation in the amount of surface water within the basin. This may also be due to the fact that the fill material for levees is often obtained in the immediately vicinity, creating borrow areas of lower elevation surrounding the levee.

When the basins affected by roads were examined by road class (state, local and private) the responses were somewhat different among the three different road classes and unaltered basins. There were a relatively small number of basins affected by state roads within the study area. This is largely due to the fact that state roads had a lower rate of occurrence within the study area and had a higher number of associated agricultural ditches, making it difficult to locate basins affected by state roads without being affected by another form of alteration. State roads seemed to impound surface and/or ground water flow, resulting in basins having more periods of inundation, more periods of stable inundation and higher duration of inundation index than unaltered basins and basins affected by local and private roads. These findings indicate that state roads may be acting as dams and impounding surface water to a greater degree than local and private roads. This is likely associated with the design standards of these structures, because they are built with a greater amount of fill and have deeper and more continuous ditches that result in a higher linear frequency of agricultural ditches. Unaltered basins and basins affected by local roads and private roads had similar duration of inundation index and number of periods of inundation and stable inundation. These findings indicate that design standards have a varying degree of impact on wetland basins. Most local and private roads are constructed at the elevation of the surrounding landscape, using little or no fill; therefore these structures may be more easily overtopped by surface water flow or penetrated by ground water flow. Unaltered basins and basins affected by private roads had a lower MSI than basins affected by state and local roads.

CHAPTER 7.

CONCLUSIONS

The extensive system of roads in the United States crisscrosses varied ecological settings. These ecological systems trace broad patterns across the landscape, whereas the traditional transportation planning process is meticulously focused on a narrow strip of land close to an existing or proposed roadway (Forman and Deblinger 2000). However, that view is changing, becoming not only feasible, but desirable to accommodate ecosystem processes in the construction and maintenance of a transportation infrastructure (Zeedyk 1996). Successful accommodation of the hydrological processes of floodplain wetlands requires knowledge of the impacts of roads and their associated structures. Results from this study increased the ecological understanding of roadway affects on temporary wetland basins within the Missouri River floodplain. This knowledge lays a foundation for future research on the relationship between roads and the hydrologic regime of wetlands. My research also provides information for agencies tasked with protecting or enhancing wetland systems. This information can be used by agencies to aid in the development of future goals and objectives for conservation or restoration of wetlands.

Results from this study provided several important findings in terms of road design and placement within the agricultural landscape of the Missouri River floodplain. State roads are built to more advanced design standards, utilizing more fill, having deeper and more continuous ditches and more water control structures than local roads. Where the valley bottom was narrow, state roads were frequently constructed in the toe-slope of the valley wall. State road ditches had a greater proportion of agricultural tie-in ditches than local road ditches. Deeper road ditches have a greater proportion of agricultural tie-in ditches than shallow road ditches. The density of agricultural ditches was highest near roads, indicating that road placement within the landscape may influence the placement of agricultural ditches. This may be due to the fact that road ditches provide convenient access to an existing ditch network that is well maintained by local or state transportation agencies. Further, roads ditches, especially those associated with state roads may be over-designed to deal with infrequent heavy rainfall events, making these ditches of sufficient size to carry the runoff flows from a larger area than originally intended.

Although this research was exploratory in nature, these results provided several important findings with regard to wetland basins within this reach of the Missouri River floodplain. Unaltered temporary wetland basins were rare within the agricultural landscape of the Missouri River floodplain, and the few seemingly unaltered basins may in fact have a modified hydrologic regime due to the many anthropogenic alterations within the landscape. When unaltered basins were compared to basins affected by roads, agricultural ditches and levees, those basins affected by roads were most similar to unaltered basins. Levees and agricultural ditches may be important in establishing and maintaining temporary wetland basins within the highly modified landscape of the Missouri River floodplain. Basins altered by agricultural ditches had a higher number of periods of inundation and duration of inundation index than unaltered basins. Basins affected by levees had a higher number periods of inundation, number of periods of stable inundation and duration of inundation index than other basin classes, indicating that these basins tended to be inundated more often and for longer periods of time than unaltered basins and basins affected by roads in the area. The different basin classes created a gradient of habitats ranging from unaltered basins that are infrequently flooded and managed for agriculture to basins affected by levees that were more frequently flooded and essentially undisturbed by agriculture tilling due to their very wet nature. Raedeke et al. (2003) noted that avian habitat use differed with the season and that the Missouri River floodplain is very dynamic and that no single habitat type provided habitat each year or every season. They also found that especially during the spring, wetland habitats within the agricultural landscape of the Missouri River were important to shorebirds, wading birds and waterfowl, particularly dabbling ducks. Shorebirds and wading birds also utilized the floodplain habitats in the agricultural landscape during the fall (Raedeke et al. 2003).

Basins affected by state roads have more periods of inundation, stable periods of inundation and are inundated for longer periods than basins affected by local and private roads. This study indicates that state roads impound surface and/or ground water flow, thus creating new wetlands or enlarging existing wetlands in some instances. However, the ecological value of these wetlands is unknown, due to factors such as wildlife disturbance, introduction of exotic species, and contamination from various chemicals ranging from road salts to petroleum products. Unaltered basins and basins affected by local or private roads had a similar mean number of periods of inundation, periods of stable inundation and lower mean duration of inundation index. This finding indicates that design standards have a varying degree of impact on the hydrologic regime of wetlands. Further study is warranted to more clearly define the extent of roadway impacts on the hydrologic regime of wetlands.

Where roads must be constructed near wetlands or across the direction of sheet flow, two different approaches may be employed to minimize hydrological modifications. Extensive use of culverts or culvert arrays could help minimize alterations to the hydrologic regime by transporting surface water under the roadbed in a more dispersed pattern than a single culvert (Forman et al. 2003, Shuldiner et al. 1979a, Zeedyk 1996). Multiple small culverts would generate a lower flow velocity than will a single large culvert (Forman et al. 2003). Multiple culverts in an array could be constructed at different levels to allow for widely varying flows. In flood prone areas, multiple small culverts could be paired with larger culverts in a tiered array with the large culverts placed above the small culverts to provide for flood protection of the road. Further, culvert outfalls could be built with velocity checks constructed of riprap, to serve as a device to disperse surface flows across the downflow areas (Zeedyk 1996). Multiple culvert arrays coupled with rock outfall structures may be especially effective where roads are constructed near the foot of a slope, as in the narrow Ozark section of the Missouri River floodplain. These structures would allow the water collected into roadside ditches and transferred under the road bed to be re-dispersed onto downslope areas in a more natural pattern. Permeable fill, also known as rock fill embankment or French Drain, is designed to allow dispersed surface water flow to travel under the roadbed with minimal disruption. A permeable fill consists of a layer of coarse rock between two layers of geotextile separation fabric. A layer of separation fabric is placed on a prepared subgrade constructed at the natural surface elevation of the surrounding landscape. The subgrade should be tilted down slightly in the direction of surface water flows in order to maintain hydraulic head through the structure. Rock from 5 to 15 cm in diameter is spread evenly over the separation fabric to a depth of 0.3 m and a second layer of separation fabric is placed over the rock fill. A road embankment is then constructed on the rock fill (Zeedyk 1996). Permeable fill techniques may be useful where the slope of the landscape is slight, allowing dispersed water movement under the road in a more natural manner than traditional fill and culvert construction. Both multiple culvert arrays and permeable fill techniques have been successfully utilized by the U.S. Forest Service on small streams in montane systems (Zeedyk 1996) and could be utilized for local roads and possibly low volume highways, especially in areas where wetland conservation or restoration is of value.

Most roads in the United States were built before ecological effects were a primary concern and new roads are being constructed at a relatively slow pace. However, highway agencies actually have numerous opportunities to take action to reduce the impacts of the existing road network and to develop the methods to make future roads more compatible with the surrounding landscape. One such opportunity is the continuous reconstruction and maintenance of the existing highway system. Over time, existing roads will undergo repairs and renovations that will allow opportunities to explore alternative measures and methods and ultimately begin a systematic process of reducing the impacts of the 6.2 million km system (Transportation Research Board 1997). Short-term budgetary constraints are common to all transportation agencies, affecting the timing, type and scale of any rehabilitation efforts. However, over the long term, budgets are adjusted to reflect changes in societal priorities. The vast size and diversity of the road system actually provides opportunities to improve our understanding of preventative and mitigative measures. Systematic monitoring and evaluation of the ways which the system interacts with ecosystems throughout the county would enable planners, designers and ecologists to make better-informed decisions (Transportation Research Board 1997).

In many instances, ecological effects of road construction are still viewed in the short-term context and as localized projects rather than part of a long-term and far-reaching set of concerns, central to the agency's mission. However, little progress can be made without active collaboration among highway engineers, planners, policy makers, and environmental specialists working toward a common goal to lessen the impacts of the surface transportation system. Bringing such professionals together early in the planning and design process and throughout the implementation process is essential to this goal. The role of ecologist should become more integrated into a highway agency's routine operation and maintenance activities as well as major construction and reconstruction projects (Transportation Research Board 1997). Thus, when highway agencies consider the effects of roadways on the surrounding landscape, there is a good potential to provide benefits to wetland dependent wildlife in combination with maintaining or improving transportation infrastructures.

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APPENDIX A

AVENUE® SCRIPT 'THEME.CALCULATEFEATUREGEOMETRY' FOR ARCVIEW 3.X

```
' Name: Theme.CalculateFeatureGeometry
'
' Description:  Calculates the length (in meters, kilometers, feet and miles) OR perimeter
' and area (acres and hectares) for the active themes
'
' Requires:
'
' Initial code:  ESRI
'
' History:  Modified by Kim Horton - May 2002 - to add additional measures.
'
' Note:  ArcView considers any text on a line to the right of a single quotation mark
(apostrophe) to be a comment, ignoring any comments in the script.
'*********************************************************************

'Calculates feature geometry values

' Get the view and it's projection if any.
theView = av.GetActiveDoc
thePrj = theView.GetProjection
if (thePrj.IsNull) then
  hasPrj = false
else
  hasPrj = true
end

' Get the list of active themes. if there aren't any, let the user know
' and exit.
theActivethemeList = theView.GetActivethemes
if (theActivethemeList.Count = 0) then
  MsgBox.Error("No active themes.","")
  Exit
end

' Loop through the list of active themes. if you can't edit the theme
' inform the user.

For Each thetheme in theActivethemeList
  theFTab = thetheme.GetFTab
  if (theFTab.CanEdit.Not) then
```

```
  MsgBox.Info("Cannot edit table for theme:"++thetheme.AsString,"")
  Continue
end

' Make the FTAB editable, and find out which type of feature it is.
theFTab.SetEditable(TRUE)
theType = theFTab.FindField("shape").GetType
if (theType = #FIELD_SHAPEPOLY) then

  ' if the data source is polygonal, check for the existence of the fields "Area",
  ' "Perimeter", "Acres" and "Hectares". If they do not exist, create them.

  if (theFTab.FindField("Area") = nil) then
    theAreaField = Field.Make("Area",#FIELD_DOUBLE,16,3)
    theFTab.AddFields({theAreaField})
  else
    ok = MsgBox.YesNo("Update Area?", "Calculate", true)
    if (ok.Not) then
      continue
    end

    theAreaField = theFTab.FindField("Area")
  end

  if (theFTab.FindField("Perimeter") = nil) then
    thePerimeterField = Field.Make("Perimeter",#FIELD_DOUBLE,16,3)
    theFTab.AddFields({thePerimeterField})

  else
    ok = MsgBox.YesNo("Update Perimeter?", "Calculate", true)
    if (ok.Not) then
      continue
    end

    thePerimeterField = theFTab.FindField("Perimeter")
  end

  if (theFTab.FindField("Acres") = nil) then
    theAcresField = Field.Make("Acres",#FIELD_DOUBLE,16,3)
    theFTab.AddFields({theAcresField})
  else
    ok = MsgBox.YesNo("Update Acres?", "Calculate", true)
    if (ok.Not) then
      continue
    end
```

```
    theAcresField = theFTab.FindField("Acres")
  end

  if (theFTab.FindField("Hectares") = nil) then
    theHectaresField = Field.Make("Hectares",#FIELD_DOUBLE,16,3)
    theFTab.AddFields({theHectaresField})

  else
    ok = MsgBox.YesNo("Update Hectares?", "Calculate", true)
    if (ok.Not) then
      continue
    end

    theHectaresField = theFTab.FindField("Hectares")
  end

  ' Loop through the FTAB and find the projected area and perimeter of each
  ' shape and set the field values appropriately.

  theShape = theFTab.ReturnValue(theFTab.FindField("shape"),0)
  For Each rec in theFTab
    theFTab.QueryShape(rec,thePrj,theShape)

    theArea = theShape.ReturnArea
    thePerimeter = theShape.ReturnLength
    theAcres = theArea*0.0002471
    theHectares = theAcres*0.4046856

    theFTab.SetValue(theAreaField,rec,theArea)
    theFTab.SetValue(thePerimeterField,rec,thePerimeter)
    theFTab.SetValue(theAcresField,rec,theAcres)
    theFTab.SetValue(theHectaresField,rec,theHectares)

  end
'-----------------------------------------------------------------------------
elseif (theType = #FIELD_SHAPELINE) then

  ' if the data source is linear, check for the existence of the
  ' field "Length", "Kilometer", "Feet", and "Miles". If it doesn't exist, create it.

  if (theFTab.FindField("Length") = nil) then
    theLengthField = Field.Make("Length",#FIELD_DOUBLE,16,3)
    theFTab.AddFields({theLengthField})

    else
    ok = MsgBox.YesNo("Update Length?", "Calculate", true)
```

```
  if (ok.Not) then
    continue
    end

  theLengthField = theFTab.FindField("Length")
 end

if (theFTab.FindField("Kilometer") = nil) then
  theKilometerField = Field.Make("Kilometer",#FIELD_DOUBLE,16,3)
  theFTab.AddFields({theKilometerField})

  else
  ok = MsgBox.YesNo("Update Kilometer?", "Calculate", true)
  if (ok.Not) then
    continue
    end

  theKilometerField = theFTab.FindField("Kilometer")
 end


if (theFTab.FindField("Feet") = nil) then
  theFeetField = Field.Make("Feet",#FIELD_DOUBLE,16,3)
  theFTab.AddFields({theFeetField})

  else
  ok = MsgBox.YesNo("Update Feet?", "Calculate", true)
  if (ok.Not) then
    continue
  end

  theFeetField = theFTab.FindField("Feet")
 end

if (theFTab.FindField("Miles") = nil) then
  theMilesField = Field.Make("Miles",#FIELD_DOUBLE,16,3)
  theFTab.AddFields({theMilesField})

  else
  ok = MsgBox.YesNo("Update Miles?", "Calculate", true)
  if (ok.Not) then
    continue
  end

  theMilesField = theFTab.FindField("Miles")
 end
```

```
    ' Loop through the FTAB and find the projected length of each shape
    ' and set the field values appropriately.
    theShape = theFTab.ReturnValue(theFTab.FindField("shape"),0)
    For Each rec in theFTab
      theFTab.QueryShape(rec,thePrj,theShape)

      theLength = theShape.ReturnLength
      theKilometer = theLength*0.001
      theFeet = theLength*3.280839895
      theMiles = theLength*0.0006213711922

      theFTab.SetValue(theLengthField,rec,theLength)
      theFTab.SetValue(theKilometerField,rec,theKilometer)
      theFTab.SetValue(theFeetField,rec,theFeet)
      theFTab.SetValue(theMilesField,rec,theMiles)
    end
  end
end

theFTab.SetEditable(FALSE)
```