Poultry Waste Generation and Land Application in the Illinois River Watershed and Phosphorus Loads to the Illinois River Watershed Streams and Rivers and Lake Tenkiller

Expert Report of Dr. B. Engel

For
State of Oklahoma
In Case No. 05-CU-329-GKF-SAJ

State of Oklahoma v. Tyson Foods, et al.
(In the United States District Court for the Northern District of Oklahoma)

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1. Executive Summary/Conclusions

Illinois River Studies
Numerous studies have explored phosphorus (P) loads in the Illinois River Watershed (IRW) to the streams and rivers within the watershed and to Lake Tenkiller. Observed data and models indicate nonpoint source pollution is the major contributor to P within the streams and rivers of the IRW and to Lake Tenkiller. Poultry waste application within the IRW to pastures is identified as a substantial contributor to overall P loads within IRW streams and rivers and Lake Tenkiller.

Poultry Waste and P Generation
Each of the defendants' poultry operations within the Illinois River Watershed (IRW) produces a substantial amount of poultry waste and phosphorus. Poultry waste produced within the IRW range between 354,000 and more than 500,000 tons annually. Phosphorus content of the poultry waste ranges from 8.7 million to nearly 10 million pounds annually.

Poultry Waste Land Application
Common practice for poultry waste disposal is land application to pasture and cropped areas. A substantial amount of the defendants' poultry waste and P is land applied within the IRW annually. The poultry waste is applied during the rainy season from late winter through spring.

Observed P Loads in the Illinois River Watershed
The P loads to Lake Tenkiller averaged approximately 505,000 lbs annually between 1997 and 2006. This represents a significant P load to the lake and is much greater per unit area than for other watersheds the region.

Point Sources of P in the Illinois River Watershed
A portion of the P in the IRW reaching Lake Tenkiller is from Waste Water Treatment Plant (WWTP) discharges. P discharges from IRW WWTP have changed over time peaking at slightly more than 204,000 lbs annually in the late 1990s and early 2000s. Beginning in 2003, WWTP P discharges decreased to a little more than 90,000 lbs annually in the IRW due to changes in WWTP technology. The defendants' processing facilities discharge a significant amount of P to WWTPs and thus contribute to point P sources within the IRW.

Phosphorus Mass Balance
A P mass balance for the Illinois River Watershed indicates poultry production is a substantial contributor to P within the Illinois River Watershed. Poultry production within the Illinois River Watershed is currently responsible for more than 76% of P movement into the watershed.

P Loads in the IRW Based on Continued Poultry Waste Land Application
Average annual P loads to water in the Illinois River Watershed attributable to poultry waste application to pastures is calculated at between 432,000 lb to nearly 500,000 lb annually based on poultry P application to the landscape and literature P loss coefficients.

Poultry House Density Correlated to Elevated P Levels in Runoff and Base Flow
The analyses of observed P in runoff and in baseflow for 14 small watersheds within the Illinois River Watershed that were sampled in 2005 and 2006 show a strong and statistically significant correlation between P in runoff and in baseflow and poultry house density. Sub-basin poultry house densities are strong predictors of stream total phosphorus concentration showing a cause and effect relationship between poultry house operations and phosphorus concentrations in IRW waters. From these analyses, it is evident that poultry waste is a substantial contributor to P in stream runoff and in the baseflow within streams of the Illinois River Watershed.

Hydrologic/Water Quality Modeling of Illinois River Watershed

1. The hydrologic/water quality model was able to accurately model the P loads to IRW rivers and streams and Lake Tenkiller.
2. For continued poultry waste application in the IRW at current levels, modeled P loads to Lake Tenkiller would increase during the first 30 years. For the next 70 years, P loads to Lake Tenkiller would decline slightly and stabilize at levels above current Lake Tenkiller P loads due to P saturation of soils.
3. Cessation of poultry waste application in the IRW would decrease P loads to Lake Tenkiller. The reductions in P loads to Lake Tenkiller due to poultry waste land application cessation would be limited to 16% during the first 10 years following cessation due to continued P load contributions from historical poultry waste application in the IRW that have elevated soil P. Following poultry waste land application cessation in the IRW, reductions in P loads to Lake Tenkiller would reach 50% by years 51-60.
4. For continued growth in the IRW poultry industry at a rate the same as that between 1982 and 2002, P loads to Lake Tenkiller would increase substantially. Within 40-50 years, P loads to Lake Tenkiller would nearly double (increase of 92%).
5. The addition of vegetated 100 foot buffers along all 3rd order and larger IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 3 and 5% compared to poultry waste application cessation alone. The addition of vegetated 100 foot buffers along all IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 10 and 13% compared to poultry waste application cessation alone.
6. P loads to Lake Tenkiller would be more than 275,000 lbs less than current levels (less than ½ of current levels) if poultry waste had never been disposed of in the IRW. It would take approximately 100 years of cessation of poultry waste application to return P loads in the IRW to what they would have been if no poultry waste land application had occurred.
7. P loads to Lake Tenkiller since 1954 have increased at approximately 10,000 lbs per year. Poultry waste application in the IRW is responsible for approximately 6,600 lbs of this increase each year.
8. Poultry waste land application in the IRW is a substantial contributor (45% between 1998 and 2006 and 59% between 2003 and 2006) to P loads to Lake Tenkiller, representing the largest P source. WWTP P loads are the second largest contributor to P loads to Lake Tenkiller. Poultry plant discharges to WWTP represent a significant portion of WWTP P loads.

9. Cattle in the IRW recycle P brought into the IRW to feed poultry that is excreted by poultry and land applied to pastures within the IRW. Although the P contribution of cattle is from poultry waste, cattle accelerate the movement of P into IRW streams and rivers when they excrete waste in and near IRW streams. Six percent of P loads to Lake Tenkiller result from cattle in and near IRW streams.
10. The contributions of septic systems to P loads in the IRW are negligible.

Additional data from the IRW continue to become available. These data will be used to refine analyses reported herein and in new analyses as appropriate. Therefore, I reserve the right to update this report.

2. Review of Illinois River Watershed Studies - P Contribution

Numerous studies have explored P loads in the Illinois River Watershed (IRW) to the streams and rivers within the watershed and to Lake Tenkiller. ***Analysis of these reports indicates that poultry waste application to pastures within the watershed is a substantial contributor to P in the streams and rivers of the watershed and to Lake Tenkiller.***

The majority of these studies indicate that P in the streams and rivers within the IRW has increased over time. These studies consistently conclude that nonpoint sources of P are a substantial contributor to total overall P loads to the Illinois River, its tributaries, and Lake Tenkiller. When these studies identified the source of nonpoint source P, they consistently identify land application of poultry waste as the primary nonpoint source. Information is summarized from these reports in the remainder of this section.

Observed data and models indicate nonpoint source pollution is the major contributor to P loads within the streams and rivers of the IRW and to Lake Tenkiller. Poultry waste application within the IRW to pastures is identified as the major and a substantial contributor to overall P loads within IRW streams and rivers and Lake Tenkiller.

The USGS (Terry et al., 1984) conducted an extensive water quality study on the Illinois River above Lake Frances from September 1978 to September 1981. The study concluded that existing water quality in the Illinois River, and several tributaries, did not meet the Arkansas State Guideline of 100 ug/l total phosphorus (as P) in streams.

Oklahoma's 305(b) Report (Oklahoma Department of Pollution Control, 1984 as reported by Gade (1998)) included an assessment of trends for certain water quality parameters at USGS gauging stations 07195500 (Illinois River at Watts), 07196000 (Flint Creek near Kansas, OK), 07196500 (Illinois River near Tahlequah), and 07197000 (Baron Fork near Eldon, OK) for the period from 1975 to 1983 done by the Oklahoma Department of Pollution Control (ODPC). The report concluded there was an apparent increasing trend in concentrations of total phosphorus at all four stations.

Walker (1987 as reported by Gade (1998)) reviewed EPA's STORET data base and Gakstatter and Katko's data (1986 as reported by Gade (1998)) and concluded that phosphorus concentrations have increased by a factor of roughly two to three over the past decade. Walker used flow-weighted annual mean total P concentrations to develop conclusions about trends. He suggested it would be proper to compare years of comparable flow to determine if total phosphorus concentrations had indeed increased. Walker also concluded the most probable cause for accelerated eutrophication in Lake Tenkiller is increased point source nutrient loadings since nonpoint sources tend to be rich in nitrogen while point sources tend to be rich in phosphorus (Walker, 1987 as reported by Gade (1998)). Walker's interpretation is incorrect because poultry waste contains significant amounts of P that is not in proportion to plant needs. Thus, when poultry waste has been applied to meet the nitrogen needs of plants there is inevitably an excessive P application to pastures in the IRW.

Jobe et al. (1996) recommended a 30-40% reduction in nutrient input into Lake Tenkiller ("Clean-Lakes" Diagnostic and Feasibility Study on Tenkiller Lake, Oklahoma).

The authors of Illinois River Water Quality, Macroinvertebrate and Fish Community Survey explored EPA STORET data. At the Savoy station, total P load increases slightly despite high P peaks in mid 80s. They noted that peak values seem to be in response to increased runoff.

Burks and Kimball (1988 as reported by Gade (1998)) performed a study evaluating existing concentrations of nutrients transported by the Illinois River to make an assessment of the potential effects of water quality in Lake Tenkiller. They used QUAL2E (a water quality model) on the lower reaches of the Illinois River above Lake Tenkiller and the upper segment of Lake Tenkiller. They found a projected decrease in P input from Tahlequah's WWTP after construction and implementation of a P removal system would be adequate in reducing the rate of eutrophication in Lake Tenkiller. However, they concluded that other point and non-point sources within the basin would still contribute to the further deterioration of water quality in Lake Tenkiller. They recommended concerted efforts to public and private agencies to reduce P input into Lake Tenkiller to prevent further deterioration.

Harton (1989 as reported by Gade (1998)) performed a modeling study of the Illinois River in an attempt to analyze contributions of point and nonpoint source P loading on Lake Tenkiller. The Fayetteville wastewater treatment plant effluent was determined to have no observable effect on eutrophication in Lake Tenkiller. Harton concluded the substantial distance from the point of entry of the effluent into the Illinois River to Lake Tenkiller was sufficient to allow for nearly total removal by biological activity. Nonpoint Source (NPS) total P loadings from Oklahoma and Arkansas were found to be the main loading sources to the lake. Harton concluded that removal of 70-90% of the total P loading from point and nonpoint sources would be necessary to bring eutrophication under control in Lake Tenkiller.

Burks et al. (1991 as reported by Gade (1998)) evaluated factors affecting water quality in the Illinois River. In-stream total P concentration exceeded the 0.1 mg/l level recommended by the EPA (US EPA, 1986) to prevent enrichment of streams or tributaries to standing bodies of water. They suggested there was "overwhelming evidence" that P loading to the upper end of Lake Tenkiller was excessive, and predicted decreases in water quality for the lake. Total N loading also was shown to be increasing over time. They suggested strict reduction of both point and nonpoint nutrient inputs into the system, and suggested that the focus be placed on P.

The Phase I Diagnostic and Feasibility Study on Tenkiller Lake (OWRB, 1996) found that mean annual concentrations of P, N, and chlorophyll a measured throughout Lake Tenkiller were indicative of eutrophic conditions. Recommendations for control of eutrophication were focused on the reduction of P from both point and nonpoint sources.

Gade (1990 as reported by Gade (1998)) presented temporal trend tests (Kendall Tau) on flow adjusted concentrations of total P at USGS gauging stations 07195500 (Illinois River at Watts, OK), 07196000 (Flint Creek near Kansas, OK), 07196500 (Illinois River near Tahlequah, OK), and 07197000 (Baron Form Creek near Eldon, OK) all indicated highly significant upward trends for the period from 1976 to 1986.

Phillips (2007) summarizes several studies that have been conducted on the IRW and its waters, including Lake Tenkiller, that document excess P in these waters and the source of the excess P. Phillips concludes that poultry waste application to soils in the IRW has contributed to the historical water quality problems within the IRW and Lake Tenkiller.

Nelson et al. (2002) analyzed 5 years of observed P data in the Illinois River at the Arkansas Highway 59 bridge just prior to the Illinois River reaching Oklahoma. TP load at the Illinois River near the Arkansas-Oklahoma border is about 208,000 kg where 45% of the annual loading is from municipal WWTPs (Haggard et al., 2003). Up to 83% of the average annual P loading from municipal WWTPs in the Illinois River can be attributed to a single WWTP (Springdale, Arkansas – see Section 6 of this report for further discussion) (Nelson et al., 2002). However, in 2003 the WWTP loads were decreased significantly such that the total load in the IRW draining to Lake Tenkiller is approximately 90,000 lb annually (compared to 226,000 lb prior to 2003). Haggard and Soerens (2006) indicated that WWTPs in the IRW have recently adopted a 1 mg/L P standard for discharge.

Nelson et al. (2002) also performed a P mass balance for the Arkansas portion of the Illinois River Watershed. They concluded that even if point sources were eliminated, the P concentrations in the Illinois River at the sampling location on Arkansas Highway 59 would exceed the 0.037 mg P standard. Their analyses identify poultry waste spread on pastures as the primary source of the nonpoint source (NPS) P in the Illinois River at Arkansas Highway 59.

Green and Haggard (2001) examined phosphorus and nitrogen concentrations and loads at the Illinois River south of Siloam Springs, Arkansas between 1997 and 1999. They found that flow-weighted nutrient concentrations and nutrient yields at the Illinois River site were about 10 to 100 times greater than national averages for undeveloped basins. Most of the phosphorus load was contributed during surface runoff. On average, base flow contributed 15 percent of the annual total phosphorus load; surface runoff contributed 85 percent of the annual total phosphorus load. On average, 72 percent of the soluble reactive phosphorus annual load was contributed during surface runoff.

Haggard et al. (2002) examined phosphorus concentrations and loads in the State of Oklahoma's scenic rivers (The Baron Fork, Flint Creek, and the Illinois River) between 1998 and 2000. They found that approximately 39% of the 367,000 kg/yr phosphorus load to Lake Tenkiller from the Illinois River and Baron Fork was in the dissolved form, and over 94% of the phosphorus load was transported during surface runoff. Annual phosphorus loads were least in 1999 (232,000 kg/yr) but were greatest in the following year (506,000 kg/yr in 2000). Lake Francis, a small impoundment near the Arkansas-Oklahoma border, retained about 26 % of the phosphorus transported from Arkansas to Oklahoma in the Illinois River. Phosphorus yields (kg/km^2) and flow-weighted concentrations from the IRW were about 10 times greater than values reported for undeveloped basins, nationally and regionally (Haggard et al. (2002)).

Pickup et al. (2003) observed phosphorus concentration for the Illinois River Basin, in Arkansas and Oklahoma between 1997and 2001. These data were used to calculate P loads and yields. Phosphorus concentrations in the Illinois River basin generally were significantly greater in runoff-event samples than in base-flow samples. Loads appeared to generally increase with time

during 1997-2001 at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999. Runoff components of the annual total phosphorus load at USGS gauges in the IRW ranged from 58.7 to 96.8% from 1997-2001. Mean flow-weighted concentrations were more than 10 times grater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States. The annual average phosphorus load entering Lake Tenkiller was about 577,000 pounds per year, and more than 86% of the load was transported to the lake by runoff which is predominately NPS P.

Tortorelli and Pickup (2006) observed phosphorus concentrations in the Illinois River Basin, Arkansas and Oklahoma between 2000-2004. They used this data to compute P loads at IRW USGS gauging stations. Annual total loads in the Illinois River from Watts to Tahlequah increased slightly for the period 2000-2002 and decreased slightly for the periods 2001-2003 and 2002-2004. Calculated mean annual runoff loads ranged from 68-96% of the calculated mean annual total phosphorus loads from 2000-2004. Calculated mean seasonal base-flow loads were generally greatest in spring (March through May) and were least in fall (September through November). Calculated mean seasonal runoff loads generally were greatest in summer (June through August) for the period 2000-2002 but were greatest in winter (December through February) for the period 2001-2003, and greatest in spring for the period 2002-2004. The calculated mean annual phosphorus load entering Lake Tenkiller ranged from about 391,000 pounds per year to 712,000 pounds per year, and from about 83 to 90 percent of the load was transported to the lake by runoff which is predominately NPS P.

The mean load of total P was calculated to be 1180 lbs/day at the upper end of Tenkiller (Harton, 1989 as reported in Burks) of which an estimated 221 lbs/day were point sources with the remainder from nonpoint sources (73%). Nonpoint source P was estimated at 415 lbs from Arkansas and 189 lbs from Oklahoma.

Vieux and Moreda (2003) used observed P concentration data and flow data for the IRW to create a relationship between stream/river flow and P concentrations. Figures 2.1 and 2.2 show P concentrations at Watts and Tahlequah that they plotted. These P concentrations were consistently above the 50 ug/l level that has commonly been recommended as a water quality threshold. They found the majority of P loading in the IRW occurred during direct runoff events and found high concentrations of P at high flow rates and low P concentrations for low flow rates. Vieux and Moreda (2003) also noted that the P generated by the poultry industry in the IRW is equivalent to a human population of 8 million people (2000 population of the IRW is slightly more than 280,000 people). They further indicated that poultry manure is stored and then applied to pastureland. They conclude that, with the large number of poultry in the IRW, the potential for contamination by poultry manure is high. They indicate that most of the P reaching Lake Tenkiller is from NPS sources.

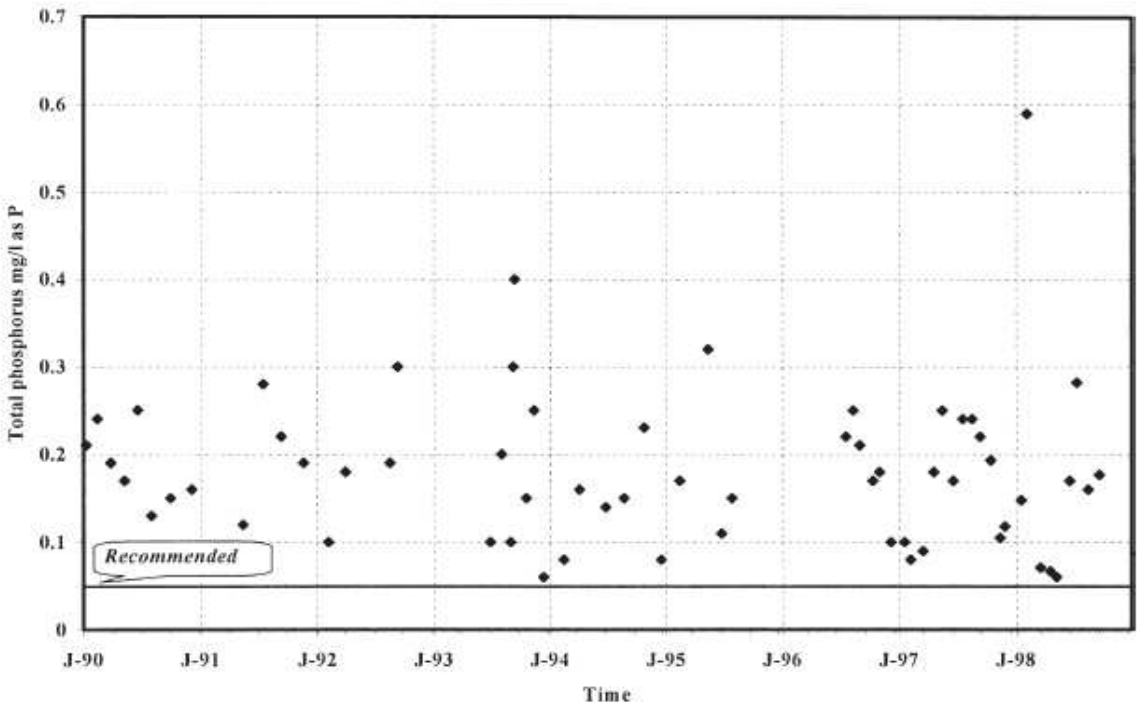


Figure 2.1. Vieux and Moreda (2002) plot of observed P at Watts Station for 1990-1998

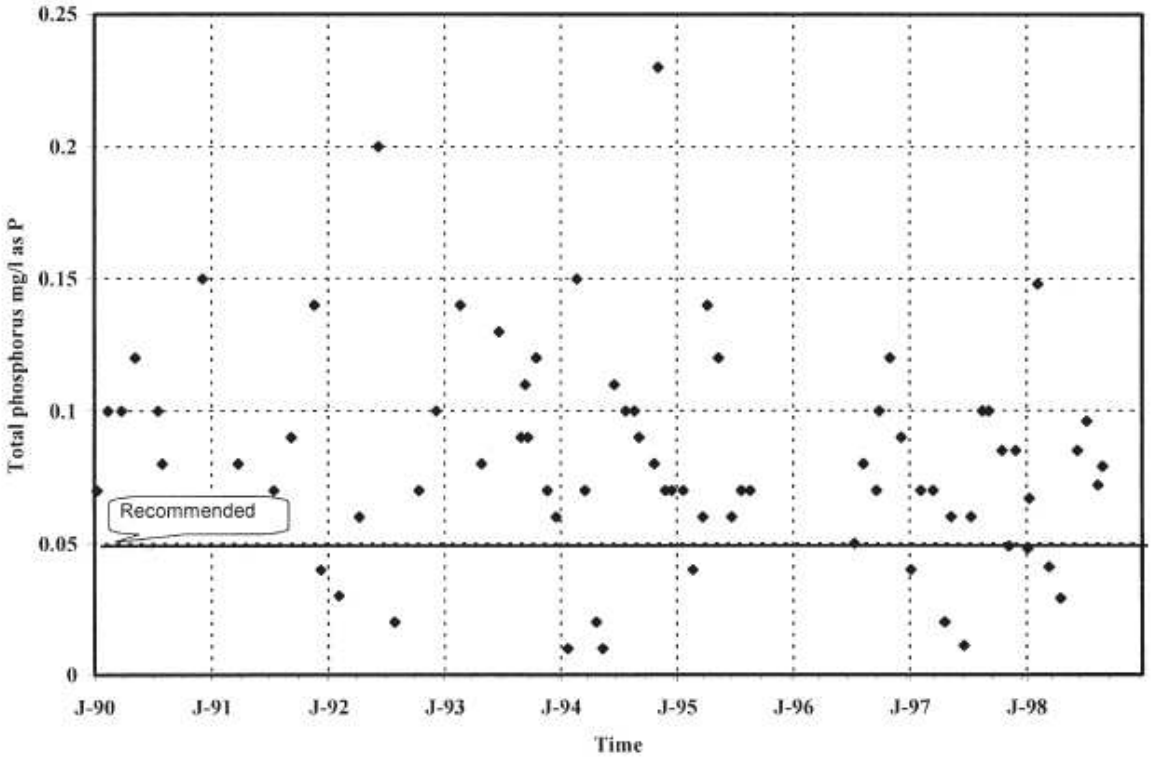


Figure 2.2. Vieux and Moreda (2002) plot of observed P at Tahlequah Station for 1990-1998

Walker (1987) used monitoring data from subwatersheds in the IRW not influenced by Waste Water Treatment Plants (WWTP) and found the average P concentration in runoff due to NPS from Arkansas was .150 mg/l and from Oklahoma was .100 mg/l.

Gade (1998) found statistically significant increasing P concentration at 07194800 (Illinois River near Savoy, AR) and 07197000 (Baron Fork Creek near Eldon, OK) for 1980-1993. Highly significant increasing total P load trends (1980-1993) were found at 07194800, 07196500 (Illinois River near Tahlequah, OK), 07196000 (Flint Creek near Kansas, OK) and 07197000.

Gade (1998) estimated P loads to Lake Tenkiller using a model of the IRW. Gade (1998) indicated that in1985 NRCS data identified 1,246 sites that had poultry houses for a total of 2,692 houses in the IRW. Gade (1998) used poultry house data to estimate P production in poultry waste, pasture applied P and pasture area by Illinois River Basin subwatershed in his modeling. The land application of P was based on house location, soil test phosphorus (STP), and distances from the houses. STP levels were highest near poultry houses. A distance from poultry houses was identified that resulted in the best fit with observed STP levels (1500-2500m). This indicates the majority of poultry waste is land applied within 2500m of poultry houses.

Gade (1998) estimated mean annual adjusted loads entering Lake Tenkiller at Horseshoe Bend are 228,000 kg P/yr. He estimated that 83.5% of P is nonpoint source pollution (190,000 kg/yr). Gade estimated that at Horseshoe Bend, the mean annual concentration of total P was 0.23 mg/l with 0.15 mg/l from nonpoint sources, 0.02 mg/l from background sources and 0.06 mg/l from point sources.

Storm et al. (1996) used SIMPLE (Spatially Integrated Model for Phosphorus Loading and Erosion) in the Illinois River basin. They used 1985 NRCS poultry house survey to calculate poultry waste P but noted there was significant expansion of the poultry industry in the Oklahoma portion of the watershed from 1985 through 1992. For the model run that considered continuous loading of P from poultry over 25 years, the average increase in P load is 324 percent. P loading was calculated at 2.30 kg/ha per year from pastures after P was applied for 25 years. Storm et al. (1996) noted that long-term reductions in P loading can only be accomplished by exporting animal manure from the watershed. They indicated that to prevent excessive buildup of soil P, litter should be diverted to fields deficient in P, and those fields with excessive soil P levels should discontinue use of poultry litter and receive nitrogen from commercial fertilizers.

Storm et al. (1996) indicated that pasture areas account for 95 percent of total nonpoint source P loading to the basin with most of this coming from pastures receiving poultry waste. They estimated that 76 percent of total P load in the IRW comes from 6 subwatersheds: Flint, Benton, Osage, Clear and Fork; although these watersheds represent 56 percent of the basin area. They indicated that overall 66 percent of P was from nonpoint source pollution (Note significant P reductions in point sources began in 2003 so this proportion would be expected to be much higher now).

Storm et al. (2006) used the SWAT in the IRW and calculated 330,000 kg/yr of total phosphorus (88,000 kg/yr was in soluble mineral forms) reached Lake Tenkiller between 1997 and 2001. They indicated point sources of P to be 35% of this total and application of litter being responsible for 15% of total phosphorus load. However, they note "This does not include the effect of increased soil phosphorus from years of poultry litter application, which increased total phosphorus load. Therefore, if litter application was suddenly eliminated, the phosphorus load would be reduced by approximately 15%. Total phosphorus load due only to elevated soil phosphorous from the application of litter was not estimated." They note that 50% of total P loads were from other NPS sources, but they did not determine the portion of this attributable to poultry.

A draft TMDL analysis was performed on the IRW and Lake Tenkiller. In reviewing the sources of nutrients, a 1989 Soil Conservation Service (USDA-SCS, 1989) inventory was reviewed that estimated more than 93,400,000 chickens and other poultry are produced in the basin each year, producing 366,000,000 kilograms of manure. Gade (1998) indicates the poultry litter cleaned from poultry houses is spread over open pastures and barren fields. The report concludes that eutrophication in Lake Tenkiller is most sensitive to changes in P loading. A 25 percent reduction in P loading was required for lake water quality to satisfy the target criteria. Point sources were estimated to contribute 23% of P to Lake Tenkiller while urban and cropland contribute 5.6% of P, and pasture (with litter) contributes 56% of P.

Smith et al. (1997) analyzed HUCs (watersheds) to identify the contributors of nutrients to streams and rivers. For the Illinois River Watershed, they found that livestock contributed 93.01 kg P per square km per year (out of a total of 118.29 kg P per square km per year), while point sources contributed 5.33 kg P per square km per year and fertilizer contributed 8.52 kg P per square km per year. The Smith et al. (1997) analysis indicates livestock are responsible for 78.63% of P in the Illinois River while point sources represent 4.5% and fertilizer represents 7.21%.

Smith and Alexander (2000) mapped P contributions from livestock as shown in the figure below (Figure 2.3). The Illinois River Watershed was identified as having between 50 and 83% of P loads in runoff attributable to livestock (more than 78% based on Smith et al. (1997)). They found that compared to national data, the Illinois River P contributions from livestock are among the highest in the nation.

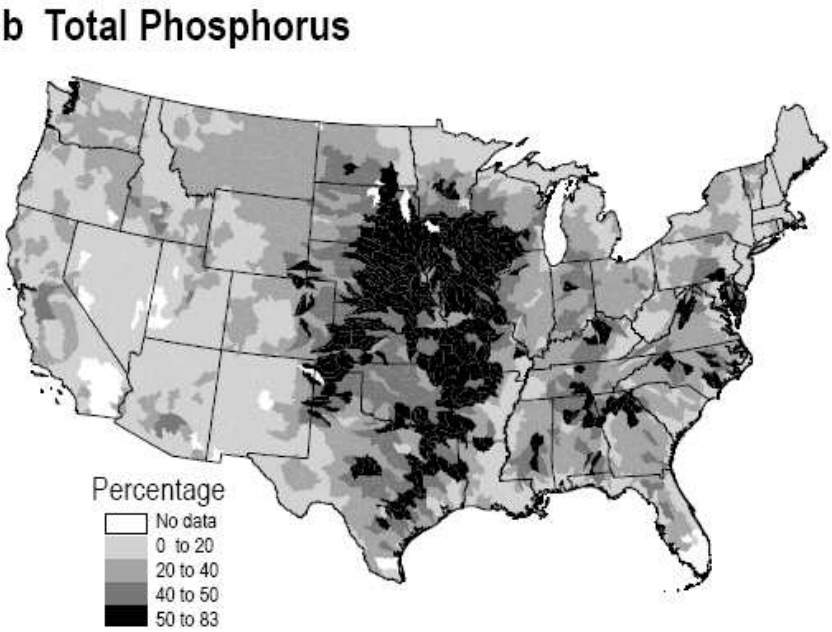


Figure 2.3. Contributions of animal agriculture to nutrient export from hydrologic units (watersheds) (from Smith and Alexander (2000))

Appendix A summarizes additional journal papers that complement the reports and literature reviewed in this section. These materials further support the analysis conducted throughout this report.

3. Poultry Waste and P Generation

Annual poultry waste generated in the Illinois River Basin was calculated using several sources of data. ***The analyses indicate each of the defendants' poultry operations within the Illinois River Watershed (IRW) produces a substantial amount of poultry waste and phosphorus. Calculated poultry waste produced within the IRW range between 354,000 and more than 500,000 tons annually. Phosphorus content of the poultry waste ranges from 8.7 million to nearly 10 million pounds annually.***

3.1 Poultry Production Data from Integrators

The 2001-2006 poultry production data for the Illinois River Basin provided by the integrators (Table 3.1) was used to calculate poultry waste and phosphorus (P) production. Not all integrators provided production data by type of poultry. Therefore, it was necessary to estimate the number of poultry by type for Tyson and Simmons. This was done by using the number of houses of each type of poultry by integrator created by Dr. Fisher (Fisher, 2008) and the average poultry production by type per house from the Arkansas Soil and Water Conservation Commission to estimate the proportion of poultry type for Tyson and Simmons. The Cobb data were combined with Tyson data.

Poultry waste production was calculated using waste values from the USDA Agricultural Waste Management Field Handbook, Ch.4 - Ag Waste Characteristics. The average weights of poultry by type were obtained from the Arkansas Soil and Water Conservation Commission data.

Table 3.1. Poultry Production in the Illinois River Basin Provided by Defendants' Discovery Responses

Defendant	2001	2002	2003	2004	2005	2006
Cal-Maine	1,135,998	879,281	633,656	403,739	200,000	0
Cargill	3,058,603	3,032,295	3,381,331	3,545,084	3,381,451	2,305,422
Cobb	1,189,358	1,279,798	1,237,193	1,250,237	1,243,562	1,244,481
George's	19,972,941	20,082,206	21,312,971	23,535,964	26,524,368	27,479,391
Peterson	13,277,715	14,454,936	14,897,458	20,981,977	18,166,724	16,887,638
Simmons	15,400,000	17,600,000	18,600,000	25,400,000	31,600,000	27,400,000
Tyson	87,027,895	88,142,559	90,098,641	95,023,680	89,719,497	88,639,337
TOTAL	**140,870,901**	**145,267,093**	**149,255,914**	**170,140,681**	**170,835,602**	**163,956,269**

The annual poultry waste and P produced by poultry based on poultry production data provided by the defendants are shown in Table 3.2 for the years 2001-2006. Phosphorus in the poultry waste shown in Table 3.2 is consistent with calculations obtained in performing a P mass balance for the Illinois River Watershed (as setout in Section 7 of this report and Appendix B). Waste ranges from nearly 420,000 tons in 2001 to more than 482,000 tons in 2004. Phosphorus in the poultry waste ranges from more than 8.7 million pounds in 2001 to nearly 10 million pounds in 2004.

Table 3.2. Poultry Waste and P Production within the IRW Based on Defendant Supplied Poultry Production Data

Year	Total Waste (tons)	Total P (lbs)
2001	420,555	8,732,752
2002	425,308	8,801,173
2003	440,920	9,176,463
2004	482,407	9,975,305
2005	476,649	9,819,383
2006	445,364	9,000,113

The annual poultry waste produced by integrator based on defendant supplied poultry production data is shown in Table 3.3. Each defendant produces a substantial amount of waste with Tyson producing approximately ½ of the waste.

Table 3.3. Poultry Waste by Defendant within the IRW Based on Defendant Supplied Poultry Production Data for 2001-2006

	Poultry Waste (tons)					
Year	Cal-Maine	Cargill	Georges	Peterson	Simmons	Tyson+Cobb
2001	18,626	45,086	69,510	27,970	40,247	219,116
2002	14,561	44,698	67,494	30,450	45,996	222,110
2003	10,821	49,843	73,401	31,382	48,610	226,862
2004	6,712	52,257	73,730	44,199	66,381	239,128
2005	3,135	49,845	76,879	38,269	82,585	225,936
2006	0	33,984	80,943	35,574	71,608	223,256

The annual P produced in poultry waste by integrator based on defendant supplied poultry production data is shown in Table 3.4. Each of the defendants' poultry operations produce a substantial amount of P in poultry waste with Tyson's producing approximately ½ of P in poultry waste.

Table 3.4. Phosphorus in Poultry Waste by Defendant within the IRW Based on Defendant Supplied Poultry Production Data for 2001-2006

	P in Poultry Waste (lbs)					
Year	Cal-Maine	Cargill	Georges	Peterson	Simmons	Tyson+Cobb
2001	396,398	1,484,311	1,452,470	543,414	768,007	4,088,152
2002	311,363	1,471,544	1,404,951	591,594	877,722	4,143,999
2003	233,511	1,640,927	1,532,054	609,705	927,592	4,232,673
2004	145,707	1,720,395	1,522,252	858,725	1,266,712	4,461,513
2005	71,837	1,640,986	1,571,747	743,505	1,575,910	4,215,398
2006	0	1,118,799	1,658,320	691,157	1,366,453	4,165,384

3.2 USDA Agriculture Census Data

In calculating poultry waste generated in the Illinois River Basin using the 2002 USDA Agriculture Census data, poultry were allocated to the basin using the proportion of pasture within counties to assign the proportion of poultry in the county to the basin. This approach calculated approximately 528,000 tons of poultry waste per year generated in the IRW.

Annual poultry waste generation was also calculated using 2002 USDA Agricultural Census data by allocating poultry to the basin proportional to the area of each county within the watershed. Calculated annual poultry waste in the IRW using this allocation approach is approximately 414,000 tons per year.

3.3 Arkansas Soil and Water Conservation Commission Data

The Arkansas Soil and Water Conservation Commission 2007 Poultry Registration data on poultry production in the Illinois River Basin were used to estimate poultry waste production in the basin. This data contained the type of poultry, weight, number, number of flocks, and number of houses. These data were provided for poultry operations that were within the basin within Benton and Washington counties. The average poultry production by type by house was computed from these data as was the average weight of poultry.

The number of active poultry houses with known integrators within the Oklahoma portion of the basin was obtained from Dr. Fisher (Fisher, 2008). These houses had an assigned poultry type as well. Poultry numbers for the Oklahoma counties were computed using the average production numbers by type of poultry from the Arkansas Soil and Water Conservation Commission data.

The poultry waste values provided by the Arkansas Soil and Water Conservation Commission used equations that are unrealistic with regard to the amount of poultry waste produced per bird as removed from poultry houses. The equations used by the Arkansas Soil and Water Conservation Commission to compute poultry waste calculate the amount of waste excreted on a dry weight basis (amount of waste excreted with all water removed and without inclusion of bedding materials). Therefore, poultry waste production was calculated using waste values from the USDA Agricultural Waste Management Field Handbook, Ch.4 - Ag Waste Characteristics. The average weights of poultry by type were obtained from the Arkansas Soil and Water Conservation Commission data.

The calculated annual poultry waste production using this approach within the IRW is approximately 477,000 tons. The poultry house data prepared by Dr. Bert Fisher that identified integrator and type of poultry were used to calculate the proportion of each poultry type produced by each integrator (Fisher, 2008). Using this information and total waste production for each type of poultry, the litter production within the IRW for each integrator was computed and is shown in Table 3.5.

Table 3.5. Calculated Annual Waste Production (tons) by Integrator Using Arkansas Soil and Water Conservation Commission Data and USDA Waste Characteristics Field Manual

Type	Poultry Waste Production (tons/yr)					
	Cal-Maine	**Cargill**	**Georges**	**Peterson**	**Simmons**	**Tyson**
Breeder	456	4,785	5,468	684	7,974	25,518
Broiler	0	1,018	56,006	38,950	58,552	148,162
Cornish	0	0	0	0	0	11,103
Turkey	0	52,073	0	0	0	0
Layer	12,362	0	11,411	6,657	0	6,657
Pullet	349	0	5,239	524	3,842	20,084
Total	13,167	57,876	78,125	46,814	70,368	211,523

The Arkansas Soil and Water Conservation Commission data show the following amounts of poultry waste generated within the Illinois River Watershed (Table 3.6). The poultry waste estimates by the Arkansas Soil and Water Conservation Commission use equations that greatly under predict poultry waste generation per bird as it would be removed from poultry houses. The equations used by the Arkansas Soil and Water Conservation Commission to compute poultry waste calculate the amount of waste excreted on a dry weight basis (amount of waste excreted with all water removed and without inclusion of bedding materials).

Table 3.6. Arkansas Soil and Water Conservation Commission (ASWCC) Estimate of Poultry Waste Generated in the Illinois River Watershed. Note the Equation Used by ANRC Underestimates Waste Production as Removed from Poultry Houses. Equation Estimates Waste Production on a Dry Weight Basis Without Bedding.

	ASWCC Poultry Waste Generated in IRW (tons)			
County	2004	2005	2006	2007
Benton	56,470	70,168	62,507	95,091
Washington	72,896	107,003	89,141	120,014

If the Arkansas Soil and Water Conservation Commission poultry waste estimate for 2007 (215,105 tons) is converted to waste as removed from poultry housing (includes some moisture and bedding material), the estimated poultry waste produced in Benton and Washington Counties is more than 376,000 tons. This is based on USDA Agricultural Waste Management Field Handbook, Ch.4 - Ag Waste Characteristics characterizations of poultry waste data (20 lbs dry weight per 1000 lbs broilers and 35 lbs as removed from housing including bedding per 1000 lbs broilers; to convert waste in Table 3.6 to as removed multiply values by 35/20 or 1.75).

3.3 Poultry Waste Generated within the IRW Based on Poultry House Data
Fisher (2008) calculated poultry waste generation within the IRW based on active poultry houses within the IRW, house sizes, type of poultry, integrator, and waste production data. Poultry houses within the IRW were identified from aerial photography and various data sources and observations were used to identify active houses (Fisher, 2008). The sizes of active houses were measured from aerial photography within a GIS. The integrator and type of poultry produced within each active house was identified from various records and observations (Fisher, 2008). The amount of waste produced per unit area of house by poultry type was calculated from data in animal waste management plans prepared under the supervision of the U. S District Court (N.D. Okl.) by the Eucha/Spavinaw Watershed Management Team. Additional details of the calculation are provided in Fisher (2008).

Table 3.7 shows the amount of poultry waste produced by each integrator within the IRW based on the data and calculations overviewed above. Each of the defendants produces a significant amount of poultry waste within the IRW.

Table 3.7.
Poultry Waste Production (tons) Within the Illinois River Watershed Calculated from a Consideration of the Total Area of Active Poultry Houses Operated by a Known Defendant (from Fisher, 2008)

Defendant	Broiler	Breeder	Turkey	Pullet	Cornish	Hen	TOTAL	%
Cal-Maine		358		112		2,280	2,750	0.78%
Cargill		2,860	15,108				17,968	5.08%
Georges	49,813	5,911		2,489		1,888	60,101	16.98%
Peterson	35,063	491		277		1,311	37,143	10.49%
Simmons	58,724	5,757		1,818			66,299	18.73%
Tyson	129,421	18,593		7,735	9,874	1,521	167,144	47.22%
Willowbrook			2,597				2,597	0.73%
TOTAL	273,022	33,970	17,704	12,430	9,874	6,999	**354,000**	
	77.12%	9.60%	5.00%	3.51%	2.79%	1.98%		

3.4 Literature Estimates of Poultry Waste and P in Poultry Waste in the IRW
Reports and published journal papers have estimated poultry waste and P in poultry waste within the IRW. The estimates in these reports as described below are consistent with the analyses presented in the preceding sections.

Willett et al. (2006) estimated more than 361,000 tons of poultry waste was generated and applied within the IRW annually. They estimated this waste contained more than 9,000 tons of P. They recommended that poultry waste be exported from the watershed to address water quality issues in the IRW.

In reviewing the sources of nutrients, a 1989 Soil Conservation Service (USDA-SCS, 1989) inventory estimated more than 93,400,000 chickens and other poultry are produced in the basin each year, producing 366,000,000 kilograms (403,000 tons) of manure. Vieux and Moreda

(2003) noted that the P generated by the poultry industry in the IRW is equivalent to a human population of 8 million people.

Smith et al. (1997) analyzed HUCs (watersheds) to identify the contributors of nutrients to streams and rivers. For the Illinois River Watershed, they found that livestock contributed 93.01 kg P per square km per year (out of a total of 118.29 kg P per square km per year), while point sources contributed 5.33 kg P per square km per year and fertilizer contributed 8.52 kg P per square km per year.

Nelson et al. (2002) found nearly 6,000,000 lbs of P annually were input into the Arkansas portion of the Illinois River Watershed (7,000,000 lbs if cattle are considered but Nelson et al. acknowledge that cattle are recycling P). Of the approximately 6,000,000 lbs of P, nearly 5,000,000 lbs of P were estimated to be from poultry litter application to pastures in the watershed.

The USDA SCS and FS (1992) estimated that poultry in the IRW generated twice as much manure as cattle in the IRW. They estimated poultry manure in the IRW contained 5 times as much P as cattle manure in the IRW.

3.4 Summary of Poultry Waste Generation in the IRW

Table 3.8 summarizes the poultry waste generation within the IRW by method and/or source. Poultry waste generated within the IRW ranges between 354,000 tons annually to more than 500,000 tons annually.

Table 3.8. Poultry Waste Generated in the Illinois River Watershed

Source	**IRW Poultry Waste (tons/yr)**
Dr. Fisher (Fisher, 2008)	354,000
Defendant supplied poultry and USDA waste coefficients (2001-2006)	421,000-482,000
USDA Census and USDA waste coefficients (2002)	414,000-528,000
Arkansas Soil and Water Conservation Commission Data, Dr. Fisher house data, USDA waste coefficients (2007)	477,000
USDA-SCS (1989)	403,000
Willett et al. (2006)	361,000

4. Poultry Waste Land Application

The common practice for poultry waste disposal is land application to pasture and cropped areas. A substantial amount of the defendants' poultry waste and P is land applied within the IRW annually. The poultry waste is applied during the rainy season from late winter through spring.

4.1 Poultry Waste Land Application Analysis

Fisher (2008) examined ODAFF records to document land application of the defendants' poultry waste within the IRW. Fisher's table summarizing this is shown in Table 4.1.

Table 4.1. Location of Waste Generation and Location of Waste Disposal by Defendant (from Fisher, 2008)						
Defendant	**Location of Waste Generation**	**Location of Waste Disposal**				
		Not Given (tons)	**Border ILLINOIS RIVER WATERSHED (tons)**	**Inside ILLINOIS RIVER WATERSHED (tons)**	**Outside ILLINOIS RIVER WATERSHED (tons)**	**Total (tons)**
Aviagen	Not Given	0	0	0	146	146
	Inside ILLINOIS RIVER WATERSHED	360	0	110	0	470
	Border ILLINOIS RIVER WATERSHED	0	0	0	0	0
	Outside ILLINOIS RIVER WATERSHED	0	0	0	2559	2559
Cal Maine Foods	Not Given	0	0	0	0	0
	Inside ILLINOIS RIVER WATERSHED	69	0	3327	792	4188
	Border ILLINOIS RIVER WATERSHED	0	0	0	0	0
	Outside ILLINOIS RIVER WATERSHED	0	0	0	0	0
Cargill	Not Given	583	0	1472	0	2055
	Inside ILLINOIS RIVER WATERSHED	0	0	3066	30	3096
	Border ILLINOIS RIVER WATERSHED	0	5777	0	714	6491
	Outside ILLINOIS RIVER WATERSHED	0	2784	0	616	3400
Cobb-Vantress (Tyson)	Not Given	7032	752	10792	43191	61768
	Inside ILLINOIS RIVER WATERSHED	364	478	31737	555	33134
	Border ILLINOIS RIVER WATERSHED	0	3740	1721	1627	7088
	Outside ILLINOIS RIVER WATERSHED	1862	3336	2740	62078	70016
Georges Inc	Not Given	415	0	0	0	415
	Inside ILLINOIS RIVER WATERSHED	0	0	3165	0	3165
	Border ILLINOIS RIVER WATERSHED	0	1096	45	108	1249
	Outside ILLINOIS RIVER WATERSHED	0		270	114	384
Peterson Farms	Not Given	2778	90	240	1056	4164
	Inside ILLINOIS RIVER WATERSHED	0	1281	2959	633	4873
	Border ILLINOIS RIVER WATERSHED	0	5110	0	1679	6789
	Outside ILLINOIS RIVER WATERSHED	301	1043	180	10277	11801
Simmons Foods	Not Given	945	405	4544	2988	8882
	Inside ILLINOIS RIVER WATERSHED	184	2733	16103	1512	20532
	Border ILLINOIS RIVER WATERSHED	219	4891	636	984	6730
	Outside ILLINOIS RIVER WATERSHED	579	748	3589	29444	34360
Tyson Foods	Not Given	717	232	2305	2570	5823
	Inside ILLINOIS RIVER WATERSHED	117	2404	23678	420	26619
	Border ILLINOIS RIVER WATERSHED	300	4486	0	2327	7113
	Outside ILLINOIS RIVER WATERSHED	66	1258	515	17920	19759
Willow Brook Foods	Not Given	0	24	345	0	369
	Inside ILLINOIS RIVER WATERSHED	0	648	0	1120	1768
	Border ILLINOIS RIVER WATERSHED	0	1194	997	2400	4591
	Outside ILLINOIS RIVER WATERSHED	0	0	0	0	0

In recent years some poultry waste has been transported out of the IRW, largely due to a program in which BMPs Inc. receives a $10 per ton subsidy for poultry waste removed from the watershed. BMPs Inc. documents (Herron, 2006) indicate there had been a market for approximately 50,000 tons of poultry waste annually with this level of subsidy. The BMPs Inc.

document further indicates "It is clear that once the subsidy program ends, most of the litter will have to be sold locally, without additional assistance."

Fisher (2008) documented movement of some poultry waste out of the IRW as shown in Table 4.2. As the BMPs Inc. documents indicate, the amount of poultry waste that will be transported without a subsidy is likely to be very limited.

Table 4.2.
Tons of Poultry Waste Hauled from the Illinois River Watershed to Locations Outside the Illinois River Watershed by BMPs, Inc. and Georges' (2003-2006) (from Fisher, 2008)

Year	2003	2004	2005	2006	**TOTAL**
BMPs, Inc. Tons	0.00	905.88	14,783.57	59,736.56	**75,426.01**
Georges' Tons	8,877.60	11,406.30	19,651.13	9,282.45	**49,217.48**
TOTAL Tons	**8,877.60**	**12,312.18**	**34,434.7**	**69,019.01**	***124,643.50***
% of Poultry Waste Produced that was Hauled	**2.51%**	**3.48%**	**9.73%**	**19.50%**	***8.80%***

4.2 Proximity of Poultry Waste Land Application - Arkansas Soil and Water Conservation Commission

The Arkansas Soil and Water Conservation Commission data show the following amounts of poultry waste land applied within the Illinois River Watershed (Table 4.3). The poultry waste estimates and land application estimates use equations that greatly under predict waste generated per bird as it would be removed from poultry houses and land applied. The equations used by the Arkansas Soil and Water Conservation Commission to compute poultry waste calculate the amount of waste excreted on a dry weight basis (amount of waste excreted with all water removed and without inclusion of bedding materials). Most of the waste generated is shown as being transferred and thus the location of land application is not provided by the Arkansas Soil and Water Conservation Commission.

Table 4.3. Arkansas Soil and Water Conservation Commission Estimate of Poultry Waste Land Applied in the Illinois River Watershed. Multiply Values by 1.75 (See Section 3.3) to Obtain Actual Waste Mass Land Applied.

	Waste Land Applied in IRW (tons)			
County	2004	2005	2006	2007
Benton	11,440	7,925	5,935.75	36,180
Washington	24,457	19,269	20,009	30,010

4.3 Proximity of Poultry Waste Land Application – ODAFF Record Analysis
Dr. Fisher (Fisher, 2008), under the direction of Dr. Engel, examined ODAFF (Oklahoma Department of Agriculture, Food and Forestry) records of poultry waste land application. For the State of Oklahoma, these data indicated that 30% of poultry waste was land applied within the square mile in which it was generated (data resolution was to the nearest section or square mile). Sixty percent of poultry waste was land applied within 2 miles of where it was generated and 80% of poultry waste was land applied within 5 miles of where it was generated.

Analysis of ODAFF records for the IRW indicates a similar pattern with poultry waste applied even closer to where it was generated. ODAFF records specific to the IRW indicate 30% of poultry waste is land applied within the square mile in which it was generated, 67.5% was land applied within 2 miles, and 80% was land applied within 3.6 miles. The overwhelming majority of poultry waste generated within the IRW is land applied near where it is generated.

Dr. Fisher's analysis (Fisher, 2008) of nutrient management plans for poultry producers within Arkansas indicate a similar pattern of land application of poultry waste.

4.4 Poultry Waste Land Application Literature
The BMPs Inc. (2007) final report to the EPA indicated that poultry waste within the IRW has been land applied in large quantities leading to potential to impact water quality. The BMPs Inc. proposal for transport of a small portion of the poultry waste out of the IRW was built on this premise.

Sharpley et al. (2007) indicate "in many areas, manure is rarely transported more than 10 miles from where it is produced. As a result manure is often applied to soils that already have sufficient nutrients to support crop growth."

The USDA SCS and FS (1992) indicated that a significant part of the water quality problems in the IRW are a result of the *large volume of poultry waste generated and disposed of in the basin*. Rausser and Dicks (2008) assumed *all* poultry waste produced in the IRW was land applied within the IRW.

Nelson found nearly 6,000,000 lbs of P annually were applied to the Arkansas portion of the Illinois River Watershed (7,000,000 lbs if cattle are considered but Nelson et al. acknowledge that cattle are recycling P). Of this total, nearly 5,000,000 lbs of P applied in the Arkansas' portion of the watershed were from poultry litter application to pastures.

Vieux and Moreda (2003) noted that the P generated by the poultry industry in the IRW is equivalent to a human population of 8 million people. They further indicated that poultry manure is stored and then applied to pastureland in the watershed.

Storm et al. (1996) found that a maximum poultry waste transport distance of 8000m (approximately 5 miles) from poultry houses in the IRW provided the best observed fit between estimated STP and observed STP.

Storm et al. (2006) applied all poultry waste within 5 km (approximately 3 miles) of poultry houses when modeling the IRW. This was based on their experiences and analysis of poultry waste transportation distance in the Eucha Spavinaw Watershed.

Other reports and literature in Section 2 "Review of Illinois River Watershed Studies - P Contribution" also indicate that poultry waste generated within the IRW is land applied within the IRW. Literature reviewed in Appendix A also indicates poultry waste is land applied near where it is generated.

4.5 Timing of Poultry Waste Application in the IRW

Dr. Fisher (Fisher, 2008) analyzed the timing of land application of poultry waste in the Oklahoma portion of the IRW using ODAFF records. Analysis of these data indicates the late winter and early spring are the primary period of poultry waste land application within the IRW. Based on disposal records from 1999 through 2004, approximately 63.4% of the poultry waste land disposed within the Illinois River Watershed is disposed during February through June as shown in Figure 4.1. This period of land application coincides with the period of greatest rainfall within the IRW, thereby increasing runoff of poultry waste to IRW waters.

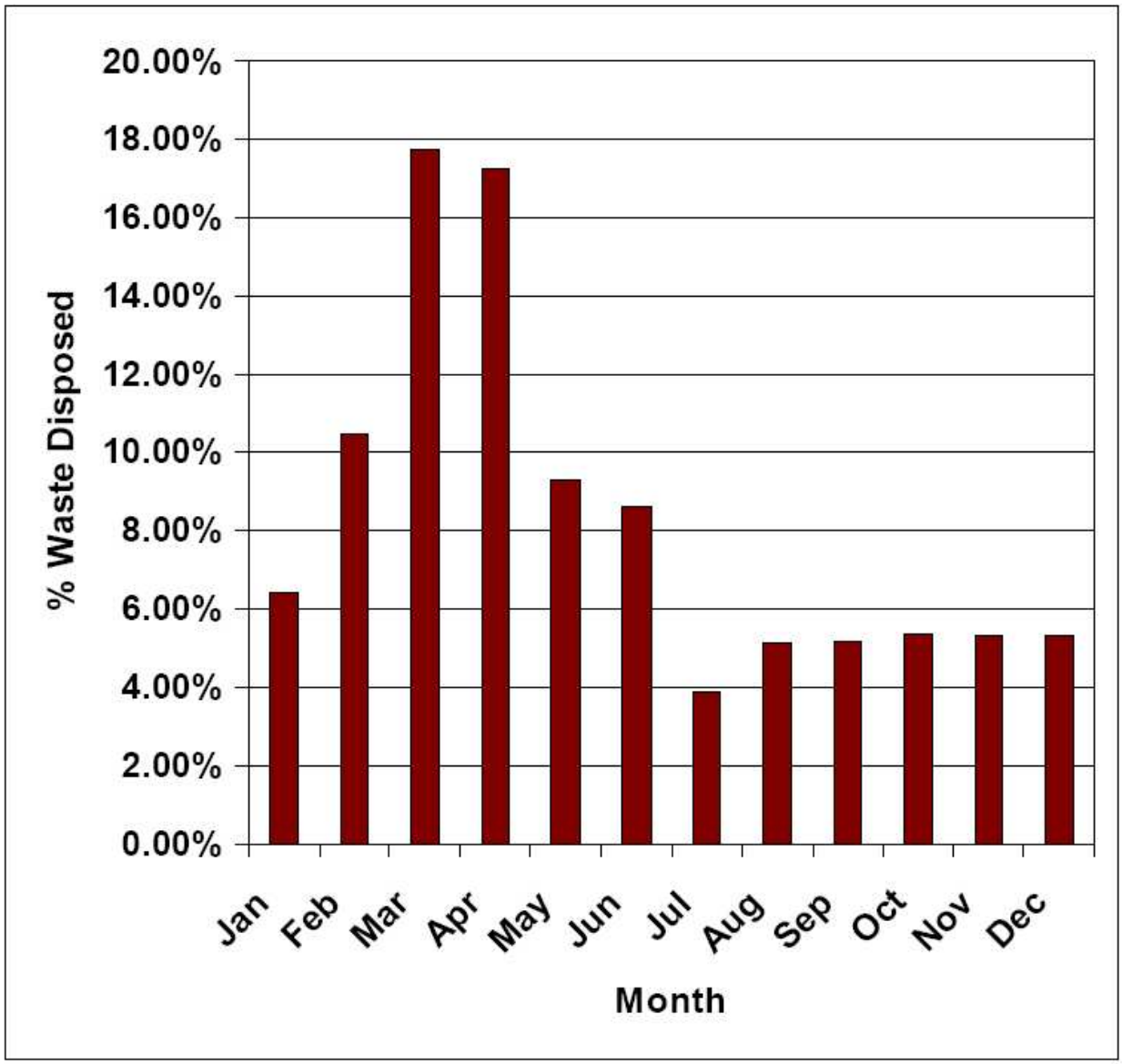


Figure 4.1. Timing of poultry waste disposal within the Oklahoma portion of the IRW determined from records maintained by ODAFF (1999-2004 data) (From Fisher, 2008).

5. Observed P Loads in the Illinois River Watershed

The P loads to Lake Tenkiller averaged approximately 505,000 lbs annually between 1997 and 2006. This represents a significant P load to the lake and is much greater per unit area than for other watersheds in the region.

The observed P loads to Lake Tenkiller indicate a substantial P load relative to other watersheds in the region (Tortorelli and Pickup, 2006 and Pickup et al., 2003). Table 5.1 provides USGS calculated P loads at the Tahlequah and Baron Fork USGS gauging stations (Tortorelli and Pickup, 2006 and Pickup et al., 2003). The P loads vary greatly from year to year due to weather variability that impacts P losses to streams and rivers and impacts water flows that carry P into Lake Tenkiller.

Table 5.1. USGS Computed Annual P Loads (Tortorelli and Pickup, 2006 and Pickup et al., 2003)

	Total Annual P (lb/yr)	
Years	**Tahlequah**	**Baron Fork**
97-99	307,000	32,800
98-00	511,000	124,000
99-01	621,000	135,000
00-02	559,000	154,000
01-03	331,000	59,000
02-04	355,000	120,000

USGS and OWRB samples analyzed for total P content were used along with USGS flow data to compute observed P loads at the Tahlequah, Baron Fork near Eldon, and Caney Creek gauging stations between 1997 and 2006. The LOADEST (load estimator) software (Runkel et al., 2004) was used along with these data in calculating P loads. Tortorelli and Pickup (2006) and Pickup et al. (2003) used this approach in computing P loads for the IRW. The approach used by Tortorelli and Pickup (2006) and Pickup et al. (2003) was used in calculating P loads. The R^2 for LOADEST calculated P and observed P is shown in Table 5.2. The fit between calculated P and observed P is a very good fit. LOADEST can be used to calculate P loads within the IRW.

Table 5.2. R^2 for LOADEST Calculated P and Observed P

	R^2		
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**
1998	0.95	0.89	0.87
1999	0.95	0.96	0.87
2000	0.96	0.94	0.95
2001	0.94	0.93	0.97
2002	0.92	0.93	0.98
2003	0.90	0.92	0.98
2004	0.94	0.97	0.98
2005	0.95	0.98	0.99
2006	0.95	0.98	0.99

The IRW P loads calculated with LOADEST are shown in Table 5.3 and show substantial variation annually due to differences in rainfall and flow into Tenkiller.

Table 5.3. Observed P Loads Based on USGS and OWRB P Data and USGS Flow Data

	Total P (lb/yr)			
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**	**Total**
1997	211,467	25,500	4,140	241,107
1998	422,906	39,887	9,024	471,817
1999	392,336	49,755	8,349	450,440
2000	771,454	298,307	55,787	1,125,548
2001	456,947	98,931	36,616	592,494
2002	301,474	52,666	16,574	370,714
2003	94,684	10,107	3,485	108,276
2004	631,798	459,054	57,086	1,147,938
2005	258,021	68,639	14,004	340,664
2006	128,415	58,300	10,574	197,289

Walker (1987) indicated that for the IRW, phosphorus concentration cannot be considered independent of flow, and thus averaging the concentrations independent of flow would yield invalid results. Thus, the use of the approach in LOADEST was necessary to account for the relationships between flow and P concentrations within the IRW.

For the period 1997 to 2006, the P loads to Lake Tenkiller range from slightly more than 197,000 lbs in 2006 to more than 1,147,000 lbs in 2004 as shown in Table 5.3. The average annual P loads to Lake Tenkiller were approximately 505,000 lbs between 1997 and 2006. Vieux and Moreda (2003) indicated that variability from year to year is expected in water quality constituents such as P if surface runoff is a dominant transport mechanism. They analyzed data

for the IRW and found that surface runoff was the dominant transport mechanism for P in this watershed. Data summarizing the variability in flows within the IRW rivers are provided in Figure 5.1 and Table 5.4. Rainfall variability is summarized in Table 5.5.

The water flows to Lake Tenkiller for the period of 1997 to 2006 are much smaller than flows that have been experienced to Lake Tenkiller in the past (Table 5.4). If the IRW had experienced flows that were similar to historical flows (1950-2007) during 1997 to 2006, the observed P loads for 1997 to 2006 would have been significantly higher.

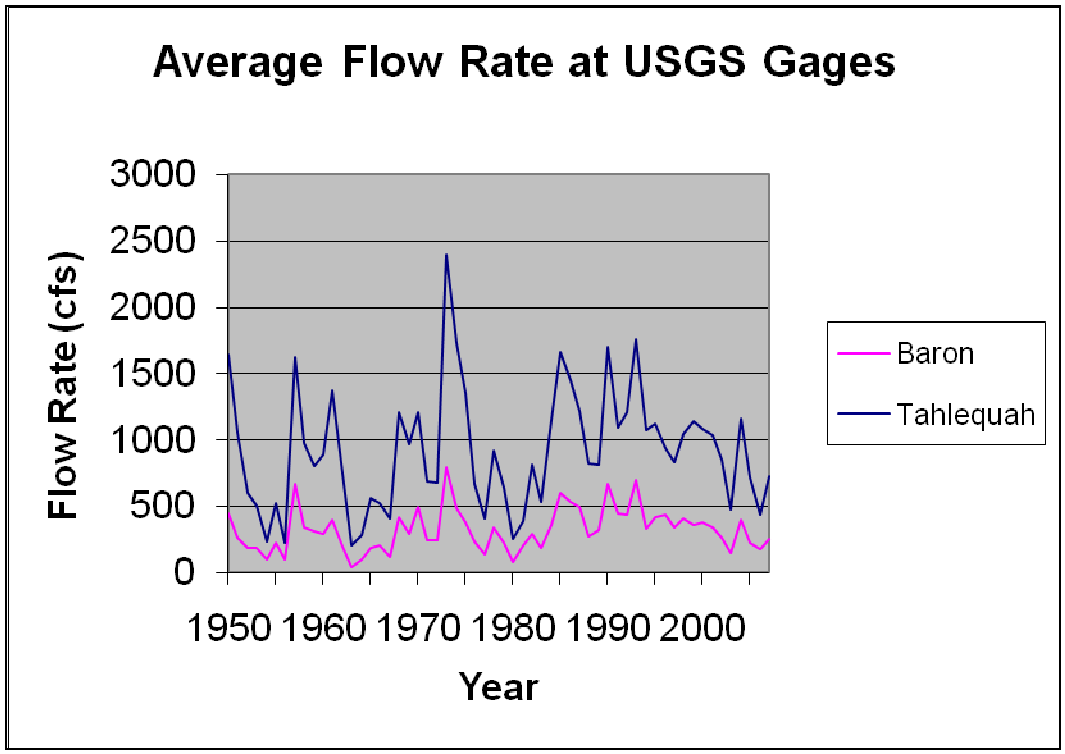


Figure 5.1. Annual Observed Daily Average Flow Rate at USGS Gauges at Tahlequah and Baron Fork near Eldon

Table 5.4. Summary of Annual Flow Data at USGS Gauges Tahlequah and Baron Fork near Eldon for 1950-2007 and 1997-2006

		1997-2006	**1950-2007**
Baron Fork	**Q ave (cfs)**	304	323
Tahlequah		878	922
Baron Fork	**Range (cfs)**	144-409	41-795
Tahlequah		439-1159	205-2393
Baron Fork	**St Dev**	95	163
Tahlequah		265	457

Table 5.5. Annual Rainfall Summary Statistics for Rain Gauge COOPID 35354 in the IRW

	Average Annual Rainfall (in)	**St. Dev**	**Range (in)**
1950-2006	50.15	10.24	27.51-81.14
1997-2006	51.34	7.20	36.44-59.65

6. Point Sources of P in the Illinois River Watershed

A portion of the P in the IRW rivers and streams and reaching Lake Tenkiller is from Waste Water Treatment Plant (WWTP) discharges. Waste Water Treatment Plants within the IRW discharge P into the streams and rivers of the IRW that eventually reaches Lake Tenkiller. ***P discharges from IRW WWTP have changed over time. WWTP P discharges into IRW streams and rivers peaked at slightly more than 204,000 lbs annually in the late 1990s and early 2000s. Beginning in 2003, WWTP P discharges decreased to a little more than 90,000 lbs annually in the IRW due to changes in WWTP technology. The defendants' processing facilities discharge a significant amount of P to WWTPs and thus contribute to point P sources within the IRW.***

WWTP contributions of P to the Illinois River for three time periods are shown in Table 6.1. Changes in WWTP technology significantly reduced P contributions beginning in 2003 (from more than 204,000 lbs annually to a little more than 90,000 lbs annually). Recent P discharges from WWTPs were computed from recent WWTP discharge data (1999-2007 Permit Compliance System (PCS) data) from the Oklahoma Department of Environmental Quality and the Arkansas Department of Environmental Quality. WWTP discharges prior to 2003 were obtained from Gade (1998), representing P discharges for the 1990s through 2002. Nelson reported similar WWTP discharges of P for the Arkansas portion of the Illinois River for the late 1990s through 2006. Nelson observed a significant reduction in WWTP P discharges beginning in 2003. Discharges from Arkansas WWTPs represent the majority of WWTP P discharges into the IRW streams and rivers.

Table 6.1. WWTP Total P Discharge to Streams and Rivers within the IRW

	Mid 70s	**Early 90s**	**2003-present**
WWTP	**P Load (lb/yr)**	**P Load (lb/yr)**	**P Load (lb/yr)**
Springdale	70,841	95,128	25,112
Siloam Springs	23,014	22,046	29,638
Fayetteville - Noland	0	9,921	5,147
Rogers	41,515	47,619	16,206
Lincoln	1,767	2,646	2,336
Prairie Grove	2,409	2,646	3,285
Tahlequah	19,235	10,362	2,738
Stillwell	15,675		2,519
Westville	2,502	6,393	840
Gentry	1,767	3,748	2,336
Watts		1,102	0
Midwestern nursery		1,323	0
Cherokee Nation Stillwell Cannery		1,168	0
Total	**178,724**	**204,101**	**90,155**

The WWTP P discharges from the late 1970s and early 80s were obtained from the Roberts/Schnorick and Associates report of 1984 and two EPA Environmental Lab (1977)

reports as shown in Table 6.2. The Roberts/Schnorick report provides WWTP discharges for 1979-1984 and the EPA values are mid 1970s values. The Roberts/Schnorick P discharge values are reported as lbs/day of phosphorus. Comparing Roberts/Schnorick P discharges for the same WWTPs with the EPA values and values reported for later in the 1980s, the Roberts/Schnorick P discharges are not phosphorus but are phosphate (P_2O_5). The discharges converted to P are shown in the far right column in Table 6.2.

Table 6.2. WWTP P Discharges into IRW Streams and Rivers for Late 1970s and Early 1980s

	Annual P Discharge (lbs/yr)		
WWTP	**Roberts/Schnorick (1984) as P_2O_5**	**Environmental Lab Las Vegas (1977)**	**Roberts/Schnorick as P**
Springdale	161,002		70,841
Siloam Springs	52,305		23,014
Fayetteville - Noland	0		0
Rogers	94,353		41,515
Lincoln	4,015	1,312	1,767
Prairie Grove	5,475		2,409
Tahlequah	46,173	19,235	20,316
Stillwell	0	15,675	0
Westville	0	2,502	0
Gentry	4,015		1,767

The Roberts/Schnorick report indicates there were three permitted point source discharges in the upper Illinois River system in addition to the WWTPs they considered. These were the Centerton Hatchery, the Swepco Flint Creek Power Plant and Gates Rubber. No P discharges from these sources were reported (permits did not include P discharge) or considered in the Roberts/Schnorick Illinois River assessment report.

The historical WWTP P discharges into streams and rivers of the IRW are shown in Table 6.3. These were needed for modeling P Loads (Section 10). The late 1970s/early 1980s WWTP P discharges shown in Table 6.2 were used to compute a waste discharge per person and the resulting value was used to compute WWTP P discharges for 1950, 1960 and 1970. WWTP P discharges from Table 6.1 were used for 1980 to present.

Table 6.3. Estimated WWTP P Discharges Historically into Streams and Rivers of the IRW

Year	**IRW population**	**Estimated P (kg/yr)**	**Estimated P (lb/yr)**	**Observed P (lb/yr)**
1950	83,874	46,701	102,958	
1960	91,552	50,977	112,383	
1970	125,496	69,877	154,050	
1980	165,695			178,724
1990	192,439			204,101
2000	280,383			90,155

A substantial amount of the P discharged from the Springdale WWTP is from industrial sources. Table 6.4 shows industrial P flows to the Springdale WWTP. The defendants discharge more than 88% of the industrial P to the Springdale WWTP (more than 257,000 lbs annually). Historically (before 2003), the Springdale WWTP P discharges were 44% of IRW WWTP P discharges and currently (since 2003) represent about 28% of IRW WWTP P discharges.

Table 6.4. P Discharges to Springdale WWTP from Industrial Sources

Facility Name	Dates	P (lb/d)
Allen Canning Co	10/87-12/90	11.8
Allen Canning Co	12/94-11/01	80.8
Blaylock Company	12/94-11/02	2.8
Cargill, Inc.	**12/94-11/03**	**118.8**
Cintas Corporation	12/94-11/03	7.6
D. B. Foods, Inc	12/94-11/01	17.4
Danaher Tool Group	10/91-9/07	29.7
Danaher Tool Group	10/87-9/91	6.7
George's Debone	**2/97-11/01**	**30.5**
George's Further Processing	**12/02-11/03**	**52.0**
George's, Inc.	**12/94-11/03**	**115.5**
J. B. Hunt Transport, Inc	12/94-11/03	0.9
J. B. Hunt Transport, Inc	12/94-11/03	0.4
Monark Egg	10/87-9/90	12.2
Midcentral Egg	10/90-9/91	6.4
Pappas Foods, L.L.C.	12/00-11/01	4.1
Sonstegard Foods Inc. of Arkansas	12/02-11/03	0.0
Superior Linen Service	7/98-11/03	3.1
Triple T Foods, Inc.	12/94-11/03	3.9
Tyson Foods, Inc. - Berry St.	**12/94-11/03**	**244.0**
Tyson Foods, Inc. - Hog Trailer Wash	**8/95-11/03**	**14.5**
Tyson Foods, Inc. - Randall Rd.	**12/94-11/03**	**123.8**
Tyson Research & Technology	**10/95-11/03**	**6.1**
Total		893.0

The defendants make a substantial contribution to point source P discharges from the Springdale WWTP. The daily P contribution to the Springdale WWTP from people is approximately 138 lbs/day (2000 census population of Springdale is 45,798 people * 1.1 lb P/person per year / 365 days/yr). The defendants discharge 705 lbs P per day to the Springdale WWTP representing 79% of P inflow to the Springdale WWTP. Based on these inflows to the Springdale WWTP, the defendants' P discharge from the Springdale WWTP represents 35% of total WWTP P discharges into IRW rivers and Lake Tenkiller historically (44% of WWTP P from Springdale * 79% of P to Springdale from defendants = 35%) (before 2003) and currently (since 2003)

represents more than 22% of total WWTP P discharges to IRW rivers and Lake Tenkiller (28 % * 79% = 22%). The defendants' portion of P discharges through the Springdale WWTP represents a substantial amount of WWTP P discharges into IRW rivers and Lake Tenkiller.

WWTP water discharges to the IRW streams and rivers since 2003 are shown in Table 6.5 as reported in the PCS data.

Table 6.5. WWTP Water Discharges Since 2003

WWTP	**Flow (mgd)**
Springdale	12.4
Siloam Springs	2.68
Fayetteville - Noland	5.18
Rogers	5.71
Lincoln	0.44
Prairie Grove	0.32
Tahlequah	2.65
Stillwell	0.81
Westville	0.14
Gentry	0.44

7. Phosphorus Mass Balance

The movement of phosphorus into and out of an area (e.g., a mass balance analysis) provides insight into the primary sources of P within an area such as a watershed. ***A P mass balance for the Illinois River Watershed indicates poultry production is a substantial contributor to P within the Illinois River Watershed. Poultry production within the Illinois River Watershed is currently responsible for more than 76% of P movement into the watershed.***

7.1 P Mass Balance Analysis for the IRW

Under my direction, M. Smith performed of an analysis that examined the flow of P into and out of the IRW system (e.g., a mass balance) (see Appendix B for full analysis). The findings include:

1. Poultry production is currently responsible for more than 76% of the net annual phosphorus additions to the IRW.
2. Historical data indicates poultry production has been the major contributor of phosphorus to the watershed since 1964. Prior to 1964, dairy cattle were responsible for the majority of the phosphorus contribution.
3. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production.
4. Other contributing sources of phosphorus (net additions) include commercial fertilizers (7.5%), dairy cattle (5.2%), humans (3.2%), swine (2.9%), industrial sources – mostly poultry processing facilities (2.7%) and beef cattle (1.7%). The remaining sources of phosphorus evaluated in this study, which include urban runoff, golf courses, wholesale nurseries, and recreational users, are negligible (< 1%).
5. Of the three phosphorus exports from the watershed (harvested crops, harvested deer, and water leaving Lake Tenkiller through the spillway) outflow of phosphorus through the spillway at the south end of Lake Tenkiller was the largest. According to current estimates, the flow of water through the spillway removes just under 1.25% of the total annual phosphorus additions to the watershed. The remaining two phosphorus exports combined remove just over 0.25% of current annual phosphorus additions to the watershed, totaling a 1.5% removal of current phosphorus additions.

Figure 7.1 shows the current additions of P to the IRW by source. As noted above, poultry is responsible for the overwhelming majority (76%) of P additions to the IRW.

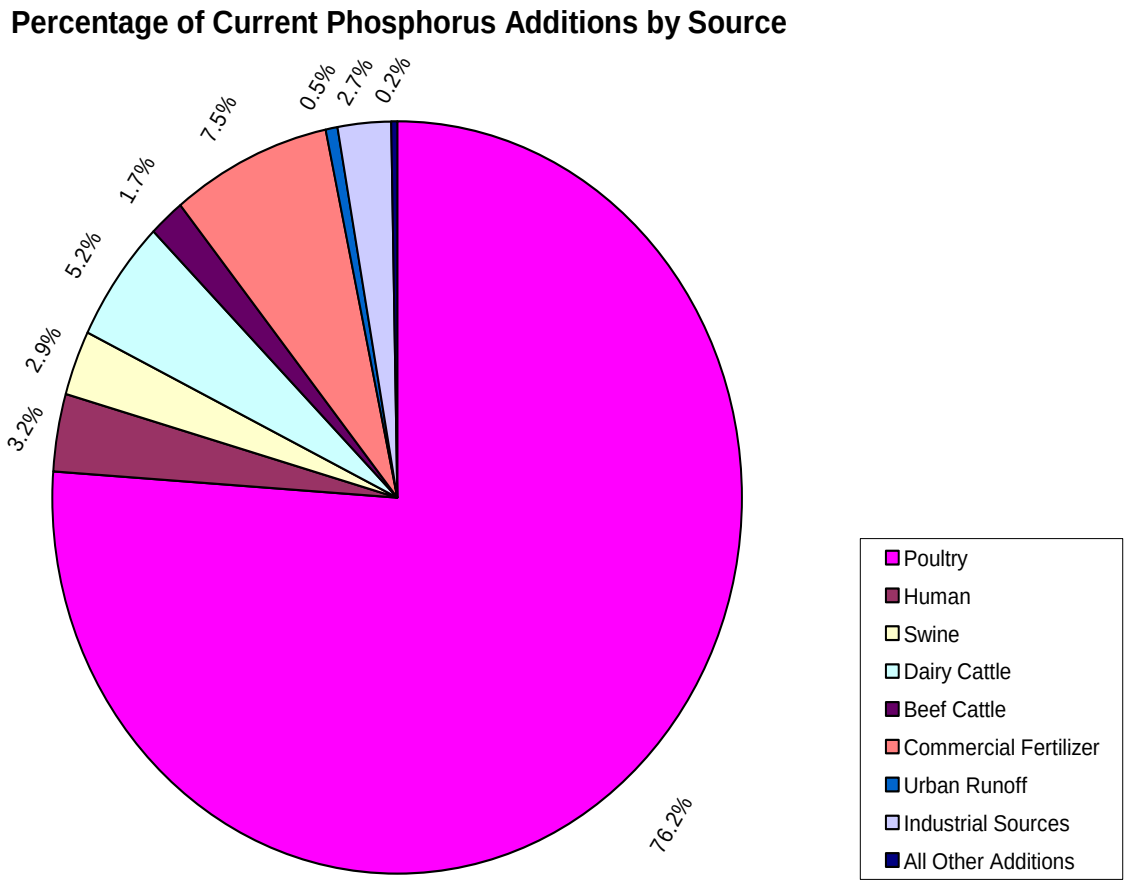


Figure 7.1. Phosphorus Additions to the IRW as a Percentage by Source

7.2 P Mass Balance Literature

The scientific literature describes similar approaches as that used by the mass balance analysis set forth in Appendix B. In addition, some of these studies include portions of the IRW and reached similar conclusions as those highlighted above and in Appendix B.

Slaton et al. (2004) indicate that a fundamental component of nutrient management strategies is to determine the balance between nutrient inputs and outputs to identify areas where soil nutrient inputs are greater than removals. Slaton et al. (2004) termed such areas as "critical areas" and indicated that nationally many such areas have been identified and these areas coincide with concentrated animal production. They identified critical nutrient areas within Arkansas by dividing Arkansas into 9 geographic regions and computing a nutrient mass balance for each region. Nutrient removal by crops and nutrient inputs from livestock production were computed based on Agricultural Statistics Service data. Livestock nutrient inputs to soils were computed based on livestock numbers and nutrient content of livestock waste by species. Nutrients contained in beef cattle manure were ignored by Slaton et al. (2004) as they indicate "a large proportion of these nutrients are obtained from forage and deposited directly (i.e., recycled) to pastures during grazing rather than collected in lagoons or stockpiled from confined animal production facilities." Nutrient inputs from inorganic fertilizers were computed based on Arkansas fertilizer sales data.

Slaton et al. (2004) found that the district with the greatest excess N and P was northwest Arkansas which includes Benton and Washington counties. This region was estimated to have an accumulated P in soils for a 5 year period of 32 kg/ha. Kellogg et al. (2000) and Kellogg (2001) conducted a national nutrient balance assessment and identified the Illinois River Watershed and the northwest Arkansas and northeast Oklahoma area as being vulnerable to P loss in runoff due to excess manure based P being land applied. Sharpley et al. (2007) indicate that the spatial separation of crop and poultry production systems results in a large-scale one-way transfer of nutrients from grain to poultry producing areas. This is certainly the case for the IRW.

A similar mass balance approach was used by Mallin and Cahoon (2003) to estimate nutrients in livestock waste within North Carolina. Stow et al. (2001) also used a similar approach in computing nutrient inputs into the Neuse River Watershed in North Carolina. Cassell et al. (2002) used a mass balance and modeling approach in exploring P losses from watersheds. Sharpley et al. (2007) computed P surpluses for farms and found that poultry farms had the greatest P surpluses. Tarkalson and Mikkelsen (2003) examined P surpluses on a typical poultry farm and found that an annual surplus of 65 kg P per ha was available for broiler farms and indicated this presents a potential hazard to surface water quality.

The accumulation of excess P in soils is problematic, since soil P levels are correlated to the amount of P in runoff (Slaton et al., 2004). One of the solutions to this problem is the transportation of manure outside the critical watersheds with substantial animal production to row-crop production areas (Slaton et al., 2004). However, they indicate that "the low economic value of poultry litter, which represents the majority of organic nutrient sources produced in Arkansas, as a fertilizer nutrient source is believed to prohibit its transport to the primary row-crop production area." Slaton et al. (2004) conclude that their assessment may help reinforce the

thought that current nutrient application strategies in western Arkansas are not sustainable without the danger of creating and/or exacerbating water quality issues from excessive nutrients.

Nelson et al. (2002) performed a phosphorus mass balance for the Arkansas portion of the Illinois River Watershed. Sources of P identified in the mass balance were livestock manure, inorganic fertilizers, sludge applications and point source inputs from wastewater treatment plants. Livestock production was estimated based on agricultural statistics by county and the portion of these livestock within the watershed was allocated based on land use (pasture). A reference value of P excreted by livestock was used with the livestock production numbers to estimate total P by livestock species. Nelson et al. (2002) included dairy and beef cattle in the mass balance calculations but indicated that "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 (i.e., no net change in phosphorus in IRDA (Illinois River Drainage Area))." A presentation to Cargill producers also acknowledges this. The annual accumulation of P in pasture soils was estimated at 8 to 9 kg P/pasture acre per year. This was largely due to the application of excess poultry litter to pastures (CARTP016287-CARTP016290).

Nelson found nearly 6,000,000 lbs of P annually were applied to the landscape in the Arkansas portion of the Illinois River Watershed (7,000,000 lbs if cattle are considered but Nelson et al. acknowledge that cattle are recycling P). Nearly 5,000,000 lbs of P were estimated to be from poultry litter application to pastures in the watershed. This represents approximately 83% of P inputs to the watershed annually.

Sharpley et al. (2007) conclude that "the capacity of watersheds to assimilate nutrients, assuming some transport of manure from P-rich to P-deficient areas, should be determined and used in strategic planning of future development, expansion, or realignment of poultry operations."

7.3 Soil Test P Data for Illinois River Watershed

The soil test phosphorus data for the Illinois River Watershed area indicate soil P levels have been built to excessive levels well beyond agronomic requirements as a result of poultry litter application to pastures in most areas (Johnson, 2008). The soil test phosphorus levels within the IRW (Table 7.1) support the P accumulation described in the IRW mass balance. These high STP levels in the IRW contribute to P loads in IRW streams and rivers and to Lake Tenkiller.

Table 7.1. Soil Test Phosphorus Levels in the IRW Indicate Elevated P Levels Due to Poultry Waste Application

County	Soil Test P	Years
Benton	504	2000-2007
Washington	446	2000-2007
Adair	182	1995-2006
Cherokee	75	1995-2006
Delaware	160	1995-2006
Sequoyah	50	1995-2006

Background STP levels in the IRW can be estimated from samples obtained at the Nickel Reserve within the IRW. STP values for forested areas at the Nickel Reserve were 17.4 to 20.6 lb/acre for the top 6 inches of soil. These values would represent a background STP value within the IRW as no P has been applied to these areas in the form of fertilizer or livestock waste. STP values for pastured areas at the Nickel Reserve were 28 to 37.4 lbs/acre for the top 6 inches of soil. Livestock waste and fertilizer have not been applied to these areas for many years, so these STP values would represent likely background levels for pastures that are occasionally grazed by livestock. STP values within the IRW soils as depicted in Table 7.1 indicate elevated STP values relative to background STP values.

8. P Loads in the IRW Based on Continued Poultry Waste Land Application

Researchers have observed that annual P loads to streams and rivers are approximately 5% of the annual application of poultry litter or annual poultry litter combined with other P applied to the landscape in circumstances where there has been a buildup in STP. Based on the annual application of poultry waste to pastures within the Illinois River Watershed and literature values of P loads to water, application of poultry waste to pastures in the Illinois River Watershed is a substantial contributor to P in the streams and rivers of the watershed and to Lake Tenkiller. ***Average annual P loads to water in the Illinois River Watershed attributable to poultry waste application to pastures is calculated at between 432,000 lb to nearly 500,000 lb annually based on poultry waste P application to the landscape and literature P loss coefficients.***

8.1 P Loads Based on P Application to Landscapes and P Loss Coefficients

P loads to runoff can be computed based on the P applied to landscapes and relationships between P in livestock waste that is spread on the land and P that is accumulated in the soil. Sharpley et al. (2007) indicates 5% of poultry waste applied to land is lost in surface runoff (see Figure 8.1). They indicate such losses are agronomically small (generally less than 2 kg P per ha). However, such losses can have significant environmental impact. With continued P application in excess of agronomic needs, the portion of P lost with runoff could be greater than 5% (see Section 10 of this report) (Stow et al., 2001).

Willett et al. (2006) modeled phosphorus loads from poultry waste application to agricultural areas in the Illinois River Watershed within Arkansas and Oklahoma. In their modeling, 33% of P was available to the crop and 67% went to building P in the soil. Of the P going to the soil, 8% was modeled as lost in runoff. Thus, 5.36% (67% of P to soil * 8% of this lost in runoff) of P applied through poultry litter applications in the watershed was lost in runoff each year (Willet et al., 2006).

Nelson et al. (2002) performed a P mass balance for the Arkansas portion of the Illinois River Watershed. They used observed P data in the Illinois River to compute the amount of annual P applied to the landscape that is exported from Arkansas in the Illinois River. Point sources of P were removed from the observed P in the Illinois River before computing the percentage of P that was applied to the landscape that reached the Illinois River and was exported. Nelson et al. (2002) found that 4% of P applied to the landscape in poultry litter, cattle manure, sludge and inorganic fertilizer was lost annually to the Illinois River. If cattle manure is removed from this, as the P contained in cattle manure is recycled P from other sources (poultry), this percentage is slightly over 5% which is comparable to the value reported by Sharpley et al. (2007) and by Willett et al. (2006).

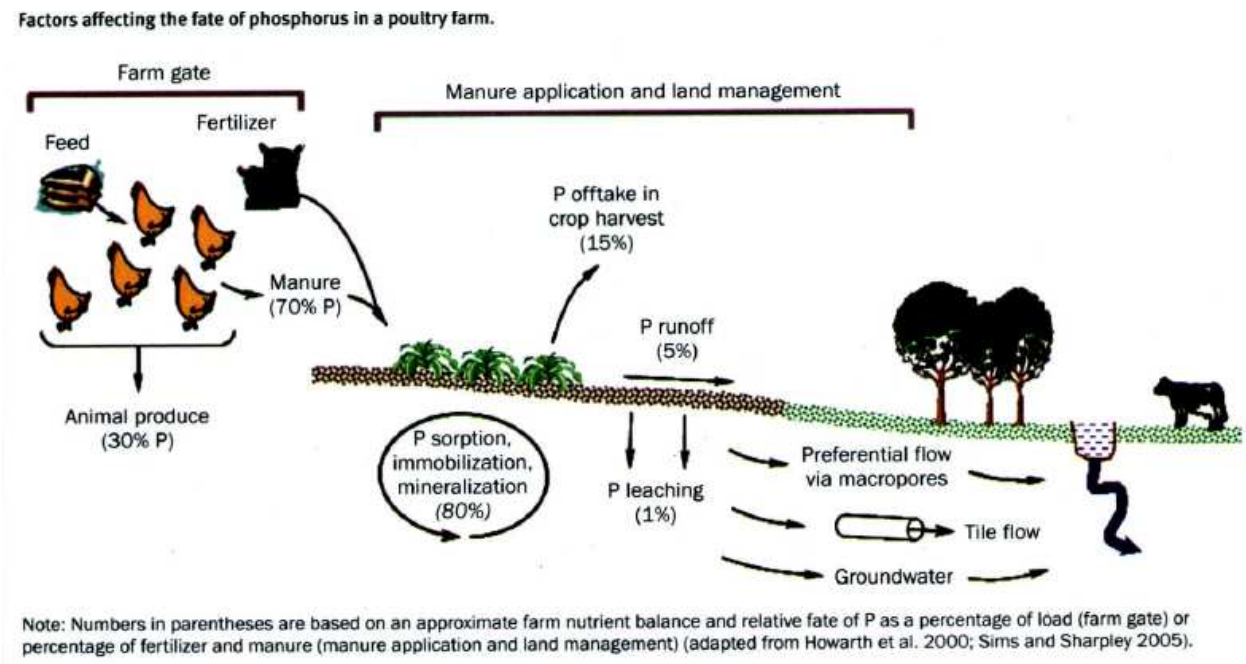


Figure 8.1. Factors affecting P loss on poultry farms (From Sharpley et al. (2007))

Elevated soil P from poultry waste application to pasture can also contribute substantially to P losses in runoff. Figures 8.2 and 8.3 show the results of a study in which poultry litter was applied to Bermuda grass plots (Sharpley et al., 2007). The soil P levels increased, resulting in greatly increased surface runoff of P, even 6 years after litter application was stopped. For high levels of STP, P loss with runoff may occur for decades and beyond as highlighted in Section 10 of this report.

Daniels et al. (1999) indicate that areas with high soil test phosphorus levels can have appreciable amounts of soluble phosphorus in runoff water and significantly impact water quality in receiving streams and lakes.

A powerpoint presentation for Cargill producers indicates that the long term effects of poultry waste land application should not be overlooked (CARTP016287-CARTP016290).

Surface soil (0 to 5 cm) Mehlich-3 P and mean annual dissolved P concentration of surface runoff and subsurface flow (70 cm depth) from bermudagrass before, during, and after poultry litter application (11 Mg ha^{-1} yr^{-1}; 140 kg P ha^{-1} yr^{-1}).

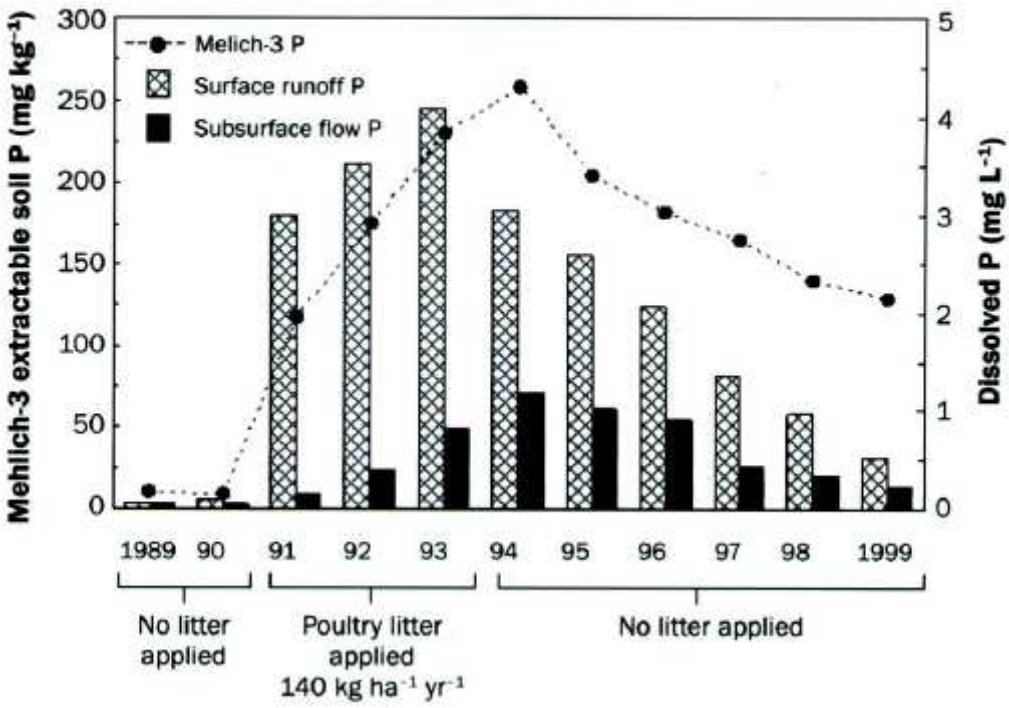


Figure 8.2. P Loads in Runoff Due to Elevated Soil P Levels (From Sharpley et al. (2007))

Phosphorus budget of poultry litter application, phosphorus uptake by bermudagrass, and total phosphorus loss in surface and subsurface flow from a Ruston fine sandy loam in Oklahoma.

		Bermudagrass		Total P loss in flow		
Year	Litter P added (kg ha^{-1} yr^{-1})	Yield (kg ha^{-1} yr^{-1})	P uptake (kg ha^{-1} yr^{-1})	Surface (kg ha^{-1} yr^{-1})	Subsurface (kg ha^{-1} yr^{-1})	P balance
Before application						
1989	0	3,500	5.9	0.2	0.1	-6.2
1990	0	4,010	6.4	0.2	0.1	-6.7
During application						
1991	140	8,110	16.9	3.8	0.1	+119.2
1992	140	8,210	18.6	5.1	0.4	+115.9
1993	140	8,510	20.0	7.8	0.5	+111.7
After application						
1994	0	8,040	22.5	5.6	0.7	-28.8
1995	0	7,120	18.2	4.2	0.6	-23.0
1994	0	6,920	15.2	2.2	0.5	-15.9
1997	0	7,510	19.2	1.6	0.4	-21.2
1998	0	7,230	18.7	1.3	0.2	-20.2
1999	0	6,900	17.4	0.9	0.2	-18.5
Total	420	76,060	179.0	32.9	3.8	+206.0

Notes: Balance of P was determined as litter P added – P uptake by grass +P loss in surface runoff + P loss in subsurface flow. Negative values indicate a net loss of P from the plots and positive values a net gain of P.

Figure 8.3. P Loads in Runoff Due to Elevated Soil P Levels (From Sharpley et al. (2007))

Sharpley et al. (2007) indicate as soil test P increases, so does P in runoff (Figure 8.4).

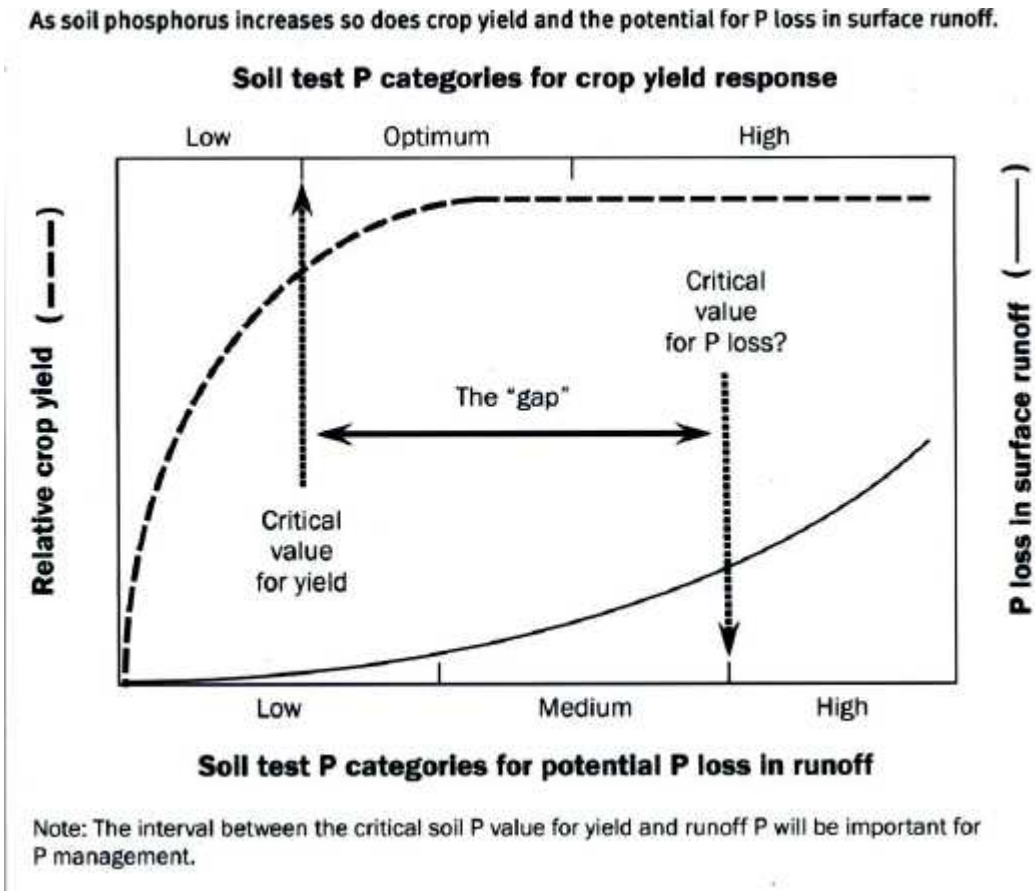


Figure 8.4. Relationship Between Soil Test P and P Loss in Surface Runoff (From Sharpley et al. (2007))

8.2 P Loads to IRW Water Based on Landscape Application and Literature P Loss Estimates
The P loads to water from NPS sources can be calculated based on the mass of P applied to the landscape annually and a coefficient (Sharpley et al., 2007; Willett et al., 2006; and Nelson et al., 2002). These authors all suggest the coefficient should be approximately 5% of P applied to the landscape. Using a coefficient of 5% and the defendants' poultry waste P content, the P losses from this poultry waste are shown in Table 8.1.

Table 8.1. Poultry P Loads in the IRW Based on Defendant Supplied Poultry Production Data and a 5% P Load Coefficient

Year	Total P (lbs)	Poultry P Load to Water (lbs)
2001	8,639,766	431,988
2002	8,702,182	435,109
2003	8,737,112	436,856
2004	9,975,305	498,765
2005	9,819,383	490,969
2006	9,000,113	450,006

As noted above, we computed a P mass balance for the IRW. The sources and amounts of P applied to the IRW crop and pasture land in 2002 are shown in Table 8.2. Based on these P applications to the landscape and a 5% loss to water, the total average annual P load in IRW water from these sources is approximately 570,000 lbs annually, with poultry waste responsible for more than 464,000 lbs annually. This is similar to the P load to water computed in Table 8.1. Poultry waste application to the landscape of the IRW results in substantial P loads to IRW waters and Lake Tenkiller.

Table 8.2. P Applied to the IRW Landscape in 2002

Source	**P (tons)**
Commercial Fertilizer	455
Poultry	4642
Swine	177
Dairy Cattle	319
Beef Cattle	105

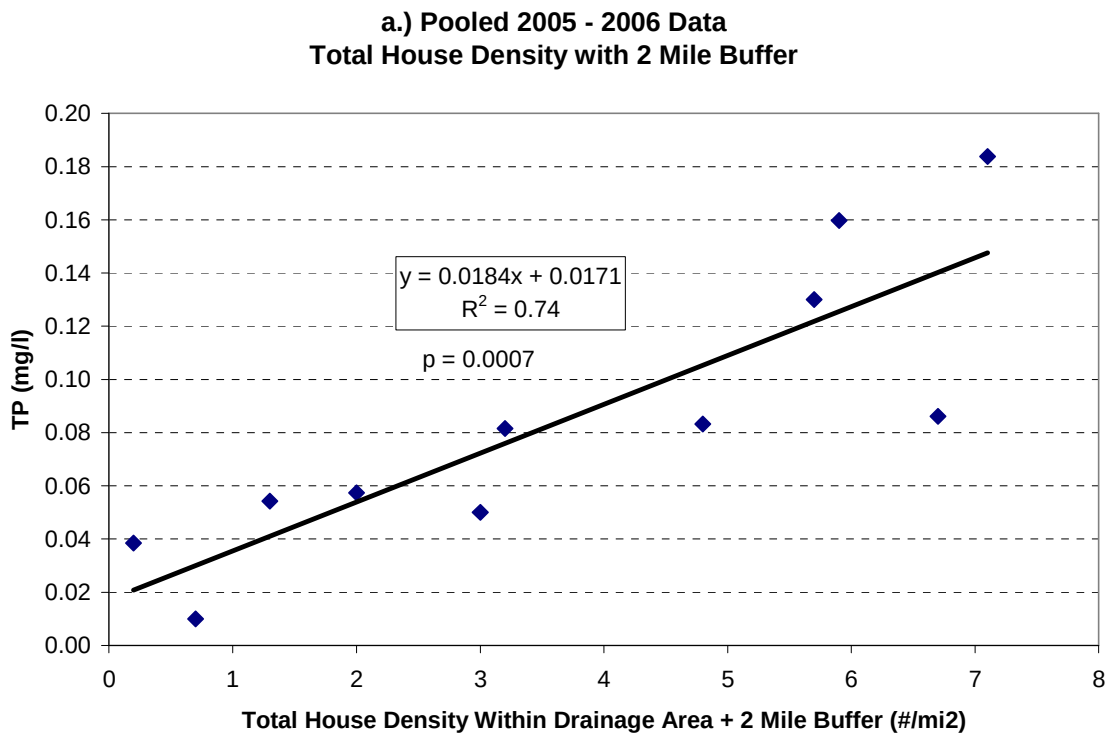
9. Poultry House Density Correlated to Elevated P Levels in Runoff and Base Flow

The analyses of observed P in runoff and in baseflow for 14 small watersheds within the Illinois River Watershed that were sampled in 2005 and 2006 show a strong and statistically significant correlation between P in runoff and in baseflow and poultry house density. Sub-basin poultry house densities are strong predictors of stream total phosphorus concentration showing a cause and effect relationship between poultry house operations and phosphorus concentrations in IRW waters. From these analyses, it is evident that poultry waste is a substantial contributor to P in stream runoff and in the baseflow within streams of the Illinois River Watershed.

Data were collected as part of the small tributary sampling program in the IRW (Olsen, 2008). Data were collected for both highflow and baseflow conditions throughout two summer periods (2005 and 2006). Data were collected from a total of fourteen sampling locations in small tributaries throughout the basin that covered a range of drainage area size and landuse characteristics. A representative range of poultry house presence (from no presence to highly active presence) was included in the sampling program. Further details of this sampling program are provided in Olsen (2008). Regression analyses were performed for measured total phosphorus concentrations as a function of a range of hypothesized potential predictor variables, including poultry house densities in and near the sampled watersheds.

As the following analysis demonstrates, sub-basin poultry house densities, in a variety of forms, are strong predictors of stream total phosphorus concentration showing a cause and effect relationship between poultry house operations and phosphorus concentrations in IRW waters. For the combined 2005-06 data sets, all 6 of the poultry house density predictor variable forms are shown to be significantly and positively correlated with total phosphorus concentrations in the receiving streams during highflow events. The strongest and most convincing correlations appear to be for the pooled 2005 – 06 phosphorus concentrations vs. total and active poultry house densities within a 2 mile buffered drainage area (see Appendix C). These results indicate that poultry house density is a good predictor of P concentration in runoff from sub-basins within the IRW. This finding is consistent with: (1) the observation that land application of poultry waste occurs near poultry houses (Section 4), (2) the fact that land disposal of poultry waste results in P loss in runoff, and (3) the fact that land disposal of poultry waste increases soil concentrations of P which also increases the amount of P in runoff water and which will elevate P levels in runoff water even after poultry waste disposal has stopped. Further details of the analysis are provided in Appendix C.

Figures 9.1 and 9.2 show the relationships between poultry house density within sub-basins (a. total and b. active) and a two mile buffer for runoff events and at baseflow, respectively. Significant relationships exist in each instance.



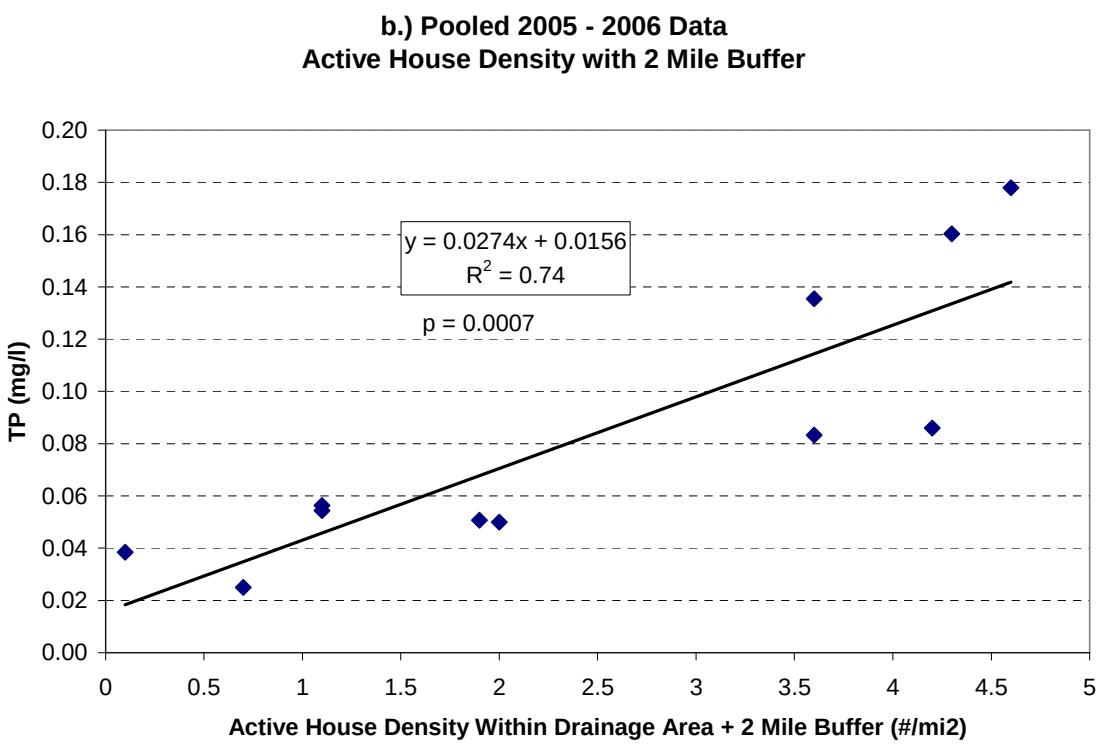
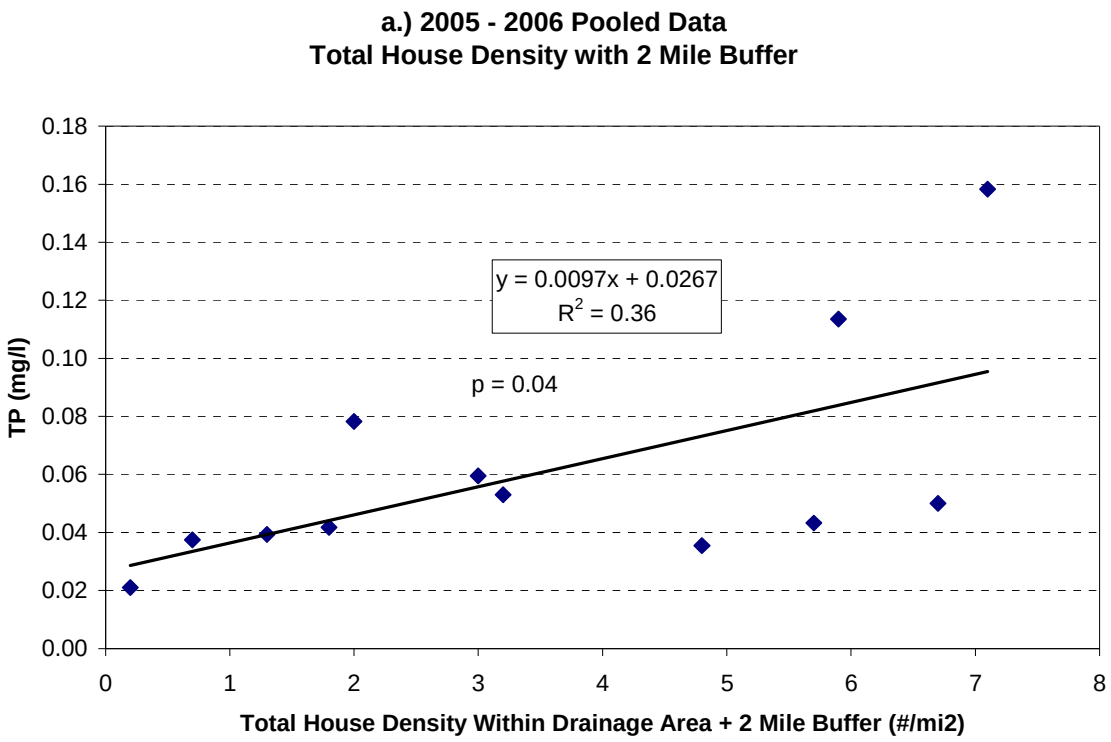


Figure 9.1. Runoff Event Regressions: Total Phosphorus Concentration vs. Poultry Presence



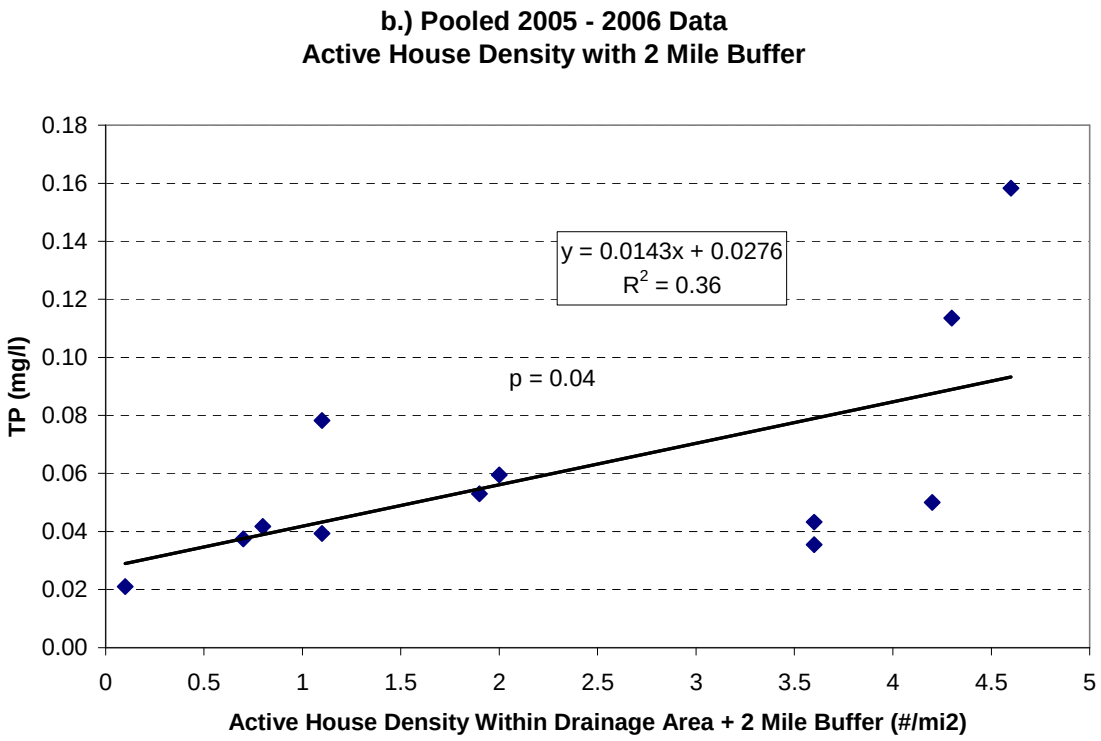


Figure 9.2. Baseflow Regressions: Total Phosphorus Concentration vs. Poultry Presence

Storm (2008) also analyzed P concentration in runoff and in baseflow from various sources for the Illinois River Watershed. Significant relationships were found between poultry house density and P in water (Figure 9.3). Relationships between urban/developed area and P in water were not significant (Figure 9.4).

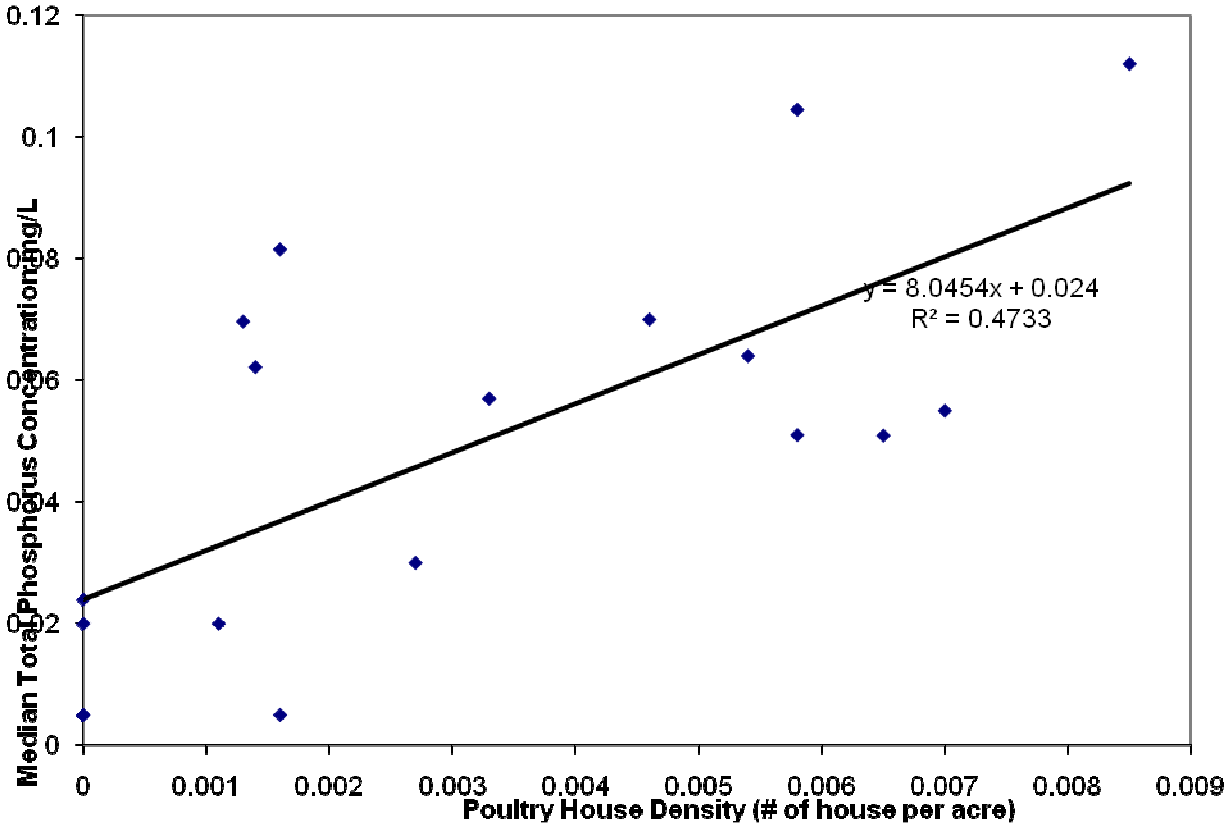


Figure 9.3. Relationship between poultry house density within a sub-basin and P concentration in water within the IRW (From Dr. Dan Storm, 2008)

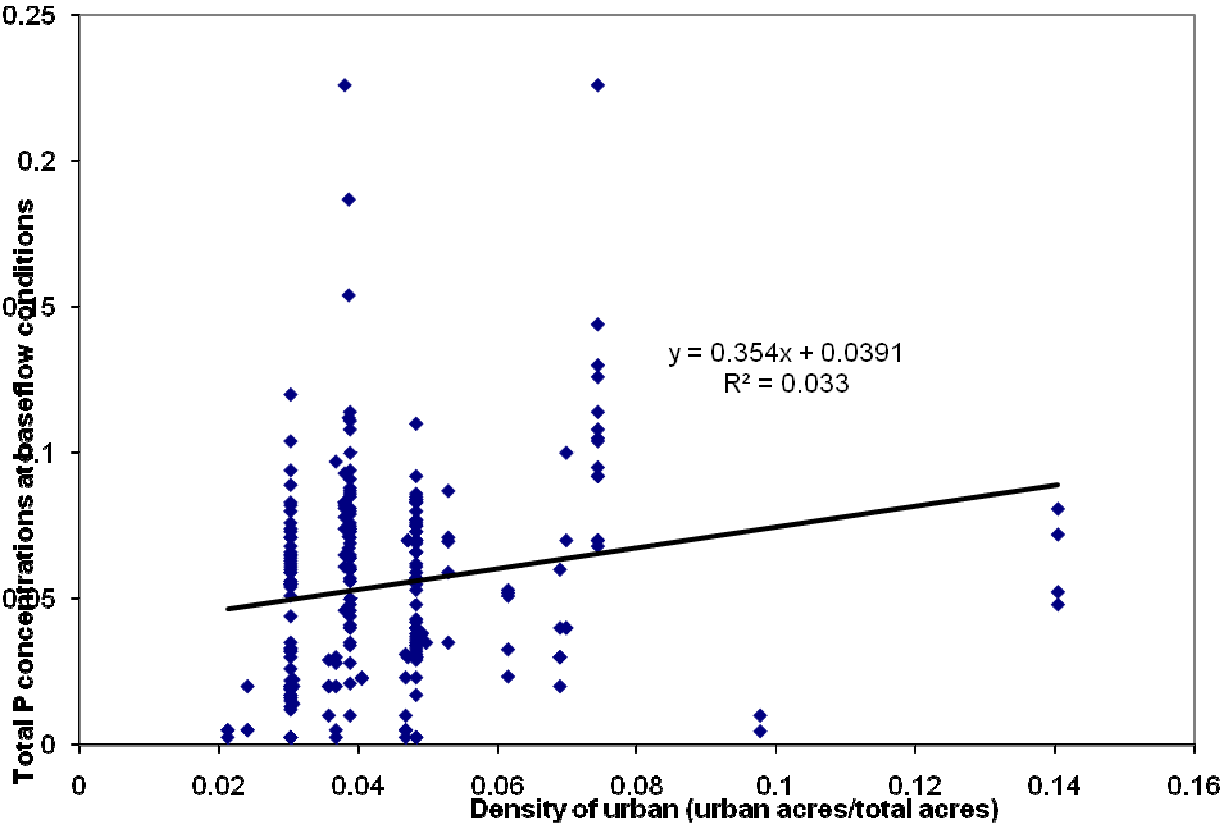


Figure 9.4. Relationship between amount of urban area and total P concentrations in water within the IRW (From Dr. Dan Storm, 2008)

10. Hydrologic/Water Quality (GLEAMS) Modeling of Illinois River Watershed

Introduction

The NPS P loads, including the defendants' NPS P loads, in the IRW streams and rivers and to Lake Tenkiller were modeled as described in Appendix D. A model (GLEAMS) was used to represent the details of hydrology, erosion processes and nutrient movement based on elevation, soil, rainfall, and land management data including poultry waste application to the IRW landscape. WWTP P loads were added to the NPS P loads reaching the IRW streams and rivers. P loads to streams and rivers were routed to Lake Tenkiller using a model based on stream/river flow and accumulated P in streams and rivers. The P loads to Lake Tenkiller are presented for: recent conditions (1997-2006), continuation of poultry waste land application in the IRW at current levels, cessation of poultry waste land application in the IRW, an increase in poultry waste land application based on continued growth in the poultry industry within the IRW, buffers along streams with cessation of poultry waste application in the IRW, and historical P loading (1950 to 1999) conditions. Also, an allocation among current principal sources of P loading to the surface waters of the IRW was performed.

10.1 Modeled P for 1997 to 2006 (Actual Conditions)

The hydrologic/water quality model was able to accurately model the P loads to IRW rivers and streams and Lake Tenkiller.

The P loads to the three gauging stations were modeled for 1997 through 2006 (Appendix D). This period was selected due to the increased sampling of P concentrations for runoff events that more accurately reflected P loads within the IRW. The modeled P loads (including both NPS and WWTP P) are shown in Table 10.1. Observed P loads for this period are also shown in Table 10.1. As both the modeled and observed P loads show, the loads vary greatly from year to year. This is due to the variation in weather and flows within the IRW. The flow and rainfall data for the IRW for this period and from 1950 through 2007 are shown in Figure 5.1 and Tables 5.3 and 5.4.

Table 10.1. Modeled P Load at Gauging Stations in Illinois River Watershed

	Modeled P Load (lb)				
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**	**Total**	**Observed Total P Load (lb)**
1997	278,955	61,794	21,874	362,623	241,107
1998	406,417	88,054	15,161	509,632	471,817
1999	430,596	53,139	7,815	491,550	450,440
2000	639,263	260,929	41,977	942,169	1,125,548
2001	386,787	73,015	26,355	486,157	592,494
2002	254,119	50,242	10,611	314,972	370,714
2003	120,477	6,381	2,993	129,851	108,276
2004	672,344	271,720	58,806	1,002,870	1,147,938
2005	333,198	58,829	12,742	404,769	340,664
2006	155,264	47,808	11,031	214,103	197,289

The point source P loads were greatly reduced beginning in 2003 due to changes in WWTP technology. However, the largest P load to Lake Tenkiller in the 1997 to 2006 period occurred in 2004. This was due to the weather and corresponding flows in that year that resulted in more NPS P load reaching Tenkiller.

The correlation between observed and modeled P loads is shown in Figure 10.1. The modeled and observed P loads exhibit a very strong correlation.

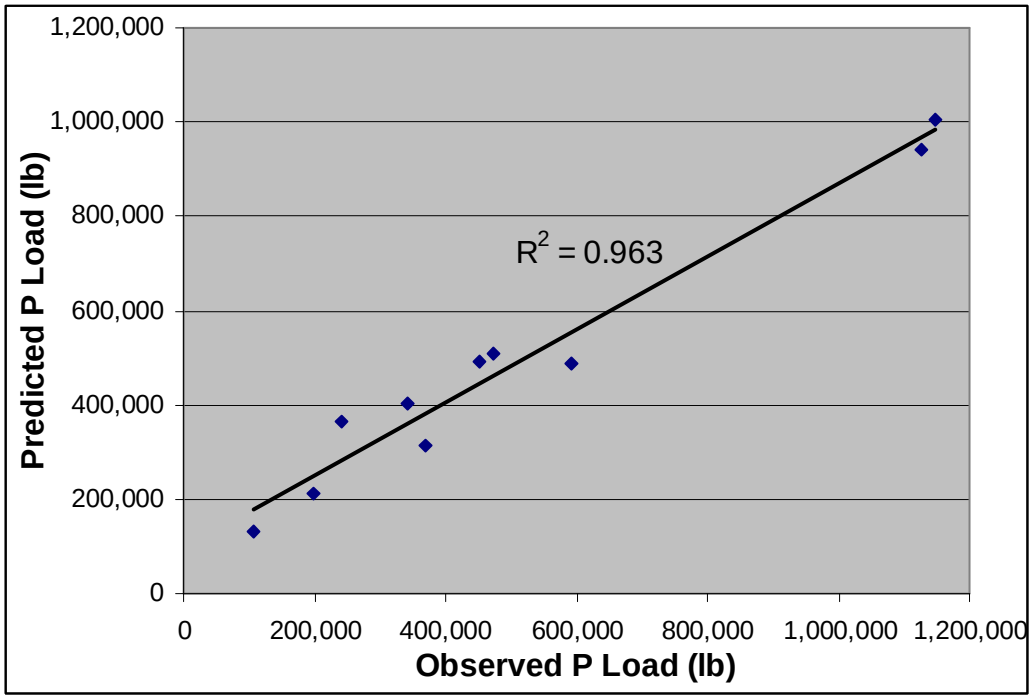


Figure 10.1. Relationship between Observed P Load and Predicted P Load to Lake Tenkiller for 1997-2006

10.2 Modeled P for Next 100 Years with (1) Continued Poultry Waste Application and (2) Poultry Waste Cessation in the IRW

For continued poultry waste application in the IRW, modeled P loads to Lake Tenkiller would increase during the first 30 years. For the next 70 years, P loads to Lake Tenkiller would decline slightly and stabilize at levels above current Lake Tenkiller P loads due to P saturation of soils. Cessation of poultry waste application in the IRW would decrease P loads to Lake Tenkiller. The reductions in P loads to Lake Tenkiller due to poultry waste land application cessation are limited to 16% during the first 10 years following cessation due to continued P load contributions from historical poultry waste application in the IRW that have elevated soil P. Following poultry waste land application cessation in the IRW, reductions in P loads to Lake Tenkiller would reach 50% by years 51-60.

The P loads at the three USGS gauging stations closest to Lake Tenkiller (Tahlequah, Baron Fork near Eldon, and Caney Creek) were modeled for (1) continued poultry waste application in

the IRW and (2) cessation of poultry waste application in the IRW. The weather from 1997 to 2006 was repeated for 100 years. The modeled P loads and trend lines are shown in Figures 10.2-10.7 and in Tables 10.2-10.6.

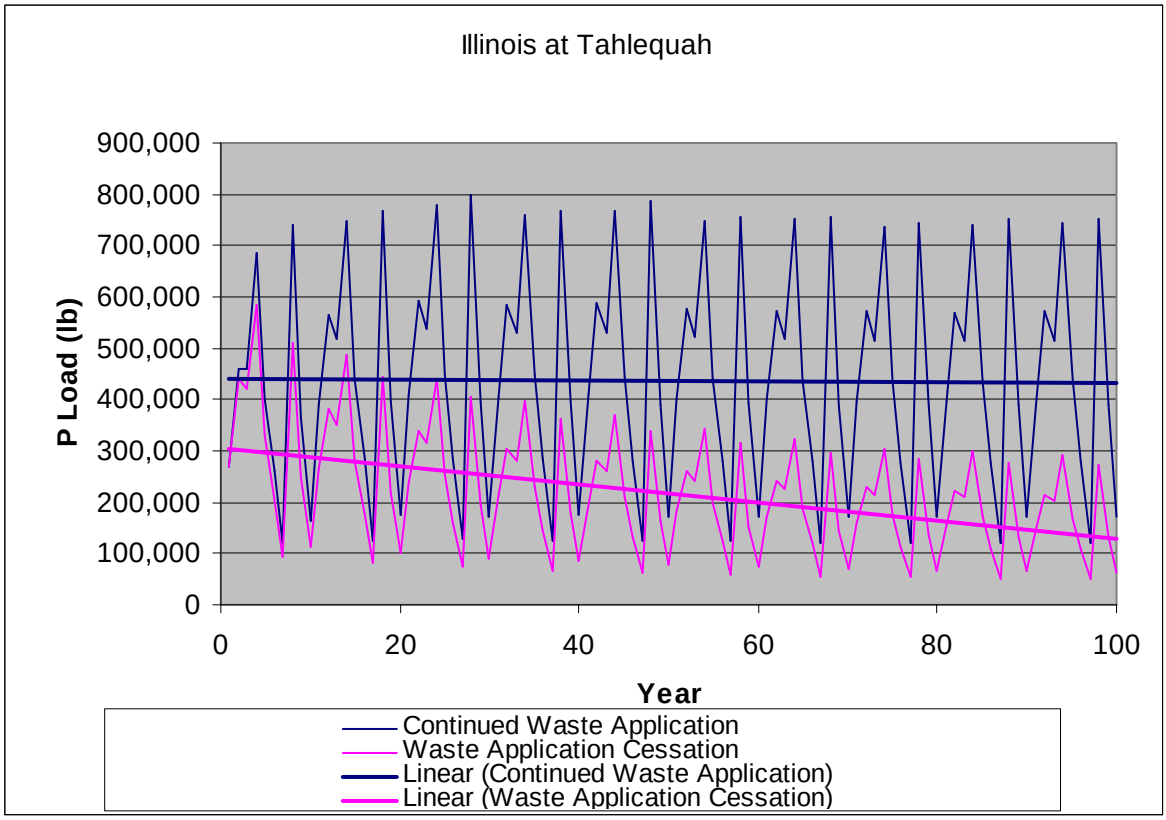


Figure 10.2. Modeled P Load at Tahlequah for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

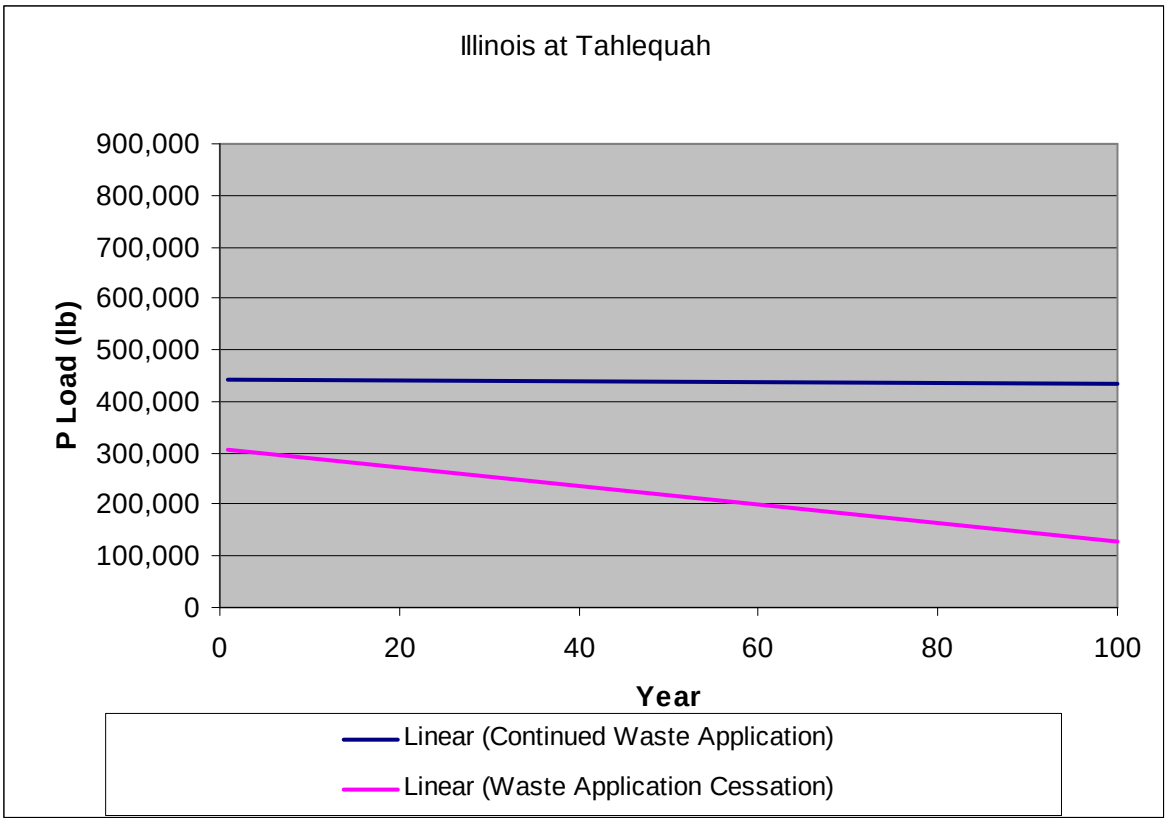


Figure 10.3. Trend Lines for Modeled P Load at Tahlequah for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

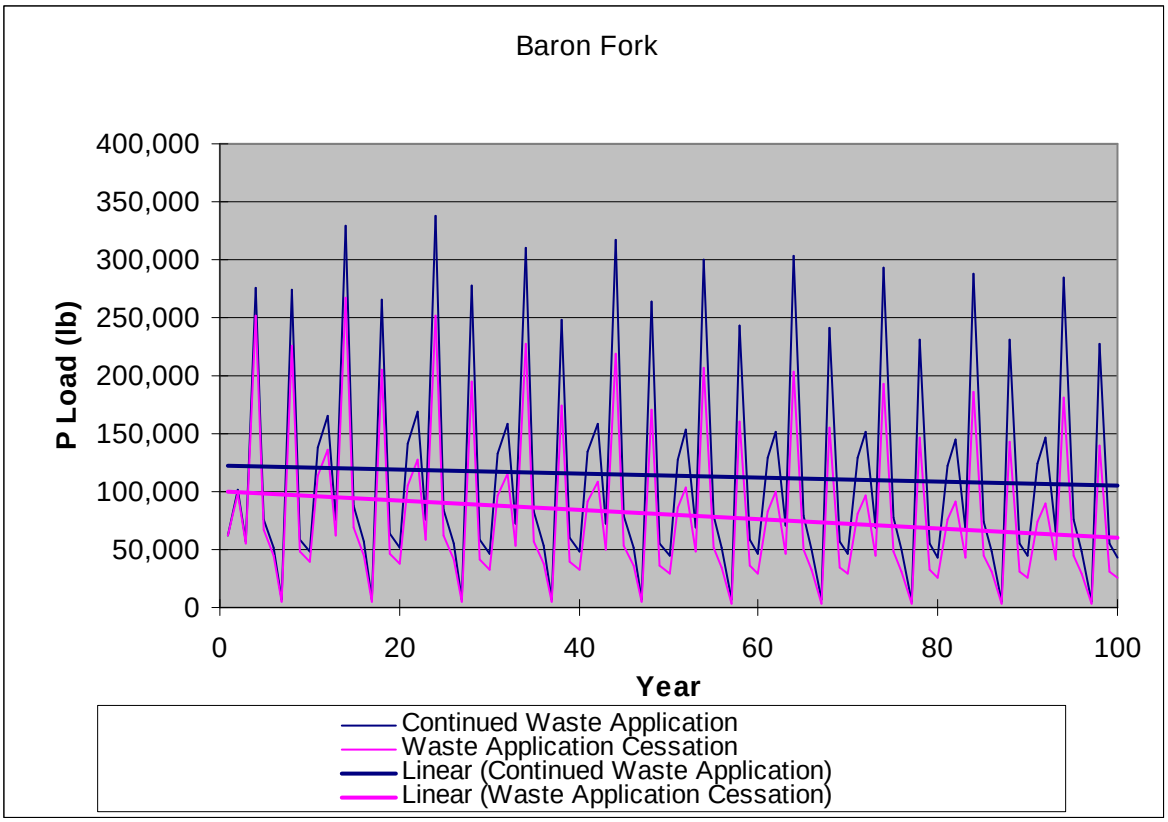


Figure 10.4. Modeled P Load at Baron Fork Gauging Station near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

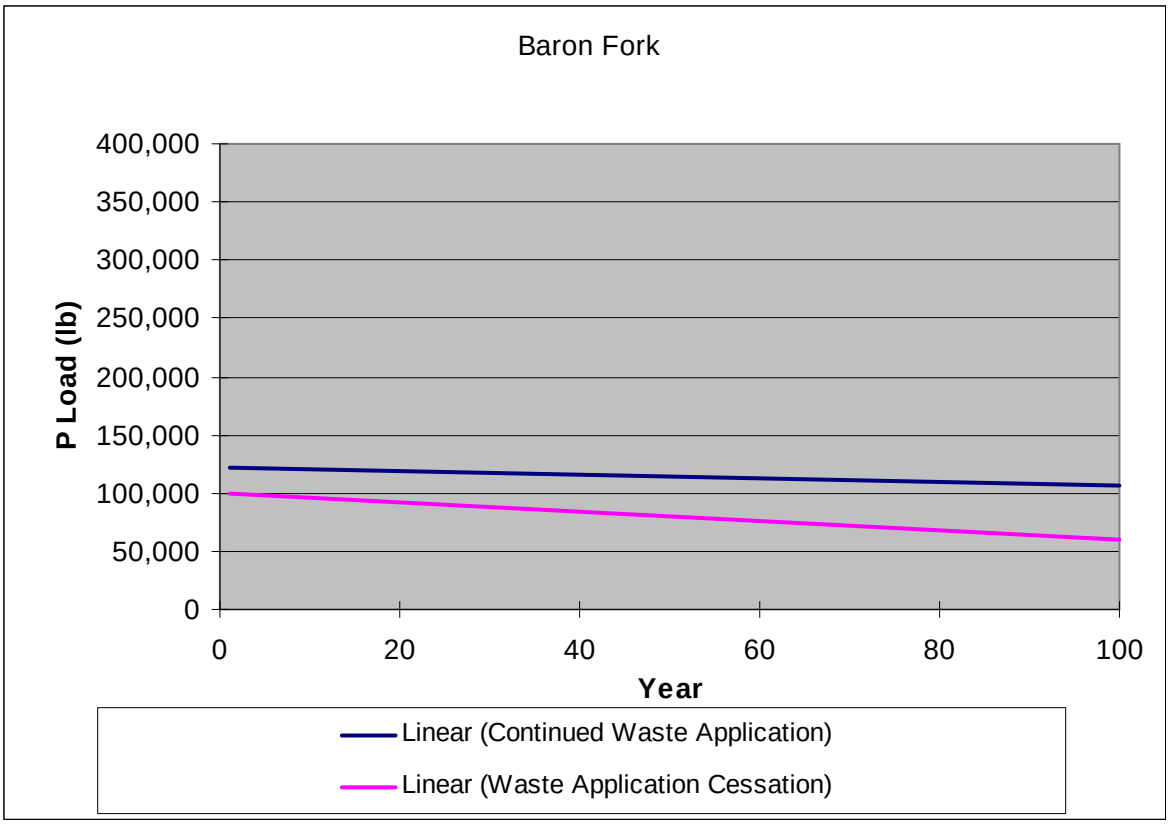


Figure 10.5. Trend Lines for Modeled P Load at Baron Fork Gauging Station Near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

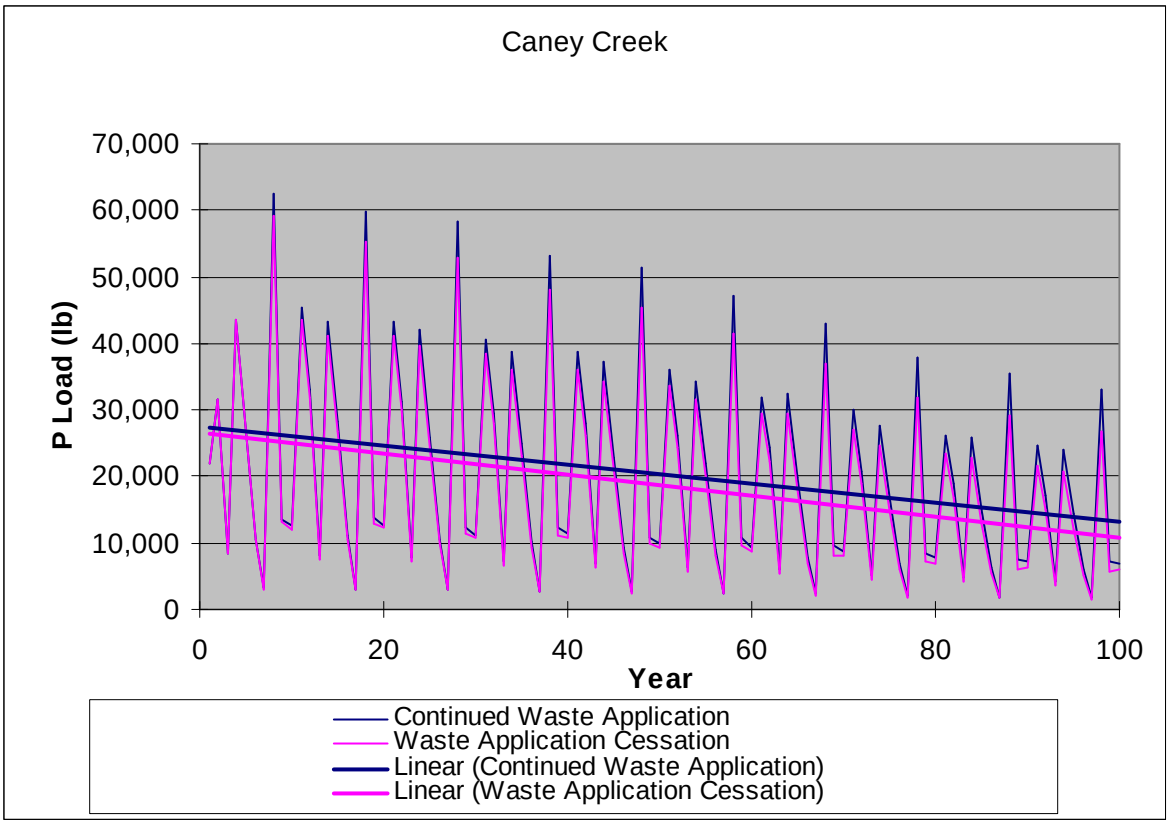


Figure 10.6. Modeled P Load at Caney Creek Gauging Station Near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

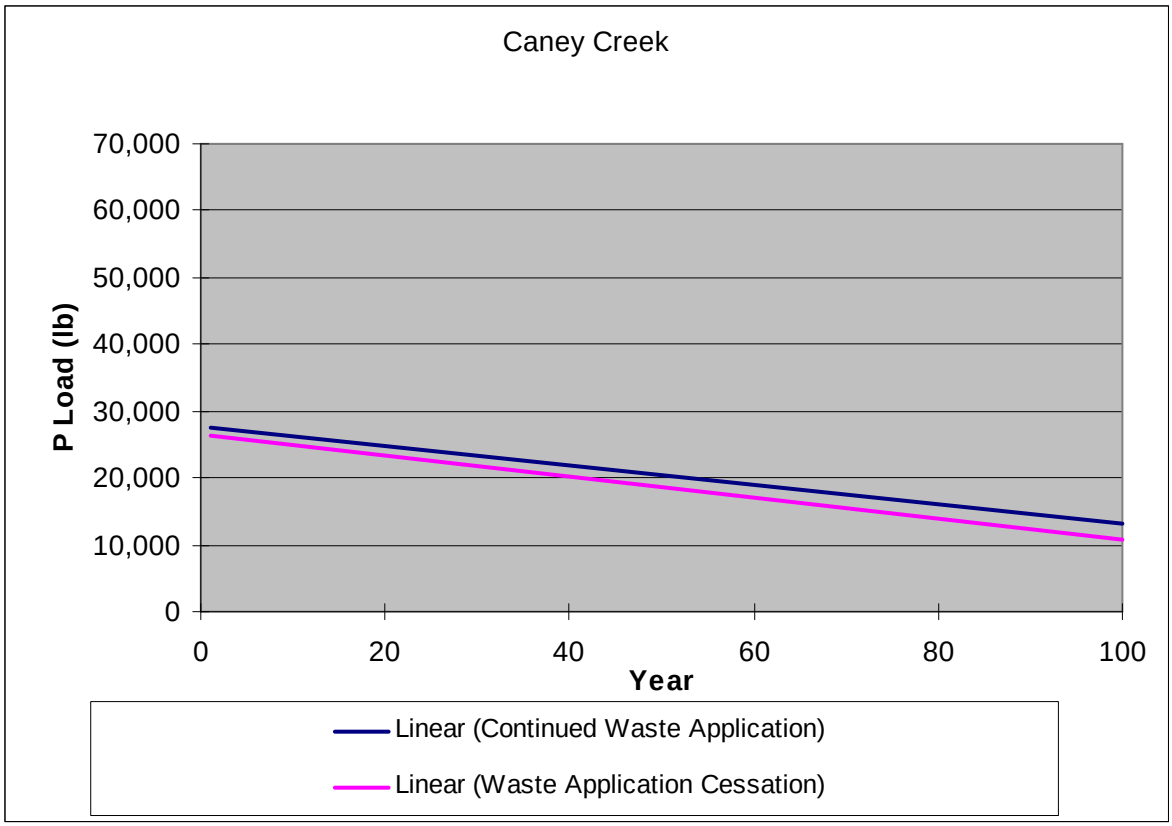


Figure 10.7. Trend Lines for Modeled P Load at Caney Creek Gauging Station near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

Table 10.2. Modeled P Loads at Illinois River Gauging Locations for Continued Poultry Waste Application and for Cessation of Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	Illinois River at Tahlequah		**Baron Fork**		**Caney Creek**	
Years	P- Continued Waste Application (lb)	P – Cessation of Waste Application (lb)	P- Continued Waste Application (lb)	P – Cessation of Waste Application (lb)	P- Continued Waste Application (lb)	P – Cessation of Waste Application (lb)
1-10	3,927,423	3,216,011	1,012,460	896,907	234,612	230,567
11-20	4,408,574	2,787,287	1,240,857	987,724	258,152	244,926
21-30	4,548,255	2,509,046	1,251,316	919,733	245,572	229,875
31-40	4,479,081	2,264,368	1,175,349	837,203	230,505	214,008
41-50	4,489,549	2,094,246	1,183,206	799,781	217,512	199,793
51-60	4,418,033	1,948,115	1,135,476	761,917	203,549	185,336
61-70	4,401,297	1,831,139	1,136,226	739,856	185,929	166,473
71-80	4,359,942	1,740,937	1,108,147	703,919	163,384	143,812
81-90	4,365,054	1,693,602	1,083,262	675,952	149,368	129,298
91-100	4,384,281	1,657,713	1,078,687	661,290	139,019	118,251

Table 10.3. Change in P Loads to Lake Tenkiller for 10 Year Periods into the Future for Continued Poultry Waste Application and Cessation of Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

Year	Total P Continued Waste (lb)	Change from Previous 10 Years (%)	Total P Waste Cessation (lb)	Change from Previous 10 Years (%)
1-10	5,174,495		4,343,485	
11-20	5,907,583	14.2	4,019,937	-7.4
21-30	6,045,143	2.3	3,658,654	-9.0
31-40	5,884,935	-2.7	3,315,579	-9.4
41-50	5,890,267	0.1	3,093,820	-6.7
51-60	5,757,058	-2.3	2,895,368	-6.4
61-70	5,723,452	-0.6	2,737,468	-5.5
71-80	5,631,473	-1.6	2,588,668	-5.4
81-90	5,597,684	-0.6	2,498,852	-3.5
91-100	5,601,987	0.1	2,437,254	-2.5

Table 10.4. Difference in P Loads to Tenkiller for Continued Poultry Waste Application Compared to Poultry Waste Application Cessation. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

Year	Total P Continued Waste (lb)	Total P Waste Cessation (lb)	Difference (%)
1-10	5,174,495	4,343,485	16.1
11-20	5,907,583	4,019,937	32.0
21-30	6,045,143	3,658,654	39.5
31-40	5,884,935	3,315,579	43.7
41-50	5,890,267	3,093,820	47.5
51-60	5,757,058	2,895,368	49.7
61-70	5,723,452	2,737,468	52.2
71-80	5,631,473	2,588,668	54.0
81-90	5,597,684	2,498,852	55.4
91-100	5,601,987	2,437,254	56.5

Table 10.5. Percentage Change in Modeled P Loads Relative to Modeled P Between 1997-2006 at Illinois River Gauging Locations for Continued Waste Application and Moratorium on Waste Application. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	Illinois River at Tahlequah		**Baron Fork**		**Caney Creek**	
Year	P Continue Waste (%)	P Stop Waste (%)	P Continue Waste (%)	P Stop Waste (%)	P Continue Waste (%)	P Stop Waste (%)
1-10	6.8	-12.5	4.2	-7.7	12.1	10.1
11-20	19.9	-24.2	27.7	1.6	23.3	17.0
21-30	23.7	-31.8	28.7	-5.4	17.3	9.8
31-40	21.8	-38.4	20.9	-13.9	10.1	2.2
41-50	22.1	-43.1	21.7	-17.7	3.9	-4.6
51-60	20.1	-47.0	16.8	-21.6	-2.8	-11.5
61-70	19.7	-50.2	16.9	-23.9	-11.2	-20.5
71-80	18.6	-52.7	14.0	-27.6	-22.0	-31.3
81-90	18.7	-53.9	11.5	-30.5	-28.7	-38.2
91-100	19.2	-54.9	11.0	-32.0	-33.6	-43.5

Table 10.6. Percentage Change in Modeled P Loads Relative to Observed P Between 1997-2006 at Illinois River Gauging Locations for Continued Waste Application and Cessation of Waste Application. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	Illinois River at Tahlequah		**Baron Fork**		**Caney Creek**	
Year	P – Continued Waste (%)	P – Waste Cessation (%)	P – Continued Waste (%)	P – Waste Cessation (%)	P – Continued Waste (%)	P – Waste Cessation (%)
1-10	7.0	-12.4	-12.8	-22.8	8.8	6.9
11-20	20.1	-24.0	6.9	-14.9	19.7	13.6
21-30	23.9	-31.6	7.8	-20.8	13.9	6.6
31-40	22.1	-38.3	1.2	-27.9	6.9	-0.8
41-50	22.3	-42.9	1.9	-31.1	0.9	-7.3
51-60	20.4	-46.9	-2.2	-34.4	-5.6	-14.1
61-70	19.9	-50.1	-2.1	-36.3	-13.8	-22.8
71-80	18.8	-52.6	-4.6	-39.4	-24.2	-33.3
81-90	19.0	-53.8	-6.7	-41.8	-30.7	-40.0
91-100	19.5	-54.8	-7.1	-43.0	-35.5	-45.2

For continued poultry waste application, the P loads at Tahlequah increase slightly for the first 30 years before stabilizing and declining slightly in subsequent years. Thus, the trend line for P loads at Tahlequah is flat. The P load results for continued poultry waste application for the Baron Fork location are similar to those at Tahlequah. The Baron Fork and Tahlequah results indicate the IRW soils in these watersheds have reached their capacity to retain additional P and thus expected P losses increase slightly over time before stabilizing and decreasing slightly. The P loads from these watersheds has reached steady state for current poultry waste land application. Note however, that tremendous variability in P loads from year to year exists due to variability in rainfall and flows in IRW streams and rivers.

The P loads for Caney Creek for continued poultry waste application decline due to the small amount of poultry waste applied in this watershed and the low STP values for soils in this watershed. More P is removed from this watershed than is applied with the poultry waste.

The P loads at Tahlequah and Baron Fork near Eldon would likely be greater than modeled loads under the continued poultry waste application scenario. The historical flows from 1950 through 2007 in the IRW were greater than flows for 1997 to 2006 (the period used for modeling the future). P loads to Tenkiller are strongly correlated with flow (Vieux and Moreda, 2003). Thus, if the weather for 1950 through 2007 repeats in the future, the P loads into Lake Tenkiller would be greater than modeled loads using 1997 through 2006 weather and flow data.

The P loads and trends for cessation of poultry waste application are shown in Figures 10.2-10.7 and Tables 10.2-10.6.

The P loads decrease by more than 16% in the first 10 years for IRW poultry waste application cessation compared to continued poultry waste application (Table 10.4 and Figure 10.8). The results indicate that poultry waste land application cessation within the IRW would provide some benefit (16% reduction in P loads to Lake Tenkiller). However, more than 70 years would be required for the P loads to be reduced to 50% of their current levels. This is due to the significant amount of P stored in the soils within the IRW as indicated by STP levels and the IRW P mass balance described in Appendix B. The large amount of P from land application of poultry waste continues to contribute to P loads reaching Tenkiller at substantial levels into the future. Even at 100 years, the accumulated P from poultry waste application continues to significantly contribute to P loads.

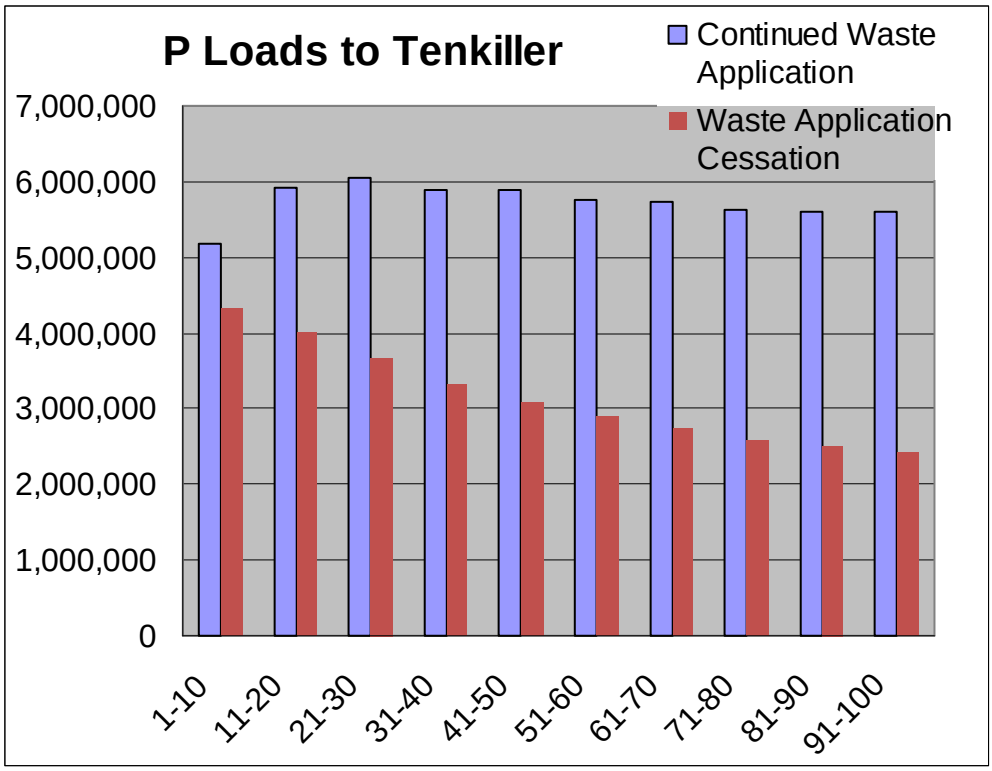


Figure 10.8. P Loads to Lake Tenkiller for Continued Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

10.3 P Loads for Increased Poultry Waste Application

For continued growth in the IRW poultry industry at a rate the same as that between 1982 and 2002, P loads to Lake Tenkiller would increase substantially. Within 40-50 years, P loads to Lake Tenkiller would nearly double (increase of 92%).

Figures 10.9-10.14 show P loads at each of the three gauging stations (Tahlequah, Baron Fork at Eldon and Caney Creek) for continued growth in IRW poultry based on the same rate of growth between 1982 and 2002 based on the USDA Agricultural Census poultry data. Figures 10.15 and 10.16 show P loads to Lake Tenkiller for this same situation. Based on this rate of growth assumption, P loads to Lake Tenkiller through the Tahlequah location would increase substantially (double in 40-50 years) as a result of increased poultry waste application in this watershed. P load changes at the Baron Fork location would increase a smaller amount (60% in 40-50 years) due to less poultry waste being applied in this watershed. P loads at the Caney Creek location would decrease slightly over time (50 years) in this scenario (but less than no changes in poultry production) due to the small amount of poultry waste applied in this watershed and the low STP levels.

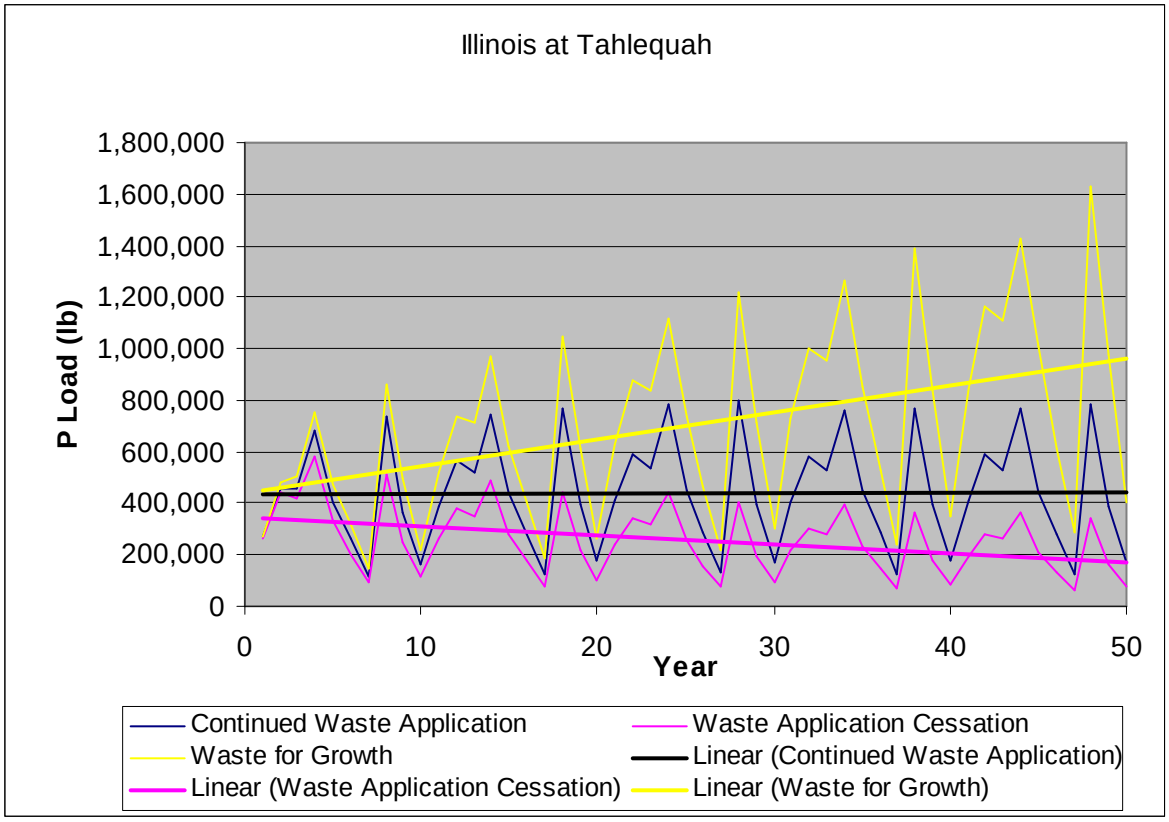


Figure 10.9. P Loading and Trend Lines at Tahlequah for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

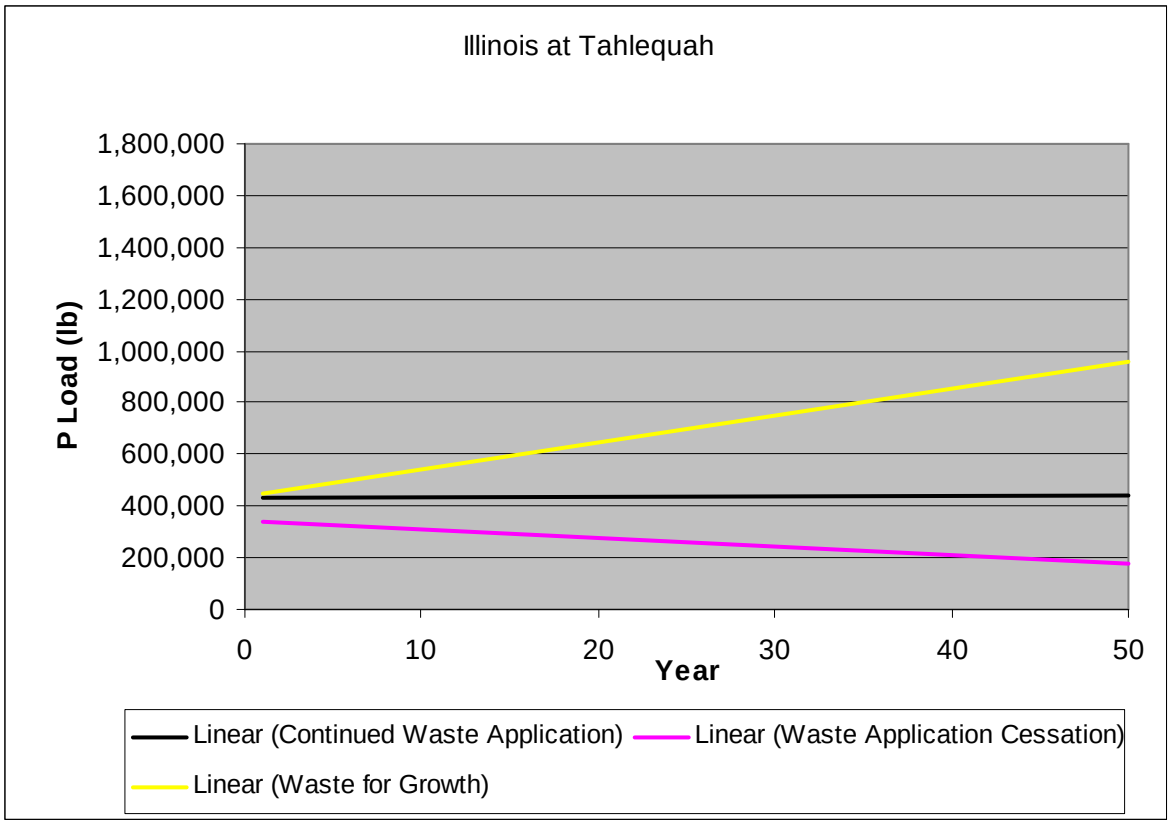


Figure 10.10. P Loading Trend Lines at Tahlequah for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

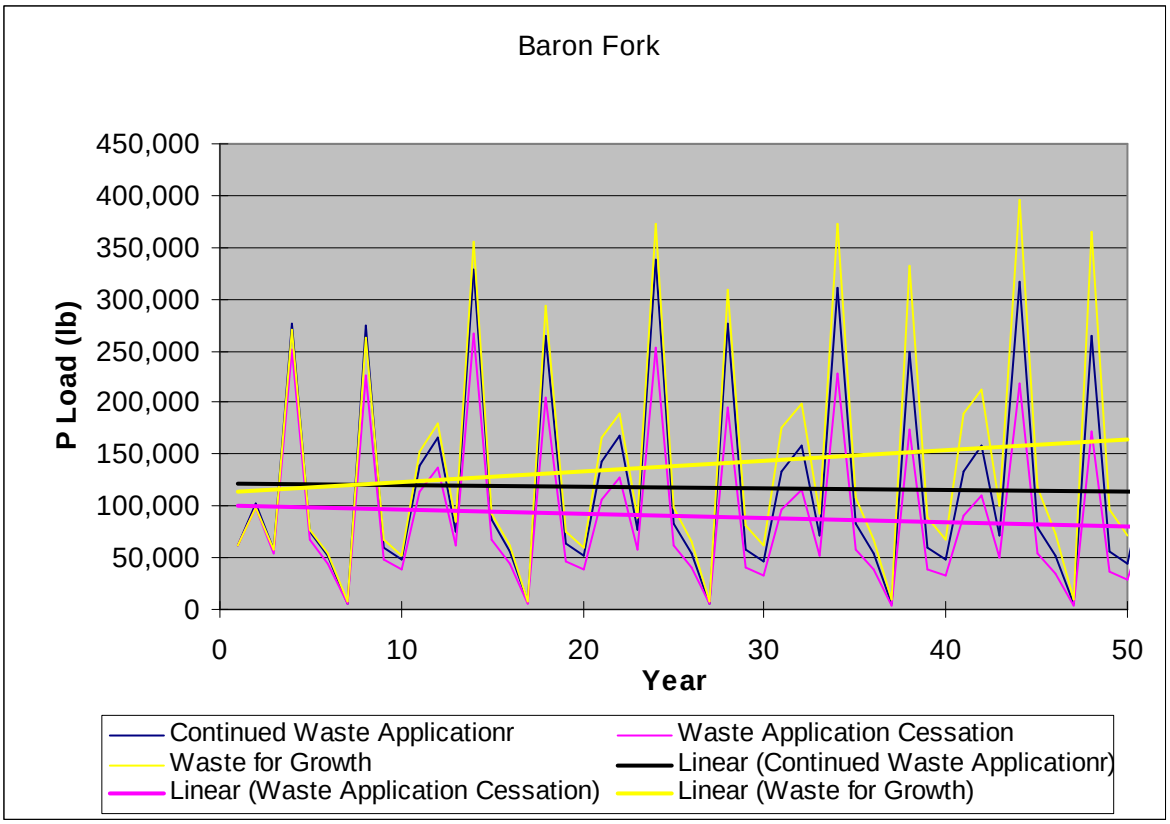


Figure 10.11. P Load and Trend Lines at Baron Fork near Eldon for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

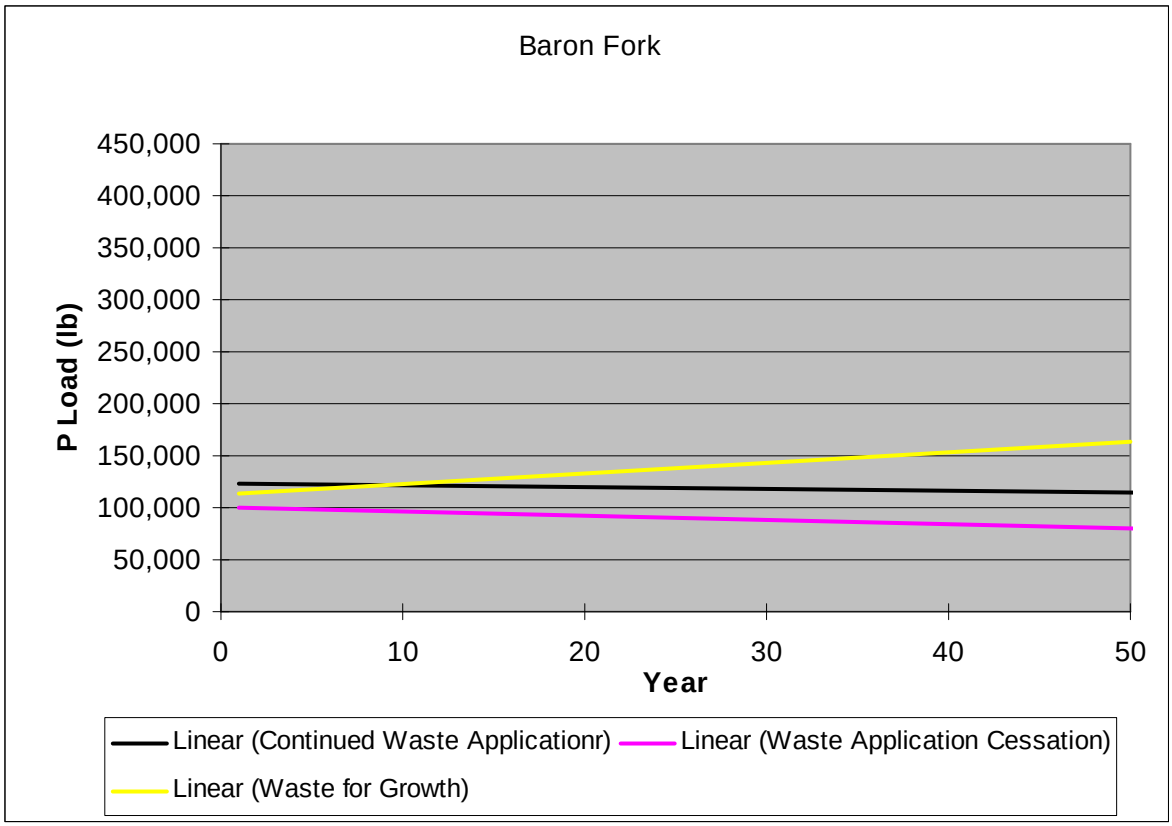


Figure 10.12. P Load Trend Lines at Baron Fork near Eldon for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

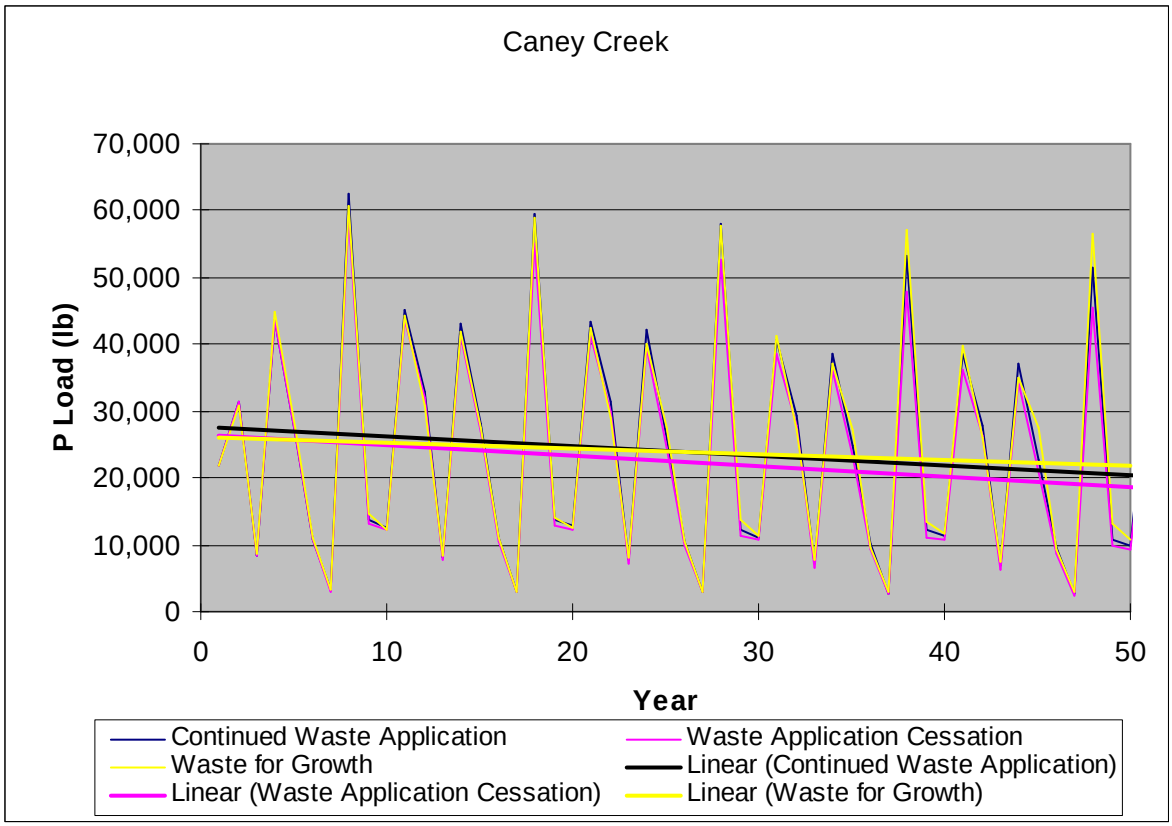


Figure 10.13. P Load and Trend Lines at Caney Creek for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

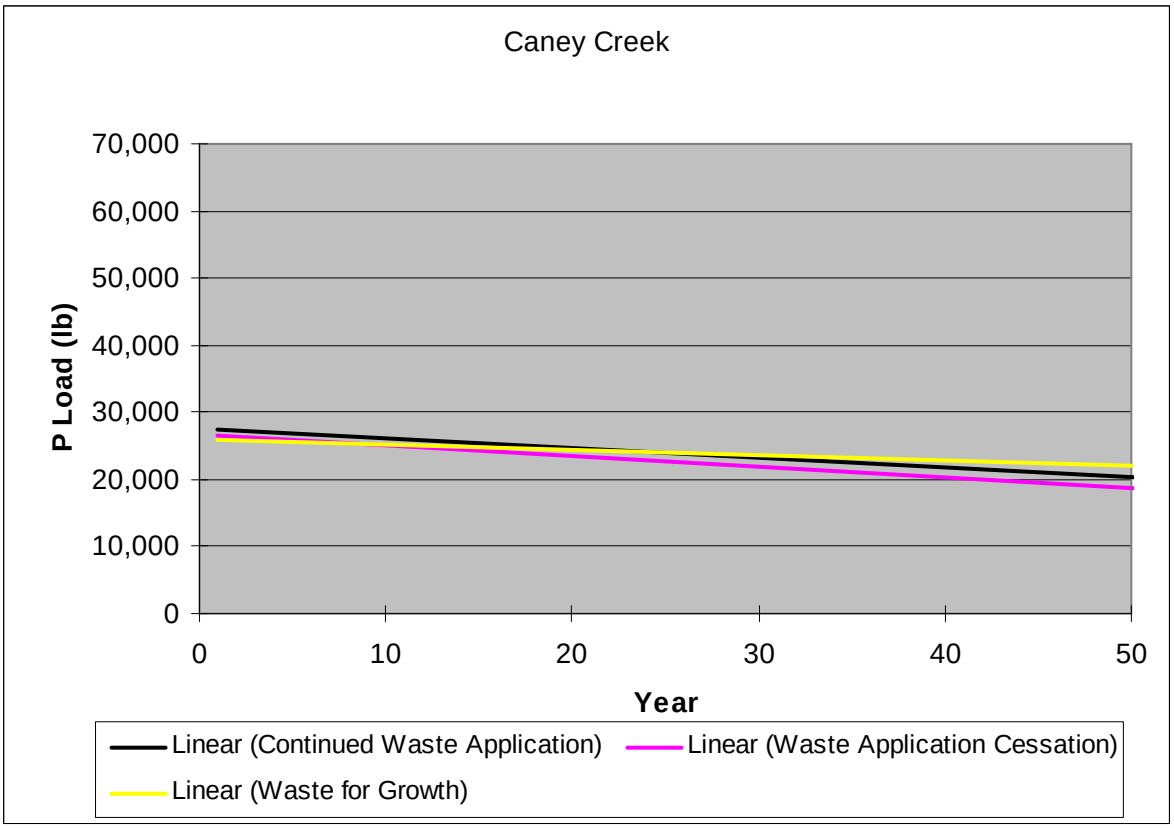


Figure 10.14. P Load Trend Lines at Caney Creek for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

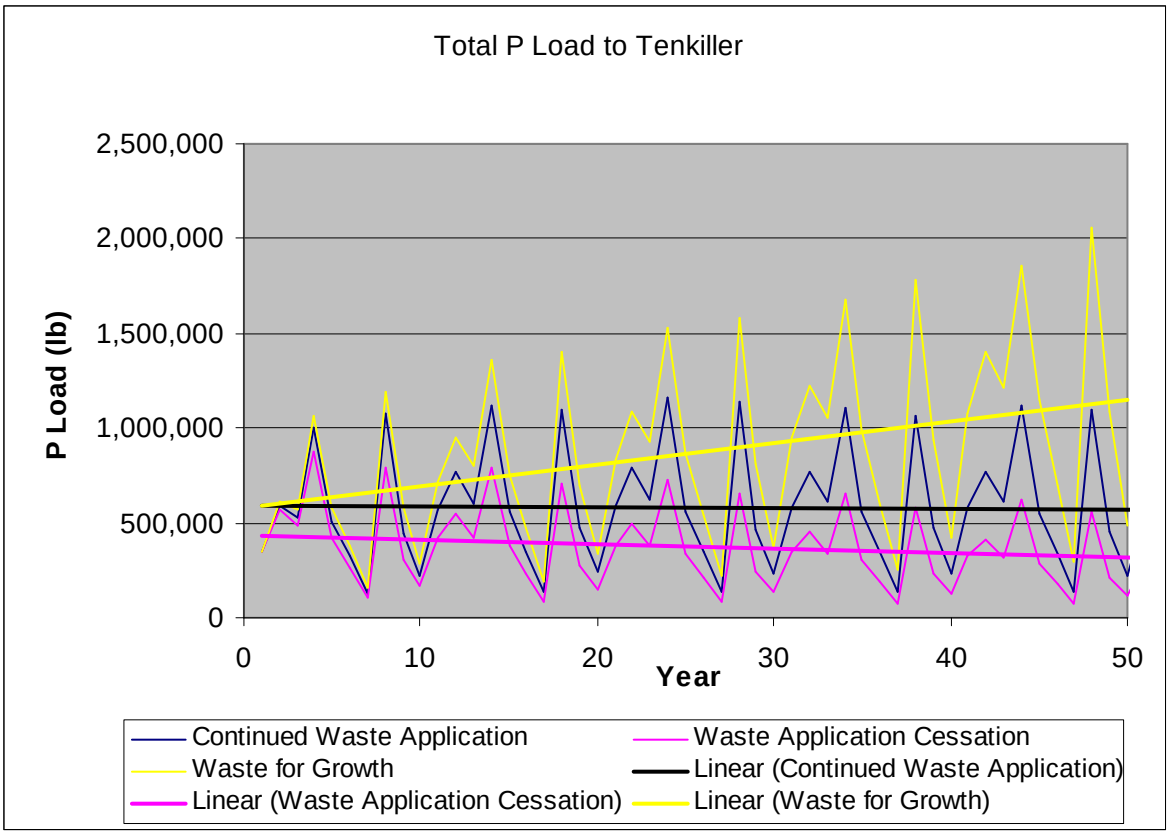


Figure 10.15. P Load and Trend Lines to Lake Tenkiller for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

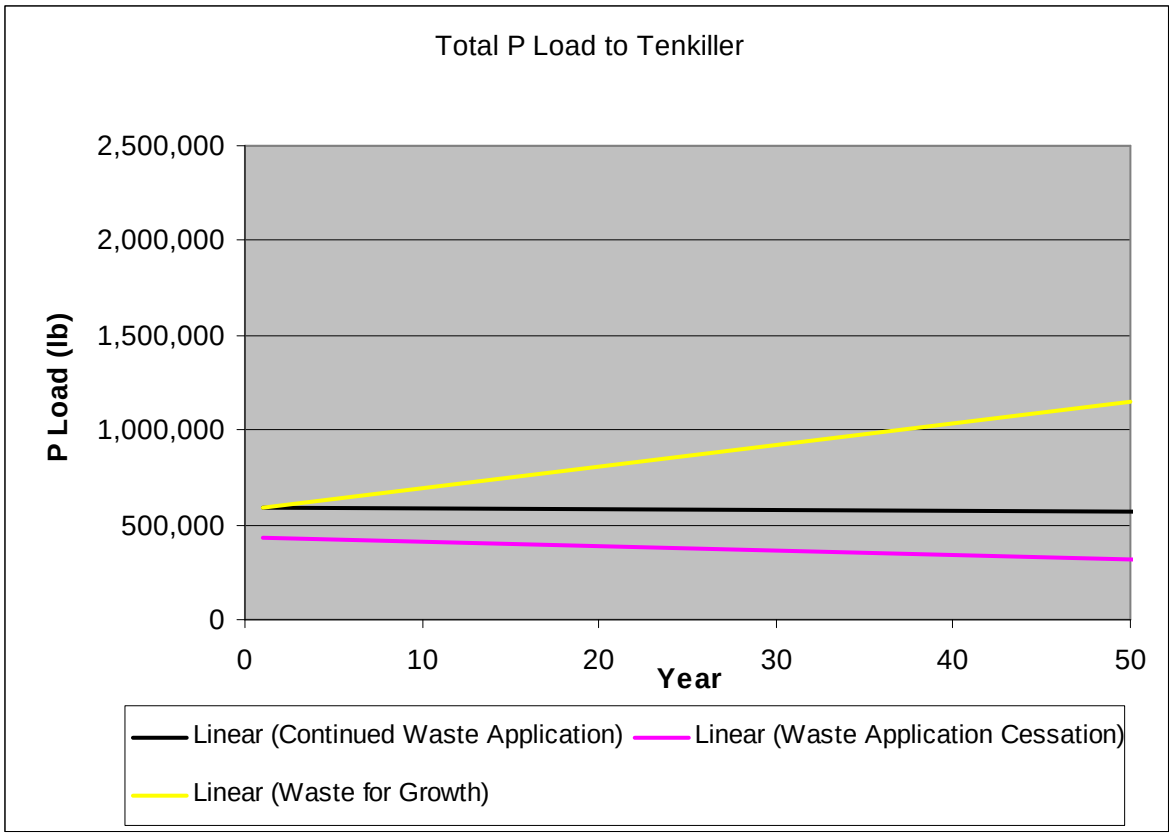


Figure 10.16. P Load Trend Lines to Lake Tenkiller for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

Table 10.7 shows individual main stream and total P loads to Lake Tenkiller for the poultry growth scenario compared to current poultry production and waste application P loads. Growth in the poultry industry in the IRW and the associated land application of this waste in the IRW would result in greatly increased P loads to Lake Tenkiller that nearly double in the 40-50 year time frame.

Table 10.7. P Loads for Growth in IRW Poultry Compared to P Load for Poultry Waste Applied to IRW at Current Rates. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	P Load (lb) for Growth in Poultry in IRW				**P Load (lb)**	
Years	Tahlequah	Baron Fork	Caney	Total	Total Continued Waste	Increase (%)
1-10	4,523,331	1,010,394	235,614	5,769,339	5,174,495	11.5
11-20	6,066,771	1,364,064	252,099	7,682,934	5,907,583	30.1
21-30	7,112,706	1,439,913	243,753	8,796,372	6,045,143	45.5
31-40	8,144,070	1,512,312	235,329	9,891,711	5,884,935	68.1
41-50	9,464,415	1,635,132	228,607	11,328,153	5,890,267	92.3

10.4 P Loads for Buffers and Poultry Waste Land Application Cessation

The addition of vegetated 100 foot buffers along all 3rd order and larger IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 3 and 5% compared to poultry waste application cessation alone. The addition of vegetated 100 foot buffers along all IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 10 and 13% compared to poultry waste application cessation alone.

P loads were calculated for three locations entering Lake Tenkiller (Tahlequah, Baron Fork at Eldon, and Caney Creek) for combined poultry waste land application cessation and 100 foot buffers placed along 3rd order and larger streams and rivers with adjacent pasture. The P loads for each of these locations are shown in Figures 10.17-10.22. The buffers would provide a modest 4-5% additional reduction (see Table 10.8 and Figure 10.23) in P loads to Lake Tenkiller relative to land application of poultry waste cessation alone as depicted in Figures 10.17-10.23.

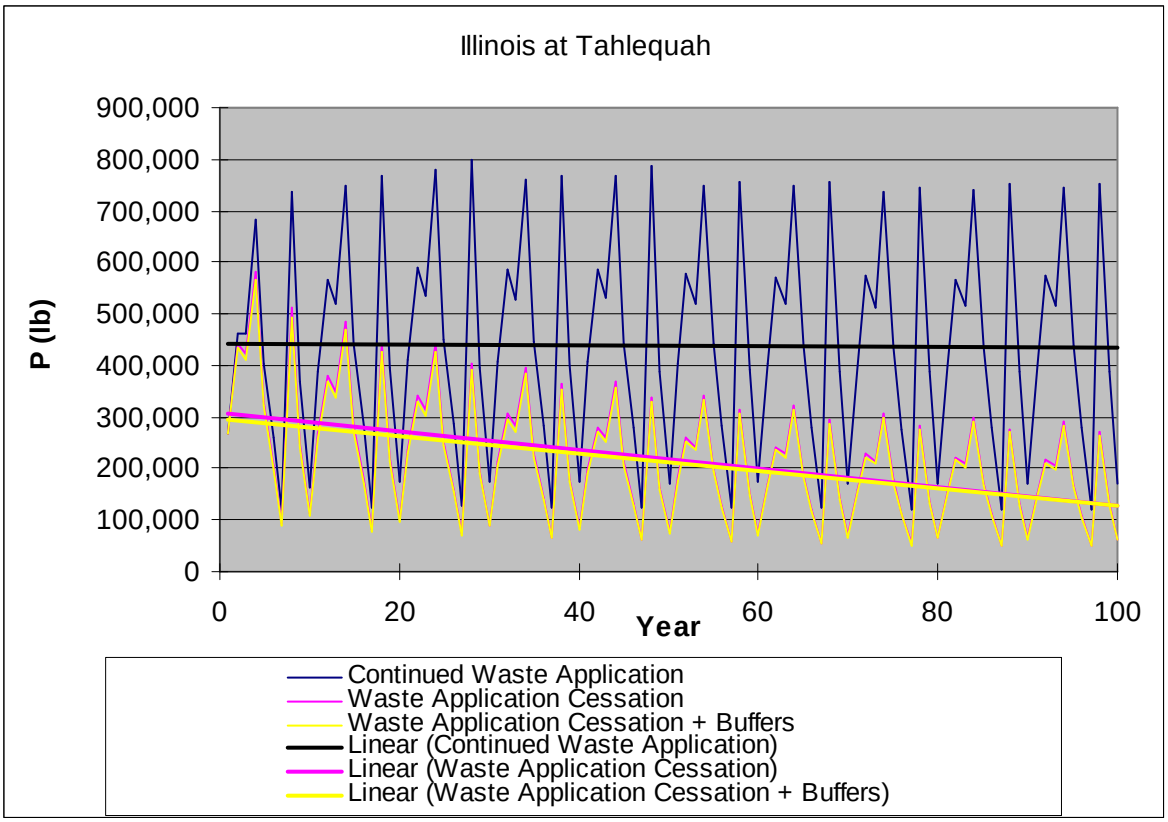


Figure 10.17. P Loads at Tahlequah for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

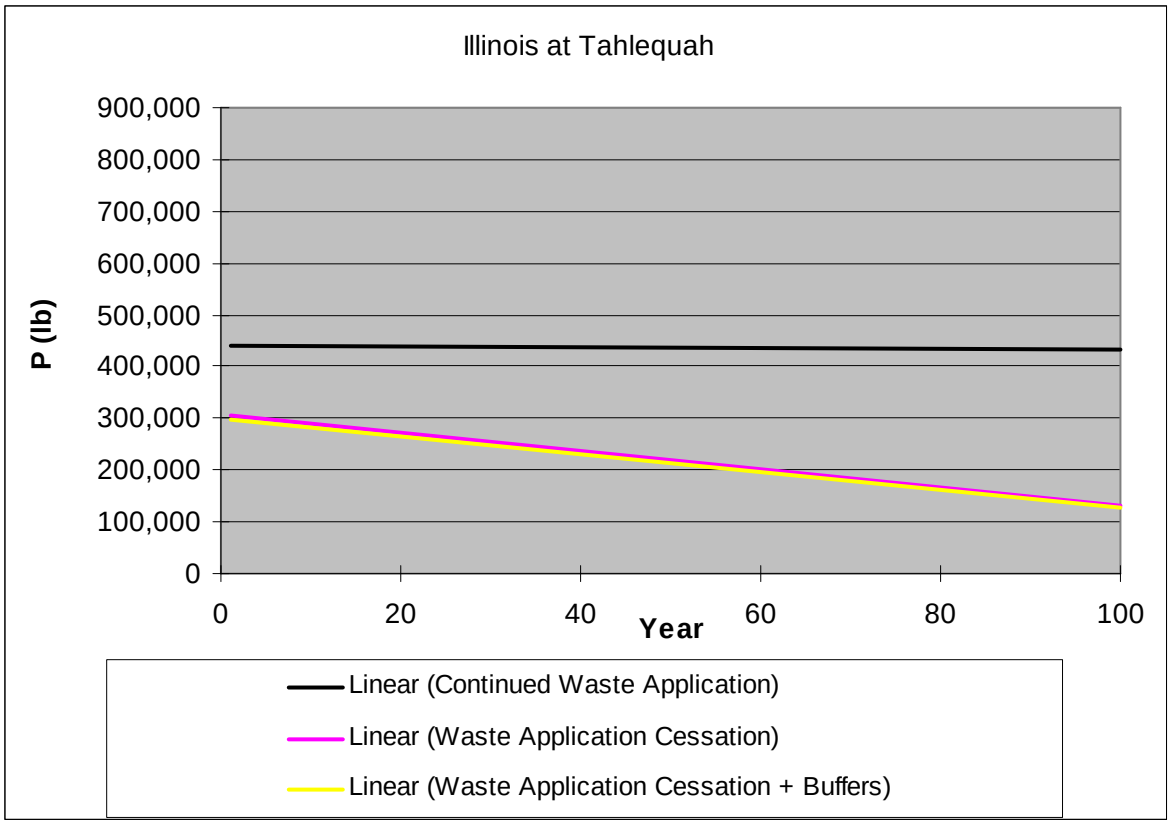


Figure 10.18. P Load Trend Lines at Tahlequah for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

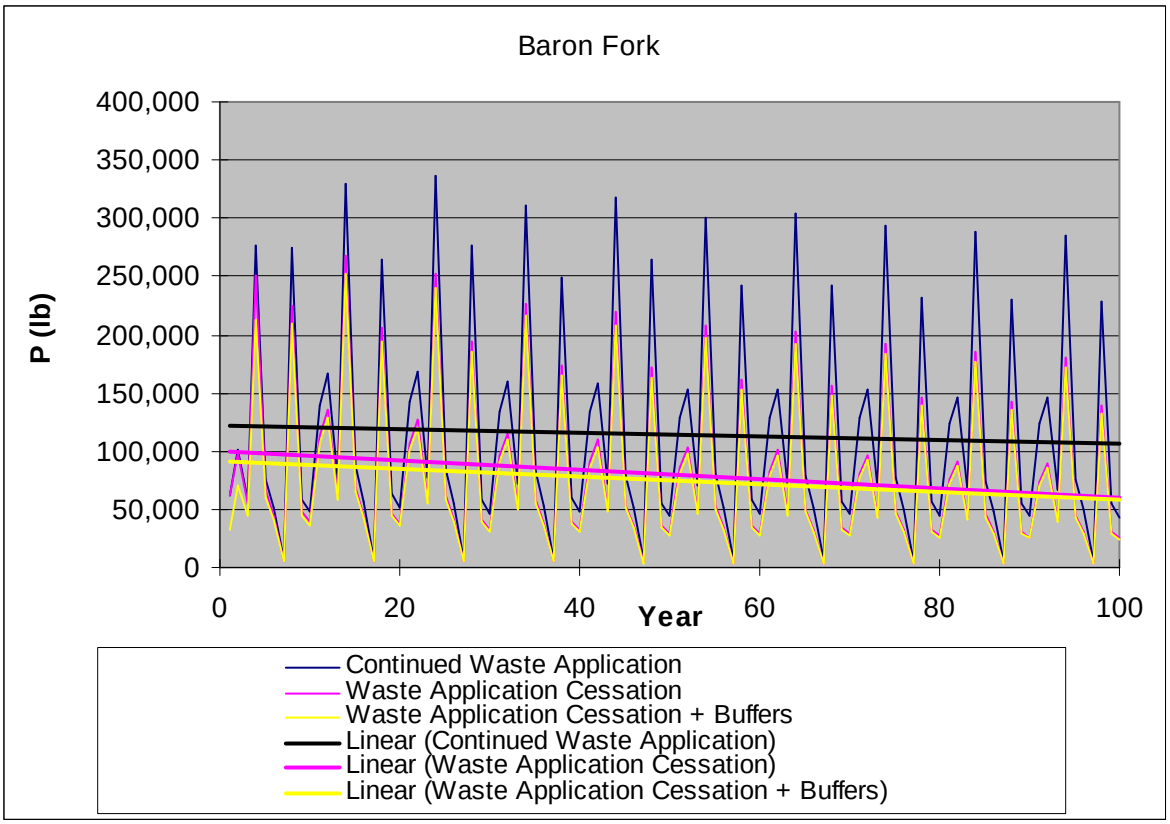


Figure 10.19. P Loads at Baron Fork Near Eldon for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

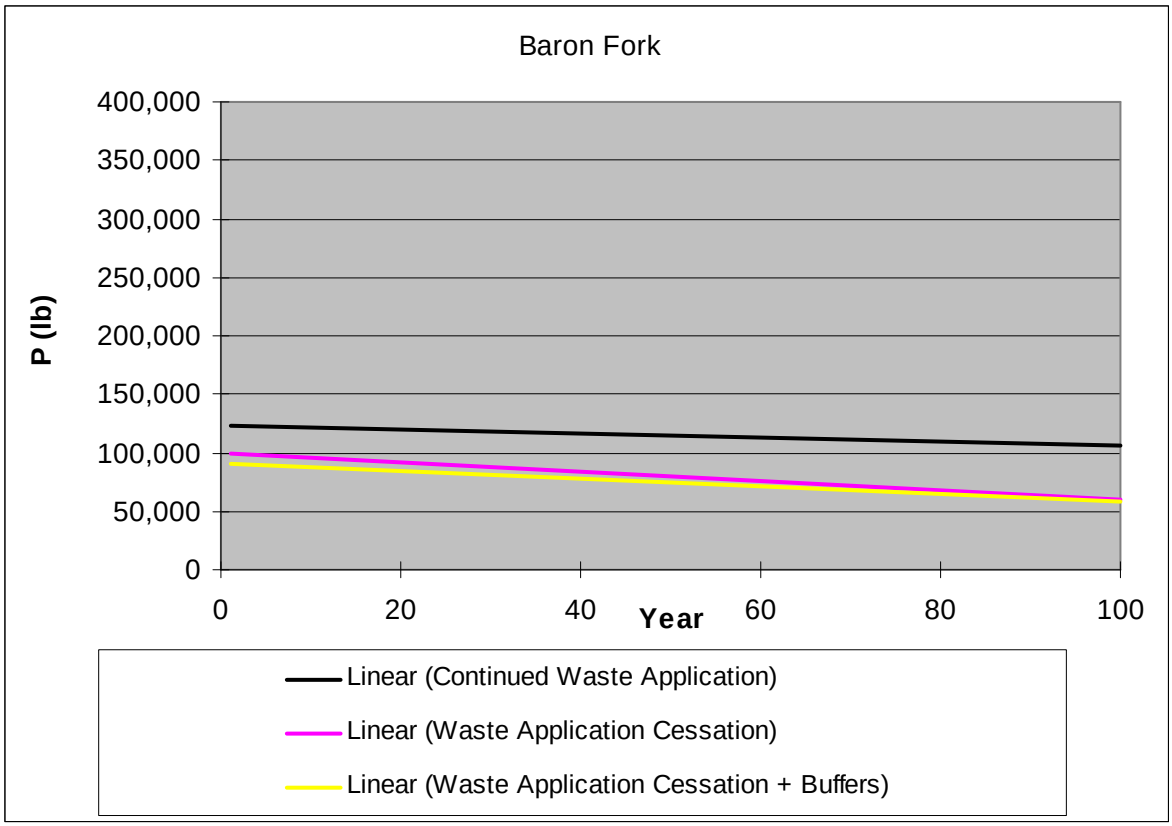


Figure 10.20. P Load Trend Lines at Baron Fork Near Eldon for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

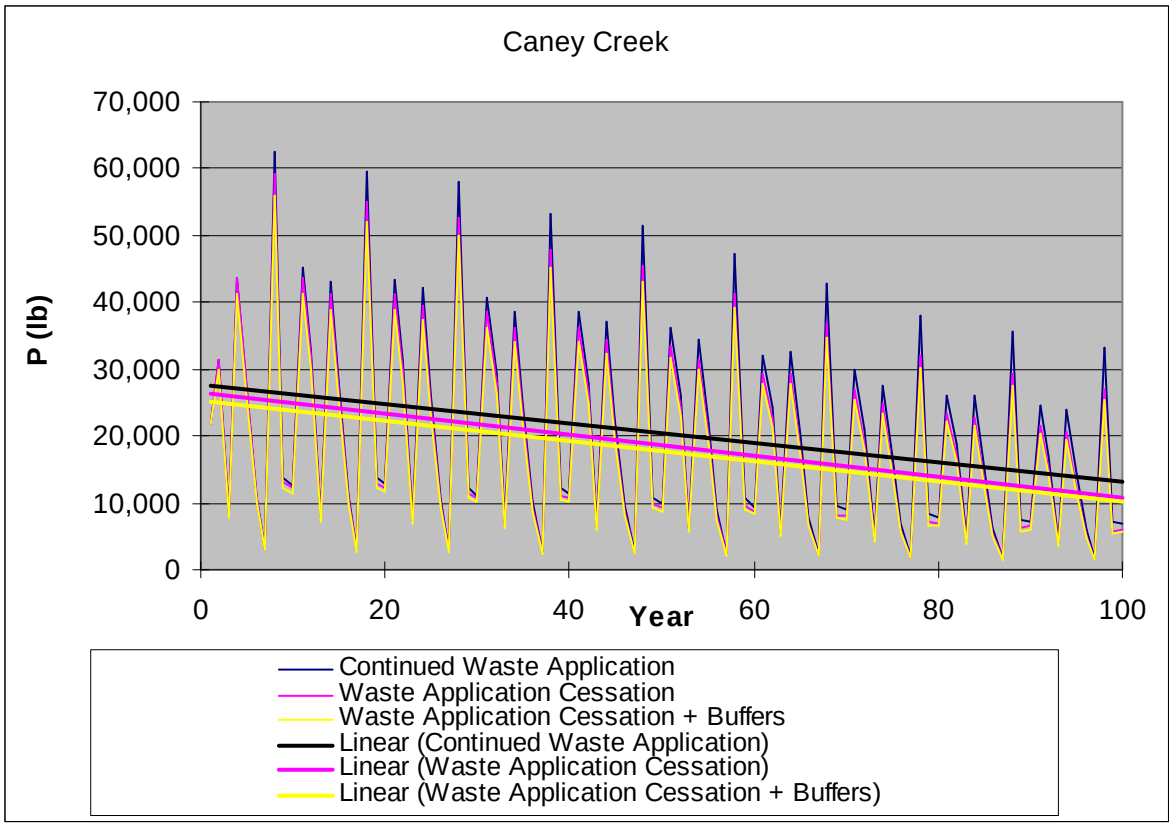


Figure 10.21. P Loads at Caney Creek for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

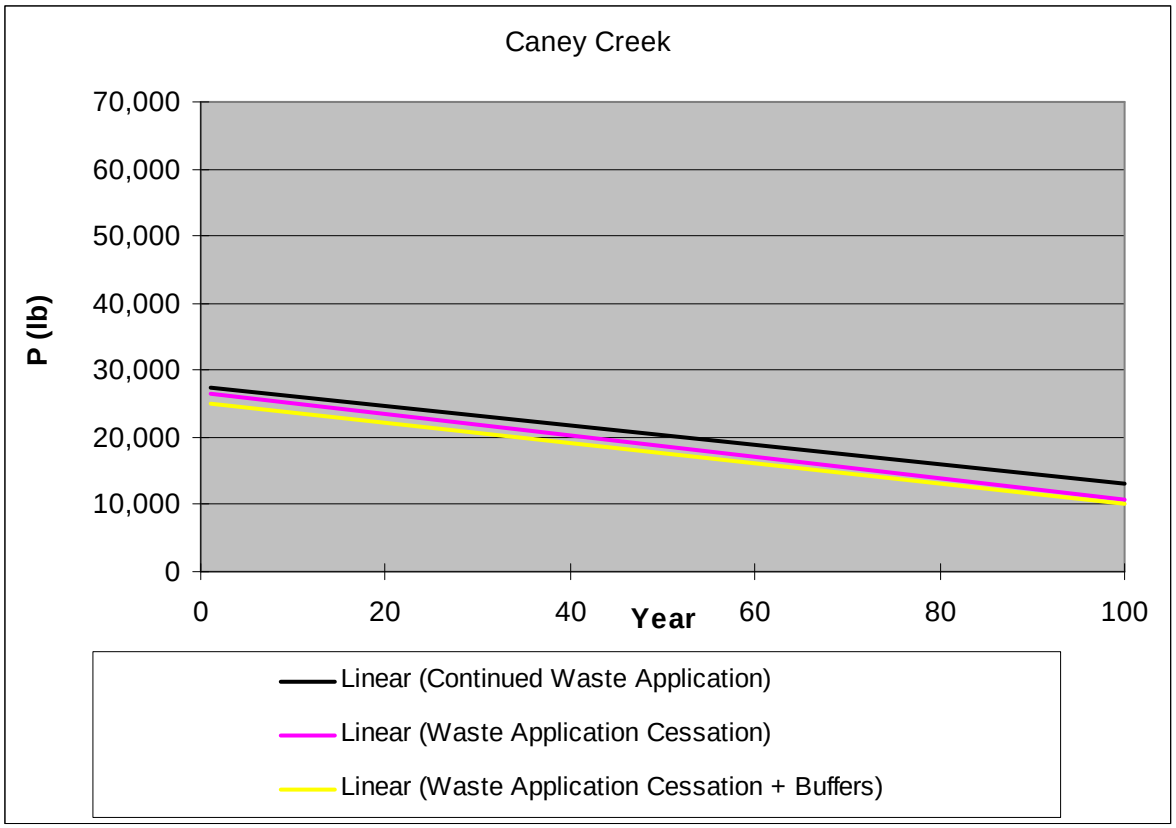


Figure 10.22. P Load Trends at Caney Creek for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

Table 10.8. P Loads for Poultry Waste Cessation and Poultry Waste Cessation Combined with Buffers Along Third Order and Larger Streams in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	P Loads (lbs)					
Years	Tahlequah	Baron	Caney	Total	Total (Cessation Only)	Buffer Reduction (%)
1-10	3,133,605	757,634	218,815	4,110,054	4,343,485	5.4
11-20	2,689,217	933,909	231,133	3,854,259	4,019,937	4.1
21-30	2,423,927	873,672	216,971	3,514,570	3,658,654	3.9
31-40	2,191,768	795,600	202,047	3,189,414	3,315,579	3.8
41-50	2,030,388	760,109	188,671	2,979,167	3,093,820	3.7
51-60	1,891,768	724,197	175,071	2,791,037	2,895,368	3.6
61-70	1,780,790	703,274	157,327	2,641,391	2,737,468	3.5
71-80	1,695,237	669,183	136,005	2,500,425	2,588,668	3.4
81-90	1,650,338	642,659	122,352	2,415,349	2,498,852	3.3
91-100	1,616,287	628,752	111,958	2,356,997	2,437,254	3.3

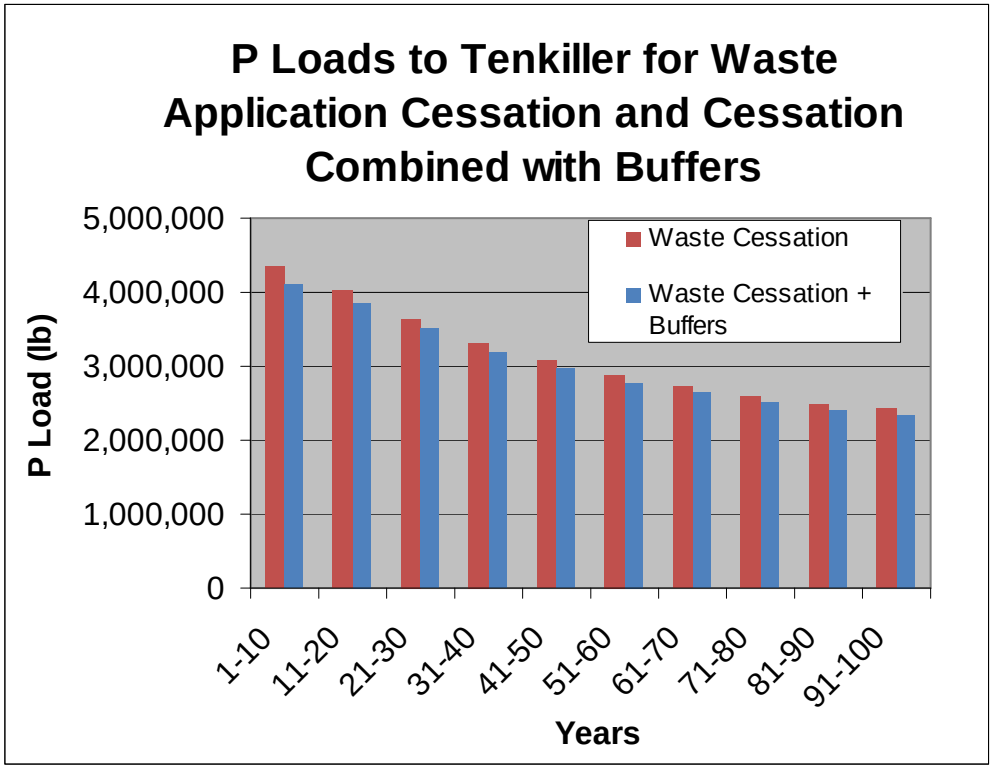


Figure 10.23. P Loads to Lake Tenkiller for Poultry Waste Application Cessation and Cessation Combined with Buffers Along Third Order Streams with Pastures. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

P loads were computed at three locations entering Lake Tenkiller (Tahlequah, Baron Fork at Eldon, and Caney Creek) for combined poultry waste land application cessation and 100 foot buffers placed along *all streams and rivers* with adjacent pasture (Figure 10.24 and Table 10.9). The buffers would provide approximately 10-13% additional reduction in P loads beyond cessation of poultry waste application in the IRW (Table 10.9).

Table 10.9. P Loads for Poultry Waste Cessation and Poultry Waste Cessation Combined with Buffers Along *All Streams* with Pasture in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	P Load (lbs)					
Years	Tahlequah	Baron	Caney	Total	Total (Cessation Only)	Buffer Reduction (%)
1-10	2,950,892	681,686	192,838	3,825,416	4,343,485	11.9
11-20	2,472,310	826,213	200,674	3,499,198	4,019,937	13
21-30	2,235,679	772,673	188,473	3,196,825	3,658,654	12.6
31-40	2,031,210	703,927	175,631	2,910,769	3,315,579	12.2
41-50	1,889,161	672,674	164,107	2,725,943	3,093,820	11.9
51-60	1,767,155	641,064	152,402	2,560,620	2,895,368	11.6
61-70	1,669,441	622,649	137,128	2,429,217	2,737,468	11.3
71-80	1,594,166	592,629	118,763	2,305,558	2,588,668	10.9
81-90	1,554,654	569,287	107,015	2,230,956	2,498,852	10.7
91-100	1,524,670	557,038	98,060	2,179,768	2,437,254	10.6

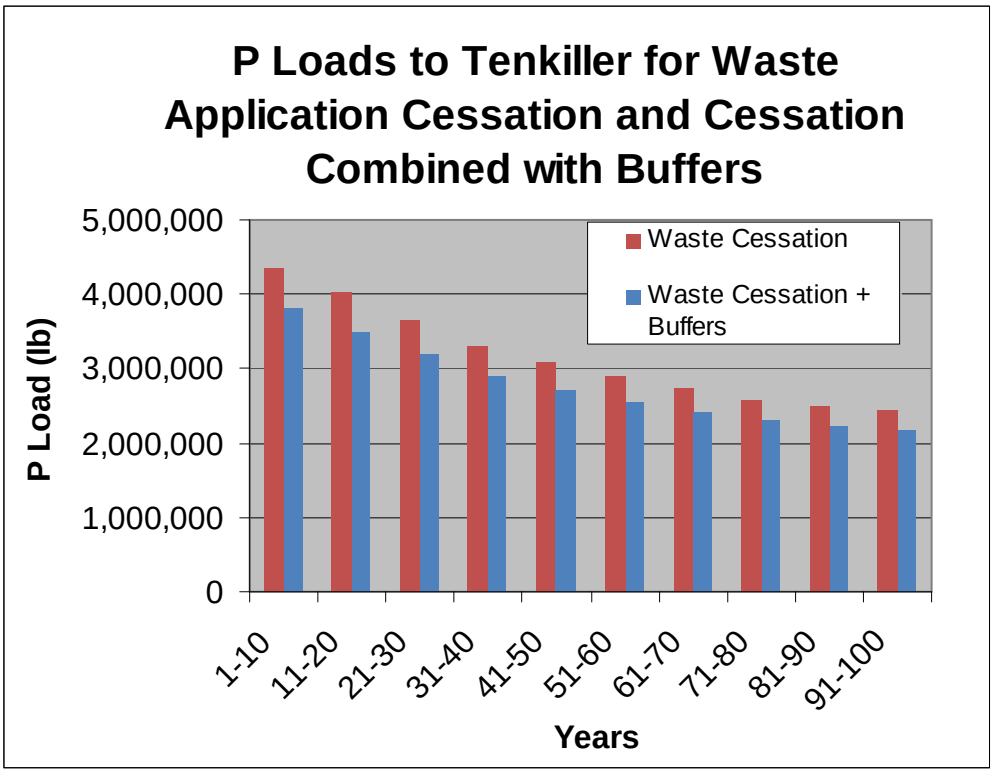


Figure 10.24. P Loads to Lake Tenkiller for Poultry Waste Application Cessation and Cessation Combined with Buffers Along *All Streams* with Pastures. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

10.5 P Loads in Illinois River Watershed Streams and Rivers Assuming No Historic or Current Poultry Operations of the Defendants

P loads to Lake Tenkiller would be more than 275,000 lbs less than current levels (less than ½ of current levels) if poultry waste had never been disposed of in the IRW. It would take approximately 100 years of cessation of poultry waste application to return P loads in the IRW to what they would have been if no poultry waste land application had occurred.

Figures 10.25-10.30 show the P loads at the three gauging stations (Tahlequah, Baron Fork at Eldon and Caney Creek) assuming no historic or current poultry operations in the IRW. This assumes no poultry industry and therefore no poultry waste application in the IRW (e.g., no poultry waste application ever). It also assumes present (2003 and later) WWTP P loads continuing into the future. This will show the present and future state of P loads in the IRW surface waters assuming the defendants poultry operations never existed.

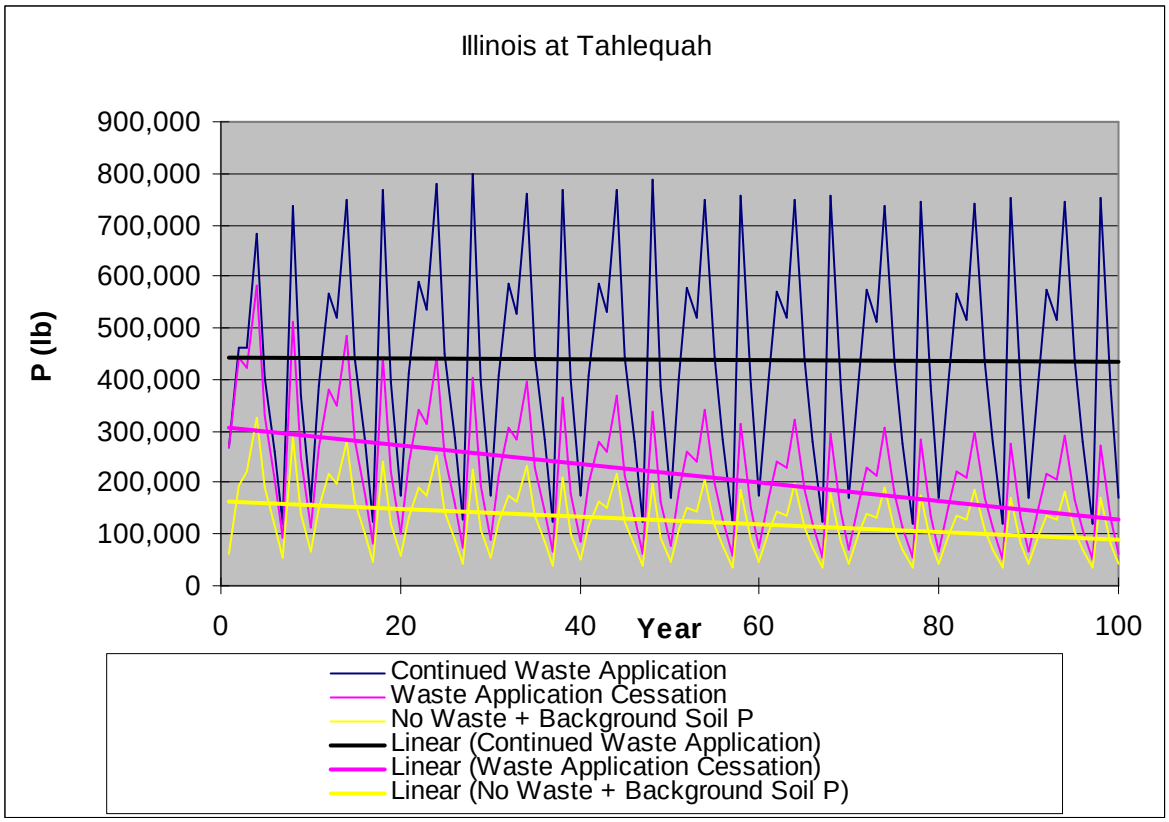


Figure 10.25. P Loads at Tahlequah for Background Soil P Levels with No Poultry Waste Application in the IRW.

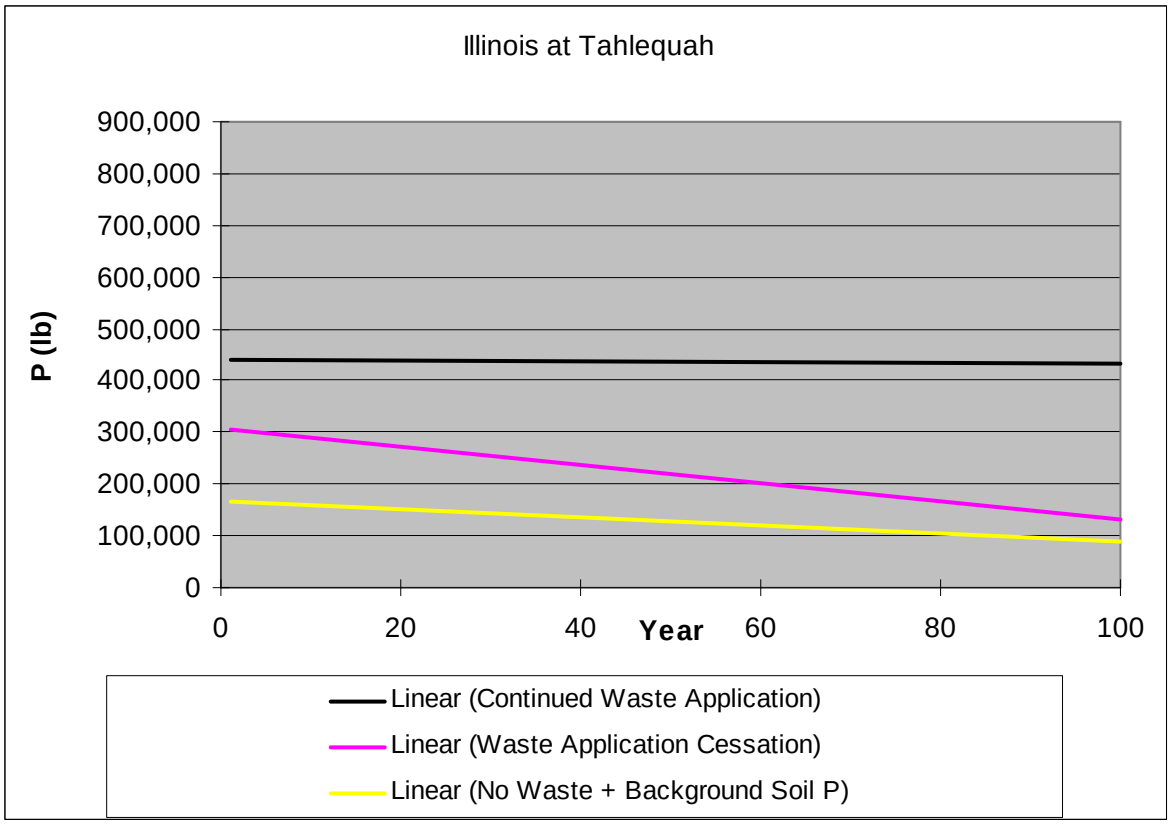


Figure 10.26. P Load Trend at Tahlequah for Background Soil P Levels with No Poultry Waste Application in the IRW.

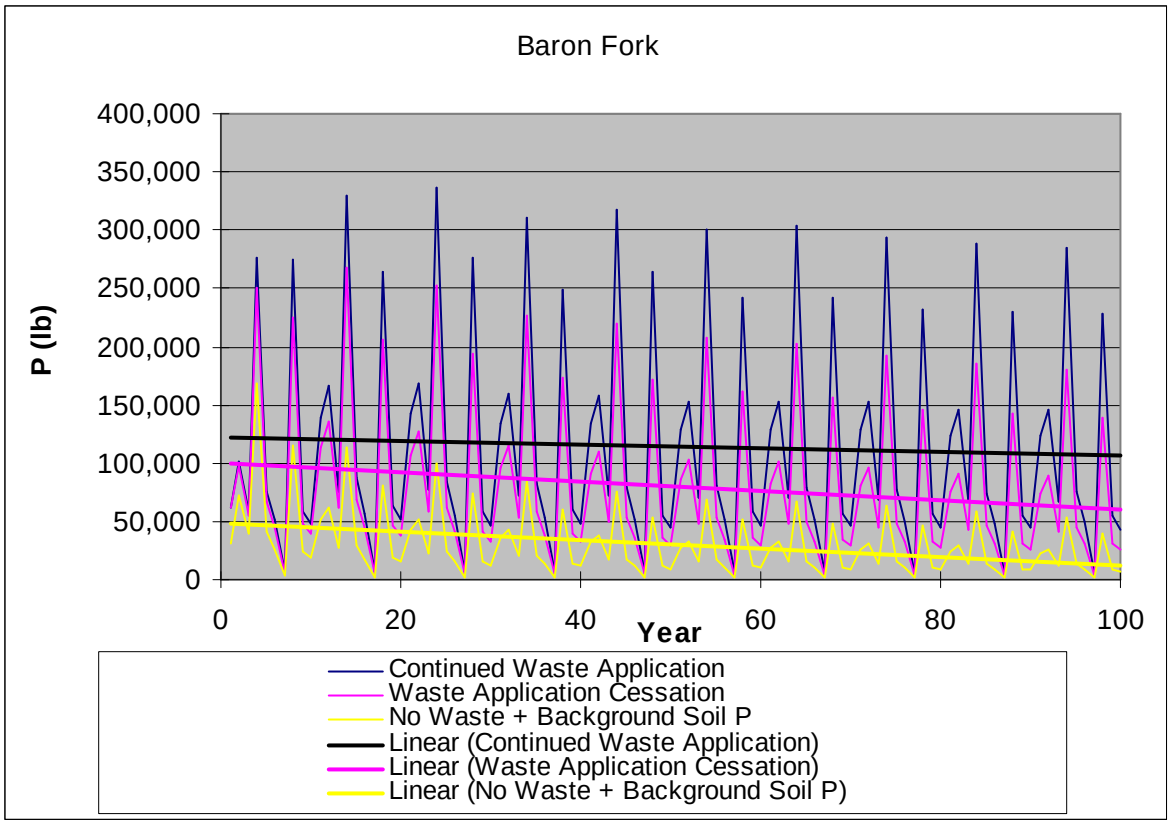


Figure 10.27. P Loads at Baron Fork near Eldon for Background Soil P Levels with No Poultry Waste Application in the IRW.

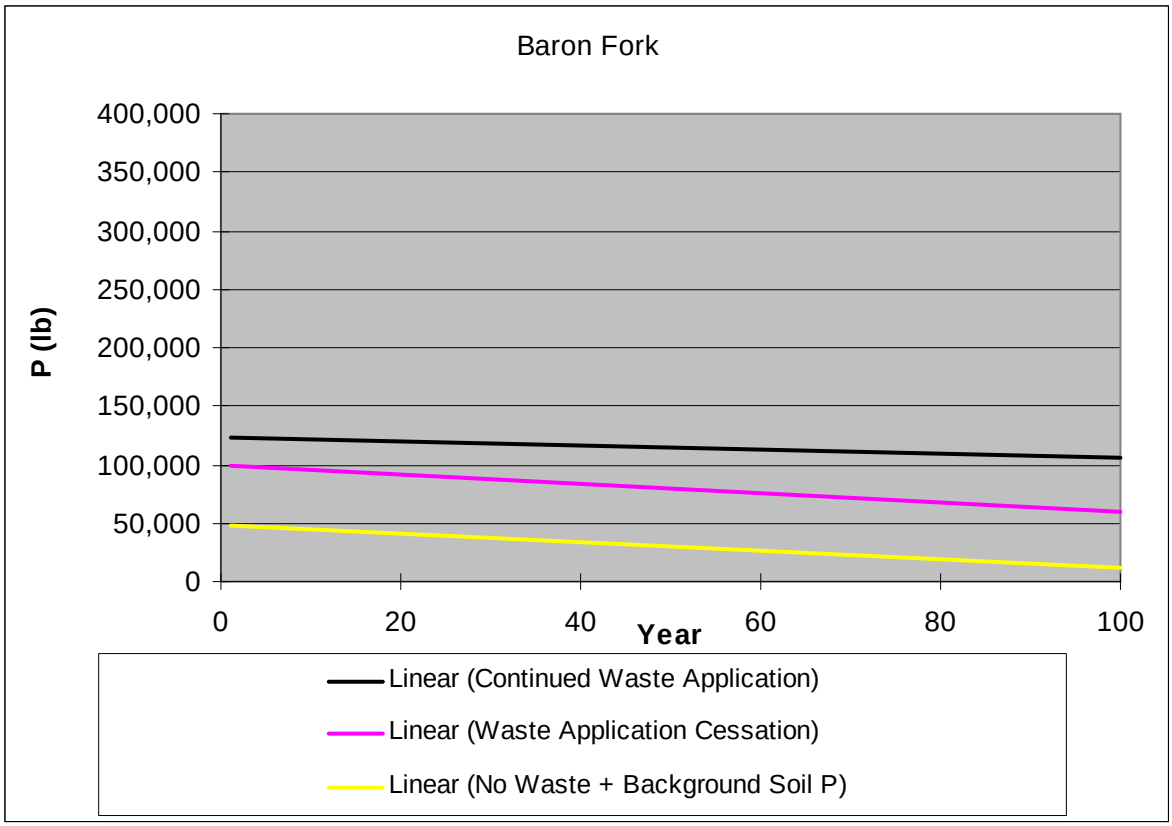


Figure 10.28. P Load Trend at Baron Fork near Eldon for Background Soil P Levels with No Poultry Waste Application in the IRW.

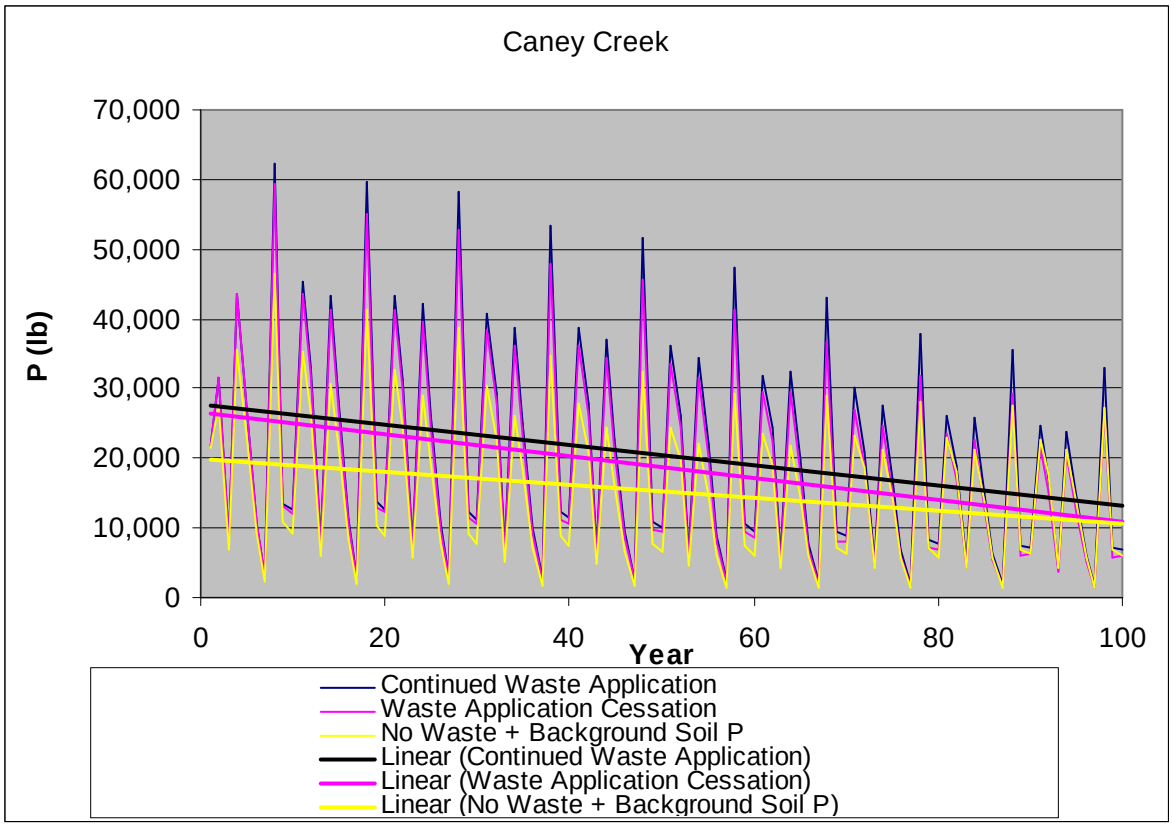


Figure 10.29. P Loads at Caney Creek for Background Soil P Levels with No Poultry Waste Application in the IRW.

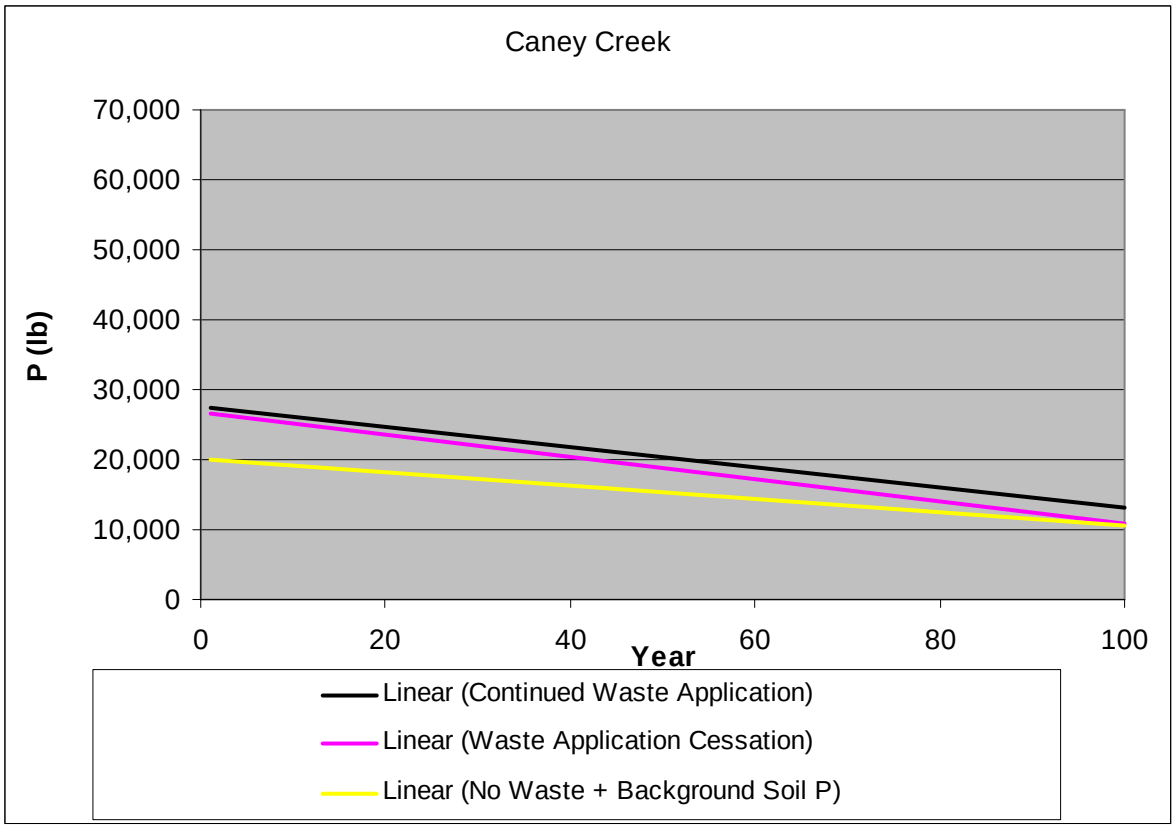


Figure 10.30. P Load Trend at Caney Creek for Background Soil P Levels with No Poultry Waste Application in the IRW.

The P loads for this scenario at Tahlequah indicate P loads would be substantially less (more than 275,000 lbs annually) than those for continued poultry waste application. The P loads for the background scenario would also remain approximately 150,000 lbs annually greater than poultry waste spreading cessation, narrowing to about 50,000 lbs annually after 100 years. This is due to the vast amount of P that has accumulated in IRW soils due to excessive poultry waste application (see Section 7. Phosphorus Mass Balance and see Johnson, 2008).

Differences between background P loads at Baron Fork near Eldon and continued poultry waste application would be approximately 75,000 lbs annually. The difference between background P loads and those with poultry waste application cessation would be approximately 50,000 lbs annually.

Differences in background P loads for the Caney Creek gauging location and continued poultry waste application would be small due to the limited poultry waste application in this watershed.

Table 10.10 summarizes the results for no historic or current poultry operations in the IRW and for poultry waste application cessation in the IRW. The P loads for no historic or current poultry operations in the IRW would decline over time due to P removal from the system (P loads to Lake Tenkiller and cattle). Even after 100 years, the waste cessation scenario indicates expected P loads to Lake Tenkiller would be greater than the P load for no historic or current poultry

operations in the IRW (years 1-10). Thus, even after 100 years of poultry waste application cessation in the IRW, the elevated soil P levels due to historic poultry waste application would continue to contribute to P loads to IRW waters.

Table 10.10. P Loads to IRW Waters with No Poultry Waste Application and Total P Load to Lake Tenkiller for Poultry Waste Application Cessation. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

	P Load (lbs)				
Years	Tahlequah	Baron	Caney	No Application Total	Total (Cessation)
1-10	1,593,185	517,044	183,305	2,293,534	4,343,485
11-20	1,577,197	418,569	191,028	2,186,795	4,019,937
21-30	1,416,532	360,511	177,237	1,954,279	3,658,654
31-40	1,316,867	305,908	162,427	1,785,203	3,315,579
41-50	1,232,647	268,748	149,734	1,651,129	3,093,820
51-60	1,155,226	245,471	136,380	1,537,077	2,895,368
61-70	1,112,297	238,307	132,631	1,483,235	2,737,468
71-80	1,077,848	225,995	130,736	1,434,579	2,588,668
81-90	1,057,895	208,819	128,060	1,394,774	2,498,852
91-100	1,044,273	192,647	127,000	1,363,920	2,437,254

10.6 Historical P Loads in Illinois River Watershed Streams and Rivers

P loads to Lake Tenkiller since 1954 have increased at approximately 10,000 lbs per year. Poultry waste application in the IRW is responsible for approximately 6,600 lbs of this increase each year.

P loads to the 3 gauging stations (Tahlequah, Baron Fork, and Caney Creek) were modeled using the same approach that has been used for modeling of results presented in prior sections. Soil P levels were assumed to be equivalent to current levels in Sequoyah County which would be considered equivalent to soil P levels for the entire watershed in 1950. WWTP P discharges were included as described in the WWTP section for 1950 through 1999 (Table 6.3). Poultry P applications to pastures in the IRW were based on historical poultry production in the watershed (Section 7).

Figures 10.31-10.33 show the modeled P loads from the IRW from 1950-1999. The trend line at the Tahlequah indicates P loads increase approximately 9,200 lbs/year and at Baron Fork by approximately 770 lbs/year. The Caney Creek watershed showed little change in P loads over this 50 year period, since its pastures received little poultry waste over this period.

Stow et al. (2001) computed historical nutrient loads in a watershed using a similar approach. Nutrient inputs to the watershed were computed for a more than 100 year period. WWTP nutrient inputs were computed using a similar approach as used within this report. Using the

nutrient inputs and historical nutrient trends in observed river water, nutrient concentrations were computed.

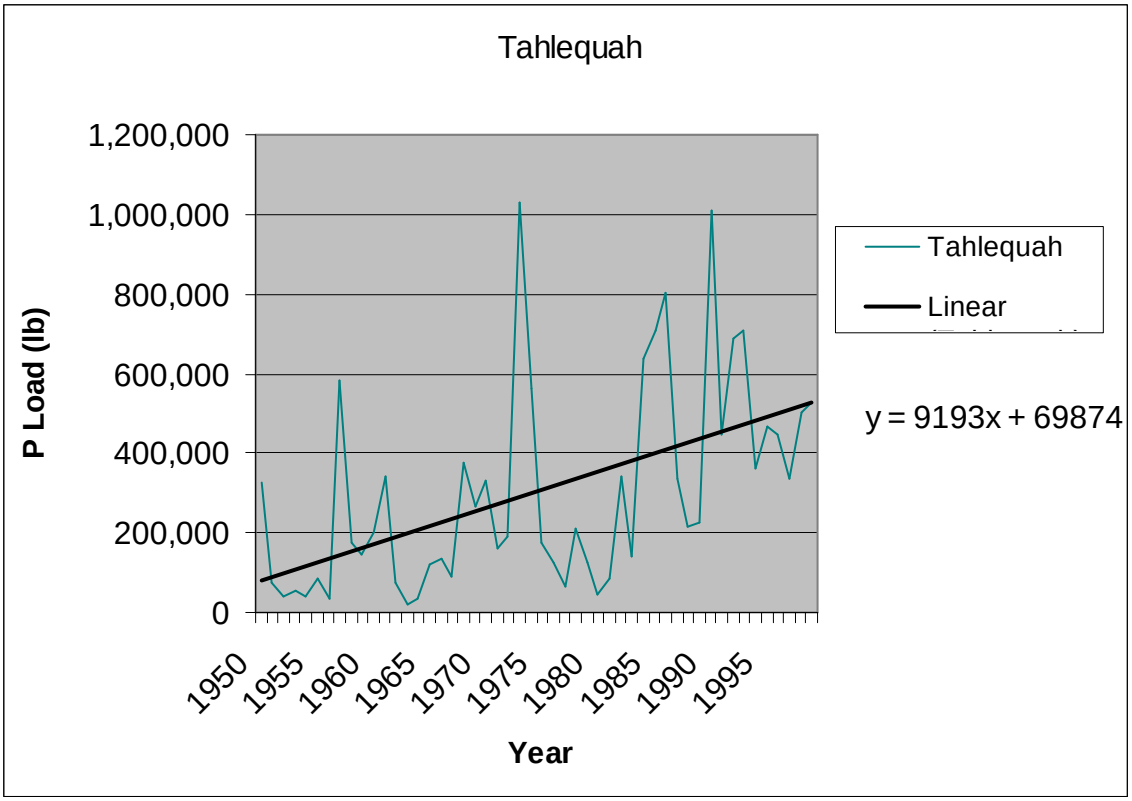


Figure 10.31. Modeled P Load and P Load Trend Line to Tahlequah from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

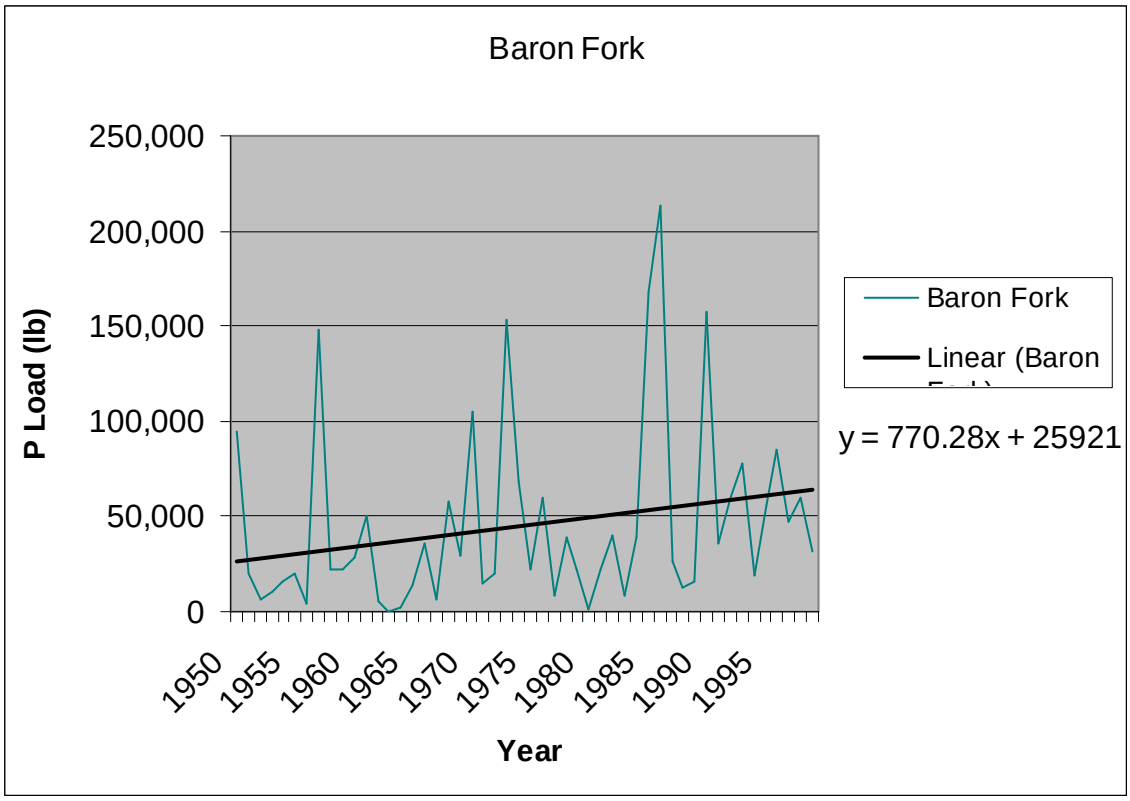


Figure 10.32. Modeled P Load and P Load Trend Line to Baron Fork near Eldon from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

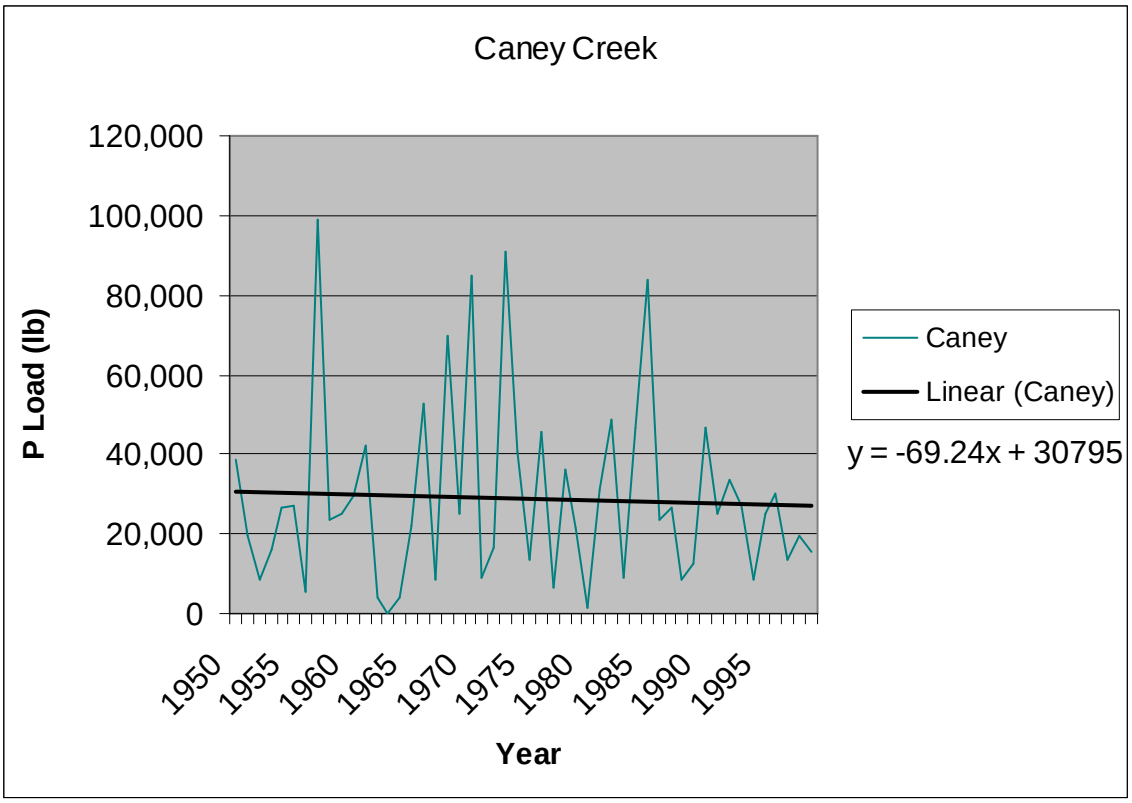


Figure 10.33. Modeled P Load and P Load Trend Line to Caney Creek from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

The NPS P loads from 1950 through 1999 are shown in Figures 10.34-10.36 for Tahlequah, Baron Fork at Eldon and Caney Creek. The WWTP P loads were not included in the results shown in Figures 10.34-10.36. The trend lines indicate P loads increase 6,700 lbs annually due to NPS sources. Nearly all of the increased P load is attributable to poultry waste application in the IRW (see P inputs into the IRW as documented in the Mass Balance Analysis in Appendix B).

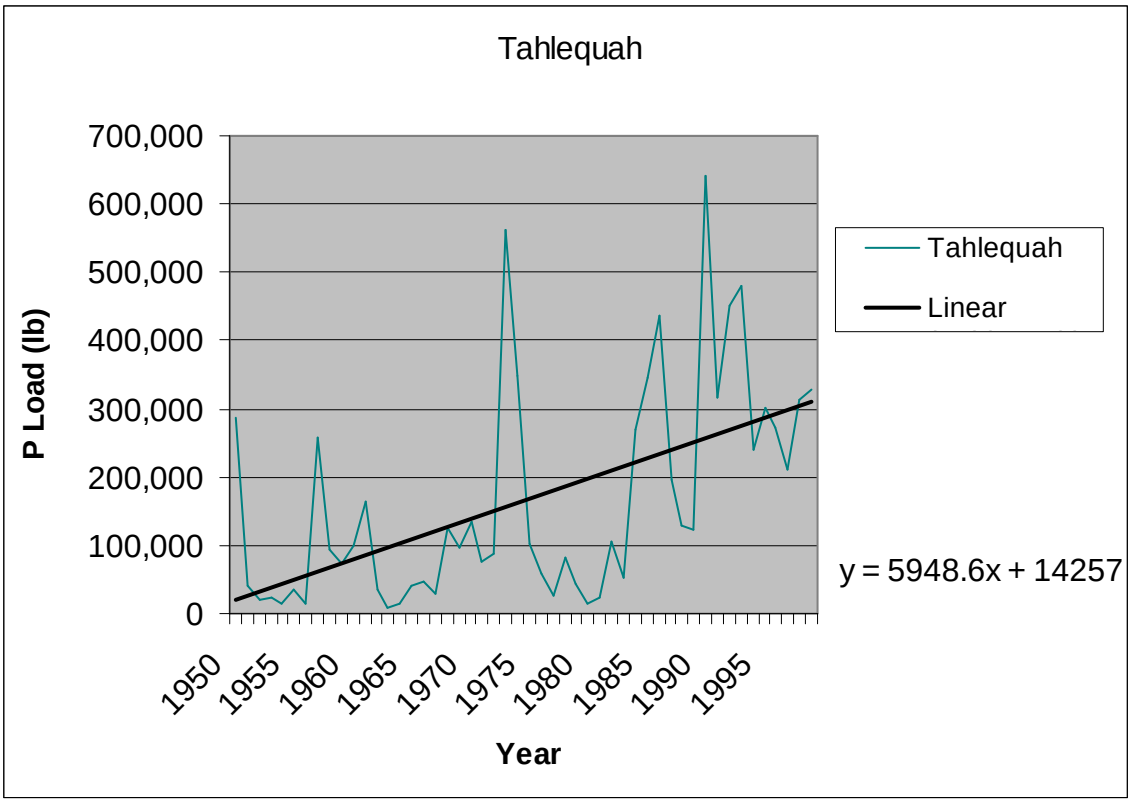


Figure 10.34. Modeled NPS P Load and NPS P Load Trend Line at Tahlequah from 1950 to 1999 Using IRW Poultry Production Data

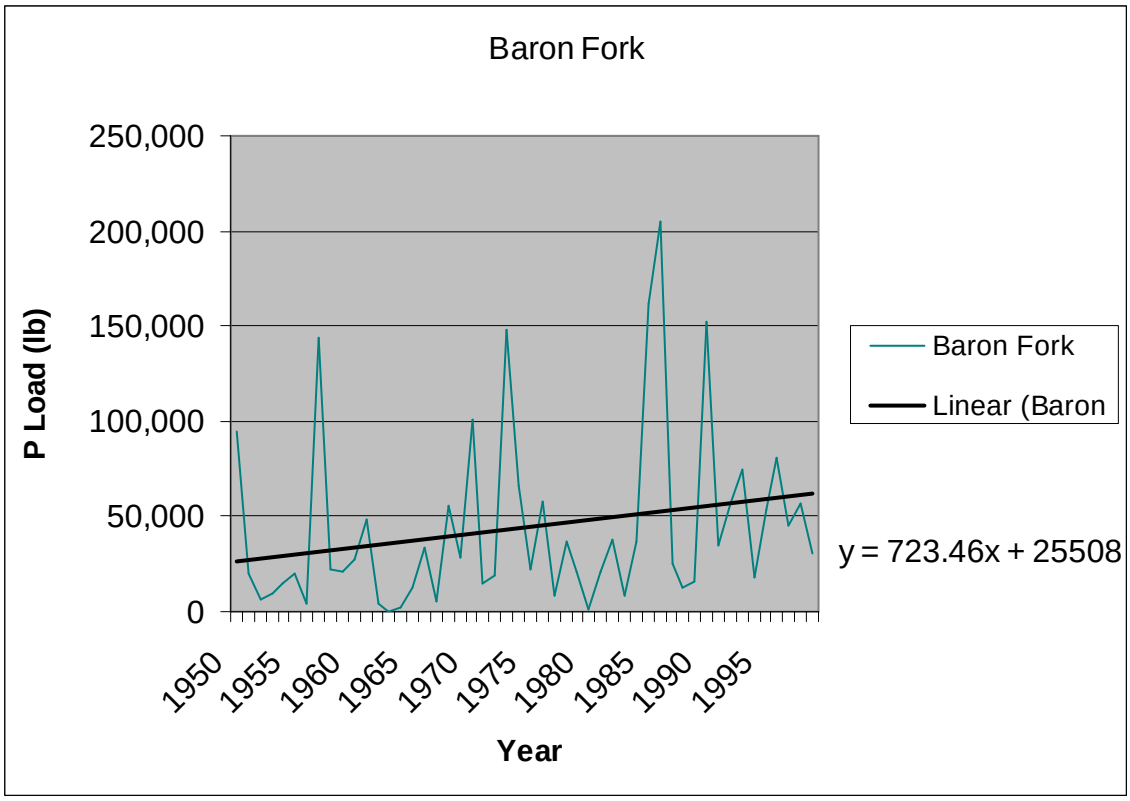


Figure 10.35. Modeled NPS P Load and NPS P Load Trend Line to Baron Fork Near Eldon from 1950 to 1999 Using IRW Poultry Production Data

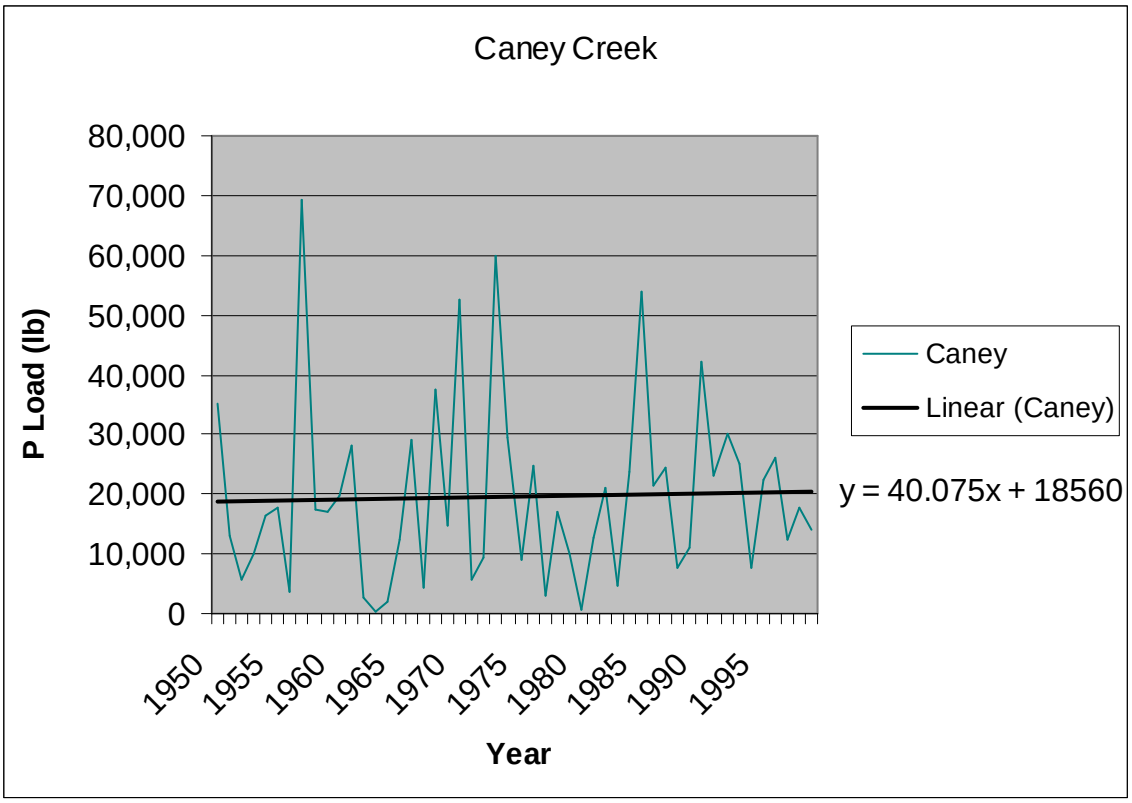


Figure 10.36. Modeled NPS P Load and NPS P Load Trend Line to Caney Creek from 1950 to 1999 Using IRW Poultry Production Data

Average annual historical P concentrations for March-June and July-September were computed for the Tahlequah and Baron Fork locations in support of Dr. Jan Stevens' analysis. Average concentrations were computed based on daily concentrations for each of the analyses periods. Figures 10.37 and 10.38 show P concentrations at Tahlequah for March-June and July-September, respectively. Average concentrations were computed based on daily concentrations for each of the analyses periods. Figures 10.39 and 10.40 show P concentrations at Baron Fork for March-June and July-September, respectively. The P concentration trends for these periods are similar to annual P load trends.

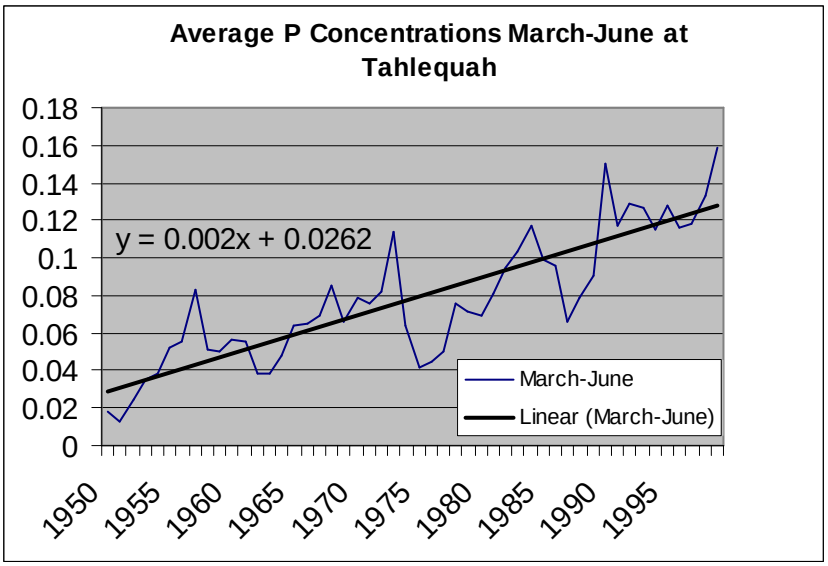


Figure 10.37. Average P Concentrations for March-June Annually at Tahlequah from 1950 Through 1999 Using IRW Poultry Production Data

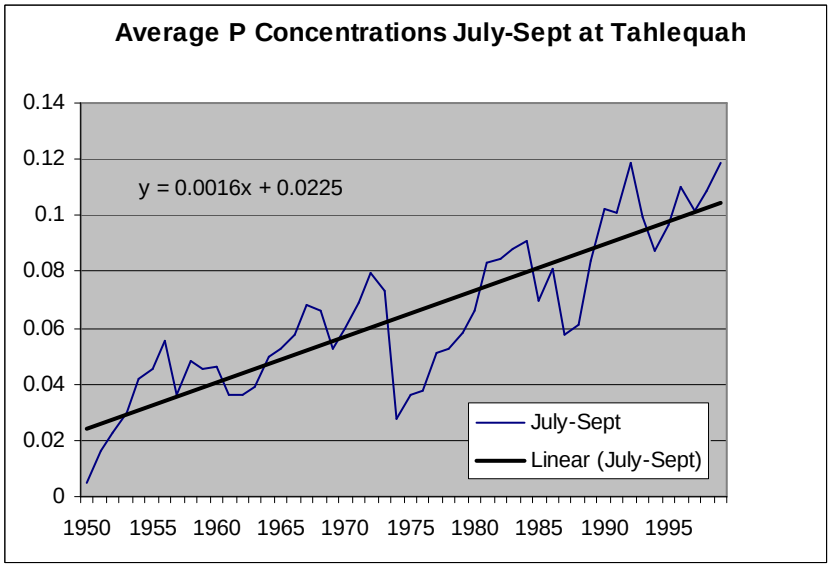


Figure 10.38. Average P Concentrations for July-September Annually at Tahlequah from 1950 Through 1999 Using IRW Poultry Production Data

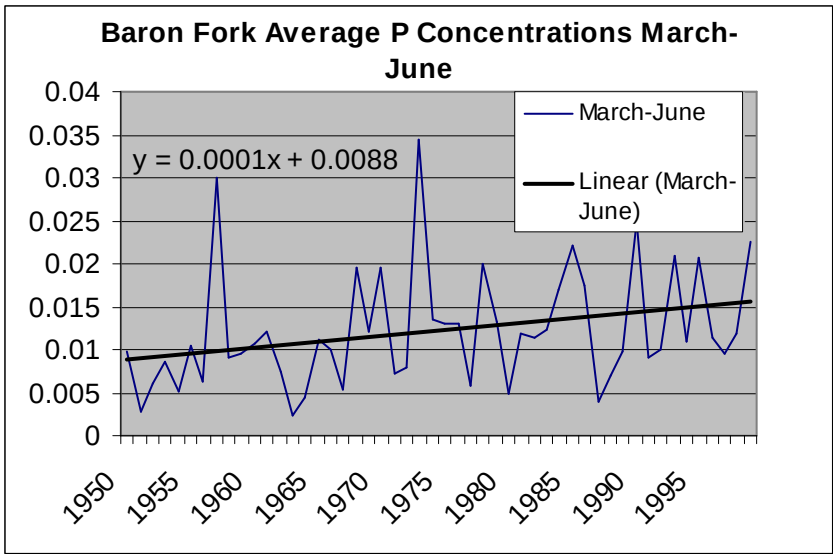


Figure 10.39. Average P Concentrations for March-June Annually at Baron Fork from 1950 Through 1999 Using IRW Poultry Production Data

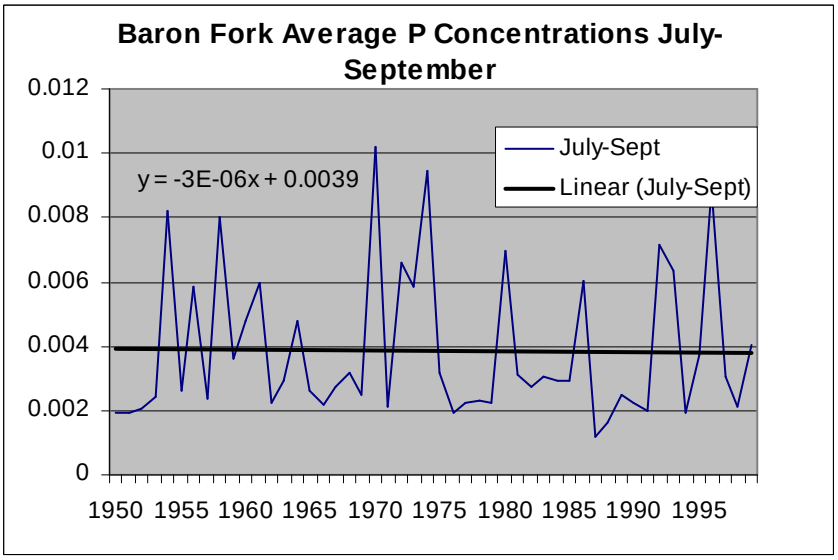


Figure 10.40. Average P Concentrations for July-September Annually at Baron Fork from 1950 Through 1999 Using IRW Poultry Production Data

10.7 Statistical Analysis of P Loads

A statistical analysis of the modeled P loads was conducted to determine if the P loads for the scenarios were statistically different. Both parametric (ANOVA) and nonparametric (Kruskal-Wallis Test) analyses were completed for each of the scenarios at each of the sites (Tahlequah, Baron Fork, and Caney).

For each location, boxplot exploratory data analysis (EDA) was used to gain insight of the distribution of the daily P losses. This was done to ensure that assumptions and constraints of Gaussian statistical procedures were not violated. For example, the validity of parametric tests such as Analysis of Variance (ANOVA) requires that the data follow a Gaussian distribution with constant variance (Montgomery, 2004). If the model assumptions of normality and constant variance are violated, then nonparametric testing procedures are usually more robust. However, in practice, an alternative approach to nonparametric tests involves the application of logarithmic transformation to the data; thereby, facilitating the use of parametric test for further analysis. This procedure stabilizes the variance while creating a distribution closer to normality. It is useful especially in cases where the data set have large or very small values. The data were log transformed for use with the parametric tests.

The ANOVA analyses and multiple comparison tests were generated using SAS/STAT® software, version 9.1.3 (SAS, 2004). The test statistics was based on the following hypothesis:
H_0: $\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = \tau_6 = 0$ versus H_1: at least one treatment is not equal
where,

H_0 = null hypothesis
H_1 = alternative hypothesis
τ_1= effects of continue waste application
τ_2= effects of waste application cessation
τ_3= effects of growth
τ_4= effects of no waste ever
τ_5= effects of waste cessation and buffer along third order and above streams
τ_6= effects of waste cessation and buffers along all streams

Tukey multiple comparison indicates that P loads for each of the six scenarios for Tahlequah and Baron Fork were statistically different (Tables 10.11 and 10.12). For Caney Creek scenarios, the P loads for 'Waste Cessation + Buffer All' (waste application cessation and buffers along all streams and rivers) and 'No Waste Background P' (no poultry waste application ever in the watershed) were not significantly ($\alpha < 0.05$) different; however, all other P loads for Caney Creek scenarios were significantly different from each other (Table 10.13).

The statistical analyses indicate the continued growth in the poultry industry within the IRW and land application of poultry waste would provide the largest P loads, continued poultry waste application would provide the next largest P loads, and cessation of land application would provide the next largest loads. Cessation of waste application with buffers along third order streams would provide the next largest loads and waste application cessation with buffers along all streams would provide the next largest P loads. The lowest P loads occur for the case in which no poultry waste application was ever applied within the IRW.

Table 10.11. Statistical summary of phosphorus scenarios based on daily P output for Illinois River at Tahlequah

Treatment	N	Mean Daily P Load (lb)
Continue Waste Application	36525	543.69[a]
Waste Cessation	36525	270.00[b]
50 Year Growth	18300	876.26[c]
No Waste Background P	36525	156.44[d]
Waste Cessation + Buffer	36525	262.07[e]
Waste Cessation + Buffer All	36525	244.51[f]

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

Table 10.12. Statistical summary of phosphorus scenarios based on daily P output for Baron Fork near Eldon

Treatment	N	Mean Daily P Load (lb)
Continue Waste Application	36525	141.64[a]
Waste Cessation	36525	99.16[b]
50 Year Growth	18300	172.58[c]
No Waste Background P	36525	37.04[d]
Waste Cessation + Buffer	36525	93.00[e]
Waste Cessation + Buffer All	36525	82.46[f]

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

Table 10.13. Statistical summary of phosphorus scenarios based on daily P output for Caney Creek

Treatment	N	Mean Daily P Load (lb)
Continue Waste Application	36525	25.18[a]
Waste Cessation	36525	23.13[b]
50 Year Growth	18300	29.63[c]
No Waste Background P	36525	18.89[d]
Waste Cessation + Buffer	36525	21.86[e]
Waste Cessation + Buffer All	36525	19.06[d]

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

10.8 Allocation of P to Sources

Poultry waste land application in the IRW is a substantial contributor (45% between 1998 and 2006 and 59% between 2003 and 2006) to P loads to Lake Tenkiller, representing the largest P source. WWTP P loads are the second largest contributor to P loads to Lake Tenkiller. Poultry plant discharges to WWTP represent a significant portion of WWTP P loads.

The P contribution of each significant source was determined using the IRW modeling (Appendix D). The P allocation to each source is shown in Tables 10.14 and 10.15. P loads from poultry waste application within the IRW represents 45% of P loads to Lake Tenkiller between 1998 and 2006. Following a change in WWTP technology that reduced WWTP P discharges, poultry waste application in the IRW was responsible for 59% of P loads to Lake Tenkiller for years 2003-2006.

Table 10.14. IRW P Load Allocation to Sources

	WWTP	**Forest**	**Crop**	**Urban**	**Pasture**
1998-2006	30	1	< 1	7	62
2003-2006	15	1	< 1	7	76

Table 10.15. IRW P Load Allocation to Sources

	WWTP					**Pasture**		
	Poultry	**Nonpoultry**	**Forest**	**Crop**	**Urban**	**Cattle Near Streams Only**	**Poultry Only**	**Swine, Dairy, Background**
1998-2006	10	20	1	< 1	7	6	45	11
2003-2006	3	12	1	< 1	7	6	59	11

WWTP discharges are the second largest contributor of P loads representing 30% of P loads between 1998 and 2006 (Table 10.14). A portion of the WWTP P load is attributable to poultry processing discharge to the Springdale WWTP as described in Section 6. Poultry processing discharges released by the Springdale WWTP represent 10% of total P loads to Lake Tenkiller between 1998 and 2006 and 3% of P loads between 2003-2006 (Table 10.15).

Pasture with swine and dairy waste application and background P from pastures is the third largest P load to Lake Tenkiller (Tables 10.14 and 10.15). Runoff from urban areas is the fourth largest contributor at 7% of P loads (Tables 10.14 and 10.15). Cattle in and near streams contribute 6% of P. However, this is almost all poultry P because cattle only facilitate the transport of P (discussion of cattle contributions follows in the next section). Other sources of P loads are responsible for 1% or less of P loads to Lake Tenkiller.

These results are consistent with other reports for the IRW (Section 2 of this report) and with studies for similar watersheds. The Draft TMDL for the IRW and Lake Tenkiller (USEPA Region 6 and Department of Environmental Quality State of Oklahoma, 2001) identified pastures on which poultry waste is applied as being responsible for 56% of P to Lake Tenkiller. Smith et al. (1997) indicated more than 78% of P loads in the IRW were attributable to livestock waste. Storm and White (2003) estimated that poultry waste was responsible for more than 49% of P loads in the Eucha Spavinaw Watershed that has similar conditions to the IRW.

10.8.1 Contribution of Cattle in and Near Streams

Cattle in the IRW recycle P brought into the IRW to feed poultry that is excreted by poultry and land applied to pastures within the IRW. Although the P contribution of cattle is from poultry waste, cattle accelerate the movement of P into IRW streams and rivers when they excrete waste in and near IRW streams. Six percent of P loads to Lake Tenkiller result from cattle in and near IRW streams.

Cattle within the Illinois River Watershed are recycling poultry waste P that has been applied to pastures. For example, nutrients contained in beef cattle manure were ignored by Slaton et al. (2004) as they indicate "a large proportion of these nutrients are obtained from forage and deposited directly (i.e., recycled) to pastures during grazing rather than collected in lagoons or stockpiled from confined animal production facilities." Cattle largely consume grass from pastures and hay produced in the watershed, and thus P is not imported into the watershed in the form of cattle feed with the exception of a small amount of supplemental feed (Section 7 and Appendix B).

The amount of cattle waste and P in that waste were computed as described in Appendix E. Cattle in the IRW produce approximately 319,000 tons of waste annually (dry weight basis). This waste contains approximately 7.8 million lbs of P of which nearly all is recycled P from poultry waste, with the exception of 210,000 lbs of this P that is imported in cattle supplement (Section 7).

Cattle can accelerate the loading of P to surface water when they excrete waste in or near streams. The amount of P deposited by cattle in or near streams was calculated based on the length of streams, pasture near streams, average pasture sizes, cattle in the watershed, and excretion data for cattle in and near streams. Calculated P deposited by cattle in or near (within 10 meters) streams is up to 35,594 lbs/yr (6% of P loads to Tenkiller). Details of the calculations are provided in Appendix F.

10.8.2 Contribution of Septic Systems

The contributions of septic systems to P loads in the IRW are negligible based on the IRW Mass Balance analysis (Section 7 and Appendix B), analysis of P loads from sub-basins within the IRW for 2005 and 2006 (Olsen, 2008 and Appendix G), and analyses of IRW septic systems (e.g., Oklahoma Department of Environmental Quality (1997); Estimated Maximum Contribution of Phosphorus from Septic Systems, Illinois Basin, 1997).

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Rate of Compensation

Dr. Engel's rate of compensation for this case is $165 per hour.

Appendix A

Overview of Related Literature

McDowell, R.W., Sharpley, A.N., Beegle, D.B., Weld, J.L. (2001). "Comparing phosphorus management strategies at a watershed scale." *Journal of Soil and Water Conservation*, 56(4), 306-315.

Starting with the premise that "The ultimate goal of P management is to balance P inputs to farm with outputs in primary production such that no excess P is applied and soil P concentrations are kept at an optimum level for agronomic performance and minimal environmental impact," this article examined three management scenarios of the USDA-EPA *Unified National Strategy for Animal Feeding Operations* to reduce phosphorus from a watershed (p. 306). Using a "site assessment phosphorus index" they found that none of the watershed was at high risk of phosphorus loss and that those areas with medium were near the stream channel. Of the three strategies, the authors endorse the phosphorus index strategy because it can take into account landscape variables that affect phosphorus loss and can "focus on defining, targeting and remediating fields that combine high soil P concentrations with areas of high erosion and overland flow potential," (p. 313). Essentially, this paper endorses the P index management strategy because it can discriminate areas that have the greatest risk of P loss from those that have lower risks of P loss and can, therefore, treat them differently.

Schärer, M., Stamm, C., Vollmer, T., Frossard, E., Oberson, A., Flühler, H., Sinaj, S. (2007). "Reducing phosphorus losses from over-fertilized grassland soils proves difficult in the short term." *Soil Use and Management*, 23(1), 154-164.

This article examines three management options for reducing P runoff from grassland soils. They found that, although omitting the application of P fertilizer would reduce soil P in the long term, more drastic measures were needed to achieve P loss reductions in the short term. They found that establishing a new P equilibrium in the soil takes years and cannot be accelerated, so it is especially important to stop further build-up of P as soon as possible. So, the article essentially says that short-term treatments are inadequate to solve the problem, so stopping further P from being applied is extremely important and is probably the only way to solve the problem.

Hansen, N.C., Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (2002). "The fate and transport of phosphorus in agricultural systems." *Journal of Soil and Water Conservation*, 57(6), 408-417.

This article investigates the importance of each transport pathway (runoff, soil interflow, deep leaching) as affected by soil type and management. The paper notes that it can take "many years to reduce P concentration in soils with a high STP concentration" (415). The ultimate conclusion that they reach for reducing P losses is site risk assessment; identifying sites with a high potential of P movement to surface water and then implementing management practices to reduce P losses from those sites.

Edwards, D.R., Daniel, T.C., Scott, H.D., Moore Jr., P.A, Murdoch, J.F., Vendrell, P.F. (1997). "Effect of BMP implementation on storm flow quality of two northwestern Arkansas streams." *American Society of Agricultural Engineers*, 40(5), 1311-1319.

This article examined whether a program of Best Management Practice (BMP) is effective at reducing storm stream flow concentrations and mass transport of nutrients. They found that significant decreases (from 23 to 75% per year) in both concentrations and mass transport of nutrients occurred concurrently with BMP implementation.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32(1), 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations. They found that the application rate of manure was related to runoff P due to increased concentrations of dissolved reactive phosphorus in runoff. That is, as the application rate increased, so did the contribution to DRP in runoff TP. Additionally, poultry and swine manure treatments tended to have higher DRP concentrations than runoff from dairy manure treatment. Repeated rainfall diminished the differences in runoff DRP and differential erosion of broadcast manure caused significant differences in runoff TP concentrations between soils. Essentially, increasing rates of manure application were associated with a higher proportion of runoff TP as DRP, which indicates that soluble P losses from manure become increasingly important at higher rates of application.

McDowell, R.W., Sharpley, A.N. (2001). "Approximating phosphorus release from soils to surface runoff and subsurface drainage." *Journal of Environmental Quality*, 30(1), 508-520.

This article investigates the P release from the surface in relation to the concentration of P in surface runoff and subsurface damage. They found a change point above which P increased at a greater rate per unit increase in STP than if below the change point. They note that the change point in STP may be used in support of agricultural and environmental P management.

Sharpley, A.N., McDowell, R.W., Kleinman, P.J.A. (2001). "Phosphorus loss from land to water: integrating agricultural and environmental management." *Plant and Soil*, 237, 287-307.

This article argues that the overall goal of efforts to reduce P loss to water should involve balancing P inputs and outputs at farm and watershed levels by optimizing animal feed rations and land application of P as mineral fertilizer and manure. They found that the loss of P originates primarily from small areas within watersheds during a few storms. These areas are those with high soil P, or P application in mineral fertilizer or manure.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Evaluation of the phosphorus source component in the phosphorus index for pastures." *Journal of Environmental Quality*, 33(1), 2192-2200.

This article evaluates the P index for pastures by applying poultry litter to test plots and by evaluating watersheds that had been fertilized with poultry litter for over ten years. The small plots indicated that soil test P, by itself, was a poor predictor of P concentrations in runoff water and that the relationship between P in runoff and the amount of soluble P applied was highly significant. The pastures with natural rainfall and annual poultry litter application indicated that the P index for pastures predicted P loss accurately without calibration. "These data indicate that the P index for pastures can accurately assess the risk of P loss from fields receiving poultry litter applications in Arkansas and provide a more realistic risk assessment than threshold soil test P levels."

Wang, X., Harmel, R.D., Williams, J.R., Harman, W.L. (2006). "Evaluation of EPIC for assessing crop yield, runoff, sediment and nutrient losses from watersheds with poultry litter fertilization." *American Society of Agricultural and Biological Engineers*, 49(1), 47-59.

This article is an evaluation of the Environmental Policy Integrated Climate (EPIC) model version 3060 and looked at runoff of several watersheds when poultry litter was added. The model accurately predicted surface P runoff on an annual, monthly, and daily basis for al watersheds. So, they conclude that EPIC is able to successfully replicate the environmental impact of poultry litter application on runoff, water quality, and crop yields.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Development of a phosphorus index for pastures fertilized with poultry liter – factors affecting phosphorus runoff." *Journal of Environmental Quality*, 33(1), 2183-2191.

This article evaluates the effects of multiple variables on P concentrations in runoff water and tries to construct P source component of a P index for pastures that incorporates these effects. Their goal is to see if recent studies that show that other factors are more indicative of P concentrations in runoff from areas where manure is being applied than an upper limit on soil test phosphorus. They found that, without manure, soil test P was directly related to soluble P concentrations in runoff water. After the poultry litter was applied, soil test P had little effect on P runoff. In other words, "once manure was applied, SRP concentrations in runoff were not correlated to Mehlich-III P, but were highly correlated to the SRP concentrations in the applied manure (2189)." So, P runoff increased with increasing soluble P concentration in the manure. They also found that runoff P varied based on the type of manure applied, with alum-treated litter having the lowest P runoff, and commercial P fertilizer and HAP or phytase litter having the highest P runoff.

Mancl, K.M., Slates, J.D. (2003). "Farmer Estimates of Manure Application Rates." Symposium, Ninth International Animal, Agricultural and Food Processing Wastes Proceedings, 200-203.

This article looks at the ability of livestock producers and growers to make visual estimates of manure application rates. Of the 101 participants, 13% estimated at or near the actual application rate, 22% estimated high application rates, while 65% underestimated the manure application rate (with 50% estimating less than one-half the actual application rate). Relying on visual estimates without training, 50% would have applied twice the desired application rate. Thus, they conclude that the tendency to underestimate manure application and

therefore over-apply manure reinforces the need to calibrate spreading equipment as a part of a manure management plan.

Gitau, M.W., Chaubey, I., Nelson, M.A., Pennington, J.H. (2007). "Analyses of BMP and land use change effects in a Northwest Arkansas agricultural watershed." ASABE Paper N. 072244. St. Joseph, Mich.: ASABE.

This article seeks to quantify the effects of implementation, timing, and spatial distribution of the Best Management Practices (BMPs) on sediment and nutrient loss reduction and watershed ecological integrity. From an analysis of historical land use and BMP implementation, they found a 9% increase in urban areas and an 11% decrease in pastured areas between 1992 and 2004. During this time about 10% of the watershed was in transitional land use, and BMP implementation increased from less than 1% to 34% of the watershed area. Also during this time, sediment loss declined by 22%, total phosphorus losses declined by 11%, and total nitrogen losses increased by 11%.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32, 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations from acidic agricultural soils over successive runoff events. The runoff boxes were broadcast with three types of manure and simulated rainfall was applied. They found that application rate of manure was related to runoff P, due to increased concentrations of dissolved reactive phosphorus in runoff; as application rate increased, so did the concentration of DRP in the runoff total phosphorus. Swine and poultry manure showed higher DRP concentrations in runoff than dairy manure.

White, M.J., Storm D.E., Stoodley, S., Smolen, M.D. (2003). "Modeling the Lake Eucha basin with SWAT in 2000." ASAE November Conference, 536-542.

The SWAT model predicted that the application of poultry litter elevated soil test phosphorus in the basin and is responsible for 49% of the current annual phosphorus load to the lakes.

Sen, S., Srivastava, P., Yoo, K., Dane, J.H., Shaw, J.N., Kang, M.S. (2007). "Runoff generation mechanism in the Appalachian plateau region of Alabama – a field investigation." ASABE Paper No. 072090. St. Joseph, Mich.: ASABE.

This article attempts to delineate spatial and temporal distribution of hydrologically active areas (HAAs) and identify surface runoff generation mechanism using distribution sensors. This research is a response to the failure of Alabama's P-index to account for differences in P loss, from poultry litter, across specific fields within a single watershed. They found that the surface runoff generation mechanism is mostly infiltration excess (rather than saturation excess) and that certain hydrologic characteristics seem to play a dominant role in surface runoff generation in this specific region of Alabama. Additionally, they further conclude

that the ability to predict the spatial and temporal distribution of HAAs can be predicted by a few variables, would lead to significantly better management of P from land-applied poultry litter.

Gitau, M.W., Gburek, W.J., Jarrett, A.R. (2005). "A tool for estimating best management practice effectiveness for phosphorus pollution control." *Journal of Soil and Water Conservation*, 60(1), 1-10.

As a response to P runoff from farms that had reached the New York City water supply, this study establishes a means of estimating BMP effectiveness, based on data available in the literature, and develops a tool that allows users to obtain BMP effectiveness estimates for their respective site soil and slope conditions.

Secchi, S., Gassman, P.W., Jha, M., Kurkalova, L., et al. (2007). "The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale." *Journal of Soil and Water Conservation*, 62(1), 10-21.

This study, performed for the Iowa Department of Natural Resources, outlines a methodology to simultaneously assess economic costs and water quality benefits associated with the hypothetical placement of a broad set of conservation practices. Annual costs range from $300 to $597 million and predicted sediment decreases from 6-65%, total P from 28-59%, and nitrate from 6-20%.

Buczko, U., Kuchenbuch R.O. (2007). "Phosphorus indices as risk-assessment tools in the U.S.A. and Europe – a review." *Journal of Plant Nutrition and Soil Science*, 170, 445-460.

This article reviews the factors of P loss which are taken into account in P indices and different modifications of P indices according to their components and structural approach. Essentially, this article looks at the different P indexes that exist and divides them into three groups: (1) additive approach, (2) multiplicative approach, and (3) multiplicative-aditive approach.

Pote, D.H., Daniel, T.C., Nicholas, D.J., Moore Jr., P.A., Miller, D.M., Edwards, D.R. (1999). "Seasonal and soil-drying effects on runoff phosphorus relationships to soil phosphorus." *Soil Science Society of America Journal*, 63, 1006-1012.

This article investigates the possibility that the correlation between increased concentrations of dissolved reactive P (DRP) in runoff from grassland and increased soil test P (STP) levels are affected by seasonal changes in field conditions and the practice of air-drying soil samples prior to analysis. They found that all correlations of STP to runoff DRP were significant, regardless of seasonal changes or STP method. Additionally, they found that DRP concentration in August runoff was almost double that of May runoff. So, seasonal changes can make a difference.

Tesfaye, D., Storm, D.E., Payton, M.E., Smolen, M.D., Basta, N.T., Zhang, H., Cabrere, M.L. (2004). "Spatial and temporal scaling effects on hydrology and phosphorus loss in runoff from pastures." ASAE Paper No. 042271.

This article attempts to investigate: the interaction of explanatory variables and their effects on response variables, the spatial and temporal scaling effects on hydrology, and DRP and TP losses in runoff from pastures. They found that DRP loss from pastures was significantly influenced by poultry liter, rainfall duration, pasture height, plot size, rainfall intensity, and runoff duration.

Erb, K.A. (2002). "Phosphorus loading per acre vs. cow populations in a dairy watershed in Northeast Wisconsin." ASAE Publication No. 2010P0102.

This article conducted a study to determine per-hectare rate of nitrogen, phosphorus, and potassium loading on farms in the Lower Fox River Basin over two years. The mass balance showed an average of 98 kg/ha nitrogen accumulation, 17kg/ha phosphorus accumulation, and 90 kg/ha potassium accumulation on dairy farms. Cash grain accumulation rates were 10, 3, and 26 kg/ha, respectively. Most of the dairy farms had already implemented nitrogen based nutrient management plans. "The study indicates that phosphorus accumulations could be reduced by more that 90% by implementing a number of additional management practices, including switching to lower phosphorus protein supplements, growing rather than purchasing protein sources, reducing the amount of phosphorus in the dairy ration, and reallocating manure across the farm to fields with the greatest phosphorus need."

Soupier, M.L., Mostaghimi, S., Yagow, E.R. (2006). "Nutrient transport from livestock manure applied to pastureland using phosphorus-based management strategies." *Journal of Environmental Quality*, 35, 1269-1278.

Recognizing that land applications of manure from confined animal systems and direct deposit by grazing animals are both major sources of nutrients in streams, this paper attempts to determine the effects of P-based manure applications on total suspended solids and nutrient losses from dairy manures and poultry litter surface applied to pasturelands and to compare the nutrient losses transported to the edge of the field during overland flow events. The study found that the nutrients are most transportable from cowpies, so a buffer zone between pastureland and streams or other appropriate management practices are necessary to reduce nutrient losses to waterbodies.

Haggard, B.E., Storm, D.E., Stanley, E.H. (2001). "Effect of a point source input on stream nutrient retention." Journal of the American Water Resources Association, 37(5), 1291-1299.

This article examined the effect of a point sources input on water chemistry and nutrient retention in an Arkansas creek. They found that, although no single factor is responsible for nutrient retention, discharge and the level of nutrient enrichment explained a substantial amount of the observed variance in the SRP.

Srinivasan, M.S., Gerard-Marchant, P., Veith, T.L., Gburek, W.J., Steenhuis, T.S. (2005). "Watershed scale modeling of critical source areas of runoff generation and phosphorus transport." Journal of the American Water Resources Association, 361-375.

This article evaluated Soil Moisture Distribution and Routing (SDMR) and SWAT by applying them to a watershed in Pennsylvania in order to identify runoff generation areas. Neither simulation matched the observed data over all seasons, but SWAT is better able to predict time series stream flow. However, neither model allows runoff routing across the watershed.

Kornecki, T.S., Sabbagh, G.J., Storm, D.E. (1999). "Evaluation of runoff, erosion, and phosphorus modeling system – SIMPLE." Journal of the American Water Resources Association, 35(4), 807-820.

This article evaluates the performance of Spatially Integrated Models for Phosphorus Loading and Erosion (SIMPLE) in predicting runoff volume, sediment loss, and phosphorus loading from two watersheds. SIMPLE tended to underestimate runoff volumes during the dormant period and the comparison between observed and predicted dissolved phosphorus showed better correlation than for observed and predicted total phosphorus loading.

Sharpley, A., Kleinman, P., Weld, J. (2004). "Assessment of best management practices to minimize the runoff of manure-borne phosphorus in the United States." *New Zealand Journal of Agricultural Research*, 47, 461-477.

This article demonstrates that the P Index can provide flexible and reliable manure management and provide farmers with options to minimize the risk of P loss.

Kronvang, B., Vagstad, N., Behrendt, H., Bogerstrand, J., Larsen. S.E. (2007). "Phosphorus losses at the catchment scale within Europe: an overview." *Soil Use and Management*, 23(10, 104-116.

This article examines the importance of phosphorus losses from agricultural land by analyzing data and two different models for the Nordic-Baltic region of Europe.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore Jr., P.A., Mullins, G. (2003). "Development of phosphorus indices for nutrient management planning strategies in the United States." *Journal of Soil and Water Conservation*, 58(3), 137-152.

This article charts the development of the indexing approach, which ranks site vulnerability to P loss by accounting for source and transport factors and outlines modifications made among States to the P index that reflect local conditions and policy. The conclude that using three management scenarios (changing the time of applied manure, riparian buffer establishment, and reduced feed P ration) that overall P index ratings can be decreased, giving farmers more options for manure management than by simply reducing application rates.

Kleinman, P.J.A., Needelman, B.A., Sharpley, A.N., McDowell, R.W. (2003). "Using soil phosphorus profile data to assess phosphorus leaching potential in manured soils." *Soil Science Society of America Journal*, 67(1), 215-224.

This article investigates whether detailed description and interpretation of soil P profile data provide adequate insight into P leaching potential. They ultimately conclude that soil P profile data appear to provide only limited insight into P leaching potential.

Gaudreau, J.E., Vietor, D.M., White, R.H., Provin, T.L., Munster, C.L. (2002). "Response of turf and quality of water runoff to manure and fertilizer." *Journal of Environmental Quality*, 31, 1316-1322.

This article evaluates responses of bermudagrass turf and volumes and P and N concentrations of surface runoff after fertilizer or composted manure applications. They found that runoff volumes were similar between manure and fertilizer sources of P and that dissolved P concentration in runoff during a rain even was five times greater for fertilizer than for manure P.

Kleinman, P.J.A., Sharpley, A.N., Moyer, B.G., Elwinger, G.F. (2002). "Effect of mineral and manure phosphorus sources on runoff phosphorus." *Journal of Environmental Quality*, 31, 2026-2033.

This article attempts to quantify the effects of alternative P sources, application methods, and initial soil P concentrations on runoff P losses from three acidic soils. They found that runoff DRP concentrations were highly correlated with water-soluble P concentration of surface-applied manure. Additionally, practices that increase P sorption at the soil surface may reduce P loss in surface runoff, even after surface application has occurred.

Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (1998). "Agricultural phosphorus and eutrophication: a symposium overview." *Journal of Environmental Quality*, 27, 251-257.

This article provides an overview of the issues discussed at a symposium titled "Agricultural Phosphorus and Eutrophication." "Generally, the loss of agricultural P in runoff is not of economic importance to a farmer. However, it can lead to significant off-site economic impacts, in some cases occurring many miles from the P source. By the time these impacts are manifest, remedial strategies are often difficult and expensive to implement: they cross political and regional boundaries…"

Edwards, D.R., Daniel, T.C. (1994). "Quality of runoff from Fescue grass plots treated with poultry litter and inorganic fertilizer." Journal of Environmental Quality, 23, 579-584.

This article assessed the impacts of fertilizer treatment and simulated rainfalls on quality of runoff from fescue grass. After the first rainfall event, the total P runoff was highest from plots that received inorganic fertilizer, while the highest concentrations of chemical oxygen demand and total suspended solids occurred in runoff from plots treated with poultry litter. The runoff from the second and third rainfall events were not significantly different than the control. So, the first rainfall event is significantly worse than subsequent rainfall events.

Pote, D.H., Daniel, T.C., Sharpley, A.N., Moore Jr., P.A., Edwards, D.R., Nichols, D.J. (1996). "Relating extractable soil phosphorus to phosphorus losses in runoff." Soil Science Society of America Journal, 60, 855-859.

This paper tested the hypothesis that soil test P correlates to dissolved reactive P and bioavailable P in runoff varies, depending on the extraction method. They found that there is a linear relationship between STP levels and DRP concentration in runoff from the soil surface.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28, 860-865.

This study compares the effects of grazing animal depositions vs. poultry litter application on nutrient runoff. Plots receiving poultry litter had significantly greater losses of most nutrient parameters for both rainfall simulations. They ultimately concluded that "a severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions at the rates used in the experiment.

Edwards, D.R., Daniel, T.C. (1992). "Environmental impacts of on-farm poultry waste disposal – a review." *Biosource Technology*, 41, 9-33.

This paper reviews information regarding the disposal of on-farm poultry wastes and the effects of poultry waste disposal on environmental quality.

Edwards, D.R., Daniel, T.C., Scott, H.D., Murdoch, J.F., Habiger, M.J., Burks, H.M. (1996) "Stream quality impacts of best management practices in a Northwestern Arkansas basin." Water Resources Bulletin, 32(3), 499-509.

This article attempts to asses the water quality effectiveness of best management practices implemented in the Lincoln Lake basin in Northwest Arkansas. Total P was highest for sub-basins with the highest proportion of pasture land use. The declines in analysis parameter concentrations are attributed to the implementation of BMPs in the basin.

Pote, D.H., Daniel, T.C., Nichols, D.J., Sharpley, A.N., Moore Jr. P.A., Miller, D.M., Edwards, D.R. (1999). "Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff." *Journal of Environmental Quality*, 28, 170-175.

This study attempts to identify the most consistent STP method for predicting runoff DRP levels, and determine effects of site hydrology on correlations between runoff DRP concentrations. They found that all correlations of STP to runoff DRP were significant, which suggests the importance of site hydrology in determining P loss in runoff and may provide a means of developing a single relationship for a range of soil series.

Nelson, M.A., Cash, W.L., Steele, K.F. (2000). "Determination of nutrient loads in Upper Moores Creek." Arkansas Soil & Water Conservation Commission.

This is a report of a monitoring project of the Lincoln Lake Basin in order to demonstrate the effectiveness of the implemented BMPs in reducing nutrient transport from the pastures in the intensively managed areas.

Chapman, S.L., Moore, B.J., Barton, L. "Water quality and poultry production in three hydrologic units in Arkansas." University of Arkansas Cooperative Extension Service.

This is a report on three USDA hydrologic projects in Arkansas. They found that, although only about 30% of the soils need phosphorus fertilization for crop production, however producers continue to apply poultry litter to the land.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28(3), 860-865.

This study compares nutrient runoff as affected by grazing animal depositions vs. poultry litter application. They found that plots receiving poultry litter had significantly greater losses of most nutrient parameters. "A severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions."

Moog, D.B., Whiting, P.J. (2002). "Climatic and agricultural factors in nutrient exports from two watersheds in Ohio." *Journal of Environmental Quality*, 31, 72-83.

This article uses a statistical analysis to identify climatic, hydrologic, and agricultural variables that best explain variations in nitrate, phosphorus, and total suspended solids between 1976 and 1995 in two watersheds that feed Lake Erie. Nitrate, total suspended solids, and total phosphorus tended to decrease when previous months were wet, except in the summer, and to decrease when snow cover was extensive. Soluble reactive phosphorus loads were negatively correlated to conservation tillage and reserves, and positively correlated to fertilizer and manure sources.

Lehmann, J., Lan, Z., Hyland, C., Sato, S., Solomon, D., Ketterings, Q.M. (2005). "Long-term dynamics of phosphorus forms and retention in manure-amended soils." Environmental Science and Technology, 39, 6672-6680.

This study investigates the relationship between organic and inorganic P in soil pools and equilibrium leachate along a chronosequence of poultry and dairy manure additions in New York. They found that long-term manuring resulted in the low retention of additional P in the soil.

Sauer, T.J., Daniel, T.C., Nichols, D.J., West, C.P., Moore Jr., P.A., Wheeler, G.L. (2000). "Runoff water quality from poultry litter-treated pasture and forest sites." *Journal of Environmental Quality*, 29, 515-521.

This study attempts to measure the effect of site characteristics and poultry litter application on runoff and nutrient transport from grazed pasture and forest sites at different landscape positions. They found that poultry litter-treated plots had consistently higher concentrations of all water quality parameters tested compared to untreated plots. Additionally, concentration of DRP in runoff from untreated plots was linearly correlated with three soil P tests and soil P on litter-treated plots had little effect on runoff DRP. Finally, the results indicate that variation in runoff has a significant effect on nutrient transport from grazed pastures receiving poultry litter.

Maguire, R.O., Hesterberg, D., Gernat, A., Anderson, K., Wineland, M., Grimes, J. (2006). "Liming poultry manures to decrease soluble phosphorus and suppress the bacteria population." *Journal of Environmental Quality*, 35, 849-857.

This study evaluated the ability of CaO and CA2 for killing manure bacterial populations and stabilizing P in poultry wastes and to investigate the influence on soils following amendment with treated wastes. They found that the liming process, when used successfully, reduced plate counts and concerns about P losses in runoff following land application.

Sharpley, A., Foy, B., Withers, P. (2000). "Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview." *Journal of Environmental Quality*, 29(1), 1-9.

This paper provides an overview of P management strategies to maintain agricultural production and protect water quality that were discussed at a conference. They concluded that there are many ways to control agricultural P transfer from soil to water including: optimizing fertilizer P use-efficiency, refining animal feed rations, using feed additives to increase P absorption by the animal, moving manure from surplus to deficit areas, and targeting conservation practices.

Nolen, S.L., Carroll, J.H., Combs, D.L., Staves, J.C. (1989). "Limnology of Tenkiller Ferry Lake, Oklahoma, 1985-1986." Proceedings of the Oklahoma Academy of Science, 69, 45-55.

This study is a response to deteriorating water quality in various watersheds, specifically the Illinois River Basin. The purpose of this study was to collect sufficient baseline water quality data to define current limnological conditions at Tenkiller Lake and to provide a basis for future water quality protection and monitoring.

Vadas, P.A., Krogstad, T., Sharpley, A.N. (2006). "Modeling phosphorus labile and nonlabile soil pools: updating the EPIC model." *Soil Science Society of America Journal*, 70, 736-743.

This study attempts to determine if replacing EPIC's constant sorption and desorption rate factor with more dynamic rate factors can more accurately predict changes in soil labile P on addition to and depletion of P from soils. They recommend improvements to EPIC's sorption and desorption rate factors by making them dynamic.

Vadas, P.A., Haggard, B.E., Gburek, W.J. (2005). "Predicting dissolved phosphorus in runoff from manured field plots." *Journal of Environmental Quality*, 34, 1347-1353.

This article tests a previously proposed model to predict manure P in runoff. It finds that, using independent field-plot data, original under predictions of manure runoff P can be improved by calculating P distribution fractions from measured runoff to rain ratios or adjusting runoff to rain ratios based on their degree of error.

Vadas, P.A., Harmel, R.D., Kleinman, P.J.A. (2007). "Transformations of soil and manure phosphorus after surface application of manure to field plots." Nutrition Cycle Agroecosystems, 77, 83-99.

This study monitors the manure and soil P over 14 to 17 months in field experiments in Texas and Pennsylvania following dairy and poultry manure surface application. They found that manure mass consistently decreased while manure total P was essentially constant through time. They ultimately concluded that management practices for water quality protection must consider the potential for manure P transformations to contribute dissolved P to runoff long after manure is applied.

Haggard, B.E., Soerens, T.S. (2006). "Sediment phosphorus release at a small impoundment on the Illinois River, Arkansas, and Oklahoma, USA." *Ecological Engineering*, 28, 280-287.

The purpose of this study is to evaluate P release from sediments accumulated at a small impoundment where the Illinois River flows from Arkansas into Oklahoma. They find that it is possible that the impound increases dissolved P concentrations in the Illinois River.

White, M.J., Storm, D.E., Zhang, H., Smolen, M.D. "PPM Plus: a tool to aid in nutrient management plan development." Oklahoma Cooperative Extension Service.

This article provides a general overview of PPM Plus and its applications for nutrient management planners and farm managers to evaluate the effect of BMPs before implementation.

Mcdowell, R., Sharply, A., Brookes, P., Poulton, P. (2001). "Relationship between soil test phosphorus and phosphorus release to solution." *Soil Science*, 166(2), 137-149.

This article examines the existence and behavior of a change point in soil P release. The change point is the point above which $CaCl_2$-P increases much more rapidly per unit increase in STP (soil test P) than if it is below that point. The change point varies greatly between soils and in relation to management. The change point can be predicted to within 40% after relatively few samples (as few as 8), and the 40% level is acceptable because most change points are more than 40% of the optimum STP required for plant growth. Essentially, putting phosphorus onto the ground in levels that far exceed the amount desired for plant growth, causes P levels to increase much more rapidly than it does at lower levels.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N., Turner, B.L. (2005). "Relating soil phosphorus to dissolved phosphorus in runoff: a single extraction coefficient for water quality modeling." *Journal of Environmental Quality*, 34(1), 572-580.

This article investigates the extradition coefficients of water-extractable soil P and soil P sorption saturation. They found that the relationship between soil P sorption saturation and runoff FRP was the same for all 10 soils investigated, and exhibited a split-line relationship where runoff FRP rapidly increased at P sorption saturation values greater than 12.5%. They concluded that a test for soil P saturation may provide the most universal prediction of dissolved P in runoff, but only for non-calcareous soils. So, essentially, they found that a single value for an extradition coefficient relating to soil P can be used across a wide range of soil, hydrology, or management scenarios. Thus, this article can be used to counter the argument that a specific location is unique and that traditional modeling practices, therefore, do not apply to it.

Vadas, P.A., Gburek, W.J., Sharpley, A.N., Kleinman, P.J.A., Moore Jr., P.A., Cabrera, M.L., Harmel, R.D. (2007). "A model for phosphorus transformation and runoff loss for surface-applied maures." *Journal of Environmental Quality*, 36(1), 324-332.

This article develops a model to assess P release and transport from surface manures. It looked at data from Texas, Pennsylvania, Georgia, and Arkansas and found that 80% of the P remains in the top 2 cm, while 20% leaches deeper. The model can differentiate the effects of the sources of P in the soil, machine-applied manure, and manure applied from grazing animals. This model can help target alternative management practices that will be most effective in mitigating P loss. There is also some discussion in this article about the application of poultry manure in Arkansas.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N. (2004). "A simple method to predict dissolved phosphorus in runoff from surface-applied manures." *Journal of Environmental Quality*, 33(1), 749-756.

This article details a simple approach to predict dissolved P release from manures based on observed trends in laboratory extraction of P in dairy, poultry, and swine manures with water over different water to manure ratios. The method was able to predict dissolved inorganic P

concentrations in runoff from surface-applied manures, which indicates its potential to improve water quality models.

Sharpley, A.N., Kleinman, P.J.A., McDowell, Gitau, M., Bryant, R.B. (2002). "Modeling phosphorus transport in agricultural watersheds: processes and possibilities." *Journal of Soil and Water Conservation*, 57(6), 425-439.

This article looks at the challenges of modeling P transport and provides a conceptual framework from which process-based P transport models might be evaluated. They found that, although extraction coefficients relating soil and flow P are variable, they can be represented as a function of land cover or erosion. The article emphasizes improving current models to accurately predict P transport.

Chaubey, I., Sahoo, D., Haggard, B.E., Matlock, M.D., Costello, T.A. (2007). "Nutrient retention, nutrient limitation, and sediment-nutrient interactions in a pasture-dominated stream." *American Society of Agricultural and Biological Engineers*, 50(1), 35-44.

This article examines the effects of nutrients in a watershed in Arkansas. They found that light, not nutrients, limited algal growth. They concluded that "even nutrient-rich streams may continue to assimilate, to some extent, increased loads of P, altering the timing and magnitude of downstream transport of P.

Appendix B

Illinois River Watershed Phosphorus Mass Balance Study

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Illinois River Watershed Phosphorus Mass Balance Study

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1.0 EXECUTIVE SUMMARY

A phosphorus mass balance study was performed on the Illinois River Watershed (IRW). The purpose of the study was to determine the source(s) of phosphorus causing eutrophication of Tenkiller Ferry Reservoir and water quality degradation of the Illinois River and its tributaries.

Based on the findings of the study, the following can be concluded:

1. Poultry production is currently responsible for more than 76% of the net annual phosphorus additions to the IRW.
2. Historical data indicates poultry production has been the major contributor of phosphorus to the watershed since 1964. Prior to 1964, dairy cattle were responsible for the majority of the phosphorus contribution.
3. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production.
4. Other contributing sources of phosphorus (net additions) include commercial fertilizers (7.5%), dairy cattle (5.2%), humans (3.2%), swine (2.9%), industrial sources – mostly poultry processing facilities (2.7%) and beef cattle (1.7%). The remaining sources of phosphorus evaluated in this study, which include urban runoff, golf courses, wholesale nurseries, and recreational users, are negligible (< 1%).
5. Of the three phosphorus exports from the watershed (harvested crops, harvested deer, and water leaving Lake Tenkiller through the spillway) outflow of phosphorus through the spillway at the south end of Lake Tenkiller was the largest. According to current estimates, the flow of water through the spillway removes just under 1.25% of the total annual phosphorus additions to the watershed. The remaining two phosphorus exports combined remove just over 0.25% of current annual phosphorus additions to the watershed, totaling a 1.5% removal of current phosphorus additions.

2.0 BACKGROUND AND OBJECTIVE

The Illinois River Watershed encompasses nearly 1,052,000 acres (1,644 square miles) in northeast Oklahoma and northwest Arkansas. The watershed spans seven counties and feeds the largest reservoir in Eastern Oklahoma, Tenkiller Ferry Reservoir (known locally as Lake Tenkiller). The seven counties in the watershed include Adair, Cherokee, Delaware, and Sequoyah Counties in Oklahoma; and Benton, Crawford, and Washington Counties in Arkansas. The very small portion of Crawford County, Arkansas that lies within the watershed boundary (just over 1,000 acres) was not included in this study.

The Illinois River was designated a "Wild and Scenic River" in 1970 and benefits from the state protection this designation provides. This protection promotes tourism in the watershed, which sees its peak between April and September when stream flow and temperatures are best for river activities (OSRC, 1998). The main recreational activity in the watershed is canoeing/kayaking, but other activities include camping, fishing, hiking, hunting, horseback riding, wildlife viewing, and sightseeing.

Reports of diminishing water quality caused by eutrophication of Lake Tenkiller and the water quality degradation of the Illinois River its tributaries have prompted concern from both local citizens and state officials (Haraughty, 1999). The eutrophication has been attributed to excess nutrients, specifically phosphorus. The objective of this study was to perform a mass balance on the IRW to determine the source(s) of this phosphorus.

3.0 APPROACH

The outline and approach for the phosphorus mass balance study of the IRW was established by Bernie Engel, Ph.D., Thomas Alexander, Ph.D., and Meagan Smith.

The first step in the study was to identify all phosphorus additions and removals within the watershed, including related assumptions. This was accomplished by first determining which additions and removals are true sources and subtractions of phosphorus; that is, they add phosphorus to or remove phosphorus from the watershed, not just recycle the phosphorus within the watershed.

The next step was to quantify all additions and removals, by source, on an annual basis. Both current and historical values were calculated in order to establish any phosphorus related trends in the watershed, as well as to aid in evaluating the historical impact the added phosphorus has had on the watershed. A mass balance could then be performed based on the calculated values.

Coupling the determined approach with a detailed literature review, the following phosphorus additions and removals were identified.

3.1 Phosphorus Additions

1. Publicly owned treatment works (POTWs) and Septic systems – Not specifically an addition. All phosphorus additions from human excrement were accounted for individually, based on the overall human population in the watershed, not by wastewater treatment plant (WWTP) discharge or septic system releases. This is based on the assumption that all treated wastewater sludge, whether from a WWTP or septic system, is eventually land applied within the basin.
2. Farm animal wastes – Addition (for poultry, swine, dairy cattle, and beef cows and heifers that calved). The additions for poultry, swine and dairy cattle are based on the phosphorus content of their wastes and assume all feed for the animals is imported to the watershed. It is assumed all litter and manure produced in the watershed is land applied in the watershed (Fisher, 2008 and Copenhaver, 1991). Phosphorus additions due to beef cows and heifers that calved are accounted for based on the phosphorus content of protein supplements fed to calving beef cattle (Lalman, 2004). No other portion of beef cattle waste is considered because beef cattle are an otherwise foraging livestock that recycle the phosphorus already in the landscape (Lalman, 2004 and Slaton

et al., 2004). Based on livestock data from the 2002 Census of Agriculture, the population numbers of all other livestock compared with the population numbers of poultry, swine, and cattle were insignificant and therefore, not considered.

3. Non-manure fertilizer application to agricultural land – Addition

4. Golf course fertilizer application – Addition

5. Urbanized areas – Addition. It is assumed this input (urban runoff) will account for all residential fertilizer application, domestic pet waste, and other phosphorus in storm water runoff.

6. Plant nurseries – Addition. Additions related to wholesale plant nurseries are accounted for using tailwater phosphorus concentrations.

7. Recreational users – Addition

8. Industrial sources (manufacturing and processing) – Addition

3.2 Phosphorus Removals

1. Crop consumption/removal from watershed – Removal. The calculations for this phosphorus removal assume all crops grown in the watershed are removed from the watershed upon harvest. The only exception to this assumption is hay/forage crops. It is assumed all harvested forage crops are used for livestock in the IRW and that for every bale of hay that may leave the IRW, an equal amount is brought into the IRW. This results in no phosphorus removal due to the harvest of forage crops.

2. Farm animal consumption/subsequent removal from watershed – Removal for beef cattle only. This is based on all beef cattle in the watershed being foraging animals, therefore recycling phosphorus, with only beef cows and heifers that calved given protein supplements, representing any phosphorus addition (Slaton et al., 2004 and Lalman, 2004). Beef cattle recycle phosphorus until they are sold and subsequently removed from the watershed, at which point all stored phosphorus is removed. Although poultry and swine are also sold and removed from the watershed, they do not remove phosphorus from the watershed because they are non-grazing animals. Based on livestock data from the 2002 Census of Agriculture, the population numbers of all other livestock populations compared with the population numbers of poultry, swine, and cattle are deemed insignificant, therefore any percentage sold out of the watershed represent a negligible removal of phosphorus.

3. Indigenous animals – Removal for harvested deer, only. These animals act to recycle phosphorus in the watershed. They are not introducing more phosphorus nor permanently removing phosphorus. The only indigenous animals permanently removing phosphorus from the watershed are deer harvested during hunting season.
4. Water leaving through spillway on Lake Tenkiller – Removal. There is a quantifiable amount of phosphorus leaving through the spillway at the south end of Lake Tenkiller.

3.3 Other Phosphorus Additions and Removals Considered

1. Indigenous animals (other than harvested deer) – Not an addition or removal. This was based on the assumption that indigenous animals are recycling phosphorus in the watershed through grazing, defecation, bodily decay, etc., not introducing more phosphorus nor permanently removing phosphorus.
2. Solid waste disposal sites – Not an addition. Solid waste disposal facilities must operate leachate collection/treatment systems, therefore eliminating them as a source of phosphorus (EPA, 40 CFR Part 258 Subpart C).
3. Mining operations – Not an addition or removal. The only mining operations in the area are for gravel and sand, which do not introduce phosphorus to the watershed. It is assumed any soils removed by mining are deposited elsewhere in the watershed. This results in no addition or removal of phosphorus through mining.
4. Sedimentation/Erosion – Not an addition or removal. Although there is aeolian and alluvial erosion occurring throughout the watershed, there is also sedimentation/deposition occurring throughout the watershed. All eroded material is captured within the watershed or reservoir, leading to no net addition or removal of phosphorus due to erosion, sedimentation, or deposition.
5. Unmanaged land (riparian areas, forests, grasslands, etc.) – Not a removal. These land areas recycle phosphorus through the natural growth and decay of plant matter. They do not introduce or permanently remove phosphorus (Daniels et al., 2000).
6. Golf course grass uptake – Not a removal. Golf courses typically mulch/compost their clippings on property (G. Hallett, personal communication, 7 August 2006). This leads to a recycling of phosphorus, not a removal of phosphorus.

Figure 1 depicts all phosphorus additions and removals from the IRW, as well as those processes which recycle phosphorus within the watershed.

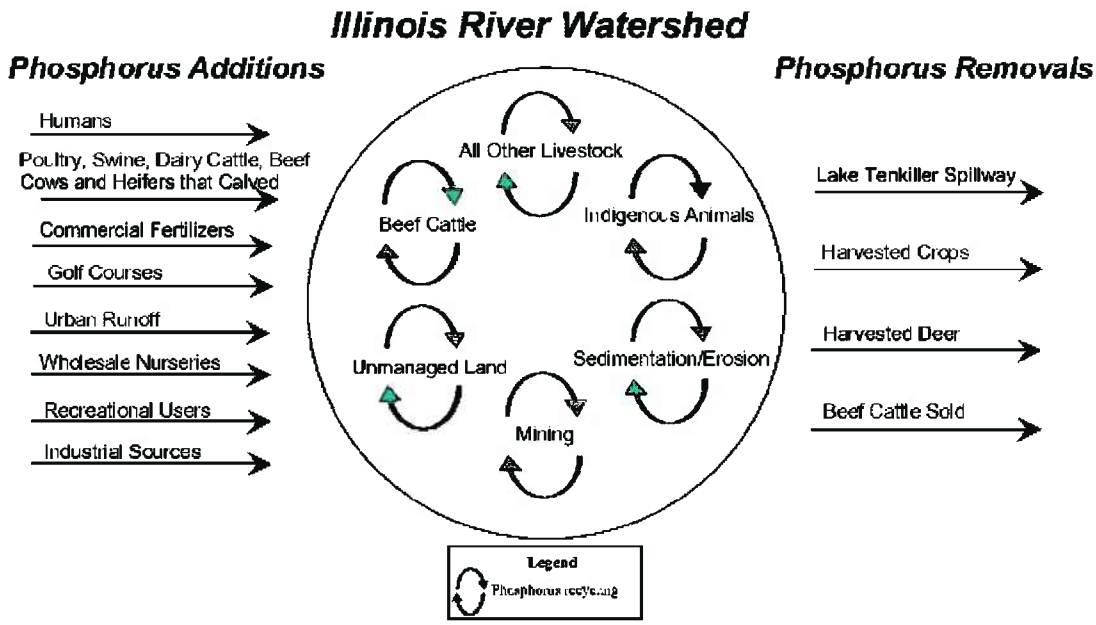

Figure 1. Phosphorus mass balance flow diagram for the Illinois River Watershed.

4.0 PHOSPHORUS CALCULATIONS

After all potential sources of phosphorus to and removals of phosphorus from the watershed were determined, these source contributions and removals were quantified on an annual basis. Both current and historical values were calculated. This was done in order to determine any phosphorus related trends in the watershed, as well as to aid in evaluating the historical impact on the watershed.

4.1 Land Use/Land Cover

Unless otherwise noted, all land use/land cover data used for this study is from the National Land Cover Dataset (NLCD) 2001, summarized by Dr. Robert van Waasbergen (van Waasbergen, personal communication, 2007). The NLCD 2001 was put together by the Multi-Resolution Land Characteristics Consortium (MRLC) and is derived from 30-meter resolution Landsat satellite imagery. There are 29 total land use classes in the data set with only 15 of those classes found in this watershed. The 15 land use classes were grouped into five categories; water, developed, forest, pasture, and crop, as shown below.

1) Open Water - Water
2) Developed, Open Space - Developed
3) Developed, Low Intensity - Developed
4) Developed, Medium Intensity - Developed
5) Developed, High Intensity - Developed
6) Barren Land (Rock/Sand/Clay) - Developed
7) Deciduous Forest - Forest
8) Evergreen Forest - Forest
9) Mixed Forest - Forest
10) Shrub/Scrub - Pasture
11) Grassland/Herbaceous - Pasture
12) Pasture/Hay - Pasture
13) Cultivated Crops - Crops
14) Woody Wetlands - Forest
15) Emergent Herbaceous Wetlands - Pasture

Table 1 shows the amount of each land use/land cover type, in acres, for the entire counties that make up the IRW and the portions of those counties that lie in the IRW. The NLCD 2001 was used for both current and historical calculations.

Table 1. Land use/Land cover for the IRW in acres

	Land Use/Land Cover Acres					
	Entire County					
County	Water	Developed	Forest	Pasture	Crop	Total
Adair	668	16,714	209,486	142,120	325	369,313
Benton	22,020	61,902	231,008	247,725	722	563,377
Cherokee	16,368	25,535	268,179	186,520	267	496,868
Delaware	35,042	28,813	219,619	219,868	3,711	507,053
Sequoyah	24,362	25,727	195,710	203,569	7,653	457,020
Washington	4,109	53,045	301,119	253,091	528	611,892
	IRW Portions					
County	Water	Developed	Forest	Pasture	Crop	Total
Adair	263	12,744	128,395	113,515	264	255,180
Benton	677	26,076	47,256	111,483	272	185,765
Cherokee	10,218	13,818	132,719	66,465	92	223,312
Delaware	35	2,975	26,077	19,710	101	48,897
Sequoyah	3,432	2,987	22,451	17,232	376	46,479
Washington	862	33,589	102,962	154,380	370	292,163
Watershed	15,486	92,189	459,860	482,785	1,476	1,051,796

4.2 Phosphorus Additions

4.2.1 Human Population

The phosphorus additions attributable to the human population in the watershed were accounted for individually, as untreated waste additions. The conservative assumption made to support this method is that all treated discharge water and sludge from both WWTPs and septic systems are eventually released into the watershed.

In order to perform the calculations, it was necessary to determine the phosphorus contributing human population in the watershed. This was done using population numbers from the United States Census Bureau sorted by county areas and total watershed areas calculated in ArcGIS (van Waasbergen, 2007). First, countywide populations were taken from the 1950, 1960, 1970, 1980, 1990, and 2000 U.S. Census. Next, all urban centers over 1,000 people located partially or entirely within the boundary of the IRW, were isolated. The populations of the urban centers in each county were then subtracted from the total county populations. The resulting rural population numbers for each county were multiplied by the percent of the rural area for each county located within the IRW and then summed. This resulted in the rural

population for the IRW for each of the six U.S. Census years. The population of all urban centers located partially or entirely within the boundary of the IRW was then added to the rural population numbers to account for all phosphorus additions due to humans. Table 2 shows the IRW populations (accounted for in each county of the IRW) every ten years starting in 1950.

Table 2. Human population in the IRW

Total Population - Illinois River Watershed							
Year	**Adair**	**Benton**	**Cherokee**	**Delaware**	**Sequoyah**	**Washington**	**IRW**
1950	10,824	21,729	11,079	1,415	1,703	37,125	83,874
1960	9,614	24,050	11,139	1,150	1,701	43,899	91,552
1970	11,077	37,156	15,441	1,361	2,242	58,218	125,496
1980	13,839	55,854	18,197	1,773	1,897	74,135	165,695
1990	13,927	69,460	20,910	2,096	2,009	84,036	192,439
2000	15,987	111,255	26,931	2,829	2,387	120,993	280,383

Two different phosphorus generation rates for the human population were identified: *Septic System Performance: A Study at Dunoon, Northern NSW* (Sarac et al., 2001) and chapter four of the Agricultural Waste Management Field Handbook (USDA, 1992) combined with Mean Body Weight, Height, and Body Mass Index, United States 1960-2002 (CDC, 2004). Sarac et al. (2001) determined annual per capita phosphorus generation rate of 1.1 lb of total phosphorus. The Agricultural Waste Management Field Handbook (USDA, 1992) breaks down the human phosphorus generation rate to 0.02 lb/day/AU of excreted phosphorus, where an AU equals 1000 lb animal live weight. Due to the ability to account for the increase in weight of the average person over the last several decades, it was concluded the preferable resource to utilize was the Agricultural Waste Management Field Handbook (USDA, 1992). Table 3 compares the phosphorus contributions of both waste characterization estimates.

Table 3. Comparison of annual phosphorus additions from humans in the IRW (tons/yr)

Phosphorus Additions (tons/yr) – Humans		
Year	**USDA**	**Sarac et al.**
1950	45	46
1960	51	50
1970	73	69
1980	97	91
1990	118	106
2000	182	154

4.2.2 Livestock

The process used to calculate phosphorus production for the various livestock in the watershed was similar to that used to calculate human phosphorus production. Livestock population numbers were combined with phosphorus production rates to determine annual phosphorus contributions for each livestock category.

The countywide livestock populations, both current inventory and livestock sold, depending on the animal type, were obtained from the United States Census of Agriculture (Ag Census) for years 1949, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, and 2002. Currently, the Census of Agriculture is conducted by the United States Department of Agriculture, but prior to 1997 the United States Census Bureau conducted the census.

After studying the various livestock population trends in the watershed, it was decided only those animals for which feed is imported into the watershed would be considered. These animals include poultry (broilers, layers, pullets, and turkeys), swine, dairy cattle, and beef cows and heifers that calved. It is assumed all calving beef cattle are fed a protein supplement in addition to their regular foraging (Lalman, 2004). Further, it is assumed all other livestock are grazing livestock, and therefore do not account for a net addition of phosphorus to the watershed (Slaton et al., 2004).

The livestock populations for each portion of county within the IRW were determined based on the percentage of pasture acreage for each county that lies inside the watershed boundary (Nelson et al., 2002). For example, if 10% of the pasture acreage for any given county lies within the boundary of the watershed, then it was assumed that 10% of the livestock population for that county resided within the watershed. This method of livestock distribution was based on the assumption that livestock would not be housed or grazed on cropland, forests, or developed areas and would be equally distributed on pasture (Nelson et al., 2002). The livestock populations accounted for include the number of broilers and turkeys sold from the watershed; the number of layers, pullets, and swine both sold from the watershed and on-hand at the time of each census; the on-hand inventory of dairy cattle at the time of each census; and the on-hand inventory of beef cows and heifers that calved. If data was not available in the Ag Census, a population of zero was assumed, resulting in a zero contribution. The calculations resulted in the current and historical phosphorus contributing livestock populations provided in Table 4.

Table 4. Phosphorus contributing livestock populations in the IRW

Livestock Populations in the Illinois River Watershed								
Year	Broilers	Layers	Pullets	Turkeys	**Total Poultry**	Swine	Dairy Cattle	Beef Cows & Heifers that Calved
1949	11,924,434	[a]	[a]	38,497	**11,962,932**	79,556	29,478	10,379
1954	18,617,043	[a]	[a]	302,795	**18,919,838**	38,281	29,877	19,842
1959	35,685,225	[a]	[a]	489,136	**36,174,360**	50,939	21,253	29,742
1964	60,681,482	1,759,742	[a]	[a]	**62,441,223**	28,423	14,886	50,503
1969	75,718,474	6,687,861	[a]	[a]	**82,406,334**	44,297	11,674	62,321
1974	80,779,485	3,881,138	[a]	[b]	**84,660,623**	57,064	9,302	86,725
1978	87,085,705	6,358,778	4,041,266	2,274,966	**99,760,715**	212,851	11,771	79,062
1982	91,645,666	7,730,130	3,951,899	2,899,320	**106,227,014**	284,402	15,620	83,235
1987	100,090,686	9,386,334	4,354,641	5,443,358	**119,275,019**	484,617	13,095	81,212
1992	124,834,505	7,550,895	4,476,492	4,013,895	**140,875,787**	324,755	12,148	85,408
1997	126,788,271	5,895,940	3,503,572	4,780,619	**140,968,402**	299,286	9,958	97,440
2002	139,700,237	4,870,617	3,186,207	4,024,094	**151,781,155**	208,243	10,280	101,367

[a]No information listed in Ag Census.
[b]Data listed as not available in Ag Census.

Table 5 presents the same livestock numbers in terms of animal units (AUs), or 1000 lb of animal liveweight. Due to the vast size difference of the animals listed, this allows for a better comparison of the "amount" of each animal type in the watershed. Average liveweights at market were used to determine the AUs. The average liveweights for broilers and turkeys have increased greatly over the past several decades. That increase was accounted for by using their liveweights at market taken from the Poultry Yearbook (ERS, 2006) for years 1964 through 2002. Prior to 1964, the liveweights for broilers and turkeys were estimated using a linear regression. The liveweights for broilers and turkeys are provided in Table 6. The average liveweights at market used to calculate the AUs for the remaining animals are 1375 lb for dairy cattle, 963 lb for beef cows and heifers that calved, 155 lb for swine (ASAE, 2005), 4 lb for layers (ASAE, 2003), and assuming a layer is a full-grown pullet, 2 lb for pullets. These liveweights at market are current estimates and are used to calculate both current and historical AUs in the watershed.

Table 5. Phosphorus contributing livestock populations in the IRW in terms of Animal Units

Livestock Populations in terms of Animal Units***								
Year	Broilers	Layers	Pullets	Turkeys	**Total Poultry**	Swine	Dairy Cattle	Beef Cows & Heifers that Calved
1949	32,792	*	*	530	**33,323**	12,331	40,532	9,995
1954	55,106	*	*	4,481	**59,588**	5,934	41,081	19,108
1959	113,122	*	*	7,743	**120,865**	7,896	29,222	28,641
1964	211,172	7,039	*	*	**218,211**	4,406	20,469	48,635
1969	272,587	26,751	*	*	**299,338**	6,866	16,052	60,015
1974	305,346	15,525	*	**	**320,871**	8,845	12,790	83,516
1978	337,893	25,435	8,083	43,202	**414,612**	32,992	16,185	76,136
1982	370,248	30,921	7,904	55,754	**464,827**	44,082	21,477	80,156
1987	430,390	37,545	8,709	110,555	**587,199**	75,116	18,006	78,207
1992	561,755	30,204	8,953	87,142	**688,053**	50,337	16,704	82,248
1997	609,852	23,584	7,007	114,544	**754,986**	46,389	13,693	93,835
2002	716,662	19,482	6,372	107,685	**850,202**	32,278	14,135	97,616

[a]1000 lbs of animal liveweight.
[b]No information listed in the Ag Census.
[c]Data listed as not available in the Ag Census.

Table 6. Historical liveweights at market for broilers and turkeys

Liveweights at Market for Broilers and Turkeys (lb)		
Year	Broilers	Turkeys
1949	2.75	13.78
1954	2.96	14.80
1959	3.17	15.83
1964	3.48	17.94
1969	3.60	18.95
1974	3.78	18.35
1978	3.88	18.99
1982	4.04	19.23
1987	4.30	20.31
1992	4.50	21.71
1997	4.81	23.96
2002	5.13	26.76

The historical animal populations in the watershed are represented graphically in Figures 2 and 3. Figure 2 depicts the historical animal population numbers and Figure 3 depicts the populations in terms of animal units.

After determining livestock populations for the watershed, multiple sources were considered to calculate the phosphorus addition for each population. The various phosphorus generation rates were combined with liveweight estimates and standard animal growth cycles, when needed, in order to calculate and compare the overall phosphorus additions from each livestock source. Standard growth cycles were used to account for multiple rotations of animals raised on a farm in a given year.

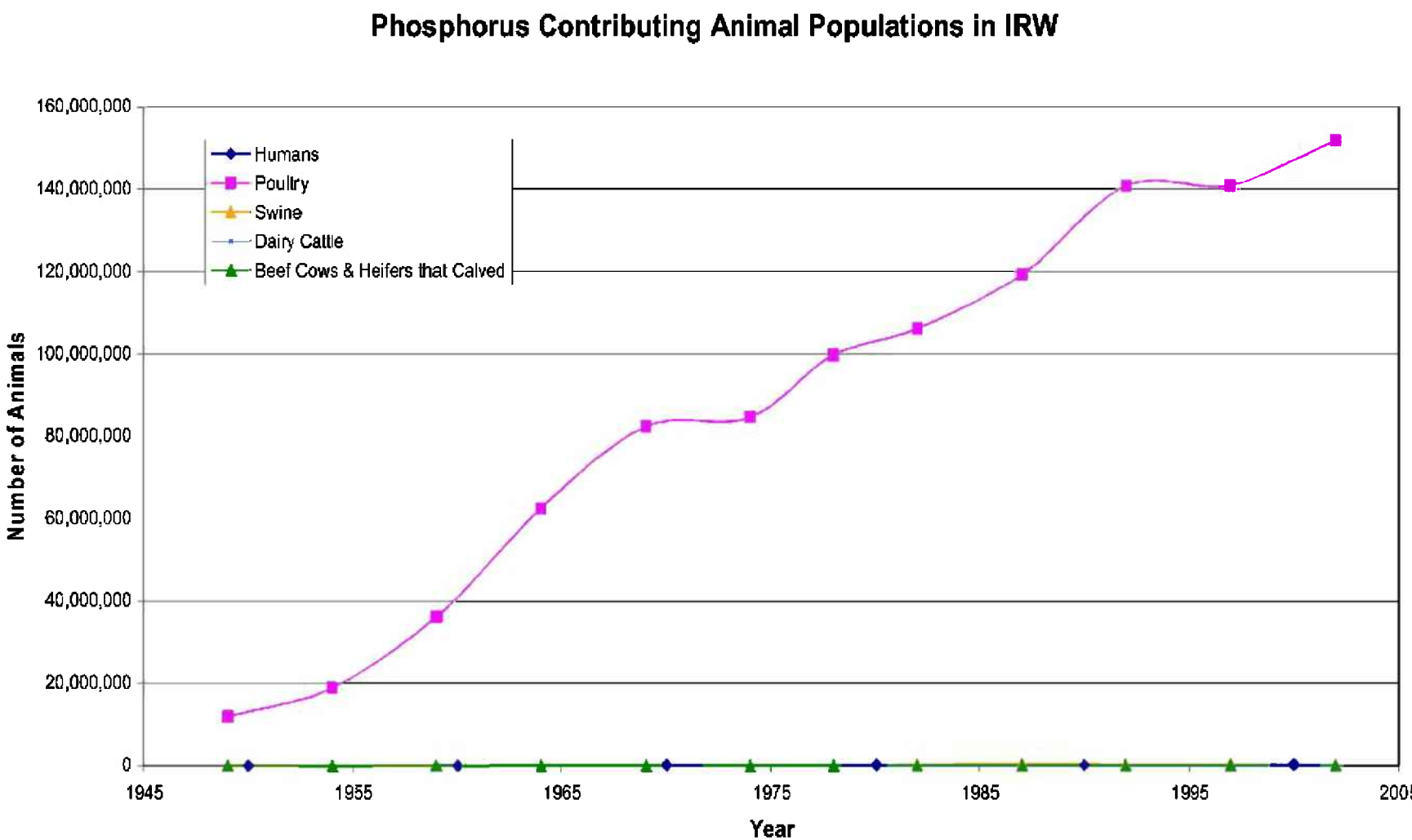

Figure 2. Annual phosphorus contributing animal populations in the IRW

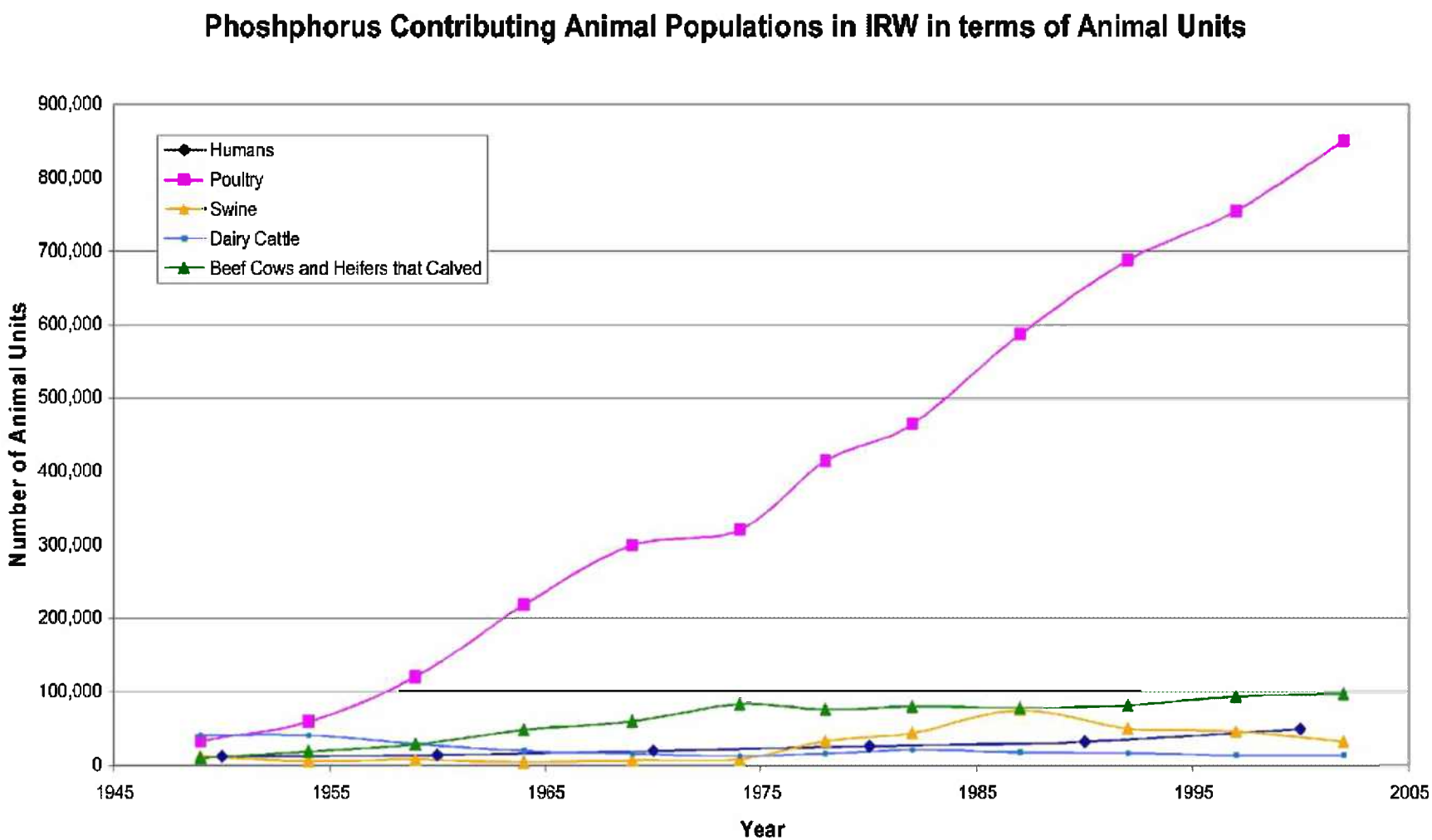

Figure 3. Annual phosphorus contributing animal populations in terms of animal units - 1000 lb. liveweight

4.2.2.1 Poultry

Four phosphorus generation rates were identified to calculate and compare the phosphorus additions attributable to the different poultry populations in the watershed. The four resources include:

- Agricultural Waste Management Field Handbook (USDA, 1992)
- ASAE Standard D384.2 MAR2005 (ASAE, 2005)
- Manure Characteristics – MWPS-18 Section 1 (MWPS, 2000)
- Data summarized from 321 Nutrient Management Plans (NMPs) from the Eucha/Spavinaw Watershed in northeastern Oklahoma. Data was summarized by Lithochimeia, Inc. (NMP, 2007).

Table 7 lists the phosphorus generation rate parameters from each resource for broilers, layers, pullets, and turkeys.

Table 7. Phosphorus generation rate parameters for poultry

Phosphorus Generation Rate Parameters for Poultry[a]				
	USDA	ASAE	MWPS	NMP
Bird Type	lb/day/AU[b]	lb/finished animal	lb/day	% manure[c]
Broiler	0.34	0.035	0.0006	2.08%
Layer	0.275	0.402[e]	0.0012	2.65%
Pullet[c]	0.24	NA	NA	1.78%
Turkey	0.4	0.26	0.0048	2.22%

[a]These rates are not directly comparable.
[b]Animal unit – 1000 lbs animal liveweight.
[c]As excreted manure values used for USDA. Values not available for ASAE or MWPS.
[d]Manure must be determined on dry basis.
[e]Converted from lb/day/animal

<u>USDA</u>

The USDA method of calculating phosphorus contributions allows one to explicitly account for the increase over time in the liveweights at market of broilers and turkeys. This is due to the phosphorus generation numbers being given in terms of animal units (AUs), defined as 1000 lb of animal. The liveweights at market for broilers and turkeys were taken from the Poultry Yearbook (ERS, 2006) for years 1964 through 2002. Prior to 1964, the liveweights were estimated using a linear regression. Table 6 lists the liveweights at market used for broilers and turkeys. The liveweights for layers and pullets were considered to be constant over time for these calculations. Layers were assumed to have a liveweight of 4lb (ASAE, 2005) and pullets

were assumed to have an average liveweight of 2 lb. When calculating the phosphorus contributions, the liveweights for broilers and turkeys were assumed to be half the listed weight in order to account for the varying ages of animals on hand.

The growth cycles used for the USDA calculations were taken from ASAE Standard D384.2 MAR2005 (ASAE, 2005) for broilers and turkeys, and were assumed to be 48 days and 119 days, respectively. It was assumed layers are on the farm year round; therefore their growth cycle is 365 days. The growth cycle for pullets was assumed to be 20 weeks or 140 days (Ag Census, 2002). Table 8 lists the annual phosphorus additions for each bird type using the USDA resource for phosphorus generation rates.

Table 8. Annual phosphorus additions to the IRW from poultry using USDA (1992)

Annual Phosphorus Additions from Poultry - USDA - tons					
Year	Broilers	Layers	Pullets	Turkeys	All Poultry
1949	134	*	*	6	140
1954	225	*	*	53	278
1959	462	*	*	92	554
1964	862	353	*	*	1,215
1969	1,112	1,343	*	*	2,455
1974	1,246	779	*	*	2,025
1978	1,379	1,277	102	514	3,271
1982	1,511	1,552	100	663	3,825
1987	1,756	1,884	110	1,316	5,066
1992	2,292	1,516	113	1,037	4,958
1997	2,488	1,184	88	1,363	5,123
2002	2,924	978	80	1,281	5,263

*Population data not available

ASAE

ASAE Standard D384.2 MAR2005 (ASAE, 2005) lists phosphorus generation rates in terms of lb phosphorus/finished animal for broilers and turkeys, and lb phosphorus/day/animal for layers. Because these units do not account for the weight of the animal in the calculation, the phosphorus generation rates were converted to lb phosphorus/lb bird for each bird type using the average bird weights listed in the ASAE document for broilers and turkeys, and the average weight of a layer listed in ASAE Standard D384.1 FEB2003 combined with a 365 day growth cycle for layers. This reference does not provide nutrient generation rates for pullets, therefore phosphorus additions due to pullets was not be calculated under this method.

Annual phosphorus contributions were then calculated using the liveweights at market for broilers and turkeys found in Table 6 and the average liveweight for a layer of 4 lb (ASAE,

2003). Table 9 lists the annual phosphorus contributions from broilers, layers, and turkeys using the ASAE resource for phosphorus generation rates.

Table 9. Annual phosphorus additions to the IRW from poultry using ASAE (2005)

Annual Phosphorus Additions from Poultry - ASAE - tons				
Year	Broilers	Layers	Turkeys	All Poultry
1949	111	*	3	113
1954	186	*	24	210
1959	381	*	41	423
1964	712	353	*	1,065
1969	919	1,343	*	2,262
1974	1,030	779	*	1,809
1978	1,139	1,277	229	2,645
1982	1,248	1,552	296	3,096
1987	1,451	1,884	587	3,922
1992	1,894	1,516	462	3,872
1997	2,056	1,184	608	3,848
2002	2,416	978	571	3,966

*Population data not available.

MWPS

Manure Characteristics – MWPS-18 Section 1 (MWPS, 2000) lists phosphorus generation rates for broilers, layers, and turkeys in units of lb phosphorus/day. Phosphorus generation rates for pullets were not listed and therefore not calculated under this method. These units were converted to lb phosphorus/lb bird by using the bird weights listed combined with the average growth cycles used in previous calculations. The weights used were 4 lb for broilers (assuming the listed weight of 2 lb is the average weight during its growth cycle), 4 lb for layers, and 20 lb for turkeys. The phosphorus generation rates in lb phosphorus/lb bird were then applied to the historical average liveweight values for broilers and turkeys found in Table 6. Table 10 lists the annual phosphorus contributions from broilers, layers, and turkeys using the MWPS resource for phosphorus generation rates.

Table 10. Annual phosphorus additions to the IRW from poultry using MWPS (2000)

Annual Phosphorus Additions from Poultry - MWPS - tons				
Year	Broilers	Layers	Turkeys	All Poultry
1949	121	*	7	129
1954	204	*	63	267
1959	418	*	109	528
1964	780	382	*	1,162
1969	1,007	1,450	*	2,457
1974	1,129	841	*	1,970
1978	1,249	1,379	611	3,238
1982	1,368	1,676	788	3,833
1987	1,591	2,035	1,563	5,189
1992	2,076	1,637	1,232	4,945
1997	2,254	1,278	1,619	5,152
2002	2,649	1,056	1,522	5,227

*Population data not available.

NMP

Data from 321 Eucha/Spavinaw watershed Nutrient Management Plans (NMPs) was summarized by Lithochimeia, Inc. (NMP, 2007). The summarization culminated in as-is average waste generation rates in lb/finished bird, average moisture contents, average % total nitrogen and average % total phosphorus on a dry basis, and average bird weights at market. Note that the waste generation rates summarized from the NMPs are based on bird capacity and not number of birds produced. Because the capacity of a house is typically greater than the number of birds generated from the house, the per bird waste generation rates are underestimated. This will, in turn, underestimate the amount of phosphorus contributed to the watershed.

In order to account for the increase in bird weight over time, the waste generation rates were converted to lb waste/lb bird on a dry basis, using the average bird weights at market listed in the NMPs: 5.5 lb for broilers, 8 lb for layers, 8 lb for pullets, and 14 lb for turkeys. Because the average bird weights at market for layers, pullets, and turkeys differed so greatly from the other calculation methods, their phosphorus contributions were calculated using a constant weight over time, the average weight at market listed in the NMPs. The lb waste/lb bird generation rate for broilers was applied to the historical liveweights listed in Table 6. The % phosphorus for each bird type was then applied to the tonnage of waste produced by the corresponding bird type. Table 11 lists the annual phosphorus contributions from each bird type using the data summarized from the NMPs.

Table 11. Annual phosphorus additions to the IRW from poultry using NMP (2007)

Annual Phosphorus Additions from Poultry - NMP - tons					
Year	Broilers	Layers	Pullets	Turkeys	All Poultry
1949	140	*	*	2	142
1954	235	*	*	18	253
1959	482	*	*	29	511
1964	899	417	*	*	1,315
1969	1,160	1,583	*	*	2,743
1974	1,300	919	*	*	2,218
1978	1,438	1,505	249	137	3,329
1982	1,576	1,830	243	174	3,823
1987	1,832	2,222	268	328	4,649
1992	2,391	1,787	275	242	4,696
1997	2,596	1,396	216	288	4,495
2002	3,051	1,153	196	242	4,642

*Population data not available.

After reviewing the methods of calculating phosphorus additions from the various poultry populations in the IRW, it was determined the most accurate method is based on the summarized Nutrient Management Plans (NMPs) for the Eucha/Spavinaw watershed. This decision takes into account various factors regarding the data, including the proximity of the Illinois River Watershed and the Eucha/Spavinaw Watershed. This proximity of location results in comparable production methods between the two watersheds. The NMP data is very recent data with the bulk of all lab tests performed at the same lab, the Agricultural Diagnostic Laboratory at the University of Arkansas in Fayetteville. This results in highly consistent, reliable data. The NMP data also provides waste and phosphorus generation rates for pullets, which two of the other sources do not. Having generation numbers for pullets allows for the calculation of the overall phosphorus contribution from the entire poultry population in the watershed. The annual phosphorus additions from poultry using NMP (2007) data are depicted graphically in Figure 4.

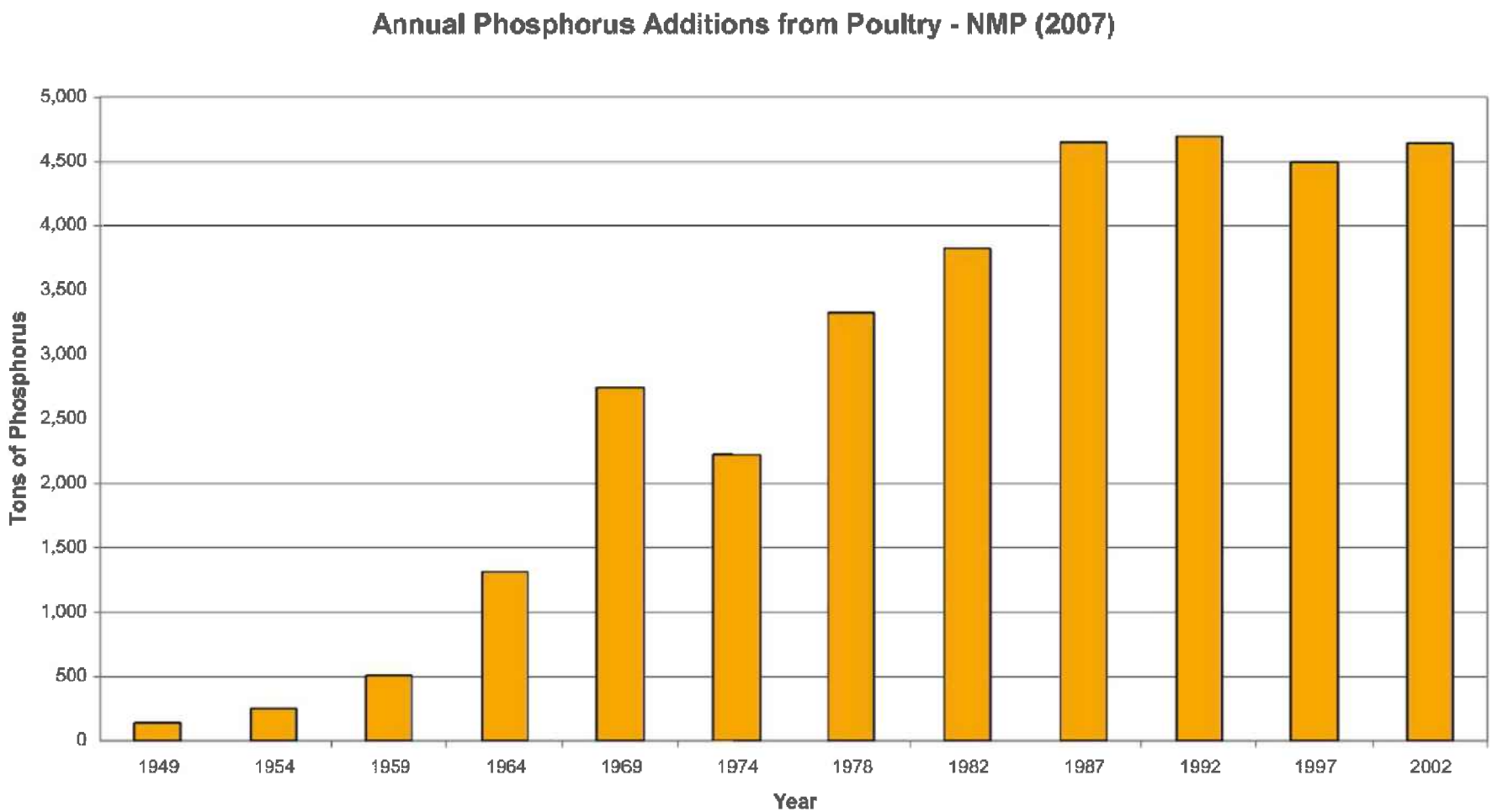

Figure 4. Annual phosphorus additions (tons) to the IRW from poultry

4.2.2.2 Swine and Dairy Cattle

Two resources for phosphorus generation rates were identified to calculate and compare the phosphorus contributions attributable to the swine and dairy cattle populations in the watershed: the Agricultural Waste Management Field Handbook (USDA, 1992) and ASAE Standard D384.2 MAR2005 (ASAE, 2005). Table 12 lists the phosphorus generation rates used in the calculations.

Table 12. Phosphorus generation rates for swine and dairy cattle

Phosphorus Generation Rate Parameters for Swine and Dairy Cattle[a]		
	USDA	ASAE
Animal Type	lb/day/AU[b]	lb/finished animal
Swine	0.16	1.7
Dairy Cattle	0.07	62[c]

[a]These rates are not directly comparable.
[b]Animal Units – 1000 lb animal liveweight.
[c]Converted from lb/day/animal

In order to calculate the overall phosphorus contributions attributable to the swine and dairy cattle populations using the USDA method, average animal liveweights and growth cycles were needed. The liveweight used for swine was 155 pounds with all swine in the watershed assumed to be grower/finishers with a growth cycle of 120 days (ASAE, 2005). The liveweight used for dairy cattle was 1375 pounds (ASAE, 2005) with all dairy cattle assumed to be full-grown and lactating and on farm year round, yielding a growth cycle of 365 days.

Calculating the overall phosphorus contributions using the ASAE method required first converting the phosphorus generation rate for dairy cattle from lb/day/animal to lb/finished animal using the growth cycle of 365 days. The phosphorus generation rates were then applied to the number of swine and dairy cattle in the watershed. The annual phosphorus contributions for swine and dairy cattle using both methods are listed in Table 13.

Table 13. Annual phosphorus additions to the IRW from swine and dairy cattle (USDA, 1992 and ASAE, 2005)

Annual Phosphorus Additions from Swine and Dairy Cattle - tons				
	USDA		ASAE	
Year	Swine	Dairy Cattle	Swine	Dairy Cattle
1949	118	518	68	915
1954	57	525	33	927
1959	76	373	43	659
1964	42	261	24	462
1969	66	205	38	362
1974	85	163	49	289
1978	317	207	181	365
1982	423	274	242	485
1987	721	230	412	406
1992	483	213	276	377
1997	445	175	254	309
2002	310	181	177	319

For comparing phosphorus contributions from swine and dairy cattle to all sources in the watershed, the ASAE Standard D384.2 MAR2005 was because it had the most recent data.

4.2.2.3 Beef Cows and Heifers that Calved

Beef cattle in the watershed are grazing animals that recycle phosphorus already in the landscape (Slaton et al., 2004 and Lalman, 2004). It was noted, however, that the implementation of a high protein supplement schedule for beef cows and heifers that calve can be beneficial to cow health (Gill and Lusby, 2003). In order to account for phosphorus additions resulting from possible protein supplementation, it was assumed all beef cows and heifers that calved in the watershed are on a winter supplementation schedule. Common supplementation strategies were taken from Supplementing Beef Cows (Lalman, 2004) and can be found in Table 14.

Table 14. Daily high protein supplementation schedule

Daily Supplementation Schedule		
Month	Spring Calving Cows	Fall Calving Cows
October	None	1 lb HP
November	1 lb HP*	2 lb HP
December	2 lb HP	3 lb HP
January	3 lb HP	3 lb HP
February	3 lb HP	3 lb HP
March	3 lb HP	3 lb HP
April	2 lb HP	2 lb HP

*HP = high protein supplement, such as 38% protein range cubes or cottonseed meal.

In order to calculate the overall phosphorus additions, the supplementation schedule includes using 41% cottonseed meal as the supplement and a 50% spring calving, 50% fall calving rate (Lalman, D., personal communication, 4 April 2008). It was also assumed the cows were in good body condition and winter weather was moderate. Note that cottonseed meal has a phosphorus content of 1.25%, the highest phosphorus content of all commonly used supplements and feeds (Lalman, 2004).

The pounds of supplement were summed for both spring and fall calving schedules and multiplied by the number of spring and fall calving cows in the watershed. The annual phosphorus contributions due to cottonseed meal supplementation are found in Table 15.

Table 15. Annual phosphorus additions to the IRW from beef cows and heifers that calved

Annual Phosphorus Additions from Beef Cows & Heifers that Calved	
Year	Tons P
1949	30
1954	58
1959	87
1964	148
1969	182
1974	254
1978	231
1982	243
1987	238
1992	250
1997	285
2002	296

4.2.3 Commercial Fertilizer

The phosphorus contributions from commercial fertilizer applications were quantified using the conservative assumption that all commercial fertilizer sold within the watershed was applied to crop and pasture acreage within the watershed.

Available fertilizer sales data was gathered from the Oklahoma Department of Agriculture and the Arkansas State Plant Board. State fertilizer sales data and fertilizer sales data for the counties in the IRW were used to project fertilizer sales spanning from 1951 to 2002 (G. Johnson, Appendix A). All fertilizer phosphorus values were reported in P_2O_5 and converted to total P using: Total P = P_2O_5 * 0.44. The projected county fertilizer sales were then multiplied by the percentage of crop and pasture acreage inside the IRW for each county. Table 16 shows total phosphorus sales for the Oklahoma and Arkansas portions of the IRW, as well as the totals for the entire watershed.

Table 16. Annual phosphorus additions to the IRW based on projected commercial fertilizer sales for the IRW in Oklahoma and Arkansas

Annual Phosphorus Additions from Commercial Fertilizer Sales in IRW - tons			
Year	Oklahoma	Arkansas	IRW
1951	253	8	261
1954	258	23	281
1959	253	49	302
1964	221	74	296
1969	189	100	289
1974	167	125	293
1978	187	146	333
1982	176	166	342
1987	178	192	369
1992	198	311	509
1997	197	248	446
2002	200	256	455

4.2.4 Golf Courses

The next step in determining the overall mass balance for phosphorus in the IRW was to consider the phosphorus addition from golf courses located in the watershed. The use of commercial fertilizers is standard practice for golf course superintendents around the country, and it is no exception for the seven 9-hole courses and thirteen 18-hole courses located within the IRW (South Central Golf Magazine and www.golfcourseportal.com). A list of all golf courses in the IRW can be found in Appendix B.

For the following calculations, it was assumed the vast majority of fertilizer for golf courses is applied to the fairways with the 18-hole courses in the watershed having average fairway acreages of 32 acres and the 9-hole courses being half that acreage, or 17.5 acres (EPA, 2007).

The amount of applied phosphorus was compared using two methods. The first method employed the following fertilizer regimen (G. Hallett, personal communication, 7 August 2006):

- May – 1 lb N/1000 ft^2 in the form of ammonia sulfate (20.5-0-0)
- June – 1 lb N/1000 ft^2 in the form of slow release fertilizer (39-0-0)
- August – 1 lb N/1000 ft^2 in the form of slow release fertilizer (39-0-0)
- September – 0.5 lb N/1000 ft^2 in the form of (5-10-31)

The second method used for calculating the amount of applied phosphorus to golf courses in the watershed was extrapolated from Martin and Hillock (2002). Martin and Hillock (2002) recommends a moderate fertilization program for Bermuda grass using the following regimen:

- May – 1 lb N/1000 ft^2 in the form of (15-5-10)
- July – 1 lb N/1000 ft^2 in the form of (20.5-0-0)
- September – 1 lb N/1000 ft^2 in the form of (15-5-10)

The tonnage of annually applied phosphorus using both methods is compared in Table 17. The results vary between the two methods, but when compared to the phosphorus additions from other sources in the watershed, either method results in a negligible amount of phosphorus from golf course fertilizer application. As such, the conservative approach of assuming the current addition of phosphorus to be constant over time was used in order to compare against other historical phosphorus additions.

Table 17. Annual phosphorus additions from golf courses in the IRW

Annual Phosphorus Additions from Golf Courses	
Calculation Method	Tons Phosphorus
Method 1	5.1
Method 2	3.4
Average	4.2

4.2.5 Urban Runoff

Another consideration in determining the overall phosphorus mass balance for the IRW concerns the phosphorus additions attributable to urban storm water runoff. Phosphorus sources for urban runoff include residential fertilizer applications and domestic pet waste. The first step in determining this addition was to establish the developed acreage in the watershed. This was done using the NLCD 2001. As seen in Table 1, there are 92,189 acres of developed land in the watershed. Combining this developed land area with urban runoff phosphorus concentrations from the National Stormwater Quality Database: Version 1.1 (Pitt et al., 2004) of 0.27 mg Total P/L and an average annual runoff for urban areas in the region of 10 inches, estimated using the Long-Term Hydraulic Assessment model (L-THIA, www.ecn.purdue.edu/runoff/lthianew/Index.html), yielded the phosphorus additions to the watershed from the developed areas.

In order to calculate historical values for phosphorus additions from urban runoff, it was first assumed that the amount of developed land using the NLCD 2001 data corresponded with the urban population from the 2000 U.S. Census. From there, a linear correlation was assumed between the acreage of developed land in the watershed and the urban population, allowing the determination of historical urban runoff phosphorus values to be calculated based on historical U.S. Census urban populations for the watershed. The results of the phosphorus calculations are listed in Table 18.

Table 18. Annual phosphorus additions to the IRW from urban runoff

Annual Phosphorus Additions from Urban Runoff	
Year	Tons Phosphorus
1950	8.4
1960	9.2
1970	12.6
1980	16.7
1990	19.4
2000	28.2

4.2.6 Wholesale Nurseries

Another potential source of phosphorus to the IRW is the large-scale plant nurseries in the IRW. The first step in calculating the phosphorus contributions was to determine the number and size of all wholesale plant nurseries in the basin. This was done using the Oklahoma Nursery & Landscape Association (ONLA) website and the Arkansas Green Industry Association (ARGIA) website. It was determined there are three wholesale nurseries in the basin, all of which are located in or near Tahlequah, Oklahoma. The nurseries vary in size with Grandview Nursery Co., Inc. being the smallest at approximately 250 acres, Park Hill Wholesale Nursery is next at approximately 500 acres, and Greenleaf Nursery Co., Inc is the largest at 570 acres.

Using a similar calculation method as used for urban runoff, the phosphorus additions from plant nurseries were quantified using average nursery tailwater concentrations for total phosphate taken from the Curtis Report (ODA, 1993) combined with average annual runoff for eastern Oklahoma of 20 inches from the Oklahoma Water Atlas (OWRB, 1990) and nursery land areas. The average tailwater concentration for phosphorus in the Curtis Report was 1 mg P_2O_5/L. This value translates to 0.44 mg total P/L. The resulting current phosphorus addition due to wholesale plant nurseries in the IRW is 1.3 tons phosphorus/year (Table 19). Note this is a conservative estimate of the phosphorus addition from plant nurseries due to the fact that at least one nursery in the watershed is equipped with total retention technology (Alexander, 1999). As such, the conservative approach of assuming the current addition of phosphorus to be constant over time was used in order to compare against other historical phosphorus additions.

Table 19. Annual phosphorus addition to the IRW from wholesale plant nurseries

Phosphorus Addition - Wholesale Nurseries
1.3 tons/yr

4.2.7 Recreational Users

The phosphorus contribution attributable to annual recreational users in the IRW was determined based on annual recreational visits to the watershed combined with phosphorus generation rates for humans. Recreational users include not only those visitors who float or canoe on the River, but also those using the banks of the River for recreational purposes and

those using Lake Tenkiller and the immediate surrounding scenic area. Illinois River and Lake Tenkiller recreational user numbers were taken from Caneday (2008). Dr. Caneday lists user numbers on the Illinois River as 155,555 per year and user numbers at Lake Tenkiller as 2,617,359 per year. The River numbers include both river floaters and non-floaters and the Lake numbers include campers, day visitors, and boaters. It is conservatively assumed that all recreational users originate from outside the watershed.

The phosphorus contributions were then calculated using the Agricultural Waste Field Handbook (USDA, 1992). The phosphorus addition due to recreational users is 4.9 tons phosphorus/year (Table 20). In order to compare the phosphorus addition from recreational users to other historical sources of phosphorus in the IRW, it was conservatively assumed the current addition of phosphorus has been constant over time.

Table 20. Annual phosphorus addition to the IRW from recreational users

Annual Phosphorus Addition Recreational Users	
Population	Tons Phosphorus
2,772,914	4.93

4.2.8 Industrial Sources

Information provided by Dr. Engel (personal communication, 10 April 2008) lists all known industrial facilities in the IRW, with a facility description, and their average daily phosphorus additions. This information is provided in Appendix C. There are thirteen companies listed with a total of 23 facilities. Inputs regarding the now closed Stilwell Cannery were not available; therefore the calculated totals do not reflect additions from this source.

The values provided were translated to average annual phosphorus additions in tons/year and are summarized to poultry and non-poultry related facilities in Table 21. Of the 162.6 tons phosphorus/year attributable to industrial sources, only 18% or 29 tons of phosphorus, comes from non-poultry related facilities. These non-poultry related facilities include Allen Canning Co., Cintas Corporation, Danaher Tool Group, J.B. Hunt Transport, Inc., Pappas Foods, L.L.C., Superior Linen Service, and Tyson Foods, Inc. – Hog Trailer Wash. The remaining 133.6 tons of phosphorus comes from egg and poultry processing facilities in the IRW. In order to account for the historical phosphorus additions from industrial sources, the current addition is used for all historical comparisons to other phosphorus sources.

Table 21. Current annual phosphorus contribution, in tons, from industrial sources in the IRW.

Annual Phosphorus Contributions - Industrial Sources	
Facility Type	**Tons Phosphorus**
Poultry Related	133.6
Non-poultry Related	29
Total	162.6

Although the majority of phosphorus being introduced to the IRW from industrial sources is attributable to the poultry industry (82%), it is not being included as a phosphorus addition from poultry production.

4.3 Summary of Phosphorus Additions

Upon quantifying the phosphorus loads coming into the Illinois River Watershed, the loads from all sources were compared in order to determine the source(s) of the greatest contribution of phosphorus. Table 22 compares current phosphorus loads from each source as well as current phosphorus loads in terms of percentage of the current total addition.

Table 22. Comparison of current annual phosphorus loads to IRW listed in tons of phosphorus and % of current total phosphorus addition

Current Phosphorus Additions to IRW[a]		
Source	Tons P	% of Current P Addition
Humans	182	2.9%
Poultry	4,642	74.0%
Swine	177	2.8%
Dairy Cattle	319	5.1%
Heifers and Beef Cows that Calved	296	4.7%
Commercial Fertilizers	455	7.3%
Urban Runoff	28.2	0.4%
Industrial Sources[b]	163	2.6%
Other Additions[c]	10.5	0.2%
Total	6,273	100.0%

[a]Total phosphorus addition, without subtracting any source removals, i.e. beef cattle.
[b]Includes phosphorus additions from poultry processing facilities.
[c]Includes golf courses, wholesale nurseries, and recreational users.

4.4 Phosphorus Removals

Four phosphorus removals were identified for the IRW. They include the phosphorus removed by grazing beef cattle sold and removed from the watershed, crops harvested, deer harvested, and water leaving Tenkiller Ferry Reservoir through the spillway.

4.4.1 Beef Cattle

Beef cattle are the only livestock considered to remove phosphorus from the watershed. This is based on the assumption that all poultry, swine, and dairy cattle are given feed brought into the watershed and are not grazing animals, therefore the waste produced would introduce phosphorus to the watershed. All beef cattle in the watershed are primarily grazing animals, recycling the phosphorus in the watershed along with all other grazing livestock (Lalman, 2004 and Slaton, 2004). However, the number of beef cattle sold is significant enough to warrant accounting for the removal of phosphorus upon being sold and removed from the watershed. The difference between the addition of phosphorus from supplementation of beef cows and heifers that calved and the removal of phosphorus from beef cattle sold will determine whether there is a net loss or addition of phosphorus to the watershed from beef cattle.

The cattle population sold from the IRW was determined in the same manner as the previous livestock calculations. The number of beef cattle sold from each county within the watershed was gathered from the 1949 through 2002 U.S. Census of Agriculture. The number of cattle sold from within the IRW was then determined based on the percentage of pasture acreage for each county that lies inside the watershed boundary. Again, this method of cattle distribution is based on the assumption that cattle would not be housed or grazed on cropland, forests, or developed areas and would be equally distributed on pasture (Nelson et al., 2002). This process provided the historical and present number of beef cattle sold from the watershed.

The amount of phosphorus removed from the watershed was then determined based on ASAE Standard D384.2 (ASAE, 2005) and Smolen et al. (1994). For calculations performed by Smolen et al. (1994), assumptions included an average beef cattle weight gain of 500 lb per head with 20% of that being protein. Combining this average weight gain and make-up with the recognized average phosphorus retention of 3.9 g per 100 g of retained protein (ASAE, 2005), yields the amount of phosphorus sold out of the watershed with each head of cattle. The retention amounts are found in Table 23.

Table 23. Tons of phosphorus removed annually by beef cattle sold

Annual Phosphorus Removal by Beef Cattle Sold	
Year	Tons P
1949	60
1954	83
1959	89
1964	114
1969	157
1974	155
1978	191
1982	167
1987	182
1992	168
1997	192
2002	192

Comparing the addition of phosphorus due to protein supplementation of beef cows and heifers that calved with the removal of phosphorus due to beef cattle sold resulted in a net addition of phosphorus to the watershed beginning in 1964. These net additions are shown in Table 24.

Table 24. Net annual phosphorus additions due to beef cattle

Net Annual Phosphorus Addition - Beef Cattle	
Year	Tons P
1949	-
1954	-
1959	-
1964	33
1969	25
1974	98
1978	41
1982	76
1987	55
1992	81
1997	94
2002	105

4.4.2 Harvested Crops

Next, the removal of phosphorus from the IRW due to harvesting crops was calculated. The first step was to determine the major crops currently and historically harvested in the watershed and their overall production or yield rates. This was established by referring to the U.S. Census of Agriculture (Ag Census, 1949-2002). After review, the crops with the greatest production in the watershed from 1964 to 2002 were determined to be corn, sorghum and wheat for grain, as well as soybeans for beans. For Ag Census years 1949, 1954, and 1959, oats for grain were also included for calculation purposes. Beginning with Ag Census year 1964, the production of oats for grain began a steep decline.

The removal of phosphorus due to forage crops was not included in these calculations. Although hay/forage crops are the major crop grown in the watershed, it was assumed all hay/forage crops harvested in the IRW remain in the IRW as feed for foraging livestock; therefore the phosphorus is being recycled, not removed from the watershed (Slaton et al., 2004 and Lalman, 2004).

The yield per acre was determined for each crop for each year for both the Oklahoma and Arkansas portions of the watershed. This was accomplished by summing the production of each crop, in either tons or bushels, and dividing by the number of acres under production for that crop (Ag Census, 1949-2002). The number of acres under production for each crop for each county was then multiplied by the percentage of cropland that actually lies within the watershed boundary for each county, resulting in the number of acres under production, for each crop, within the watershed boundary.

The yield per acre for each crop was used with the Crop Nutrient Tool on the Natural Resources Conservation Service website (NRCS; npk.nrcs.usda.gov) to determine the phosphorus removed by harvest in lb/acre. The results were then multiplied by the number of acres under production for each crop for each state. The final phosphorus removal results are found in Table 23. A detailed list of the amount of nutrients removed by each crop can be found in Appendix D.

Table 25. Tons of phosphorus removed annually by harvested crops

Annual Phosphorus Removal by Harvested Crops	
Year	Tons P
1949	74
1954	37
1959	43
1964	17
1969	14
1974	11
1978	19
1982	28
1987	15
1992	11
1997	12
2002	14

4.4.3 Deer

The phosphorus removed by deer harvested from the watershed during hunting season was quantified in order to determine its share of removal of phosphorus. The first step for these calculations was to determine the number of deer harvested from each of the counties within the IRW. This information was gathered for years 2001 to 2005 from the Oklahoma Department of Wildlife Conservation and years 2002-2003 through 2005-2006 from the Arkansas Game and Fish Commission. The harvest numbers for the two states are reported in different formats. For Oklahoma the numbers are reported on an annual basis and for Arkansas they are reported on a seasonal basis. Upon reviewing available harvest data, it was concluded the most appropriate harvest numbers to use were those from the most recent reporting year, 2005 for Oklahoma and 2005-2006 for Arkansas, and assume them constant over time if needed.

For this calculation, harvest densities were calculated using the pasture, crop, and forest acreage for each county within the watershed, yielding the number of deer harvested per acre. The harvest density values were then multiplied to the pasture, crop, and forest acreages that lie within the boundary of the watershed for each county to determine the harvest numbers for the watershed. This resulted in a total of 3,982 deer harvested and removed from the IRW.

Once the deer harvest numbers were established, phosphorus removal values were determined based on literature values. Two assumptions were made in order to perform the

necessary calculations: 1) all deer harvested were bucks with an average hog-dressed weight of 103 lb (Masters et al., 2004) and 2) all deer harvested were white-tail deer with a meat protein content of 23.6 g protein/100 g meat (UIUC, 2006). Using the recognized average phosphorus retention rate of 3.9 g of retained phosphorus per 100 g of retained protein (ASAE, 2005) yields a phosphorus removal of 1.9 tons phosphorus/year (Table 26). Because historical deer harvest values were not available, the current removal rate of phosphorus due to harvested deer in the watershed was assumed to remain constant over time in order to compare with other historical phosphorus removals.

Table 26. Tons of phosphorus removed annually from the IRW by harvested deer

Annual Phosphorus Removal by Harvested Deer	
Year	Tons Phosphorus
2005	1.9

4.4.4 Lake Tenkiller Spillway

The dam located at the south end of Lake Tenkiller has an average annual release of 236 billion gallons (Dr. Engel, personal communication, 10 April 2008). Due to the lake acting as a catch basin for phosphorus, the phosphorus in the water column is removed from the watershed as water is released through the spillway. As determined by Dr. Engel, the average phosphorus outflow through the spillway is 75 tons P/year (Table 27) (Dr. Engel, personal communication, 10 April 2008). Given that historical phosphorus data for the spillway is unavailable, the current removal of phosphorus through the spillway was assumed to be constant over time in order to compare with other historical removals.

Table 27. Tons of phosphorus removed from the IRW by the spillway on Lake Tenkiller

Phosphorus Removal - Lake Tenkiller Spillway
75 tons/yr

4.5 Summary of Phosphorus Removals

Upon quantifying the total mass of phosphorus leaving the Illinois River Watershed, the values were compared in order to determine the greatest removal of phosphorus. Table 28 compares the current removals of phosphorus from the IRW. Note it was determined the flow of phosphorus in the watershed due to beef cattle resulted in a net addition of phosphorus.

Table 28. Comparison of current annual phosphorus removals from the IRW

Current Phosphorus Removals from IRW	
Source	Tons P
Spillway	75
Harvested Crops	14
Deer	1.9
Total	91.2

The total current phosphorus removals from the IRW remove 1.5% of the current phosphorus additions to the IRW.

4.6 Overall Net Addition of Phosphorus

The net addition of phosphorus in the Illinois River Watershed from 1949 to 2002 was determined using linear interpolation where needed. Data that did not have corresponding years with the Ag Census (additions due to human population and urban runoff) were linearly interpolated to account for those years. Table 29 lists the annual phosphorus additions from all sources to the IRW for the Ag Census years from 1949 to 2002. Table 30 lists the annual phosphorus removals from the IRW for the Ag Census years from 1949 to 2002. The net additions and removals for the interim years without data were then determined using linear interpolation. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production. There was an overall net addition from 1949 to 2002 of nearly 214,000 tons of phosphorus to the IRW.

Table 29. Annual phosphorus additions, in tons, to the Illinois River Watershed. Includes the percentage of the total addition from poultry.

Phosphorus Additions by Source for the IRW - tons											
Year	Human	Poultry	Swine	Dairy Cattle	Beef Cattle[a]	Commercial Fertilizer	Urban Runoff	Industrial Sources[b]	All Other Additions[c]	Total	% from Poultry
1949	44	142	68	915	-	261	8	163	10.5	1,611	9%
1954	47	253	33	927	-	281	9	163	10.5	1,723	15%
1959	51	511	43	659	-	302	9	163	10.5	1,748	29%
1964	60	1,315	24	462	33	296	11	163	10.5	2,374	55%
1969	71	2,743	38	362	25	289	11	163	10.5	3,712	74%
1974	82	2,218	49	289	98	293	14	163	10.5	3,216	69%
1978	92	3,329	181	365	41	333	16	163	10.5	4,529	74%
1982	101	3,823	242	485	76	342	17	163	10.5	5,259	73%
1987	112	4,649	412	406	55	369	19	163	10.5	6,196	75%
1992	131	4,696	276	377	81	509	21	163	10.5	6,264	75%
1997	163	4,495	254	309	94	446	26	163	10.5	5,959	75%
2002	195	4,642	177	319	105	455	30	163	10.5	6,095	76%

[a]Phosphorus addition from beef cows and heifers that calved minus removal from beef cattle sold.
[b]Includes poultry processing facilities
[c]Includes golf courses, wholesale nurseries, and recreational users.

Table 30. Annual phosphorus removals for the Illinois River Watershed.

Phosphorus Removals - tons				
Year	Spillway	Harvested Crops	Harvested Deer	Total
1949	75	74	1.89	151
1954	75	37	1.89	114
1959	75	43	1.89	119
1964	75	17	1.89	93
1969	75	14	1.89	91
1974	75	11	1.89	88
1978	75	19	1.89	96
1982	75	28	1.89	104
1987	75	15	1.89	92
1992	75	11	1.89	88
1997	75	12	1.89	88
2002	75	14	1.89	91

4.7 Summary of Findings

Figure 5 illustrates the current phosphorus additions and removals, in tons, to the Illinois River Watershed. This figure demonstrates there is more phosphorus coming into the IRW than is being removed, with poultry production being responsible for a large majority of the phosphorus addition (> 76%).

Figure 6 illustrates the current and historical phosphorus additions to and removals from the IRW. This figure demonstrates that for decades, the addition of phosphorus to the watershed has been greater than the removal of phosphorus. This results in an accumulation of phosphorus over time. It can be seen from this figure that poultry production has been by far the greatest contributor of phosphorus to the IRW since, at the very latest, 1964.

Figure 7 illustrates the current percentage of phosphorus additions to the IRW by source. This figure demonstrates that poultry, by far, is the major contributor of phosphorus to the watershed, being responsible for more than 76% of the current phosphorus additions.

Figure 8 illustrates the current and historical percentages of the phosphorus additions in the IRW attributable to poultry. This figure demonstrates a drastic increase in the percent of phosphorus addition due to poultry from 1949 to 1969, from 9% to 74 % From 1974 to 2002 there has been a steady increase in the percentage of the overall phosphorus addition in the IRW due to poultry, from 69% to 76%. Note that over the past three decades, poultry production has consistently been responsible for approximately 75% of the total annual phosphorus additions to the watershed.

Figure 9 illustrates a comparison of the current and historical percentages of phosphorus additions in the IRW attributable to poultry and the percentage attributable to all other sources combined (humans, swine, dairy cattle, beef cattle, commercial fertilizer, urban runoff, industrial sources, golf courses, wholesale nurseries, and recreational users). This figure demonstrates that the percentage of the overall phosphorus additions in the IRW due to poultry has been increasing over time while the percentage of overall phosphorus additions in the IRW due to all other sources has been decreasing over time.

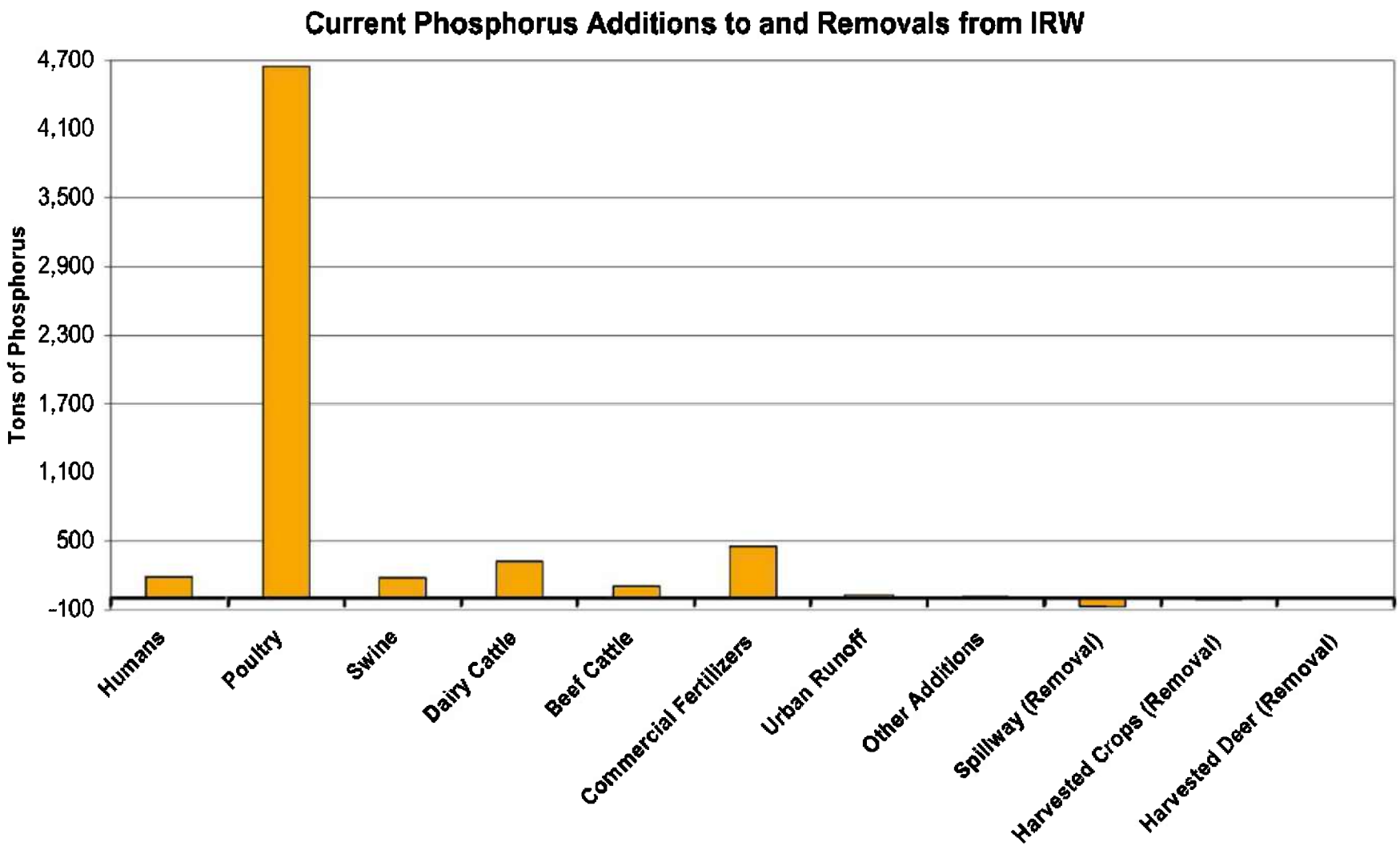

Figure 5. Current phosphorus additions to and removals from the Illinois River Watershed

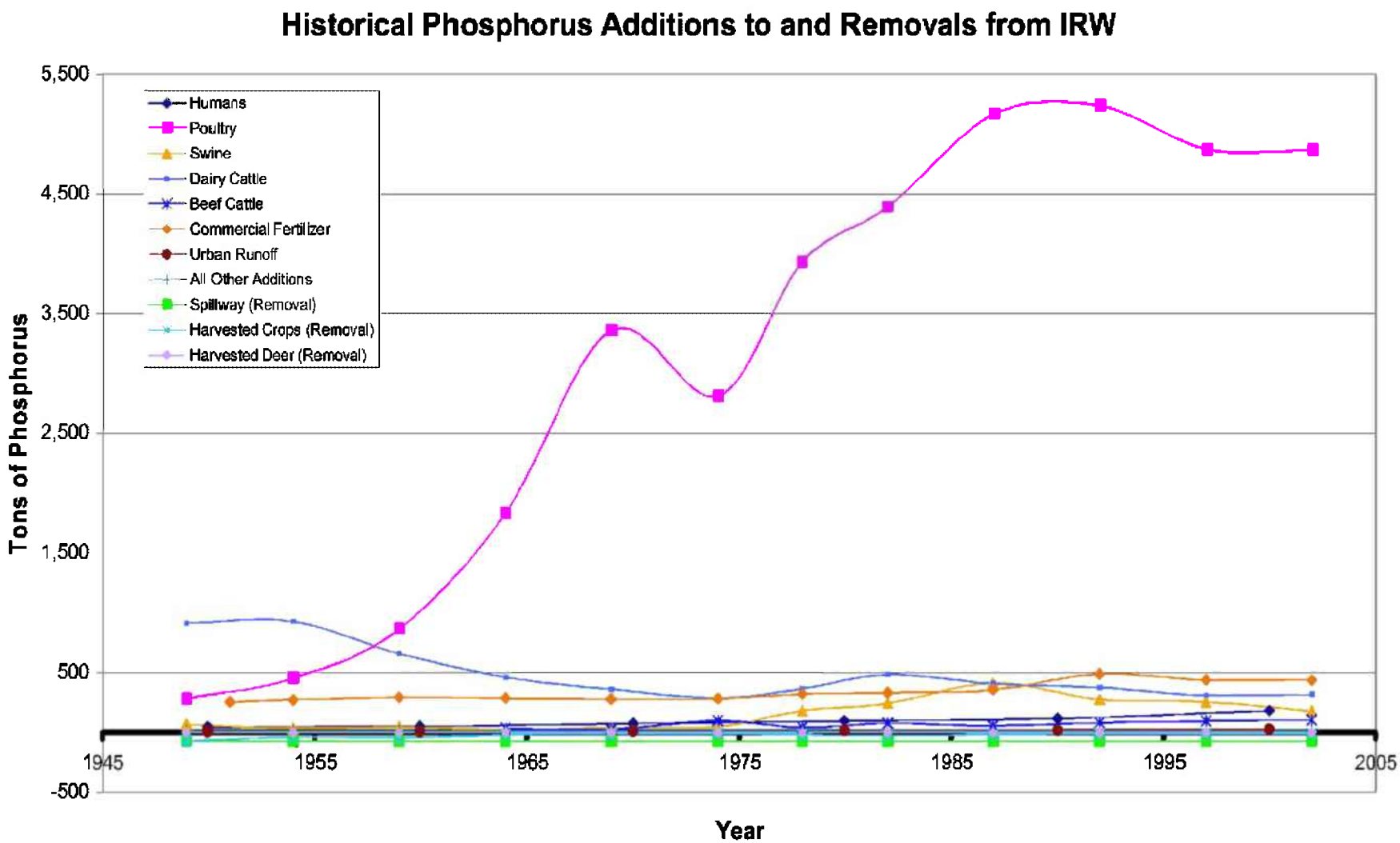

Figure 6. Historical phosphorus additions to and removals from the Illinois River Watershed

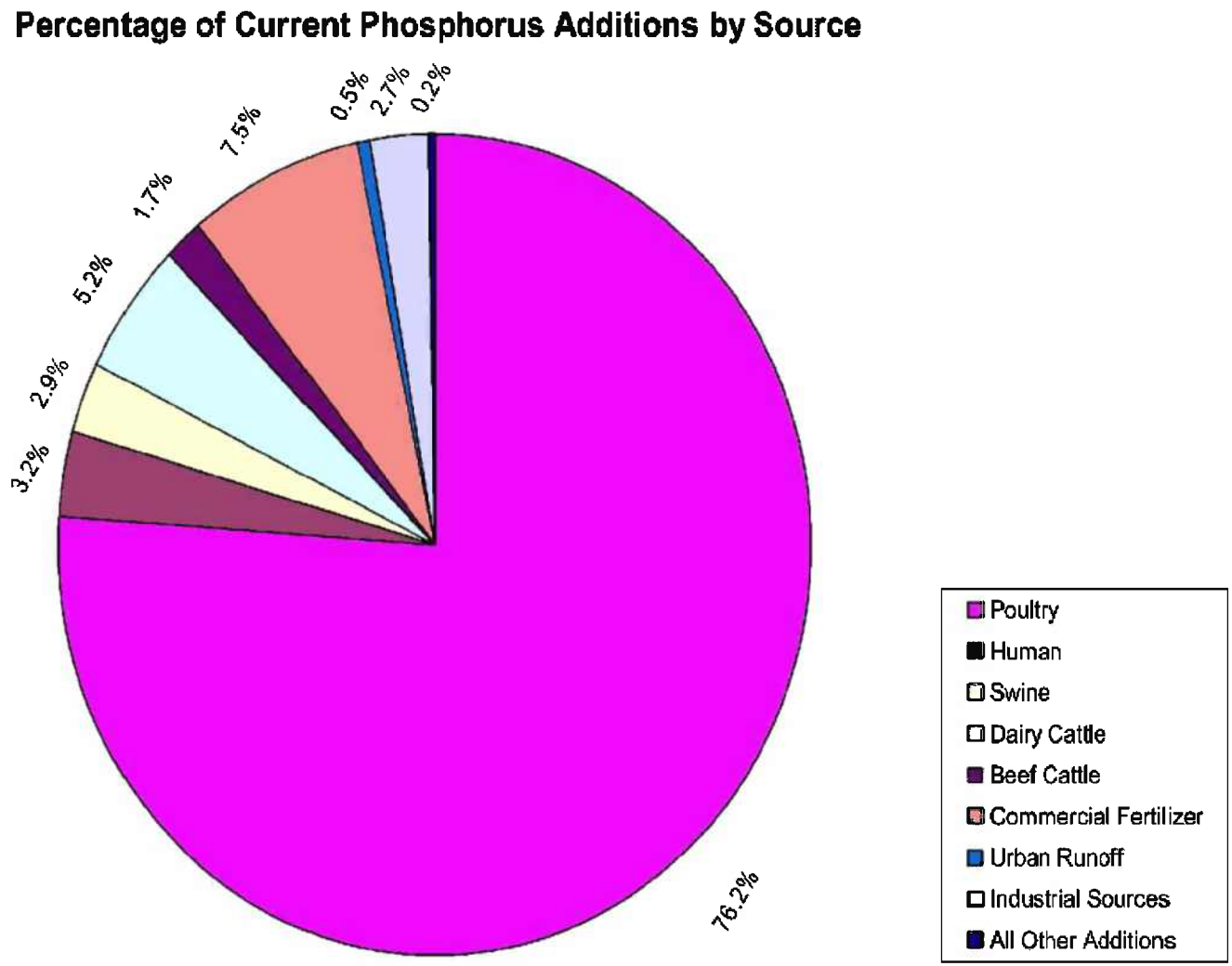

Figure 7. Percentage of current phosphorus additions to the IRW by source

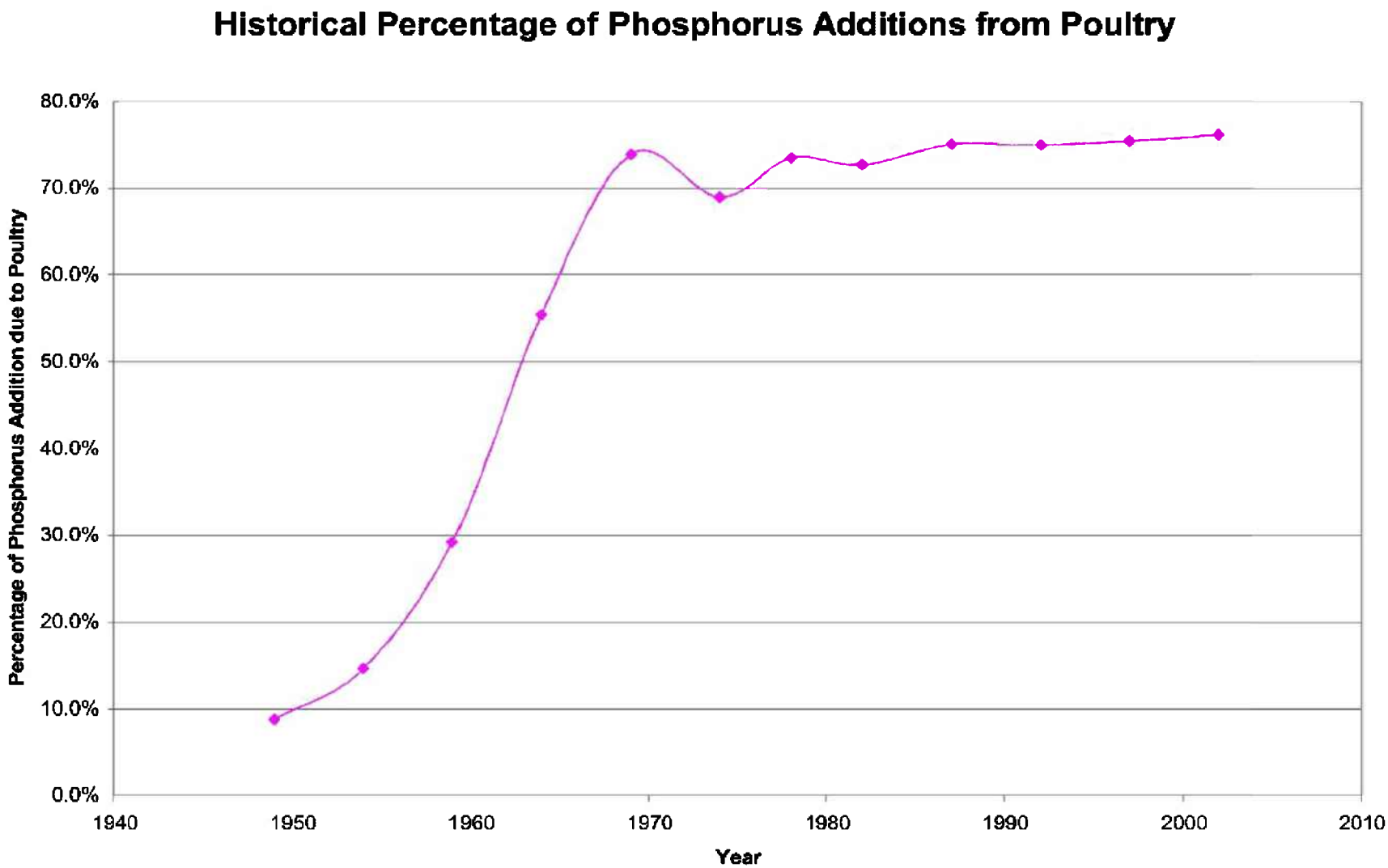

Figure 8. Historical percentage of phophorus additions to the IRW from poultry production

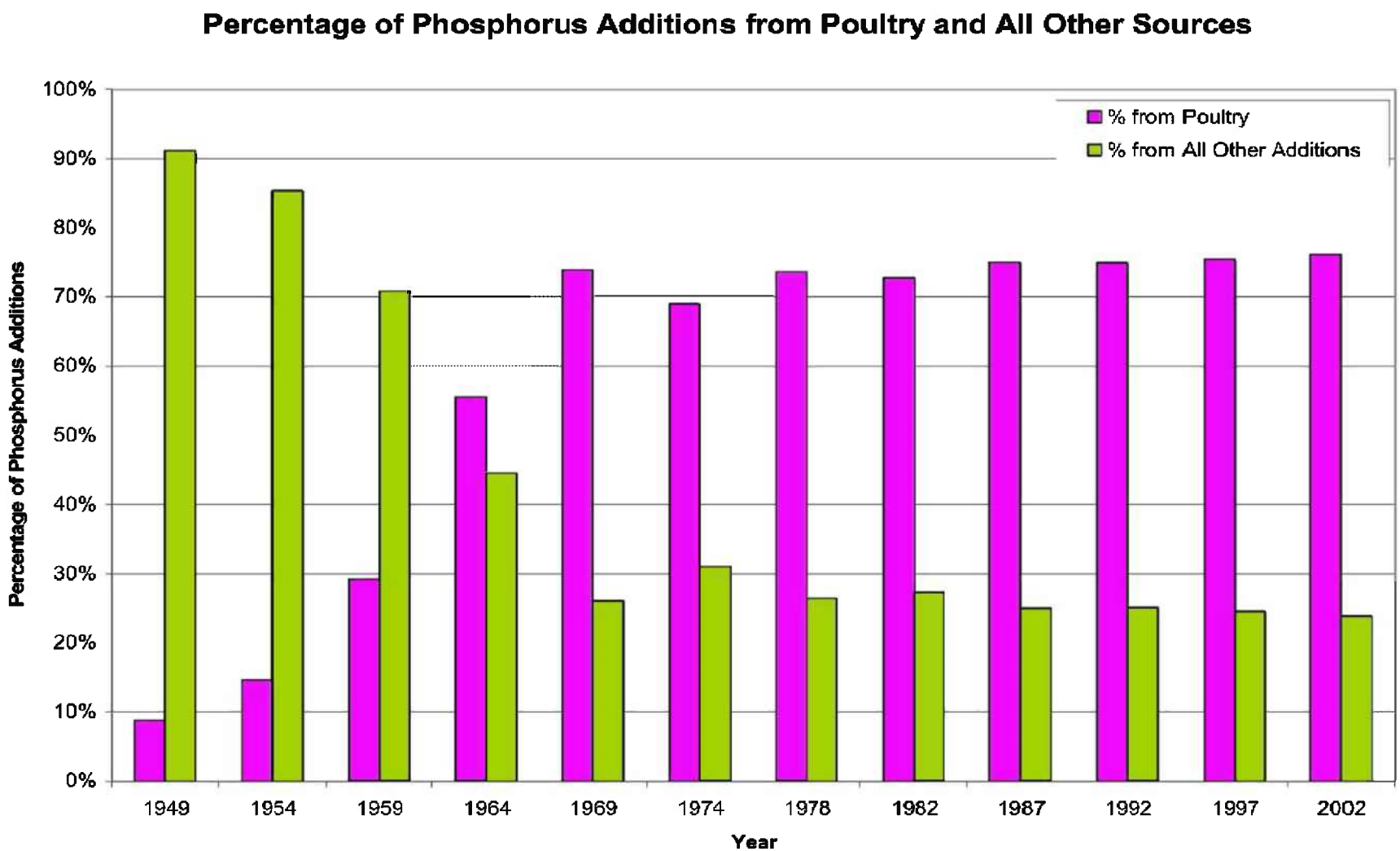

Figure 9. Historical percentage of phosphorus additions from poultry and all other sources (humans, dairy cattle, swine, beef cattle, commercial fertilizer, urban runoff, golf courses, wholesale nurseries, recreational users, and industrial sources)

5.0 CONCLUSIONS

Based on the findings of the study, the following can be concluded:

1. Poultry production is currently responsible for more than 76% of the net annual phosphorus additions to the Illinois River Watershed.
2. Historical data indicates poultry production has been the major contributor of phosphorus to the watershed since 1964. Prior to 1964, dairy cattle were responsible for the majority of the phosphorus contribution.
3. From 1949 to 2002, there was more than 219,000 tons of phosphorus added to the IRW. Almost 68% of that addition, more than 148,000 tons, was attributable to poultry production.
4. Other contributing sources of phosphorus (net additions) include commercial fertilizers (7.5%), dairy cattle (5.2%), humans (3.2%), swine (2.9%), industrial sources – mostly poultry processing facilities (2.7%), and beef cattle (1.7%). The remaining sources of phosphorus evaluated in this study, which include urban runoff, golf courses, wholesale nurseries, and recreational users, are negligible (< 1%).
5. Of the three phosphorus exports from the watershed (harvested crops, harvested deer, and water leaving Lake Tenkiller through the spillway) outflow of phosphorus through the spillway at the south end of Lake Tenkiller was the largest. According to current estimates, the flow of water through the spillway removes just under 1.25% of the total annual phosphorus additions to the watershed. The remaining two phosphorus exports combined remove just over 0.25% of current annual phosphorus additions to the watershed, totaling a 1.5% removal of current phosphorus additions.

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APPENDIX A

Projected Fertilizer Sales from 1951 – 2002

Provided by Dr. Gordon Johnson

Oklahoma

Year	State Phosphorus as P2O5 x1000*	Projected P2O5 sales for counties (tons)			
		Adair	Cherokee	Delaware	Sequoyah
1951	25	615	138	399	0
1952	30	596	147	381	0
1953	23	623	134	406	0
1954	21	630	131	413	0
1955	19	638	127	420	0
1956	21	630	131	413	0
1957	18	642	125	423	0
1958	18	642	125	423	0
1959	25	615	138	399	0
1960	26	611	140	395	0
1961	34	581	154	367	0
1962	45	539	174	329	36
1963	49	524	181	315	52
1964	54	505	190	297	72
1965	61	478	203	273	100
1966	69	448	217	245	132
1967	79	410	235	210	172
1968	76	421	230	220	160
1969	85	387	246	189	196
1970	90	368	255	171	216
1971	98	338	269	143	248
1972	97	341	268	147	244
1973	110	292	291	101	296
1974	106	307	284	115	280
1975	95	349	264	154	236
1976	105	311	282	119	276
1977	116	269	302	80	320
1978	87	379	250	182	204
1979	115	273	300	84	316
1980	115	273	300	84	316
1981	109	296	289	105	292
1982	98	338	269	143	248
1983	97	341	268	147	244
1984	99	334	271	140	252
1985	104	315	280	122	272
1986	90	368	255	171	216
1987	96	345	266	150	240
1988	96	345	266	150	240
1989	104	315	280	122	272
1990	91	364	257	168	220

Year	State Phosphorus as P2O5 x1000*	Projected P2O5 sales for counties (tons)			
		Adair	Cherokee	Delaware	Sequoyah
1991	77	417	232	217	164
1992	76.9	418	231	217	164
1993	83.8	392	244	193	191
1994	90.6	366	256	169	218
1995	85.8	384	247	186	199
1996	80.2	405	237	205	177
1997	77	417	232	217	164
1998	79	410	235	210	172
1999	62.7	472	206	267	107
2000	68	452	215	248	128
2001	56.1	497	194	290	80
2002	75	425	228	224	156
2003	46	535	176	325	40
2004	56	498	193	291	79
2005	53	510	188	302	66
2006	49	523	182	314	53
2007	46	536	175	326	39
2008	42	549	169	338	25

*From files used to print Oklahoma Soil Fertility Handbook; from OSDA reports.

Shaded cells are based on State totals projected from sales since 1980.

Arkansas

Fertilizer P2O5 and N Tonnage for Arkansas and Selected Counties

Year	Benton	Washington	Benton	Washington
	Total tons P2O5		Total tons N	
1951	23	12	43	21
1952	38	20	72	35
1953	53	28	100	49
1954	68	36	129	62
1955	83	44	157	76
1956	98	52	185	90
1957	113	60	214	104
1958	128	68	242	117
1959	143	76	270	131
1960	158	84	299	145
1961	173	92	327	159
1962	188	100	355	172
1963	203	108	384	186
1964	218	116	412	200
1965	233	124	440	214
1966	248	132	469	227
1967	263	140	497	241
1968	278	148	526	255
1969	293	156	554	269
1970	308	164	582	282
1971	322	172	611	296
1972	337	180	639	310
1973	352	188	667	324
1974	367	196	696	337
1975	382	204	724	351
1976	397	212	752	365
1977	412	220	781	379
1978	427	228	809	392
1979	442	236	837	406
1980	457	244	866	420
1981	472	252	894	434
1982	487	260	923	448
1983	502	268	951	461
1984	517	276	979	475
1985	532	284	1,008	489
1986	547	292	1,036	503
1987	562	300	1,064	516
1988	577	308	1,093	530
1989	592	316	1,121	544
1990	607	324	1,149	558
1991	622	331	1,178	571
1992	962	450	1,001	370

Fertilizer P2O5 and N Tonnage for Arkansas and Selected Counties

Year	Benton	Washington	Benton	Washington
	Total tons P2O5		Total tons N	
1993	858	481	887	388
1994	837	466	984	443
1995	816	451	1,081	499
1996	796	435	1,179	554
1997	591	489	717	379
1998	754	405	1,373	664
1999	734	390	1,470	720
2000	713	375	1,567	775
2001	692	360	1,664	830
2002	800	363	2,339	1,332
2003	651	330	1,858	941
2004	630	315	1,955	996
2005	582	259	1,823	795

Values in shaded cells were estimated from tonnage reports.

Values in shaded cells were estimated from regression of total tonnage and time, followed by fraction of total that is P2O5 or N.

APPENDIX B

Golf Courses in the Illinois River Watershed

Oklahoma

Cherokee Trails Golf Course – 22706 South 504 Road Hwy 62, Tahlequah, OK 74441, (918)458-4294, semi-private, 9 hole

Cherry Springs Golf Club – 700 E Ballentine Rd, Tahlequah, OK 74464, (918)456-5100, public, 18 hole

Tahlequah City Golf Course – Bryant Rd, Tahlequah, OK 74464, (918)456-3761, public, 9 hole

Deer Valley Golf Club – Hwy 10, Kansas, OK 74347, (918)597-3636, private, 9 hole

Section 1.01 Arkansas

Lost Springs Golf & Athletic Club – 3024 N 22nd St, Rogers, AR 72756, (501)631-9988, private, 18 hole

Pinnacle Country Club – 3 Clubhouse Dr, Rogers, AR 72758, (501)273-0555, private, 18 hole

Prairie Creek Country Club – Hwy 12 E & Country Club Rd, Rogers, AR 72757, (501)925-2414, semi-private, 18 hole

Shadow Valley Country Club – 7001 Shadow Valley Road, Rogers, AR 72758, (479) 203-0000, private, 18 hole

Brush Creek Golf Course – 6220 Har Ber Ave, Springdale, AR 72762, (501)750-0606, public, 9 hole

Springdale Country Club – 4705 S Thompson, Springdale, AR 72764, (501)751-5185, private, 18 hole

Dawn Hill Golf & Racquet Club – Dawn Hill Rd, Siloam Springs, AR 72761, (800)423-3786, resort, 18 hole

Siloam Springs Country Club – 801 N Country Club Rd, Siloam Springs, AR 72761, (501)524-4269, semi-private, 9 hole

Links at Bentonville Golf & Athletic Club – 2101 SE Hilton Head Dr, Bentonville, AR 72712, (479)271-0163, public, 9 hole

Fayetteville Country Club – 3335 Country Club Dr, Fayetteville, AR 72701, (501)442-5112, private, 18 hole

Paradise Valley – 3728 Old Missouri Rd, Fayetteville, AR 72703, (501)521-5841, private, 18 hole

Razorback Park Golf Course – 2514 W Lori Dr, Fayetteville, AR 72704, (501)443-5862, public, 18 hole

Stonebridge Meadows Golf Club – 3495 E Goff Farms Rd, Fayetteville, AR 72701, (479)571-3673, public, 18 hole

Lakeside Village Golf Course – 200 Village Lake Drive, Fayetteville, AR 72703, (479)442-7748, public, 9 hole

The Blessings Country Club – 5826 Clear Creek Blvd, Fayetteville, AR 72704, (479)444-6330, private, 18 hole

The Creeks Public Links – 190 S Hwy 112, Cave Springs, AR 72718, (501)248-1000, public, 18 hole

APPENDIX C

Industrial Sources

Facility Descriptions and Average Phosphorus Inputs

Provided by Dr. Bernie Engel

Facility Name	Description
Allen Canning Co	Spinach and other greens, green beans, and dry-pack beans are processed and canned.
Blaylock Company	Poultry product is ground, frozen, stored, and shipped to pet food manufacturing facilities
Cargill, Inc.	Turkey slaughter, deboning, and further processing
Cintas Corporation	Laundering and processing of industrial uniforms, shop towels, mats, and mops
D. B. Foods, Inc	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated.
D. B. Foods, Inc.	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated
Danaher Tool Group	Forging, stamping, broaching, grinding, and electroplating wrenches
George's Further Processing	Raw chicken is deboned and shipped out fresh. Some is marinated, cooked, etc., and shipped out
George's, Inc.	Poultry slaughter, chilling, cutting, packing, and shipping.
J. B. Hunt Transport, Inc	Truck and trailer maintenance, including washing, fueling, mechanical and wreck repair.
Pappas Foods, L.L.C.	Fruit is delivered, pressed, pasteurized, and stored in refrigerated tanks. Various fruit ingredients are blended and filtered. Bottles are filled, packed, palletized, and shipped. A non-fruit (sports drink) is also prepared at this facility. The only fresh fruit processed is grapes and cranberries. All other fruit comes in as a prepared concentrate
Sonstegard Foods Inc. of Arkansas	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated
Superior Linen Service	Washing and drying rental linen - napkins, table cloths, towels, sheets, pillow cases, floor mats, etc.
Triple T Foods, Inc.	Poultry products are ground and frozen, then shipped off for use as animal feed
Tyson Foods, Inc. - Berry St.	Chickens are unloaded, killed, scalded, picked, eviscerated, chilled, weighed, cut up, breaded, cooked, frozen, packed, weighed, boxed, stored, and shipped.
Tyson Foods, Inc. - Hog Trailer Wash	Washing of hog trailers
Tyson Foods, Inc. - Randall Rd.	Chickens are received, slaughtered, eviscerated, packed, frozen, and shipped
Tyson Research & Technology	Further processing of products made from chicken, research and development

Facility Name	P ave (kg/d)
Allen Canning Co	5.35
Allen Canning Co	36.64
Blaylock Company	1.28
Cargill, Inc.	53.90
Cintas Corporation	3.47
D. B. Foods, Inc	7.89
Danaher Tool Group	13.46
Danaher Tool Group	3.05
George's Debone	13.83
George's Further Processing	23.60
George's, Inc.	52.39
J. B. Hunt Transport, Inc	0.39
J. B. Hunt Transport, Inc	0.19
Monark Egg	5.54
Midcentral Egg	2.89
Pappas Foods, L.L.C.	1.84
Sonstegard Foods Inc. of Arkansas	0.00
Superior Linen Service	1.43
Triple T Foods, Inc.	1.79
Tyson Foods, Inc. - Berry St.	110.69
Tyson Foods, Inc. - Hog Trailer Wash	6.58
Tyson Foods, Inc. - Randall Rd.	56.14
Tyson Research & Technology	2.76
Total	**405.07**

APPENDIX D

Pounds of Nutrients Removed by Harvested Crops

Year	Nutrient (lb)	Corn for Grain	Sorghum for Grain	Wheat for Grain	Oats	Soybeans for Beans
1949	N	532,012	6,213	43,669	188,881	5,481
	P	101,569	1,107	8,247	36,499	561
	K	111,921	1,287	9,242	41,885	1,287
1954	N	21,728	2,090	35,213	342,784	9,510
	P	4,148	372	6,650	62,530	974
	K	4,571	433	7,440	76,013	2,232
1959	N	247,431	52,146	61,793	67,045	48,927
	P	47,238	9,292	11,669	12,230	5,012
	K	52,052	10,799	13,057	14,867	11,485
1964	N	43,881	13,148	74,763	-	82,142
	P	8,378	2,343	14,119	-	8,414
	K	9,231	2,723	15,797	-	19,282
1969	N	19,810	32,167	49,149	-	95,045
	P	3,782	5,732	9,281	-	9,736
	K	4,167	6,662	10,385	-	22,310
1974	N	10,422	18,865	35,140	-	103,845
	P	1,990	3,361	6,636	-	10,637
	K	2,193	3,907	7,425	-	24,376
1978	N	12,818	31,033	67,179	-	170,065
	P	2,447	5,530	12,686	-	17,420
	K	2,696	6,427	14,195	-	39,920
1982	N	5,791	16,184	151,071	-	221,323
	P	1,106	2,884	28,529	-	22,671
	K	1,218	3,352	31,921	-	51,952
1987	N	0	15,664	26,020	-	182,735
	P	0	2,791	9,194	-	18,718
	K	0	3,244	10,287	-	42,894
1992	N	0	2,308	48,866	-	126,606
	P	0	411	9,228	-	12,969
	K	0	478	10,325	-	29,719
1997	N	15,405	1,892	48,206	-	104,954
	P	2,941	337	9,103	-	10,751
	K	3,241	392	10,186	-	24,636
2002	N	21,378	1,733	95,512	-	63,993
	P	4,081	309	18,037	-	6,555
	K	4,497	359	20,182	-	15,021

Appendix C

River Phosphorus Concentrations vs. Poultry House Density

The analyses described in this appendix were a collaborative effort of Dr. Roger Olsen, Dr. Tim Cox, and Dr. Bernard Engel. Dr. Cox prepared the text contained in this appendix.

Objectives

The primary objective of this analysis was to investigate for causal links between selected sub-basin characteristics and total phosphorus concentrations in tributaries of the Illinois River. In particular, the impacts of poultry house presence on stream water quality were investigated. A secondary objective was to develop the basis for a simple empirical predictive tool to assist in watershed management.

Methods

This work involved linear regression analyses of data collected as part of the small tributary sampling program in the basin. Data were collected for both highflow and baseflow conditions throughout two summer periods (2005 and 2006). Data were collected from a total of fourteen sampling locations in small tributaries throughout the basin that covered a range of drainage area size and landuse characteristics. In particular, a representative range of poultry house presence (from no presence to highly active presence) was included in the sampling program. Further details of this sampling program are provided in Olsen (2008).

Regression analyses were performed for measured total phosphorus concentrations as a function of a range of hypothesized potential predictor variables, including poultry house densities in local drainage areas. Table 1 summarizes the predictor variables included in the analysis. Predictor variables were generally quantified using a combination of GIS mapping, aerial photographs, and field reconnaissance. Poultry house densities were determined by first identifying and locating potential poultry houses using up-to-date aerial photography of the watershed. These houses were then confirmed through field reconnaissance and categorized as either “active”, “temporarily inactive”, or “abandoned”. The house locations were then mapped in GIS and densities were calculated as the number of houses in the targeted sub-basin divided by the area of the sub-basin (Fisher, 2008). Only active houses were included in the “active house density - AHD” calculations while all houses (active + inactive + abandoned) were included in the “total house density – THD” calculations. Soil Conservation Service Curve Numbers (SCS CN) were estimated by first intersecting GIS layers of soil hydrologic type (A – D) and landuse category. Table 2 of the USDA Technical Release-55 (“Urban Hydrology for Small Watersheds”) was then used to assign curve numbers to each intersection area of each sub-basin. Finally, these values were used to calculate area-weighted average curve numbers for each sub-basin. Other parameters listed in 1 were calculated using standard GIS mapping and calculation methods.

High flow and baseflow data were separated for this analysis. Total phosphorus concentration data were pooled in three ways: 2005 only, 2006 only, and combined 2005 – 2006. For the high flow analysis, flow-composited samples from each event were averaged for each time period pool for each sampling station. In other words, a single average value was generated for each

pool and each station. The flow-weighted averaging method used here applied weightings to each event based on the relative size of the event. Flow-weighted averages were calculated as:

$$TP_{avg} = \frac{1}{\sum_{n=1}^{numEvents} Vol_i} \sum_{n=1}^{numEvents} EMC_i Vol_i$$

where TP_{avg} = the flow-weighted average phosphorus concentration, i = index for a given sampled storm event, numEvents = number of sampled storm events, Vol_i = total runoff volume for storm event i, and EMC_i = measured event mean phosphorus concentration for event i. In this way, the values assigned to each station better capture the relationships between total mass *loads* and sub-basin characteristics. Thus, a small runoff event that results in high phosphorus concentrations is weighted less in the calculations than a large event which results in lower concentrations to reflect the relative mass loads of the two events.

Straight averaging across sampling events was used for the baseflow data.

Two of the sampling stations, Site HFS 04 and HFS 22, were excluded from the statistical analysis described here due to the presence of point sources within the station sub-basins. Stream water quality at these two sites is dominated by effluent from the City of Siloam Springs wastewater treatment plant and the City of Lincoln wastewater treatment plant, respectively. These sites were sampled to provide information on the mass loads contributed by these types of facilities but are not appropriate for inclusion in the analysis described here. Additionally, 2006 data from HFS 14 were excluded from the analysis. While this site was a verified reference site in 2005 (no poultry activity in the sub-basin), poultry waste spreading was observed on a field immediately upstream of the sampling site in 2006. Therefore, the original landuse designation (forested) and poultry house density (0 houses/mi.) were not valid in 2006 and the data collected during this sampling period were omitted from the analysis.

Microsoft Excel was used to calculate correlation coefficients (R^2 values) and significance levels (p values) for each pairing of predictor variable and total phosphorus concentration. A statistically significant correlation was defined as one in which $p \leq 0.05$ (95% significance level).

Results and Discussion

Table 2 summarizes the results of the regression analysis. Graphical results of two sets of regressed data with high correlation coefficients, high significance, and good data spread are shown in Figures 1 and 2.

As can be seen, sub-basin poultry house densities, in a variety of forms, appear to be strong predictors of stream total phosphorus concentration. This is particularly true when the 2005 and 2006 data are pooled and a more comprehensive data set is formed. For the combined 2005-06 data sets, all 6 of the poultry house density predictor variable forms are shown to be significantly and positively correlated with total phosphorus concentrations in the receiving streams during highflow events. Overall, 21 out the 36 TP vs. poultry density regressions show significant and positive correlations. The strongest and most convincing correlations appear to be for the pooled 2005 – 06 phosphorus concentrations vs. total and active poultry house densities within a 2 mile

buffered drainage area (Figures 1 and 2). These results indicate that poultry house density could be used as a predictor of stream phosphorus concentrations in this watershed. Additionally, the relationships established here could be used to guide watershed management decisions.

Septic tank density is also shown to be a statistically significant predictor of stream phosphorus concentration for most of the data combinations. However, these correlations are not generally as strong as those associated with poultry house density, particularly for high flow conditions. Additionally, a strong cross correlation is observed between septic tanks and total poultry house density within the 2 mile buffered area (see Figure 3). In other words, in areas with high poultry house development, human dwellings are also relatively high. This is not unexpected. Finally, an independent analysis of the total phosphorus loading expected from septic tanks in the watershed has shown these contributions to be negligible relative to the total mass loading in the systems (see Appendix G). These factors lead us to conclude that a true causal relationship between septic tanks and stream phosphorus concentration does not exist. Rather, the perceived correlation between these variables is simply an artifact of the cross-correlation between residential dwellings and poultry house presence.

The Soil Conservation Service Curve Number (SCS CN) is shown to be a significant predictor of the 2005 baseflow TP concentrations (positive correlation). Similarly, the percent of the sub-basin stream length with riparian buffers is shown to be a significant predictor of 2006 highflow TP concentrations (negative correlation). Both of these parameters are significantly correlated with only one of the six TP datasets, and neither is significantly correlated with the most comprehensive dataset (pooled 2005-06 data). Therefore, we conclude that these parameters are, at best, weak predictors of stream phosphorus concentration.

Table 1
Potential Total Phosphorus Predictor Variables

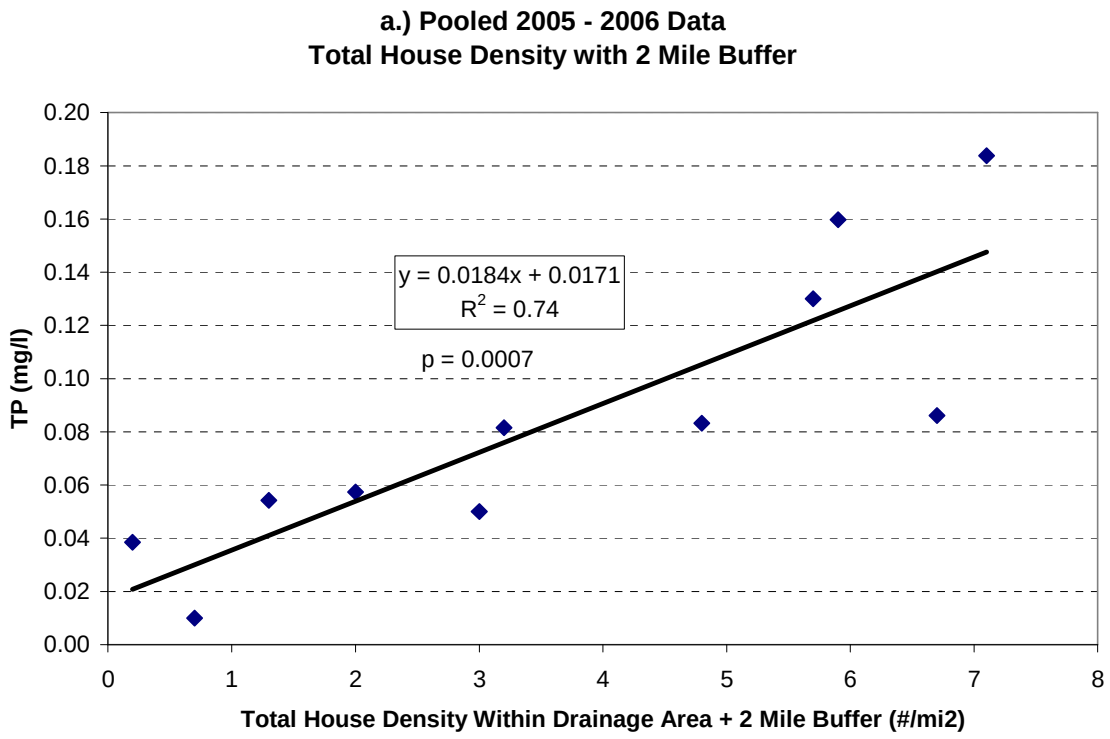
Variable	*Description*	*Rationale*
Total House Density (THD)	density (houses per mi^2) of all identified poultry houses, including inactive houses, in sub-basin	poultry waste is spread on fields in vicinity of poultry houses *(expected positive correlation*)
Active House Density (AHD)	density (houses per mi^2) of all identified active poultry houses in sub-basin	“”
THD – 1 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 1 mile perimeter buffer	tributary water quality may be impacted by poultry houses a short distance outside of sub-basin (waste transported from a house outside the basin to a field inside the basin) *(expected positive correlation*)
AHD – 1 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 1 mile perimeter buffer	“”

THD – 2 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 2 mile perimeter buffer	approximately 80% of poultry waste is spread on fields within 2 miles of poultry house (Fisher, 2008) *(expected positive correlation)*
AHD – 2 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 2 mile perimeter buffer	“”
SCS CN	Soil Conservation Service Curve Number	sub-basins with varying runoff potential may differ in their impact on receiving stream water quality
Septic Tank Density	estimated density (tanks per mi^2) of septic tanks in sub-basin	leaching from septic tanks may carry a significant phosphorus load *(expected positive correlation)*
% Pasture	percent of pasture in sub-basin	amount of pasture in a sub-basin can serve as a surrogate for agricultural activity which may be a good predictor of stream phosphorus concentration *(expected positive correlation)*
% Riparian Buffer	percent of stream length in sub-basin that is buffered by forest	riparian buffers can filter nutrients from runoff prior to entering streams *(expected negative correlation)*
Median Distance to Chicken Houses	median of distances (mi) from poultry houses in the sub-basin to the sampling site	poultry houses closer to the stream may have a greater impact on water quality than those further away *(expected negative correlation)*

Table 2
Regression Analysis Results Summary[1]

	2005 Highflow	**2005 Baseflow**	**2006 Highflow**	**2006 Baseflow**	**2005 – 06 Highflow**	**2005 – 06 Baseflow**
THD	0.64	0.86	0.14	0.66	0.76	0.68
AHD	0.32	0.73	0.26	0.49	0.56	0.47
THD – 1 mi	0.28	0.63	0.39	0.31	0.65	0.3
AHD – 1 mi	0.13	0.42	0.49	0.18	0.49	0.19
THD – 2 mi	0.48	0.63	0.27	0.35	0.74	0.36
AHD – 2 mi	0.49	0.64	0.28	0.33	0.74	0.36
SCS CN	0.18	0.43	0.14	0.40	0.23	0.27
Septic Tanks	0.48	0.52	0.15	0.57	0.37	0.41
% Pasture	0.13	0.13	0.09	0.01	0.12	0.01
% Rip. Buff.	0.03	0.09	0.49	0.19	0.18	0.12
Med. Dist. CH	0.11	0.07	-0.25	0.01	0.04	0.001

1 = statistically significant correlations ($p \leq 0.05$) indicated by highlighting



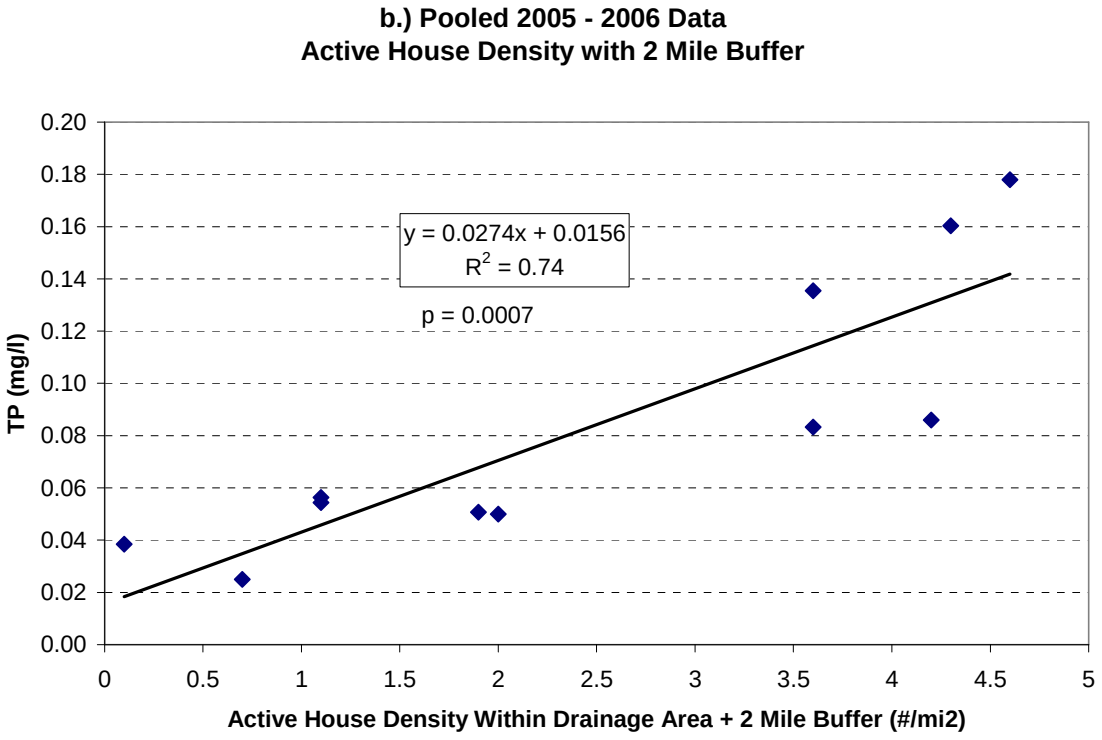
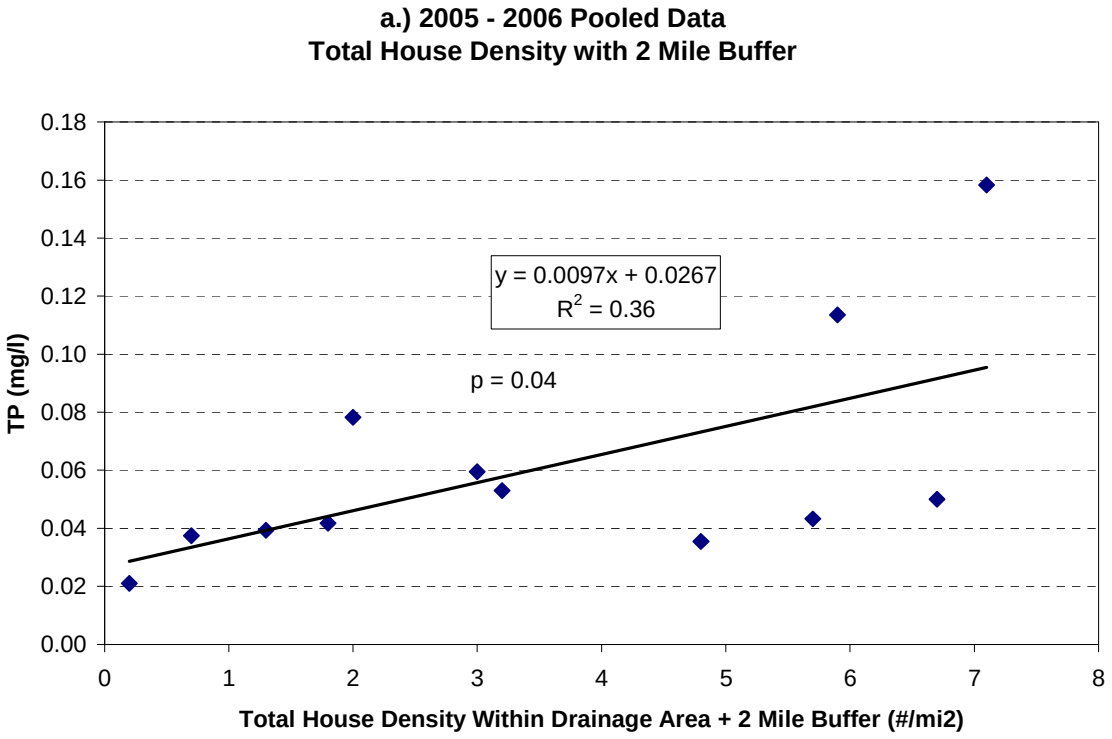


Figure 1. Highflow Regressions: Total Phosphorus Concentration vs. Poultry Presence



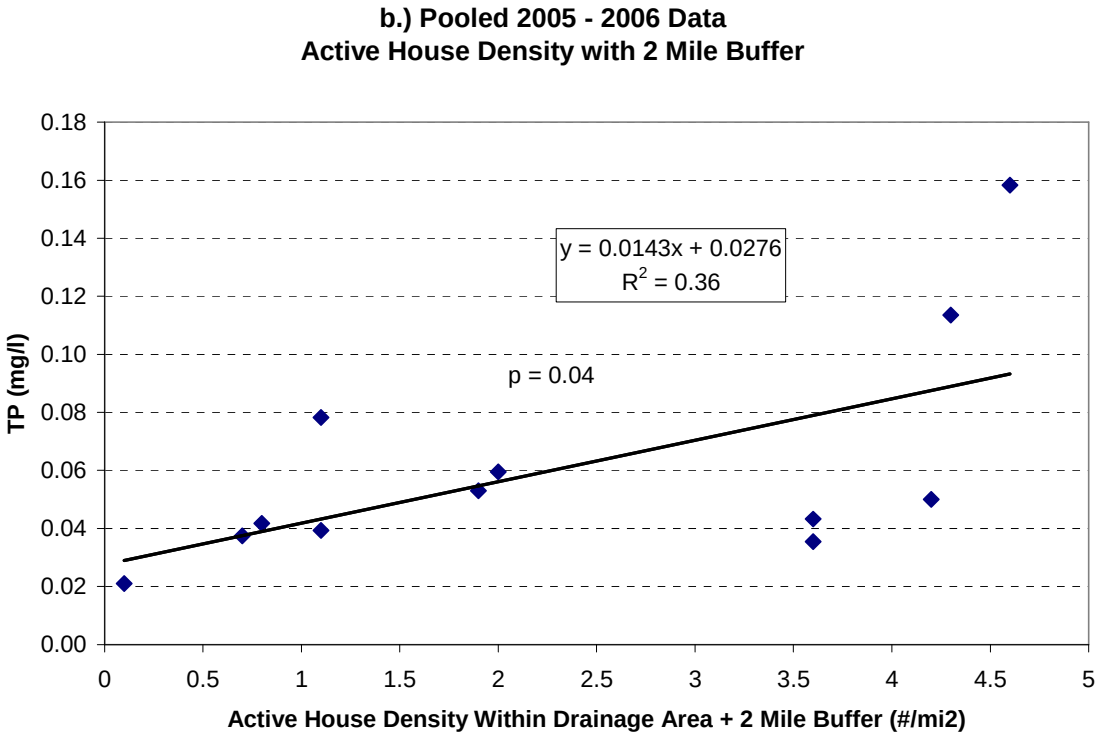


Figure 2. Baseflow Regressions: Total Phosphorus Concentration vs. Poultry Presence

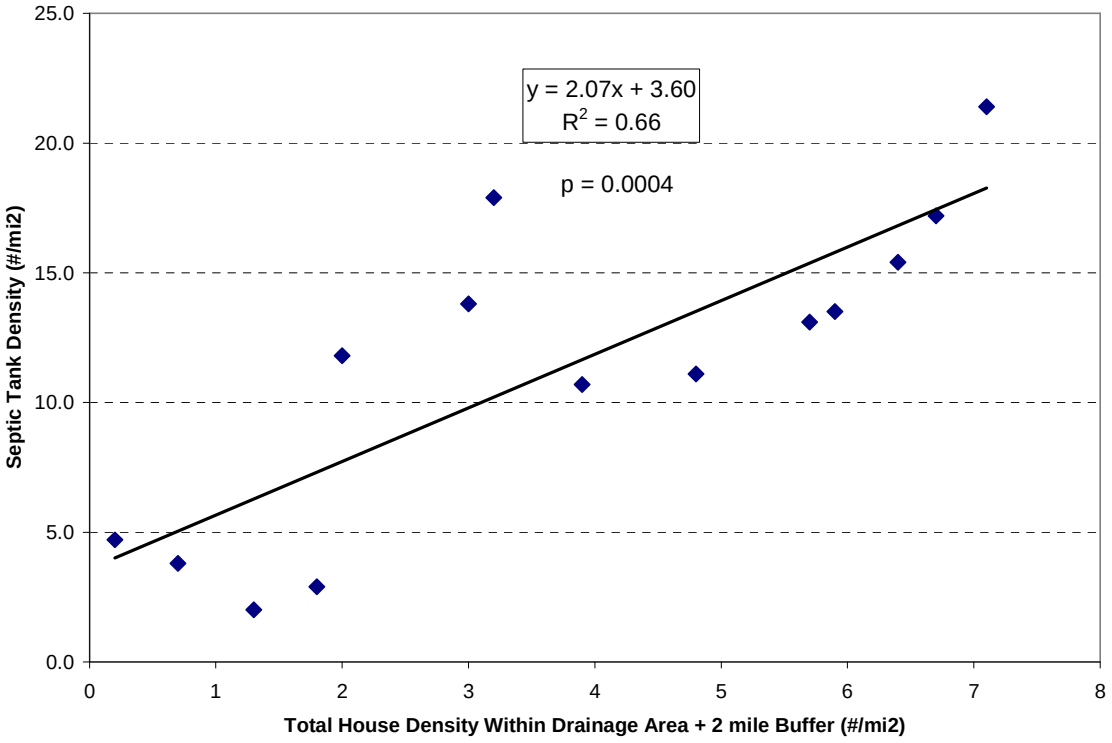


Figure 3 Cross Correlation Between Septic Tank Density and Poultry Presence

Appendix D
Hydrologic/Water Quality Modeling

Data Sources and Preparation

Spatial data for land cover, soil, elevation, soil test phosphorus (STP), poultry litter application, other nutrient applications to the landscape, and weather gage stations were used for preparation of the GLEAMS model inputs. These spatial data were processed in ArcView software in the GIS grid file format. Observed weather data were processed for GLEAMS input file generation. Observed USGS stream flow and water quality data were used for model calibration/validation processes. OWRB water quality data were also used for model calibration and validation.

Land Cover

The land cover is important information for GLEAMS modeling because land cover type influences the water budget and pollutant loading from watersheds. Most watershed models generally simulate runoff and pollutant loadings for each hydrologic response unit (HRU) which is typically defined based on land cover or a combination of land cover and soil type. Figure 1 shows the land cover for the Illinois River Basin based on the most recently available National Land Cover Dataset (NLCD) for 2001. Land use was divided into five categories: water, crop, pasture, urban and forest. The Illinois River Basin area is 4,277 km^2 and the primary land use type is pasture at about 50% (2,126 km^2) of total area followed by forest with about 40% (1,728 km^2) of total area.

Soil

Soil information is also import for GLEAMS modeling. Its characteristics influence water movement, soil erosion processes and nutrient movement. The spatial distribution of soil data was obtained from the State Soil Geographic (STATSGO) database (available from the USEPA web site (http://www.epa.gov/waterscience/htp/basins/gisdata/huc/)). The soil groups can be

divided into 14 categories by STMUID and major soil group as shown in Figure 2. The STATSGO database contains numerous soil properties for each soil group that were used in parameterizing GLEAMS.

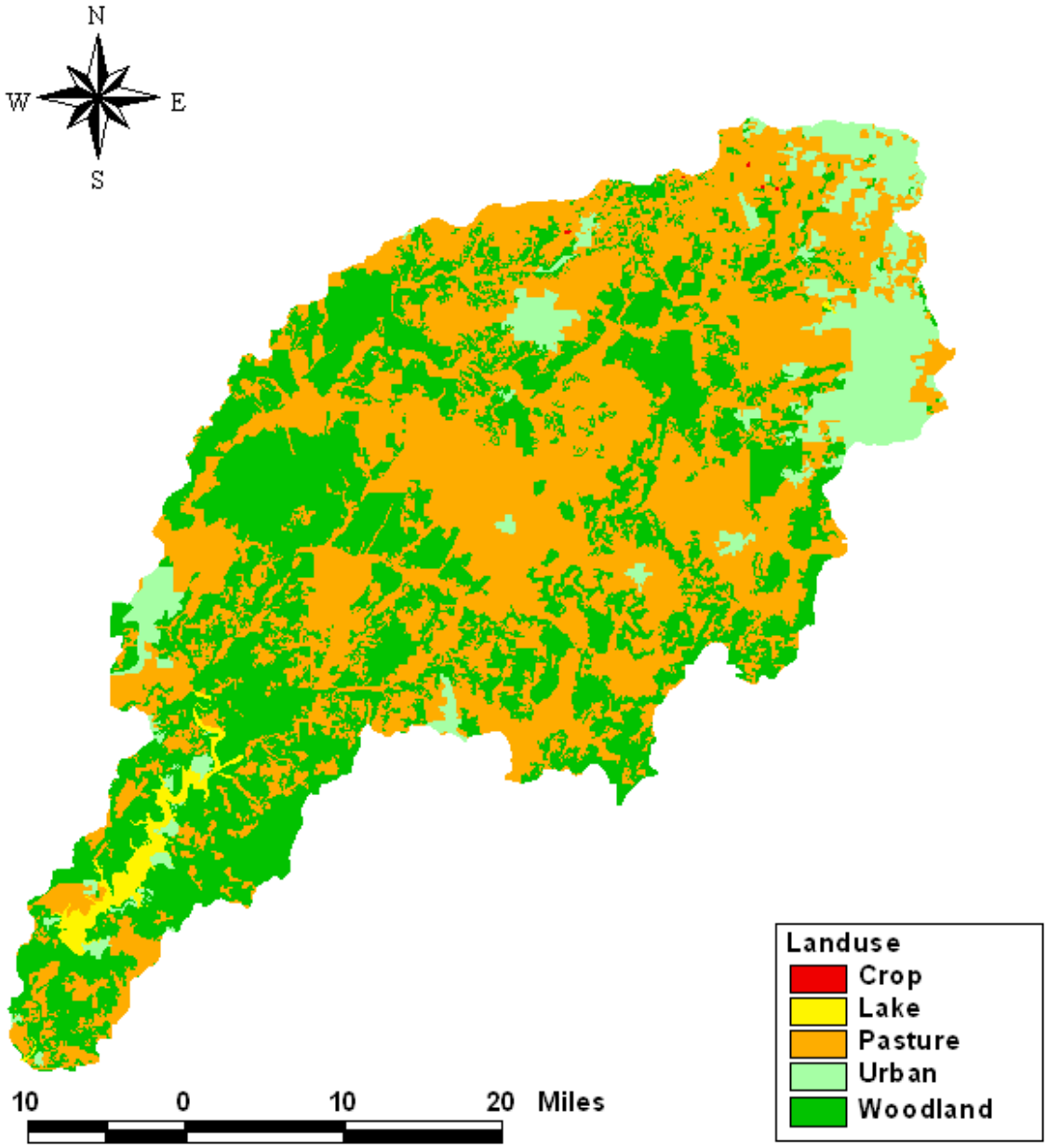


Figure 1. Land cover distribution for Illinois River Basin based on NLCD 2001 data

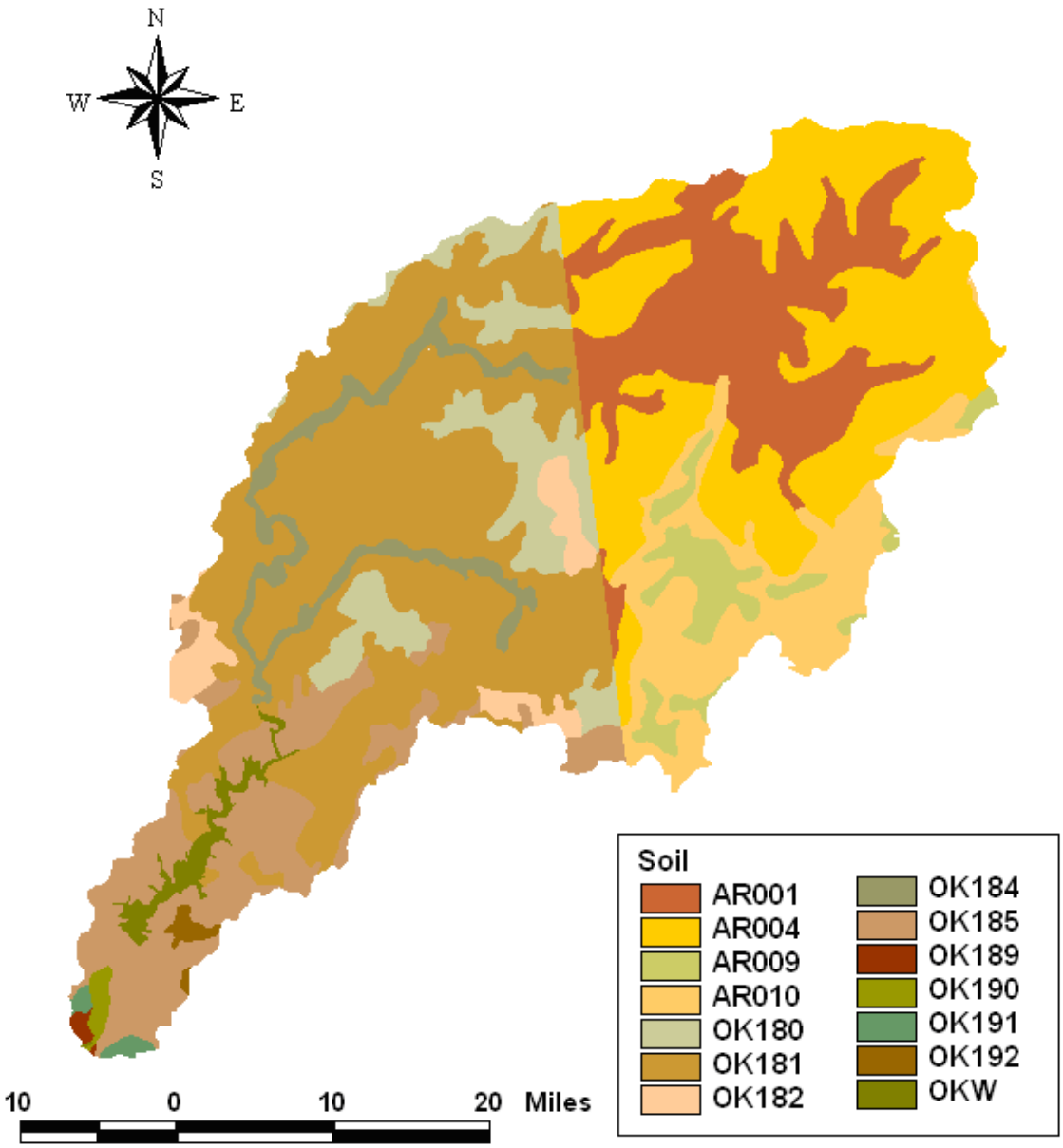


Figure 2. STATSGO soil type distribution for Illinois River Basin

Topography

The topographic characteristics determine the water movement within watersheds and can be defined by a digital elevation model (DEM). The DEM for the Illinois River Watershed was obtained from the USGS with a 30m grid cell resolution and is shown in Figure 3.

Weather Data

Observed daily precipitation and average monthly temperature were used in the GLEAMS modeling. Weather data were obtained from the National Climatic Data Center (NCDC).

Weather Stations

There are several weather stations in the Illinois River Basin. Various precipitation patterns need to be considered in GLEAMS model application. Therefore, the distribution of weather gage stations was generated as ArcView (GIS) point data using latitude and longitude information of weather stations at the NCDC website (Figure 4). Thessien polygons for the weather stations were generated using the weather station gage location data (Figure 4) to identify appropriate rainfall gages to use for locations within the Illinois River Watershed. All weather stations have not been monitored continuously and most weather stations which are being monitored for rainfall have not been monitored for temperature at the same station. Table 1 shows the selected weather stations which are operated currently.

Table 1. Weather stations used to model Baron Fork, Illinois River, and Caney Creek Basins

	Baron Fork	Illinois River	Caney Creek
Rainfall stations	035354, 348506	032444, 344672, 348677	348506
Temperature station	9450	9450	9450

Weather Data

Daily rainfall and temperature data were downloaded from the NCDC website. Average monthly temperature data were obtained using the last 30 years of daily temperature data from the stations identified in Table 1.

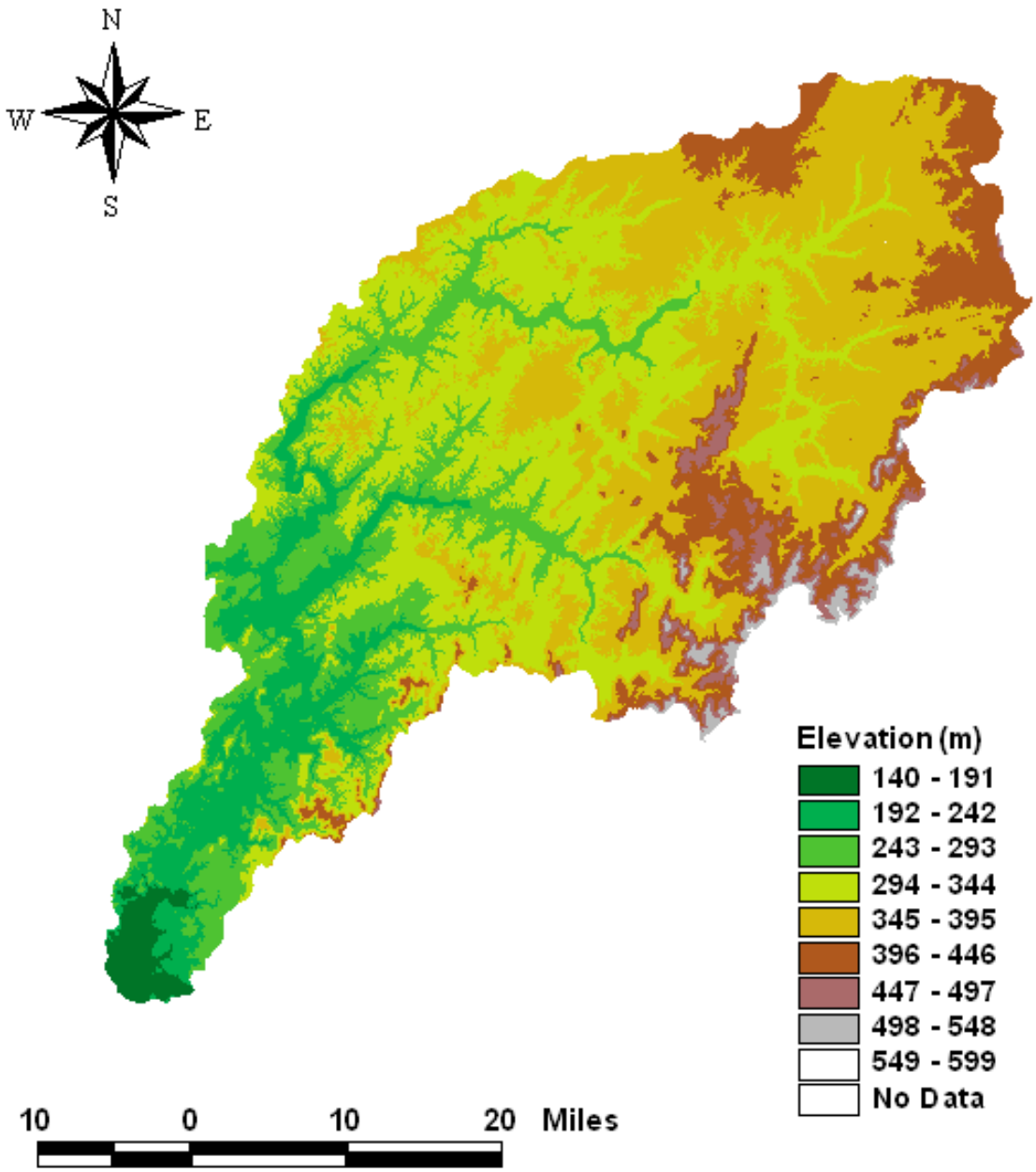


Figure 3. USGS DEM for the Illinois River Basin

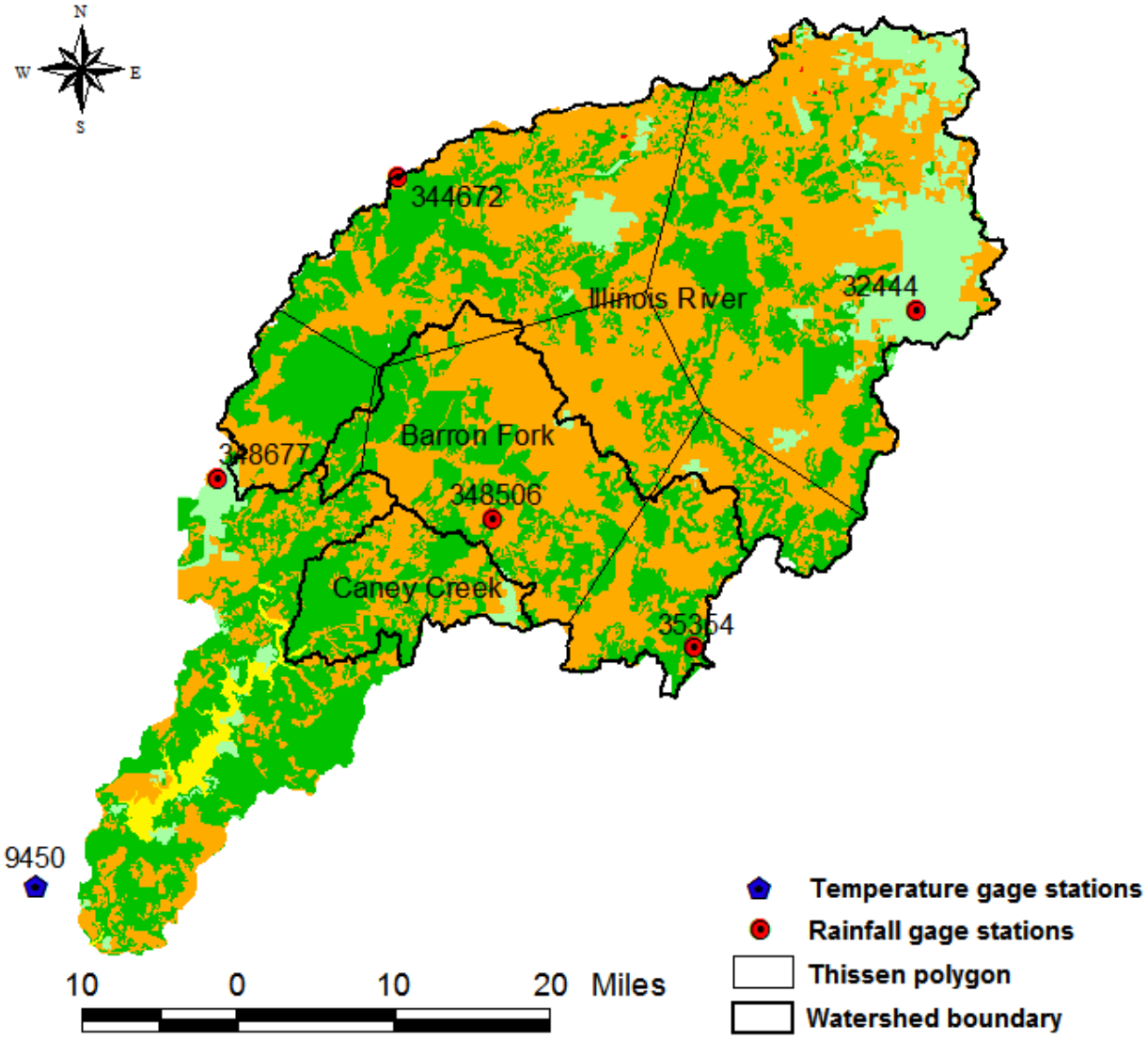


Figure 4. Rainfall gage station locations and rainfall Thiessen polygons derived from these gages

Stream flow data

Streamflow data were obtained from USGS streamflow gauging stations, and each USGS streamflow gauging station with name of the study watersheds is listed in Table 2.

Table 2. USGS gage stations for each watershed

	USGS gage station
Illinois River	USGS 07196500 Illinois River near Tahlequah, OK
Barron Fork	USGS 07197000 Barron Fork at Eldon, OK
Caney Creek	USGS 07197360 Caney Creek near Barber, OK

GLEAMS Modeling Approach

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a one-dimensional mathematical model for field-scale assessment and it assumes that the area to which it is applied is homogenous for hydrological and pollutant loading characteristics. Therefore, input files were generated and the GLEAMS model was used to represent landuse, soil, management, and weather combinations for watershed scale application. For the hydrologic simulation, the combination of land use and soil type is a hydrologic response unit so GLEAMS input file for hydrologic simulation were generated based on these two combinations. For the pollutant loading simulation, the combination of land use type and pollutant loading characteristics of watershed form a homogenous loading response unit so four zones were created using poultry house density (Figure 6). GLEAMS input files for pollutant loading simulation were generated as the combination of land use type and four zones. Therefore, several hydrologic input files which have the same land use type but different soil type shared pollutant loading input files which had the same land use type (Figure 5).

Additional details about GLEAMS are provided in the GLEAMS User's Manual and in Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007).

Hydrologic simulation input file generation

Most hydrologic parameters for the GLEAMS model came from STATSGO information and the GLEAMS manual as follows.

DAREA is the area for each hydrologic response unit and was generated using the clipped GIS layer for the combination of land use, soil and poultry house density.

RC is the effective saturated conductivity of the soil horizon immediately below the root zone (cm/hr). This value was obtained from the saturated hydraulic conductivity information (SOL_K) of the deepest STATSGO soil layer.

CONA is the soil evaporation parameter and was obtained from the GLEAMS manual as shown in Table 3.

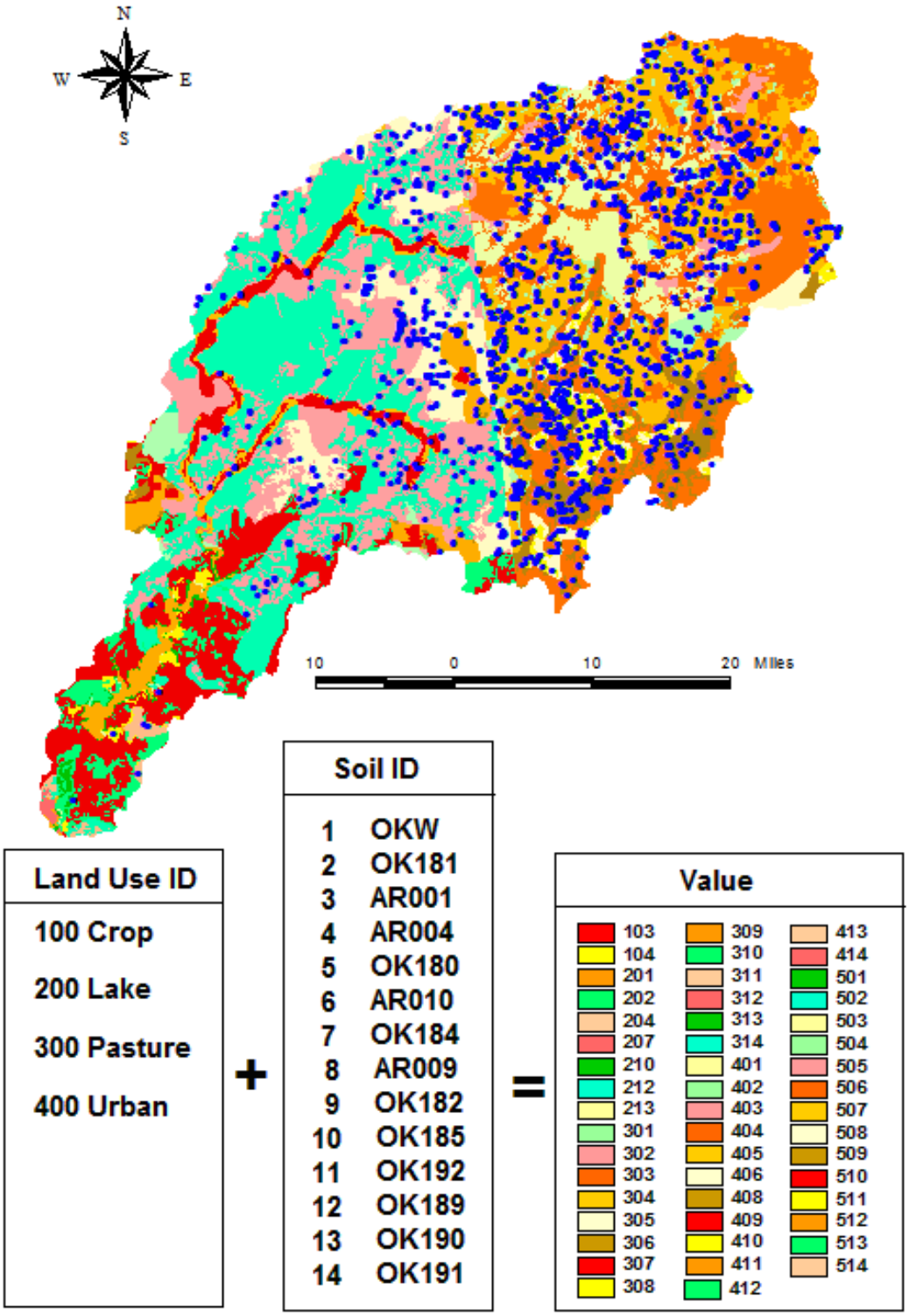


Figure 5. The combination of land use and soil

Table 3. Physical properties of soils by textural classification from GLEAMS manual Table H-3.

Texture	Field capacity (cm/cm)	Wilting Point 1500 kPa (cm/cm)	Evap. Const. ($mm/d^{0.5}$)
Coarse sand	0.11	0.03	3.3
Sand	0.16	0.03	3.3
Find sand	0.18	0.03	3.3
Very fine sand	0.27	0.03	3.3
Loamy coarse sand	0.16	0.05	3.3
Loamy sand	0.19	0.05	3.3
Loamy fine sand	0.22	0.05	3.3
Loamy very find sand	0.37	0.05	3.3
Coarse sandy loam	0.19	0.08	3.3
Sandy loam	0.22	0.08	3.5
Fine sandy loam	0.27	0.08	3.5
Very fine sandy loam	0.37	0.08	3.5
Loam	0.26	0.11	4.5
Silt loam	0.32	0.12	4.5
Silt	0.27	0.13	4.0
Sandy clay loam	0.30	0.18	4.0
Clay loam	0.35	0.22	4.0
Silty clay loam	0.36	0.20	4.0
Sandy clay	0.28	0.20	3.5
Silty clay	0.40	0.30	3.5
Clay	0.39	0.28	3.5

CN2 is the curve number for AMC II condition. This value can be obtained from an NRCS-USDA table knowing the combination of land use and hydrologic soil type. Although land use and hydrologic soil type is the same, the CN values vary by agricultural management activity for cropped land, percentage of impervious area for urban land, cover condition for forest, and grazing condition for pasture. Whereas, exact conditions for each watershed are unknown, therefore an averaged CN value for each combination of land use and hydrologic soil group types was used (Table 4) as a starting point.

Table 4. CN values for the combination of land use and hydrologic soil group.

	Hydrologic soil group			
	A	B	C	D
Crop	64	77	84	87
Pasture	49	69	79	84
Urban	77	85	89	92
Forest	44	64	76	82

CHS is the hydraulic slope of a field and is defined as the slope of the longest flow path. The longest flow path is the flow line from the most remote point of the field boundary to the outlet of the field. This length and difference in elevation from the most remote point to the outlet are the same as those used in estimating a time of concentration of a drainage area. CHS was generated using the following equation from the GLEAMS manual.

$$CHS = \frac{ELEV_{mx} - ELEV_{mn}}{LFP}$$

Where, $ELEV_{mx}$ and $ELEV_{mn}$ is maximum and minimum elevation of the drainage area, respectively, and was obtained from the DEM. LFP is the length of the longest flow path and was obtained using the USEPA Reach File 1 (RF1) which was downloaded from the USEPA web site (http://www.epa.gov/waterscience/htp/basins/gisdata/huc/).

WLW, a ratio of the watershed, or field, length to the width is a relative measure of the elongation, is used in the empirical relationship to estimate peak rate of daily runoff. As WLW

increases, the peak rate of runoff decreases and a watershed length width ratio was calculated as follows using an equation from the GLEAMS manual.

$$WLW = \frac{(length\ of\ longest\ flow\ path\ in\ \ field, m)^2}{Drainage\ area(m^2)}$$

Where length of longest flow path in field was generated using RF1.

RD, an effective rooting depth, was defined in GLEAMS as that which gives the best estimate of surface runoff. These values came from depth from soil surface to the bottom of the deepest layer (SOL_Z) of the soil in STATSGO.

ELEV and LAT is mean sea level elevation and location information of weather gage station which is used to estimate potential evapotranspiration by the Penman-Monteith method and was obtained from the NCDC weather station web site.

NSOHZ, number of soil horizons in the root zone, was generated from the STATSGO data.

BOTHOR, depth of bottom of each soil layer, is needed to define the profile physical dimensions. The number of horizons and their thickness enable the model to set the computational layers within the horizons and this information was obtained from SOL_Z of the last soil layer of STATSGO.

POR, soil porosity for each soil horizon, represents the maximum amount of water that a unit volume of soil can hold without any drainage. These values were calculated using bulk density using the following equation from the GLEAMS manual.

$$POR = 1 - \frac{BD}{2.65}$$

Where BD is bulk density obtained from bulk density information (SOL_BD) in STATSGO.

FC, the agronomic definition of field capacity, is used for the volumetric water content after 24 hours of drainage. This value was obtained using each soil's texture (obtained from STATSGO) and data from the GLEAMS manual as shown in Table 3.

BR15, wilting point, is defined as the volumetric water content at 1,5000 kPa matric potential. The volume of water at wilting is needed since that water contains pesticides and nutrients that react with each chemical pulse and this value is obtained using texture (obtained for each soil from STATSGO) and the GLEAMS manual as shown in Table 3.

SATK, saturated conductivity in each soil horizon, was generated from SOL_K of each soil layer using STATSGO data.

CLAY and SILT, percent of clay and silt mass in each soil horizon, respectively, are important data in the GLEAMS model because the relative amounts determine the textural classification which are used in estimating porosity and field capacity. These were obtained from STATSGO data.

Table 5. Original soil properties and calibrated soil properties for four soils

	AR001				AR009			
	Original	Illinois River	Barron Fork	Caney Creek	Original	Illinois River	Barron Fork	Caney Creek
RC	0.004	0.003	0.005	0.006	0.607	0.509	0.825	0.894
RD	61.71	34.29	32.96	83.93	28.54	15.86	15.24	38.82
BOTHOR(1)	10.03	5.57	5.36	13.64	3.86	2.14	2.06	5.25
BOTHOR(2)	36.26	20.15	19.36	49.32	7.71	4.28	4.12	10.49
BOTHOR(3)	61.71	34.29	32.96	83.93	19.28	10.71	10.30	26.22
BOTHOR(4)					27.00	15.00	14.42	36.72
BOTHOR(5)					28.54	15.86	15.24	38.82
FC(1)	0.509	0.444	0.482	0.330	0.453	0.395	0.429	0.293
FC(2)	0.479	0.418	0.453	0.310	0.453	0.395	0.429	0.293
FC(3)	0.509	0.444	0.482	0.330	0.453	0.395	0.429	0.293
FC(4)					0.453	0.395	0.429	0.293
FC(5)					0.057	0.050	0.054	0.037
BR(1)	0.320	0.338	0.350	0.256	0.270	0.285	0.296	0.216
BR(2)	0.360	0.380	0.394	0.288	0.260	0.275	0.285	0.208
BR(3)	0.390	0.412	0.427	0.312	0.300	0.317	0.329	0.240
BR(4)					0.300	0.317	0.329	0.240
BR(5)					0.010	0.011	0.011	0.008
SATK(1)	0.120	0.105	0.119	0.101	0.080	0.070	0.079	0.067
SATK(2)	0.200	0.174	0.199	0.168	0.110	0.096	0.109	0.092
SATK(3)	0.280	0.244	0.278	0.235	0.180	0.157	0.179	0.151
SATK(4)					0.180	0.157	0.179	0.151
SATK(5)					0.009	0.008	0.009	0.007
OM(1)	0.070	0.059	0.095	0.103	2.551	2.137	3.465	3.756

OM(2)	0.013	0.011	0.018	0.019	0.607	0.509	0.825	0.894
OM(3)	0.004	0.003	0.005	0.006	0.607	0.509	0.825	0.894
OM(4)					0.425	0.356	0.577	0.626
OM(5)					12.148	10.178	16.502	17.888

	AR010				OK182			
	Original	Illinois River	Barron Fork	Caney Creek	Original	Illinois River	Barron Fork	Caney Creek
RC	0.010	0.008	0.014		0.004	0.003	0.005	0.006
RD	47.83	26.57	25.54		37.03	20.57	19.78	50.36
BOTHOR(1)	1.54	0.86	0.82		9.26	5.14	4.95	12.59
BOTHOR(2)	3.86	2.14	2.06		12.34	6.86	6.59	16.78
BOTHOR(3)	6.17	3.43	3.30		35.48	19.71	18.95	48.26
BOTHOR(4)	30.08	16.71	16.06		37.03	20.57	19.78	50.36
BOTHOR(5)	47.83	26.57	25.54					
FC(1)	0.479	0.418	0.453		0.453	0.395	0.429	0.293
FC(2)	0.479	0.418	0.453		0.426	0.372	0.403	0.296
FC(3)	0.472	0.412	0.447		0.442	0.386	0.418	0.336
FC(4)	0.509	0.444	0.482		0.057	0.050	0.054	0.037
FC(5)	0.498	0.435	0.471					
BR(1)	0.260	0.275	0.285		0.360	0.380	0.394	0.288
BR(2)	0.260	0.275	0.285		0.360	0.380	0.394	0.288
BR(3)	0.360	0.380	0.394		0.400	0.423	0.438	0.320
BR(4)	0.320	0.338	0.350		0.040	0.042	0.011	0.032
BR(5)	0.320	0.338	0.350					
SATK(1)	0.110	0.096	0.109		0.200	0.174	0.199	0.168
SATK(2)	0.110	0.096	0.109		0.200	0.174	0.199	0.168
SATK(3)	0.200	0.174	0.199		0.300	0.262	0.298	0.252
SATK(4)	0.120	0.105	0.119		0.030	0.026	0.009	0.025
SATK(5)	0.120	0.105	0.119					
OM(1)	0.547	0.458	0.743		0.152	0.127	0.206	0.224
OM(2)	0.516	0.432	0.701		0.009	0.008	0.012	0.013
OM(3)	0.011	0.009	0.015		0.004	0.003	0.005	0.006
OM(4)	0.005	0.004	0.007		6.074	5.089	8.215	8.944
OM(5)	0.004	0.003	0.005					

Phosphorus simulation input file generation

For the phosphorus simulation, parameters related to phosphorus simulation were selected and determined from various data sources. The parameters for each Zone were estimated based on the observed data from the watershed and number of poultry houses.

Total poultry houses in study area: 3662

Total poultry houses in Zone 1: 759

Total poultry houses in Zone 2: 662

Total poultry houses in Zone 3: 2200

Total poultry houses in Zone 4: 41

CLAB(), labile phosphorus concentration in the soil horizon, was estimated for pasture land uses based on observed data. The CLAB() values for zones 1 and 2 ranged from 80 to 300, and for zone 3 ranged from 300 to 700 (Table 6).

Table 6. Observed CLAB for each county

County name	CLAB	County name	CLAB
Benton	655	Delaware	204
Washington	581	Cherokee	110
Adair	229	Sequoyah	82

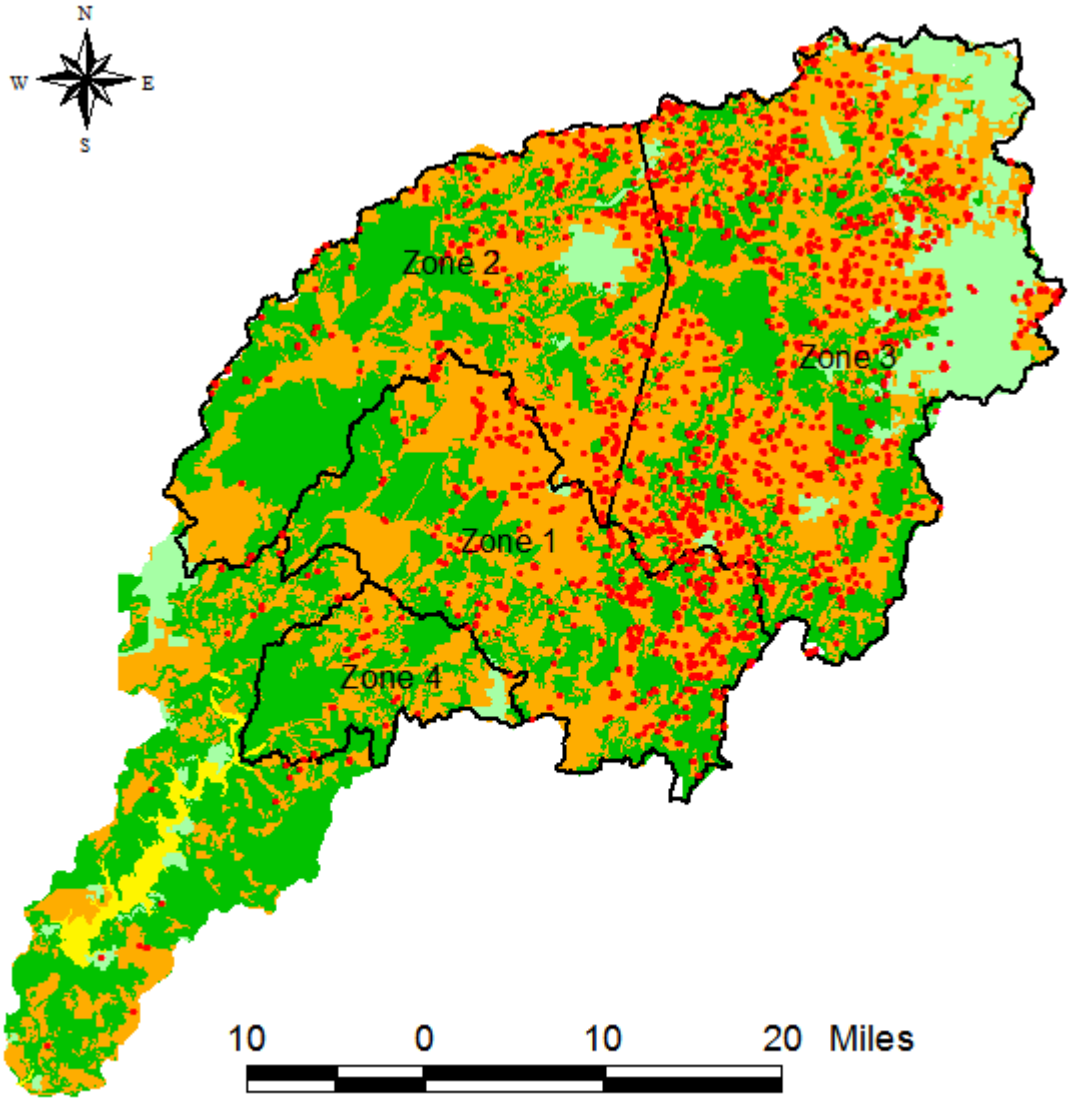


Figure 6. Four zones divided by number of poultry houses for nutrient simulation.

RATE, rate of application, represents animal waste application as solid, slurry, or liquid and is expressed as kg/ha dry matter. This value for pasture land use type is generated using observed poultry litter data as follows.

Total applied litter for the study area was 223,000 tons/yr on a dry weight basis.

Total applied litter for Zone 1:

$$= 223,000 tons/yr \times \frac{759\ poultry\ houses}{3536\ polutry\ houses\ \ for\ toal} \times \frac{1}{47,720 ha} = 1.00 tons/ha$$

Total applied litter for Zone 2:

$$= 223,000 tons/yr \times \frac{662\ poultry\ houses}{3536\ polutry\ houses\ \ for\ toal} \times \frac{1}{49,457 ha} = 0.84 tons/ha$$

Total applied litter for Zone 3:

$$= 223,000 tons/yr \times \frac{2200\ poultry\ houses}{3536\ polutry\ houses\ \ for\ toal} \times \frac{1}{85,658 ha} = 1.62 tons/ha$$

Total applied litter for Zone 4:

$$= 223,000 tons/yr \times \frac{41\ poultry\ houses}{3536\ polutry\ houses\ \ for\ toal} \times \frac{1}{10,915 ha} = 0.24 tons/ha$$

APHOS, total phosphorus content as a % in animal waste, was estimated by observed data. Total applied litter and phosphorus within the study area were 223,000 tons/yr on a dry basis and 4,642 P tons/yr (Mass Balance Analysis), respectively.

$$APHOS = \frac{4642\ P\ tons/yr}{223000\ litter\ tons/yr} = 0.0208 = 2.08\%$$

APORGP, organic phosphorus content in animal waste, was generated using APHOS and the ratio of organic and total phosphorus as described in the GLEAMS manual as follows.

	Range (Organic P/TP)	Average
Solid	0.95-1.00	0.98

Fertilizer in GLEAMS was set as animal waste (MFERT=1) for poultry waste and applied April 1 (NF=91 as Julian day).

Additional nutrient inputs were applied based on the nutrient inputs into the IRW identified by the Mass Balance Analysis. These include P from the following sources in the following amounts: swine 177 tons, dairy cattle 319 tons, beef cattle 105 tons and commercial fertilizer 455 tons.

Point source consideration

To estimate the total loads of P in streams and into Lake Tenkiller, point source pollution needs to be considered. However, GLEAMS does not consider the point source pollution, so point source pollution was added to nonpoint source pollution simulated by GLEAMS. Point source pollution in the study area is shown in Table 6.

Table 6. WWTP Total P Discharge to Streams and Rivers within the IRW

	Early 90s-2002	**2003-present**
WWTP	**P Load (lb/yr)**	**P Load (lb/yr)**
Springdale	95,128	25,112
Siloam Springs	22,046	29,638
Fayetteville - Noland	9,921	5,147
Rogers	47,619	16,206
Lincoln	2,646	2,336
Prairie Grove	2,646	3,285
Tahlequah	10,362	2,738
Stillwell	0	2,519
Westville	6,393	840
Gentry	3,748	2,336
Watts	1,102	0
Midwestern nursery	1,323	0
Cherokee Nation	1,168	0
Total	**204,101**	**90,155**

Calibration

The GLEAMS model was linked with the Shuffled Complex Evolution Algorithm (SCE-UA) because it is widely used to optimize hydrologic models. Optimization approaches are typically faster and less subjective than manual methods of model calibration. In addition, it is likely that model results are better than that which could be manually obtained. Calibration and validation processes were performed based on approximately 10 year simulation periods, considering available data. For the hydrologic simulation, both calibration (1996-2005) and validation (1986-1995) were performed. For the phosphorus simulation, calibration was performed with 1998 through 2002 data, and validation was performed using 2003 through 2006 data. Beginning in 1998, runoff events were targeted for P sampling and thus P data from 1998 through 2006 were used in the P calibration and validation.

Calibration parameters were selected by referring to the GLEAMS manual. The GLEAMS manual explains which parameters are most sensitive. Most parameters were generated based on observed data and documented databases so the optimization range was set as ±50% of estimated values to avoid searching extreme values and to insure that calibrated parameters were within reasonable ranges. For optimizing the model parameters for soil series, multiple factors were obtained as optimized parameters to maintain the relationship among the soil series. Therefore, calibrated values for soil series were obtained by multiplying the optimized factors and default values related to soil series.

P Routing Model

The GLEAMS model simulates nutrient movement to the bottom of the root zone and to the edge of HRUs. Therefore, an additional model to route nutrients through streams/rivers and to Lake Tenkiller was necessary. An empirical model was selected that used observed data to create a relationship between stream or river flow and P accumulation in the streams and rivers. This is similar to the approach used in various modeling tools including LOADEST (Runkel et al.,

2004). A P routing model was created for each gauging location used in the modeling effort (Tahlequah, Baron Fork near Eldon, and Caney Creek). The equations were of the form:

$$P\ Load = a + b * Q * P\ Accumulation + c * Q^2 * P\ Accumulation$$

Where P Load is a daily P load in lbs

a, b, and c are coefficients obtained during equation development

Q is average daily flow rate at USGS gauge

P Accumulation is computed P accumulated in the stream or river

GLEAMS Model Calibration and Validation

P Routing Model

The P routing model coefficients were determined for the three USGS locations used in the modeling effort (Tahlequah, Baron Fork near Eldon, and Caney Creek). An iterative process was used to model P with GLEAMS and use USGS flow data to fit the coefficients for observed P loads between 1998 through 2002. The routing model coefficients were optimized using an automated Shuffled Complex Evolution approach.

The optimized coefficients for each location are shown in Table 7.

Table 7. Coefficients for P load routing models

Location	a	b	c	Initial P Accumulation (lbs)
Tahlequah	0.101	$4.88 * 10^{-7}$	$1.26 * 10^{-10}$	500,000
Baron Fork	0.101	$5.46 * 10^{-13}$	$1.00 * 10^{-9}$	100,003
Caney Creek	0.101	$8.93 * 10^{-12}$	$5.10 * 10^{-8}$	10,000

Hydrologic Calibration

The performance of the GLEAMS hydrologic simulation following automatic calibration shows GLEAMS is able to estimate monthly runoff values well. Monthly calibration for Baron Fork River and Illinois River produced Nash-Sutcliffe efficiencies (NS) of 0.64 and 0.63, respectively (Table 8). Time-series and 1:1 scatter plots of simulated and observed stream flow illustrated the fit is reasonable at the two gage sites. For the yearly NS, the highest value was obtained for 2005 with NS values of 0.94 for Baron Fork River and 0.86 for the Illinois River. The worst NS was obtained for 2003 which was a dry year.

Figures 7-12 show predicted and observed flows during the calibration period.

Table 8. Calibrated model performance for runoff

	Baron Fork		Illinois River		Caney Creek	
	NS	R^2	NS	R^2	NS	R^2
1996	0.79	0.82	0.45	0.80	Data is not available	
1997	0.45	0.48	0.22	0.31	Data is not available	
1998	0.53	0.54	0.45	0.49	0.79	0.84
1999	0.72	0.76	0.67	0.84	0.62	0.74
2000	0.79	0.83	0.79	0.85	0.64	0.65
2001	0.73	0.75	0.73	0.76	0.78	0.83
2002	0.17	0.33	0.45	0.61	0.64	0.80
2003	-20.22	0.00	-0.06	0.19	-1.89	0.03
2004	0.68	0.94	0.39	0.51	-0.49	0.47
2005	0.94	0.98	0.81	0.96	0.97	0.99
Average	0.64	0.65	0.63	0.68	0.51	0.60

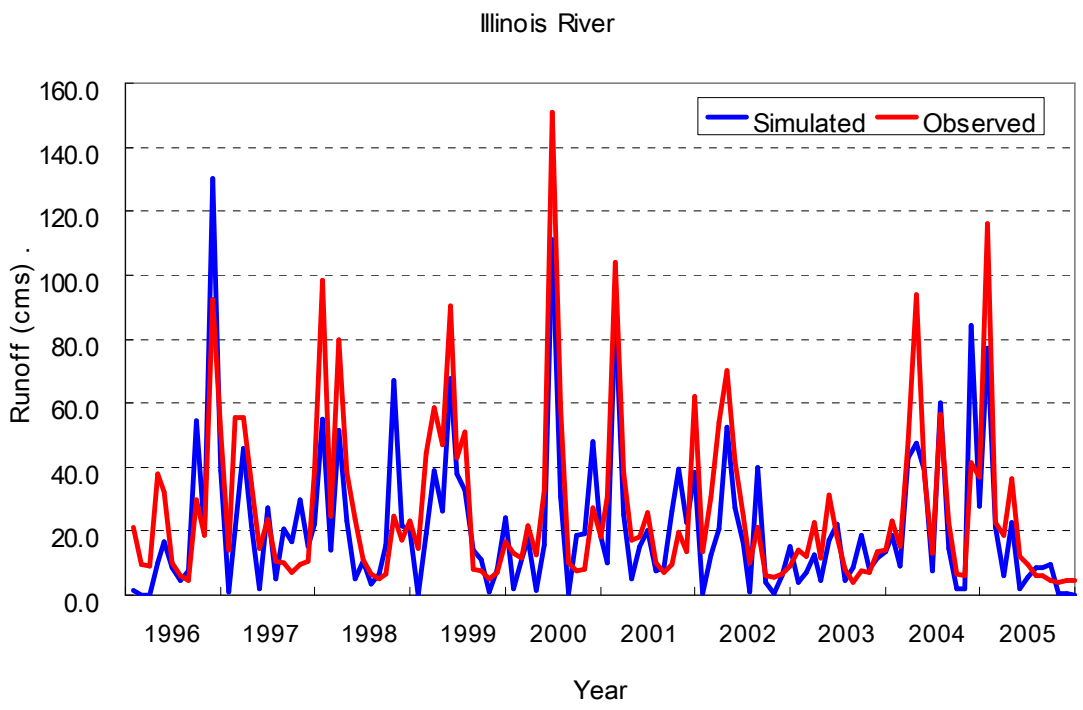


Figure 7. Hydrologic calibration for Illinois River Basin at Tahlequah.

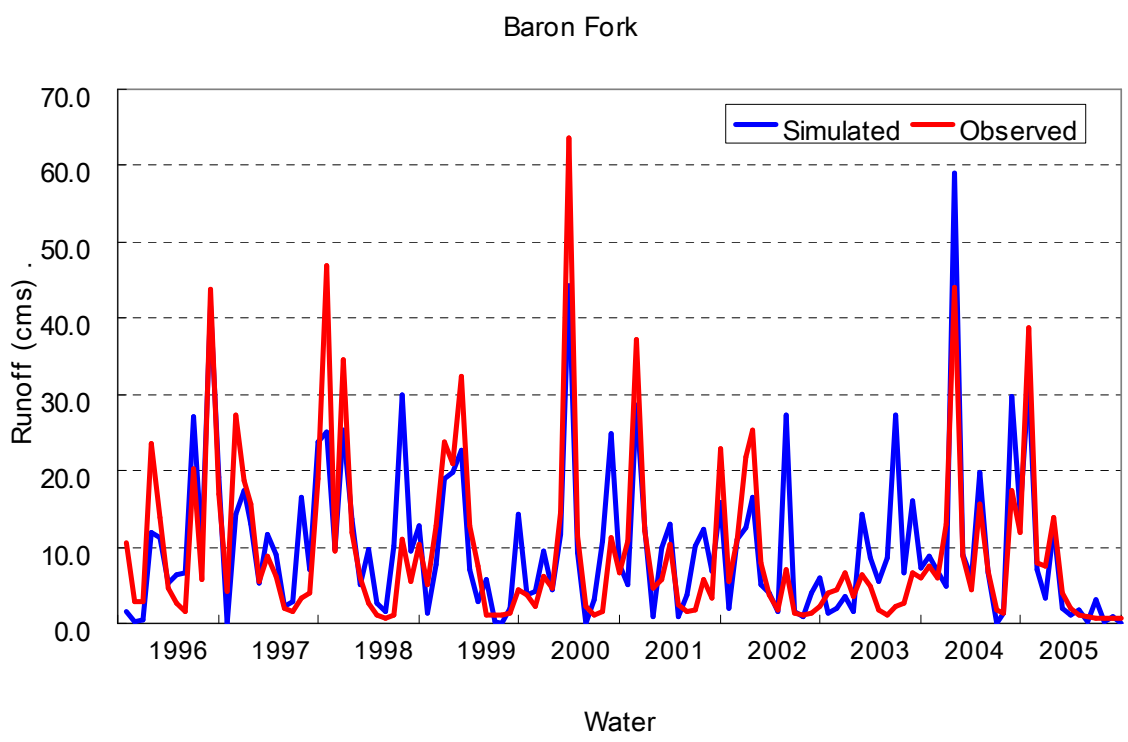


Figure 8. Hydrologic calibration for Baron Fork Basin.

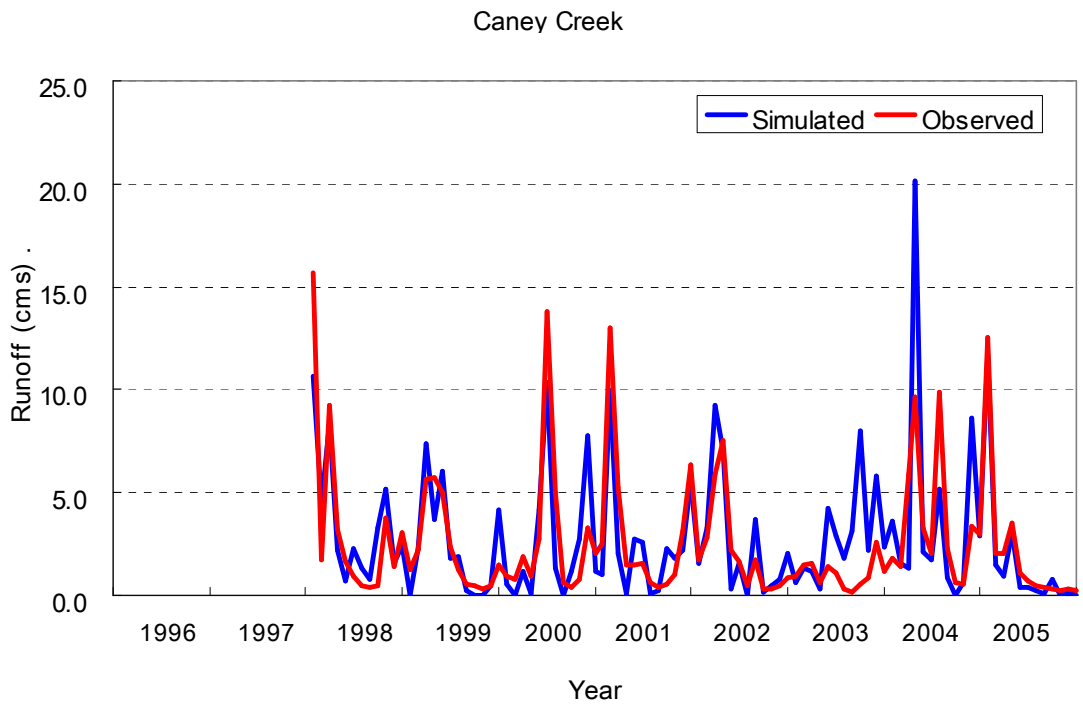


Figure 9. Hydrologic calibration for Caney Creek Basin.

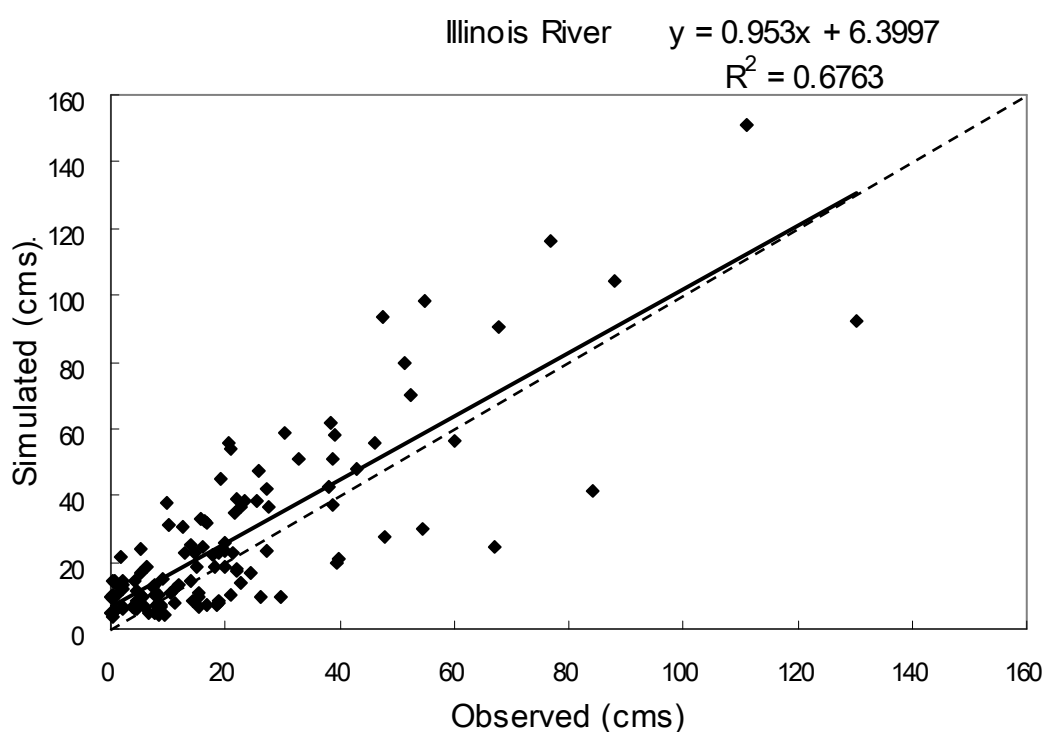


Figure 10. Scatter plot of hydrologic calibration for Illinois River Basin at Tahlequah

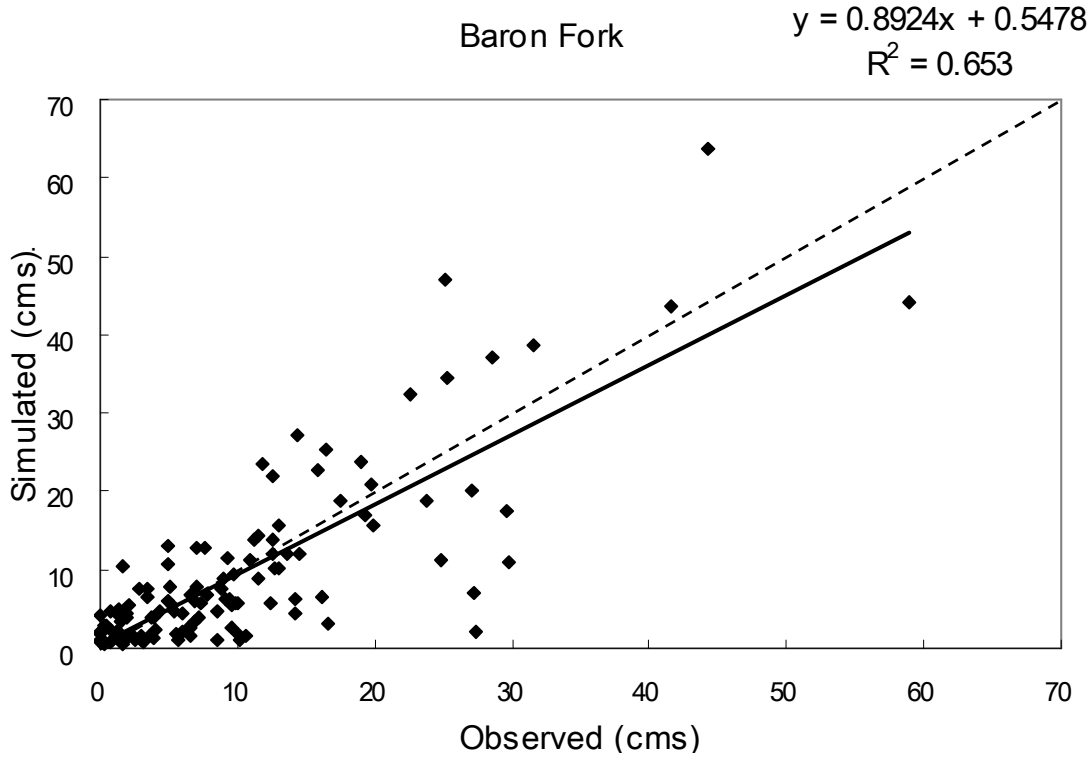


Figure 11. Scatter plot of hydrologic calibration for Baron Fork Basin

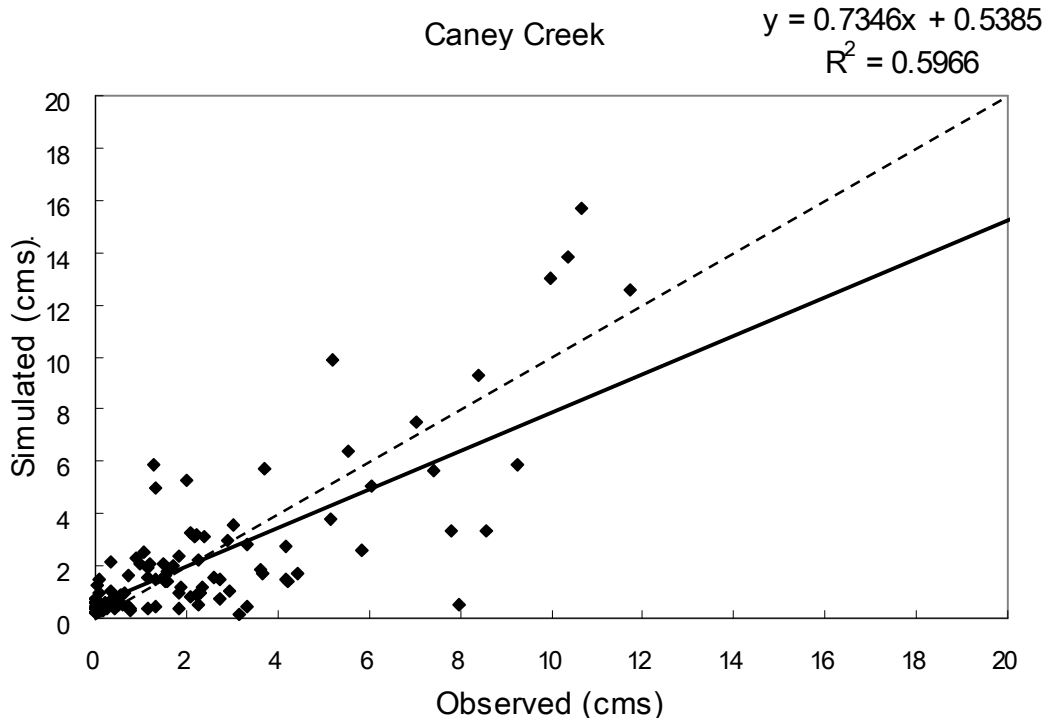


Figure 12. Scatter plot of hydrologic calibration for Baron Fork Basin

Hydrologic Validation

Validation is a subsequent testing of a pre-calibrated model with additional field data, usually under different external conditions, to further examine the model's ability to predict future conditions. Validation improves the reliability of the model and reduces the uncertainty in its predictions. Hydrologic validation was performed using 1986-1995 data for the two watersheds. The NS values for Baron Fork and Illinois River were 0.73 and 0.59, respectively, and illustrated that the calibrated GLEAMS model could predict for a range of conditions (Table 9). Based on these results, the calibrated model can be used to model scenarios of interest with confidence. The best and worst NS values for the Baron Fork were for 1990 and 1994 with 0.87 and 0.26, respectively, and those for the Illinois River were for 1990 and 1993 with 0.83 and -0.09, respectively.

Table 9. Results for hydrologic validation

	Baron Fork		Illinois River		Caney Creek	
	NS	R^2	NS	R^2	NS	R^2
1986	0.69	0.75	0.24	0.49	Data is not available	
1987	0.76	0.79	0.62	0.69		
1988	0.41	0.49	0.46	0.61		
1989	0.82	0.88	0.77	0.82		
1990	0.84	0.85	0.83	0.86		
1991	0.69	0.69	0.59	0.70		
1992	0.87	0.87	0.78	0.84		
1993	0.35	0.56	-0.09	0.65		
1994	0.26	0.51	0.47	0.59		
1995	0.76	0.80	0.50	0.82		
Average	0.73	0.73	0.59	0.67		

Note: Yearly NS is that NS value calculated for each year using monthly results so 12 monthly data values were used to calculate yearly NS.

Figures 11-14 show the model performance relative to observed flow data during validation.

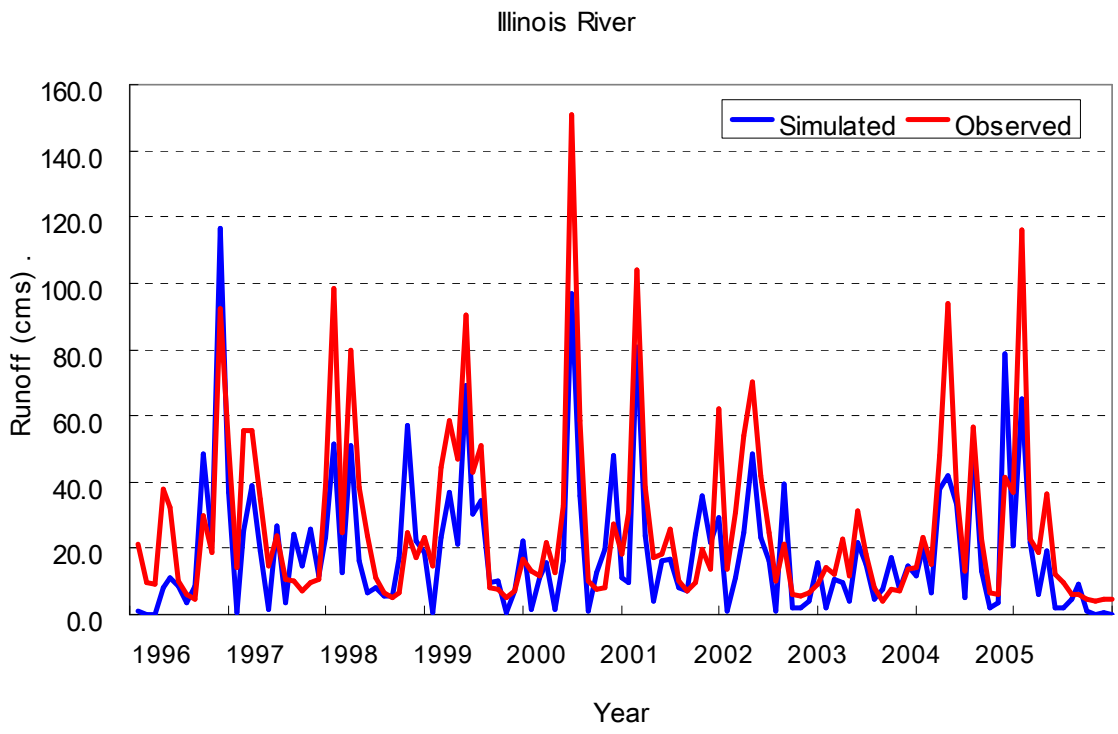


Figure 11. Hydrologic validation for Illinois River Basin at Tahlequah

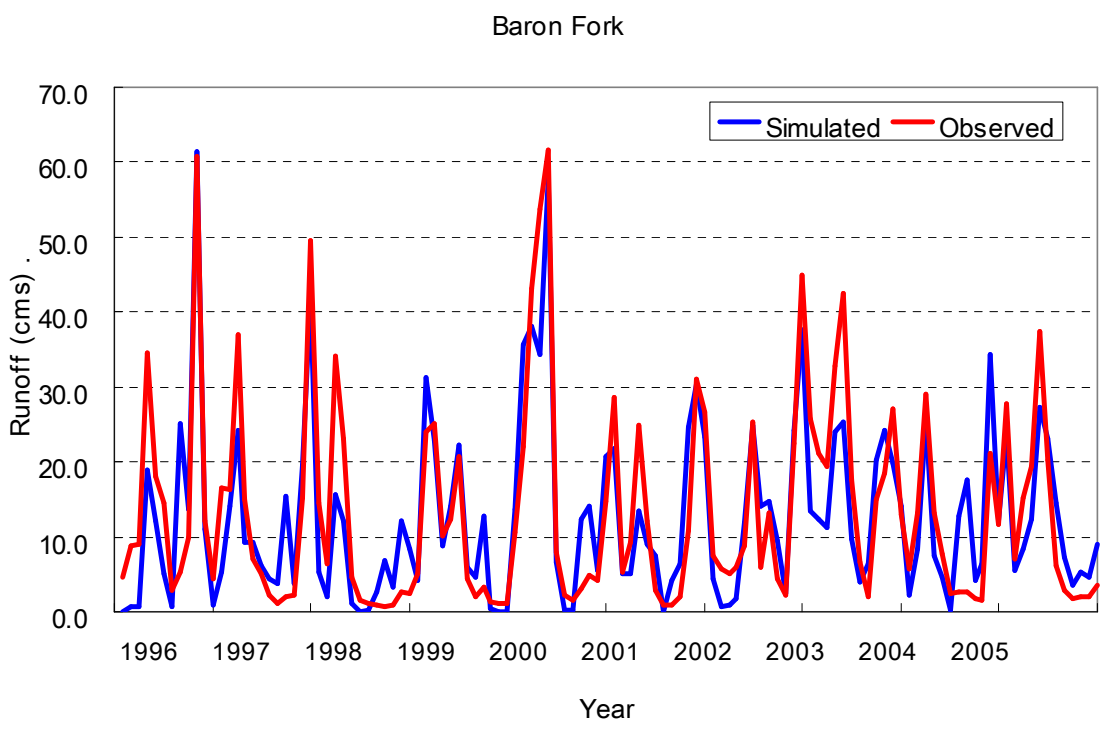


Figure 12. Hydrologic validation for Baron Fork River Basin

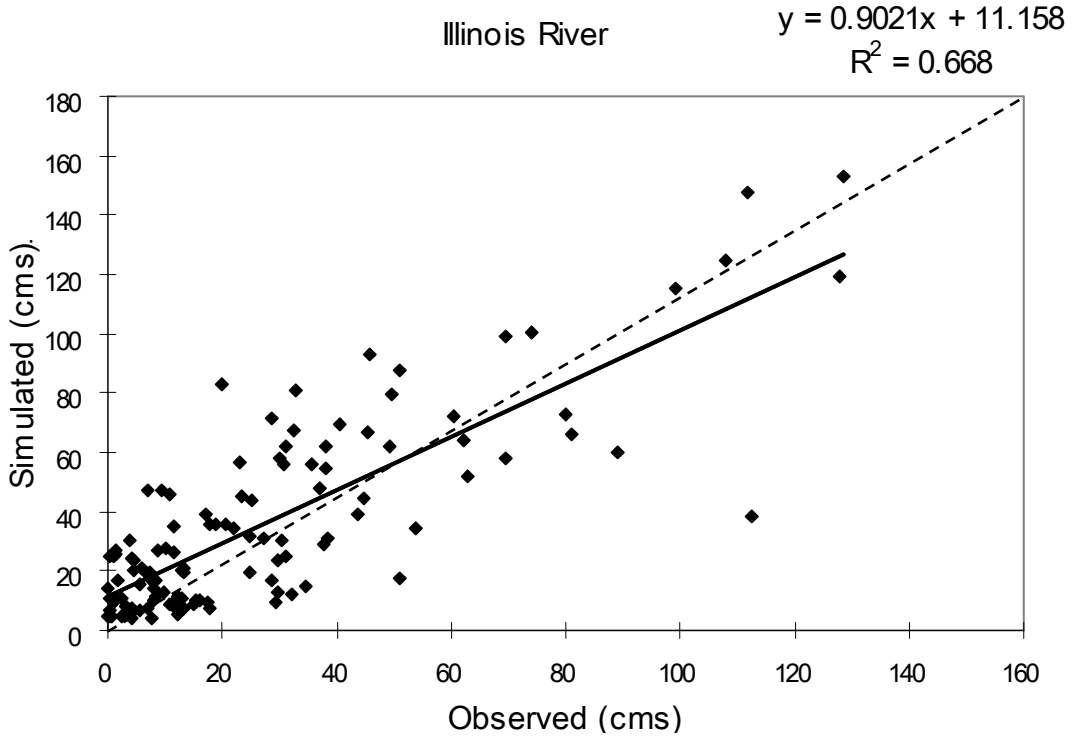


Figure 13. Scatter plot of hydrologic calibration for Illinois River Basin

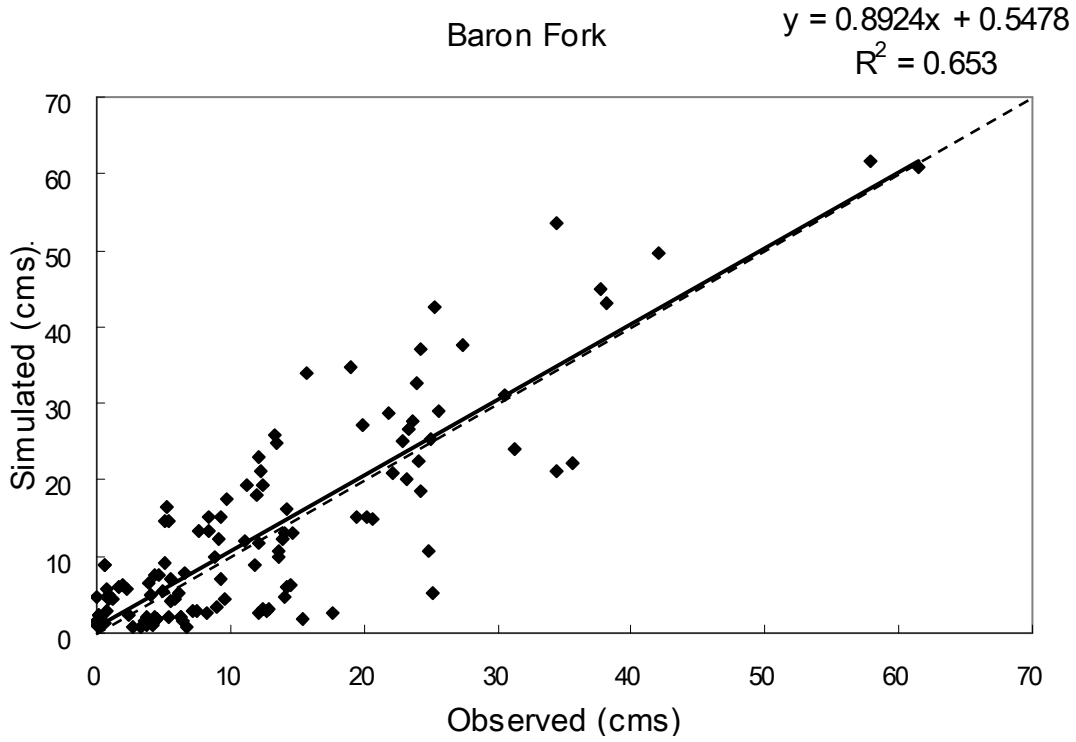


Figure 14. Scatter plot of hydrologic calibration for Baron Fork River Basin

Phosphorus Loading Calibration and Validation

For the phosphorus simulation, calibration was performed with 1998 through 2002 data, and validation was performed using 2003 through 2006 data. Beginning in 1998, runoff events were targeted for P sampling, and thus P data from 1998 through 2006 were used in the P calibration and validation. USGS and OWRB samples analyzed for total P content were used along with USGS flow data to compute observed P loads at the Tahlequah, Baron Fork near Eldon, and Caney Creek gauging stations between 1997 and 2006. The LOADEST (load estimator) software (Runkel et al., 2004) was used along with these data in calculating P loads. Tortorelli and Pickup (2006) and Pickup et al. (2003) used this approach in computing P loads for the IRW. The approach used by Tortorelli and Pickup (2006) and Pickup et al. (2003) was used in calculating P loads. The R^2 for LOADEST calculated P and observed P is shown in Table 10. The fit between calculated P and observed P is a very good fit. LOADEST can be used to calculate P loads within the IRW.

Table 10. R^2 for LOADEST Calculated P and Observed P

	R^2		
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**
1998	0.95	0.89	0.87
1999	0.95	0.96	0.87
2000	0.96	0.94	0.95
2001	0.94	0.93	0.97
2002	0.92	0.93	0.98
2003	0.90	0.92	0.98
2004	0.94	0.97	0.98
2005	0.95	0.98	0.99
2006	0.95	0.98	0.99

The IRW P loads calculated with LOADEST are shown in Table 11 and show substantial variation annually due to differences in rainfall and flow into Tenkiller.

Table 11. Observed P Loads Based on USGS and OWRB P Data and USGS Flow Data

	Total P (lb/yr)			
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**	**Total**
1997	211,467	25,500	4,140	241,107
1998	422,906	39,887	9,024	471,817
1999	392,336	49,755	8,349	450,440
2000	771,454	298,307	55,787	1,125,548
2001	456,947	98,931	36,616	592,494
2002	301,474	52,666	16,574	370,714
2003	94,684	10,107	3,485	108,276
2004	631,798	459,054	57,086	1,147,938
2005	258,021	68,639	14,004	340,664
2006	128,415	58,300	10,574	197,289

The daily calibration R^2 results for 1998 through 2002 are shown in Figures 15-17. The daily Nash-Sutcliffe Coefficients are: Tahlequah 0.95, Baron Fork 0.98, and Caney Creek 0.94 (Table 12).

The daily validation R^2 results for 2003 through 2006 are shown in Figures 18-20.

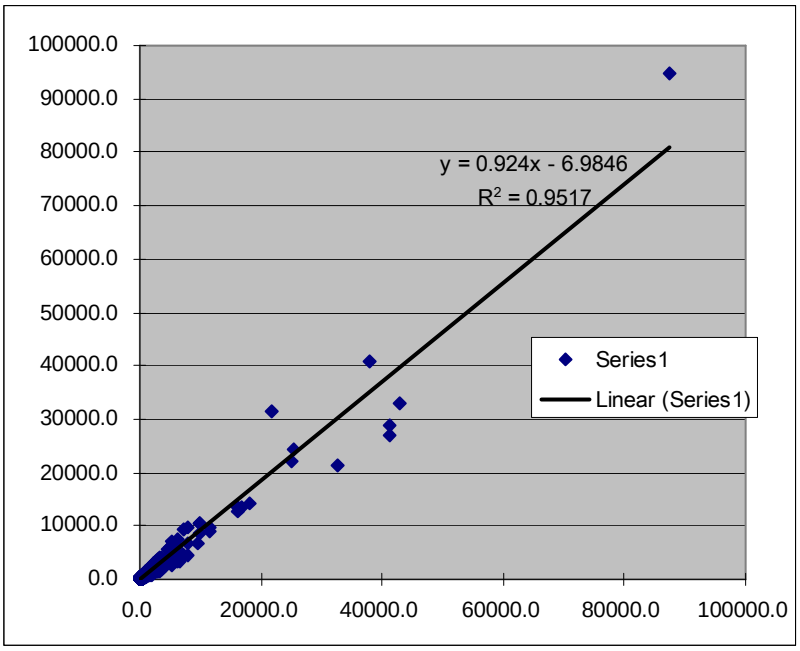


Figure 15. Calibration for Daily P Load at Tahlequah

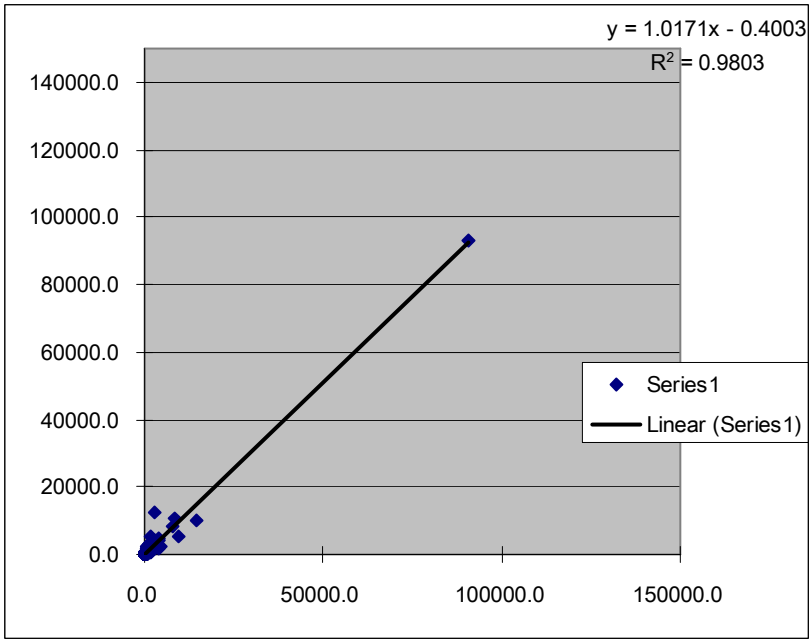


Figure 16. Calibration Results for Daily P Load at Baron Fork near Eldon

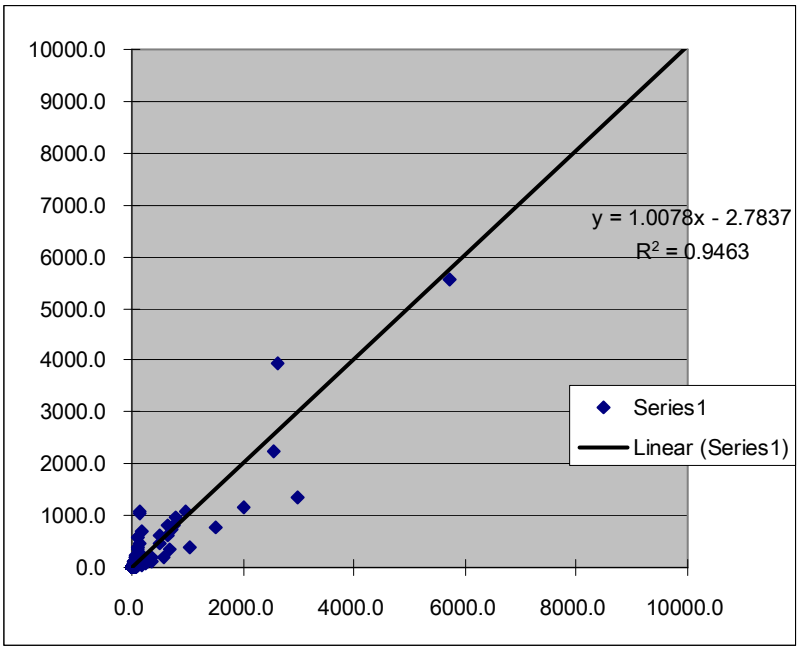


Figure 17. Calibration Results for Daily P Load at Caney Creek

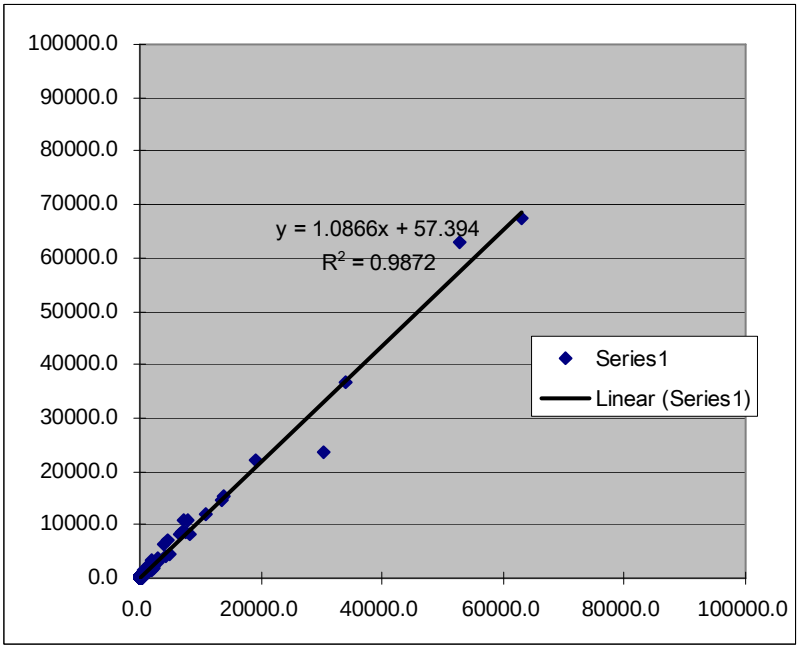


Figure 18. Validation Results for Daily P Load at Tahlequah

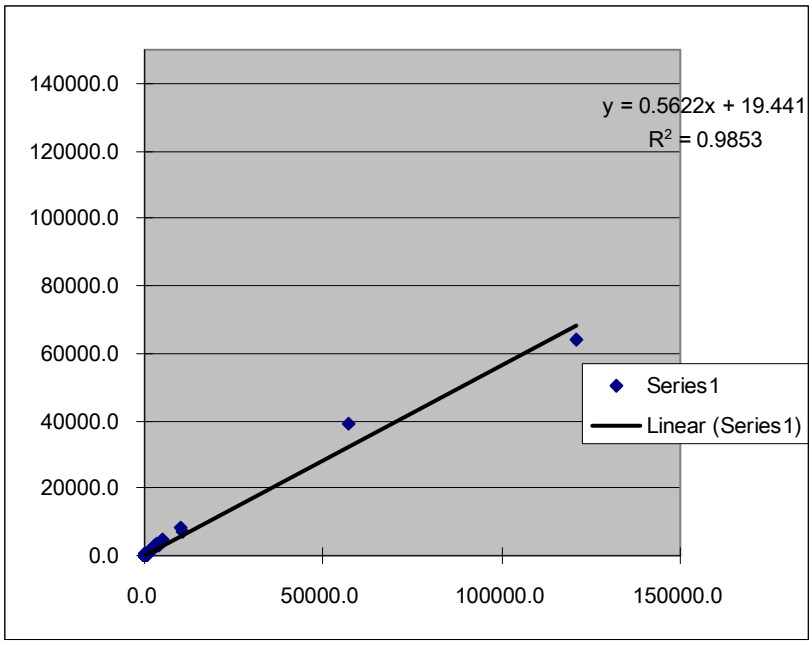


Figure 19. Validation Results for Daily P Load at Baron Fork near Eldon

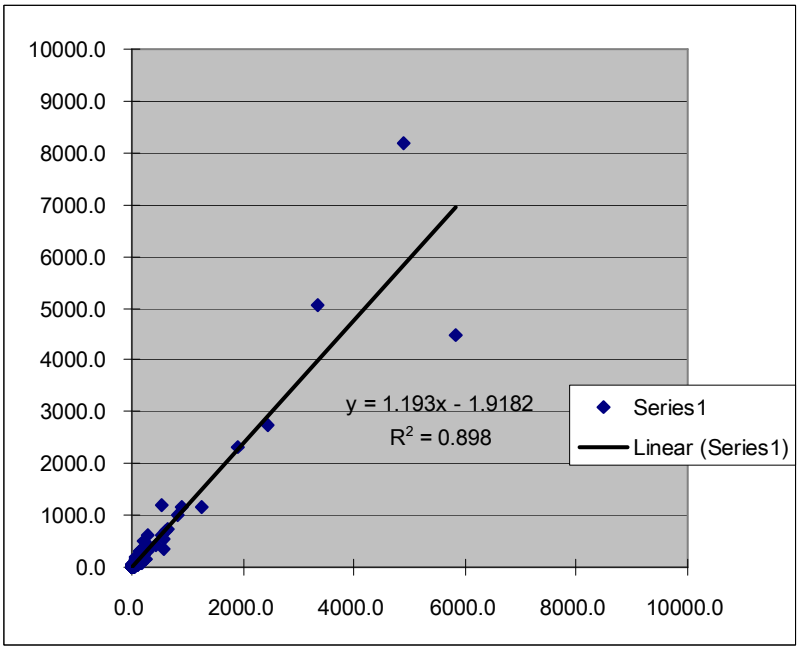


Figure 20. Validation Results for Daily P Load at Caney Creek

The daily Nash-Sutcliffe Coefficients for P load calibration and validation are shown in Table 12. Based on these values and the R^2 values for P loads, the model performs at an acceptable level for use in this project.

Table 12. Nash-Sutcliffe Coefficients (Daily) for P load calibration and validation

Location	**Calibration**	**Validation**
Tahlequah	0.95	0.98
Baron Fork	0.98	0.80
Caney Creek	0.94	0.80

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Modeling Protocol for GLEAMS Application to the Illinois River Watershed

Bernard Engel, Ph.D., P.E.

Problem Definition/Background

Excessive phosphorus loads to the streams and rivers of the Illinois River Watershed (IRW) and to Lake Tenkiller are a concern. Numerous studies have been collected regarding the IRW as described in Engel (2008).

The goals of the hydrologic/water quality modeling of the IRW are to:

1. Quantify phosphorus load magnitudes to streams and rivers in the IRW and to Lake Tenkiller
    a. Historically (1950 to present)
    b. Future scenarios (continued poultry waste application to pastures, cessation of poultry waste application, growth in IRW poultry numbers and corresponding waste application, remediation scenarios)
    c. Background (background soil phosphorus and no poultry waste application)
2. Allocate P loads to the most significant sources

A modeling approach will be needed to complement observed data, prior modeling and analysis as described in various reports on the IRW, and expert opinion. The data documenting historical P loads is limited and modeling provides an opportunity to extend P load estimation spatially and temporally. Modeling will be valuable in predicting various future scenarios for which observed data are not available. The modeling of future scenarios can help identify expected P loads for a range of scenarios. The literature and expert experience provide insight to such scenarios as well and modeling can help conform and further quantify such expert opinions.

Several models have been applied previously to the IRW to determine P loads. Additional details can be found in Engel (2008) and the reports reviewed by Engel. Several studies have used relatively simple modeling approaches that use coefficients based on observed data. Smith et al. (1997) analyzed HUCs (watersheds) to identify the contributors of nutrients to streams and rivers. The Smith et al. (1997) model analysis indicates livestock are responsible for 78.63% of P in the Illinois River while point sources represent 4.5% and fertilizer represents 7.21%. Willett et al. (2006) modeled phosphorus loads from poultry waste application to agricultural areas in the Illinois River Watershed within Arkansas and Oklahoma. In their modeling, 33% of P was available to the crop and 67% went to building P in the soil. Of the P going to the soil, 8% was modeled as lost in runoff. Thus, 5.36% (67% of P to soil * 8% of this lost in runoff) of P applied through poultry litter applications in the watershed was lost in runoff each year (Willet et al., 2006). Nelson et al. (2002) performed a P mass balance for the Arkansas portion of the Illinois River Watershed. They used observed P data in the Illinois River to compute the amount of annual P applied to the landscape that is exported from Arkansas in the Illinois River. Point sources of P were removed from the observed P in the Illinois River before computing the percentage of P that was applied to the landscape that reached the Illinois River and was exported. Nelson et al. (2002) found that 4% of P applied to the landscape in poultry litter, cattle

manure, sludge and inorganic fertilizer was lost annually to the Illinois River. If cattle manure is removed from this, as the P contained in cattle manure is recycled P from other sources, this percentage is slightly over 5% which is comparable to the value reported by Willett et al. (2006).

More complex models have also been applied to the IRW. Storm et al. (1996) used SIMPLE (Spatially Integrated Model for Phosphorus Loading and Erosion) in the Illinois River basin. P loading was estimated at 2.30 kg/ha per year (2.05 lb/acre/yr) from pastures after P was applied for 25 years. Storm et al. (2006) used SWAT and a routing model in the IRW and estimated 330,000 kg/yr of total phosphorus (88,000 kg/yr was in soluble mineral forms) reached Lake Tenkiller between 1997 and 2001. The development of a draft TMDL for the IRW and Lake Tenkiller was completed with HSPF which found pasture with poultry waste application responsible for 56% of P loads to Lake Tenkiller (0.90 lb P/acre).

The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model was selected for this project due to its ability to describe the hydrologic and water quality processes of importance. One of the strengths of the model is its ability to describe agricultural management systems. In addition, the science within GLEAMS has the same origin of that in SWAT, thus facilitating the potential to use both models without raising concerns about differences in the underlying science.

Model application goals, objectives and hypothesis

The specific objectives of the modeling effort were to:

1. Quantify P loads to the three gauging station locations on streams and rivers closest to Lake Tenkiller (Tahlequah, Baron Fork near Eldon and Caney Creek) for the following:
    a. Historical (1950-1999) conditions
    b. Background (background soil phosphorus and no poultry waste application) – no poultry waste ever in the IRW
    c. Future scenarios
        i. continued poultry waste application to pastures
        ii. cessation of poultry waste application
        iii. growth in IRW poultry numbers and corresponding waste application
        iv. cessation of poultry waste application combined with buffers along streams
2. Allocate P loads to the most significant sources for current conditions

To model future scenarios, weather data representing the 1997-2006 period will be used as this period has the best available data for the IRW and will be used for model calibration and validation. In addition, the rainfall and flows into Tenkiller for this period are variable representing much of the anticipated level of variability that would be expected.

Data for the model scenarios outlined in the modeling objectives will be prepared. Graphs providing comparisons of the results will be created. The continued poultry waste application scenario will provide a basis of comparison for many of the results.

Model selection

The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model was selected for this project due to its ability to describe the hydrologic and water quality processes of importance. One of the strengths of the model is its ability to describe agricultural management systems. In addition, the science within GLEAMS has the same origin of that in SWAT, thus facilitating the potential to use both models without raising concerns about differences in the underlying science.

Further details regarding the GLEAMS model can be found in the GLEAMS manual, Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007).

A model will be required to route P modeled by the GLEAMS model as being lost to streams through the streams/rivers to Lake Tenkiller. Several models were considered for this purpose. A simple empirical approach based on flows in streams and rivers of the IRW and P accumulated in these streams and rivers will be used for routing P loads.

Model sensitivity analysis

The sensitivity of the GLEAMS model to its parameters is well documented in the literature. Dr. Engel has extensive experience in working with GLEAMS based on prior work (Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007)). The theses and dissertation from which this work was published describe the GLEAMS parameter sensitivity in more detail.

Available Data

Various spatial data are available for the Illinois River Watershed from various sources. The key data include:

1. Elevation data - USGS
2. Land Cover - National Land Cover Dataset (NLCD) for 2001
3. Soil - State Soil Geographic (STATSGO) data

Numerous other spatial data sets for the IRW have been collected and are available from Dr. Robert van Waasbergen.

Weather data for the watershed and surrounding areas are available from the NCDC (National Climate Data Center). The weather stations with the most complete data suitable for use in the IRW are shown in Table 1.

Table 1. Weather stations with data for IRW

	Baron Fork	Illinois River	Caney Creek
Rainfall stations	035354, 348506	032444, 344672, 348677	348506
Temperature station	9450	9450	9450

Streamflow data are available at USGS streamflow gauging stations within the IRW. The gauge locations nearest Lake Tenkiller will be used for the analysis and are listed in Table 2. The period of record for the gauge on Caney Creek is limited in that it starts in October 1997.

Table 2. USGS gauge stations in the IRW nearest Lake Tenkiller

	USGS gage station
Illinois River	USGS 07196500 Illinois River near Tahlequah, OK
Barron Fork	USGS 07197000 Barron Fork at Eldon, OK
Caney Creek	USGS 07197360 Caney Creek near Barber, OK

Phosphorus concentrations in water are available at the USGS gauging stations in Table 2 from the USGS and the OWRB. Beginning in 1998, phosphorus data at these locations were collected for baseflow as well as some storm events. Prior to 1998, efforts were not made to sample storm runoff, and thus nearly all water samples were taken at baseflow conditions. The water samples beginning in 1998 are most appropriate for the modeling effort since the majority of P is moved from the landscape during rainfall events, thus creating nonpoint source (NPS) movement of P. The modeling effort for this project is focused on modeling P movement during rainfall events in addition to daily P movement in IRW streams/rivers to Lake Tenkiller.

Soil Test Phosphorus (STP) data are available from the University of Arkansas and Oklahoma State University. These data can be summarized by county.

Poultry house location and supporting attributes were developed by Dr. Bert Fisher for the IRW.

Poultry waste production and its nutrient content can be computed based on Dr. Fisher's data, Agricultural Census data, integrator poultry data and nutrient content in poultry waste data.

Additional data to be collected

Data quantifying poultry waste amounts and its nutrient content are needed. These will be generated by Dr. Bert Fisher and Dr. Engel. Data describing poultry waste land application patters will be obtained from the literature and analyses to be conducted by Dr. Fisher.

Model representation issues

A P mass balance for the IRW will be completed to identify the important P sources to be considered in modeling. Point and nonpoint sources of P of significance (> 2% of P based on mass balance) will be considered. Point sources (waste water treatment plants) will have the P load directly input to streams and rivers for routing through the streams/rivers to Lake Tenkiller.

The IRW will be divided into hydrologic response units (HRUs) and the GLEAMS model applied to each HRU. This approach is used by other models such as SWAT. Land use and soil data will be intersected in GIS to identify HRUs. GIS elevation and watershed boundary data will be used to subdivide HRUs to place them within subwatersheds.

Individual BMPs within each HRU will not be considered by the model, rather calibration will be used incorporate consideration of BMPs into the modeling effort. The calibrated model will account for existing BMPs. If BMPs are to be modeled in scenario evaluation, these BMPs will be represented as they represent new management efforts.

Some soil parameters will be initially estimated from STATSGO soil properties and then calibrated based on observed runoff and nutrient loss data. These include:

- Effective saturated conductivity
- CN
- Rooting depth
- Depth of bottom of each soil layer
- Soil field capacity
- Soil wilting point
- Soil saturated hydraulic conductivity
- Soil organic matter

The relative values of soil parameters across soils will be linked so it will only be necessary to calibrate one parameter linking soil properties rather than each soil property for each soil.

The parameters most sensitive for calibration of P loads are:
1. CLAB(); Labile phosphorus concentration, ppm, in the soil horizon
2. DF: Date of fertilizer application
3. RATE; Application rate for animal waste
4. APHOS; Total phosphorus content, %, in animal waste
5. APORGP; Organic phosphorus content, %, in animal waste
6. AOM; Organic matter content, %, in animal waste
7. RESDW; Crop residue, kg/ha, on the ground surface when simulation begins

Model Calibration

The hydrology (runoff) will be calibrated first and will use observed flow data at the USGS gauging locations identified in Table 2. The calibration period for hydrology will be 1996-2005 (note data at Caney Creek are not available for all years). The P calibration period will differ as

described earlier in this document due to availability of P concentration data in water samples at the gauging sites that represent runoff events. For P, the calibration period will be 1998 through 2002.

Calibration Procedures

An automated calibration approach will be used based on the Shuffled Complex Evolution algorithm approach. This will avoid the potential to bias the model calibration. Hydrology will be calibrated and if results are acceptable, calibration will be extended to P.

Goodness of fit (R^2) and Nash-Sutcliffe coefficients will be used for evaluating calibration success. The runoff calibration will be considered successful if the average monthly R^2 is greater than or equal to 0.60 and the average monthly Nash-Sutcliffe coefficients are greater than or equal to 0.50. For nutrient calibration, values greater than 0.40 for average monthly R^2 and the average monthly Nash-Sutcliffe coefficients will be considered successful.

Model Validation

The runoff validation period will be 1986 through 1995 for the USGS gauging stations identified in Table 2. Note that data are unavailable for this period for Caney Creek. However, Caney Creek contributes little runoff and P to Lake Tenkiller so is far less important than the Tahlequah and Baron Fork near Eldon locations.

The P validation period will be 2003 through 2006.

Average monthly R^2 and the average monthly Nash-Sutcliffe coefficients will be used to assess validation. Values 0.1 less than the calibration success levels will be used to identify successful model validation. If the model performs satisfactorily during validation, it will be applied to model the scenarios of interest.

Model scenario prediction

The calibrated model will be applied to the scenarios identified in the Model Applications section of this document. Continued poultry waste application will serve as the base case for comparison of other modeled results.

Results interpretation/hypothesis testing

A ten year weather cycle will be used in modeling future scenarios (weather and flows from 1997 through 2006). This weather and flow data represent years with rainfall and flow much greater than average as well as years with rainfall and flows much below long-term averages. This 10 year weather cycle will be repeated to model periods longer than 10 years into the future.

Results will be compared to assess the impacts of various scenarios. Appropriate statistical tests will be performed to determine if the P loads for the various scenarios are statistically different.

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Appendix E

Cattle Manure Generation

The amount of cattle manure produced within the IRW was calculated. In addition the amount of P in this manure was calculated. Note that P in the cattle manure is almost entirely P that was deposited within the IRW when poultry waste was spread on pastures (Slaton et al., 2004).

The number of cattle in the IRW was calculated using the 2002 USDA Agricultural Census data and the land uses within the IRW. The census reports cattle numbers by county. To distribute the cattle within counties to the IRW, the amount of pasture within each county was used to perform the distribution in a manner similar to Nelson et al. (2002). Data used in computing manure and P excreted are shown in Table 1. The number of cattle within the IRW by type of cattle is shown in Table 2.

The amount of cattle manure and P produced annually within the IRW is shown in Table 2. Cattle produce approximately 319,000 tons of manure annually on a dry weight basis that contains approximately 7.79 million pounds of P. Note however, that the P contained in this manure is almost entirely from P imported into the IRW for poultry production (Section 7 and Slaton et al., 2004).

Table 1. Data for computing cattle manure and P excreted (from the Agricultural Waste Management Field Handbook)

Cattle Type	P Excreted (lbs/day)	Average Weight (lbs)	Time in Watershed (days)	Manure (dry) (lbs/day)
Beef cows that calved	0.12	1100	365	7.3
Dairy cows	0.07	1300	365	10
Other cattle	0.07	650	365	7.3
Calves and cattle sold	0.07	500	300	7.3
Calves	0.03	300	240	7.3

Table 2. Number of cattle within the IRW by type of cattle as calculated from 2002 Agricultural Census data and IRW land use data

Cattle Type	Number in Watershed	P (lb/yr)	Waste (tons/yr)
Beef cows that calved	101,367	4,883,857	148,551
Dairy cows	10,280	341,455	24,390
Other cattle	81,535	1,354,094	70,606
Calves and cattle sold	98,455	1,033,782	53,904
Calves	81,481	175,999	21,413
Total		7,789,186	318,864

Appendix F

Contribution of Cattle in Streams to P Loads in the Illinois River Watershed

Cattle standing in or near streams and defecating in these areas make phosphorus (P) more readily available to water in the streams than would be the case if they were fenced from these streams. Although the P excreted by cattle in the Illinois River Watershed is P initially placed in the watershed through the production of poultry, some of these cattle have access to streams and deposit some P in or near the streams. The amount of P deposited in or near streams (within 10 meters) was estimated following a procedure described below. ***Cattle P deposited in or near streams represents 6% of the annual P loads to Lake Tenkiller.***

Cattle in the Illinois River Watershed

The number of cattle in the watershed was estimated based on the 2002 Census of Agriculture and the Illinois River Watershed (IRW) land use data. The number of cattle in each county that were also within the IRW was estimated based on the percentage of pasture within a county that was within the IRW and the census estimate of cattle in the county. A similar allocation approach was used by Nelson et al (2002).

The number of cattle within each of the counties within the IRW as reported in the 2002 Census of Agriculture are shown in Table 1. The portion of each county's pasture that is within the IRW is shown in Table 2. Estimates of the number of cattle by type within the IRW were obtained by multiplying the data from Tables 1 and 2. The results are shown in Table 3.

Table 1. USDA 2002 Census of Agriculture Cattle in Illinois River Watershed Counties

Cattle Type	Adair	Benton	Cherokee	Delaware	Sequoyah	Washington
cows that calved (included in cattle and calves)	35554	64383	27709	43146	22199	63281
beef (included in cows that calved)	28028	60948	25333	40089	22126	60753
cattle and calves	59033	113588	45573	74719	37889	112650
other (included in cattle and calves)	23479	49205	17864	31573	15,690	49369
cattle and calves sold	34,174	54172	25,183	40,251	23,453	52811
calves < 500 sold	13,574	25514	8,927	14,450	8,061	26950
calves and cattle > 500 sold	20600	28658	16256	25801	15392	25861
dairy (included in cattle and calves)	7526	3435	2528	3057	73	2528
cattle on feed (included in cattle and calves)	101	944	192	219	530	651

Table 2. Portion of pasture within each county in IRW

County	Portion of Pasture in Watershed
Adair	0.799
Benton	0.450
Cherokee	0.356
Delaware	0.090
Sequoyah	0.085
Washington	0.610

Table 3. Cattle in the IRW

Cattle Type	Number in Watershed
Beef cows that calved	101367
Dairy cows	10280
Other cattle	81535
Calves and cattle sold	98455
Calves	81481

Cattle with Access to Streams

The cattle with access to streams were calculated by performing a capture zone analysis within GIS to identify pastures with stream access and estimating the number of cattle within these pastures. Pasture sizes were identified from ODAFF records that identified the size of pasture on which poultry waste was spread. Pastures were assumed to be square and were assumed to randomly intersect streams and rivers within the IRW. Using the pasture sizes, capture zone (or buffer) distances to use along streams and rivers for identification of pastures with access to streams and rivers were computed. The distances were 522 ft, 582 ft, 617 ft, and 660 ft. Pasture within each of these distances from 3rd order and larger streams (streams that typically have water) were identified (Table 4). Cattle by various types were assumed to be uniformly distributed within these pastures (Table 5).

Table 4. Area of pasture within capture zone distance of Third order and higher streams in the IRW

Pasture Area by Zone (acres)			
522 ft	**582 ft**	**617 ft**	**660 ft**
24,548	27,575	29,449	31,494

Table 5. Cattle density in IRW pastures and number of cattle by capture zone distance

Cattle Type	Density (animals/acre of pasture)	522 ft Number of cattle	582 ft Number of cattle	617 ft Number of cattle	660 ft Number of cattle
Beef cows that calved	0.210	5154	5790	6183	6613
Dairy cows	0.021	523	587	627	671
Other cattle	0.169	4146	4657	4974	5319
Calves and cattle sold	0.204	5006	5624	6006	6423
Calves	0.169	4143	4654	4970	5315

Not all pastures provide access to streams or rivers within the IRW. Ed Fite indicated between 40 and 50% of pastures that would touch streams or rivers within the IRW fence cattle from the stream or river.

Cattle P in and Near Streams

James et al. (2007) observed cattle in and near streams and determine the amount of waste excreted in these areas and the amount of P in cow patties. They found that cattle excreted approximately 0.0076 lb/day of P in or within 10m of streams. Gary et al. (1983) observed cattle in and near streams and found that 8% of cattle excrement was deposited in or within 10m of streams. Using 8% of waste, P in cattle waste from the USDA Waste Characteristics Handbook, and assuming 1000 lb cattle, the daily P deposited in or near streams (within 10m) is 0.0096 lb/day.

Using a daily P deposited value of 0.0096 lb/day, the cattle with potential access as shown in Table 5, and assuming 45% of cattle with potential for access are fenced from the stream or river, the annual P deposited in or within 10m of streams was computed as shown in Table 6. Cattle were assumed to preferentially prefer defecating in or near streams year around. In reality not all cattle have access to streams throughout the year nor do they preferentially prefer to be near streams in cooler periods of the year. Thus, the estimates of P excreted in Table 6 overestimate the P actually deposited in these areas.

Table 6. Estimated P deposited by cattle in and near (within 10m) of streams in the IRW

	P (lb/yr)			
Cattle Type	**522 ft**	**582 ft**	**617 ft**	**660 ft**
Beef cows that calved	11920	13390	14300	15293
Dairy cows	1209	1358	1450	1551
Other cattle	4794	5385	5751	6150
Calves and cattle sold	6946	7803	8333	8912
Calves	2874	3229	3448	3688
Total	27743	31165	33283	35594

To put the P estimates from Table 6 in perspective, the average annual P observed at the three gauging stations closest to Lake Tenkiller (Tahlequah, Baron Fork and Caney Creek) between 1998 and 2006 (years with the most complete P data) is slightly less than 500,000 lbs. Cattle P deposited in or near streams would represent 6% of the annual P loads to Lake Tenkiller.

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Appendix G

Potential Septic Tank Contribution

An analysis was conducted to estimate the potential P inputs into the highflow watersheds based on human populations. Properly functioning septic systems would allow no or very little P to be discharged into the streams within these watersheds. The Oklahoma Department of Environmental Quality (1997) investigation of septic systems in the Illinois River concludes "systems identified in this study were found to pose no apparent significant threat to the quality of the Illinois River."

P loads to septic systems within each of the highflow watersheds were computed based on the number of houses identified from aerial photos within each watershed, household size from the census, and P excreted per person from a literature source. P exports from these watersheds were estimated for a small number of runoff events and baseflow from 2005 and 2006.

Estimated P exported from the watersheds for the runoff events sampled and from baseflow greatly exceeded P loads to septic systems for most of the watersheds (Table 1). ***Based on this analysis and the Oklahoma Department of Environmental Quality report on septic systems, the septic systems in the highflow watersheds are not the primary source of P exports in runoff and baseflow.***

2.49 people/household in Arkansas from http://quickfacts.census.gov/qfd/states/05000.html

2.49 people/household in Oklahoma from http://quickfacts.census.gov/qfd/states/40000.html

1.1 lb P per person per year (Sarac et al., 2001)

P contribution per household per year
2.49 people * 1.1 lb/person = 2.74 lb per household per year

Table 1. P loads from sub-basins compared to human P in sub-basins

Site ID	2005 baseflow P (kg)	2006 baseflow P (kg)	2005 highflow P (kg)	2006 highflow P (kg)	Annual Human P (kg)
HFS 02	7.348942	34.45084	369.8509	357.2	236.9436
HFS 04	0	0	0	0	244.2534
HFS 05	5.157429	16.03391	1165.365	375.06	204.5985
HFS 08	0.670428	0	371.9345	0	196.241
HFS 14	0.063186	0	95.10451	142.88	16.64032
HFS 16	0.343191	0.080233	133.4142	2.4111	21.35549
HFS 20	0.327493	1.83129	74.34226	19.646	45.46773
HFS 21	0.081386	20.34333	0	40.185	77.23901
HFS 22	0	0	0	0	65.31386
HFS 23	78.45195	24.6948	250.04	371.488	578.3071
HFS 26	0.0221	0	154.0425	0	25.12264
HFS 28A	0	3.977095	103.1415	3.572	17.71308
HFS 29	0	1.900684	0	25.004	52.61533
HFS 30	0	15.15998	0	178.6	28.72762

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