Arkansas Water
Resources Center

ILLINOIS RIVER
PHOSPHORUS SAMPLING RESULTS AND MASS BALANCE COMPUTATION

Prepared by:

Marc Nelson, K.L. White and T. S. Soerens

MSC-336

2002

ARKANSAS WATER RESOURCES CENTER
UNIVERSITY OF ARKANSAS
112 OZARK HALL
FAYETTEVILLE, ARKANSAS 72701

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ABSTRACT

Phosphorus levels in the Illinois River are of great interest to the people of the States of Arkansas and Oklahoma. A great deal of effort has been expended to ascertain and modify the phosphorus impacts on the river. An automatic water sampling station was installed on the Illinois River just upstream from the State line in 1996 to accurately quantify the phosphorus in the Arkansas portion of the watershed. This paper summarizes five years worth of phosphorus sampling results at that site. In addition, a simple mass balance for phosphorus in the Illinois River Watershed above the sampling station was developed. The mass balance consisted of determining phosphorus inputs in the drainage area and comparing these to phosphorus outputs, during the same five-year period, allowing for an estimation of phosphorus accumulation. Sampling results showed that phosphorus levels were rapidly increasing in the Illinois River at the State line. Input information showed that over 7 million pounds of phosphorus were discharged into the 575 square mile basin annually. Mass balance calculations indicated that the point source discharges were responsible for up to 43% of the phosphorus in the river. The calculations indicate that only 4% of the phosphorus applied in the watershed reached the river annually. The remaining 96% accumulated in the watershed at an average rate of 8 kg per pasture acre per year. The effect of point source reductions was investigated and resulting mean concentrations were compared to a 0.037 mg/l in-stream phosphorus limit recently adopted by the State of Oklahoma.

INTRODUCTION

The Illinois River is located in Northwest Arkansas and flows west across the AR-OK border into Oklahoma. The river crosses the state line just south of Siloam Springs at the Arkansas Highway 59 bridge. The Illinois River Drainage Area in Arkansas (IRDA) is part of the Illinois River Watershed (HUC: 11110103), and is identified in Figure 1. Based on 1999 GIS data, IRDA landuse is estimated at 58% pasture, 36% forest, and 6% urban (http://www.cast.uark.edu/cast/geostor/).

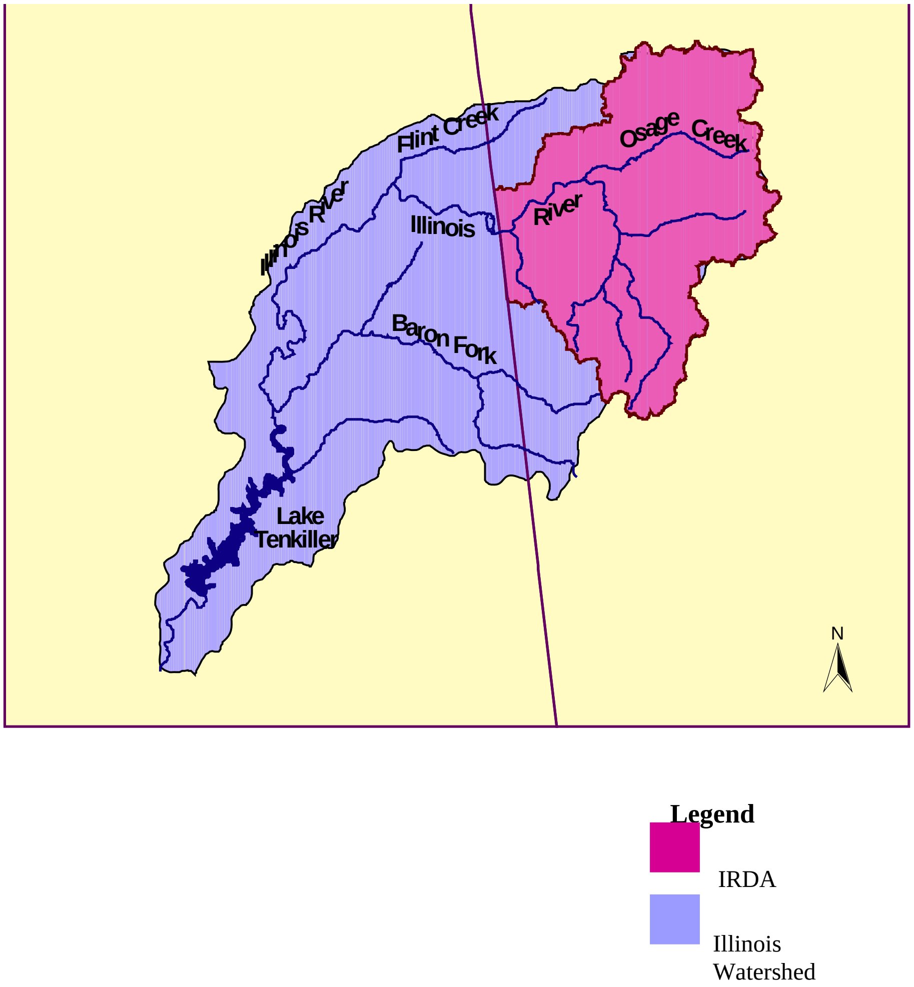


Figure 1 Illinois River Watershed

The IRDA is characterized by fast growing urban areas and intensive agricultural animal production. The IRDA is located in and comprises about half of two counties in northwest Arkansas, Benton and Washington counties. According to the US Census Bureau, the population of these two counties increased by 45% between 1990 and 2000 (http://www.census.gov/). About 92% of this population are considered by the Census Bureau to live in the Fayetteville-Springdale-Rogers Metropolitan area. Approximately half of this metropolitan area is in the IRDA. The other half drains toward the east into the White River Basin. Arkansas ranked second in the nation in broiler production in 1998. Benton and Washington counties ranked first and second respectively in the state. Producing over 235 million broilers in 1998. Other livestock production such as turkey, cattle and hogs are all significant in this area.

The states of Arkansas and Oklahoma are both keenly interested in the water quality of the intrastate Illinois River. The Oklahoma portion of the Illinois River is identified as a “scenic river” and an “outstanding resource water” for the state of Oklahoma. In addition, the Illinois River feeds Lake Tenkiller, which is a drinking water supply. The Illinois River has long been appreciated as a resource for fishing and canoeing enthusiast in Arkansas. Several studies have been performed to assess the water quality in the river and to determine the sources of impairment.

A comprehensive study of the Illinois River Watershed was conducted in 1990, at Oklahoma State University, investigating the sources and transport of nonpoint source nutrients (Gade, 1990). The study indicated that the loading of phosphorus and nitrogen into Lake Tenkiller was excessive and causing degradation of lake water quality. This study was limited by data constraints such as an 80 m DEMs for portions of Arkansas; landuse data from 1985; cattle not being included in the estimating of nutrient loading, and model limitations in evaluating tributary processes. (Gade, 1990).

A report was compiled on the Illinois River Basin in 1991 through the cooperative efforts of the University of Arkansas and Oklahoma State University. This study looked at trends in grab sample data taken at several sites in the basin for a period of around twenty years. The authors concluded that excessive phosphorus loading was occurring in Lake Tenkiller (Burks, et al, 1991).

In 1996 a study was performed by researchers at the University of Arkansas to determine the potential sources of phosphorus in the Arkansas portion of the Illinois River Watershed. The authors developed a method for and prioritized the sub-basins in the watershed for phosphorus contribution (Parker, et al. 1996: Williams, 1997).

A “Clean Lakes Program Phase I Diagnostic and Feasibility Study” was performed on Lake Tenkiller Lake, Oklahoma in 1996 (Jobe et al,1996). This study estimated the nutrient loading to the lake and concluded that nitrogen, phosphorus and chlorophyll a levels indicated eutrophication in the lake. This study recommended at 40% reduction of nutrients to maintain current lake status and prevent accelerated eutrophication.

The Arkansas Department of Pollution Control and Ecology performed an in-stream water quality study to determine the impacts of urban discharges on the receiving streams and the Illinois River at the state line. The study concluded that the WWTPs were a significant portion of the phosphorus load to the receiving streams and that Spring Creek dominated the phosphorus load in the Illinois River (ADPC&E,1997).

The Arkansas Oklahoma Arkansas River Compact Commission (AOARCC) was formed between the two states in 1970. In 1996 the Commission adopted a monitoring, evaluation and implementation plan that attempted to measure the phosphorus loading in the Illinois Basin, set a 40 % reduction as its goal, and promulgated voluntary farm best management practices (BMPs). This effort used monthly grab samples as the water quality data. The average phosphorus load measured at the Illinois River near Siloam Springs between 1980 and 1993 was used as a baseline. They agreed to use a five-year moving average to evaluate the phosphorus loads in order to dampen some of the effects of changing annual precipitation. The annual base line P load was 190,000 kg (418,000 lb.) per year and the target after 40% reduction was 114,000 kg (250,000 lb.) per year.

In 1995 the Arkansas Water Resources Center (AWRC) established a water quality monitoring station at the Highway 59 bridge over the Illinois River south of Siloam Springs, about a mile upstream from the Oklahoma border. This station was established in conjunction with the AOARCC, ASWCC and the USGS to accurately measure nutrient loads during both base flow and storm flow events.

Recently, the Oklahoma Water Resources Board recommended a phosphorus limit to be set at the AR-OK boarder where the Illinois River enters into Oklahoma of 0.037 mg/L (Smith, 2002). The value was approved by the Governor of Oklahoma. The latest value reported to the AOARCC in 2001 was 0.368 mg/l in the Illinois River near Siloam Springs.

In 2002, the authors began to compile data on the sources of phosphorus in the IRDA and to develop a mass balance for phosphorus using the AWRC water quality data. This report summarizes the results of the monitoring effort, the compilation of input sources and the mass balance computation for the IRDA.

METHODS AND RESULTS

Monitoring

In 1995 the AWRC established a water quality monitoring station at the Highway 59 Bridge on the Illinois River. The sampler operated in conjunction with a USGS gauging station at the site that measures and computes discharge. . The monitoring station uses automatic sampling equipment to take water samples every two weeks during base flow conditions and during all storm events. The protocol has varied during the five years of monitoring data included in this report. During about two years in 1997 to 1999, the storms were sampled with discrete samples every 30 to 60 minutes. These samples were analyzed individually to be able to identify the changes in concentrations during storm events. This information was used to determine how often storm events should be sampled to make accurate determinations of nutrient loads. During the rest of the time, storm samples were taken when a given volume of flow had passed the sampler and then composited into a single sample for analysis. These flow-weighted composite samples have similar accuracy as the discrete samples but yield less information. During the study period, all storm flows (defined as flows above five feet of stage) were sampled with the exception of a couple of events where equipment failed. The concentrations for storms that were not sampled were estimated using stage – concentration regressions developed from the discrete samples. The concentrations and discharges were integrated to develop annual loads and mean concentrations for nitrogen (TKN and nitrate), phosphorus (total P and soluble reactive P) and total suspended solids. Table 1 contains the annual flow volume, total phosphorus load and mean phosphorus concentrations at the outlet of the Illinois River drainage in Arkansas (IRDA).

Table 1: Water quality data from AWRC

	Flow *(m^3)*	*Total phosphorus* *(kg)*	*Total Phosphorus* *(mg/l)*
1997	458,460,000	127,000	0.28
1998	588,000,000	232,000	0.39
1999	635,000,000	267,000	0.42
2000	536,000,000	283,000	0.53
2001	532,100,000	254,000	0.48

Phosphorus Inputs

Four categories of phosphorus inputs were identified and considered in the mass balance: agricultural animal production manures, inorganic fertilizers, sludge applications, and point source inputs from municipal wastewater treatment plants. Phosphorus loading and physical locations were estimated for each phosphorus input on an annual basis from 1997 to 2001.

Annual animal production rates were obtained from Arkansas Agricultural Statistics (AAS) (http://www.nass.usda.gov/ar/). The primary production animals in the IRDA were chickens (broilers and layers), turkeys, pigs, and cows (beef and dairy). For broilers and layers, only one year of data (1997) was available; a growth rate of 4% per year was assumed for subsequent years (Watkins, 2002). Animal production was provided by AAS on 'head per county' basis. A landuse distribution was implemented to determine the portion of animals in the study area. (The total pasture area in the two counties was calculated, and the portion of pasture area inside the IRDA was estimated. This portion was multiplied by the county animal head numbers.) ASAE standards for manure production rates and nutrient concentrations were used (ASAE, 1999). The average animal size was obtained from AAS. The average lifespan of each animal was estimated through conversations with Dr. P Moore (Moore, 2002). All these components were combined to determine the annual phosphorus loads and manure production for the IRDA from agricultural animal production.

Inorganic fertilizer contributions were calculated using information provided by the Arkansas State Plant Board (ASPB). ASPB publishes fertilizer sales by weight and type (common name or N-P-K) for each county. The phosphorus portion of each fertilizer was tabulated to determine the amount of phosphorus purchased in each county. All landuses that might be applied with inorganic fertilizer were identified (urban, agriculture, pastures). The portion of these within the IRDA boundaries was calculated, and this percentage was multiplied by the total amount of inorganic phosphorus reported sold by ASPB. This process provided the annual phosphorus load for the IRDA from inorganic fertilizer.

Sludge application rates and concentrations were obtained from each point source facility. Three point source facilities apply sludge in the IRDA. Sludge was applied in the following sub-basins: Muddy Fork, Osage Creek, and Spring Creek. Phosphorus loadings were determined on an annual basis.

Four point sources are located in the study area that discharge effluent directly into stream flow. Point sources discharge into the following sub-basins : Mud Creek, Muddy Fork, Osage Creek, and Spring Creek. Phosphorus loading and flow rates were obtained from each point source. Point source loadings were tabulated annually. Phosphorus loads are summarized in the Table 2.

Table 2: Phosphorus outputs and inputs collected for the IRDA

	1997	**1998**	**1999**	**2000**	**2001**
	(kg P)	(kg P)	(kg P)	(kg P)	(kg P)
INPUTS					
EFFLUENT					
Mud Creek	1,859	2,500	1,579	2,361	1,366
Muddy Fork	1,812	1,897	1,855	1,096	1,211
Osage Creek	20,026	8,651	18,803	9,607	7,002
Spring Creek	59,521	53,684	79,998	91,128	101,363
Sum of point sources	*83,219*	*66,732*	*102,235*	*104,192*	*110,942*
SLUDGE					
Mud Creek[1]	0	0	0	0	0
Muddy Fork - Blue Mtn	101	171	106	0	0
Muddy Fork - Apple Hill	0	0	455	8,452	228
Muddy Fork - Blue Mist	57	0	0	0	0
Osage Creek	26,838	34,845	31,131	32,413	34,711
Spring Creek	54,969	49,648	56,297	60,904	87,254
Sum of sludge inputs/yr	*81,965*	*84,664*	*87,990*	*101,768*	*122,193*
ANIMALS					
Hogs/swines	52,896	51,642	48,485	47,483	45,800
Broilers	1,370,247	1,425,057	1,512,935	1,573,453	1,669,786
Layers	211,469	221,470	231,398	244,542	247,192
Turkeys	327,307	320,448	310,556	256,015	325,896
Cattle-beef	798,483	807,058	835,421	827,756	820,545
Dairy	47,920	43,118	36,721	36,721	36,179
Sum of animal inputs/yr	*2,808,322*	*2,868,793*	*2,975,517*	*2,985,969*	*3,145,398*
FERTILIZER					
Fertilizer	149,966	148,623	160,506	176,066	187,212
TOTAL INPUTS	3,123,472	3,168,811	3,326,248	3,367,996	3,565,744

Mass Balance

A mass balance is a simple way to investigate a system by looking at the inputs and outputs from a system. If the element that is being considered is conservative, that is, does not leave the system except through the measured output location, the mass balance can be illustrated with the following simple formula:

ACCUMULATION = INPUTS – OUTPUTS

In this case the system being investigated is the IRDA. The inputs to the system are the phosphorus inputs listed above and the outputs from the system are the measured phosphorus leaving the IRDA at the highway 59 bridge. The accumulation is the phosphorus that is remaining within the IRDA.

For animal inputs in the Table 2, cattle-beef and dairy are the only animals that obtain the majority of their phosphorus through grazing. Therefore, they are consuming plant phosphorus and depositing manure phosphorus (ie no net change in phosphorus in IRDA). However, the location of the phosphorus is changing. The phosphorus is being removed from the soil where it is bound to the soil particles and is being deposited on the land surface where it is subject surface transport. Thus, it is included as an input to the basin, but is removed from the basin as grazing output and does not contribute to the accumulation. The other animals (chickens, turkeys, hogs) are grown in houses and therefore eat feed brought into the IRDA (non-grazing). Table 3 provides the total phosphorus mass balance in the IRDA. The accumulation is given as total mass and as kilograms per IRDA pasture acres.

Table 3: Phosphorus mass balance in the IRDA

	Inputs (kg)	River Outputs (kg)	Grazing outputs (kg)	Accumulation (kg)	Accumulation (kg/pasture acre)
1997	3,004,000	127,000	848,000	2,155,000	8
1998	2,947,000	232,000	852,000	2,095,000	8
1999	3,066,000	267,000	874,000	2,192,000	8
2000	3,093,000	283,000	866,000	2,227,000	8
2001	3,317,000	254,000	859,000	2,459,000	9
average	3,086,000	206,000	860,000	2,226,000	8

DISCUSSION

In order to estimate the nonpoint source phosphorus loads into the IRDA, many estimates were made. Estimates were made concerning the number of animals in the IRDA, the average animal weights, the average daily manure produced, and the average phosphorus concentrations of manures. Estimates were also made distributing the animals throughout the IRDA. The primary assumptions in estimated inorganic fertilizer mass loading into the IRDA was the partitioning the county numbers into fraction within the IRDA and portion outside of the IRDA. Calculation of sludge mass loading did not involve these types of assumptions because concentrations, application rates, and locations were available. The effect of the uncertainties on the mass balance calculations occurs in the accumulation of P in the basin. Since the animal phosphorus inputs were based upon uncertain estimates, the accumulation of P in the basin should be considered a very uncertain estimate.

The estimates of point source discharges should be considered fairly accurate. Each of the permitted dischargers was asked the same series of questions to ascertain the methods of sample collection and analysis for phosphorus. The results were reported slightly differently with some reporting daily concentrations and some reporting monthly averages. But, they all represented flow-weighted mean values of total phosphorus. After receipt and compilation of the data, the dischargers were provided the results and conclusions and given a chance to verify their data and comment.

The estimates of outputs from the IRDA at the Highway 59 bridge are fairly accurate. They provide the best estimates of loading of any of the methods used historically, particularly for estimates of storm flow loads. Most of the past studies were performed with grab samples taken on even intervals (monthly). This type of sampling tends to have low precision and has an overall low bias (Nelson, et al, 1999). This type of sampling tends to miss storm events and thus does not adequately characterize the effects of the re-suspension of stream sediments.

A key concept for understanding this interpretation of the phosphorus mass balance is that once phosphorus is in the stream its is not being removed from the stream except downstream. That is not to say that it is not changing forms or perhaps even leaving the system temporarily, but that there is no net accumulation or removal from the stream. Phosphorus does go through a process called nutrient spiraling, where it goes through processes of biotic and abiotic transformations (Newbold, 1992, McClain et al, 1998). It is used as a nutrient by the steam biota such as algae and periphyton. The biota eventually dies and releases the nutrients back to the water to be used again. Or, it can be adsorbed to the sediments and organic matter accumulated in the stream bottom. The biota and sediments are also washed down stream during storm events. It may take several life cycles or several storm events to move from the headwaters of the system to the state line, but it all eventually does. There may be some minor exceptions to this and the true system is much more complicated than this simplification. For instance, the algae that consume the phosphorus are in turn consumed and the phosphorus is transferred up the food chain. It can eventually be transferred to land animals or insects that deposit the phosphorus in their manure or dead bodies on the land surface and not back in the river. But, there are probably as many of these processes transferring phosphorus from the land back to the river, so the net effect is zero.

This concept forms of phosphorus conservation is key to determining the different impacts of point and non-point source inputs. It is the viewpoint taken in this analysis and illustrated in Table 4. Point source inputs are discharged directly to the stream. The non-point source inputs identified are inputs to the surface of the land in the stream's watershed. The concept of P conservation in the stream implies that the point source discharges, which averaged 94,000 kg per year, accounted for 43% of the average river output of 243,000 kg per year. This, in turn, implies that the remaining 57% of the phosphorus in the river output originated from the non-point sources.

The loads can be differentiated between base flow and storm flow, which is defined as all flows and loads above five feet stage. The average base flow loads at the bridge were 62,000 kg. The average point source inputs were 94,000 kg. Thus, some of the PS inputs are being taken up during base flows. An estimate of the percentage that reached the bridge of 56% was used in this analysis. This percentage was not measured in this project. But, this percentage is similar to what was measured and computed by ADEQ (Maner, 1996). For this project, the remaining 44% of the PS phosphorus was applied to the storm loads, as would occur due to re-suspension. For the ADEQ analysis the remaining phosphorus was assumed to have been permanently removed from the system. The portions of the measured outputs that were not attributed to PS input were applied to NPS inputs. The NPS inputs thus accounted for 57% of the total measured outputs, twelve percent of the base flow outputs and 73% of the storm flow outputs. This means that only 4% of the total NPS inputs applied to the watershed actually showed up in the river output.

Table 4. Watershed mass balance and partition between base and storm flows and point and non-point source inputs.

	Outputs		Point source inputs					Non point source inputs			
	59 bridge		Water Shed inputs	River out puts	% of	% of		Water Shed inputs	River out puts	% of	% of
	kg		kg	kg	point source inputs	total out put		kg	kg	non-point source inputs	total out put
all t-p	232,000		94,000	94,000	100%	43%		3,224,000	138,000	4%	57%
base t-p	62,000		Base t-p	54,000	56%	88%		Base t-p	8,000	0%	12%
storm t-p	170,000		Storm t-p	40,000	44%	27%		Storm t-p	130,000	4%	73%

Mean concentrations of phosphorus can be calculated from the loads calculated at the IRDA output by dividing the annual load by the annual discharge. Trend determination can be best investigated with mean concentrations because some of the variation of loads results from differences in annual precipitation. Not all of the variation can be removed because storm event concentration tends to be a function of storm intensity. A greater number of storm events appear to have a cleansing or diluting effect on base flow concentrations. So years with more storm events have higher storm flow concentrations with lower base flow concentrations and visa versa. Trends should therefore, not be determined from year to year but over enough years to smooth out the variability in precipitation. Five years is considered a minimum period for realistic trend determination (Spooner, 1993).

Figure 2 shows the mean concentrations determined at the IRDA outlet for the five years that adequate data is available. Plotted are the annual mean values for storm flow, base flow and for combined flow. A trend line for each type of flow determined from a linear least squares regression is also plotted along with the equation determined for the trend line. The slope of each trend line is given in the equation as the coefficient of x and represents the average rate of change of the concentration in milligrams per liter per year. In all cases the trends are increasing. The base flow concentrations increased at an average of 0.017 mg/l per year or 3.5% per year. The storm flow concentration showed a much greater increase. They increased at an average of 0.99 mg/l per year or 26% per year. In this same time period total phosphorus inputs to the basin increased by an average of 3% per year and the PS discharges increased by an average of 6.5% per year. The PS loads increased by 28,000 kg and the base flow loads increased by 34,000 kg. Figure 3 shows the relationship between PS inputs to the IRDA and base flow outputs measured at the 59 bridge.

It appears that the base flow and some of the storm flow increases can be attributed to the point sources. However, the combined flow percentage increase was greater than the percentage increase of total inputs. This could be attributed to several factors. An increase in development in the IRDA could have caused greater soil disturbance and more erodable phosphorus containing soils that are washed off during storm events. The rapid increase in the urban areas could be causing greater phosphorus discharges due to the excess use of more soluble forms of phosphorus from commercial fertilizers on lawns and golf courses. The accumulation of phosphorus in the watershed soils, as illustrated with the mass balance calculations, could mean that greater amounts of soil phosphorus are being transported during storm events with a given amount of soil.

Figure 2. Trends and values of mean concentrations

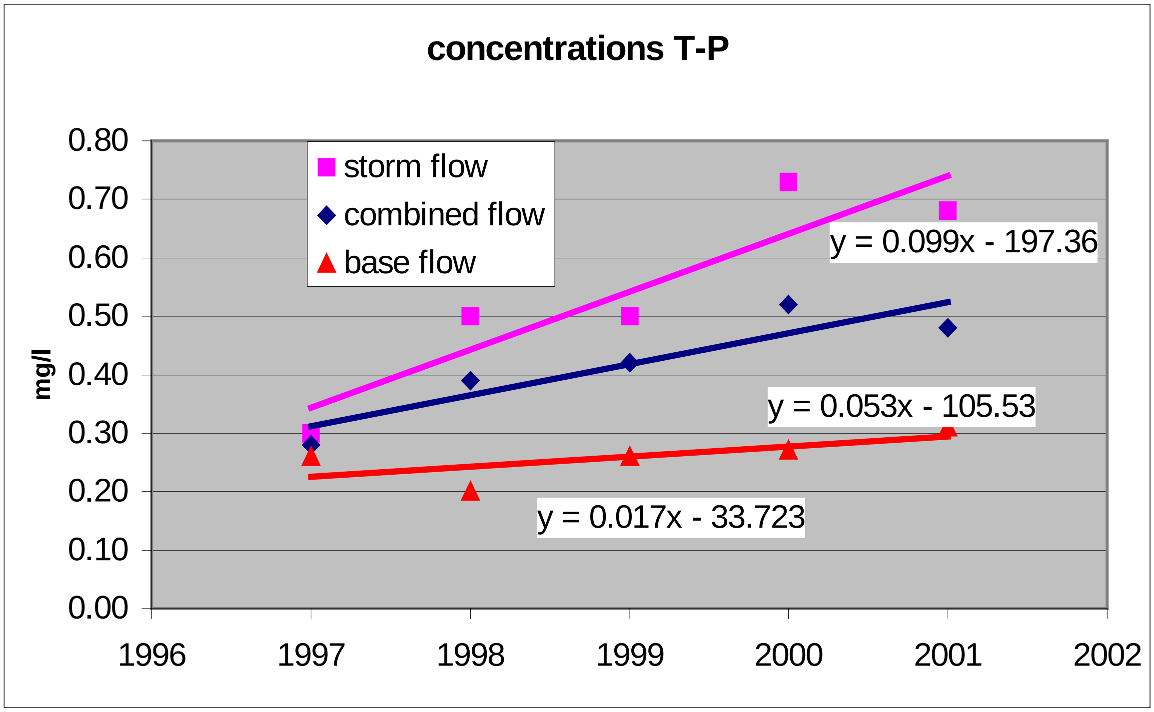
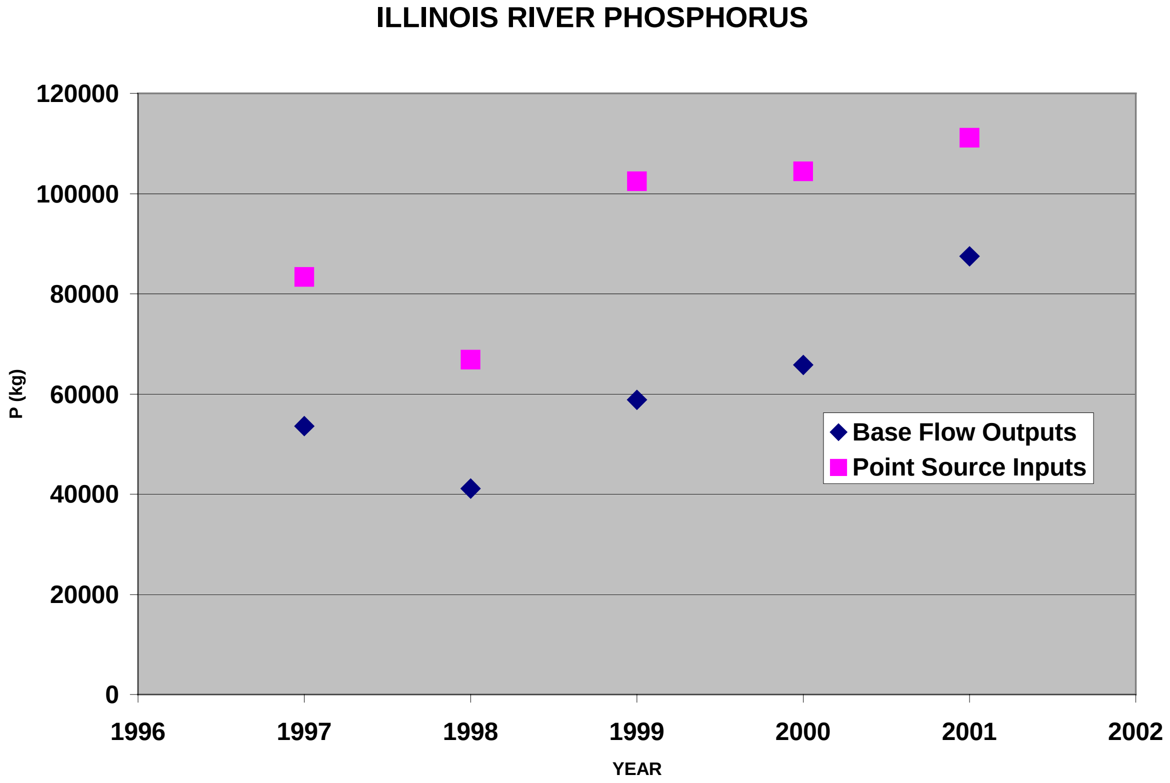


Figure 3. Relationships between the base flow outputs and the point source inputs to the IRDA.



Recently the Oklahoma Water Resources Board proposed and the Oklahoma Governor approved that the Illinois River in Oklahoma be adopted as a scenic river in Oklahoma and that there be a numerical in-stream phosphorus limit of 0.037 mg/l. The U.S. Supreme Court decision of 1992 that Arkansas must adhere to Oklahoma's water standards on the Illinois may require that the IRDA phosphorus concentration be reduced to this level. Current levels of phosphorus at the state line far exceed this standard.

The mass balance relationship developed for current conditions was used to investigate the effect of changing the PS loading to the river. Table 5 illustrates the effect of reducing PS concentrations of the IRDA concentrations. The PS discharges have ranged from a five year average of 0.5 mg/l to 4.9 mg/l with the average value around 4 mg/l. The mass balance relationship developed was modified by reducing the point source contributions by 75 % and 100% while keeping the NPS contributions fixed. These results are not meant to represent the actual results, especially in the short term.

They are meant to illustrate the potential effect of managing PS contributions on river concentrations.

The 75% reduction simulates the effect of reducing the average PS discharge to one mg/l. One mg/l is a realistic level for WWTP discharges and is achievable with current treatment technologies. This analysis shows that a reduction to one mg/l could have a significant impact on river concentrations. It reduced the combined concentrations by 31%. However, the concentrations are still far above the proposed Oklahoma standard. Even looking at just base flow values, they are 2.5 times higher. If the PS discharges were reduced to zero, this analysis shows that the combined concentrations would still greatly exceed the standard.

Table 5. Current and potential concentrations (mg/l) at different PS discharges

	current levels	WWTP @ 1 mg/l	WWTP @ 0 mg/l
combined	**0.418**	**0.289**	**0.246**
1997	0.276	0.139	0.094
1998	0.388	0.303	0.274
1999	0.420	0.299	0.259
2000	0.527	0.381	0.332
2001	0.481	0.324	0.272
base	**0.259**	**0.089**	**0.033**
1997	0.259	0.088	0.031
1998	0.198	0.061	0.016
1999	0.261	0.068	0.004
2000	0.272	0.089	0.028
2001	0.306	0.141	0.086
storm	**0.546**	**0.443**	**0.409**
1997	0.296	0.186	0.149
1998	0.503	0.445	0.426
1999	0.509	0.428	0.400
2000	0.739	0.623	0.584
2001	0.683	0.536	0.487

SUMMARY AND CONCLUSIONS

This analysis makes three important points for future management of the IRDA. It is apparent that a realistic reduction in PS discharges could dramatically effect the phosphorus concentrations at the state line. A reduction of 30% would still not meet the Compact Commission goal of 40% reduction not to mention the proposed numerical limit. Additional reductions would need to be achieved by reducing the impact from non point sources. However, even the 40% reduction that the states have been working toward would not come close to meeting the 0.037 mg/l limit. Especially if looking at combined flows. If just base flow samples were used to characterize the concentrations, then a PS reduction to 1 mg/l along with additional reductions in NPS contributions could achieve this limit. However, base flow samples do not adequately characterize the effect of NPS pollution. If grab sampling protocols are modified to begin targeting storm events, the determined loads will increase even with no change in water quality. This points out the importance of defining the sampling and load calculation protocols that will be used to determine the phosphorus levels in the IRDA.

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