UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

June 2010

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WATER QUALITY AND WATERSHED CONDITIONS IN THE UPPER ILLINOIS RIVER WATERSHED

Funded by Arkansas Natural Resources Commission
and the Walton Family Foundation through the
Illinois River Watershed Partnership
MSC Publication 359 | Arkansas Water Resources Center

ARKANSAS WATER RESOURCES CENTER – UNIVERSITY OF ARKANSAS
TECHNICAL PUBLICATION NUMBER MSC 359 – YEAR 2010

Water Quality and Watershed Conditions in the Upper Illinois River Watershed

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The Illinois River and its tributaries have many uses that have been designated by the Arkansas Department of Environmental Quality including fisheries, aquatic life, primary contact waters, secondary contact waters, drinking water supply, and agricultural and industrial water supply, and water quality affects whether these uses can be supported. Since water quality can be quite complex, many types of measurements can be used as water quality indicators; some common water quality measurements include pH, dissolved oxygen concentration, and conductivity. More complicated measurements include determining nutrients, sediment and bacteria in the water, as well as assessing the aquatic life—aquatic insects, fish, algae and plants that are present within a stream. Most of these parameters are related to the type and use of land surrounding the stream and thus can be impacted by human activities. This publication details stream use classification and use support, impaired reaches in the Arkansas portion of the Illinois River, general water quality conditions across the Upper Illinois River Watershed, and trends in water quality in the Illinois River over the past decade. This publication serves as companion material to MSC Publication 355, Final Report to the Illinois River Watershed Partnership: Recommended Watershed Based Strategy for the Upper Illinois River Watershed, Northwest Arkansas.

Keywords: Water Quality, Illinois River, Designated Uses, Trends

Acknowledgements: The historical monitoring program at the Illinois River at Highway 59 referenced in this document was funded by the Arkansas Natural Resources Commission 319 Nonpoint Source Program. The authors would like to thank Sheri Herron, Coleen Gaston, and the Watershed Advisory Group of the Illinois River Watershed Partnership for reviewing an earlier version of this publication, and the Arkansas Department of Environmental Quality, especially Jim Wise, for reviewing the 2008 303(d) listings provided in this document.

STREAM CLASSIFICATIONS AND USE SUPPORT

Arkansas has established designated uses for all waters of the State including streams and publicly-owned lakes in the Upper Illinois River Watershed (UIRW). The definitions of these designated uses are based on Regulation 2, which establishes water quality standards for the State of Arkansas.

- *Extraordinary Resource Waters (ERWs):* These waters are designated for their scenic beauty, aesthetics, scientific values, broad recreation potential and social values based on a combination of chemical, physical, and biological characteristics. Any and all areas in the UIRW that support the Arkansas darter, least darter, Oklahoma salamander, and cave fish, snails and crawfish would be considered ERWs.

- *Natural and Scenic Waterways (NSWs):* These waters have been legislatively adopted into a state or federal system of natural and scenic waterways. No streams in the UIRW are designated with this use by the State of Arkansas.

- *Ecologically Sensitive Waterbodies (ESWs):* These waters are known to provide habitat within the existing range of threatened, endangered or endemic species of aquatic or semi-aquatic organisms. In the UIRW, the following portions are considered ESWs: 1) Illinois River (From the Arkansas – Oklahoma state line upstream to its confluence with Muddy Fork), and any other portion where the Neosho mussel is known to inhabit 2) Little Osage (From its confluence with Osage Creek approximately 2.5 miles upstream) 3) Numerous springs and spring-fed tributaries, which support threatened, endangered or endemic species (11 locations within the UIRW).

- *Primary Contact Recreation:* These waters are designated for primary contact recreation, or full body contact, use. All streams with drainage areas greater than 10 square miles and all lakes and reservoirs are designnated with this use within the UIRW; this designated use typically applies from May 1st through September 30th.

- *Secondary Contact Recreation:* These waters are designated for secondary recreational activities including boating, fishing, or wading. All waters are designated with this use in the UIRW.

- *Domestic, Industrial Agricultural Water Supply:* These waters are designated for use as domestic, industrial or agricultural water supply. All waters are designated with this use in the UIRW.

- *Fisheries:* These waters are designated for the protection and propagation of fish, shellfish and other forms of aquatic life. In the UIRW, the following waterbodies are designated with this use or subsets of the use: 1) all lakes and reservoirs; 2) perennial fisheries—all streams with drainage area equal to or greater than 10 square miles; and 3) seasonal fisheries—all streams with drainage area less than 10 square miles during the primary season (generally mid-September to mid-May). Seasonal fishery streams may be designated as perennial fisheries with further evaluation of water sources or aquatic communities.

Tables 1 and 2 identify stream reaches and lakes in the UIRW are meeting their designated uses as monitored, assessed and evaluated by Arkansas Department of Environmental Quality (ADEQ).

IMPAIRED STREAM REACHES IN THE ILLINOIS RIVER

ADEQ submits a list of waterbodies that do not meet current water quality standards, assessment criteria, and designated beneficial uses

Table 1. Designated uses and use assessment for select stream reaches in the Upper Illinois River Watershed (ADEQ, 2008)

					Designated Use Supported?					
Stream	Reach	Length (miles)	Assessment Method	Monitoring Station	Fisheries	Aquatic Life	Primary Contact	Secondary Contact	Drinking Water	Agricultural and Industrial Use
Evansville Creek	012	9	Unassessed							
Baron Fork	013	10	Monitored	ARK07	Yes	Yes	Yes	Yes	Yes	Yes
Illinois River	020	1.6	Monitored	ARK06	Yes	***No***	Yes	Yes	Yes	
Cincinnati Creek	021	9	Monitored	ARK141	Yes	Yes	Yes	Yes	Yes	
Illinois River	022	10.8	Monitored	ARK06A	Yes	Yes	Yes	Yes	Yes	Yes
Illinois River	023	8.1	Evaluated		Yes	Yes	Yes	Yes	Yes	Yes
Illinois River	024	2.5	Monitored	ARK40	Yes	***No***	Yes	Yes	Yes	Yes
Muddy Fork	025	3.2	Monitored	MF104+	Yes	Yes	Yes	Yes	Yes	
Moores Creek	026	9.8	Unassessed							
Muddy Fork	027	11	Monitored	MF102B+	Yes	Yes	Yes	Yes	Yes	
Illinois River	028	19.9	Monitored	Ill01	Yes	Yes	Yes	Yes	Yes	
Clear Creek	029	13.5	Monitored	ARK10C	Yes	Yes	***No***	Yes	Yes	Yes
Osage Creek	030	15	Monitored	ARK41	Yes	Yes	Yes	Yes	Yes	Yes
Osage Creek	930	5	Monitored	OSC03+	Yes	Yes	Yes	Yes	Yes	
Spring Creek	931	6	Monitored	SPG03+	Yes	Yes	Yes	Yes	Yes	
Flint Creek	031	9.6	Monitored	ARK04A	Yes	Yes	Yes	Yes	Yes	Yes
Sager Creek	932	8	Monitored	ARK05	Yes	Yes	Yes	Yes	***No***	Yes

From ADEQ's perspective and assessment, these selected stream reaches in the UIRW are generally meeting the designated uses – there were four of the selected stream reaches that were monitored where one designated use (e.g., aquatic life, primary contact, or drinking water were not supported. Thus, these stream reaches were placed on the 303(d) list submitted by ADEQ to EPA in 2008.

Table 2. Designated uses and use assessment for select lakes in the Upper Illinois River Watershed (ADEQ, 2008)

					Designated Use Supported?					
Lake	Size (acres)	Depth[*] (ft)	Purpose	Assessment Method	Fisheries	Aquatic Life	Primary Contact	Secondary Contact	Drinking Water	Agricultural and Industrial Use
Wedington	102	16	Recreation	Monitored	Yes	Yes	Yes	Yes	Yes	
Elmdale	180	8	Recreation	Monitored	Yes	Yes	Yes	Yes	Yes	Yes
Fayetteville	196	15	Recreation	Monitored	Yes	Yes	Yes	Yes		
Bobb Kidd	200	13	Fishing	Monitored	Yes	Yes	Yes	Yes		
SWEPCO	531	17	Water Supply	Monitored	Yes	***No***	Yes	Yes	Yes	Yes

[*] Average depth; the select lakes or small reservoirs monitored and assessed by ADEQ were supporting the designated uses, with one exception – Lake SWEPCO, which was not supporting the its designated aquatic life use and the cause for this impairment was unknown.

called the 303(d) list to U.S. Environmental Protection Agency (EPA). ADEQ submitted the most recent list to EPA in 2008 based on evaluation of data collected between July 1, 2002 and June 30, 2007 (Tables 1 and 2). ADEQ indicated that four segments within the UIRW were impaired; however, EPA added additional segments to this list for a total of 14 stream reaches or reservoirs in the UIRW, and the map of the UIRW depicts the location of these stream reaches and the single reservoir (Figure 1, Table 3).

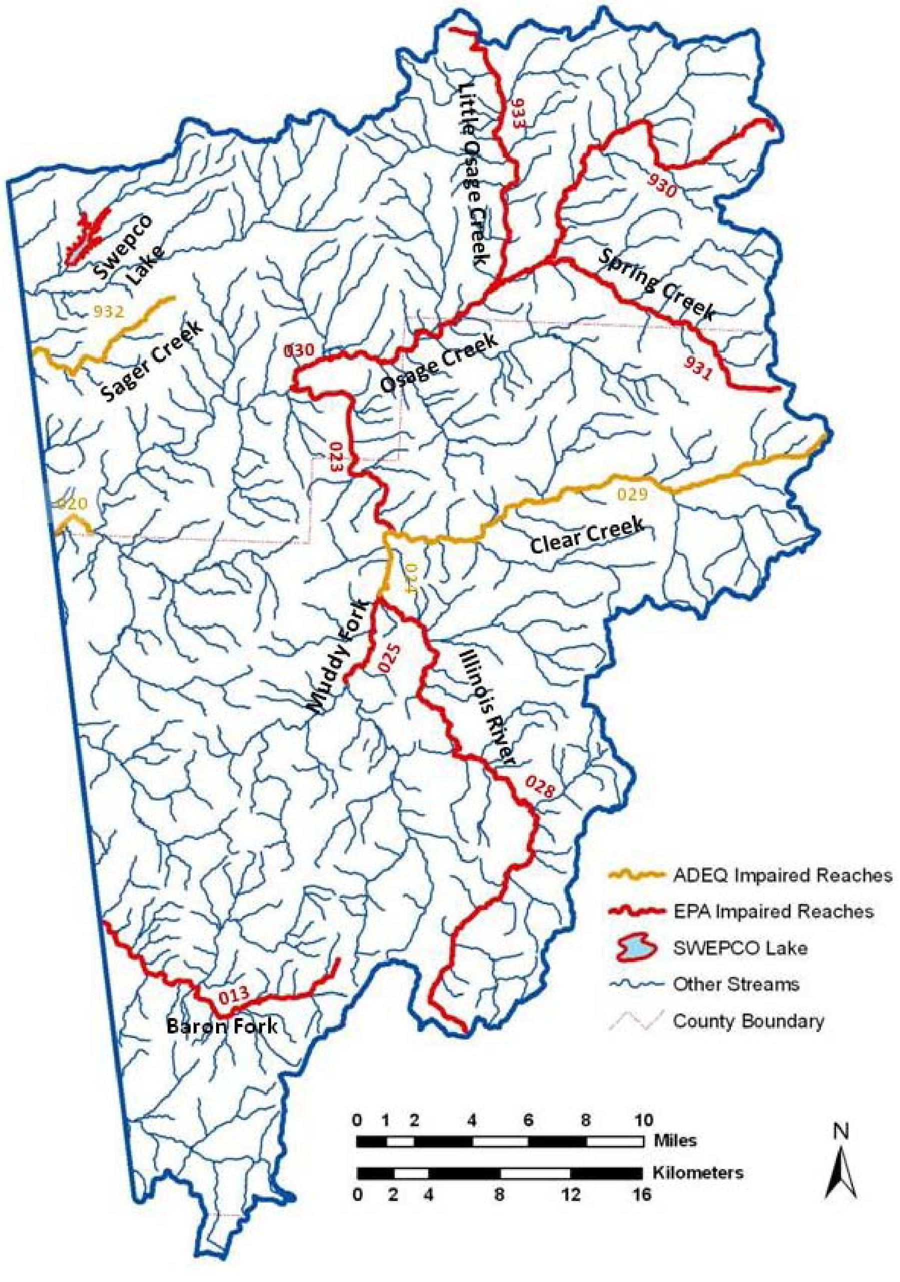

Figure 1. 303(d) listed reaches within the Upper Illinois River Watershed (provided by the UA Center for Advanced Spatial Technology)

Table 3. 303(d) listed stream segments or reservoirs within the Upper Illinois River Watershed in 2008

Stream Name	Reach	Length (miles)	Pollutant	Category	Priority[4]
Illinois River	020	1.6	Siltation	5d [1]	Low
Illinois River	024	2.5	Siltation	5d [1]	Low
Clear Creek	029	13.5	Pathogen	5d [1]	Low
Sager Creek	932	8.0	Nitrate	5e [2]	Low
Baron Fork	013	10.0	Pathogen	5g [3]	Low
Illinois River	023	8.1	Pathogen	5g [3]	Low
Illinois River	024	2.5	Pathogen	5g [3]	Low
Muddy Fork	025	3.2	Pathogen	5g [3]	Low
Muddy Fork	025	3.2	Total Phosphorus	5g [3]	Low
Illinois River	028	19.9	Pathogen	5g [3]	Low
Osage Creek	030	15.0	Total Phosphorus	5g [3]	Low
Osage Creek	030	15.0	Pathogen	5g [3]	Low
Osage Creek	930	10.2	Total Phosphorus	5g [3]	Low
Little Osage Creek	933	10.2	Pathogen	5g [3]	Low
Spring Creek	931	8.4	Total Phosphorus	5g [3]	Low
Swepco Lake	Lake	NA	Unknown	5g [3]	Low

[1] Additional data is needed to determine the extent of impairment
[2] Future permit restrictions are expected
[3] Reach listed by the US Environmental Protection Agency
[4] The priority status for these segments was provided by ADEQ.

Explanation of the 303(d) listed reaches

Baron Fork (Reach 013). EPA added Reach 013 of Baron Fork to the 303(d) list as not supporting its primary contact recreation use due to elevated bacteria concentrations, specifically *Escherichia coli*. The impairment was listed under Category 5g meaning that the reach was added by EPA.

Illinois River (Reaches 020, 023, 024, and 028). ADEQ listed Reaches 020 and 024 of the Illinois River due to siltation that impaired the aquatic life designated use. The listed source of the impairment is surface erosion. The impairment is listed under Category 5d meaning that additional data is needed to verify the use impairment.

EPA added Reaches 023, 024, and 028 of the Illinois River to the 303(d) list as not supporting its primary contact recreation use due to elevated bacteria concentrations, specifically *Escherichia coli*. The impairment was listed under Category 5g meaning that the reach was added by EPA.

Muddy Fork (Reaches 025 and 027). EPA added Reach 025 of the Muddy Fork to the 303(d) list as not supporting its primary contact recreation use due to elevated bacteria concentrations, specifically *Escherichia coli*. The impairment was listed under Category 5g meaning that the reach the reach was added by EPA.

EPA added Reach 027 of the Muddy Fork to the 303(d) list as not supporting the aquatic life designated use due to elevated total phosphorus (TP) concentrations. The impairment was listed under Category 5g meaning that the reach the reach was added by EPA.

Clear Creek (Reach 029). ADEQ listed Reach 029 of Clear Creek due to elevated fecal coliform concentrations impairing the primary contact recreation designated use. The listed source of the impairment is urban runoff, and the impairment is listed under Category 5d meaning that additional data is needed to verify the use impairment.

Osage Creek (Reaches 030 and 930). EPA added Reach 030 of Osage Creek to the 303(d) list as not supporting the primary contact recreation use due to elevated bacteria concentrations, specifically *Escherichia coli*. The impairment was listed under Category 5g meaning that the reach was added by EPA.

EPA added Reaches 030 and 930 of Osage Creek to the 303(d) list as not supporting the aquatic life designated use due to elevated TP concentrations. The impairment was listed under Category 5g meaning that the reach was added by EPA.

Little Osage Creek (Reach 930). EPA added Reach 930 of the Little Osage Creek to the 303(d) list as not supporting the primary contact recreation designated use due to elevated bacteria concentrations, specifically *Escherichia coli*. The impairment was listed under Category 5g meaning that the reach was added by EPA.

Spring Creek (Reach 931). EPA added Reach 931 of Spring Creek to the 303(d) list as not supporting the primary contact recreation designated use due to elevated bacteria concentration, specifically *Escherichia coli*. Reach 931 was also listed as not supporting the aquatic life designated use due to elevated concentrations of TP. Both impairments were listed under Category 5g meaning that the reach was added by EPA.

Sager Creek (Reach 932). ADEQ listed Reach 932 of Sager Creek due to elevated nitrate (NO_3) concentrations impairing the drinking water designated use. The listed source of the impairment is municipal point source(s). The impairment is listed under Category 5e meaning that future permit restrictions on the municipal point source(s) are expected to eliminate the impairment.

Swepco Lake. EPA added Swepco Lake to the 303(d) list for unspecified pollutants. The impairment is listed under Category 5d meaning that additional data is needed to verify the use impairment, and its source.

The above list and brief explanations focus on stream reaches and one reservoir listed as impaired for not meeting one of its designated uses; however, these listings do not give a sense as to general water quality trends across the UIRW.

GENERAL WATER QUALITY CONDITIONS IN THE UPPER ILLINOIS RIVER WATERSHED

Concentrations, Loads and Sources within the Upper Illinois River Watershed

Water flowing in the Illinois River and its tributaries comes from groundwater flow, runoff from adjacent land, and from water discharged from pipes such as effluent discharges. Often, stream flow or discharge is discussed in terms of *Base Flow* and *Surface Runoff*. Base flow describes the stream flow contributed from groundwater inflows, as well as water that flows laterally below the soil surface. Surface runoff describes the elevated water levels that occur when storm water runoff from the surrounding land flows into the stream channel. Stream flow is an important aspect of water quality, because the flowing water is the mechanism for downstream transport. During storm events, runoff carries materials from the adjacent landscape into streams, and the elevated stream flow may scour the stream bottom resuspending materials into the overlying water. This may elevate nutrients (nitrogen (N) and phosphorus (P)), sediment and bacteria concentrations in the stream; many constituent concentrations often increase with increases in stream flow. At the same time, higher stream flows can dilute concentrations of other constituents in streams if the source of the constituent is not from runoff.

The Illinois River has been monitored near the Arkansas–Oklahoma state line for many years, and specifically, constituent loads have been estimated at the Illinois River south of Siloam Springs on Arkansas Highway 59. Several different agencies have collected water samples at this site including ADEQ, the Arkansas Water Resources Center (AWRC), U.S. Geological Survey (USGS), and other entities. The two most important databases come from the AWRC and USGS, where the AWRC has estimated constituent loads based upon water samples collected manually and using automated equipment and the USGS has maintained a stream discharge monitoring station. The water samples and continuous recording of stream flow can be combined to estimate constituent loads at the Illinois River, representing the amounts of N, P and sediment transported from its drainage area in northwest Arkansas. Other sites are being or have been monitored by the AWRC and USGS to estimate constituent loads within the UIRW, including Ballard Creek, Baron Fork, Flint Creek, Moores Creek, and Osage Creek. In 2009, the concentrations of N, P and sediment during base flow conditions near the Arkansas–Oklahoma border ranged from 2.6-5.2 mg L^{-1}, 0.05-0.08 mg L^{-1}, and 1.6-20.8 mg L^{-1}, respectively (based on data from the HUC 12 monitoring program, Haggard et al., 2010), but historic P concentrations in the Illinois River have been as high as 0.4 mg L^{-1} near the Arkansas–Oklahoma border during base flow conditions over the last decade. The concentrations of P show some distinct patterns with distance, e.g., river miles, upstream from the state line (Figure 2), where-as N does not show a strong longitudinal gradient (e.g., pattern from the watershed outlet upstream) and sediment concentrations are especially low during base flow within the Illinois River. The pattern with P concentrations from the Illinois River at Arkansas Highway 59, south of Siloam Springs, upstream to its headwaters near Hogeye show the influence of two specific tributaries—one large tributary, i.e. Osage Creek, and one smaller tributary, i.e. Goose Creek; each tributary significantly increases the P concentration in the Illinois River. P concentrations generally increase from the Arkansas–Oklahoma border upstream to Osage Creek and then decrease substantially upstream from the confluence with Osage Creek. Phosphorus concentrations in the Illinois River generally increase upstream to its confluence with Goose Creek; decreasing again above this smaller tributary, remaining relatively low up-stream to its headwaters. These two tributaries have one thing in common; both receive effluent discharge from major wastewater treatment

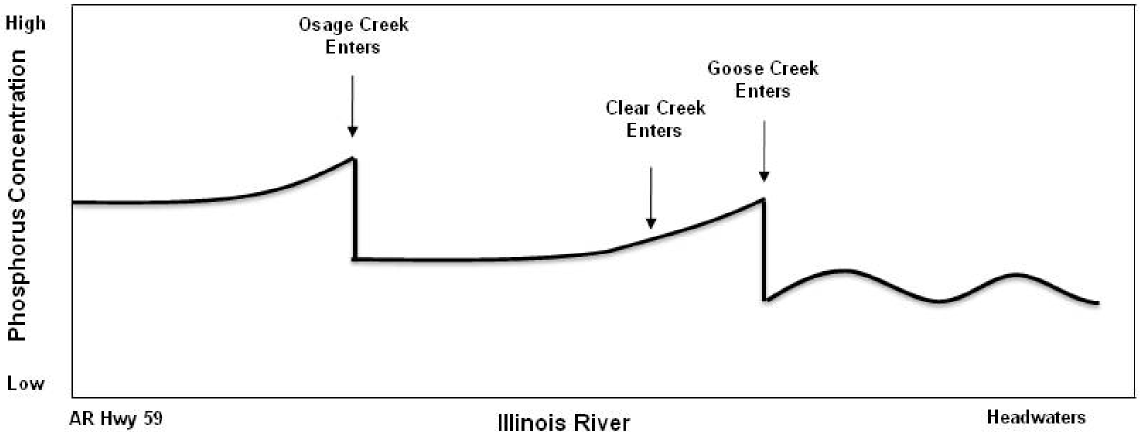

Figure 2. A conceptual model of the longitudinal gradient in phosphorus concentrations along the Illinois River and how select tributaries influence these concentrations during base flow conditions.

facilities within the UIRW, e.g. effluent discharges from Fayetteville, Rogers and Springdale. The influence of these effluent discharges may be seen in the P concentrations observed during base flow conditions within the Illinois River.

The annual loads for N, P and sediment are variable between years (Figure 3), and these loads generally follow the same pattern as the water volume or discharge within a given year (Massey et al., 2009a). The similar patterns between annual constituent load and water volume illustrate how important the connection is between rainfall, runoff and constituent transport within the UIRW. Therefore, it is difficult to set goals regarding selected percent reductions in annual loads because the transport of the target constituents is strongly tied to climatic conditions and how much rainfall and runoff occurs. The link between rainfall, runoff and constituent loads is further demonstrated in the proportion of the load occurring during base flow or surface runoff conditions, and the partitioning of the loads between stream flows differs between constituents.

How are Nutrients and Sediment Typically Transported through the Watershed?

Nitrogen: About half of N transport in the Illinois River occurs during base flow conditions, because the majority of N is transported in the form of NO_3 which is readily soluble and moves easily via ground-water and stormwater runoff from the landscape.

Phosphorus: Unlike N, less than 25 per-cent of the annual P load is trans-ported during base flow conditions because the dissolved form of P is highly reactive and it has the ability to bind to sediments within the stream channel delaying its transport downstream; the remaining 75 percent or more of the load is transported during surface runoff conditions from nonpoint sources and the resuspension of P stored within the stream channel.

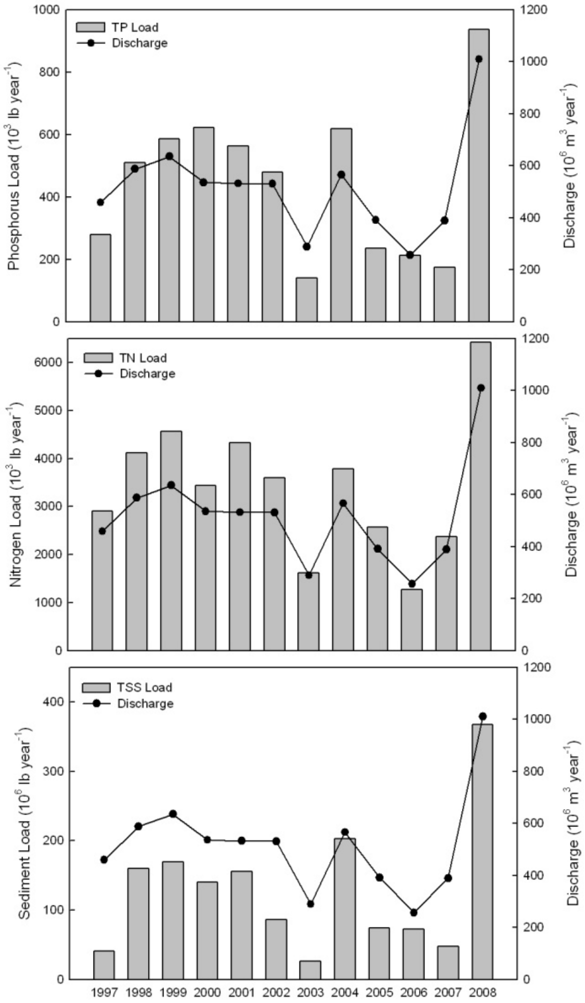

Figure 3. Annual discharge volume and loads of phosphorus, nitrogen and suspended sediments have varied in the Illinois River over the past decade. In the figures above, the bars represent the total load and the line the total discharge during the calendar year (data from Massey et al., 2009a).

Sediment: Almost all of the sediment moved downstream within the UIRW will occur during surface runoff conditions, as the Illinois River and its tributaries have low suspended sediment concentration (or turbidity) in the water column during base flow.

The high flows that occur during the storm events have the ability to resuspend sediment and P stored within the fluvial channel, and then transport these materials downstream. The percent of these constituents moved downstream during surface runoff conditions depends greatly on the amount of rainfall and runoff that occurs within a given year.

When the Illinois River experiences more water movement downstream during a given year the annual constituent loads will be increased, and the proportion of the load transported during surface runoff conditions will likely be much greater than that occurring during base flow (Figure 4). This dynamic process needs to be kept in mind when evaluating differences between constituent loads on a year to year basis (e.g., see Figure 3), and when designing monitoring programs to measure load reductions resulting from the implementation of best management practices or other watershed management changes.

There are several ways that constituent transport in streams is often presented, including loads, yields and flow-weighted concentrations. While these terms may look technical, the definitions are easily explainable:

- **Loads –** the total amount of a constituent transported during a time period, e.g., lb year^{-1};
- **Yield –** the load divided be the size of the watershed, e.g., lb mile^{-2} year^{-1}; and
- **Flow–Weighted Concentration –** the load divided by the total amount of runoff, e.g., mg L^{-1}.

Yields. Yields represent constituent loads on a unit area basis (e.g., lb mile^{-2} year^{-1}) which allows comparisons across basins of relatively similar size; however, constituent yields are not necessarily independent of the size of the watershed because yields typically increase in magnitude as the watershed gets smaller. So, it is not as simple as comparing yields across watersheds with largely different drainage areas—but yields do provide a value with which to compare across watersheds.

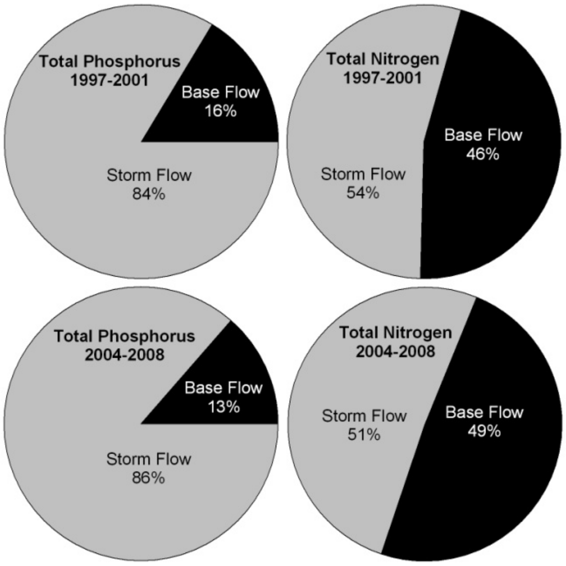

Figure 4. Average phosphorus and nitrogen loads transported during base flow and storm events at the Highway 59 Bridge just upstream of the Arkansas-Oklahoma border from 1997-2001 and 2005-2008.

Flow–Weighted Concentrations. Flow-weighted concentrations are the constituent loads divided by the water volume during a given period of time (e.g., mg L^{-1}), which represents an average concentration for the constituent and theoretically would remove the influence which increased rainfall and runoff would have on constituent loads. So, it would be possible to evaluate how flow-weighted concentrations changed over time where the change in load over time reflects changes in overall stream flow.

In the UIRW, there are many sources that can contribute to constituent loads, particularly for N, P and sediment. The non-point or diffuse sources include runoff from urban areas, agricultural lands and the application of manure, whereas point sources represent a discrete source such as the effluent discharges in this watershed. Basically, the constituent load can be partitioned between nonpoint and point sources when it is assumed that the constituents entering the Illinois River from point sources are conservatively transported downstream to the watershed outlet. '*Conservatively*' simply means that the amount input from point sources leaves the watershed on an annual basis. Making this assumption, the proportion of the constituent load from nonpoint sources can be estimated.

The partitioning between nonpoint and point source constituent loads is not as simple when substantial management changes have occurred throughout the time period of interest. For example, P loads from wastewater treatment plants (WWTPs) have been significantly reduced from 2003 to present day. The average P load from WWTPs was ~200,000 lb year^{-1} from 1997 through 2000, and it decreased over 75 percent after 2003; the average load was only 48,000 lb year^{-1} from 2004 through 2006 (Figure 5). This large decrease in WWTP loading was from facility improvements at the Springdale WWTP; the other major WWTPs (e.g. Fayetteville and Rogers) had undergone upgrades to reduce P loads prior to 1997.

Looking at the data from the Illinois River prior to WWTP changes in late 2002, it is possible to estimate that on average approximately 45 percent of the annual P load (on average ~200,000 lb year^{-1}) may be attributed to inputs from WWTPs (see also Green and Haggard, 2001), particularly the major effluent discharges in Fayetteville, Rogers and especially Springdale. The remaining 55 percent (on average ~244,000 lb year^{-1}) would be assumed to be from nonpoint sources of P within the UIRW, including urban development, animal agriculture and the management of pastures. Thus, the historic focus should have been on the management of both point and nonpoint sources because of the near equal contributions to annual P loads. The reduction in P concentrations and loads from Springdale's WWTP effluent discharge was a substantial first step to reducing P output from the UIRW.

Following the management change and facility improvements at Springdale's WWTP, the proportion of the P load between nonpoint and point sources changed dramatically with the 75 percent reduction in WWTP P inputs. But, this change in P inputs from effluent discharges also raised questions related to the storage of these historic P inputs within the fluvial channel and especially Lake Frances near the Arkansas–Oklahoma border on the Illinois River. After 2003, the P load from WWTPs was less than 14 percent of the total annual P load on average from 2004 through 2006—when the average annual load at the Illinois River was ~356,000 lb year^{-1}. However, one important question would be how much of this load transported at the Illinois River would be from P stored from historical WWTP inputs, often referred to as legacy P. Historical P contributions may be stored within the stream channel and definitely Lake Frances along the Illinois River, and this legacy P could be released into the water column during base flow or even resuspended during the high flow events from rainfall and runoff.

What is Legacy Phosphorus?

This term often refers to dissolved P that has been adsorbed or taken up by bottom sediments in streams, especially downstream from effluent discharges; this stored or legacy P can be released later when dissolved P concentrations in the stream are reduced or during high flow events which scour the stream bottom. Thus, legacy P can delay decreases in stream concentrations to the levels expected by watershed management changes.

Therefore, some of the annual P loads in recent times might represent release of the legacy P within the UIRW—thus, the loads attributed to nonpoint sources may be lower than the estimates presented here. Unfortunately, it is difficult or nearly impossible to trace the exact source of the P in the Illinois River as it crosses from Arkansas into Oklahoma. Watershed–scale assessment models are often used to partition P loads measured in streams into sour-

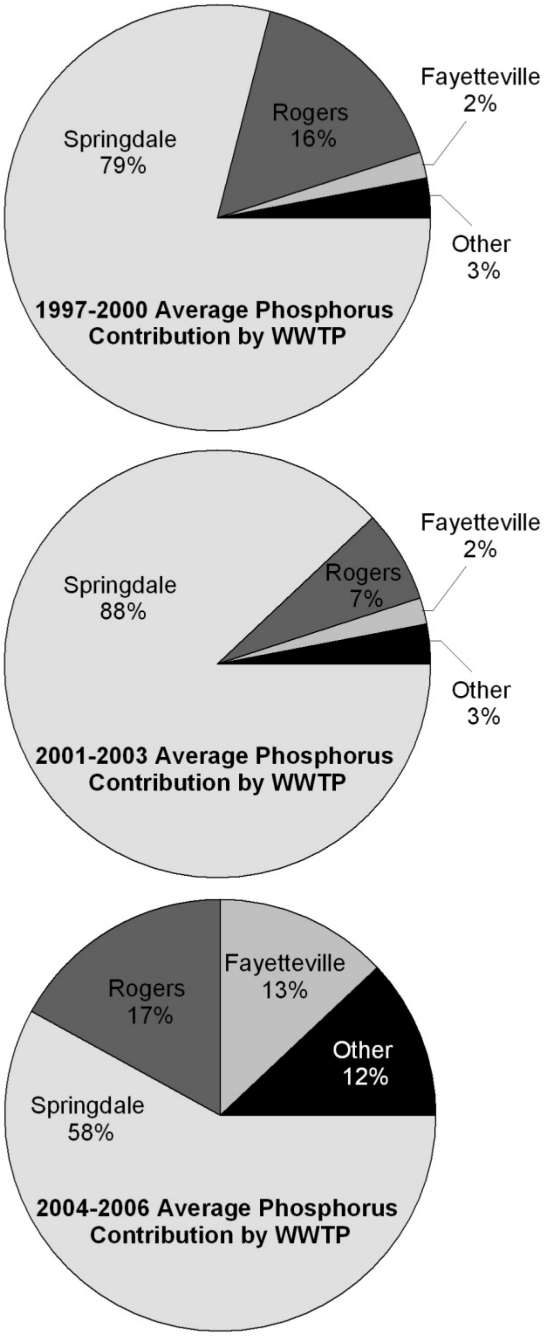

Figure 5. Annual phosphorus load contributed by wastewater treatment plants (WWTPs) in the Upper Illinois River Watershed from 1997-2000, 2001-2003 and 2004-2006. Average annual phosphorus load from the WWTPs was 200,000 lb year^{-1} from 1997-2000; 160,000 lb year^{-1} from 2001-2003; and 48,000 lb year^{-1} from 2004-2006.

ces may be lower than the estimates presented here. Unfortunately, it is difficult or nearly impossible to trace the exact source of the P in the Illinois River as it crosses from Arkansas into Oklahoma. Watershed–scale assessment models are often used to partition P loads measured in streams into sources, such as WWTPs, urban development, pasture and land application of animal manure or commercial fertilizers. However, these models are only as good as the parameters and other inputs used during the simulations and much of the time there is limited measured data available or coarse spatial data used. The use of watershed- scale assessment models should not exclude the use of actual water quality monitoring to measure P concentrations and loads in streams within the UIRW. In fact, these two approaches should be used in concert, as the approach of widespread monitoring and watershed–scale modeling would provide a more complete assessment of the distribution of P sources within the UIRW.

Surface Water Chemistry across the Upper Illinois River Watershed

The following sections describe how select constituents in the UIRW are related to the surrounding land use during base flow and surface runoff conditions. Figures 6 and 9 depict how strongly the constituent concentration is related, either positively or negatively, to surrounding land use. Positive relations suggest that constituent concentrations increase as the amount of the selected land use category (e.g., pasture and urban) increases, whereas negative relations show that the constituent tends to decrease as the selected land use categories (e.g., forest and herbaceous areas) increases. In Figures 6 and 9, the r value of the linear trend line indicates the strength of the relation. The closer the r value is to one, the stronger the relationship between land use classification and constituent concentration, where the concentrations from various streams would fall closer to the line showing less variability across the land use category. These graphs represent a visual display of how constituent concentrations change with land use across the UIRW, and recently collected data were used to develop these graphs.

Phosphorus. Streams need nutrients to support plant and animal growth in the ecosystem, but excessive P levels may also become an environmental concern—excess P can lead to algae blooms and the depletion of dissolved oxygen in the water; otherwise known as accelerated eutrophication. P occurs in both dissolved and particulate (within organic matter or attached to sediment or soil particles) forms in stream water. TP describes both the dissolved and particulate P in the water. Dissolved P can be taken up immediately by algae and aquatic plants and is the bioavailable form of P; thus, dissolved P is often removed from the water becoming particulate P in organic matter. On the other hand, particulate P can be a long-term source when organic matter, sediment and soils are deposited in stream beds of lakes and reservoirs; they can slowly release P to overlying waters for several years.

Dissolved P concentrations during base flow conditions in the UIRW range from less than 0.005 mg L^{-1}, levels observed in relatively pristine Ozark streams, to historic concentrations greater than 0.5 mg L^{-1} (Haggard et al., 2010), levels seen downstream of WWTP effluent discharges before facility improvements. The dissolved P concentrations observed in the UIRW during base flow conditions are strongly correlated to pasture and urban landuse within the watershed—the more pasture and urban lands surrounding the stream, the higher the observed dissolved concentrations in the water (Figure 6). Dissolved P concentrations in streams show some variability during base flow conditions and downstream from effluent discharges often decrease with increasing discharge, showing the effects of dilution. During storm events, P concentrations in streams would generally follow the same patterns with land use categories as expressed during base flow conditions—however, the strength of the relation might be slightly less.

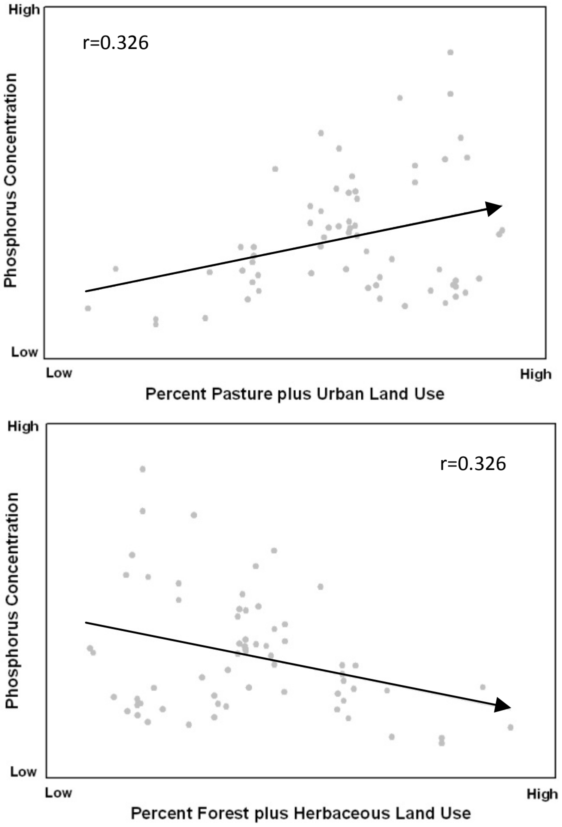

Figure 6. In the Upper Illinois River Watershed, phosphorus concentrations increase in streams as the amount of pasture and urban area within the watershed increases; the opposite relationship is true when streams are surrounded by forests—phosphorus concentrations decrease as the amount of forest area surrounding the streams increases.

Total P concentrations in stream water during base flow and storm flow also increase as the amount of pasture and urban land surrounding the water increases. Total P concentrations in streams draining the UIRW range from 0.006 mg L^{-1} to historic concentrations greater than 0.5 mg L^{-1} during base flow conditions and from 0.1 mg L^{-1} to over 0.8 mg L^{-1} during storm flow (Haggard et al., 2010). However, TP concentrations are often more variable between streams across land use gradients, and even within individual streams reflecting changes of P uptake into organic matter, phosphorus storage within sediments, and the effect of stream discharge on P concentrations. Dissolved P concentrations decrease, increase or remain similar during storm events compared to base flow conditions while TP concentrations increase with increasing stream flow. The dynamics of P transport and uptake add to the variability in TP concentrations observed throughout the streams draining the UIRW.

Point sources also have an influence on P concentrations in streams within the UIRW, especially during base flow conditions. In fact, streams downstream from WWTPs often have P concentrations that are greater than what concentrations would usually be for a watershed with its urban and agricultural land use signature. Four major WWTPs in Fayetteville, Springdale, Rogers, and Siloam Springs and several minor plants (Gentry, Prairie Grove, Lincoln, and other locations) discharge their treated effluent to tributaries to the Illinois River. P concentrations increase downstream from these effluent discharges compared to that measured upstream from the effluent discharge (see Figure 7). Permit limits have been established for the amount of TP that the major WWTPs can discharge in treated effluent, which are based on a discharge concentration threshold of 1 mg L^{-1} for the major four WWTPs. Before these limits, some plants were discharging effluent with concentrations over 10 mg L^{-1} TP and elevated P concentration in the Illinois River could be traced over 28 river miles upstream to one individual WWTP, i.e. Springdale's facility, in spring 2002. Prior to 2003, P concentrations at the Illinois River near the Arkansas–Oklahoma border were often as high as 0.4 mg L^{-1} during base flow conditions in the summertime.

But since the late 1990's and early 2000's, most of the major WWTP have undergone plant upgrades which have allowed the facilities to meet established permit limits and significantly reduced P concentrations in the effluent discharge and the streams receiving these discharges. Specifically, Springdale's facility made substantial improvements reducing effluent concentrations from as high as 10 mg L^{-1} in 2002 to less than 0.5 mg L^{-1} by the end of 2003. Springdale's effluent P concentrations have remained low (relative to historic effluent concentrations) averaging less than 0.4 mg L^{-1} in recent years, and these reductions in effluent concentrations have resulted in subsequent reductions in P concentrations within Spring Creek, Osage Creek and even the Illinois River (Haggard, 2005). The improvement in P management by all the major WWTPs within the UIRW have contributed to the decrease in base flow concentrations observed over the last decade or more. However, bottom sediments within the fluvial channel of the streams downstream from the effluent discharges have stored much of the dissolved P released from the WWTPs (e.g., legacy P), because as dissolved P moves downstream it may bind to sediments or even be consumed by microbes living on the stream bottom. So, even though WWTPs continue to reduce the amount P these facilities discharge, the sediments and or organic matter may continue to slowly release P to the water

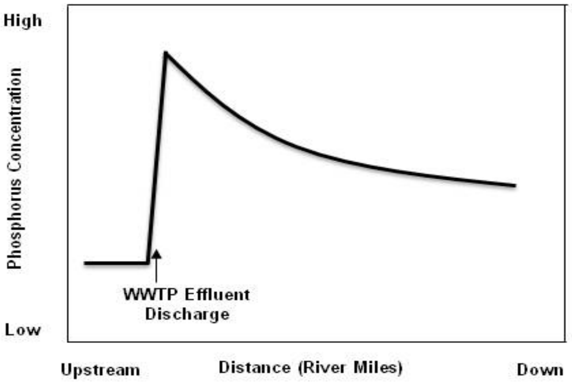

Figure 7. Conceptual model of the effect of wastewater treatment plants in the Upper Illinois River Watershed. Effluent discharges increase phosphorus concentrations in streams and then the concentrations generally decrease with increasing distance downstream from the point source. Phosphorus concentrations often stay greater than upstream or background concentrations for several miles down-stream.

column making the WWTP reductions less in the streams compared to that measured directly in the effluent. It is then likely that P concentrations at the Illinois River near the state line will continue to slowly decrease until the majority of this legacy P has been released from the stream bottom sediments and then transported downstream (See Haggard, 2010).

P concentrations during base flow conditions at the Illinois River have decreased significantly over the last decade, and a distinct seasonal pattern is visible which relates to the dilution of the WWTP effluent discharge during elevated base flow during the wet season, e.g. late winter through spring. P concentrations are least at the Illinois River during elevated base flow conditions, where concentrations have reduced from more than 0.2 mg L^{-1} observed in spring 2002 to less than 0.05 mg L^{-1} observed in spring 2004 and each year elevated seasonal base flow discharge was observed since (Haggard, 2005). So, the current message would be that P concentrations in the Illinois River flowing from Arkansas into Oklahoma have significantly decreased over the last decade—however, further decreases are likely possible with the implementation of best management practices within the UIRW, particularly targeted at riparian areas that are not currently forested, because P can be taken up by plants or infiltrated within the riparian zone. However, in 2008 the EPA listed four stream segments within the UIRW as being impaired due to elevated phosphorus concentrations despite the fact that ADEQ does not have numeric criteria for P in streams and that ADEQ did not list those stream reaches for P within the submitted 303(d) list to EPA.

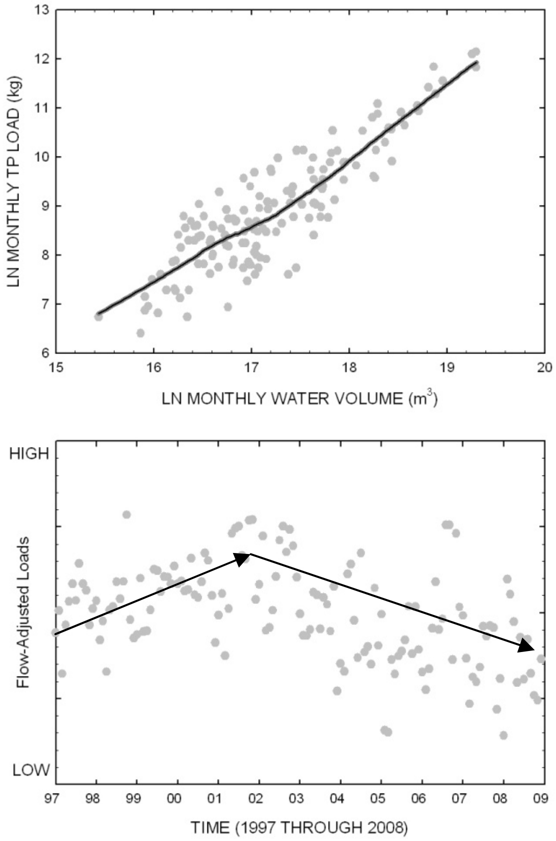

Figure 8. Monthly phosphorus loads as a function of monthly discharge at the Illinois River near the Arkansas and Oklahoma border, and the change in flow adjusted loads over time from 1997 through 2008 (data from Haggard, 2010).

The best way to determine how P loads have changed over time is to look at trends in monthly P loads normalized for changes in monthly water volumes, since loads are closely tied to discharge volume at the Illinois River (Figure 8). The residuals from the locally weighted scatterplot smoothing (LOESS) technique represent the monthly loads as adjusted for changes in monthly water volumes, referred to as flow-adjusted loads. The flow adjusted loads show a distinct pattern in P over time where loads increased from 1997 to 2002 and then decreased from 2002 to 2008 (Haggard, 2010). This is consistent with the changes in P management at the wastewater treatments within the watershed, as well as other changes in poultry litter application, management and transport in this watershed.

Nitrogen. Like P, N is also a necessary component for plant and animal growth in aquatic ecosystems, but excessive concentrations of N can also lead to water quality concerns. While P, tends to be more of a regional concern, nitrogen is also the focus nationally within the Mississippi River Basin and its influence on Gulf hypoxia as recently reported. In the UIRW, N is contributed by both point and non-point sources (e.g., groundwater inflows and surface runoff from agriculture and fertilizers and WWTP effluent discharges). N, unlike P, may be removed from aquatic systems through the process of denitrification. Despite this potential loss pathway, approximately 3,300,000 lbs (i.e., 1,500,000 kg) of N are exported from the watershed annually which is basically split evenly between base flow conditions and high flow events during storms.

NO_3 is usually the most abundant form of N in water, and it is generally much more mobile or less reactive than dissolved P. NO_3 concentrations in streams often show a seasonal pattern reflective of seasonal base flow discharge and the potential for denitrification as water moves through groundwater inflows and downstream. The general pattern in stream NO_3 concentrations is elevated concentrations during spring when seasonal base flow discharge is greater and lower concentrations during summer when biological activity is high. Because NO_3 is more mobile, N concentrations generally show stronger relationships with watershed land use than P. NO_3 concentrations generally increase as the percentage of agricultural land increases and decreases as the percentage of forest land increases (Figure 9); this relation holds true during both base flow conditions and storm flow events. NO_3 concentrations in streams within the UIRW generally range from less than 0.5 mg L^{-1} to more than 5.0 mg L^{-1} to greater than 5.0 mg L^{-1} (as N) during storm flow (based on data from Haggard et al., 2010). ADEQ does not have numeric N criteria in streams, other than EPA established a maximum contaminant level of 10 mg L^{-1} for NO_3 (as N) in drinking water—streams rarely, if ever, exceed this water quality standard in the UIRW.

Total N concentrations (TN; particulate and dissolved N) in the streams draining the watershed typically range from approximately 0.5 mg L^{-1} to more than 5.0 mg L^{-1} during base flow and 0.5 mg L^{-1} to more than 5.0 mg L^{-1} during storm flow (based on data from Haggard et al., 2010). Like NO_3, TN concentrations increase as pasture and urban land use increases and decrease as forest land use increases (Figure 9) and the strength of this relation is often similar to that of NO_3, because NO_3 generally makes up the largest fraction of TN.

Again, this relation between TN and the various land use categories holds true during base flow conditions and even elevated discharge occurring during storm events.

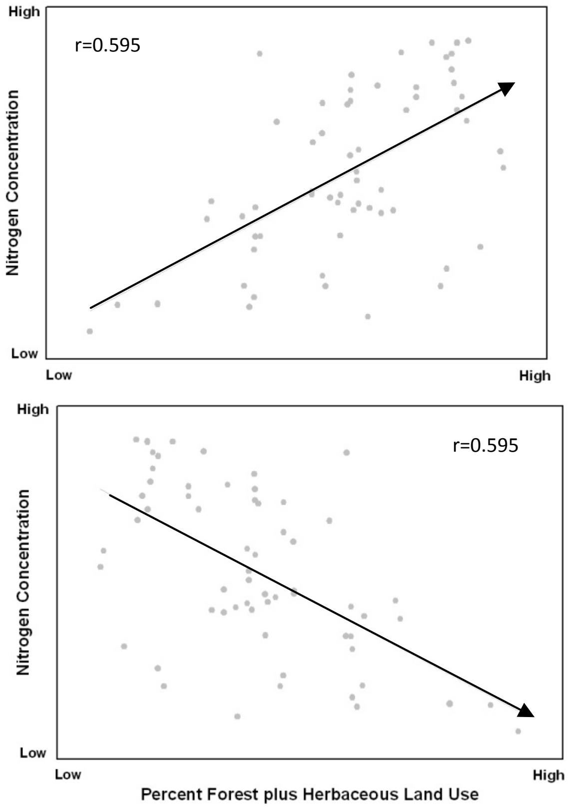

Figure 9. In the Upper Illinois River Watershed, stream nitrogen concentrations increase as the amount of pasture and urban areas increases within the watershed; nitrogen levels typically decrease in streams as forest area increases within its catchment or riparian zone (data from Haggard et al., 2010 and Massey et al., 2009b).

Point sources such as WWTPs also have the ability to influence N concentrations in streams, although the impact of effluent discharges may be highly variable and would be dependent on the background or upstream N concentrations. The effluent discharge might (figure 10):

a) Have relatively little influence on the observed N concentrations because effluent and the stream have relatively similar concentrations;
b) Increase the observed N concentrations, because the effluent has more N in it than the stream water; however, the gradient with increasing distance downstream from the effluent discharge does not necessarily mimic that of P (or chloride); or
c) Decrease the observed N concentrations, because the background concentrations in the stream might be greater than that seen in the effluent.

The majority of the N released in effluent discharge is in the form of NO_3 and organic N, especially in the major WWTPs—whereas smaller facilities may discharge more N in the reduced form such as dissolved ammonia (NH_3) and organic N. This reduced N is usually quickly converted to NO_3 in aquatic systems through nitrification, a natural biologically-mediated process. Within the UIRW, the impact of WWTP effluent discharge on stream N concentrations is variable (see Figure 10) and the N concentrations observed further downstream are more reflective of landscape influences and less influenced by WWTPs.

Chloride. Chloride (Cl) is a conservative element in streams, meaning that Cl does not react with anything within the stream channel and it is simply transported downstream with the flowing water after it enters the stream. Why should we measure Cl in streams? Well, Cl is an excellent indicator of human impacts on streams within watersheds because of its conservative nature in streams—the various sources of Cl that might enter streams includes salts used to deice roads during winter, animal manure and commercial fertilizer applied to the landscape, and effluent discharges from WWTPs. The range in Cl concentrations during base flow conditions within the streams draining the UIRW was from 4.0 mg L^{-1} in a primarily forested stream to 8.0 mg L^{-1} in a stream draining a watershed with primarily pasture land use to 22.0 mg L^{-1} downstream an effluent discharge (based on data from Haggard et al., 2010). Within the UIRW, stream Cl concentrations generally increase as the proportion of pasture and urban development increases within the watershed, as likewise concentrations decrease with more forest and herbaceous lands within the catchment.

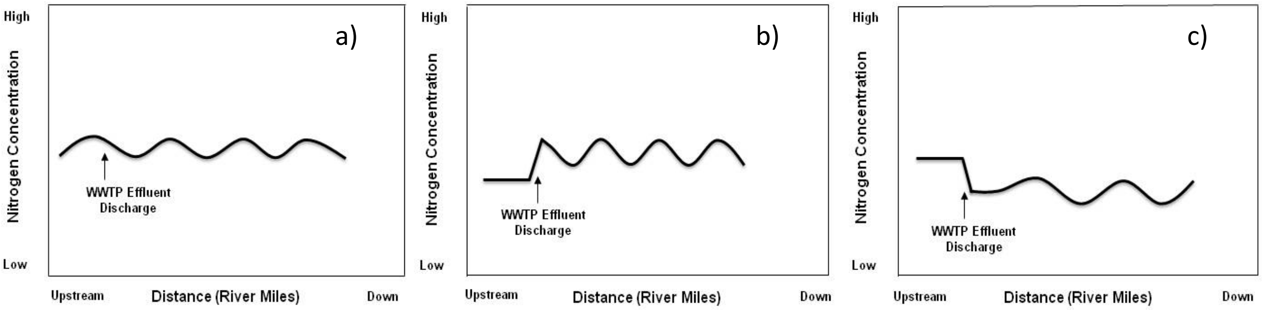

Figure 10. Conceptual model of the effect of WWTP effluent discharge on nitrogen concentrations in streams can be highly variable, where the effluent might have no influence, increase or even decrease observed conenecetrations downstream; nitrogen concentrations much further downstream are generally more reflective of the influence of the catchment land use than the effluent discharge.

Regulation 2 from ADEQ states that monthly average Cl concentrations should not exceed 20 mg L^{-1} in the Illinois River itself, and Cl concentrations are generally less than 10 mg L^{-1}. Effluent discharge from WWTPs often have high concentrations of Cl, because chlorine is used as a disinfection agent during the treatment process. Chloride concentrations are often as high as 50 mg L^{-1} downstream from some effluent discharges and eventually return to background levels, because of dilution from groundwater and other lateral inflows from other streams (Figure 11).

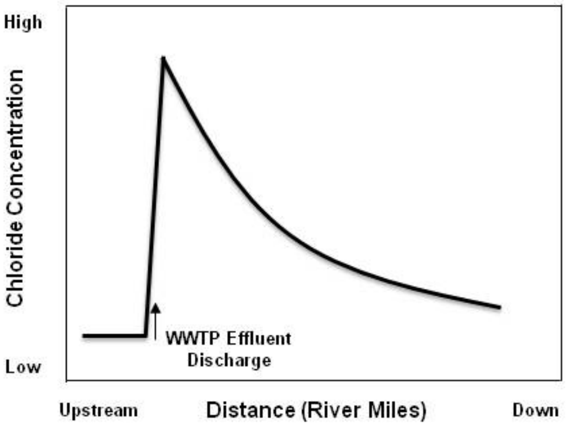

Figure 11. Wastewater treatment plant effluent increases chloride concentrations in tributaries to the Illinois River; elevated chloride concentrations persist for several miles downstream from the effluent discharge point, showing the length of influence and how dilution may decrease concentrations.

Sediments and Turbidity. Sediment is the loose sand, clay, silt and other particles that settle to the bottom of the streams or sometimes stay suspended within the water column, and the EPA lists sediment as the most common pollutant in rivers and streams across the US. The natural process of erosion causes some sedimentation to occur, but accelerated erosion from human activities and alterations of the hydrologic cycle (e.g., peak stream flow) contributes much more sediment to waterbodies than natural processes. In fact, the top three sources of sediment in the northwest Arkansas are all linked to human activities, such as urban and sub-urban land uses.

Sediment is commonly measured as total suspended solids (TSS) within the water column of streams for water quality assessment. In the UIRW, TSS concentrations are weakly related to surrounding land use suggesting that TSS concentrations increase as the percentage of pasture and urban area increases within a watershed; the opposite relation is true for percent forest. Overall, TSS concentrations during base flow conditions in the UIRW are low relative to other waters across the state and the U.S. Average TSS concentrations range from 0.1 mg L^{-1} to almost 20 mg L^{-1} throughout the UIRW during base flow conditions and as high as 500 mg L^{-1} during storm flow (based on data from Haggard et al., 2010). Sediment concentrations in stream water increase with increasing stream flow, because the faster water moves the more sediment it can carry (i.e., carrying capacity) and the more force it has to cause erosion of the streambank and channel. On average, the UIRW exports approximately 46,000,000 lbs TSS annually, ranging from 12,000,000 lbs during relatively dry years to more than 70,000,000 lbs during wet years (data from Massey et al., 2009a).

Sediments may influence water quality of streams in two different ways—1) turbidity within the water column of streams, and 2) sediment embeddedness of the stream bottom. Turbidity is an indicator of the amount of solids suspended in water, whether algae, detritus (dead organic matter) or inorganic, suspended sediment. Turbidity measures the amount of light scattered within a water sample—the more suspended particles, the more light is scattered. Turbidity is relatively easy to measure and is measured in Nephelometric Turbidity Units (NTUs) where higher values indicate more cloudy, turbid waters.

Turbidity levels in streams vary naturally based on the stream characteristics (e.g., flow, bank slope, riparian soils), although human activities can play an important role. Regulation 2 from ADEQ sets turbidity limits during base flow conditions at 10 NTUs for the Illinois River and its tributaries, which reflects the relative natural clarity of streams in this region of the Ozark Highlands and Boston Mountains. Average turbidity measurements in the Illinois River and its tributaries are below 10 NTUs, ranging from less than one to 8 NTUs during base flow conditions across the UIRW (data from Haggard et al., 2010). If turbidity was a problem within the UIRW, then it would be related to its impacts on the biological community of the streams as high levels of turbidity may impact the aquatic ecosystem.

High turbidity may cause light limitation of algal and plant growth within the stream and the decreased clarity may interfere with fish and aquatic insects that feed by sight. Ultimately, the increased turbidity would alter the biological community from its natural conditions, i.e., its aquatic life designated use.

When the sediment settles to the stream bottom, it may cause embeddedness—meaning that there are a lot of fine sediments in between the larger gravel substrate on the stream bottom. These smaller size or fine sediments fill in the spaces between the larger gravel, limiting the suitable habitat for some fish and aquatic insects. A few studies in the UIRW have suggested that the designated beneficial use of aquatic life may be threatened by increased sedimentation, or siltation, within the stream channel, which changes bottom habitat and the biological community from its natural assemblage. In fact, two stream reaches along the Illinois River are on the 303(d) for siltation as placed by ADEQ.

Bacteria. Fecal coliform bacteria live in the intestines of warm-blooded animals, and the presence of these bacteria in streams is indicative of contamination by fecal matter from some source—either pets, wildlife, animal manure, wastewater treatment plants and or septic systems. Although fecal bacteria are not necessarily pathogens (i.e., disease causing organisms), these bacteria may indicate the presence of pathogenic organisms. For example, *Escherichia coli (E. coli)* is a type of fecal coliform that is an indicator organism for other pathogens that may be present in feces. Regulation 2 from ADEQ provides information on the water quality standards related to fecal coliform bacteria, and *E. coli.* The water quality standard specific to *E. coli* is between May 1 and September 30, *E. coli* colony counts should not exceed a geometric mean of more than 126 colonies per 100 mL or a monthly maximum value of not more that 410 colonies per 100 mL. During the remainder of the calendar year, *E. coli* values should not exceed the geometric mean of 630 colonies per 100 mL or a monthly maximum of 2050 colonies per 100 mL.

Overall, there is relatively little bacterial data available from the streams draining the UIRW—or at least little data widely available to the general public. Little information is also available from the scientific literature; however, the publications available in the general literature would suggest that the potential bacterial sources include land application of animal manure (e.g., poultry litter), direct deposition of manure from cattle or wildlife within the stream or riparian corridor and septic systems or other wastewater drainage systems within the watershed. It is not likely that effluent discharges from municipal WWTPs would be a major source of fecal coliform, because each facility would have more stringent permitted levels for coliform in the effluent discharge than that allowable in the streams under secondary or primary contact standards. Several stream reaches have been included on the 303(d) list for bacteria (i.e., pathogens) by ADEQ and EPA, where ADEQ included Clear Creek and EPA added reaches along the Baron Fork, Illinois River, Little Osage Creek and the Muddy Fork to the list.

Biological Data. Biological monitoring is a valuable tool for watershed assessment and management, because biological organisms integrate the cumulative impacts from point and nonpoint sources. Thus, biological monitoring provides a more complete picture of environmental condition from its habitat to general physico–chemical conditions than simple grab water samples alone. Fish, aquatic insects (i.e., macroinvertebrates), and algae are commonly used in biological monitoring. These organisms provide a robust measure of the integrated chemical, physical and biological condition of the water body.

The community structure of the fish, aquatic insects, and algae are evaluated to determine what particular species are present. Then, assessments of the biological community would be based on structure and function:

- **Structure:** The composition of the biological community looking at the number of organisms, individual species, and distribution of populations
- **Function:** The biological community based upon the feeding characteristics of groups of organisms and how the biological communities consume organic carbon (e.g., perphyton, plants, decaying organic matter or other animals) and dissolved oxygen over several days.

Both structural and functional indicators of the biological community should be used in the overall assessment, and the most common approach to integrating these two factors together would be the Rapid Bioassessment Protocol (RBP) developed and then revised by the EPA. This is the type of assessment often used to determine if a water body is meeting its designated beneficial use of aquatic life per ADEQ's Regulation 2.

There have been few published or available large–scale evaluations of the biological community integrating chemical and physical assessments within the UIRW, but these study and other ancillary projects have suggested that biological communities and ecological integrity are threatened by alteration of the landscape, modification of hydrologic flow regime, loss of riparian zones, and enhanced primary production from nutrient enrichment.

The physical changes occurring in streams within the UIRW are that the stream bottoms are shifting from gravel–cobble substrate (i.e., larger bottom material) to sand–gravel (i.e., large material filled in with finer sediments), and that the channel morphology (i.e., structure) is shifting from riffle–pools to runs. The role of stream habitat, especially riparian zones, in protecting and maintaining aquatic life use in the UIRW cannot be overstated, as it is the riparian zone which controls how streams might express nutrient–enriched (or eutrophic) conditions. The lack of a riparian zone would allow an enriched stream to have increased algal growth and shifts in algal communities to filamentous organisms, which then shifts the fish and aquatic insect communities to those that may not support the designated aquatic life use.

Groundwater

Nutrient and bacteria concentrations in groundwater are affected by hydrologic and geologic factors. The Illinois River Watershed largely drains the Springfield Plateau area, which is characterized by karst geology where there are frequent solution channels, sinkholes, caves, and springs. These subsurface pathways provide a quick and close transportation between surface and groundwater, and can rapidly introduce constituents found in surface water into the groundwater system during rainfall events (Tables 4 and 5).

Like in surface water, nutrient and bacteria concentrations in groundwater are often related to nearby land use, where NO_3 concentrations in groundwater are generally greater under pastures compared to other land uses

Table 4. Physico-chemical parameters of groundwater in the Upper Illinois River Watershed

	Water Temperature (^oC)		pH		Conductivity (µs cm^{-1})	
Land use	Range	Mean	Range	Mean	Range	Mean
Pasture	12.8-25.0	15.0	6.0-7.4	6.8	214-258	329.1
Mixed	14.1-21.0	16.4	6.6-7.5	7.1	102-522	280.7
Other	15.5-16.7	16.1	7.1-8.9	6.0	322-405	361.1

Table 5. Constituent concentrations in groundwater across Benton and Washington Counties, northwest Arkansas

	Ammonia		Nitrate		Phosphorus		Chloride	
Land use	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Pasture	<0.01-0.15	0.02	<0.05-8.30	2.13	<0.01-0.17	0.01	1.2-28.0	6.6
Mixed	<0.01-0.11	0.02	<0.05-4.90	0.28	<0.01-0.08	0.02	1.2-61.0	6.0
Other	<0.01	<0.01	1.40-3.90	2.34	<0.01	<0.01	2.7-7.9	4.6

(e.g., forested areas). Because of the close interaction between surface water and groundwater in the area, springs exhibit elevated concentrations of NO_3 but well below the drinking water criterion for NO_3 of 10 mg L^{-1} (as N). For the same reason, springs in the area often exhibit elevated bacteria (fecal coliform) levels during storm events as suggested by studies which have followed the transport of bacteria through groundwater into springs within the UIRW. The presence of karst also increases the risk of introduction of pesticide and herbicides into groundwater. While the use of pesticides and herbicides in the region is minimal, several herbicides have been detected in groundwater samples including atrazine, prometon, desethyl-atrazine and simazine at concentrations below Maximum Contaminant Levels (MCL) or health advisory levels set by the EPA for drinking water. These compounds were more prevalent in agricultural areas than in forested areas.

Groundwater also supports unique cave ecosystems in the karst terrain of northwest Arkansas. The Cave Springs Cave Natural Area supports several endangered species and other species of concern; the Ozarks has the largest population of the threatened Ozark cavefish (*Amblyopsis rosae*l). The presence of these endangered species and or other aquatic species of concerns have designated several areas within the UIRW as Ecologically Sensitive Waters (ESWs) as defined by ADEQ.

EXISTING WATER QUALITY DATA IN THE ILLINOIS RIVER WATERSHED

The waterbodies in the UIRW are monitored by agencies including Arkansas Department of Environmental Quality, U.S. Geological Survey, Arkansas Water Resources Center, municipalities, and volunteers. The collected data is used to characterize waters, identify trends in water quality over time, identify emerging problems, predict future problems, and determine if pollution control programs are working.

Arkansas Department of Environmental Quality

ADEQ has been monitoring select reaches of the Illinois River and its tributaries since the early 1990's. ADEQ's surface water quality monitoring stations data files are available on the web at http://www.adeq.state.ar.us/techsvs/water_quality/monitors.asp.

U.S. Geological Survey

The U.S. Geological Survey (USGS) has been monitoring several of the same sites that ADEQ monitors, as well as additional sites in the watershed. Data from the USGS is available online at the USGS National Water Quality Assessment Data Warehouse (NAWQA; http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:0). The USGS measures stream discharge continuously at seven sites within the UIRW.

These sites include Mud Creek tributary at Township Road (USGS Station No. 07194809), on Osage Creek near Elm Springs (USGS Station No. 07195000), on the Baron Fork near Dutch Mills (USGS Station No. 07196900), on Flint Creek near West Siloam Springs (USGS Station No. 07195855) and at Springtown (USGS No. 07195800), on the Illinois River at Arkansas Highway 59 (USGS Station No. 07195430) and at Savoy (USGS Station No. 07194800).

Arkansas Water Resources Center

The AWRC has been monitoring water quality at the Illinois River since 1995 and at Ballard Creek, a tributary to the Illinois River since 2002. The available data is viewable online at http://www.uark.edu/depts/awrc/pubs-MSC.htm.

HISTORIC AND ONGOING STUDIES OF WATER QUALITY IN THE UPPER ILLINOIS RIVER WATERSHED

Literature Cited and Completed Scientific Studies

Water quality studies in the UIRW primarily began in the early 1980s and have become more frequent and in-depth as the watershed has changed from its natural characteristics to an urban and agricultural dominated watershed; the following are citations of water quality studies that have been completed in the UIRW.

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