Grand Lake Basin Management Plan

Phase 1: Identification of Critical Area

1993 104(b)(3)

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Submitted to:

U.S. Environmental Protection Agency, Region 6
Dallas, Texas

May 2, 1996

Acknowledgements

This report would not have been possible without the cooperation and assistance of individuals from state and federal agencies in Arkansas, Kansas, Missouri, and Oklahoma. Mr. Earl Smith, Jr., Chief of the Water Management Division of the Arkansas Soil & Water Conservation Commission provided the point source information required from Arkansas. Mr. Karl Mueldener and Mr. Donald Snethen, of the State of Kansas Department of Health and Environment Bureau of Water, and their staff including Mr. Francis Bennett, and especially Mr. Mike Butler, provided more data than was needed. The GIS data provided was especially useful. Ms. Diana Fawks, the Clean Lakes Coordinator for the State of Missouri Department of Natural Resources provided excellent information on the NPDES facilities from Missouri. The data provided was complete and exactly what was required. Ms. Cynthia McElfresh of the Oklahoma Department of Environmental Quality provided data on the Oklahoma NPDES facilities. The efforts of each of these people is appreciated. The point source loading estimates could not have been accomplished without their input.

Hydraulic information was obtained from USGS field offices in Kansas, Oklahoma and Missouri. Mr. Butch Lakok from Kansas, Mr. Sternes from Missouri, and Mr. Bob Blazs from Oklahoma. All provided valuable information on the hydraulics within the basin.

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1. Introduction

Grand Lake O' the Cherokees is located in northeastern Oklahoma in Delaware, Mayes, and Ottawa Counties (Figure 1). The Grand Lake dam, the longest multiple arch dam in the world, was constructed by the Grand River Dam Authority in 1940 at a total cost of $28,953,276. It is the third largest reservoir in Oklahoma in both capacity and surface area with a shoreline length of 1,300 miles. At normal pool elevation the mean depth is 35.9 feet, the maximum depth is 164 feet. The lake covers 46,500 acres and holds 1,672,000 acre-feet of water (OWRB, 1990). The drainage area of Grand Lake is 10,298 square miles in Arkansas, Kansas, Missouri, and Oklahoma. Three rivers, the Neosho River, the Spring River, and the Elk River drain into the lake.

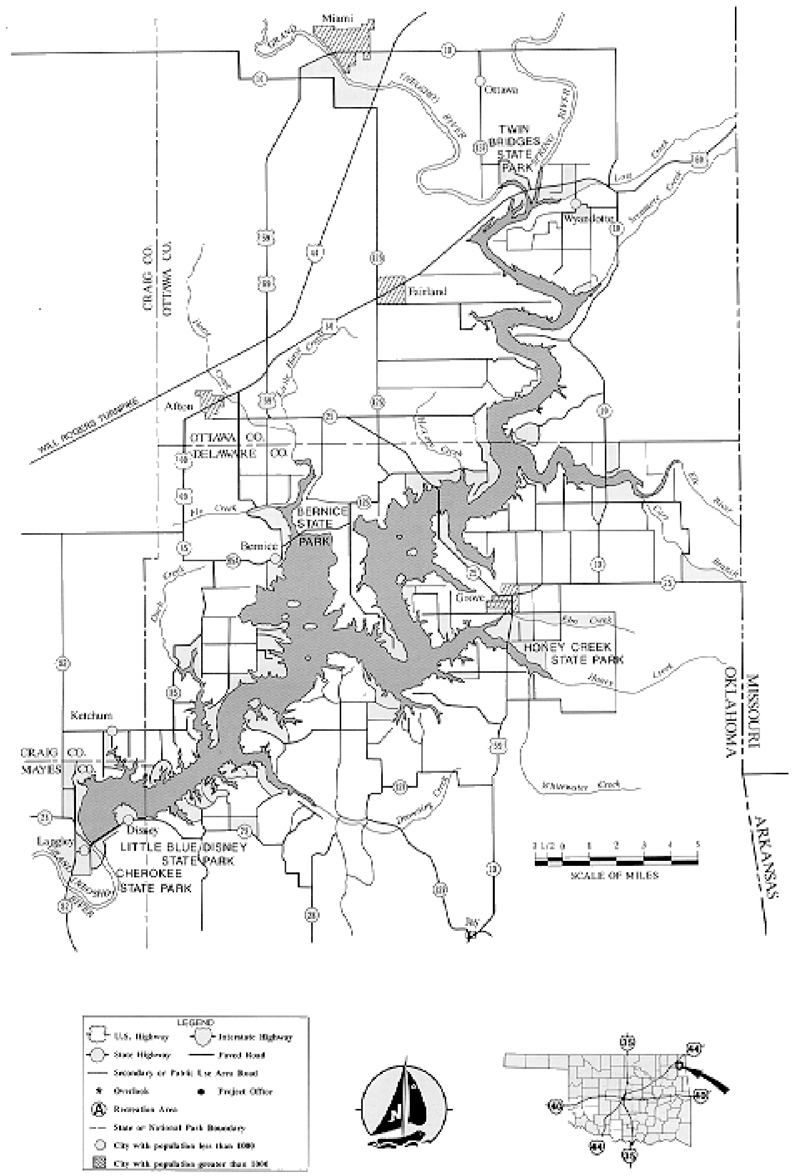


Figure 1.1: Grand Lake O' the Cherokees map (OWRB, 1990)

2. Problem Statement and Objectives

In recent years, concerns have arisen that the water quality in the Grand Lake basin, particularly within Grand Lake is deteriorating. Historical water quality data, as well as anecdotal evidence, tend to justify this concern. Eutrophication of the lake appears to be occurring at a more rapid rate than could be considered natural. The suspected cause for the accelerated eutrophication of Grand Lake is excessive nutrient loadings from within the basin.

A Clean Lakes Study conducted by Oklahoma State University (OSU) in coordination with the Oklahoma Water Resources Board (OWRB) supports this position (Burks et al., 1995). The study found that Grand Lake is experiencing accelerated eutrophication as a result of ever increasing nutrient loadings. The study also determined that the algal growth in the lake was phosphorous limited. In other words, according to the report, reducing the phosphorous loading to the lake will decrease the productivity more than reducing the nitrogen loadings. In fact, large reductions in the nitrogen loadings were seen to have little, if any, effect on lake productivity.

Prior to the Clean Lakes Study being released, the State of Oklahoma and the Oklahoma Conservation Commission were awarded a grant, from the United States Environmental Protection Agency (EPA), to develop the Grand Lake Basin Management Plan (GLBMP). The primary goal of the GLBMP is to prevent further degradation of the water quality within the Grand Lake basin including Grand Lake itself. The GLBMP will ultimately detail a strategy, or plan, for determining the desirable water quality that can reasonably be attained within the basin and the lake. It will also describe the tasks and procedures that must be implemented to achieve this desired water quality.

This is no easy task. Scientific studies can determine the water quality of the Lake. They can also determine thet levels of water quality that can be achieved if nutrient loadings to the Lake are reduced by various amounts. They can't tell us what is desirable, i.e., what the people want. Scuba divers, for instance, may prefer a perfectly clear lake in which the turbidity is low so that the visibility is great. Bass anglers, on the other hand, may prefer a more productive lake since a more turbid lake makes for better fishing. People living along the rivers draining the basin may be more concerned with the water quality in the rivers than in the lake.

These so called socio-technological aspects must be adequately addressed if the GLBMP is to be successful and effective. These decisions can't, or at least shouldn't, be made by engineers and scientists in isolation. Rather, these are policies that should be made by the general public at large and by the politicians that represent them. The GLBMP, when complete, could impact hundreds of thousands of people with various backgrounds, lifestyles and world views, from four different states. The people most affected by the GLBMP are the ones that must make the socio-technological decisions that will drive the final development of the plan and ultimately determine it's success or failure.

Phase One of the Grand Lake Basin Management Plan does not address the socio-technological issues involved, that will be left for later. The primary objectives of Phase One are to estimate the current loadings of phosphorous to the lake, and to target potentially critical pollutant source areas for further monitoring, modeling, and eventual implementation of controls.

3. Nonpoint Source Phosphorus Loading

Introduction

The water quality of Grand Lake has been analyzed and the levels of certain nutrients including Phosphorus and Nitrogen have been identified as posing a threat to the overall quality of the lake. In order to develop a management plan to maintain an acceptable level of water quality, the areas contributing to the water quality of Grand Lake were delineated. This drainage basin was then subdivided into smaller sub-basins using a 1:250,000 Digital Elevation Model (DEM). Classified satellite imagery provided a land cover classification that was used to apply nonpoint source loading estimates to areas within the watershed. Ancillary point source data acquired through the EPA-STORET database were included with the nonpoint source estimates and included in the river modeling portion of the project. Output of this NPS analysis was presented in a combination of digital and analog forms for use in the modeling efforts and status reports.

Watershed Delineation

The study area for this project was defined by nine one-degree DEMs located in Arkansas, Kansas, Missouri, and Oklahoma. The original map projection was defined as Geographic (Latitude, Longitude) but all of the data were projected into a common map projection -- Universal Transverse Mercator. All spatial data processing were conducted using ARC/INFO on a SUN Workstation.

The elevation data were obtained electronically from the USGS via *ftp* in the form of 1:250,000 DEMs which have a sampling interval of approximately 90 meters. The nine, separate DEMS were merged into one comprehensive DEM layer using [ARC command] **Merge**. A depressionless elevation model was created using [ARC command] **Fill** to allow calculation of the stream network. Next, the direction of flow across the elevation surface was calculated using [ARC command] **Flowdirection**. To delineate the area contributing to Grand Lake, [ARC command] **Basins** was used on the uninterrupted flow surface. Calculating the stream network involved the [ARC commands] **Flowaccumulation, Streamorder and Streamline** algorithms. These algorithms calculated the accumulation of flow across the elevation surface, calculated the Strahler Stream Order, and vectorized the resulting network. A stream order value of six was used as a threshold for displaying the vector network. The basin was next subdivided into sub-basins by two hierarchical methods. First, the locations of USGS water quality gauges were used to define the pour points for each sub-basin, and then these sub-basins were subdivided according to the mouth of the named tributaries identified on the study base map. This process used the [ARC command] **Watershed** algorithm. A flow chart of the digital terrain model is given in Figure 3.1. River miles were calculated for each pour point and tributary mouth using the derived stream network.

Land Cover Characterization

The land cover data used to apply nonpoint source loading estimates to areas within the watershed were derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery which has a spatial resolution of 1.1 kilometers. The generalized land cover classification was developed by the U.S. Geological Survey (USGS) as a prototype data set for global environmental research. The prototype land cover characteristics data base for the conterminous United States was derived from the classification of 1990 AVHRR time-series data, with post-classification refinement based on other digital earth science data sets, including topography, climate, soils, and ecoregions. The classification of land cover regions followed several steps: (1) image classification, (2) class labeling and description, and (3) post-classification refinement (EROS Data Center, 1990).

The generalized land cover classification is composed of 159 categories based on the USGS Land Use/Land Cover system defined to illustrate national patterns of land cover (Anderson et al., 1976). The categories include Anderson Level 2 modifications that reflect regional vegetation types and mosaics of land cover that occur at a 1.1 kilometer resolution. The land use categories and basin area are given in Table 3.1 for the Grand Lake basin.

Unit Area Loading Estimates

To estimate the non-point source loadings for each sub-basin, each land cover type was assigned an unit area loading in units of kg/ha/yr. These loadings were accumulated for the sub-basin using the [ARC command] **Flowaccumulation** algorithm. This tied the total estimated nonpoint source pollution for each sub-basin to the corresponding pour point or tributary mouth. These data were then input into the river model presented later in the report.

A detailed evaluation of unit area loadings in the literature was performed. A limited summary of the unit area loading sources is given in Table 3.2. All of the reported unit area loadings were from monitoring projects outside the Grand Lake basin and most were in areas drastically different from the study area. Therefore, median total phosphorus loadings from Beaulac and Reckhow (1982) were used for this project (Table 3.3). Beaulac and Reckhow (1982) complied an extensive data base of observed unit area loading values from across the United States. For the purposes of the Phase One Portion of the GLBM project, we concluded that these median total phosphorus loadings were reasonable approximations. Table 3.4 gives a condensed summary of the nonpoint source unit area total phosphorus loadings by land use and Table 3.5 gives the loadings by AVHRR classification code. A summarized land use based on the AVHRR imagery is given in Figure 3.2.

Results

A summary of the nonpoint source loading of total phosphorus for the Grand Lake basin by sub-basin is given in Tables 3.6 and 3.7. Table 3.8 presents a detailed summary of the total phosphorus loadings by sub-basin and land use. Table 9 presents mean, standard deviation, and minimum maximum cell slope by sub-basin tributary code. To supplement the phosphorus loading estimates, county level statistics are given in Tables 10 and 11. The state and county areas are given in Table 3.12 and Table 3.13 gives the county areas by sub-basin.

Table 3.1 AVHRR Land Use Categories and Area by Reference Number for the Grand Lake Basin.

Code	Cover	Species	Area (m^2)	Area (ha)
2	cropland/grassland	sorghum/small grains/bluestem/wheat grass	$6.7x10^7$	6,700
3	cropland	spring wheat	$5.6x10^9$	560,000
19	pasture/cropland	native pasture/mixed small grains	$1.9x10^9$	190,000
21	cropland/range	wheat/sorghum/bluestem/wheat grass	$6.9x10^9$	690,000
43	cropland/forest	corn/soybean/flax/wheat/northern hardwoods	$2.6x10^7$	2,600
47	cropland/woodlots	corn/soybeans/sorghum/mixed	$1.2x10^9$	120,000
53	woodland/crop/pasture	maple/birch/beech/corn/soybeans	$1.2x10^8$	12,000
58	southern forest/crop	oak/hickory/mixed pine/mixed cropland	$3.7x10^9$	370,000
93	woodland/pasture	beech/birch/maple/oak/pasture	$1.1x10^7$	1,100
94	mixed hardwoods	poplar/beech/walnut/oak/hickory	$1.2x10^9$	120,000
100	pine forest	western white/ponderosa/lodgepole pine	$1.3x10^6$	130
115	western conifer	w. white/ponderosa/lodgepole/doug fir	$1.3x10^6$	130
117	southern pine	loblolly/longleaf/slash/shortleaf	$4.5x10^8$	45,000
139	mixed forest	loblolly/slash/short leaf/oak/gum/poplar	$2.0x10^8$	20,000
60	grassland	wheat grass/blue grama/needle and thread	$4.8x10^9$	480,000
69	desert shrubs/grass	sage/grease woods/rice grass/blue	$3.9x10^6$	390
83	grassland/shrubs	blue/grama/buffalo grass/big sage/salt brush	$6.6x10^6$	660
151	savanna	oak/elm/blue stem/indian grass/switch grass	$2.4x10^8$	24,000
159	water	water	$2.9x10^8$	29,000

Table 3.2 Nonpoint Source Unit Area Loading Literature.

Alberts et al., 1978	Beaulac and Reckhow, 1982
Blalock, 1987	Bradford, 1974
Burwell et al., 1975	Casman, 1989
Chesters et al., 1978	Chichester et al., 1979
Converse et al., 1976	Corell et al., 1977
Frink, 1982	Gordon and Simpson, 1990
Haith, and Tubbs, 1981	Handbook of Nonpoint Pollution
Harms et al., 1974	Hensler et al., 1970
Hession et al., 1992	Johnson, 1980
Kilmer et al., 1974	Klausner et al., 1976
Krebs and Golley, 1977	Loehr, 1974
Loehr, 1972	Long et al., 1975
McCaskey et al., 1971	McDowell et al., 1978
McDowell and Omernik 1979	McElroy et al., 1976
Menzel et al., 1978	Minshall et al., 1970
Olness et al., 1980	Overcash et al., 1976
Ritter, 1994	Schuman et al., 1973b
Schuman et al., 1973a	Smith et al., 1978
Sonzogni et al., 1978	Timmons and Holt, 1978
Young and Holt, 1977	Young and Mutchler, 1976

Table 3.3 Unit Area Loading Estimates (Beaulac and Reckhow, 1982).

Land Use	Total P Loading (kg/ha/yr)
row crops	2.2
non-row crops	0.7
grazed and pastured	0.8
forest	0.2

Table 3.4 Unit Area Loading Estimates for AVHRR Land Use Classification.

Land Use	Total P Loading (kg/ha/yr)
water	0.0
grassland	0.2
range	0.2
savanna	0.2
desert shrubs, shrubs	0.2
forest, woodlands - all	0.2
cropland - small grains	0.7
cropland - row crop	2.2
cropland - mixed	1.5
pasture	0.8

Table 3.5 Unit Area Loading Estimates for AVHRR Land Use Classification by Code.

Code	Cover	Total P Loading (kg/ha/yr)
2	cropland/grassland	0.9
3	cropland	0.7
19	pasture/cropland	0.8
21	cropland/range	0.9
43	cropland/forest	0.9
47	cropland/woodlots	1.2
53	woodland/crop/pasture	1.2
58	southern forest/crop	0.9
93	woodland/pasture	0.5
94	mixed hardwoods	0.2
100	pine forest	0.2
115	western conifer	0.2
117	southern pine	0.2
139	mixed forest	0.2
60	grassland	0.2
69	desert shrubs/grass	0.2
83	grassland/shrubs	0.2
151	savanna	0.2
159	water	0.0

Table 3.6 Nonpoint Source Total Phosphorous Loading and average annual stream flow by Sub-basin.

Sub-Basin Number	Area (ha)	Area (%)	Total Phosphorus Loading (kg/yr)	Total Phosphorus Loading (kg/ha/yr)	Total Phosphorus Loading (%)	Average Annual Flow (cfs)
1	184,000	7.0	140,000	0.74	7.7	
2	253,700	9.7	90,000	0.33	4.8	
3	157,700	6.0	52,000	0.33	2.9	
4	177,300	6.8	95,000	0.54	5.4	1700
5	172,100	6.6	130,000	0.73	7.1	200
6	282,300	10.8	230,000	0.81	12.9	900
7	270,500	10.3	210,000	0.78	11.9	1000
8	287,600	11.0	240,000	0.83	13.5	900
9	346,500	13.2	280,000	0.81	15.8	1200
10	217,300	8.3	130,000	0.58	7.1	800
11	267,800	10.2	200,000	0.72	11.0	700

Table 3.7 Nonpoint Source Total Phosphorous Loading by sub-basin with DTM pour point locations.

Long-itude	Latitude	Sub-Basin ID	Trib-utary ID	Pour Point ID	Stream	Mile	Area (ha)	Cumul-ative P Loading (Mg/yr)	Sub-Basin Loading (Mg/yr)	Sub-Basin Loading (Mg/ha/yr)
-96.8770	38.2392	1	6	51	Cottonwood	62	188489	138	138	0.73
-96.3559	38.3996	2	5	50	Cottonwood	21	257105	223	86	0.33
-96.4933	38.6667	3	2	45	Neosho	196	65989	24	24	0.37
-96.2500	38.4747	3	3	44	Neosho	176	92788	52	27	0.30
-95.7358	38.1932	4	4	43	Neosho	137	180160	369	94	0.52
-95.6692	38.1085	5	7	424	Long	129	20573	15	15	0.74
-95.4318	37.8991	5	8	42	Neosho	105	54182	494	42	0.77
-95.6271	38.0523	5	9	423	Crooked	122	11459	11	11	0.94
-95.6701	38.0724	5	10	4235	Big	126	51624	32	32	0.63
-95.4402	37.9526	5	11	421	Deer	109	29734	20	20	0.66
-95.4784	37.9683	5	12	422	Indian	111	6950	5	5	0.75
-95.4659	37.8244	6	13	416	Owl	99	49803	40	40	0.80
-95.1092	37.3275	6	14	41	Neosho	53	125580	726	104	0.83
-95.3409	37.6264	6	15	414	Big	80	28361	24	24	0.83
-95.3039	37.5716	6	16	412	Canville	75	19865	15	15	0.78
-95.4277	37.7073	6	17	415	?	89	13746	10	10	0.76
-95.1657	37.4942	6	18	411	Walnut	65	38461	30	30	0.78
-95.3221	37.5933	6	20	413	Elk Cr.	77	11086	8	8	0.72
-95.0697	37.1732	7	19	404	Lightning	39	56869	45	45	0.79
-94.9633	36.9293	7	23	40	Neosho	18	71439	938	55	0.78
-95.0339	36.9888	7	24	401	Labette	25	103189	78	78	0.75
-95.0685	37.0921	7	27	403	Cherry	33	27986	22	22	0.79
-95.0206	37.0251	7	33	402	Fly	26	15104	13	13	0.83
-94.5307	37.2717	8	22	3115	North Fork	45	134777	111	111	0.82
-94.5350	37.2700	8	25	311	L. North	45	22335	18	18	0.81
-94.5610	37.2485	8	26	31	Spring	43	68443	240	57	0.84
-94.1688	37.1625	8	29	312	W. Oak	69	16892	15	15	0.87
-93.8734	37.0936	8	32	313	Mt.Vernon	89	12909	10	10	0.80
-93.8413	37.0630	8	35	32	Spring	91	35247	29	29	0.81
-94.6443	37.1875	9	21	303	Cow	36	65359	52	52	0.80
-94.6841	37.0946	9	28	3015	Shawnee	26	15216	13	13	0.85
-94.7441	36.9344	9	30	30	Spring	12	66065	520	53	0.80
-94.6171	37.1492	9	31	302	Center	33	77457	65	65	0.83
-94.7173	37.0580	9	34	301	Shoal	23	124167	97	97	0.79
-94.4536	36.5774	10	37	202	Indian	25	61653	40	40	0.65
-94.1812	36.6253	10	38	204	N. B. Sugar	45	17984	8	8	0.45
-94.5866	36.6275	10	39	20	ELK	13	66977	127	36	0.53
-94.0457	36.5123	10	40	21	ELK	60	11159	6	6	0.51
-94.3861	36.5879	10	41	203	L. Sugar	29	50584	31	31	0.61
-94.4912	36.5480	10	42	201	?	22	12284	7	7	0.53
-95.0343	36.4652	11	36	10	Grand	0	272757	1782	196	0.72

Table 3.8 Nonpoint Source Total Phosphorous Loading by sub-basin and Land Use.

Sub-Basin	Land Use Category	Area (ha)	Area (%)	Total P Loading (kg/yr)	Total P Loading (kg/ha/yr)	Total P Loading (%)
1	CROPLAND/GRASSLAND	1951	1.1	1756	0.9	1.3
	CROPLAND	60184	32.7	42129	0.7	30.9
	PASTURE/CROPLAND	63486	34.5	50789	0.8	37.3
	CROPLAND/RANGE	42029	22.8	37826	0.9	27.8
	CROPLAND/WOODLOTS	1017	0.6	1220	1.2	0.9
	SOUTHERN-PINE	262	0.1	52	0.2	0.0
	GRASSLAND	6609	3.6	1322	0.2	1.0
	GRASSLANDS/SHRUBS	115	0.1	23	0.2	0.0
	SAVANNA	5503	3.0	1101	0.2	0.8
	WATER	2863	1.6	0	0.0	0.0
2	CROPLAND	31208	12.3	21845	0.7	25.8
	PASTURE/CROPLAND	929	0.4	743	0.8	0.9
	CROPLAND/RANGE	19606	7.7	17645	0.9	20.9
	CROPLAND/FOREST	1276	0.5	1148	0.9	1.4
	CROPLAND/WOODLOTS	2459	1.0	2950	1.2	3.5
	WOODLANDCROPPASTURE	547	0.2	657	1.2	0.8
	GRASSLAND	197530	77.9	39506	0.2	46.7
	SAVANNA	137	0.1	27	0.2	0.0
3	CROPLAND	18254	11.6	12778	0.7	24.8
	PASTURE/CROPLAND	607	0.4	486	0.8	0.9
	CROPLAND/RANGE	9928	6.3	8936	0.9	17.4
	CROPLAND/FOREST	410	0.3	369	0.9	0.7
	CROPLAND/WOODLOTS	2580	1.6	3096	1.2	6.0
	WOODLANDCROPPASTURE	902	0.6	1082	1.2	2.1
	GRASSLAND	123765	78.5	24753	0.2	48.1
	WATER	1289	0.8	0	0.0	0.0
4	CROPLAND/GRASSLAND	1233	0.7	1110	0.9	1.2
	CROPLAND	39720	22.4	27804	0.7	29.1
	PASTURE/CROPLAND	2157	1.2	1726	0.8	1.8
	CROPLAND/RANGE	17396	9.8	15657	0.9	16.4
	CROPLAND/FOREST	787	0.4	708	0.9	0.7
	CROPLAND/WOODLOTS	23833	13.4	28599	1.2	30.0
	WOODLANDCROPPASTURE	2015	1.1	2418	1.2	2.5
	PINE-FOREST	125	0.1	25	0.2	0.0
	GRASSLAND	86671	48.9	17334	0.2	18.2
	DESERT-SHRUBS/GRASS	251	0.1	50	0.2	0.1
	WATER	3124	1.8	0	0.0	0.0

Table 3.8 (continued). Nonpoint Source Total Phosphorous Loading by sub-basin and Land Use.

Sub-Basin	Land Use Category	Area (ha)	Area (%)	Total P Loading (kg/yr)	Total P Loading (kg/ha/yr)	Total P Loading (%)
5	CROPLAND/GRASSLAND	172	0.1	155	0.9	0.1
	CROPLAND	46611	27.1	32628	0.7	26.1
	PASTURE/CROPLAND	19657	11.4	15726	0.8	12.6
	CROPLAND/RANGE	7577	4.4	6819	0.9	5.5
	CROPLAND/FOREST	125	0.1	113	0.9	0.1
	CROPLAND/WOODLOTS	44541	25.9	53449	1.2	42.7
	WOODLANDCROPPASTURE	5824	3.4	6988	1.2	5.6
	SOUTHERN-FOREST/CRO	125	0.1	113	0.9	0.1
	GRASSLAND	44776	26.0	8955	0.2	7.2
	SAVANNA	513	0.3	103	0.2	0.1
	WATER	2215	1.3	0	0.0	0.0
6	CROPLAND/GRASSLAND	536	0.2	482	0.9	0.2
	CROPLAND	139906	49.6	97934	0.7	42.8
	PASTURE/CROPLAND	50663	17.9	40530	0.8	17.7
	CROPLAND/RANGE	44245	15.7	39821	0.9	17.4
	CROPLAND/WOODLOTS	36715	13.0	44058	1.2	19.2
	WOODLANDCROPPASTURE	2624	0.9	3149	1.2	1.4
	SOUTHERN-FOREST/CRO	2022	0.7	1819	0.9	0.8
	SOUTHERN-PINE	262	0.1	52	0.2	0.0
	GRASSLAND	4785	1.7	957	0.2	0.4
	SAVANNA	524	0.2	105	0.2	0.0
7	CROPLAND/GRASSLAND	125	0.0	113	0.9	0.1
	CROPLAND	97663	36.1	68364	0.7	32.4
	PASTURE/CROPLAND	8948	3.3	7158	0.8	3.4
	CROPLAND/RANGE	140274	51.9	126247	0.9	59.9
	CROPLAND/WOODLOTS	3839	1.4	4607	1.2	2.2
	SOUTHERN-FOREST/CRO	675	0.2	608	0.9	0.3
	SOUTHERN-PINE	2223	0.8	445	0.2	0.2
	GRASSLAND	1758	0.6	352	0.2	0.2
	SAVANNA	14761	5.5	2952	0.2	1.4
	WATER	240	0.1	0	0.0	0.0
8	CROPLAND	26065	9.1	18246	0.7	7.6
	PASTURE/CROPLAND	26965	9.4	21572	0.8	9.0
	CROPLAND/RANGE	130853	45.5	117768	0.9	49.3
	CROPLAND/WOODLOTS	884	0.3	1061	1.2	0.4
	SOUTHERN-FOREST/CRO	85567	29.7	77010	0.9	32.2
	WESTERN-CONIFER	137	0.0	27	0.2	0.0
	SOUTHERN-PINE	11768	4.1	2354	0.2	1.0
	MIXED-FOREST	5382	1.9	1076	0.2	0.5

Table 3.8 (continued). Nonpoint Source Total Phosphorous Loading by sub-basin and Land Use.

Sub-Basin	Land Use Category	Area (ha)	Area (%)	Total P Loading (kg/yr)	Total P Loading (kg/ha/yr)	Total P Loading (%)
9	CROPLAND/GRASSLAND	514	0.1	463	0.9	0.2
	CROPLAND	49533	14.3	34673	0.7	12.4
	PASTURE/CROPLAND	6111	1.8	4889	0.8	1.8
	CROPLAND/RANGE	161055	46.5	144950	0.9	51.9
	CROPLAND/WOODLOTS	2169	0.6	2603	1.2	0.9
	SOUTHERN-FOREST/CRO	94823	27.4	85341	0.9	30.6
	MIXED-HARDWOODS	8788	2.5	1758	0.2	0.6
	SOUTHERN-PINE	15890	4.6	3178	0.2	1.1
	MIXED-FOREST	5099	1.5	1020	0.2	0.4
	GRASSLAND	764	0.2	153	0.2	0.1
	SAVANNA	1470	0.4	294	0.2	0.1
	WATER	274	0.1	0	0.0	0.0
10	CROPLAND	2201	1.0	1541	0.7	1.2
	PASTURE/CROPLAND	388	0.2	310	0.8	0.2
	CROPLAND/RANGE	33424	15.4	30081	0.9	24.0
	CROPLAND/WOODLOTS	125	0.1	150	1.2	0.1
	SOUTHERN-FOREST/CRO	81475	37.5	73327	0.9	58.5
	WOODLAND/PASTURE	481	0.2	240	0.5	0.2
	MIXED-HARDWOODS	80461	37.0	16092	0.2	12.8
	SOUTHERN-PINE	10788	5.0	2158	0.2	1.7
	MIXED-FOREST	7728	3.6	1546	0.2	1.2
	WATER	262	0.1	0	0.0	0.0
11	CROPLAND/GRASSLAND	2120	0.8	1908	0.9	1.0
	CROPLAND	37839	14.1	26488	0.7	13.6
	PASTURE/CROPLAND	3601	1.3	2880	0.8	1.5
	CROPLAND/RANGE	74250	27.7	66825	0.9	34.4
	CROPLAND/WOODLOTS	1173	0.4	1408	1.2	0.7
	SOUTHERN-FOREST/CRO	97720	36.5	87948	0.9	45.3
	WOODLAND/PASTURE	502	0.2	251	0.5	0.1
	MIXED-HARDWOODS	25159	9.4	5032	0.2	2.6
	SOUTHERN-PINE	2887	1.1	577	0.2	0.3
	MIXED-FOREST	1044	0.4	209	0.2	0.1
	GRASSLAND	765	0.3	153	0.2	0.1
	DESERT-SHRUBS/GRASS	137	0.1	27	0.2	0.0
	GRASSLANDS/SHRUBS	514	0.2	103	0.2	0.1
	SAVANNA	1197	0.4	239	0.2	0.1
	WATER	18841	7.0	0	0.0	0.0

Table 3.9 Slope statistics by sub-basin tribgrid.

Pour Point ID	Area (ha)	Mean (%)	SD (%)	Min (%)	Max (%)
10	32759	2.1	2.73	0	25
20	8044	4.4	4.32	0	28
21	1340	5	4.64	0	28
30	7935	1.2	1.56	0	19
31	8220	1.3	1.25	0	12
32	4233	1.4	1.26	0	16
40	8580	0.8	1.03	0	15
41	15083	0.8	0.87	0	10
42	6507	0.9	0.99	0	17
43	21638	1.1	1.25	0	16
44	11144	2	2.04	0	16
45	7926	1.5	1.64	0	13
50	30879	2	2.14	0	24
51	22634	0.9	0.98	0	11
201	1475	5	4.66	0	26
202	7405	2.2	2.75	0	25
203	6075	4	4.25	0	29
204	2160	3.6	4.04	0	24
301	14913	1.7	1.78	0	18
302	9303	1.2	1.24	0	15
303	7850	0.7	0.8	0	9
311	2683	0.7	0.85	0	8
312	2029	1.6	1.48	0	11
313	1550	1.1	1.08	0	8
401	12393	0.8	0.73	0	8
402	1814	0.6	0.55	0	5
403	3361	0.5	0.44	0	4
404	6830	0.8	0.74	0	8
411	4619	0.9	0.95	0	12
412	2386	1.3	1.21	0	8
413	1331	0.9	0.75	0	6
414	3406	1	1	0	9
415	1651	0.8	0.78	0	7

Table 3.10 County level agricultural statistics[1].

State	County	Total Cattle (#)	Beef Cows (#)	Milk Cows (#)	Corn (ac)	Wheat (ac)	Sorg-hum (ac)	Alfalfa (ac)	Hay (ac)	Soy-beans (ac)
Arkansas[2]										
	Benton	108000	na	7000	1100	1500	0	na	na	2300
Kansas[3]	Allen	34700	na	2450	7900	40000	17400	4000	23500	63700
	Anderson	39200	na	1400	19400	38400	19300	4500	37100	73200
	Bourbon	56000	na	1500	4900	16500	11300	2600	42000	32600
	Butler	115200	na	850	2500	75000	65500	14000	38800	23500
	Chase	24800	na	300	2500	18700	10500	5100	9100	11600
	Cherokee	23300	na	200	6700	86000	21700	600	18200	84700
	Coffey	35000	na	200	12600	35600	23400	3100	30400	73700
	Crawford	32900	na	850	14800	45200	23700	1400	30800	67100
	Geary	20800	na	900	15500	23500	10500	2800	9000	6800
	Greenwood	62500	na	1400	2100	14500	8300	7700	28000	16500
	Harvey	31500	na	1750	12700	118100	67900	7400	10800	17700
	Labette	62600	na	1200	4900	73500	24600	1800	28800	50000
	Lyon	69200	na	300	12800	28000	35900	5500	42000	47900
	Marion	62700	na	5550	5500	161700	75600	26000	28700	7800
	McPherson	62100	na	3700	12800	243000	51100	18000	10900	16800
	Morris	54900	na	1300	3700	51500	39900	13700	24900	16600
	Neosho	27900	na	1750	6700	48500	21500	4500	20600	39900
	Wabaunsee	47600	na	750	6500	20500	19000	8900	38000	15300
	Wilson	35200	na	400	4600	56200	24700	5600	22000	51800
	Woodson	28100	na	200	4100	24700	15500	2000	32000	29700
Missouri[4]										
	Barry	84800	39800	7450	400	250	<500	4909	50300	<500
	Barton	49800	23300	1700	10700	52700	29800	9620	400000	50600
	Dade	60900	30900	1550	2500	22200	7400	6421	37600	18900
	Jasper	59600	27500	4400	2800	31300	11400	7361	44900	24700
	Lawrence	109100	43200	11300	1500	8500	3300	<500	78100	7200
	McDonald	55900	26900	2500	<500	500	<500	5429	31700	<500
	Newton	78200	35300	4800	550	4700	1600	9141	56100	3600
Oklahoma[5]										
	Craig	97000	40000	1200	1300	18000	10700	1000	55000	14200
	Delaware	57000	28000	3500	0	5000	900	1000	42000	2200
	Mayes	70000	30000	6400	1600	7500	2400	2000	43000	6500
	Ottawa	63000	30000	2600	3700	31000	13200	1000	43000	29500

[1]na indicated data not available
[2]Cattle numbers based on 1993 data and crop numbers based on 1992 data
[3]Numbers based on 1992 data
[4]Cattle numbers based on 1992-1993 data and crop numbers based on 1992 data
[5]Cattle numbers based on 1993 data and crop numbers based on 1992 data

Table 3.11 County level miscellaneous statistics.

State	County	Forest Area (ac)	Rural Area (ac)	Urban Area (ac)	Coal Mines (#)	Sand Ext. (#)	Other Mines (#)
Arkansas							
	Benton		229473	7887	0	16	243
Kansas							
	Allen	11400	130794	1626	0	75	150
	Anderson	19500	149442	1107	0	37	80
	Bourbon	43400	165500	826	1376	93	0
	Butler	24100	374253	4681	0	81	0
	Chase	10500	200465	431	0	28	91
	Cherokee	27000	203055	728	0	0	0
	Coffey	12500	169903	1246	47	75	217
	Crawford	24200	154881	3879	8134	0	32
	Geary		103859	4881	0	12	14
	Greenwood	29000	297849	1070	0	0	0
	Harvey	1900	139859	3595	0	0	0
	Labette	20200	169385	830	239	0	202
	Lyon	12400	220667	2655	0	81	0
	Marion	4000	248380	1814	0	0	0
	McPherson	9300	232063	2934	0	465	166
	Morris	17100	183112	919	0	0	162
	Neosho	32800	152032	1246	0	348	0
	Wabaunsee	15800	205904	678	0	67	0
	Wilson	32800	148665	1526	0	0	151
	Woodson	15800	130535	1002	0	32	65
Missouri							
	Barry	201700	207199	3575	0	0	4
	Barton	38700	153845	1429	5233	0	8
	Dade	40200	130535	1717	101	24	2
	Jasper	54900	166277	10277	20	0	3226
	Lawrence	58200	160320	3460	0	0	64
	McDonald	184700	139859	1855	0	0	0
	Newton	97600	162910	5970	0	0	325
Oklahoma							
	Craig		197875	1467	1934	40	0
	Delaware	214	201760	2420	0	20	0
	Mayes	125	178191	10824	53	0	0
	Ottawa	47	125096	2432	0	40	3411

Table 3.12 State and county areas for the Grand Lake Basin.

State	County	Area (km^2)	Area (%)
Arkansas	n/a	556	2.10
	Benton	556	2.10
Kansas	n/a	16114	60.95
	Allen	1032	3.90
	Anderson	297	1.13
	Bourbon	33	0.13
	Butler	73	0.28
	Chase	1842	6.97
	Cherokee	1476	5.58
	Coffey	1344	5.08
	Crawford	1244	4.71
	Geary	1	0.00
	Greenwood	67	0.25
	Harvey	55	0.21
	Labette	1020	3.86
	Lyon	1526	5.77
	Marion	2118	8.01
	McPherson	64	0.24
	Morris	1453	5.50
	Neosho	1365	5.16
	Wabauns	185	0.70
	Wilson	89	0.34
	Woodson	828	3.13
Missouri	n/a	7470	28.25
	Barry	666	2.52
	Barton	825	3.12
	Christi	14	0.05
	Dade	142	0.54
	Jasper	1612	6.10
	Lawrence	1148	4.34
	McDonald	1430	5.41
	Newton	1632	6.17
	Stone	0	0.00
Oklahoma	n/a	2298	8.69
	Craig	192	0.73
	Delaware	905	3.42
	Mayes	21	0.08
	Ottawa	1180	4.47

Table 3.13 County areas by sub-basin for the Grand Lake Basin.

County	State	Area (square kilometers)										
		Sub-Basin Number										
		1	2	3	4	5	6	7	8	9	10	11
Morris	Kansas	15										
Harvey	Kansas	55										
McPherson	Kansas	64										
Marion	Kansas	1744										
Lyon	Kansas		0									
Greenwood	Kansas		46									
Butler	Kansas		73									
Morris	Kansas		303									
Marion	Kansas		374									
Chase	Kansas		1765									
Geary	Kansas			1								
Chase	Kansas			18								
Wabaunsee	Kansas			185								
Lyon	Kansas			244								
Morris	Kansas			1134								
Greenwood	Kansas				3							
Chase	Kansas				58							
Coffey	Kansas				456							
Lyon	Kansas				1279							
Lyon	Kansas					3						
Greenwood	Kansas					19						
Allen	Kansas					235						
Woodson	Kansas					297						
Anderson	Kansas					297						
Coffey	Kansas					888						
Bourbon	Kansas						33					
Labette	Kansas						60					
Wilson	Kansas						89					
Crawford	Kansas						216					
Woodson	Kansas						531					
Allen	Kansas						797					
Neosho	Kansas						1132					
Ottawa	Oklahoma							68				
Craig	Oklahoma							153				
Neosho	Kansas							232				
Crawford	Kansas							576				
Cherokee	Kansas							749				
Labette	Kansas							960				

Table 3.13 (continued) County areas by sub-basin for the Grand Lake Basin.

County	State	Area (square kilometers)										
		Sub-Basin Number										
		1	2	3	4	5	6	7	8	9	10	11
Barton	Missouri								26			
Ottawa	Oklahoma								85			
Lawrence	Missouri								230			
Barry	Missouri								375			
Crawford	Kansas								453			
Jasper	Missouri								621			
Cherokee	Kansas								683			
Newton	Missouri								998			
Cherokee	Kansas									0		
Stone	Missouri									0		
Christian	Missouri									14		
Barry	Missouri									31		
Dade	Missouri									142		
Barton	Missouri									800		
Lawrence	Missouri									918		
Jasper	Missouri									991		
Barry	Missouri										260	
Newton	Missouri										265	
Benton	Arkansas										519	
McDonald	Missouri										1155	
Mayes	Oklahoma											21
Benton	Arkansas											37
Craig	Oklahoma											39
Cherokee	Kansas											44
McDonald	Missouri											275
Newton	Missouri											369
Delaware	Oklahoma											905
Ottawa	Oklahoma											1028

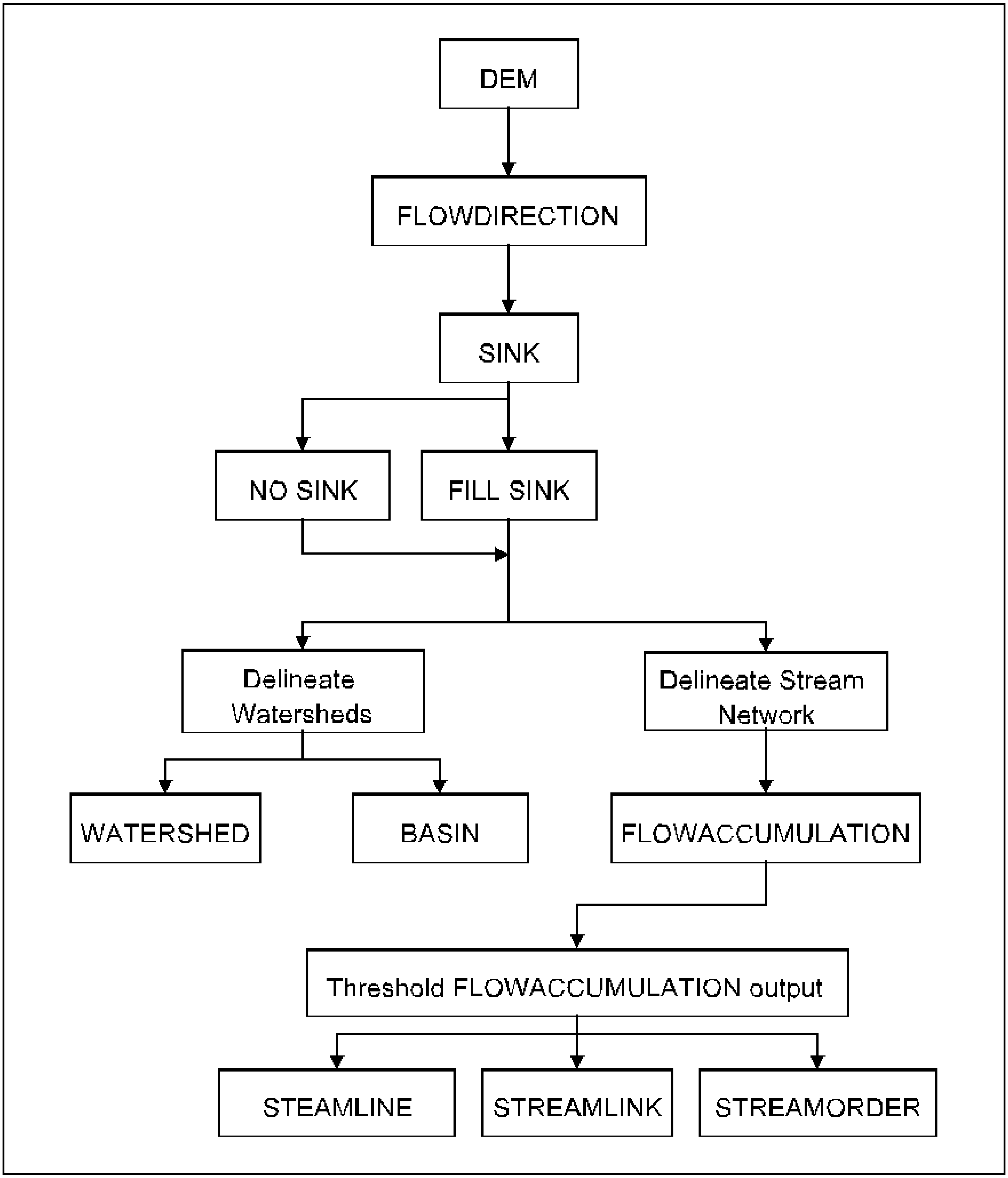


Figure 3.1 Flow Chart of the digital terrain model in ARC/INFO.

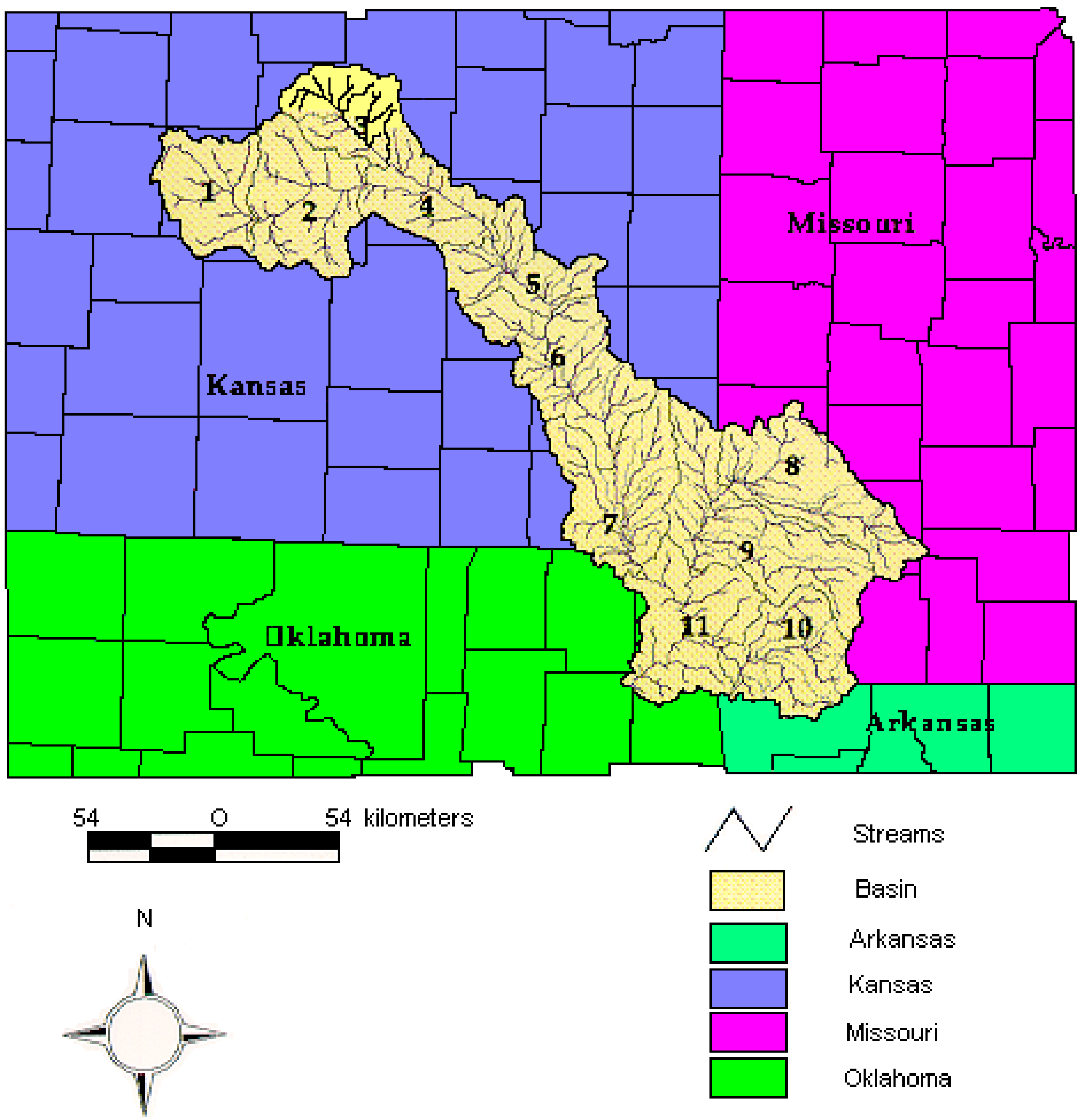


Figure 3.2: Grand Lake Basin showing sub-basins and stream network.

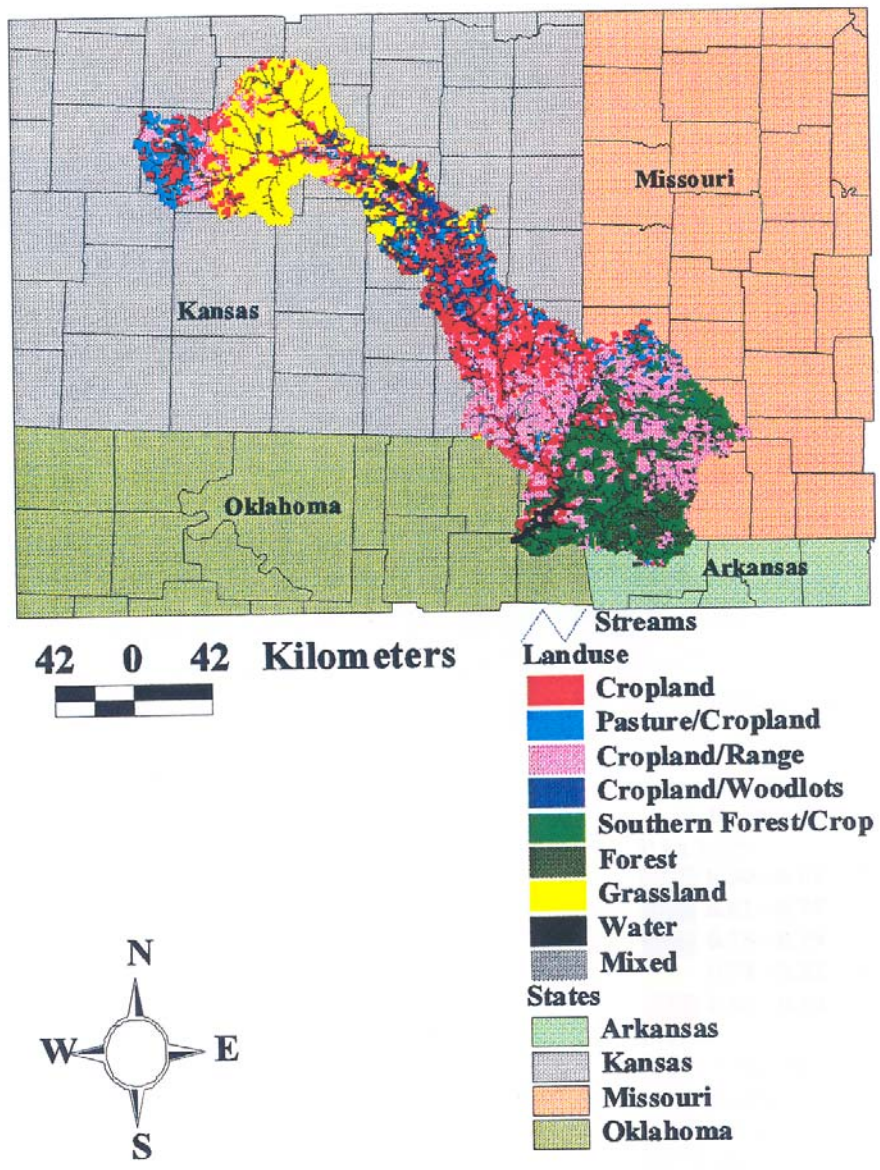


Figure 3.3. Land use classification for Grand Lake Basin based on AVHRR imagery.

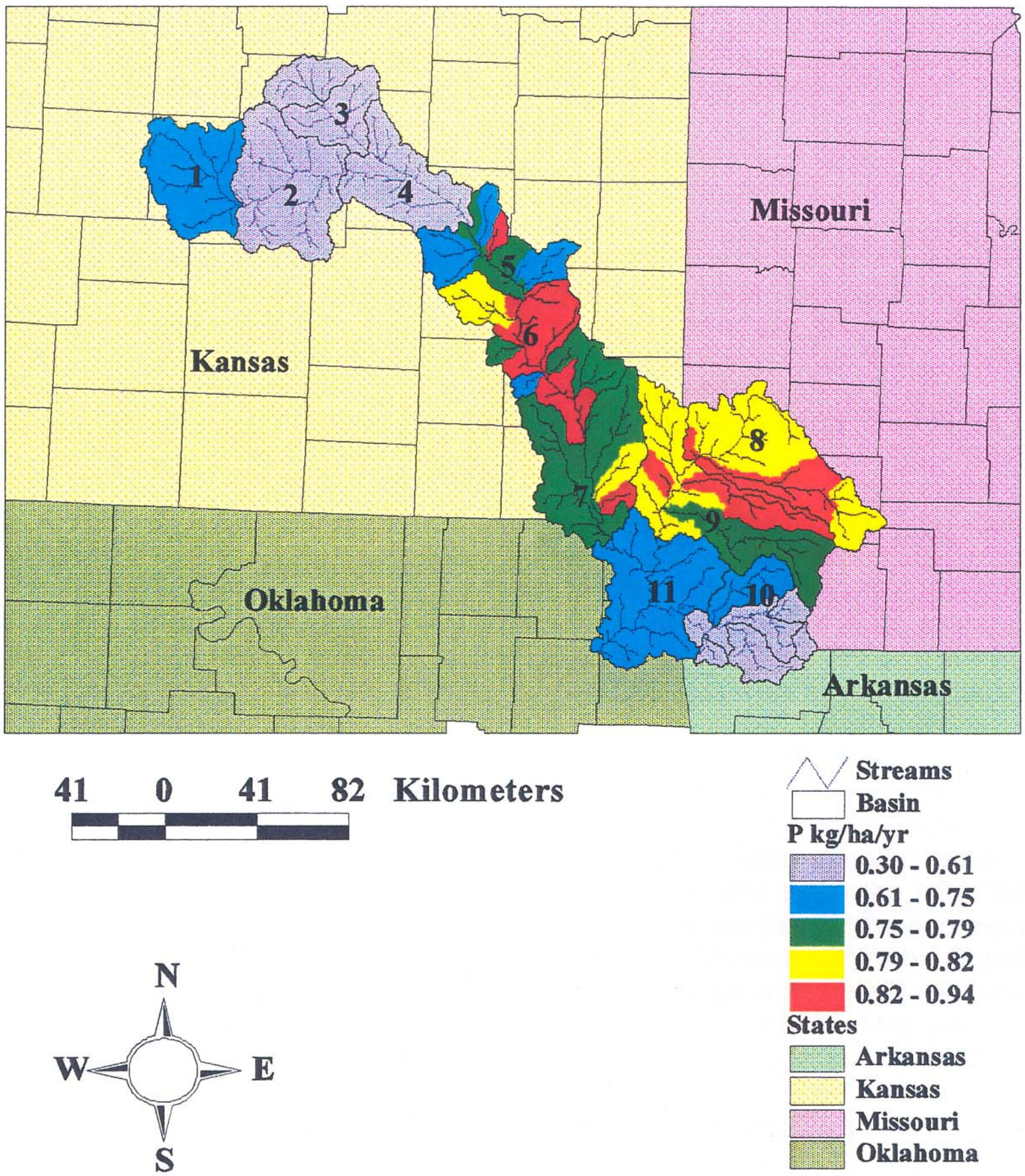


Figure 3.4 NPS total phosphorous loading by sub-basin with stream network.

4. Point Source Loading Estimates

Point source loading estimates were accomplished with the coordination of agencies from four states. The agencies contacted for the point source information contained in this report include the Arkansas Soil and Water Conservation Commission, the Kansas Department of Health and Environment, the Missouri Department of Natural Resources and the Oklahoma Department of Environmental Quality. The work could not have been completed without the cooperation of these agencies.

The quantity and quality of data received from these agencies varied significantly, but in all cases the data were adequate to complete our objectives. In fact, much of the data received were not needed at this point, but may be useful in subsequent phases. The only point source data used in Phase One were the facility location, facility type (agricultural, industrial, municipal or commercial), facility treatment type (lagoon, trickling filter, etc.), and facility design discharge rate. According to the data received, none of the facilities within the basin currently have a permit limit for phosphorous. As a result, monitoring data for phosphorous is virtually non-existent. The point source loading estimates were therefore determined from literature values based on facility treatment type.

The point source data received from the various agencies were compiled using Quatro Pro 5.0 for Windows. A list of the facilities in the Grand Lake Basin which are currently permitted to discharge under NPDES is given in *Appendix A*. Figure 4.1 shows the location of all the point sources in the Grand Lake Basin, including the agricultural discharges. It was generated using a GIS and the facility locations as received from the various states and compiled in Quatro Pro 5.0. Kansas had already put the location of their facilities onto a GIS, so their GIS data were simply merged into the Quatro Pro 5.0 file.

The total number of NPDES permitted point source discharge facilities in the Grand Lake Basin is 351, (Table 4.1). The majority of these facilities, 201, are located in Missouri. However, 95 of these facilities are permitted agricultural stormwater discharges. Since the other states aren't currently permitting these activities, or at least didn't report it, and since the NPS loadings accounted for runoff, these sources were not considered to be point sources for the purpose of this project. This reduces the effective number of point sources in Missouri within the Grand Lake Basin to 106, which is only slightly less than the 113 point sources within the Basin located in Kansas. Kansas and Missouri therefore combine for 219 of 256, or about 86% of the point sources located within the Basin. Figures 4.2 and 4.3 show this information graphically.

The NPDES permitted discharges, or facility design flows, for the point sources within the basin are also given in *Appendix A*. The discharge information is not complete, as it was unavailable for several facilities. The Agricultural discharges in Missouri, for example, have no flows associated with their permits, and personnel at the Missouri Department of Natural Resources stated that they didn't maintain records of these data. This was an additional factor that was considered in the decision to exclude the agricultural point sources as point sources in this phase of the project.

Discharge data were also unavailable for several industrial facilities. With a few exceptions, these facilities were typically gravel mines or other industrial discharges not expected to contain significant quantities of phosphorous. On the other hand, discharge data were available for all the municipal and commercial conventional waste discharges. Considering the scope of this phase of the project, the data that were available were deemed sufficient. It is doubtful that one or two missed discharges would significantly effect the outcome or direction of the project.

The distribution of total discharge from point sources by state is given in Figure 4.4. Not surprisingly, since Missouri has the largest number of point source discharges in the basin, they also contribute the largest average daily flow of effluent to the basin. In fact, about 54% of the discharge to the basin from point sources comes from Missouri. Kansas also has a significant point source effluent contribution at 34.5%. This too is not surprising considering the large amount of the basin that drains from Kansas. Arkansas and Oklahoma, on the other hand, collectively only contribute 11.5% of the point source discharge to the basin.

As indicated earlier, phosphorous loading data from the point sources in the basin are essentially non-existent. Since phosphorous isn't regulated in any of the point source permits within the basin, compliance monitoring is not performed. Therefore, there is no consistent, reliable data to indicate the loading rates from the point source discharges within the basin. Because of the limited scope of Phase One and the lack of existing data, it was necessary to use literature values to estimate the point source phosphorous loads in the basin.

In 1972 the U.S. Environmental Protection Agency (EPA) initiated the National Eutrophication Study (NES) to identify and sample lakes and reservoirs in the 48 contiguous states which were impacted by municipal effluents and to determine the significance of nutrient contributions from those sources. The analysis of phosphorous and nitrogen in municipal wastewater treatment plant effluent was a part of the NES. As part of this effort, from 5 to 14 effluent samples were obtained from each of 809 municipal wastewater treatment plants serving nearly 10 million people in 48 states. Gakstatter et al. (1978) reported the results of this survey. Table 4.2 is a partial reproduction of a table presented by Gakstatter et al., which shows mean phosphorous concentrations in wastewater effluents from three conventional treatment processes.

It can be seen from Table 4.2 that there isn't much difference between the amount of phosphorous discharged from an activated sludge plant versus that discharged from a stabilization pond. Trickling filters discharge slightly more phosphorous than do activated sludge plants or stabilization ponds, though the difference is small. Gakstatter et al., postulate that the longer biological contact time in activated sludge plants and stabilization ponds may account for the lower phosphorous levels. In any event, the mean values given in Table 4.2 were used to estimate the point source total phosphorous loading in the Grand Lake Basin.

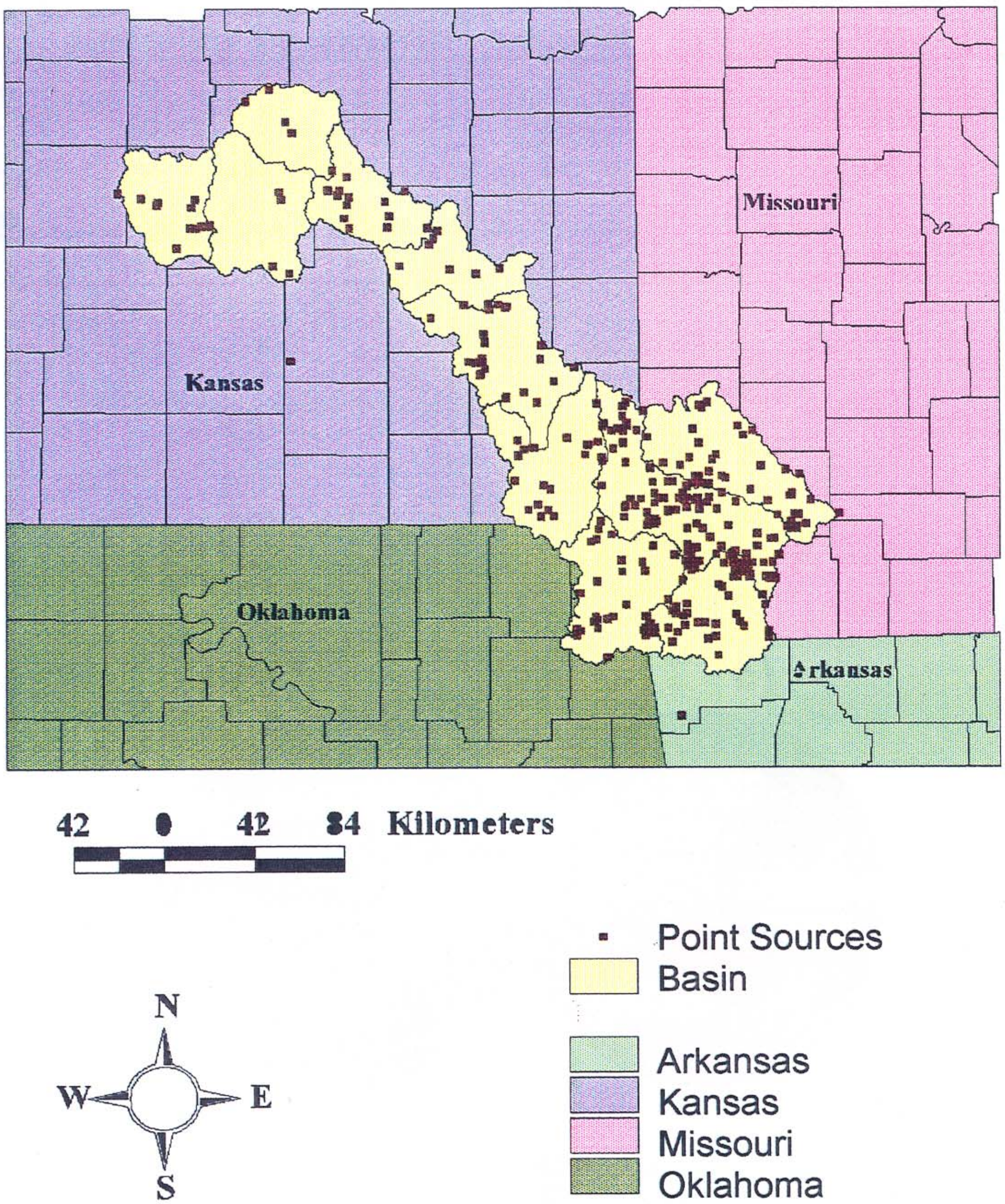


Figure 4.1 Point Source Locations within Grand Lake Basin.

Table 4.1 Number of Point Source Discharges in the Grand Lake Basin by Type and Location.

State	Treatment Type					
	Agricultural	**Commercial**	**Industrial**	**Municipal**	**Total**	**Total w/o Ag**
Arkansas	0	2	0	3	5	5
Kansas	0	10	49	54	113	113
Missouri	95	27	44	35	201	106
Oklahoma	0	10	7	15	32	32
Total	95	49	100	107	**351**	256

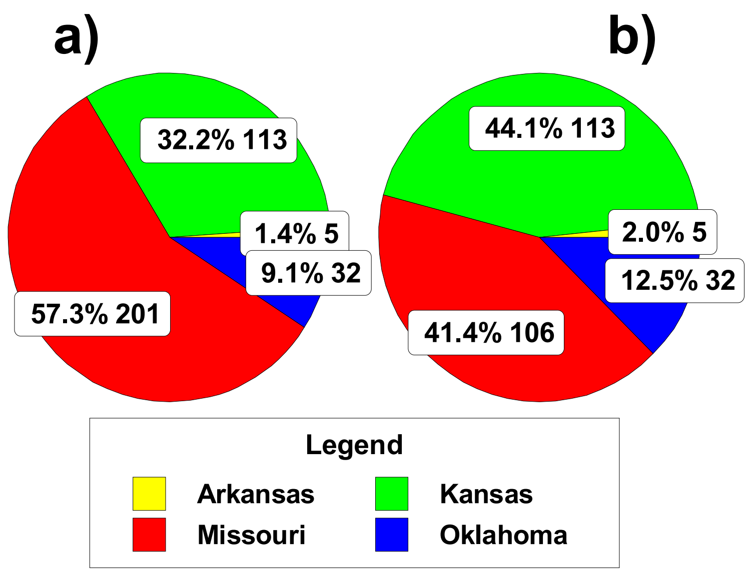


Figure 4.2 Grand Lake Basin NPDES point source distribution among states. a) Includes Agricultural NPDES facilities in Missouri and b) excludes them.

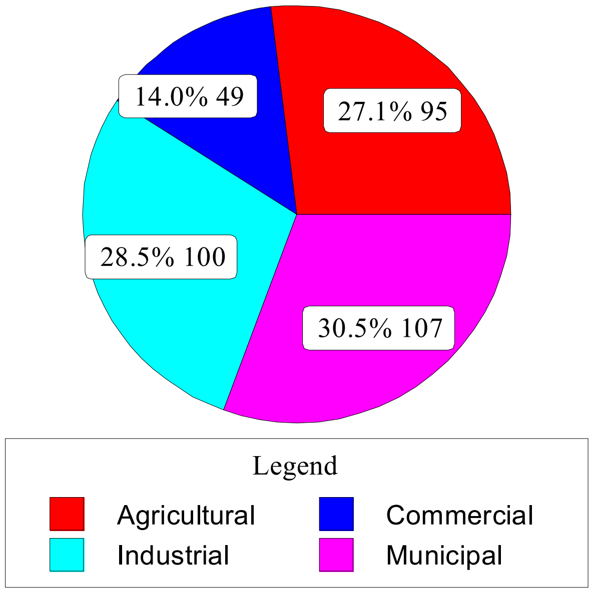


Figure 4.3. Grand Lake Basin NPDES Point Source Types

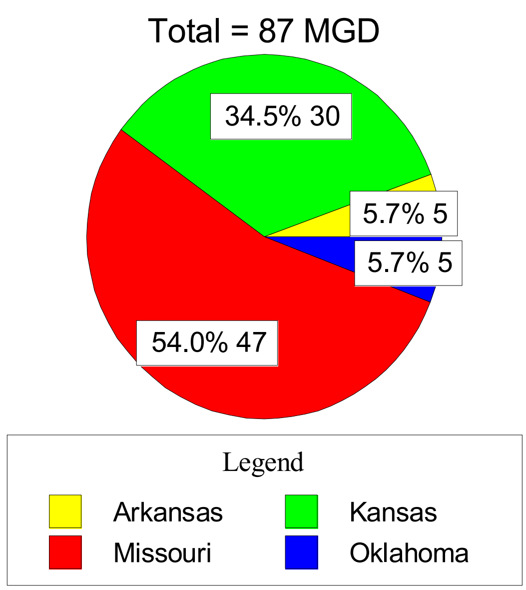


Figure 4.4 Total Point Source Discharge, MGD

Table 4.2 Mean phosphorous concentrations from various wastewater treatment processes. (Gakstatter et al., 1978)

	Trickling Filter	Activated Sludge	Stabilization Pond
# of Sampled Plants	244	244	119
Total Population Served	3,459,893	4,357,138	270,287
Ortho-P Conc. (mg/L)	5.4 " 0.38*	5.3 " 0.40	4.8 " 0.62
Total-P Conc. (mg/L)	7.2 " 0.50	6.8 " 0.51	6.6 " 0.81

* Value " 1 standard error.

For the purpose of this study, the Grand Lake Basin was divided into 11 sub-basins. The sub-basins were divided to encompass roughly the same land area, but were oriented such that existing USGS gauging stations were at the outlet of each sub-basin. Segmentation was done in this manner to permit hydraulic balances to be conducted for each sub-basin. A list of the sub-basins as delineated in this study is presented below. A GIS plot of the Grand Lake Basin showing the sub-basins and the stream network is given in Figure 4.5.

Basin Number	Basin Name	Number of Reaches
1	Upper Neosho Headwaters	3
2	Upper Cottonwood	3
3	Lower Cottonwood	6
4	Upper Neosho	6
5	Upper Middle Neosho	7
6	Lower Middle Neosho	6
7	Lower Neosho	5
8	Upper Spring River	5
9	Lower Spring River	7
10	Elk River	4
11	Grand Lake	N/A

The resulting point source phosphorous loadings to the Grand Lake Basin from the 11 sub-basins are given in Table 4.3. The data are shown graphically in Figure 4.6. The most striking feature of the data is that sub-basin 9 accounts for 2300 lbs/day of the 4140 lbs/day of phosphorous discharged by point sources in the Grand Lake Basin. Thus, 55.6% of the point source phosphorous loading in the Grand Lake Basin is to sub-basin 9, which, as discussed earlier, is the Lower Spring River. Joplin, Missouri, the largest metropolitan center in the Grand Lake Basin, is located in sub-basin 9, so it is no surprise that the highest point source loadings are found there.

Phosphorous loadings from near lake septic tanks have been perceived as being a major source of phosphorous to Grand Lake. The Grand River Dam Authority has allowed the construction of lake shore residental areas, most of which use septic tanks for wastewater disposal. This fact, combined with the cherty soils typical of the Ozark Uplands, makes this a legitimate concern. It therefore seemed prudent to include an assessment of septic tank phosphorous loadings in the assessment.

Burks et al. (1991) report that 8,093 homes are within 500 feet of the lake perimeter at flood pool elevation, and that 1,273 homes are between 500 feet and 1/4 mile of the perimeter. They further made the assumption that 3.5 people lived in each residence and stayed at the lakeside cabins an average of 60 days/year. Using a formulation presented by Reckhow and Chapra (1983) they concluded that these residential units could contribute between 1,400 kg/year (8.4 lbs/day) and 4700 kg/year (28 lbs/day) of phosphorous to the lake. Thus, the near lake septic tanks may not be contributing as much phosphorous to Grand Lake as was feared.

Combining the point source loading estimates with the NPS loading estimates presented earlier results in an estimate of the total annual phosphorous load by sub-basin in the Grand Lake Basin. Table 4.4 and Figure 4.7 show these sub-basin phosphorous loads. Table 4.4 is a tabular summary of the total phosphorous loading by sub-basin. Figure 4.7 is a pie chart of this same data, graphically showing the percentage loading from each basin. The results indicate that total phosphorous loadings in sub-basin 9 are more than twice as high as in any other sub-basin and represents almost 27% of the total phosphorous loading to the basin. The basin with the next highest total phosphorous loading is sub-basin 8. Thus, the two sub-basins with the highest total phosphorous load are the Lower and Upper Spring River.

Table 4.3 Grand Lake Basin Point Source Phosphorous Loading by Sub-basin

	POINT SOURCES				
BASIN	**AVG. FLOW (CFS)**	**ORG-P MASS (lbs/day)**	**DIS-P MASS (lbs/day)**	**TOTAL P (lbs/day)**	**TOTAL P (kg/year)**
1-4	14.2	90	260	350	57,000
5	0.9	10	20	30	5,000
6	10.0	90	230	320	53,000
7	7.3	70	190	260	43,000
8	9.3	70	230	300	50,000
9	67.6	580	1,700	2,300	383,000
10	8.4	70	240	310	51,000
11	7.8	70	210	270	45,000
TOTAL	125.5	1050	3080	4140	687,000

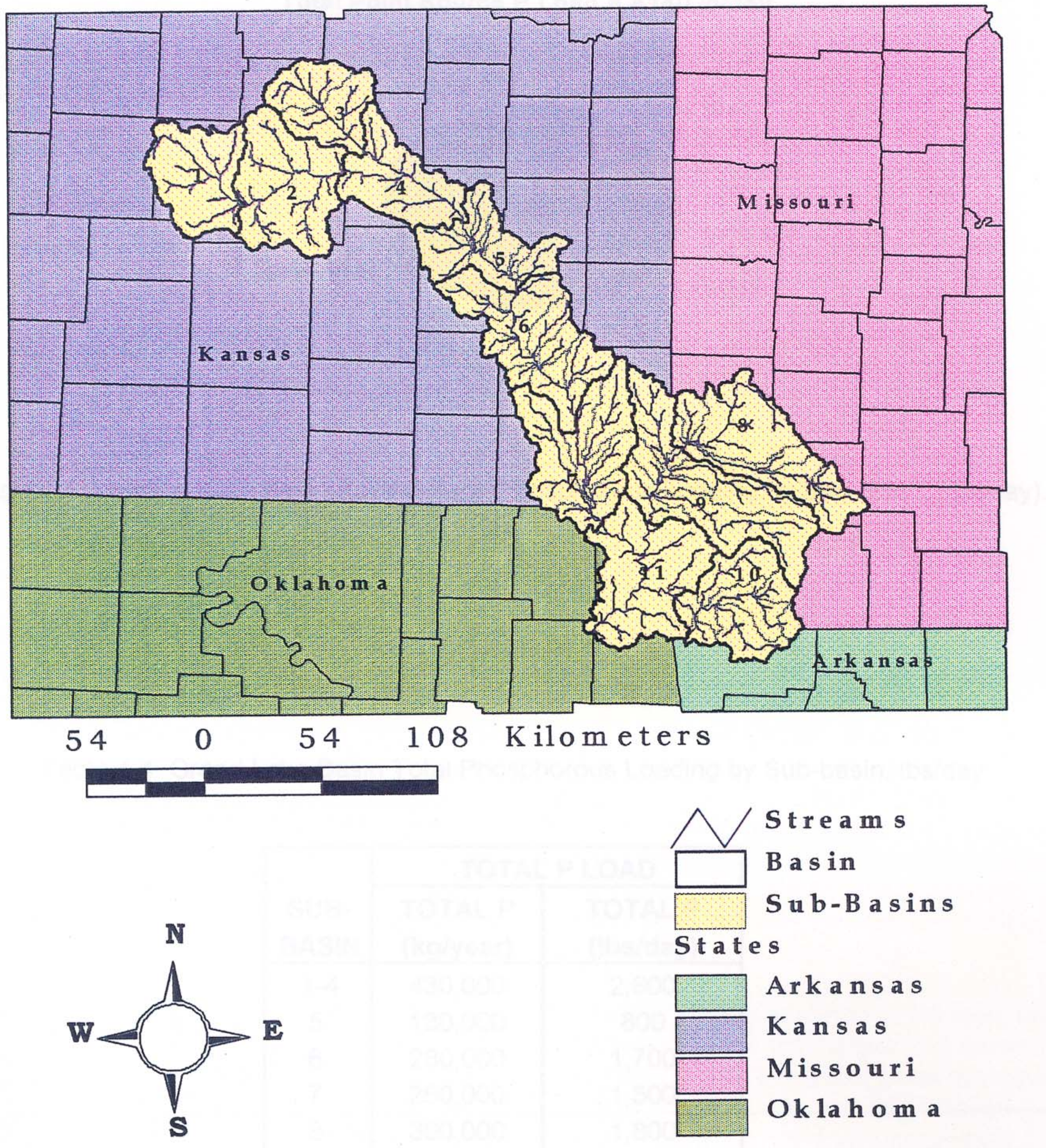


Figure 4.5: GIS plot of Grand Lake Basin showing sub-basins and stream network.

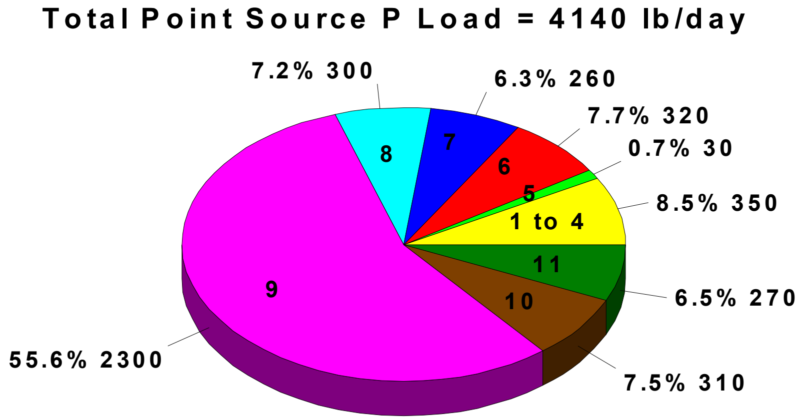


Figure 4.6 Grand Lake Basin Point Source Phosphorous Loading by Sub-basin, (lbs/day).

Table 4.4 Grand Lake Basin Total Phosphorous Loading by Sub-basin, lbs/day

SUB-BASIN	TOTAL P LOAD	
	TOTAL P (kg/year)	TOTAL P (lbs/day)
1-4	430,000	2,600
5	130,000	800
6	280,000	1,700
7	260,000	1,500
8	300,000	1,800
9	660,000	4,000
10	180,000	1,000
11	250,000	1,500
TOTAL	2,490,000	14,900

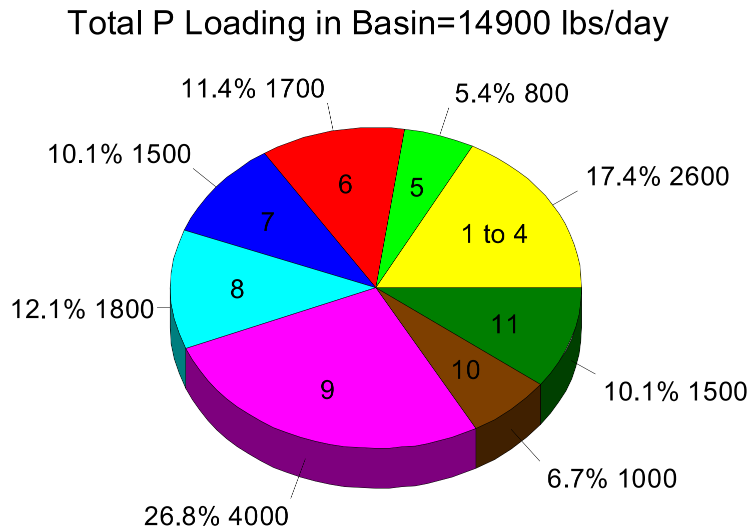


Figure 4.7 Grand Lake Basin Total Phosphorous Loading by Sub-basin, lbs/day.

Figure 4.8 shows the total point source and NPS phosphorous loading in each sub-basin in a slightly different format. The conclusions are the same. Sub-basin 9 has the highest point source phosphorous loading and the highest NPS phosphorous loading in the Grand Lake Basin. The point source loading in sub-basin 9 is especially significant, and represents over 15% of the entire loading in the Grand Lake Basin. The NPS loadings in Sub-basins 1-4, 5, 6, and 7 (the Neosho River Sub-basin) are also significant. Collectively the NPS loadings from these sub-basins total 5700 lbs/day, which is about 38% of the total loading in the Grand Lake Basin. Sub-basins 10 and 11 (the Elk River and near Grand Lake Sub-basins) by contrast, collectively contribute only 17% of the total Grand Lake basin phosphorous loading. As expected, the major sources of phosphorous to Grand Lake is from the two big rivers, the Neosho and the Spring. Future work should most certainly focus on these areas.

It should be kept in mind that the loadings discussed this far are not loadings to the lake, rather they are loadings in the Basin. Every pound of phosphorous that is discharged in a given sub-basin doesn't necessarily make it to the lake, and a pound in one sub-basin does not equal a pound in another. Several mechanisms including settling, plant uptake, and degradation tie up some of the phosphorous before it reaches the lake. The rates at which these processes occur are site specific and temperature dependent. In order to account for these processes a stream model was utilized to determine how much of the discharged phosphorous actually reaches the Lake. Model selection and development, as well as the results of the model, will be discussed in Section 6. The next section will address the search for and evalation of existing hydraulic and chemical data for the Neosho, Spring and Elk Rivers.

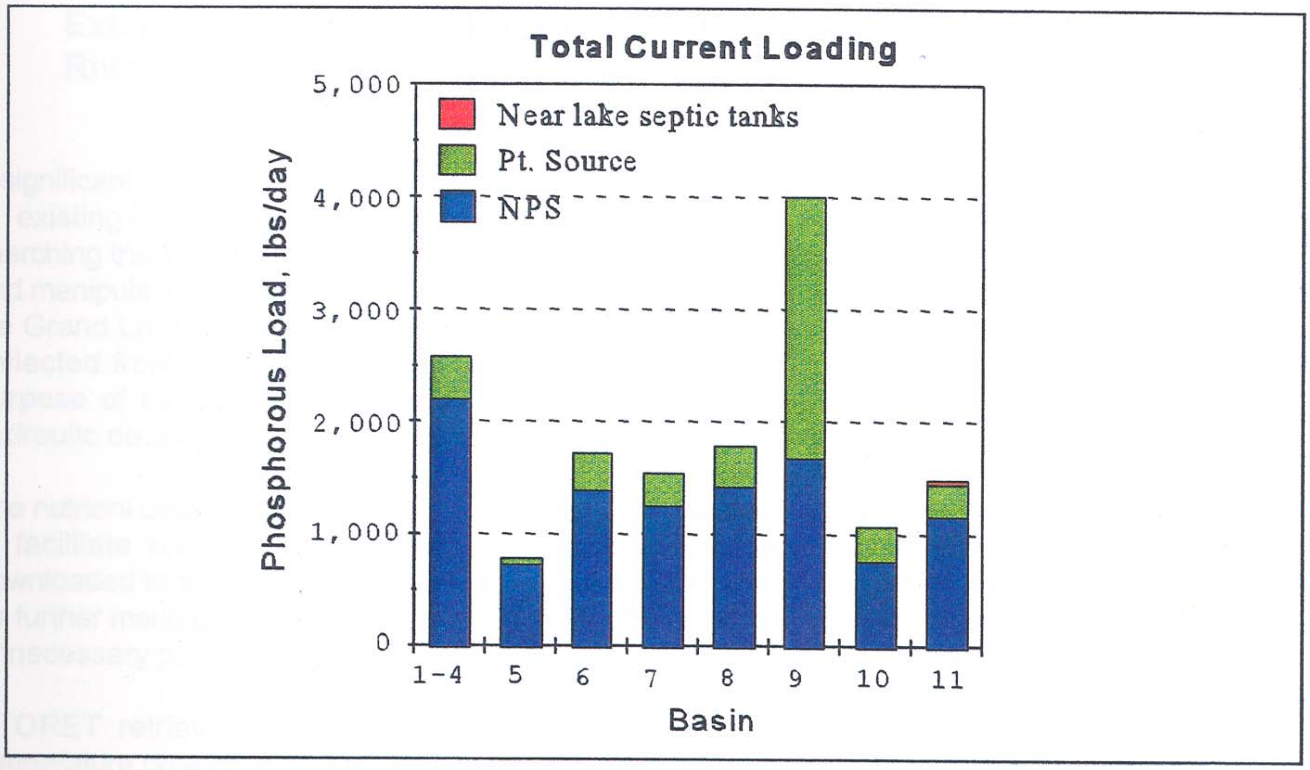


Figure 4.8 Grand Lake Basin Point Source and NPS Total Phosphorous Loading by Sub-basin.

5. Existing Hydraulic and Chemical Data for the Neosho, Elk and Spring Rivers

A significant amount of work in any nutrient loading study involves the collection and interpretation of existing hydraulic and chemical data. This study was no exception. Many hours were spent searching the EPA STORET database for existing nutrient data, downloading the available data, and manipulating the retrieved data. Surprisingly, there was very little nutrient data available for the Grand Lake Basin on STORET. It is suspected that much of the data results that have been collected from the basin in the past have not been entered in STORET. Nevertheless, for the purpose of this study, the data search was restricted to STORET, with the exception of the hydraulic data which were acquired from the U.S.G.S.

The nutrient data that were available on STORET were obtained by requesting retrievals structured to facilitate creation of a comma delineated ASCII file. The ASCII file was subsequently downloaded to a laptop computer. The retrieved ASCII data file was then imported into Quatro Pro for further manipulation and evaluation. Finally, the retrieval request was cancelled so as to avoid unnecessary paper waste.

STORET retrievals were obtained for discharge, total phosphorous, ammonia, nitrate and temperature on a county by county basis. The ammonia and nitrate data were not used in Phase One, but may be utilized in subsequent phases. The discharge data available on STORET were limited. For that reason, hydraulic data were also acquired from U.S.G.S. field offices. These data also had to be manipulated for use in the present study.

Temperature data were obtained for the entire basin, but only data from the Neosho, Spring and Elk Rivers were used. Sites where temperature data were used in this project include the Neosho River at Burlington, Kansas, the Neosho River near Parsons, Kansas, the Spring River near Waco, Missouri, the Spring River near Quapaw, Oklahoma, and the Elk River near Tiff City, Missouri. These sites correspond to the U.S.G.S. monitoring sites within the basin. (Table 5.1) The downloaded temperature data were sorted by month and averaged to determine average monthly temperatures at each site. The downloaded temperature data, as converted in Quatro Pro, are given in Appendix B.

Total phosphorous concentration data were also obtained for the entire basin. Some of the data were from small tributaries and thus were not useful in this phase of the project. The only useful data were from the Neosho River at Burlington, Kansas, the Neosho River near Parsons, Kansas, the Spring River near Waco, Missouri, and the Elk River near Tiff City, Missouri. There are no data available for the Rivers as they enter the lake, nor are there any data available below the dam. It was therefore not possible to do a phosphorous balance for the lake using existing data. After downloading the data files and importing them to Quatro Pro the data were sorted by month and year. The resulting data tables are given in Appendix C.

Table 5.1: USGS Monitoring Stations by Sub-basin

Sub-basin Number	USGS Station ID	USGS Station Name
1 to 4	7182510	Neosho River at Burlington, Kansas
5	7183000	Neosho River near Iola, Kansas
6	7183500	Neosho River near Parsons, Kansas
7	7185000	Neosho River near Commerce, Oklahoma
8	7186000	Spring River near Waco, Missouri
9	7188000	Spring River near Quapaw, Oklahoma
10	7189000	Elk River near Tiff City, Missouri
11	7190500	Neosho River near Langley, Oklahoma

As previously mentioned, hydraulic data were obtained from U.S.G.S. The data from Kansas and Missouri were obtained as hard copy, and had to be manually entered into Quatro Pro. The data from Oklahoma was downloaded from U.S.G.S. and imported into Quatro Pro. The ASCII format in which it was received was not entirely compatible with Quatro Pro and took considerable effort to parse correctly. Data obtained included long term average monthly flow rates as well as data for determining stage-discharge and velocity-discharge relationships. The long term monthly average discharge data is presented in Appendix D and the stage-discharge and velocity-discharge data are given in Appendix E.

Figure 5.1 shows plots of the monthly mean discharge rates for the U.S.G.S. gauging stations located on the Neosho, Spring, and Elk Rivers. The numbers associated with each curve represent the basin number where that particular gauging station is located. The gauging stations are at the downstream, or pour point of the corresponding basin. The curves therefore represent the flow out of each basin, and as expected, increase in the downstream direction. The curves labeled "All" represent the mean monthly discharge below the Grand Lake dam at a U.S.G.S. gauging station near Langley, Oklahoma. It is shown on all three figures for scale.

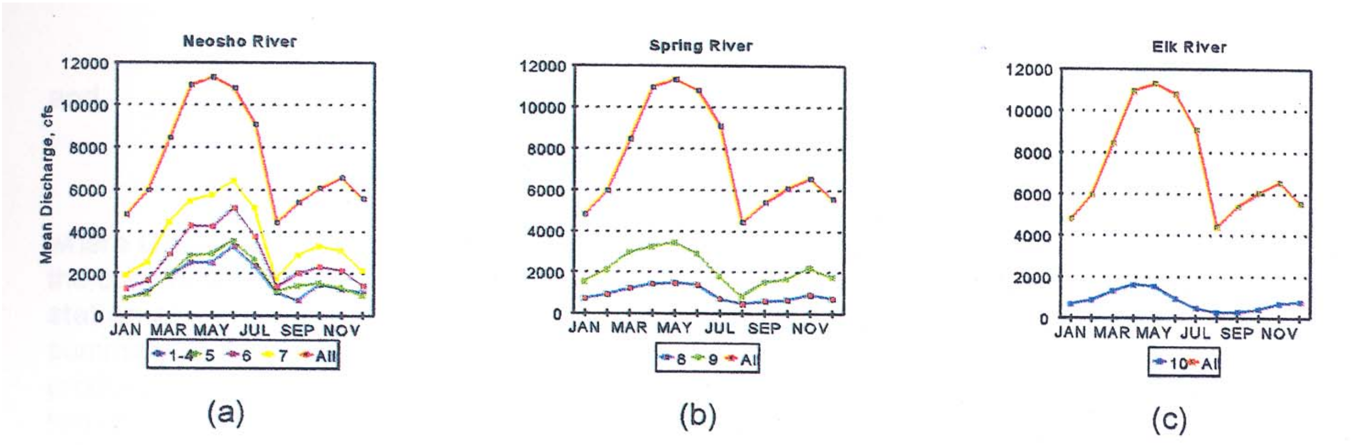


Figure 5.1: Mean monthly discharge rates in the Grand Lake Basin as recorded by U.S.G.S. gauging stations.

Average monthly total phosphorous loads at a given site were determined by two methods. The first method involved simply multiplying the long term monthly average flow for each month by the long term average total phosphorous concentration for the corresponding month. The second method is called the "un-biased stratified ratio estimator" as presented by Thomann and Mueller (1987). This method is considered preferrable in cases where "there is extensive flow data but concentration data are sparse." Another advantage of the method is that the flow record may be divided into various periods such as seasonal or monthly. The mean load as given by the un-biased stratified ratio estimator is then

$$\overline{Wp} = \overline{Qp}\frac{\overline{Wc}}{\overline{Qc}}\_\frac{1+(1/n)(Sqw/\overline{Qc}OVERLINEWc)}{1+(1/n)(Sq^2/\overline{Qc^2})}\_ \tag{5.1}$$

where

$\overline{Wp} =$ Estimated average load for the period *p*

$\overline{Qp} =$ Mean flow for the period

$\overline{Wc} =$ Mean daily loading for the days on which concentrations were determined

$\overline{Qc} =$ Mean daily flow for the days on which concentrations were determined

n = Number of days when concentrations were measured

Also,

$$S_{QW} = [1/(n-1)][(\Sigma Q_{ci} W_{ci}) - n\overline{Q_c}\,\overline{W_c}] \tag{5.2}$$

and

$$S_Q^{\,2} = [1/(n-1)][(\Sigma Q_{ci}^{\,2}) - n\overline{Q_c}^{\,2}] \tag{5.3}$$

where Q_{ci} are the individually measured flows and W_{ci} is the daily loading for each day on which the concentration was measured. The monthly and annual loadings as calculated for each gauging station using both of the methods referred to above is included in Appendix F. A graphical summary of the data presented in Appendix F is given in Figure 5.2. Note that the two methods produce comparable results for the Spring and Elk River stations, but vastly different results for the two Neosho River stations. For the Neosho River at Burlington, Kansas site, the annual average values using the two different methods are again comparable whereas the annual average values for the Neosho River near Parsons, Kansas site vary by 1000 lbs/day.

No effort was made to explain the reasons for this difference, but it is suspected that it is a result of high flow sampling at the Parsons site. In any event, existing data on total phosphorous are so sparse as to be of limited value in this project. The mass of total phosphorous entering the lake and leaving the lake cannot be estimated with any cetainty using existing data. It is therefore recommended that an effective long term monitoring project for the Grand Lake Basin be implemented. This will be paramount to the development of a viable basin management plan in the future and will be necessary for determining the effectiveness of any implemented control measures.

Burks et al. (1991) evaluate the existing data and present quartile values as well as mean values of total phosphorous concentrations. They also present a trend analysis of the existing data. Their results were mixed with some sites displaying increasing trends and others showing no significant trends. Given the relatively limited amount of available data, these results may be somewhat questionable, nevertheless interested readers are referred to the document by Burks et al. for more information on this topic.

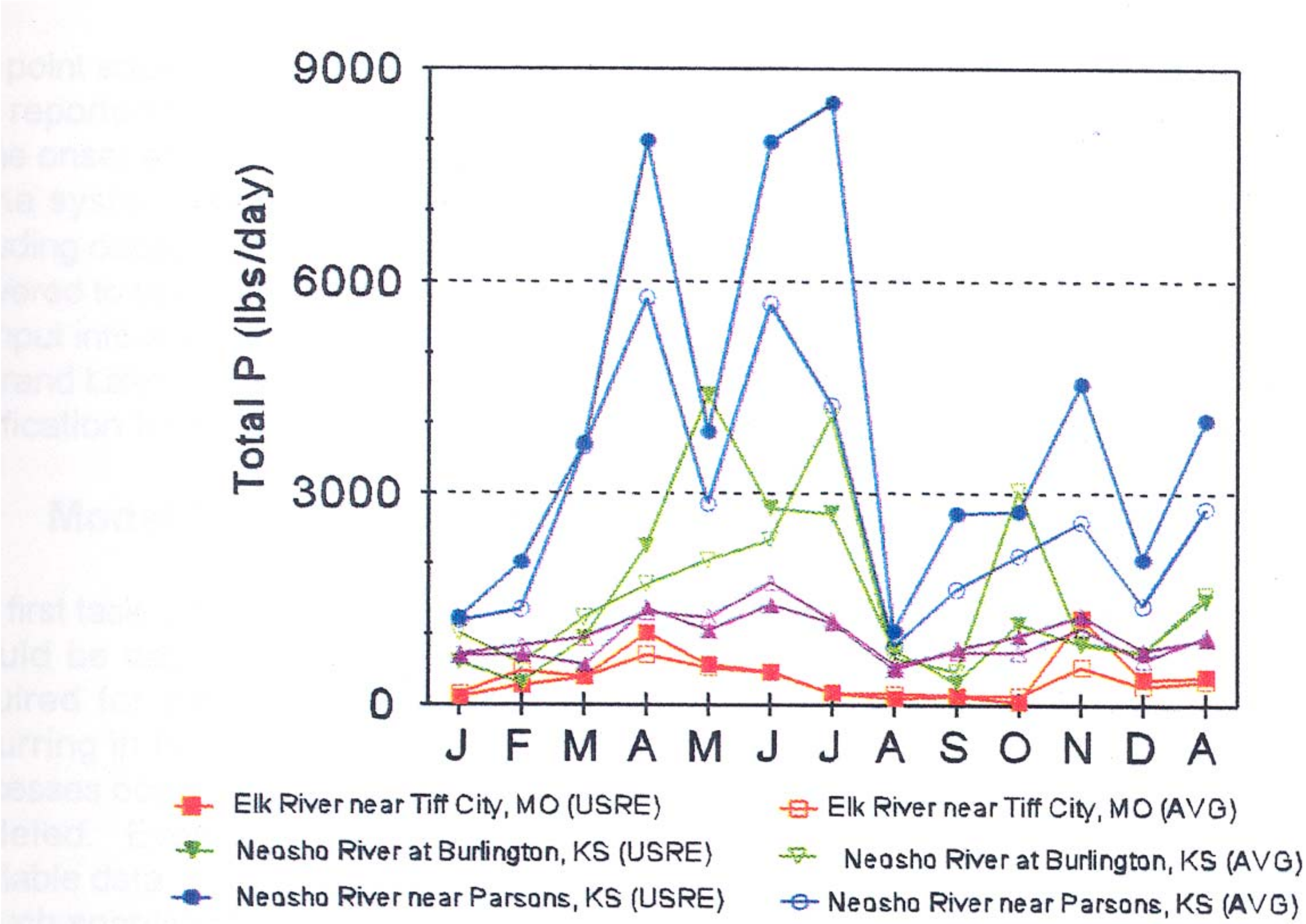


Figure 5.2: Summary of Existing Total Phosphorous Loading Data (lbs/day).

6. In-stream Water Quality Model

The point source and nonpoint source loading estimates were previously presented in this report. The reported loadings, however, were just loadings and did not include any instream dynamics. At the onset of this project it was reasoned that only a portion of the total phosphorous delivered to the system would be transported to Grand Lake. It was reasoned that instream processes, including decay and settling, would reduce the amount of total phosphorous that would actually be delivered to the lake. It was therefore decided that the point and nonpoint source loadings should be input into a water quality stream model to predict the fate and transport of the total phosphorous in Grand Lake. This section describes the model selection, model development and description, justification for selection of modeling parameters and the results of the model.

a. Model Selection

The first task in any modeling exercise is the selection of an appropriate model. Candidate models should be capable of adequately representing the system to be modeled at the level of detail required for the problem at hand. Ultimately, a model would simulate every process that is occurring in the system in a dynamic, continuous simulation mode. Unfortunately, many of the processes occurring in a stream system aren't fully understood and therefore cannot be effectively modeled. Even if all of the processes were known, and could be simulated, the limitations of available data, and resources for collecting and analyzing additional data often preclude the use of such sophisticated models.

The appropriate model therefore is one that adequately simulates the dominant processes within a system at an acceptable level of detail, given the available or reasonably obtainable data. A sophisticated, dynamic, continuous simulation model may appear desirable, but if there isn't data to support it, the results of the model are at best questionable. Similarly, a simple screening level model may be appropriate for qualitative assessments, but if reliable quantitative results are desired, and data availability isn't limited then use of a more sophisticated model would be more appropriate. In short, the selected model should be of sufficient detail to accomplish the stated objectives with the available data.

A second consideration in the selection of a model is the source of the model. There are numerous models available in both the public and private sectors that can model almost any process with varying degrees of complexity. There are steady-state models, dynamic models, and continuous simulation models. There are models based on a simplified Streeter-Phelps simulation, models that include nutrient and algal dynamics, and sediment interaction, and models with capabilities somewhere between these extremes. Some of the available models are supported by the distributor, some are not. This may be important, especially if the person or persons performing the modeling do not have a lot of experience with models. Unsupported models can be frustrating and result in wasted resources.

Another option is to develop a model specifically for the project. As with any model selection there are positive and negative reasons for electing to develop a project specific model. Positive reasons include: project specificity, sufficient detail and complexity, and thorough understanding of the processes involved. Additionally, existing models may not have the capabilities to model the processes of concern so that developing a model is necessary.

Negative reasons for developing a project specific model include: resource intensity, questionable model reliability, and lack of support. Developing a model for a specific project can be very labor intensive and may result in a model with uncertain reliability and no visible means of support. These obstacles may be overcome with deliberate and careful development and verification of the model. In any event, model selection is a critical first step in the modeling process and must be done carefully with full consideration to all the factors considered above.

For the purpose of this project, several models were initially considered. Private sector models were not considered due to the proprietary nature of the models and the expense of acquiring them. Models developed and supported by EPA were preferred because they are readily available, fully supported and have been extensively used by the water quality community. The models considered for this project included the Water Analysis Simulation Program, WASP4 (Ambrose et al., 1991), and the Enhanced Stream Water Quality Model, QUAL2E (Brown and Barnwell, 1987).

WASP4 is a dynamic compartment modeling program for aquatic systems including the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. WASP4 can be used to evaluate a variety of water quality problems in such diverse water bodies as ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters. WASP4 was considered under the premise that the model could be set up and executed as a screening level model with existing data, and in the future, when more data became available it could be upgraded and calibrated for use as a predictive water quality tool. Unfortunately, the lack of existing data on the phosphorous series within the basin and the fact that the NPS phosphorous loads are not partitioned made it difficult to justify the effort required to develop a WASP4 model for the basin at this point in time. So although WASP4 may be utilized in subsequent phases of this project, it was deemed to be too data intensive for the purpose of Phase 1 and was therefore eliminated for further consideration.

QUAL2E is a steady state model that can simulate up to 15 water quality constituents, including DO, BOD, temperature, algae as chlorophyll *a*, organic nitrogen, ammonia, nitrite, nitrate, organic phosphorous, dissolved phosphorous, coliform, and arbitrary nonconservative and conservative constituents. QUAL2E includes the major interactions of the nutrient cycles, algae production, benthic oxygen demand, carbonaceous carbon uptake, atmospheric aeration and their effect on the behavior of dissolved oxygen. Figure 6.1 is a schematic diagram showing the major constituent interactions in QUAL2E. QUAL2E has been extensively used for predicting the dissolved oxygen response in streams as a result of point source loadings for the purpose of establishing wasteload allocations (WLAs) used to drive permit limits under the NPDES program. QUAL2E has also seen recent use for NPS assessments.

In the present study the parameter of concern is total phosphorous. QUAL2E may be configured to simulate only the phosphorous cycle and algal production, and serious consideration was given to using QUAL2E to simulate the in-stream fate and transport of the phosphorous within the Grand Lake basin. The problem is that modeling the Grand Lake Basin with QUAL2E would necessitate development of QUAL2E models for each of the three main river systems flowing into the Grand Lake; the Neosho River, the Spring River, and the Elk River. Since twelve monthly runs would be required for each model to determine annual loadings to the lake, each run would require 36 model runs. This seemed prohibitive.

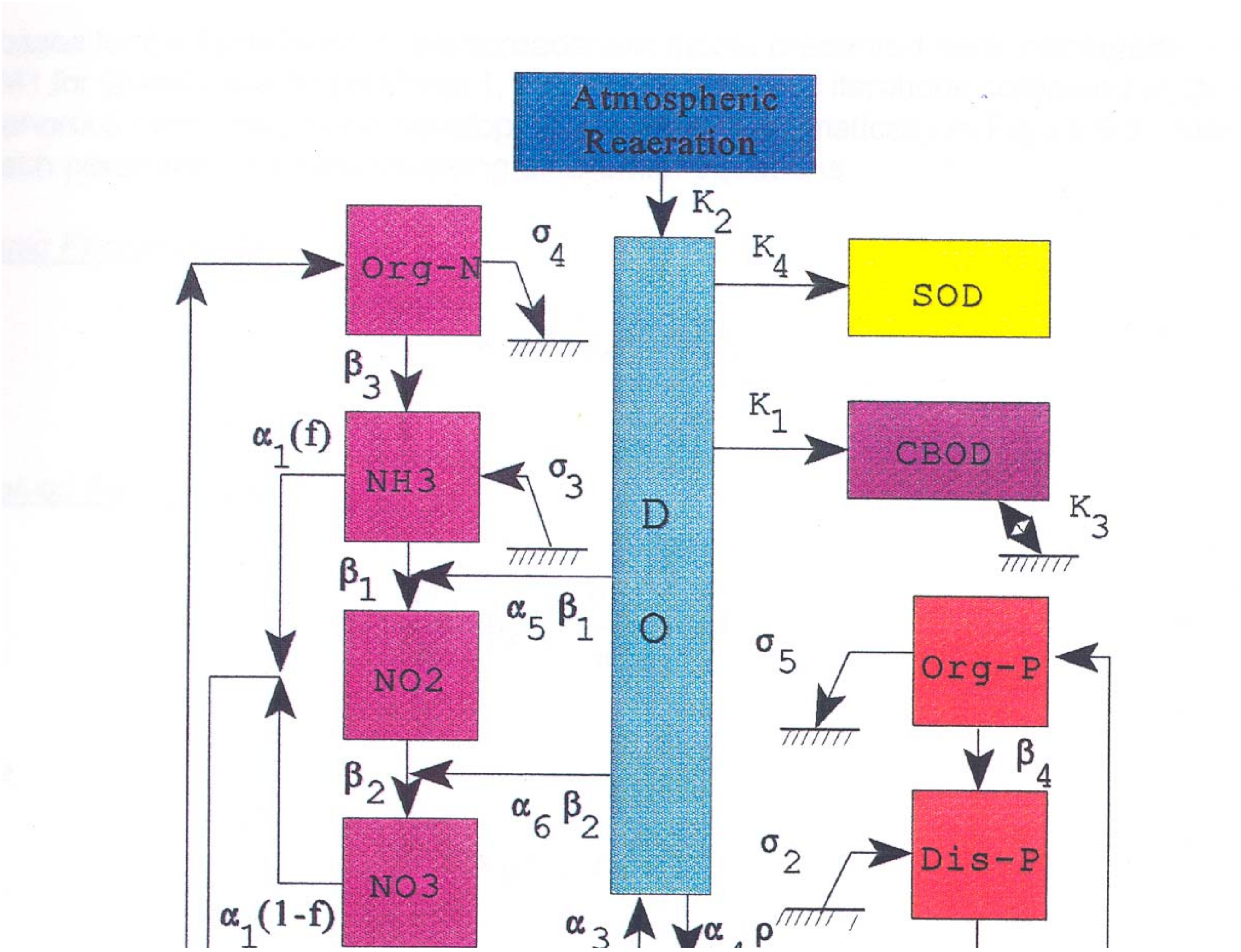


Figure 6.1. Schematic Diagram Showing the Major Constituent Interactions in QUAL2E. (Brown and Barnwell, 1987).

Developing a spreadsheet containing the same phosphorous iterations as QUAL2E was considered as a possible alternative to using QUAL2E, the trade off being development time versus model run time. Development of a spreadsheet model is a time consuming process, but once the spreadsheet is developed model simulations are far simpler and much less time consuming to perform. Setting up the QUAL2E models would be easily accomplished but the model runs would be numerous. There would also be the problem of recording, and keeping track of the data outputs so that they could all be added together. Not an impossible task, but a complicated one, subject to errors. After much consideration, it was decided that a spreadsheet model would be developed. The next section details the development of the spreadsheet model used to simulate the fate and transport of total phosphorous within the Grand Lake basin.

b. Spreadsheet Model (GLBM1) Development

The bases for the formulation of the spreadsheet model presented here, henceforth referred to as GLBM1 for Grand Lake Basin Model 1, are the phosphorous iterations contained in QUAL2E. The phosphorous cycle used in this development is shown schematically in Figure 6.2. Mass balances for each parameter yield the following differential equations:

Organic Phosphorous

$$\frac{dP_1}{dt} = \alpha_2 \rho A - \beta_4 P_1 - \sigma_5 P_1 \tag{6.1}$$

Dissolved Phosphorous

$$\frac{dP_2}{dt} = \beta_4 P_1 + \frac{\sigma_2}{d} - \alpha_2 \mu A \tag{6.2}$$

Algae

$$\frac{dA}{dt} = \mu A - \rho A - \frac{\sigma_1 A}{d} \tag{6.3}$$

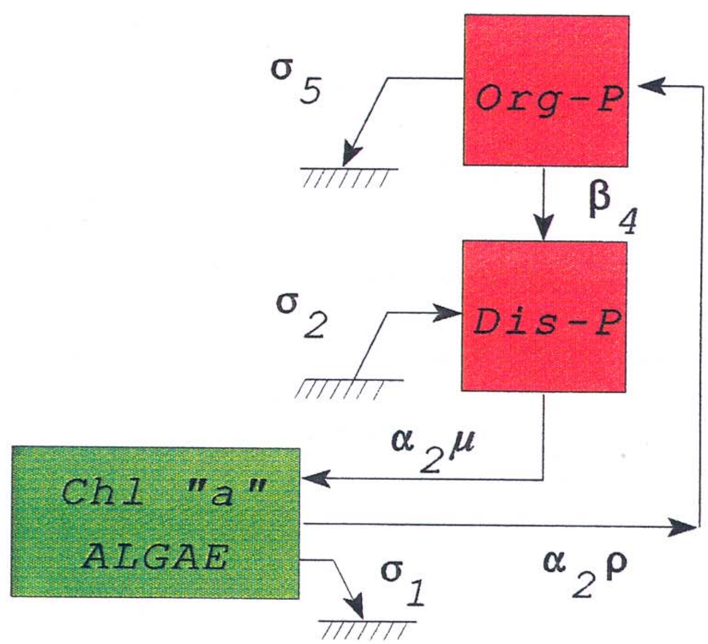


Figure 6.2. Schematic of phosphorous cycle used in GLBM1.

where,

P_1 = Organic phosphorous concentration, mg-P/L,
P_2 = Dissolved phosphorous concentration, mg-P/L,
α_2 = Phosphorous content of algae, mg-P/mg-A,
ρ = Algal respiration rate, /day,
A = Algal biomass concentration, mg-A/L
= chl $\underline{a}$ / α_o,
β_4 = Organic phosphorous decay rate, /day,
σ_5 = Organic phosphorous settling rate, /day,
σ_2 = Benthos source rate for dissolved phosphorous, mg-P/ft^2*day,
d = Mean stream depth, ft,
μ = Algal growth rate, /day
= μ_{max}(FL)Min(FN, FP),
μ_{max}= Maximum algal growth rate, /day,
FL = Algal growth limitation factor for light,
= AFACT*f*FL_1
f = fraction of daylight,
FL_1 = Growth attenuation factor
= $(1/\lambda d) * \ln[(K_L + I_{alg})/(K_L + I_{alg}e^{-\lambda d})]$,
K_L = Half saturation constant = 5.0,
$I_{alg} = I_{Total} / N$,
I_{Total} = Total daily photoactive solar radiation, BTU/ft^2,
N = Daylight hours,
$\lambda = \lambda_o + \lambda_1\alpha_o A$,
λ_o = Non-algal light extension coefficient, /ft,
= 1.66/secchi - $0.043\alpha_o A$,
λ_1 = Linear algal shading coefficient, 1/ft/(μg- chl$\underline{a}$/L),
α_o = Ratio of chlorophyll $\underline{a}$ to algae, μg-chl$\underline{a}$/mg-A
FN = Algal growth limitation factor for nitrogen,
FP = Algal growth limitation factor for phosphorous,
= $P_2 / (P_2 + K_p)$,
K_p = Half saturation constant for phosphorous, mg-P/L,
σ_1 = Algal settling rate, ft/day.

The solutions to equations 6.1, 6.2 and 6.3 are presented below.

Organic Phosphorous

Rearranging equation 6.1 yields,

$$\frac{dP_1}{dt} + (\beta_4 + \sigma_5) P_1 = \alpha_2 \rho A \tag{6.4}$$

which is a first order linear differential equation. Solving equation 6.4 for $P_1(t)$ yields,

$$P_1(t) = e^{-(\beta_4+\sigma_5)t}\left[\int e^{(\beta_4+\sigma_5)t}(\alpha_2 \rho A)dt + C\right] \tag{6.5}$$

where C is a constant of integration. Solving the integral and simplifying yields,

$$P_1(t) = \frac{\alpha_2 \rho A}{\beta_4+\sigma_5} + Ce^{-(\beta_4+\sigma_5)t} \tag{6.6}$$

Applying the initial condition that,

$$P_1(0) = P_{1o}$$

yields,

$$C = P_{1o} - \frac{\alpha_2 \rho A}{\beta_4+\sigma_5} \tag{6.7}$$

Combining equations (6.6) and (6.7) gives,

$$P_1(t) = \frac{\alpha_2 \rho A}{\beta_4+\sigma_5} + \left(P_{1o} - \frac{\alpha_2 \rho A}{\beta_4+\sigma_5}\right)e^{-(\beta_4+\sigma_5)t} \tag{6.8}$$

Which is the time dependent equation for organic phosphorous used in the GLBM1 model.

Dissolved Phosphorous

Integration of equation (6.2) yields,

$$P_2(t) = \left(\beta_4 P_1 + \frac{\sigma_2}{d} - \alpha_2 \mu A\right)t + C \tag{6.9}$$

where C is an integration constant. Applying the initial condition that,

$$P_2(0) = P_{2o}$$

yields,

$$C = P_{2o} \tag{6.10}$$

Combining equations (6.9) and (6.10) gives,

$$P_2(t) = (\beta_4 P_1 + \frac{\sigma_2}{d} - \alpha_2 \mu A)t + P_{2o} \tag{6.11}$$

Which is the time dependent equation for dissolved phosphorous used in the GLBM1 model.

Algae

Rearranging equation (6.3) yields,

$$\frac{dA}{A} = ((\mu - \rho) - \frac{\sigma_1}{d})dt \tag{6.12}$$

which when integrated gives,

$$\ln(A) = ((\mu - \rho) - \frac{\sigma_1}{d})t + C \tag{6.13}$$

where once again C is a constant of integration. Simplifying equation (6.13) gives,

$$A(t) = Ce^{((\mu - \rho) - \frac{\sigma_1}{d})t} \tag{6.14}$$

Applying the initial condition that,

$$A(0) = A_o$$

yields,

$$C = A_o \tag{6.15}$$

which upon combining equations (6.14) and (6.15) gives,

$$A(t) = Ao * e^{((\mu - \rho) - \frac{\sigma_1}{d})t} \tag{6.16}$$

Equation (6.16) is the time dependent equation for algae used in the GLBM1 model.

Conceptually, the GLBM1 model differs from QUAL2E in that dispersion is not included. Physically, the stream system is represented in the same manner. Each reach is divided into n computational elements of equal length, Δx. Since the stream hydraulic regime is steady-state; i.e., $\partial Q/\partial t = 0$, the hydrologic balance for the ith computational element can be written,

$$\left(\frac{\partial Q}{\partial x}\right)_i = (Q_x)_i \tag{6.17}$$

where $(Q_x)_i$ is the sum of the external inflows and/or withdrawals to the ith element. After solving equation (6.17) for Q, the velocity and depth can be determined by equations of the form:

$$u = aQ^b \tag{6.18}$$

and

$$b = cQ^d \tag{6.19}$$

where u is the average velocity and b is the depth in the ith element. The coefficients a and c, and exponents b and d are empirical constants estimated using USGS stage-discharge rating curve data. The data used to calculate these coefficients and exponents are given in Appendix E. Once the velocity and depth are calculated using equations (6.18) and (6.19) the time step, t, for each computational element, can be determined from the relationship $t = \Delta x/u$. This t can then be used to solve equations (6.8), (6.11), and (6.16) for each element.

The solution requires first calculating the algae concentration using equation (6.16). The algal growth rate, μ, in equation (6.16) was shown above to be a function of the minimum of the algal growth limitation factor for phosphorous, FP, and the algal growth limitation factor for nitrogen, FN. For the purpose of the Phase 1 modeling effort, however, nitrogen was not considered, therefore GLBM1 does not allow for nitrogen limited algal growth.

The algal growth limitation factor for phosphorous was shown above to be a function of the dissolved phosphorous concentration, P_2. Solution of equation (6.16) thus requires an initial estimate for P_2. The calculated algae concentration, A, is then used in equation (6.8) to calculate the organic phosphorous concentration, P_1, which is used with A in equation (6.11) to estimate P_2. Equations (6.16), (6.11), and (6.16) are solved iteratively until there is no significant difference between the estimated P_2 used to find A and the calculated value of P_2

The solution proceeds downstream until the dissolved and organic phosphorous concentrations are determined for each computational element of the stream reach being modeled.. This process was performed twelve times, one for each month of the year, for each stream reach being modeled.

In this study, stream modeling was not performed for sub-basins 1 to 4, rather the discharge and loadings out of Basin 4 were used as headwater flows to sub-basin 5. This was done because the outlet to sub-basin 4 was chosen as the spillway of John Redmond Reservoir. In-stream modeling of this sub-basin would have necessitated including a reservoir model for John Redmond Reservoir, which was deemed to be out of the scope of this project.

The GLBM1 model therefore consisted of six in-stream water quality models, one for each of the sub-basins 5 through 10. The output of sub-basin 5, the Upper Middle Neosho, was used as headwater input to sub-basin 6, the Lower Middle Neosho, the output of which was used as headwater input to sub-basin 7, the Lower Neosho. Similarly, the output from sub-basin 8, the Upper Spring River, was used as headwater input to sub-basin 9, the Lower Spring River. Finally, the outputs from sub-basin 7, the Lower Neosho River, sub-basin 9, the Lower Spring River, and sub-basin 10, the Elk River were combined with the loadings in sub-basin 11, the Grand Lake, to determine total phosphorous loadings to Grand Lake. A schematic diagram showing the spreadsheet files and links for GLBM1 is given in Figure 6.3.

As indicated earlier, modeling was done on a monthly basis for each of the sub-basins. The average monthly loadings from each sub-basin were then summed to estimate the average annual phosphorous load delivered to Grand Lake under current loadings. In the next section, justification for selection of the GLBM1 model parameters, including loadings, hydraulics, and kinetics will be discussed.

c. Model Parameters used in GLBM1

Perhaps one of the most difficult tasks in any modeling exercise, and the most important if the model is to be representative, is selection of the parameter values to be used in the model development. The GLBM1 was no exception. The parameters required for in-stream water quality modeling fall under three basic categories; loadings, hydraulics, and kinetics. Each of these are addressed below.

i.) Loadings

Pollutant loadings in the Grand Lake basin originate from two sources, point sources and non-point sources (NPS). Justification for the parameters used in determining the NPS phosphorous loadings were described earlier in the report. Similarly, assumptions made in determining loadings from the point sources was also sufficiently addressed. The GLBM1 model however, requires organic phosphorous and dissolved phosphorous concentrations as input, and not total phosphorous loads. Since the loadings from the NPS modeling effort were for total phosphorous and since discharge was not simulated, a means had to be devised to convert the total phosphorous loads to organic phosphorous and dissolved phosphorous loads and to account for flows within each sub-basin so that these loads could be converted to concentrations.

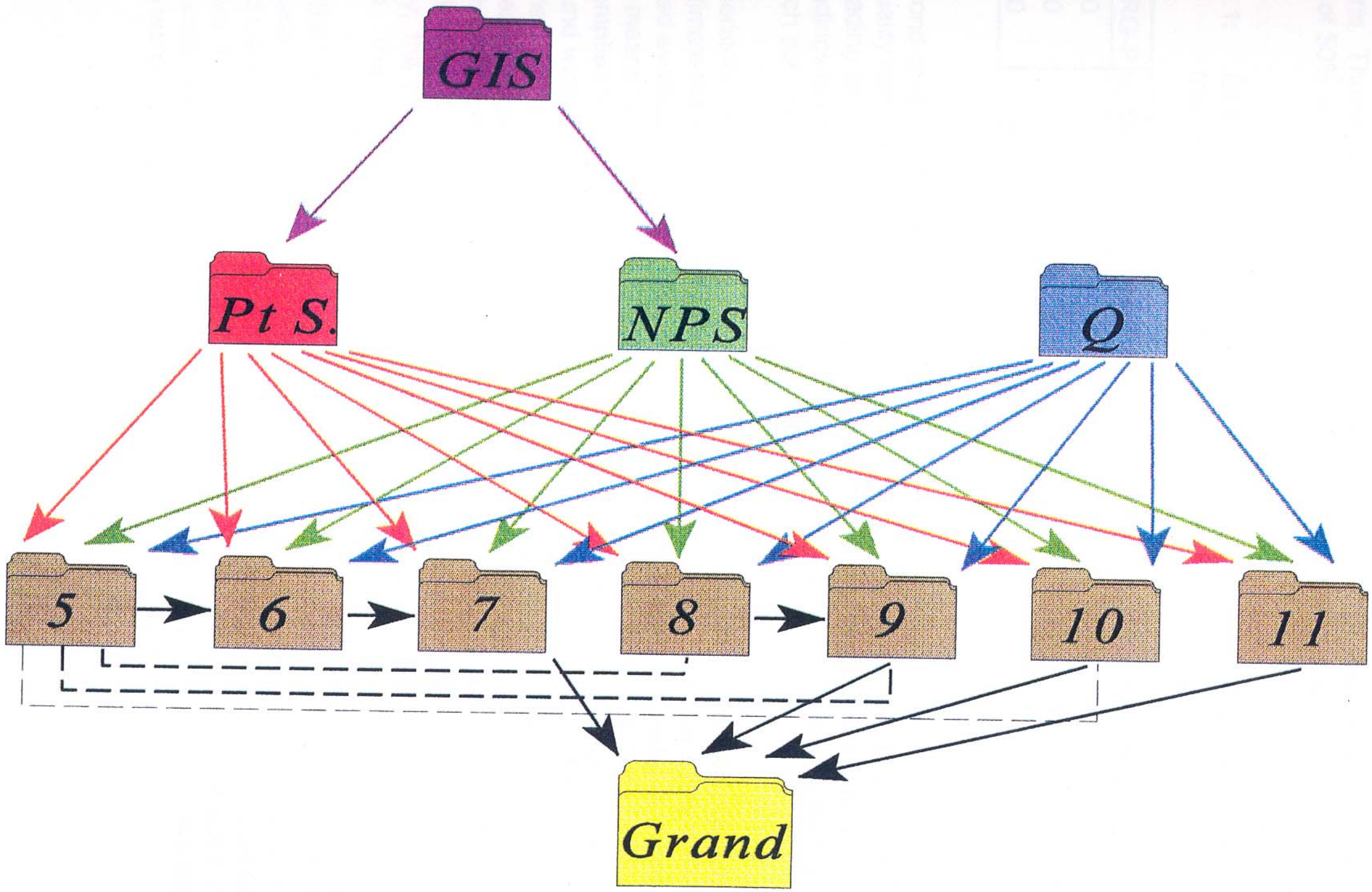


Figure 6.3: Schematic diagram showing the QuatroPro spreadsheet files and links for GLBM1.

The first problem, that of delineating the total phosphorous into organic and dissolved fractions, was accomplished by simply multiplying the total phosphorous by appropriate fractions. Table 6.1 shows the GLBM1 model results for various fractions of dissolved and organic phosphorous from the NPS loadings. It can be seen that the model is not particularly sensitive to these input conditions. Therefore, for the purpose of this study, the NPS total phosphorous was assumed to consist of 50% organic phosphorous and 50% dissolved phosphorous.

Table 6.1: GLBM1 model results for various fractions of Dissolved and Organic Phosphorous from NPS loadings. (lbs/day)

% ORG-P	% DIS-P	BASINS 5-7	BASINS 8&9	BASIN 10	BASIN 11	TOTAL
90	10	6,192	5,898	1,023	1,470	14,583
50	50	6,058	6,045	1,032	1,470	14,605
10	90	5,994	6,202	1,043	1,470	14,709

The second consideration that was addressed in order to input the NPS loadings to the in-stream water quality model was that of flow. As previously mentioned, the NPS loadings were developed using loading functions which did not address the quantity of runoff. However, in order to input the NPS loadings to the in-stream water quality model, the flow associated with the predicted loadings from each sub-basin was required.

It was therefore necessary to use the existing U.S.G.S. discharge data, as presented in Appendix D, to estimate the average monthly flow from each sub-basin. This was somewhat complicated by the limited availability of data. Since in-stream flow data are only available at one point for each basin, a means had to be devised to determine the flow from each sub-basin within a given basin. To accomplish this, it was assumed that all water additions to the stream were from the surface. All ground water influences were ignored. The average monthly runoff for each basin was then determined by subtracting the reported monthly discharge for the upstream gauge station from the downstream gauge station. This average monthly basin flow was partitioned among the sub-basins by assuming a uniform distribution of the runoff source. Thus the fractional area of a given sub-basin with respect to the basin area was multiplied by the basin flow to estimate the sub-basin flow. Similarly, the NPS annual phosphorous load had to be converted to monthly average daily loadings. This was done on a flow weighted basis.

The GLBM1 was developed to determine the fate and transport of total phosphorous within the Grand Lake basin at a screening level, in order to identify the primary sources of total phosphorous to Grand Lake. Since the total phosphorous cycle is dependent on, and crucial to, algal growth, as shown in Figures 6.1 and 6.2, the algal cycle was necessarily included in the GLBM1. Unfortunately, STORET searches found no useful data on chlorophyll-*a* within the basin. All inputs of algae were therefore assumed to be in concentrations of 10 ug/l.

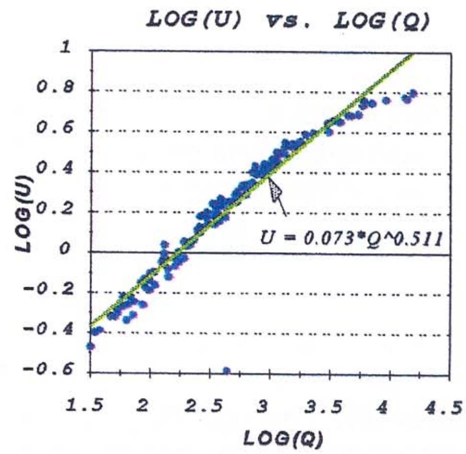
ii.) Hydraulics

Data for obtaining the hydraulic parameters used in the GLBM1 were obtained from the U.S.G.S. A summary of the data are presented in Appendix E. These data were used to obtain the exponents and coefficients used in equations (6.18) and (6.19) to determine the velocity and depth of each stream segment for a given discharge. Ideally, stage-discharge and velocity-discharge data would be available for each stream segment. Unfortunately, this is seldom the case, and certainly wasn't the case for this study. Rather, data were only available for the U.S.G.S. gauging stations as previously identified. Therefore, the data for the gauging station at the downstream pour point of a basin was used to represent every stream segment within that basin.

Figure 6.4: Velocity-Discharge Plot and Linear Regression Output for Spring River near Waco, Missouri. (U.S.G.S. Station 07186000)

LOG(U) vs. LOG(Q)
Regression Output:

Constant	-1.137545
Std Err of Y Est	0.0944905
R Squared	0.9141472
No. of Observations	124
Degrees of Freedom	122
X Coefficient(s)	0.5107821
Std Err of Coef.	0.0141718



The first step in determining the hydraulic parameters used in GLBM1 was to take the logarithms of the available flow, depth, width, and velocity data. Plots of log(depth) vs. log(flow), log(width) vs. log(flow), and log(velocity) vs. log(flow) were then prepared and linear regressions were performed using QuatroPro. An example of the resulting plots and regression output is shown in Figure 6.5. The remaining plots and regression output are provided in Appendix G. The coefficients and exponents used in the GLBM1 model were obtained from the equation describing the regression line fitting the data. Not all of the plots exhibited the nice correlation to the regression plot as shown in Figure 6.5, for the Spring River near Waco, Missouri, but most exhibited fairly decent correlation. Some of the plots, particularly those for the depths, seemed to exhibit other than a log-log relationship, but no effort was made to determine more appropriate relationships in these cases. Table 6.2 shows the exponents and coefficients used in equations (6.18) and (6.19) to determine the velocity and depth of each stream segment for each basin.

Table 6.2: Hydraulic Coefficients and Exponents used in GLBM1.

BASIN NUMBER	BASIN NAME	VELOCITY		DEPTH	
		a	b	c	d
5	Upper Middle Neosho	0.347	0.281	3.380	0.146
6	Lower Middle Neosho	0.321	0.250	0.846	0.280
7	Lower Neosho	0.438	0.219	3.532	0.154
8	Upper Spring River	0.364	0.224	0.769	0.310
9	Lower Spring River	0.073	0.511	0.296	0.385
10	Elk River	0.326	0.281	0.281	0.180

iii.) Kinetics

As can be seen on page 6-5, the number of parameters required to execute the GLBM1 is quite extensive. Only a few of the required parameters are related to loading and hydraulics. The rest of the parameters may be considered to be involved with the kinetics of the phosphorous cycle and algal growth. The kinetic parameters required in the GLBM1 model are addressed below.

The first parameters required were the reach variable phosphorous and algae coefficients, including the organic phosphorous decay coefficient, the organic phosphorous settling coefficient, the benthos source rate for dissolved phosphorous, and the algal settling rate. The values used for these parameters were obtained from "QUAL2E Seminar Notes" (1989) obtained from a QUAL2E seminar held at the U.S. Environmental Protection Agency Center for Exposure Assessment Modeling (CEAM), in Athens, Georgia, July 10-14, 1989. The QUAL2E Seminar Notes contain some recommended options and parameters for QUAL2E developed by Bill Walker. The values for the phosphorous and algae coefficients recommended in the QUAL2E Seminar Notes are given below in Table 6.3. The lower end values were used for the benthos source rate for dissolved phosphorous and the algal settling rate since data were not available for calibration. Values for several other phosphorous and algae coefficients required by GLBM1 that were assumed constant basin wide are also given in Table 6.3.

Table 6.3: Recommended values for phosphorous and algae coefficients.

Parameter	Recommended Value
Organic phosphorous decay coefficient	0.1 /day
Organic phosphorous settling coefficient	0.001 /day
Benthos source rate for dissolved phosphorous	0 -5 mg/m^2-day (impoundments)
Algal settling rate	0.6 - 0.75 m/day (calibrate; 0.2 - 1.0)
Phosphorous content of algae	0.011 mg-P/mg-A
Algal respiration rate	0.12 /day (5% of max. growth rate)
Maximum algal growth rate	2.3 /day
Algal growth limitation factor (light)	0.85-0.95
Half-saturation constant for light	1.2 - 6.0 (5.0) BTU/ft^2-hr
Chlorophyll-a to algae ratio	10 mg- chl A / gm algae
Linear algal shading coefficient	0.043 (1/ft)/(ug-chl A/L)
Half-saturation constant for phosphorous	0.005 mg-P/L

Several of the parameters presented in Table 6.3 are temperature dependent. The values given are for 20^{o}C so that the values must be corrected to the local temperature. This correction is done by using Equation 6.20, based on the Arrenius equation, as presented by Bowie et al. (1985):

$$K_T = K_{20} \theta^{(T-20)} \tag{6.20}$$

where,

K_T = Rate constant at temperature T
K_{20} = Rate constant at 20 ^{o}C
θ = Empirical temperature correction coefficient

The empirical temperature correction coefficient, θ, varies from parameter to parameter. Table 6.4 shows the values of θ used for the various temperature dependent parameters found in GLBM1. The local temperatures used in the model were obtained from the STORET temperature data presented in Appendix B. Once again the data obtained from a given gauging station was used to represent conditions, in this case the temperature, in the entire basin upstream. Perhaps interpolations could have been performed to smooth the temperature out between gauging stations, but this was deemed unnecessary at the level of simulation being conducted in this study.

Table 6.4: Temperature Correction Values (θ) for the temperature dependent parameters of GLBM1.

Parameter	Temperature Correction Value (θ)
Organic phosphorous decay coefficient	1.047
Organic phosphorous settling coefficient	1.024
Benthos source rate for dissolved phosphorous	1.074
Maximum algal growth rate	1.047
Algal settling rate	1.024
Algal respiration rate	1.047

Another important factor affecting algal growth rates is the water clarity or transparency in terms of Secchi depth. When the model was developed, it was assumed that along with good algae data, Secchi depth data would be plentiful, or at least available, but such was not the case. An exhaustive search of the STORET system turned up no Secchi depth data for the basin. It was therefore necessary to assume a Secchi depth for every reach of every sub-basin in the Grand Lake basin. A Secchi depth of three feet was assumed uniformly throughout the Grand Lake basin. The final information required by the GLBM1 was the total daily solar radiation and daylight hour data. For the purpose of phase one, this information was not obtained for every basin, rather it was obtained for Tulsa, Oklahoma, and used uniformly throughout the basin. The average total daily solar radiation and daylight hour data as reported for Tulsa, Oklahoma are given in Table 6.5.

d. Model Results

Many model simulations were performed using GLBM1 and the model parameter values presented above. Several of the results of the GLBM1 simulations are summarized below. Keeping in mind that the objective of the phase one modeling effort is to estimate the current loadings of total phosphorous to the lake, and to target areas for further monitoring, modeling, and eventual implementation of controls, the concern is average annual total phosphorous loading. So even though GLBM1 was run on a monthly basis to allow for variations in temperature, solar radiation, and day length, all of which affect algae growth, only the annual loading results are presented

Table 6.5: Average total daily solar radiation and daylight hour data as reported for Tulsa, Oklahoma.

Month	Total Daily Solar Radiation (BTU/ft^2)	# of Daylight Hours
January	730.9	9.9
February	977.4	10.7
March	1305.0	11.8
April	1601.7	12.9
May	1821.0	13.8
June	2019.1	14.3
July	1864.2	14.1
August	2028.8	13.3
September	1471.4	12.2
October	1163.2	11.1
November	826.9	10.1
December	658.7	9.6

Table 6.6 shows the in-stream total phosphorous loads at the outflow of each basin as predicted by the GLBM1 model. The total phosphorous loading to Grand Lake is the sum of the loadings from each of the sub-basins, which is about 15,000 lbs/day. The loadings in Table 6.6 are significantly higher than the loadings observed in the existing data as given in Appendix F. However, the objective at this point is not to quantify the total phosphorous loadings to Grand Lake, but to determine the relative loadings of total phosphorous to Grand Lake by sub-basin. The GLBM1 allows a comparative evaluation of total phosphorous load reductions within the basin that result in the largest reductions of total phosphorous delivered to the lake.

Table 6.6 In-stream total phosphorous loads at the outflow of each basin as predicted by the GLBM1 model.

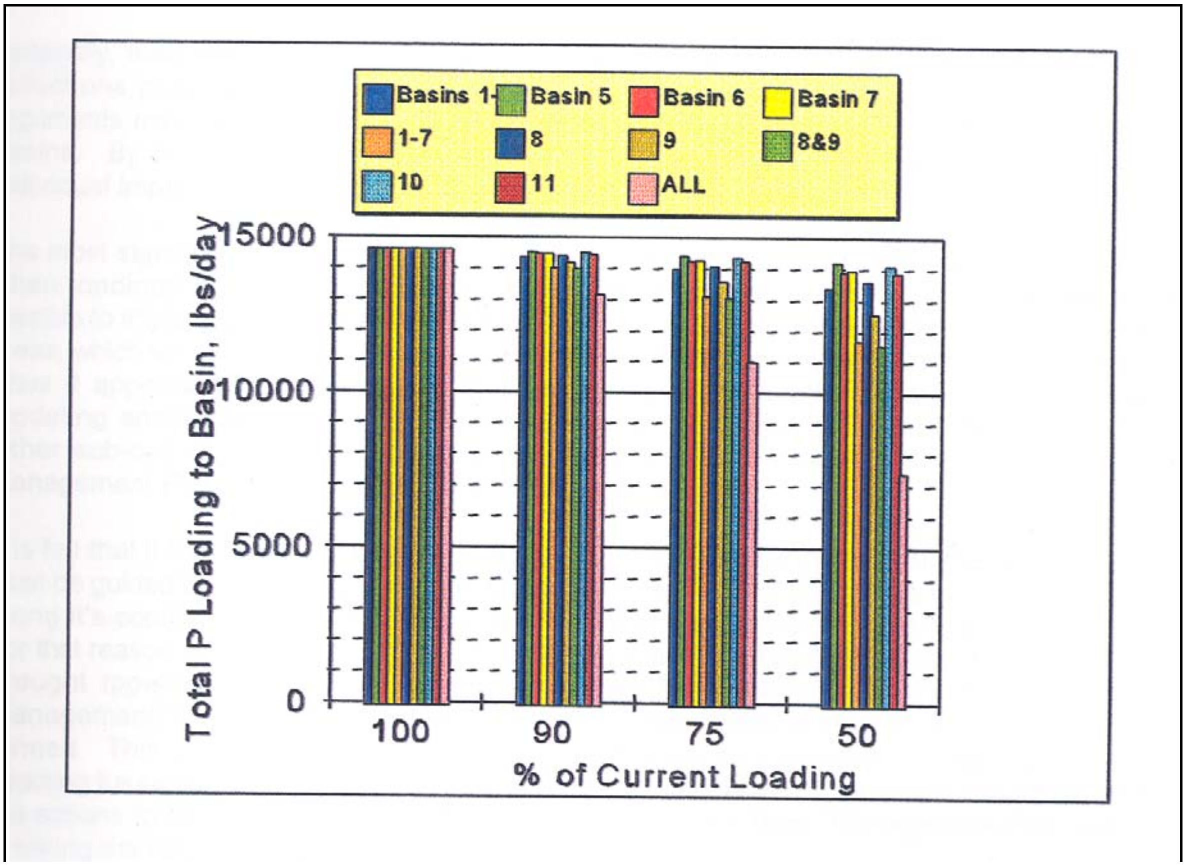
Basin Name	Basin Number	Total P Load (lbs/day)
	1-4	2600
Neosho River	5	3300
	6	4700
	7	**6000**
Spring River	8	1800
	9	**6000**
Elk River	**10**	**1000**
Grand Lake	**11**	**1500**

Given the existing loading to Grand Lake as given in Table 6.6, the next question to be addressed is how reducing the existing loadings from the various sub-basins would effect the total loadings to Grand Lake. This was accomplished by reducing the loadings in each sub-basin individually by 10, 25 and 50%. The point and NPS loadings were reduced by the same percentage in each sub-basin. The GLBM1 model was then executed for each scenario and the total phosphorous loading to the lake was recorded. The model was also executed assuming the same 10, 25, and 50% reductions were applied uniformly throughout the entire Grand Lake basin. A plot of the results is shown in Figure 6.6, with the output data used to generate the plot provided in Appendix H.

To interpret Figure 6.5, the column group on the left hand side of the plot represents the current estimated loading of total phosphorous to Grand Lake, about 15,000 lbs/day. Note that all ten of the columns are at the same level because each basin is at 100% of the existing load. In the second, third, and fourth column groups, each column represents the total phosphorous delivered to Grand Lake if that particular basin's loads were reduced to 90%, 75%, and 50% of the current estimated load, respectively. In each column group, the leftmost, blue column represents the total phosphorous delivered to Grand Lake if the total phosphorous loads from basins 1 through 4 are reduced to 90%, 75%, and 50%, and the loads from the other basins remain unchanged. The next three columns, the green, the red, and the yellow, represent responses to reductions in basins 5, 6, and 7, respectively. The fifth column, the orange column, represents the total phosphorous loading to Grand Lake with reductions in loading for every basin on the Neosho River, i.e. Basins 1-7. The basins on the Spring River, the Elk River, and the Grand Lake were not reduced. The responses to reductions in Basin 8 and 9 are represented by the sixth and seventh (dark blue and beige) columns, with the response to reductions in the entire Spring River watershed being represented by the eigth (dark green) column. The response to reductions in the Elk River watershed are given by the ninth (light blue) column and responses to reductions in loadings to the

Grand Lake sub-basin are given by the tenth (burgundy) column. Finally, the last (pink) column represents total phosphorous loadings to Grand Lake if reductions are made uniformly throughout the entire Grand Lake basin.

Figure 6.5 Results of Sub-basin loading reductions to Grand Lake Total Phosphorous Loadings.



7. Comments

Some comments about the interpretation of these results are appropriate. First, the load reductions in sub-basins 1-4 should be addressed by considering a TMDL study for the John Redmond Reservoir. It can be seen in Figure 6.5, however, that even a 50% reduction in the loadings from these basins alone doesn't result in a large reduction in the amount of total phosphorous being delivered to Grand Lake. In addition, the unit areal total phosphorous loading is relatively low in these sub-basins. For these reasons, load reductions from sub-basins 1-4 was not addressed.

Secondly, load reductions in sub-basins 5, 6, and 7 independently do not result in significant reductions in the amount of total phosphorous being delivered to Grand Lake either. Similar arguments may be made for the Elk River (sub-basin 10) and Grand Lake (sub-basin 11) sub-basins. By contrast, reductions in sub-basins 8 and 9 (the Spring River) have the greatest individual impact on the amount of total phosphorous being delivered to Grand Lake.

The most significant reductions in the total phosphorous loading to Grand Lake obviously occur when loadings are reduced throughout the basin. However, due to limited resources it is not feasible to implement controls throughout the basin. It is therefore desirable to target the area, or areas, which will result in the largest reductions in total phosphorous loadings to the Grand Lake. Thus it appears from these results that the Spring River should be targeted for monitoring, modeling and implementation in the next phases of the Grand Lake Basin Management Plan. Other sub-basins should also be addressed in subsequent phases of the Grand Lake Basin Management Plan, in order to have a comprehensive plan.

It is felt that if the Grand Lake Basin Management Plan is to be successful the direction it takes must be guided by the people most effected by it. This includes the people living on the lake and along it's contributing stream systems, the regulated community, and the regulating authorities. For that reason, it is recommended that federal, state and local authorities and interest groups be brought together with the purpose of guiding the future direction of the Grand Lake Basin Management Plan. Perhaps a Grand Lake Basin Management Plan Adisory Group could be formed. This group should use the results of this report and previous reports to assist them in directing future water quality activities within the Grand Lake basin. This group should recommend the actions to be taken in the next phase of the Grand Lake Basin Management Plan and assist in taking the necessary steps to accomplish those tasks.

Finally, it is important that the results of this modeling study be interpreted in the proper context. This modeling effort was conducted on a large basin with readily available data and information. The point source loading data were based on design discharge rates and concentrations were based on literature values. In addition, the river routing model used default parameters from QUAL2E and were not based on observed data. In addition, the river routing model used default parameters from QUAL2E and were not based on observed data. There are also limitations to the nonpoint source loading estimates. Due to the size of the basin and available data, unit area loading estimates were used based only on generalized land use. Soil type, slope, and detailed land use were not utilized in predicting total phosphorous loading. Therefore, conclusions and recommendations resulting rom this study should be kept in the context of the modeling limitations.

REFERENCES

Alberts, E.E., G.E. Schuman, and R.E. Burwell, 1978. Seasonal Runoff Losses of Nitrogen and Phosphorus from Missouri Valley Loess Watersheds. J. Environ. Qual. 7(2):203-208.

Ambrose, R.B., Jr., Wool, T.A., Martin, J.L., Connolly, J.P., and Schanz, R.W., 1991, Wasp4, A Hydrodynamic and Water Quality Model- Model Theory, User's Manual, and Programmer's Guide, U.S. Environmental Protection Agency, Athens, GA.

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, U.S. Geological Survey Professional Paper 964, 28 p.

Beaulac, M.N. and K.H. Reckhow, 1982. An Examination of Land Use - Nutrient Export Relationships. Water Resources Bulletin 18(6):1013-1024.

Beaulac, M.N. and K.H. Reckhow, 1982. An Examination of Land Use - Nutrient Relationships. Water Resources Bulletin 16(6):1013-1022.

Blalock, L.L., 1987. Nonpoint Source Pollution Loading Factors and Related Parameters. N.C. State University, Water Quality Group, Raleigh, NC.

Bowie, G.L., Mills, W.B., Porcella, D.B., Campbell, C.L., Pagenkopf, J.R., Rupp, G.L., Johnson, K.M., Chan, P.W., Gherini, S.A., and Chamberlin, C.E., June, 1985, Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition), Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA. EPA/600/3-85/040.

Bradford, R.R., 1974. Nitrogen-Phosphorus Losses from Agronomy Plots in North Alabama. U.S. Environmental Protection Agency, EPA-660/2-74-033.

Brown, L.C. and Barnwell, T.O., Jr., 1987, The Enhanced Stream Water Quality Models, QUAL2E and QUAL2E-UNCAS: Documentation and User Manual, U.S. Environmental Protection Agency, Athens, GA. EPA/600/3-87-007.

Burks, S.L. , Wilhm, J., Hampton, D., Jobe, N., Reed, D., and Schut, D., 1991, Environmental Protection Agency "Clean Lakes" Project, Phase 1: Output Tasks for Diagnostic-Feasibility Study of Grand Lake O' the Cherokees, Oklahoma, Grant S-006336-01-0, DRAFT.

Burwell, R.E., D.R. Timmons, and R.F. Holt, 1975. Nutrient Transport in Surface Runoff as Influenced by Soil Cover and Seasonal Periods. Soil. Sci. Soc. Amer. Proc. 39(3)523-528.

Casman, Elizabeth, 1989. Parameters and Concepts for Modeling Tillage Practices, Animal Waste Management Systems and Vegetated Filter Strips. The Interstate Commission on the Potomac River Basin in cooperation with the Maryland Department of the Environment.

Chesters, G., J. Robinson, R. Strefgel, R. Ostry, T. Bahr, D.R. Cootl and D.M. Whitt. 1978. Pilot Watershed Studies. Summary report. International Joint Commission, Windsor, Ontario.

Chichester, F.W., R.W. Van Keuren, and J.L. McGuineess, 1979. Hydrology and Chemical Quality of Flow from Small Pastured Watersheds: II Chemical Quality. J. Environ. Qual. 8(2):167-171.

Converse, J. C. , G.D. Bubenzer, and W.J. Paulson, 1976. Nutrient Losses in Surface Runoff from Winter Spread Manure. Trans. ASAE 19(3)517-519.

Corell, D.L., T.L. Wu, E.S. Friebele, and J. Miklas, 1977. Nutrient Losses in Surface Runoff from Winter Spread Manure. Trans. Americ. Soc. Agri. Eng. 19:517-519.

Environmental Systems Research Institute, Inc.. 1992. Cell-based Modeling with GRID 6.1: Supplement - Hydrologic and distance modeling tools, *ARC/INFO User's Guide*. ESRI, Inc. pp 1-1 - 1-17.

EROS Data Center. 1990. Conterminous U.S. Land Cover Characteristics Data Set, U.S. Geological Survey and Center for Advanced Land Management Information Technologies. CD-ROM #9307.

Frink, C.R.. 1982. Estimating Nutrient Exports to Estuaries. J. Environ. Qual, 20:717-724.

Gakstatter, J.H., Allum, M.O., Dominguez, S.E., and Crouse, M.R., April, 1978, "A Survey of Phosphorous and Nitrogen Levels in Treated Municipal Wastewater", Journal of the Water Pollution Control Federation.

Gordon, S.I. and J.W. Simpson, 1990. The Big Darby Creek Watershed Project. Ohio State University, Department of City and Regional Planning. June.

Haith, D.A., and L.J. Tubbs, 1981. Watershed Loading Functions for Nonpoint Sources. Journal of the Environmental Engineering Division. Feb:121-137.

Handbook of Nonpoint Pollution.

Harms, L.L., J.N. Dornbush, and J.R. Anderson, 1974. Physical and Chemical Quality of Agricultural Land Runoff. J. Water Poll. Contr. Fed. 46(11):2460-2470.

Hensler, R.F., R.J. Olsen, S.A. Witzel, O.J. Attoe, W.H. Paulson, and R.F. Johannes, 1970. Effect of Method of Manure Handling on Crop Yields, Nutrient Recovery and Runoff Losses. Trans. Amer. Soc. Agr. Engr. 13:726-731.

Hession, W.C., J.M. Flagg, S.D. Wilson, R.W. Biddix and V.O. Shanholtz. 1992. Targeting Virginia's Nonpoint Source Programs. Paper presented at ASAE Summer Meeting, Charlotte, NC, June 21-24.

Jensen S. 1991. Applications of Hydrologic Information Automatically Extracted from Digital Elevation Models, *Hydrological Processes*. 5:31-44.

Jensen S. and J. Domingue. 1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, *Photogrammetric Engineering and Remote Sensing*. 54(11):1593-1600.

Johnson, R.J., 1980. Modeling Phosphorus Loading and Lake Response Under Certainty: A Manual and Compilation of Export Coefficients. U.S. Environmental Protection Agency.

Kilmer, V.J., J.W. Gilliam, J.F. Lutz, R. T. Joyce and C.D. Eklund, 1974. Nutrient Losses from Fertilized Grassed Watershed in Western North Carolina. J. Environ. Quality 3(3):214-219.

Klausner, S.D., P.J. Zwerman and D.F. Ellis, 1976. Nitrogen and Phosphorus Losses from Winter Disposal of Dairy Manure. J. Environ. Qual 5:47-49.

Krebs, J.E. and F. B. Golley, 1977. Budget of Selected Mineral Nutrients for Two Watershed Ecosystems in the Southeastern Piedmont. NTIS PB 272-286.

Loehr, R.C., 1974, Characteristics and Comparative Magnitude of Nonpoint Sources. J. Water Pollut. Control Fed. (WPCF), 46:1849-1872.

Loehr, R.C., 1972. Agricultural Runoff-Characterization and Control. J. Sanitary Eng. Div., Proc. ASCE, 98:909-923.

Long, F.L., Z.F. Lund and R.E. Hermanson. 1975. Effect of Soil-Incorporated Dairy Cattle Manure on Runoff Water Quality. J. Environ. Qual. 8:215-218.

McCaskey, T.A., H.G. Rollins, and J.A. Little, 1971. Water Quality of Runoff from Grassland Applied with Liquid, Semi-Liquid, and Dairy 'Dry" Waste. In Livestock Waste Management and Pollution Abatement. ASAE Proc-271. ASAE. St. Joseph, MI. 239-242.

McDowell, L.L., M.E. Ryan, K.C. McGregor and J.C. Greer, 1978. Nitrogen and Phosphorus Losses in Runoff from No-till Soybeans. Presented Paper 78-2508, 1978 Winter Meeting ASAE, Palmer House Hotel, Chicago, Illinois, December 18-20, 1978.

McDowell, T.R., J.M. Omernik. 1979. Nonpoint Source- Stream Nutrient Level relationships: A Nationwide Study. U.S. Environmental Protection Agency EPA/600/3-79-103.

McElroy, A.D., S.Y. Chiu, J.W. Nebgen, A. Aleti and F.W. Bennett. 1976. Loading Functions for Assessment of Water Pollution from Nonpoint Sources. U.S. Environmental Protection Agency, EPA/600/2-76-151.

Menzel, R.G., E. D. Rhoades, A.E. Olness and S.J. Smith, 1978. Variability of Annual Nutrient and Sediment Discharges in Runoff from Oklahoma Cropland and Rangeland, J. Environ. Qual 7(3):401-406.

Minshall, N.E., S.A. Witzel, and M.S. Nichols, 1970. Stream Enrichment from Farm Operations. ASCE J. Sanitary Eng. Div. 96(SA2):513-524.

Minshall, N.E., S.A. Witzel, and M.S. Nichols, 1970. Stream Enrichment from Farm Operations. J. San Engr. Div., American Society Chemical Engineers 96(SA2):513-524.

Moore, I., R. Grayson and A. Ladson. 1991. Digital Terrain Modelling I: Review of Applications, *Digital Terrain Modelling: A Review of Hydrological, Geomorphological, and Biological Applications, Hydrological Processes*. New York: Wiley and Sons.

Oklahoma Water Resources Board (OWRB), May 1990, Oklahoma Water Atlas, Publication 135.

Olness, A.E., D. Rhodes, S.J. Smith, and R.G. Menzel, 1980. Fertilizer Nutrient Losses from Rangeland Watersheds in Central Oklahoma. J. Environ. Qual. 9(1):81-85.

Overcash, M.R. and F.J. Humenki, 1976. State-of-the-Art: Swine Waste Production and Pretreatment Processes. EPA-600/2-76-290. Pp. 170.

Reckhow, K.H. and Chapra, S.C., 1983, Engineering Approaches for Lake Management, *Volume 1: Data Analysis and Empirical Modeling*, Butterworth Publishers, Woburn, MA, pp. 278 - 285.

Ritter, W.F., Strategies for Phosphorus Reduction in the Appoquinimink Watershed, 1994. Paper presented 1994 ASAE Summer Meeting, Kansas City, Missouri. June 19-22

Schuman, G.E., R.E. Burwell, R. F. Piest and R.G. Spomer, 1973b. Nitrogen Losses in Surface Runoff from Agricultural Watersheds on Missouri Valley Loess., J. Environ. Qual. 2(2):299-302.

Schuman, G.E., R.G. Spomer, and R.F. Piest, 1973a. Phosphorus Losses from Four Agricultural Watersheds on Missouri Valley Loess. Soil Sci. Soc. Amer., Proc. 37:424-427.

Smith, C.N., R.A. Leonard, G.W. Langdale and G.W. Bailey, 1978. Transport of Agricultural Chemicals from Small Upland Piedment Watersheds. U.S. Environmental Protection Agency, EPA-600/3-78-056.

Sonzogni, W.C., G. Chesters, D.R. Coote, D.N. Jeffs, J.C. Konrad, R.C. Ostry, and J.B. Robinson. 1978. Pollution from land runoff. Environmental Science and Technology 14(2):148-153.

Sonzogni, W.C., T.J. Monteith, W.N. Bach and V.G. Hughes, 1978. United States Great Lakes tributary loadings. International Joint Commission, Windsor, Ontario.

Tarboton D., R. Bras and I. Rodriguez-Iturbe. 1991. On the Extraction of Channel Networks from Digital Elevation Data, *Hydrological Processes.* 5:81-100.

Thomann, R.V. and Mueller, J.A., 1987, Principles of Surface Water Quality Modeling and Control, Harper Collins Publishers, New York, NY, pg. 14.

Timmons, D.R. and R.F. Holt. Nutrient Losses in Surface Runoff from a Native Prairie. J. Environ. Qual. 6(4):369-373.

U.S. Environmental Protection Agency, 1989, QUAL2E Seminar Notes, July 10-14, 1989, U.S. Environmental Protection Agency Center for Exposure Assessment Modeling, Athens, GA.

Young, R.A. and R.F. Holt, 1977. Winter-Applied Manure: Effects of Annual Runoff, Erosion, and Nutrient Movement, J. Soil and Water Cons. 32(5):219-222.

Young, R.A. and C. K. Mutchler, 1976. Pollution Potential of Manure Spread on Frozen Ground. J. Environ. Qual. 5(2):174-179.

APPENDIX A
Point Source Discharges

REF#	FACILITY	TREATMENT TYPE	FLOW (MGD)
AR001	City of Bentonville	Act. Sludge/Settling	4.000
AR002	City of Pea Ridge	Lagoon/Sand filtration	0.300
AR003	City of Sulpher Springs	Ext. Air/Sand filters	0.100
AR004	Village WW Co., Inc.	Ext. Air/Settling	0.070
AR005	Village WW Co., Inc.-North	Act. Sludge	0.200
KS001	Allen Co. Quarry	Unclassified	
KS002	Allen Co. S.D. #1	Waste Stbl Pond, Disch	0.035
KS003	Humbolt MWTP	RBC	0.250
KS004	Iola MWTP	Waste Stbl Pond, Disch	1.630
KS005	Iola Power Plant	Stabl-Pond, TR	0.010
KS006	La Harpe WWTP	Oxidation Ditch	0.135
KS007	Monarch Cement Co.	Unclassified	0.800
KS008	Monarch Cement Co.	Unclassified	
KS009	Nelson Quarry	Unclassified	
KS010	Savonburg MWTP	Waste Stbl Pond, Disch	0.140
KS011	Colony MWTP	Waste Stbl Pond, Disch	0.049
KS012	Killough Inc (Settlemyer)	Unclassified	
KS013	Cottonwood Falls	Waste Stbl Pond, Disch	0.001
KS014	KS Turnpike (Matfield Green)	Waste Stbl Pond, Disch	0.012
KS015	Strong City MWTP	Waste Stbl Pond, Disch	0.100
KS016	Allco Chemical		
KS017	Allied Signal Chemical	Stabl-Pond, TR	
KS018	Baxter Springs MWTP	Waste Stbl Pond, Disch	0.600
KS019	Bradford Acres MHP	Waste Stbl Pond, Disch	0.001
KS020	Cherokee County S.D. #1	Activated Sludge	0.150
KS021	Columbus MWTP	Waste Stbl Pond, Disch	0.420
KS022	Empire Dist Electric Com	Unclassified	
KS023	Galena MWTP	Waste Stbl Pond, Disch	0.550
KS024	KDHE Surface Mining		
KS025	Midwest Minerals Inc.(#21)	Unclassified	0.001
KS026	Puritan Bennet Corp- Mil Pl	Unclassified	0.020
KS027	Scammon MWTP	Waste Stbl Pond, Disch	0.051
KS028	Simone Ramp Project	Unclassified	
KS029	Southern Hills MHP	Waste Stbl Pond, Disch	0.024

KS030	Treece MWTP	Waste Stbl Pond, Disch	0.168
KS031	Weir MWTP	Waste Stbl Pond, Disch	0.085
KS032	West Mineral MWTP	Waste Stbl Pond, Disch	0.010
KS033	Burlington MWTP	Waste Stbl Pond, Disch	0.350
KS034	Gridley MWTP	Waste Stbl Pond, Disch	0.054
KS035	Lebo MWTP	Waste Stbl Pond, Disch	0.140
KS036	Leroy MWTP	Waste Stbl Pond, Disch	0.100
KS037	New Strawn	Waste Stbl Pond, Disch	0.001
KS038	Panhandle Eastern Pipeline	Unclassified	
KS039	Wolf Creek Nuclear Op Corp	Unclassified	0.020
KS040	Arma MWTP	Waste Stbl Pond, Disch	0.240
KS041	Cherokee MWTP	Waste Stbl Pond, Disch	0.085
KS042	E.Quincy AML Recl. Proj.	Unclassified	
KS043	Frontenac MWTP	Waste Stbl Pond, Disch	0.350
KS044	Girard MWTP	Waste Stbl Pond, Disch	0.325
KS045	Hepler MWTP	Waste Stbl Pond, Disch	0.024
KS046	Iron Horse Mine	Unclassified	0.010
KS047	KS City Southern RR	Unclassified	0.035
KS048	McCune MWTP	Waste Stbl Pond, Disch	0.070
KS049	Midwest Minerals Inc.(#5)	Unclassified	
KS050	Mission Clay Products	Unclassified	
KS051	Nelson Quarry-Pittsburgh	Unclassified	
KS052	Oak Hill MHP	Waste Stbl Pond, Disch	0.010
KS053	Pittsburg MWTP	Waste Stbl Pond, Disch	6.000
KS054	Quality Coal- Santa Fe #1	Unclassified	
KS055	Walnut	Waste Stbl Pond, Disch	0.001
KS056	Whispering Pines MHP	Activated Sludge	0.023
KS057	Altamont MWTP	Waste Stbl Pond, Disch	0.145
KS058	Bartlett MWTP	Waste Stbl Pond, Disch	0.030
KS059	Chetopa MWTP	Waste Stbl Pond, Disch	0.192
KS060	KS Army Ammunition Plant	Waste Stbl Pond, Disch	
KS061	Midwest Minerals Inc.(#3)	Unclassified	0.001
KS062	Midwest Minerals Inc.(#40)	Unclassified	
KS063	Occidental - Chetopa Mine	Unclassified	
KS064	Oswego Coal- Alpha Mine	Unclassified	
KS065	Oswego MWTP	Waste Stbl Pond, Disch	0.305
KS066	Parsons MWTP	Waste Stbl Pond, Disch	3.500
KS067	Rancher's Coal-Bartlett	Unclassified	
KS068	SAC Corporation	Waste Stbl Pond, Disch	
KS069	Tomkins Ind. Inc.	Waste Stbl Pond, Disch	

KS070	Union Pacific R.R.-Parsons	Unclassified	
KS071	Americus MWTP	Waste Stbl Pond, Disch	0.048
KS072	Country Park MHP	Waste Stbl Pond, Disch	0.010
KS073	Didde Webb Press	Unclassified	
KS074	Emporia MWTP	Trickle Filter Mult Stg	4.000
KS075	Flint Hills Mobile Est.	Act. Sludge - Ext Aer	0.050
KS076	Hartford MWTP	Waste Stbl Pond, Disch	0.050
KS077	IBP Inc (Emporia)	Unclassified	3.000
KS078	JH Shears' Sons (Stokes)	Unclassified	
KS079	KS Turnpike (Emporia)	Waste Stbl Pond, Disch	0.008
KS080	Modine Mfg. Co.	Unclassified	
KS081	Neosho Rapids	Waste Stbl Pond, Disch	0.030
KS082	Olpe MWTP	Waste Stbl Pond, Disch	0.050
KS083	Assoc. Milk Producers	Unclassified	0.080
KS084	Circle D	Waste Stbl Pond, Disch	0.001
KS085	Harshman Const (Flo. Quarry)	Unclassified	
KS086	Hillsboro MWTP	Activated Sludge	0.420
KS087	Lehigh MWTP	Waste Stbl Pond, Disch	0.030
KS088	Marion MWTP	Waste Stbl Pond, Disch	0.238
KS089	Martin Marietta (Het Quarry)	Unclassified	
KS090	Martin Marietta (Mar Quarry)	Unclassified	0.001
KS091	Martin Marietta (Sun Quarry)	Unclassified	
KS092	Peabody MWTP	RBC	0.210
KS093	Canton MWTP	Trickle Filter	0.150
KS094	Council Grove MWTP	Waste Stbl Pond, Disch	0.408
KS095	Dwight	Waste Stbl Pond, Disch	0.050
KS096	Quality Profile Services	Unclassified	
KS097	White City MWTP	Trickle Filter	0.080
KS098	White Memorial Camp	Activated Sludge	0.005
KS099	Ash Grove Cement	Unclassified	0.010
KS100	Ash Grove Cement	Unclassified	
KS101	Chanute (new)	Trickle Filter Mult	2.200
KS102	Chanute Power Plant #1	Unclassified	0.200
KS103	Chanute Power Plant #3	Unclassified	0.001
KS104	Erie MWTP	Waste Stbl Pond, Disch	0.750
KS105	Harry Byers & Sons	Unclassified	
KS106	Midwest Minerals Inc.(#7)	Unclassified	
KS107	Nelson Quarries	Unclassified	
KS108	St. Paul	Waste Stbl Pond, Disch	0.121
KS109	Stark MWTP	Activated Sludge	0.015

KS110	Western Resources	Unclassified	
KS111	Wilson Co. S.D. #1	Waste Stbl Pond, Disch	0.018
KS112	Woodson Co. Imp. Dist #2	Waste Stbl Pond, Disch	0.017
KS113	Yates Center MWTP	Activated Sludge	0.300
MO001	Aurora WWTP	OXI D SAN F	0.620
MO002	Carthage WWTF	OXI D CHLOR	2.700
MO003	Freistatt WWTF	1 LAG SP IR	0.017
MO004	Marionville WWTF	AE LAG SET B	0.200
MO005	Miller WWTF	2C AE SLLAG	0.074
MO006	Mount Vernon WWTF	TRI F CHLOR	1.068
MO007	Verona WWTF	OXI D LA AP	0.065
MO008	Ball, Bill & Marjorie	DMSTO CMPST	
MO009	Empire, Asbury PP	COL W	0.720
MO010	Empire, Asbury PP	ASHPO	
MO011	Mackie Clemens Fuel	EXAIR 1 LAG	0.002
MO012	Leeru Dairy	AN LA	
MO013	McCormick, George	AN LA	
MO014	Art, David	AN LA	
MO015	Hurn, Steve and Carl	DMSTO CMPST	
MO016	Freeman Farms	DMSTO CMPST	
MO017	Hubbard, Dwayne & P	DMSTO CMPST	
MO018	Moneymaker, John	9 PIT CMPST	
MO019	Beard, H.O.	DMSTO CMPST	
MO020	Syntex Agribusiness	COL W	0.020
MO021	Syntex Agribusiness	STO R	
MO022	Butterball Turkey Co	3 LAG NO T	0.018
MO023	Nickerson Farms	EXAIR CHLOR	0.002
MO024	Conoco, Mt. Vernon	STO R W SEP	0.158
MO025	Fairview Greenhouse	1 LAG SEP T	0.001
MO026	Mo Baptist Children's H	EXAIR CHLOR	0.002
MO027	Truckstops of America	W SEP STO R	0.036
MO028	Inland Products	COL W	0.576
MO029	Darrco, ADF W Sote	STO R LA AP	
MO030	Darrco, ADF Hwy P Site	STO R LA AP	
MO031	Moneymaker Feeds	E PIT E PIT	
MO032	Jantz, Norman & Char	DMSTO	
MO033	Minden Acres	SEP T ROC F	0.002
MO034	Alba WWTP	OXI D HTANK	0.040
MO035	Golden City WWTF	TRI F AN DI	0.043
MO036	Jasper WWTF	1 LAG IRRIG	0.155

MO037	Lamar WWTF	1 LAG WETL	0.400
MO038	D & J Turkey Farm	DMSTO CMPST	
MO039	Hartman, Lawrence	DMSTO CMPST	
MO040	Long, Henry & June	DMSTO CMPST	
MO041	Bruffett, Charles	DMSTO CMPST	
MO042	Ball, Darrel & Lan	DMSTO CMPST	
MO043	Scott Brothers	AN LA	
MO044	Hackney Poultry Farm	DMSTO CMPST	
MO045	Blue Top Motel	2 LAG	0.010
MO046	Angel Est & Courtesy	EXAIR CHLOR	0.005
MO047	Carl Junction WWTF	OXI D SLSTO	0.300
MO048	Carterville Lift Sta	L STA 2 LAG	0.480
MO049	Center Creek WWTF	OXI D UV DI	1.800
MO050	Sarcoxie WWTF	3 LAG SLLAG	0.125
MO051	Page, Glenn	C PIT	
MO052	Dunaway Stock Farm	DMSTO CMPST	
MO053	Schoenhals, Roy	DMSTO CMPST	
MO054	Lundien, Larry & Melba	DMSTO CMPST	
MO055	Wright, Felix	DMSTO CMPST	
MO056	Meadows, Tim & Deb	DMSTO CMPST	
MO057	Ireco Inc.	SET B PHNEU	0.020
MO058	Ireco Inc.	PRO W NO T	0.001
MO059	Ireco Inc.	COL W PRO W	0.162
MO060	WR Grace & Company	STO R SET B	
MO061	ICI Explosives USA I		0.500
MO062	ICI Explosives USA I	COL W	0.500
MO063	ICI Explosives USA I	PRO W COL W	
MO064	International Foods	DAF ACT S	0.056
MO065	Independent Asphalt	SET B (3)	0.004
MO066	Fountain Road Park Vill	ACT S FILTER	0.020
MO067	ICI Explosives Env C	STO S POND	0.001
MO068	Hickory Lane MHP	3 LAG SLLAG	0.015
MO069	Bell Egg Farm		
MO070	Mo-Ark Egg Process P	1 LAG	
MO071	Mo-Ark Top Notch Farms	E PIT C PIT	
MO072	Mo-Ark Fleck Farm	E PIT	
MO073	Mo-Ark Tackborne-Smith	STO R	
MO074	Joplin, Turkey Creek	TRI F AN DI	12.000
MO075	Farmers Chemical	COL W STO R	
MO076	Tamko Asphalt Prod	STO R	1.460

MO077	Tamko Asphalt Prod	STO R	0.990
MO078	Eagle-Picher Industry	NO T STO R	
MO079	Vickers Incorporated	RE CL STO R	0.001
MO080	Vickers Incorporated	ACT C AIR S	0.001
MO081	Fibrex Inc, Joplin P	PRO W	0.056
MO082	Fibrex Inc, Joplin P	COL W	0.011
MO083	Diamond W WWTF	2 LAG IRRIG	0.208
MO084	Granby WWTF	ACT S UV DI	0.190
MO085	Joplin, Shoal Creek	TRI F CHLOR	6.500
MO086	Monett WWTF	RO BI CHLOR	3.500
MO087	Neosho, Shoal Creek	OXI D HTANK	2.200
MO088	Pierce City WWTP	OXI D DRY B	0.100
MO089	Purdy W Lagoon	1 LAG SLLAG	0.015
MO090	Jesse's Truck Stop	2 LAG	0.006
MO091	Pronto Travel Plaza	EXAIR CHLOR	0.005
MO092	Pronto Travel Plaza	W SEP	0.001
MO093	Loma Linda Estates	COL S LA AP	0.020
MO094	Joplin Transport Center	EXAIR SAN F	0.032
MO095	Bartkoski, Danny		
MO096	Tomlinson, Homer & R	AN LA	
MO097	Tomlinson, Homer & R	AN LA	
MO098	Hudson Farms - Rolling	DMSTO	
MO099	Hudson Farms - Terry F	DMSTO	
MO100	Carter, Bob	AN LA	0.009
MO100	Hudson, Knoll Hill	DMSTO CMPST	
MO101	Scott, Glen W.	DMSTO CMPST	
MO102	Hudson Farms - Rocky R	DMSTO CMPST	
MO103	Hudson Farms - Knight	DMSTO CMPST	
MO104	Hudson Farms - Highway	DMSTO CMPST	
MO105	West, Marvin	DMSTO CMPST	
MO106	Carder, Robert	DMSTO CMPST	
MO107	Brittenham, Phillip	DMSTO CMPST	
MO108	Gobblers Knob	DMSTO CMPST	
MO109	Freeman, Melvin	DMSTO CMPST	
MO110	Zaharadka, James	DMSTO CMPST	
MO111	Walker, Joe & Ivy	DMSTO CMPST	
MO112	Neosho WTP	WAT T SET B	
MO113	USFWS, Neosho Fish Hat	OVER	2.600
MO114	Sabreliner Corp	STO R WAT S	
MO115	Shady Lane MHP	EXAIR CHLOR	0.008

MO116	Fag Bearing Corp	COL W	0.160
MO117	Winter Haven MHP	AE LA SLLAG	0.013
MO118	Melody MHP	EXAIR FILTER	0.010
MO119	George's Proc, Barry	AE LA AN LA	1.200
MO120	George's Proc, Barry	IRRIG	1.200
MO121	Missouri-Nebraska Ex	W SEP SEP T	0.006
MO122	Shell, Diamond Station	W SEP STO R	
MO123	Talbot Indus Inc Pla	NO T	0.402
MO124	Talbot Indus Inc Pla	NO T	0.961
MO125	Tyson-Monett Process	LAAP DAF	0.005
MO126	Mo-Ark, 5 Farms	DMSTO	
MO127	Bunch, Jerry		
MO128	Berg, Bill	DMSTO CMPST	
MO129	MHTD, I-44 Rest Area	3 LAG SLLAG	0.002
MO130	Anderson WWTF	EXAIR CHLOR	0.150
MO131	Fairview WWTF	2 LAG IRRIG	0.020
MO132	Goodman WWTP	OXI D SAN F	0.089
MO133	Neosho, Crowder WWTF	TRI F CHLOR	0.400
MO134	Noel WWTF	OXI D UV DI	0.143
MO135	Pineville WWTF	CON S AE DI	0.039
MO136	Seligman WWTF	1 LAG IRRIG	0.100
MO137	Southwest City WWTF	2C AE	
MO138	Wheaton WWTF	1 LAG IRRIG	0.104
MO139	Hobbs, Max	DMSTO C PIT	
MO140	Brown, James	C PIT	
MO141	Harper, Larry	DMSTO CMPST	
MO142	Simmons #25	DMSTO	
MO143	Simmons #24	DMSTO	
MO144	Simmons #23	DMSTO	
MO145	Simmons #22	DMSTO	
MO146	Simmons #21	DMSTO	
MO147	Simmons #26	DMSTO	
MO148	Simmons #27	DMSTO	
MO149	Simmons #28	DMSTO	
MO150	Simmons Industries I	2 LAG	
MO151	Simmons Industries I	OVER DAF	0.430
MO152	Simmons Industries I	DAF AE LA	
MO153	Simmons #30	DMSTO	
MO154	Simmons #29	DMSTO	
MO155	Simmons #31	DMSTO	

MO156	Simmons #32	DMSTO	
MO157	Simmons #33	DMSTO	
MO158	Simmons #34	DMSTO	
MO159	V-B Feeds	C PIT C PIT	0.005
MO160	Garrison, Dale(No 1)	DMSTO CMPST	
MO161	Wilson, Bill & Charl	DMSTO	
MO162	Hudson Foods Inc	ACT S CHLOR	0.800
MO163	Praxair Plant 909	COL W STO R	0.031
MO164	Ginger Blue Retreat	EXAIR CHLOR	0.003
MO165	Tyson Lee Pine Farm	C PIT	
MO166	Tyson Valley High Farm	C PIT	
MO167	Tyson Bear Hollow	C PIT	
MO168	Cobb-Vantress, Inc	DMSTO INCIN	
MO169	Lucariello, Mike	DMSTO CMPST	
MO170	Stephenson's Restaraunt	EXAIR	0.002
MO171	Simmons Hatchery	COL W NO T	0.009
MO172	B & B Sand & Gravel	SET B FILTR	0.003
MO173	Harvey, Bill	AN LA	
MO174	Tyson Musteen Farm	C PIT	
MO175	Tyson Pea Ridge Farm	C PIT	
MO176	Barber, George	C PIT	0.001
MO177	Speight, Robert	DMSTO CMPST	
MO178	Hudson Farms - Anderson	DMSTO CMPST	
MO179	Squires, Bob & Kay	DMSTO CMPST	
MO180	Carlin, Joe	DMSTO CMPST	
MO181	MoArk Sawmill Farm	DMSTO	
MO182	Booth, Kevin	EXAIR CHLOR	
MO183	Crook, E. A.	EXAIR CONHL	
MO184	Lanagan Housing Auth	C PIT	0.001
MO185	Lanagan Housing Auth	AN LA	0.002
MO186	Mattis, Paul	AN LA	
MO187	Boles, D.F.	DMSTO CMPST	
MO188	Moger, Robert	DMSTO CMPST	0.010
MO189	Hounschell, Don	DMSTO CMPST	
MO190	North Country Farm	DMSTO CMPST	
MO191	Hudson Farms-Twin Ce	E PIT E PIT	
MO192	Bank Farms Inc.	C PIT	
MO193	Evans, James	DMSTO CMPST	
MO194	Clark, Rick	DMSTO CMPST	
MO195	Hudson, Williams FArm	DMSTO CMPST	

MO196	Hudson, Wirth Farm	DMSTO CMPST	
MO197	Hudson Farms-Brown F	DMSTO CMPST	
MO198	Mitchell, Charlie	DMSTO CMPST	
MO199	Osh-Kosh Farm	DMSTO CMPST	
MO200	Hudson Farms-Wheaton	DMSTO CMPST	
OK001	Coves Master Assn.	Act. Sludge	0.038
OK002	Grove Mun. Serv. Auth.	Act. Sludge	0.288
OK003	Grove MSA (Quail)	Act. Sludge	0.034
OK004	Hallett Matls.-Kirby Q		
OK005	Harbors Area Assoc.	Act. Sludge	0.020
OK006	Heritage Point Dev.	Ext. Air	0.030
OK007	Town of Jay	Act. Sludge	0.880
OK008	Pine Island RV Resort	Lagoon	0.040
OK009	Port Duncan #1	Act. Sludge	0.015
OK010	Silver Key Homeowner's	Ext. Air	0.012
OK011	Spinnaker Pt. HA	Act. Sludge	0.024
OK012	White Chapel HA	Ext. Air	0.009
OK013	Afton PWA	Oxidation Ditch	0.140
OK014	B.F. Goodrich		
OK015	Blitz U.S.A.		
OK016	City of Cardin	Lagoon	0.050
OK017	City of Commerce	Lagoon	0.320
OK018	Eagle Picher I.-Ottawa	Lagoon -TR	
OK019	Fairland PWA	Lagoon	0.115
OK020	HiPoint Estates HA	Act. Sludge	0.013
OK021	Mainstay & Beacon Hill	Ext. Air	0.015
OK022	City of Miami (Main)	Ext. Air	1.500
OK023	City of Miami Utilities	Ext. Air	0.550
OK024	Ottawa Co. RWSD #1	Ext. Air	0.045
OK025	City of Picher	Lagoon	0.218
OK026	Port Duncan Res. Marina	Act. Sludge	0.015
OK027	Quapaw PWA	Lagoon	0.130
OK028	Seneca-Cayuga Tribe	Lagoon	0.020
OK029	City of Seneca (MO)	Lagoon	0.353
OK030	Shell Pipeline-Gr Lake		
OK031	TJ Claibourne DBA Roger		
OK032	US Metal Container Co.		

APPENDIX B
STORET Temperature Data Summary
(^oF)

Elk River near Tiff City, MO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1952											11.7	
1953	7.2	10	12.2	12.2	18.3	24.4	28.9	26.7	22.8			
1956		9.4		15.6	15.6							
1962								25.5	24.5	24.5	13	8.5
1963	6	8.5	9.5	16	25.5	25.5						
1965											17.2	9.4
1966	10.6	9.4	13.9	20	24.4	29.4	30.6	25	21.7	18	15	8
1967	6.5	8	12	16	21	28	26	26.5	22	17	13	11
1968	6	6	7	18	19	22	26	25	21	15	10	9
1969	7	9	9	16	19	23	27	27	24.5	18.5	10.5	6
1970	1.5	5	11	14	17	20.5	24	26	25		11.5	15
1971		5	9.5	11.5		21	27	24.5	25			
1972		3					24				11	
1973	7.5		13			20.5			23.5	20.5	12.5	12
1974	6	9	12	14	17	17	26	23	19	17	12	7.5
1975	7.5	8	7	8.5	17.5	19	24.5				16.5	9
1976	6	13	12	19	18	26	24	27	22	13	7	3
1977		4.5	12	16	21	24.5	27	25	22			
1980										21.5	7	9.5
1981	4	10	12	17	18	24	30.5	24	22			
1982										18	13.5	8
1983	5.5	7.5	14	9.5	13.5	18	24.5	27.5	19	15	7.5	
1984	3.5	6.5	9	10	16.5	21	28.5	31	27.5	20.5	13.5	5.5
1985	7.5	9	12.5	15.5	18	18	24.5	18	25	19	15	10
1986	3	3	12	12.5	20	22	28.5	25	20.5	16	14.5	7.5
1987	6.5	9	10	13.5	24	23.5	27	29.5	27	15	17.5	13
1988	5	6	10.5	13.5	18.5	23	26.5	30.5	21.5	17	16	9.5
1989	8.5	4	6.5	13	16.5	19.5	22	22	24.5	20.5	12.5	8.5
1990	4.5	9.5	10.5	11.5	16.5	19						
1992											15	8.5
1993	6	9.5	11	14.7	15.2	21.1	22.1	26	17.4	17.5	11.2	8.7
AVG	**6.0**	**7.6**	**10.8**	**14.2**	**18.6**	**22.2**	**26.1**	**25.7**	**22.7**	**18.0**	**12.7**	**8.9**

Neosho River at Burlington, KS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1965	8.3	1.1	2.2	21.6				26.1	16.1	21.6	13.3	1.1
1966	0.5	3.8	9.9	9.4	19.9	19.4	30.5	25.5	19.9			
1967	3.3	6.6	4.9	12.7	15.5	18.8	23.3	23.8		22		
1968	2			16			26			18		
1969	5	3	2	15	18					12		
1970	1		9	6.5	21.5		26			11		
1971	1.5	5.5		16			27			19.5	5	
1972	1			10			25.5			20.5	11	2
1973	2	4		13.5			27.5	27.5	18.5	15	10	
1974	-1	5	8	16.5	20	22	27.8	24.4		16.7	7.8	2.2
1975	1.1	1.1	11.5	15	22.2	24	28.3	27.2	17.8	16.7	10	2.2
1976	2.8	4	12.2	16	19.4	21	26	25	24	16	5	-1
1977	1	4.5	13	19	18	26	28	25	22	18	12.5	0
1978	1	2	1	14	14	20	26		25	20	10	4
1979		1	6	6	20	22	22	28	25	18	14	5
1980	1	0.5	2	9.5	15.5	26	29	25.5	20	16	7	6
1981	6	10	15	15	17.5	26	25	28	21.5	18	12	5.5
1982	1	4.5	7	14	20	20	23	28	18.5	19	17	4
1983	2	1	10	7	17	23	29	28	25.5	16	6	0
1984	3	4.5	4	6.5	16	26.5	27	27	22	19	12	3.5
1985	1	2	6	13	19	20	27	25	25	13	12	3
1986	0	5	8	15	19	23	26	23	20	14	10	3
1987	2	3	8	10	23	25	27	27	24	14	16	7
1988	2	3	9	12	24		28	22	24	12	10	7
1989	5		7	15	23	22	25	24	18	16	10	
1990											8	
1991		5	10.5	15.5	14.5	25	29	24		25	5	4
1992		4.5	9	14		27		26.5	25	17		
1993	1		4.5	16.5	16		26.5	25	18			
AVG	**2.1**	**3.7**	**7.5**	**13.2**	**18.8**	**23.0**	**26.6**	**25.7**	**21.5**	**17.1**	**10.2**	**3.3**

Neosho River near Parsons, KS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1961					15.6							
1964										15.5	6.1	4.4
1965	7.7	1.6	3.8	21.6	22.2	22.7	28.3	28.3	20.5	15.5	11.1	6.6
1966			4.9	10.5	19.4	22.7	33.8	24.9	26.6	16.1	11.6	2.7
1967	6.1	6.6	12.7	14.9	19.4	22.7	26.1	12.7	23.8	21	8	6
1968	2	8	9	5	17	27	26	27		19		4
1969	6	4		19	19	22	29	29	18	12	8	6
1970	0	2	11	10.5	22	22	27	31.5	26.5	18.5	9	10
1971	0.5	1	10.5	18	21	20.5	28	24	27	19.5	15.5	6
1972	1	0	7.5	13	14.5	23.5	24	26.5	24	20	11.5	3
1973	1	3	11.5	12	19.5	22.5	25	29	19.5	20	12.5	2
1974	0	5	8	19	23.5	21.5	31	27.5	17	14.5	11	3
1975	1	2.5	10	17	23	24	29	26	21	18	11.5	4
1976	3	9	13.5	17.5	20	26	26	28	22	14	7	4
1977	0.5	5.5	16	20		25	29	24		19	13.5	
1978	2	0.5	14.5		17	25.5	29			22	9.5	
1979			12	11.5	21.5	22.5	23	25	23	19	9.5	1
1980	0.5	0.5	9	12	20	26	32	30	22	17	8	1.5
1981	5	4	13	13.5	14.5	15.5	25				13	6
1982	1		8.5	17		20.5	26.5	25.5		20	7.5	4
1983		1.5	7		14.5	25.5		32.5	25.5	13.5		3
1984	0	4		14	23		30	28	20		6	3.5
1985	0.5		7.5		19	20	29.5	22		16.5		
1986	0.5	1.5			21	30			24	16		5.5
1987	0.5	6.5		12		29		32			18	1.5
1988			8.5	14			30.5	32.5			13.5	
1989	6		12		19	21		25.5				
1990										12.5	13.5	
1991	1	7		19			29.5	27	20.5	16.5	6.5	7
1992		6.5	9.5		19		23		23	18		
1993			7	11		24		27.5				
AVG	**2.1**	**3.8**	**9.9**	**14.6**	**19.3**	**23.4**	**27.8**	**26.9**	**22.4**	**17.2**	**10.5**	**4.3**

Spring River near Waco, MO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1964									22.8			
1965											15	7.8
1966	5	8.9	11.1	18.3	21.7	30.6	28.3	21.7	19.4	14.5	12	4
1967	2	11	9	17	15.5	23.5	24	23	22	13	11	8
1968	4	4	11	16	22	19	26	23	21	12	10	8
1969	6	7	5	17	21	21	28	25		15.5	9	4
1970	2	4		11.5		21.5		25.5		18.5		14
1971		2	8		17	22.5	24				6	
1972		5		18	25	25	26	27	25		6	2
1973		5		12		23		26		21		6.5
1974		7		15		19.5		23.5		15.5		4.5
1975		5		7		22		27				5
1976	2	4	12		18	20	23	23	22	13	7	0
1977		2	5	11	19	22	29.5	27	21.5	12.5	13	6.5
1978	0.5	2.5	7.5	16.5	14	19	26.5	27.5	28.5	19	9	6
1979		3	10	8	18	20	23	25	23	20	8	4
1980		2	5	12	19	24	29	27	25	18	5	5
1981	3	7	11	18	17	21	27.5	25	22.5	17	14	7
1982	2		10	10	19	21	27	23	22	21	13	7
1983	5	4	10	8	13	19	23	25	25	18	14	3
1984	0	3	6	12	16	22	25	27	22	18	12	5
1985	6	1	11	11	16	21	24	25	24	16	11	1
1986	2	12	5	16	18	21	25	23	18	14	13	4
1987	5	8	7	12	22	23	23	26	23	11	16	11
1988	4	4	10	13	21		25	29	22	14	10	7
1989	6		12	14	16	19	27	21	19	15	11	
AVG	**3.4**	**5.1**	**8.7**	**13.3**	**18.4**	**21.7**	**25.7**	**25.0**	**22.5**	**16.0**	**10.7**	**5.7**

Spring River near Quapaw,OK

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1950			15.6									
1951									20		14.5	
1952	6.5	10.5	9.5		22	26	30	28.5	26	18.9	6.1	3.9
1953		10	11.7	15			30	29.4	21.1	20		
1954	5.5		10.5		21			29.5		22		
1955	4.5	4.5	13.5	15	23.5			29.5		13.9		6.1
1956	2.2			17.8		22.2		21.1		23		4.5
1957	6	6.5					29.5				12	
1958	4.5		4.5									
1969							33					
1972										19		
1975											17	9
1976	3	11	9	18	16.5	25	26	29	23	12	7	3
1977		5	12	19	23	21	28	26	22	14	12	6
1978	1	0.5	11	15	20	24	27	27	27	15	12	5
1979		4	10	18	19	25	26	26	20	21	8	1
1980		9	10	13	21	20	28	33	23	14.5	4	6.5
1981	8	15	19	24.5	17	24.5	28	24	25	16.5	12	6.5
1982	7	9	19	14	21	23	30	21	22.5	15	13.5	8.5
1983	5	12	8	18	21	25	33	31	23	15	5.5	0.1
1984	4	11	10.5	16	23	26	32	30	18	17	10	8
1985	0.5	10	16	22	21	26	23	25	21	20	8	7
1986	3	12	15	18	24	29	31	29	26			
1987								27				
1988		8				25.5	27	26	19	28.5	11	17
1989		2						29				
1990		5.5						29				
1991		9			20.8				21			
1992			13						22			
AVG	**4.3**	**8.1**	**12.1**	**17.4**	**20.9**	**24.4**	**28.8**	**27.5**	**22.3**	**18.0**	**10.2**	**6.1**

APPENDIX C
STORET Total Phosphorous Data Summary (mg/L)

Elk River near Tiff City, MO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1969								0.04	0.05	0.02	0.04	0.06
1970	0.04	0.04	0.09	0.42	0.09	0.57	0.06	0.06	0.06		0.29	0.28
1971		0.07	0.06	0.19		0.02	0.02	0.12	0.07			
1972		0.02					0.064				0.66	
1973	0.007		0.061			0.05			0.04	0.06	0.06	0.09
1974	0.03	0.01	0.05	0.03	0.04	0.03	0.01	0.02	0.05	0.02	0.08	0.02
1975	0.03	0.02	0.04	0.02	0.04	0.04	0.11					0.01
1976	0.07	1	0.08	0.08	0.08	0.08	0.03	0.08	0.16	0.1	0.03	0.03
1977		0.08	0.08	0.04	0.07	0.061		0.096	0.062			
1980										0.11	0.12	0.07
1981	0.06	0.09	0.06	0.1	0.07	0.15	0.02	0.04	0.06			
1982										0.06	0.1	0.05
1983	0.05	0.1	0.05	0.05	0.06	0.06	0.15	0.08	0.1		0.05	0.03
1984	0.03	0.01	0.05	0.04	0.03	0.03	0.04	0.07	0.09	0.06	0.04	0.02
1985	0.04	0.02	0.03	0.02	0.03	0.04	0.04	0.09	0.05	0.04	0.11	0.04
1986	0.01	0.04	0.05	0.1	0.05	0.06	0.05	0.62	0.19	0.05	0.55	0.04
1987	0.02	0.04	0.05	0.04	0.1	0.09	0.09	0.11	0.09	0.06	0.04	0.05
1988	0.06	0.05	0.05	0.05	0.05	0.07	0.09	0.08	0.07	0.06	0.07	0.04
1989	0.06	0.07	0.06	0.05	0.07	0.08	0.18	0.08	0.1	0.08	0.07	0.12
1990	0.08	0.05	0.05	0.04	0.06	0.05						
1992											0.06	0.08
1993	0.05	0.04	0.04	0.03	0.1	0.06	0.05	0.04	0.14	0.03	0.07	0.04
MEAN	0.04	0.10	0.06	0.08	0.06	0.09	0.07	0.11	0.09	0.06	0.14	0.06

Neosho River at Burlington,KS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1971										0.04	0.16	
1972	0.10			0.03			0.05			4.60		
1973	1.30			0.13			0.03	0.05		0.15	0.16	
1974		0.11	0.05	0.08			0.09			0.13		
1975	0.10		0.14	0.11		0.11	0.16					
1977					0.13	0.19	2.40	0.19	0.30	0.18	0.17	0.16
1978	0.13	0.27	0.22	0.13	0.08	0.13	0.07	0.08	0.05	0.04		
1979		0.10	0.21	0.18	0.11	0.07	0.30	0.15	0.07	0.05		0.11
1980		0.05	0.15	0.19	0.18	0.08	0.06		0.09		0.03	0.25
1981	0.09	0.08	0.02	0.06	0.08	0.18	0.12	0.04	0.17	0.03	0.15	0.20
1982	0.09		0.09	0.12	0.05	0.21	0.23	0.09	0.15	0.10	0.08	0.05
1983	0.08	0.10	0.18	0.13	0.15	0.18	0.19	0.07	0.07	0.03	0.16	0.15
1984	0.16	0.14	0.09	0.33	0.83	0.15	0.12	0.06	0.06	0.02	0.10	0.02
1985	0.11	0.08	0.09	0.08	0.13	0.15	0.78	0.30	0.11	0.21	0.17	0.13
1986	0.52	0.01	0.06	0.07	0.03	0.07	0.16	0.08	0.12	0.25	0.17	0.14
1987	0.07	0.03	0.15	0.20	0.10	0.13	0.18	0.15	0.09	0.12	0.10	0.08
1988	0.14	0.12	0.12	0.17	0.09	0.08	0.14	0.14	0.06	0.02	0.05	0.07
1989	0.12		0.14	0.01	0.01	0.11	0.39	0.07	0.23	0.17	0.19	
MEAN	0.23	0.10	0.12	0.13	0.15	0.13	0.32	0.11	0.12	0.38	0.13	0.12

Neosho River near Parsons, KS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1971										0.16	0.11	0.18
1972	0.08		0.06	0.03	0.11	0.02	0.09	0.11	0.06	0.23	0.22	0.10
1973	0.10	0.15	0.16	0.20	0.07	0.08	0.08	0.06	0.16	0.18	0.27	0.22
1974	0.15	0.13	0.12	0.12	0.12	0.13	0.06	0.10	0.19	0.13	0.20	0.18
1975	0.09	0.06	0.90	0.15	0.08	0.15	0.10	0.17	0.05			
1977					0.24	0.67	0.27	0.16	0.34	0.25	0.56	0.24
1978	0.10	0.02	0.24	0.17	0.10	0.15	0.07	0.07	0.08	0.10	0.10	
1979		0.20	0.26	0.30	0.11	0.09	0.71	0.26	0.11	0.11	0.14	
1980		0.07	0.17	0.44	0.14	0.07	0.08		0.12		0.06	0.00
1981	0.12	0.13	0.06	0.04	0.07	0.34	0.12	0.07	0.17	0.03	0.15	0.45
1982	0.10		0.31	0.53	0.07	0.38	0.28	0.13	0.12	0.11	0.09	0.15
1983	0.38	0.31	0.48	0.62	0.28	0.29	0.50	0.09	0.08	0.06		0.23
1984	0.20	0.11	0.10	0.41	0.20	0.18	0.11	0.05	0.10	0.16	0.21	0.08
1985	0.17	0.17	0.26	0.12	0.14	0.26	0.47	0.05	0.25	0.16	0.17	0.14
1986	0.59	0.40	0.05	0.22	0.06	0.12	0.13	0.13	0.15	0.36	0.28	0.34
1987	0.15	0.12	0.14	0.40	0.10	0.19	0.35	0.10	0.14	0.21	0.05	0.15
1988	0.07	0.15	0.18	0.26	0.12	0.07	0.10	0.06	0.07	0.08	0.09	0.19
1989	0.19		0.21	0.13	0.09	0.30	0.15	0.12	0.34	0.35	1.06	
1990											0.05	
1991	0.06	0.09		0.09			0.11	0.13		0.18		0.12
MEAN	0.17	0.15	0.23	0.25	0.12	0.21	0.21	0.11	0.15	0.17	0.22	0.18

Spring River near Waco, MO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1969								0.26		0.19		0.13
1970		0.63		0.27		0.27		0.29		0.29		0.11
1971		0.14				0.15					0.10	
1972				0.09		0.58		0.10				0.13
1973		0.08								0.18		0.28
1974		0.06		0.06		0.20		0.15		0.13		0.21
1975		0.18		0.08		0.19						
1977					0.22	0.42	0.13	0.22	0.29	0.18	0.24	0.11
1978	0.13	0.13	0.23	0.39	0.41	0.26	0.34	0.72	0.23			
1979		0.12	0.10	0.15	0.13	0.11	0.12	0.18	0.28	0.14		0.09
1980		0.12	0.08	0.13	0.12	0.26	0.13	0.16	0.26	0.31	0.35	0.28
1981	0.15	0.27	0.62	0.22	0.22	0.28	0.18	0.38	0.20	0.05	0.21	
1982	0.22	0.04	0.12	0.12	0.18	0.19	0.14	0.17	0.18	0.19	0.39	
1983	0.15	0.12	0.09	0.34	0.11	0.15	1.10	0.13	0.15	0.15	0.18	
1984	0.32	0.22	0.06	0.23	0.09	0.10	0.32	0.14	0.23	0.27	0.14	0.05
1985	0.08	0.10	0.07	0.11	0.09	0.16	0.61	0.03	0.07	0.19	0.11	0.27
1986	0.64	0.35	0.02	0.26	0.07	0.15	0.15	0.25	0.30	0.12	0.09	0.20
1987	0.05	0.07	0.05	0.10	0.20	0.23	0.35	0.48	0.25	0.60	0.30	0.12
1988	0.05	0.08	0.08	0.19	0.12	0.14	0.18	0.15	0.27	0.19	0.26	0.12
1989	0.10		0.23	0.02	0.06	0.32	0.35	0.17	0.31	0.20	0.31	
MEAN	0.19	0.17	0.15	0.17	0.16	0.23	0.32	0.23	0.23	0.21	0.22	0.16

Spring River near Quapaw,OK

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1975												0.42
1976	0.4	0.4	0.23	0.3	0.22	0.19	0.17	0.16	0.21	0.29	0.39	0.46
1977		0.59	0.60	0.56	0.37	0.31		0.26	0.30	0.26	0.22	0.20
1978	0.283	0.267	0.187	0.131	0.795	0.16	0.185	0.235	0.265	0.309	0.347	0.186
1979		0.3	0.39	0.16	0.32	0.14	0.25	0.185	0.12			
1980		0.185	0.105	0.43	0.2	0.26	0.15	0.26	0.14	0.16	0.13	0.32
1981	0.26	0.3	0.31	0.33	0.39	0.21	0.29	0.15	0.13	0.25	0.2	0.18
1982	0.24	0.15	0.16	0.33	0.23	0.17	0.136	0.044	0.125	0.121	0.18	0.348
1983	0.104	0.167	0.33	0.216	0.185	0.68	0.54	0.42	0.304	0.3	0.34	0.4
1984	0.19	0.19	0.17	0.18	0.103	0.179	0.16	0.43	0.22	0.27	0.24	0.188
1985	0.28	0.398	0.029	0.21	0.2	0.17	0.27	0.245	0.41	0.26	0.58	0.26
1986	0.15	0.288	0.153	0.213	0.223	0.098	0.246	0.163	0.198			
1987								0.22				
1988		0.47						0.45				
1989		0.174						0.34				
1990		0.138						0.13				
1991		0.01							0.23			
1992			0.23						0.15			
MEAN	0.24	0.27	0.24	0.28	0.29	0.23	0.24	0.25	0.22	0.25	0.29	0.30

APPENDIX D
U.S.G.S. Discharge Data Summary
(cfs)

Station Name: **Elk River Near Tiff City, Missouri**
Station ID: **0718900**
Period of Record: **1940 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	678	864	1309	1625	1542	947	488	272	307	431	704	777	829
MAX	2509	2971	5020	6119	8964	4160	2565	2418	2164	2938	4094	3651	
MIN	55.9	70.7	75.7	145	227	78.6	14.3	12	30.9	25.7	49.8	58.5	

Station Name: **Neosho River at Burlington, Kansas**
Station ID: **07182510**
Period of Record: **1961 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
MEAN	812	1094	1873	2505	2507	3288	2361	1093	721	1468	1265	1099	1674
MAX	3578	5363	7637	8191	9632	8449	7332	10330	3771	11540	7543	6925	
MIN	17.7	17.1	13.8	21.5	44.5	162	66	45	32.4	22.4	12	12.4	

Station Name: **Neosho River near Iola, Kansas**
Station ID: **07183000**
Period of Record: **1899 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	814	1019	1909	2864	2940	3579	2673	1165	1427	1532	1332	951	1850
MAX	4773	6994	11010	19580	14270	11690	43540	10700	11140	15890	10150	9116	
MIN	1.33	3.24	11.4	19.8	82.3	126	10.8	1.1	0.64	0.21	0.52	1.39	

Station Name: **Neosho River near Parsons, Kansas**
Station ID: **07183500**
Period of Record: **1922 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	1287	1667	2933	4300	4268	5138	3754	1403	2-035	2323	2143	1412	2722
MAX	7762	9492	18100	25520	22110	17010	52780	11140	15030	25520	13340	12760	
MIN	0	0	8.1	18.6	282	210	10.8	0	0.9	0	0	0	

Station Name: **Neosho River near Commerce, Oklahoma**
Station ID: **07185000**
Period of Record: **1940 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	1933	2540	4458	5469	5749	6431	5131	1741	2881	3340	3135	2155	3747
MAX	10090	13980	21630	23270	29560	15820	53350	11680	16390	33400	19190	17280	
MIN	8.6	24.9	11.9	62.6	395	289	21.1	0	1.52	0	1.6	6.33	

Station Name: **Neosho River near Langley, Oklahoma**
Station ID: **07190500**
Period of Record: **1940 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	4820	5969	8456	10960	11320	10800	9092	4433	5398	6073	6569	5572	7455
MAX	21440	23460	33250	50780	77710	32490	67920	20910	30350	51120	38870	35580	
MIN	144	243	321	38.1	71.4	33.1	26.5	25.6	77.1	37.5	63	40.9	

Station Name: **Spring River near Waco, Missouri**
Station ID: **07186000**
Period of Record: **1924 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	705	914	1217	1417	1474	1389	710	457	599	652	901	727	930
MAX	3222	6372	5809	7542	11640	5521	4323	7812	10260	6997	6726	4704	
MIN	29.7	31	33.6	38.2	120	73.4	15.2	7.71	22	21	30.5	33.3	

Station Name: **Spring River near Quapaw, Oklahoma**
Station ID: **07188000**
Period of Record: **1940 - 1993**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
MEAN	1533	2096	2969	3234	3444	2901	1797	815	1513	1664	2220	1751	2161
MAX	6495	13300	12050	15100	26940	12140	10140	8622	18390	14880	14810	10720	
MIN	116	129	123	169	481	233	34.3	29.3	76	75.8	111	116	

APPENDIX E

***U.S.G.S.
Stage-Discharge
and
Velocity- Discharge
Data Summary***

Station Name: Elk River Near Tiff City, Missouri
Station ID: 0718900
Period of Record: July 1987 - June 1994

WIDTH (FT)	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
134	210	1.11	4.2	234
120	104	1.07	3.87	112
152	242	2.6	4.56	630
290	561	2.03	5.02	1140
148	194	1.17	3.97	227
104	97.1	0.97	3.63	93.9
150	340	2.12	4.89	719
140	203	1.69	4.23	343
310	1150	2.99	7.68	3440
160	264	2.71	5.01	715
146	186	1.63	4.4	305
147	171	1.81	4.4	310
126	181	1.8	4.39	326
122	218	2.21	4.66	482
97	65.2	1.7	3.71	111
309	1010	2.5	6.5	2530
307	869	2.72	6.29	2360
125	148	1.51	4.08	224
133	322	0.61	3.97	195
192	307	1.95	4.44	600
158	313	1.36	4.23	426
125	108	1.28	4.11	138
57	52.5	1.32	3.8	69.3
100	113	1.32	4.09	150
224	388	2.71	5.1	1050
134	178	1.52	4.44	270
107	164	1.58	4.42	259
118	148	1.33	3.95	197
89	74.9	1.6	3.63	120
300	917	2.6	6.37	2390
290	24	1.97	5.4	1230
170	305	1.23	3.99	375
258	440	3.59	5.68	1580
150	150	2.64	3.96	396
301	1580	3.65	8.93	5770
165	163	3.2	4.38	368

Station Name: **Neosho River at Burlington, Kansas**
Station ID: **07182510**
Period of Record: **January 1987 - July 1994**

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
164	239	1.55	7.07	370
121	748	4.76	10.76	3560
82	504	2.33	8.26	1180
82	480	1.84	7.91	882
168	279	1.87	7.29	521
161	201	1.35	6.82	271
84	397	2.62	8.03	1040
175	2150	5.4	19.76	11600
123	82.8	0.74	6.1	61.2
170	311	1.99	7.52	619
112	487	3.37	8.74	1640
170	233	1.96	7.17	457
134	956	5.61	12.25	5360
157	152	1.05	6.49	159
43	16.2	1.13	5.82	18.3
74.5	35.4	1.97	6.06	69.8
151	102	0.76	6.16	77
130	89.4	0.78	6.09	69.6
30	11.6	1.87	5.84	21.7
132	87.8	0.27	5.92	23.5
118	35.6	0.71	5.9	25.4
120	25.4	0.67	5.84	17.1
116	25.9	0.68	5.85	17.5
116	35.9	0.57	5.83	20.6
116	514	3.46	8.91	1780
179	350	1.67	7.64	584
171	1680	4.68	16.06	7870
127	50.6	0.93	5.94	46.9
59.5	41	1.39	5.96	57.1
76	96.8	1.47	6.28	142
74	74.7	0.7	6.14	106
98.5	168	2.46	7.11	413
60.5	41.6	0.77	5.8	32.2
64.5	55.6	1.36	6.02	75.9
99	432	1.93	7.89	835
59	40.7	0.85	5.84	34.7
44.5	18.2	1.37	5.82	24.9
36	12	0.87	5.77	10.4
105	93.4	1.45	6.34	135
73	66	1.03	6.07	67.7
43.5	19.4	1.03	5.83	20
43.5	19.2	0.93	5.83	17.9
101	445	2.04	8.09	906
115	645	4.02	9.78	2590
41	21.8	1.98	5.97	43.2
131	60.9	0.92	5.99	56.1
42	19.9	1.08	5.84	21.5
41.8	19.6	1.17	5.83	22.9
44.2	20.3	1.2	5.86	24.4
43	31.6	0.73	5.85	22.8
132	982	5.04	12.38	4950
107	536	2.61	8.56	1400
109	535	2.62	8.54	1400
242	1900	5.13	17.32	9740
77	78.4	1.62	6.28	127
71	24.3	0.94	5.86	22.8
183	313	1.3	7.13	406
105	544	2.39	8.44	1300
183	393	1.93	7.83	760
307	3360	4.26	22.5	14300
102	513	2.67	8.54	1370
310	3230	4.15	23.15	13400
100	127	2.39	6.9	303
84	98.6	1.52	6.36	150
109	491	2.18	8.34	1070
43.5	26.8	0.65	5.87	28.4
111	664	3.35	9.45	2220
105	420	1.43	7.46	602

Station Name: Neosho River near Iola, Kansas
Station ID: 07183000
Period of Record: February 1987 - August 1984

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
178	1600	2.71	8.23	4340
173	1240	1.9	6.29	2350
185	1880	3.19	9.81	5990
165	960	1.11	4.85	1070
171	1080	1.48	5.45	1600
165	964	1.08	4.84	1040
96	46.7	1.04	2.68	48.7
187	2030	3.36	10.66	6810
169	1020	1.19	5.09	1220
171	1140	1.56	5.83	1780
200	2740	4.34	13.96	11900
170	945	0.97	4.64	920
162	325	1.46	3.86	475
92.5	54.4	1.37	2.78	74.5
43	28	0.9	2.46	25.3
90.5	60.2	0.65	2.64	38.9
43	31.2	0.84	2.48	26.2
61	32.3	1.08	2.63	34.7
73	41.4	1.22	2.68	50.3
45	21.3	0.64	2.4	13.6
168	976	1.05	4.83	1020
99	54.1	1.33	2.77	71.8
158	333	1.55	4.07	517
150	218	2.55	4.1	556
182	1880	3.25	9.75	6110
205	2920	4.49	15.37	13100
112	140	1.09	3.07	153
67.5	33.4	1.21	2.6	40.5
60.5	27.3	1.05	2.51	28.8
54	22.4	0.8	2.47	17.9
158	317	0.96	3.54	303
88	45.2	1.44	2.7	65
67.5	38.5	1.36	2.67	52.5
167	1200	1.89	6.28	2270
135	123	1.09	3	134
140	113	0.44	2.62	49.5
54	27.9	0.61	2.4	17
92	43.4	0.66	2.49	28.6
99	65.5	0.76	2.67	49.6
147	128	1.43	3.2	184
170	1040	1.28	5.17	1330
167	431	2.44	4.14	620

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
177	1440	2.31	7.39	3330
413	5440	4.83	25.37	26300
198	2570	4.35	13.46	11200
162	285	1.68	3.85	480
150	120	0.34	2.59	40.8
197	2550	4.31	13.35	11000
239	4770	5.22	23.16	24900
171	1080	1.42	5.34	1530
187	2020	3.75	10.55	7570
220	3410	4.9	17.43	16700
173	1190	1.79	6.23	2130
202	2910	4.64	15.06	13500
171	1080	1.37	5.36	1480
170	1240	1.72	5.99	2130
153	208	1	3.26	208
187	2220	3.65	11.15	8100
152	181	0.65	2.96	118
88	88	1.44	2.78	78.4

Station Name: **Neosho River near Parsons, Kansas**
Station ID: **07183500**
Period of Record: **June 1987 - August 1994**

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
174	1990	1.73	10.21	3440
255	2660	2.35	11.95	6260
207	217	1.51	7.58	328
205	220	1.55	7.61	342
231	1910	0.68	8.53	1300
181	126	0.72	7	90.6
214	323	1.7	7.84	551
228	3220	3.03	15.05	9750
173	1820	1.06	9.17	1930
185	1370	2.83	10.42	3880
186	2080	4.86	14.18	10100
214	340	1.92	8.01	651
218	411	2.16	8.22	888
184	92.5	0.78	6.97	72.3
62	44.8	1.15	6.84	51.6
31	19	0.94	6.58	17.9
61	70.2	1.27	7.08	89.4
198	159	1.45	7.46	230
180	134	1.02	7.24	137
34	24.6	1.87	6.79	46.1
190	1990	4.12	13.03	8200
62	53.8	1.6	7.06	86
199	156	1.85	7.54	288
48	99.3	1.5	7.3	149
163	120	1.89	7.44	227
212	3720	5.49	21.28	20440
159	931	1.94	9.03	1810
930	11500	3.29	26.7	37800
168	95.6	1.36	7.9	130
220	423	2.44	8.41	1030
38	29.8	1.98	6.91	58.9
19.5	12.2	0.78	6.44	9.54
27	19.3	1.11	6.6	21.4
38	15.8	1.41	6.83	36.5
198	119	0.89	7.13	106
171	129	1.12	7.3	145
172	1070	2.28	9.42	2440
58.5	29.6	0.8	6.66	23.6
58	35.7	0.68	6.64	24.1
56	26.2	0.57	6.55	15
20.5	10.5	0.34	6.3	3.55
59	53.3	0.93	6.87	49.8

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
62	52.8	1.47	7.03	77.6
195	2300	2.16	11.14	4970
211	343	2	8.02	687
364	5280	4	22.02	21140
212	241	1.99	7.79	480
213	132	1.29	7.28	170
187	2010	4.26	13.8	8560
855	11200	3.39	26.44	38000
188	1940	4.24	13.17	8230
196	2560	4.5	16.49	11520
881	8130	2.89	22.06	23500
213	3390	5.72	20.14	19400
199	2650	5.06	16.58	13400
170	1430	3.41	11.2	4880
212	234	1.76	7.73	413
211	195	1.75	7.64	342
171	1180	2.53	9.92	2980
966	12520	3.71	27.66	46400
212	175	1.36	7.43	239
194	108	1.69	7.32	182

Station Name: **Neosho River near Commerce, Oklahoma**
Station ID: **07185000**
Period of Record: **July, 1987 - June, 1993**

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
252	1200	2.68	4.8	3220
125	274	2.38	3.22	651
120	163	0.72	2.44	118
332	536	2.5	3.78	1340
250	1180	2.07	4.35	2440
337	486	1.98	3.47	961
239	173	0.8	2.46	162
64	42.6	2.91	2.34	124
89	81.3	2.71	2.51	220
257	1110	1.39	3.72	1550
265	1350	2.73	4.98	3690
99	107.	2.6	2.68	279
57	29.3	2.02	2.21	59.3
260	1247	2.95	4.93	3690
121	123	1.19	2.67	146
121	120	1.12	2.67	134
115	210	1.43	2.73	300
115	205	1.41	2.71	289
235	967	1.38	3.81	1340
1057	8270	3.2	18.02	26500
1087	9620	3.35	19.34	32200
1142	11400	3.39	20.26	38700
310	4010	4.89	14.78	19600
235	1020	1.36	3.83	1390
70	85.9	1.77	2.46	152
209	154	0.51	2.25	78.5
60	76.3	1.14	2.25	86.7
99	171	1.33	2.6	227
49	40.1	1.03	2.08	41.5
53	62.7	0.7	2.1	44
224	860	1.24	3.56	1070
93	145	1.28	2.49	186
227	1090	2.04	4.26	2220
257	3400	5.91	13.91	20100
227	841	0.94	3.29	791
270	3650	6.08	15.1	22200
1060	9770	3.46	19.8	33800
64	131	1.53	2.59	210
293	4500	5.82	16.85	26200
240	1680	3.88	6.42	6520
233	2210	4.42	7.95	9050
792	10100	4.09	20.17	41300

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
255	2790	4.62	10.88	12900
358	10200	5.06	24.08	71700
240	1083	1.74	4.24	1880
239	896	1.58	3.72	1180
159	231	1.69	2.92	390
241	1340	3.14	5.19	4210

Station Name: **Spring River near Waco, Missouri**
Station ID: **07186000**
Period of Record: **July, 1987 - August, 1994**

WIDTH (FT)	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)	WIDTH (FT)	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
96	87.1	0.40	1.62	34.6	108	129	0.57	1.85	74
104	92.6	0.34	1.62	31.9	109	139	0.90	2.04	125
108	107	0.50	1.77	53.8	100	356	2.54	3.78	904
108	116	0.71	1.87	82.8	101	442	3.39	4.66	1500
104	106	0.48	1.73	50.7	97	281	2.19	3.26	638
104	115	0.60	1.83	68.6	121	674	4.45	6.80	3000
106	110	0.54	1.78	59.1	100	353	2.54	3.74	895
108	122	0.74	1.92	90	114	576	3.94	5.90	2270
133	1100	4.91	9.87	5400	110	189	1.31	2.41	248
102	313	2.25	3.36	706	111	217	1.40	2.60	304
106	119	1.10	1.98	131	101	490	3.43	5.00	1681
98	349	0.26	2.87	440	122	263	1.43	2.73	375
110	185	1.60	2.41	296	99	352	2.90	3.83	1020
112	205	1.76	2.56	360	110	198	1.16	2.36	230
128	844	4.50	8.00	3800	109	160	0.69	2.01	110
100	338	2.47	3.55	835	109	146	0.49	1.84	72
131	979	4.82	9.06	4720	99	253	1.49	2.72	378
106	187	1.76	2.50	330	97	291	1.79	3.02	521
110	208	1.86	2.66	386	96	274	1.95	3.08	534
95	307	2.50	3.52	766	98	374	2.86	4.02	1070
107	170	1.52	2.30	259	112	318	1.95	3.34	621
92	391	3.35	4.45	1310	99	373	2.92	4.04	1090
108	130	0.99	1.95	129	104	171	0.98	2.27	167
104	126	0.79	1.87	99.5	104	136	0.67	2.02	91
104	378	3.16	4.14	1190	108	158	0.55	1.95	87
98	263	2.01	3.02	528	99	390	2.67	4.05	1040
96	269	2.15	3.06	579	99	381	2.78	4.19	1060
98	371	3.10	4.20	1150	97	268	1.76	3.09	472
128	920	4.83	8.50	4440	156	1560	5.79	12.48	9040
98	276	2.17	3.25	600	115	247	1.39	2.82	344
99	294	2.12	3.26	623	110	186	0.76	2.13	141
106	139	0.94	2.12	130	110	192	0.90	2.24	173
108	133	0.80	2.02	107	110	167	0.83	2.07	139
112	220	1.75	2.76	386	98	311	2.22	3.36	691
101	488	3.61	5.09	1760	98	358	2.69	3.82	963
124	730	4.55	7.04	3320	97	366	2.79	3.95	1020
99	251	1.81	2.82	455	106	190	1.13	2.20	215
101	414	3.14	4.39	1300	108	170	0.94	2.04	160
98	389	3.11	4.28	1210	104	194	1.27	2.32	248
99	262	1.94	2.95	507	112	232	1.72	2.61	400
109	190	1.53	2.53	290	111	152	0.65	1.91	99
108	134	0.73	1.98	98	84	141	0.46	1.75	64

Station Name: Spring River near Waco, Missouri (Continued)

WIDTH (FT)	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
98	308	2.48	3.65	764
99	390	2.87	4.14	1120
99	360	2.92	3.85	1050
176	2430	6.30	18.07	15300
175	2300	5.87	17.48	13500
112	280	1.51	2.83	423
109	205	0.94	2.24	192
110	197	1.09	2.21	214
110	185	0.86	2.10	160
99	366	2.59	3.97	947
99	357	2.73	3.80	976
110	224	1.54	2.43	345
108	197	1.49	2.31	294
110	190	1.35	2.19	257
107	99	0.60	1.40	59
96	118	0.55	1.40	65
91	93	0.41	1.15	38
92	98	0.48	1.24	47
90	102	0.52	1.28	53
102	168	1.01	1.87	170
102	168	1.14	1.91	191
104	204	1.27	2.12	260
104	219	1.62	2.33	354
102	184	1.08	1.93	198
99	335	2.62	3.52	879
166	2200	5.95	16.95	13100
98	504	3.89	4.98	1960
127	759	4.04	7.12	3070
167	372	3.55	4.31	1320
101	439	3.48	4.36	1530
138	1244	5.60	10.26	6970
130	1080	5.44	9.64	5870
112	234	1.50	2.53	351
98	356	3.17	4.07	1130
98	275	2.71	3.26	746
113	214	1.65	2.61	354
125	1030	5.76	9.24	5930
95	281	2.53	3.32	710
97	323	2.75	3.59	887
106	168	1.14	2.02	191

Station Name: Spring River near Quapaw, Oklahoma
Station ID: 07188000
Period of Record: July, 1987 - June, 1994

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
238	1160	1.66	7.46	1920
115	209	1.63	5.27	341
114	190	1.43	5.27	272
260	1550	1.22	6.79	1270
260	1310	1.17	6.83	1530
260	1710	1.29	7.55	2200
255	1500	0.93	6.56	1400
119	228	0.55	5.6	413
123	224	2.5	5.59	564
260	1550	0.95	6.84	1480
262	1960	1.87	8.62	3670
254	1494	1	6.79	1500
249	1234	0.7	5.89	866
122	144	3.03	5.47	437
101	103	2.51	4.98	259
111	125	1.83	4.89	229
250	1260	0.76	6.07	953
348	6730	7.09	24.25	47500
265	1720	1.8	8.39	3100
265	1840	1.89	8.76	3480
246	1150	0.75	6.05	827
131	182	3.48	5.67	633
245	1180	0.86	6.41	1020
250	1570	1.71	8.05	2680
140	221	3.69	5.91	816
115	142	2.75	5.15	390
94	71.8	2.24	4.57	161
110	101	2.64	4.76	267
140	227	3.62	5.86	822
131	180	3.24	5.44	584
120	183	3.39	5.56	621
290	3460	4.25	14.32	14700
125	190	3.28	5.6	624
300	4470	5.03	17.39	22500
255	1700	1.95	8.5	3310
260	1510	1.3	7.56	2110
335	6140	6.49	22.45	39900
260	1570	1.25	7.45	1960
270	2300	2.52	10.14	5800
330	5890	6.23	21.4	36500
258	1780	1.56	8.3	2780

WIDTH	AREA	MEAN VEL.	GAGE HEIGHT	FLOW (CFS)
250	1620	1.18	7.3	1910
730	14500	6.82	34.63	98900
750	14500	6.57	33.8	95200
264	2110	0.96	8.27	2030
260	1780	0.54	7.21	954
275	2670	1.72	10.18	4600
290	3790	3.72	14.24	14100

APPENDIX F

U.S.G.S. Phosphorous Loading Data Summary

Station Name: **Elk River Near Tiff City, Missouri**
Station ID: **0718900**

Average Phosphorous Loading and Parameters used for "Unbiased Stratified Ratio Estimator"

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV		AVG
n, Number of P Samples	5	6	6	5	4	6	6	5	4	2	4	5	
Qp, Mean Daily Flow (cfs)	678	864	1309	1625	1542	947	488	272	307	431	704	777	
Wc, Daily Loading for days sampled (lbs/day)	128	254	538	730	455	673	150	78	139	40	4437	1347	
Qc, Mean Daily Flow on sample days (cfs)	797	658	1773	1037	1257	1146	466	221	333	368	2502	2873	
(S)qw	46689.05	-61578	357096.1	5660.92	180566.5	140421.1	43303.89	6942.536	16430.12	17206.23	5177261	1062834	
(S)q^2	339246.8	342970.3	1295262	667603.7	292675.7	1743025	63320.27	16255	65862.67	159612.5	3313300	2191108	
Wp, Estimated Average Load (lbs/day)	**107**	**276**	**395**	**1020**	**576**	**469**	**166**	**97**	**122**	**46**	**1231**	**369**	**406**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.12	0.32	0.45	1.17	0.66	0.54	0.19	0.11	0.14	0.05	1.41	0.42	**0.47**

Average Phosphorous Loading (from Average values)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Wp, Estimated Average Load (lbs/day)	**155**	**479**	**395**	**712**	**521**	**463**	**176**	**159**	**143**	**134**	**545**	**264**	**345**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.18	0.55	0.45	0.82	0.60	0.53	0.20	0.18	0.16	0.15	0.62	0.30	**0.40**

Station Name: **Neosho River at Burlington, Kansas**
Station ID: **07182510**

Average Phosphorous Loading and Parameters used for "Unbiased Stratified Ratio Estimator"

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
n, Number of P Samples	11	9	13	13	12	13	17	12	12	12	10	9	
Qp, Mean Daily Flow (cfs)	812	1094	1873	2505	2507	3288	2361	1093	721	1468	1265	1099	
Wc, Daily Loading for days sampled (lbs/day)	673	229	1627	3635	4928	3908	2741	733	801	1517	2116	1378	
Qc, Mean Daily Flow on sample days (cfs)	891	740	2985	3710	2737	4273	2126	776	1176	1193	2402	1739	
(S)qw	191194	7819.85	-23063	-269546	1.4E+07	569353	-36222	-54856	-93736	-14425	-73080	-23677	
(S)q^2	357539	596043	928563	1342802	1.1E+07	2.6E+07	912983	158500	754078	1.1E+07	1.6E+07	462056	
Wp, Estimated Average Load (lbs/day)	**606**	**303**	**942**	**2248**	**4395**	**2785**	**2711**	**779**	**310**	**1145**	**858**	**737**	**1485**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.20	0.10	0.31	0.74	1.44	0.92	0.89	0.26	0.10	0.38	0.28	0.24	**0.49**

Average Phosphorous Loading (from Average values)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Wp, Estimated Average Load (lbs/day)	**1013**	**584**	**1233**	**1705**	**2048**	**2329**	**4095**	**666**	**469**	**3036**	**886**	**732**	**1566**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.33	0.19	0.41	0.56	0.67	0.77	1.35	0.22	0.15	1.00	0.29	0.24	**0.51**

Station Name: **Neosho River near Parsons, Kansas**
Station ID: **07183500**

Average Phosphorous Loading and Parameters used for "Unbiased Stratified Ratio Estimator"

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
n, Number of P Samples	9	11	11	14	12	15	12	14	12	12	12	11	
Qp, Mean Daily Flow (cfs)	1287	1667	2933	4300	4268	5138	3754	1403	2035	2323	2143	1412	
Wc, Daily Loading for days sampled (lbs/day)	1842	3745	6579	14892	2777	7401	11750	772	2427	4776	9653	5597	
Qc, Mean Daily Flow on sample days (cfs)	1892	3222	5187	8200	3118	4779	5355	1045	1852	4000	4835	3907	
(S)qw	104453	1.9E+07	3.8E+07	1.6E+08	1.6E+07	4.1E+07	9.4E+07	753946	1.6E+07	6E+07	1.8E+08	3.7E+07	
(S)q^2	203572	1.2E+07	3.1E+07	6.4E+07	1.6E+07	2.6E+07	3E+07	903542	1.1E+07	5.3E+07	6.7E+07	2.2E+07	
Wp, Estimated Average Load (lbs/day)	**1218**	**2010**	**3706**	**7983**	**3864**	**7974**	**8516**	**1044**	**2703**	**2738**	**4547**	**2060**	**4030**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.25	0.41	0.76	1.63	0.79	1.63	1.74	0.21	0.55	0.56	0.93	0.42	**0.82**

Average Phosphorous Loading (from Average values)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Wp, Estimated Average Load (lbs/day)	**1179**	**1354**	**3656**	**5767**	**2842**	**5685**	**4249**	**827**	**1632**	**2106**	**2589**	**1405**	**2774**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.27	0.31	0.85	1.34	0.66	1.32	0.99	0.19	0.38	0.49	0.60	0.33	**0.65**

Station Name: Spring River near Waco, Missouri
Station ID: 07186000

Average Phosphorous Loading and Parameters used for "Unbiased Stratified Ratio Estimator"

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
n, Number of P Samples	7	15	11	15	12	17	12	16	12	15	11	13	
Qp, Mean Daily Flow (cfs)	705	914	1217	1417	1474	1389	710	457	599	652	901	727	
Wc, Daily Loading for days sampled (lbs/day)	1448	875	330	1984	486	517	3177	198	237	256	880	2026	
Qc, Mean Daily Flow on sample days (cfs)	1334	1112	659	2076	664	498	1988	175	180	175	655	2139	
(S)qw	1.2E+06	1.8E+06	3.4E+04	6.3E+06	4.1E+04	1.1E+05	4.1E+07	1.4E+04	5.6E+04	5.8E+04	1.1E+06	2.0E+07	
(S)q^2	2.4E+06	2.4E+06	4.2E+05	5.9E+06	1.6E+05	1.7E+05	2.4E+07	1.8E+04	3.9E+04	2.8E+04	5.4E+05	1.3E+07	
Wp, Estimated Average Load (lbs/day)	**697**	**715**	**567**	**1367**	**1058**	**1418**	**1165**	**509**	**795**	**977**	**1269**	**770**	**942**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.60	0.61	0.49	1.17	0.91	1.22	1.00	0.44	0.68	0.84	1.09	0.66	**0.81**

Average Phosphorous Loading (from Average values)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Wp, Estimated Average Load (lbs/day)	**718**	**834**	**957**	**1317**	**1235**	**1730**	**1207**	**577**	**750**	**742**	**1085**	**633**	**982**
(Wp)a, Average Areal Load (lbs/day/mi^2)	0.62	0.72	0.82	1.13	1.06	1.49	1.04	0.50	0.64	0.64	0.93	0.54	**0.84**

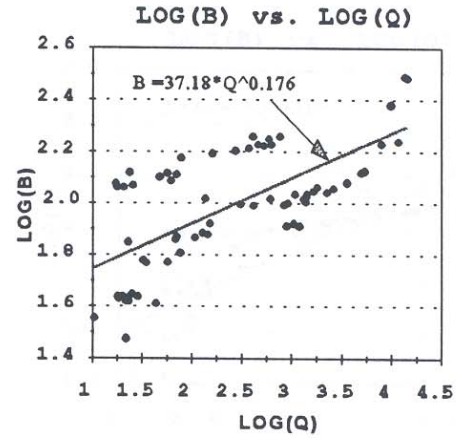
APPENDIX G

Stage-Discharge, Velocity-Discharge, and Width-Discharge Plots

Station Name: Neosho River at Burlington, Kansas
Station ID: 07182510
Period of Record: January 1987 - July 1994

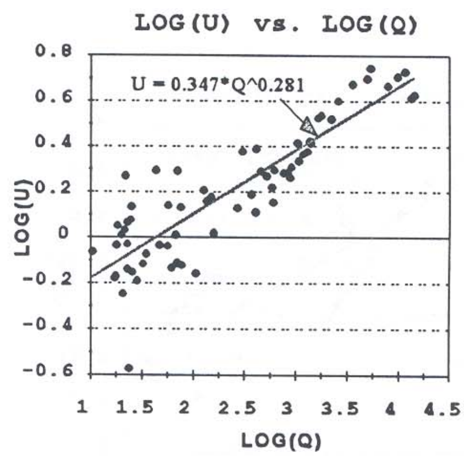
LOG(B) vs. LOG(Q)
Regression Output:

Constant	1.5703056
R Squared	0.4666953
No. of Observations	68
Degrees of Freedom	66
X Coefficient(s)	0.1763125
Std Err of Coef.	0.0231997



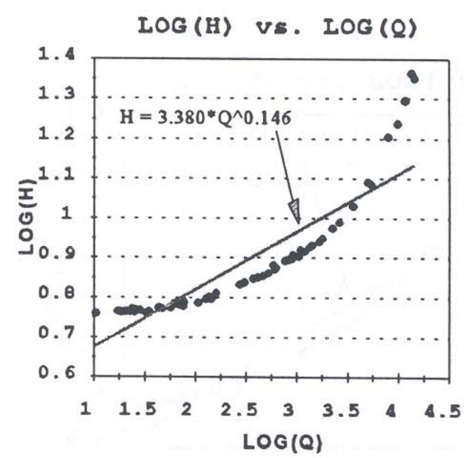
LOG(U) vs. LOG(Q)
Regression Output:

Constant	-0.459386
Std Err of Y Est	0.1349551
R Squared	0.7758046
No. of Observations	68
Degrees of Freedom	66
X Coefficient(s)	0.2809675
Std Err of Coef.	0.0185918



LOG(H) vs. LOG(Q)
Regression Output:

Constant	0.5289033
Std Err of Y Est	0.0660227
R Squared	0.7956286
No. of Observations	68
Degrees of Freedom	66
X Coefficient(s)	0.1457949
Std Err of Coef.	0.0090955

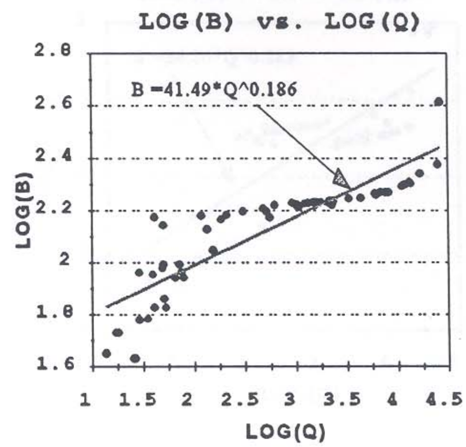


Station Name: Neosho River near Iola, Kansas
Station ID: 07183000
Period of Record: February 1987 - August 1984

LOG(B) vs. LOG(Q)

Regression Output:

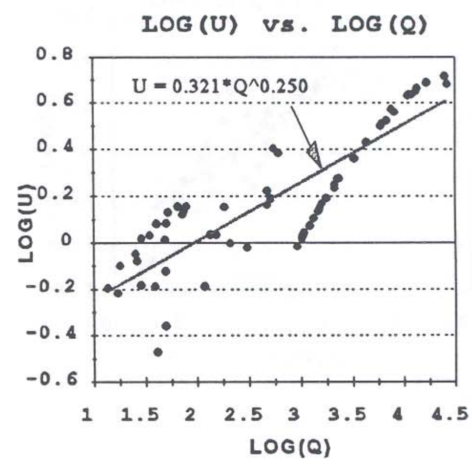
Constant	1.6178904
Std Err of Y Est	0.100713
R Squared	0.7683482
No. of Observations	60
Degrees of Freedom	58
X Coefficient(s)	0.1859756
Std Err of Coef.	0.0134085



LOG(U) vs. LOG(Q)

Regression Output:

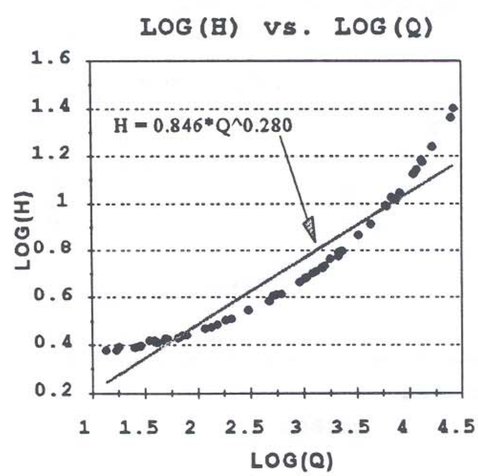
Constant	-0.493793
Std Err of Y Est	0.1453866
R Squared	0.7426966
No. of Observations	60
Degrees of Freedom	58
X Coefficient(s)	0.2504474
Std Err of Coef.	0.0193562



LOG(H) vs. LOG(Q)

Regression Output:

Constant	-0.072577
Std Err of Y Est	0.0811528
R Squared	0.9203542
No. of Observations	60
Degrees of Freedom	58
X Coefficient(s)	0.2797104
Std Err of Coef.	0.0108043

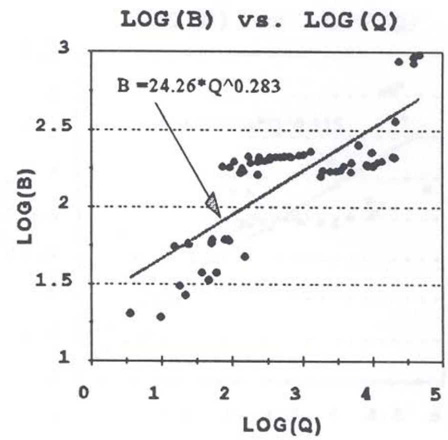


Station Name: Neosho River near Parsons, Kansas
Station ID: 07183500
Period of Record: June 1987 - August 1994

LOG(B) vs. LOG(Q)

Regression Output:

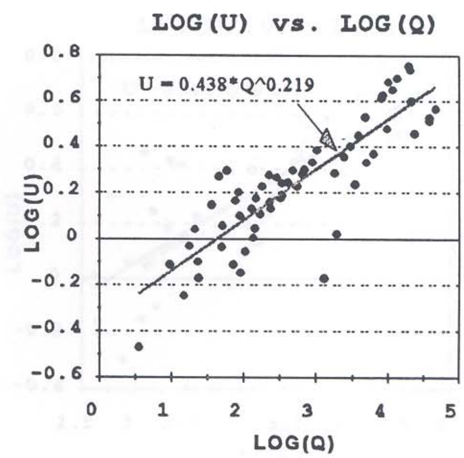
Constant	1.3847945
R Squared	0.64429
No. of Observations	62
Degrees of Freedom	60
X Coefficient(s)	0.2828608
Std Err of Coef.	0.0271334



LOG(U) vs. LOG(Q)

Regression Output:

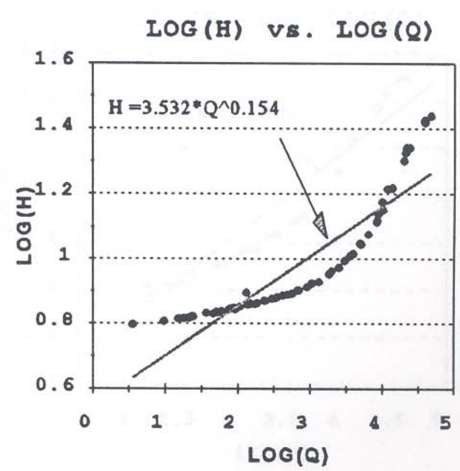
Constant	-0.35809
Std Err of Y Est	0.1366132
R Squared	0.7447851
No. of Observations	62
Degrees of Freedom	60
X Coefficient(s)	0.2194299
Std Err of Coef.	0.0165828



LOG(H) vs. LOG(Q)

Regression Output:

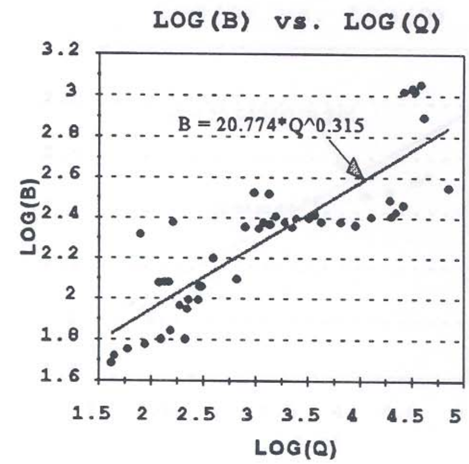
Constant	0.5480014
Std Err of Y Est	0.0766006
R Squared	0.8202482
No. of Observations	62
Degrees of Freedom	60
X Coefficient(s)	0.1538541
Std Err of Coef.	0.0092982



Station Name: Neosho River near Commerce, Oklahoma
Station ID: 07185000
Period of Record: July, 1987 - June, 1993

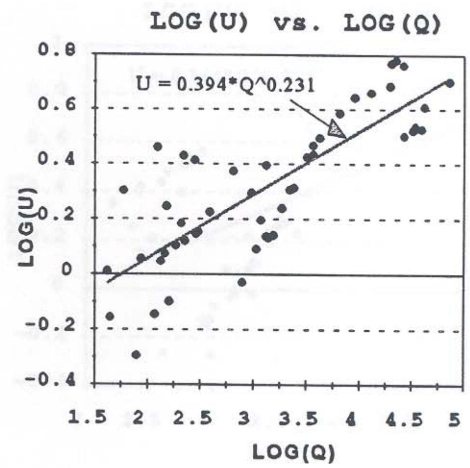
LOG(B) vs. LOG(Q)
Regression Output:

Constant	1.3175105
R Squared	0.7303607
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.314785
Std Err of Coef.	0.0282006



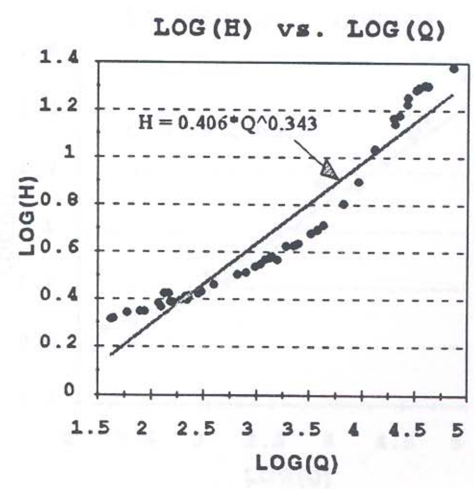
LOG(U) vs. LOG(Q)
Regression Output:

Constant	-0.405036
Std Err of Y Est	0.1562253
R Squared	0.662865
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.2311712
Std Err of Coef.	0.0243077



LOG(H) vs. LOG(Q)
Regression Output:

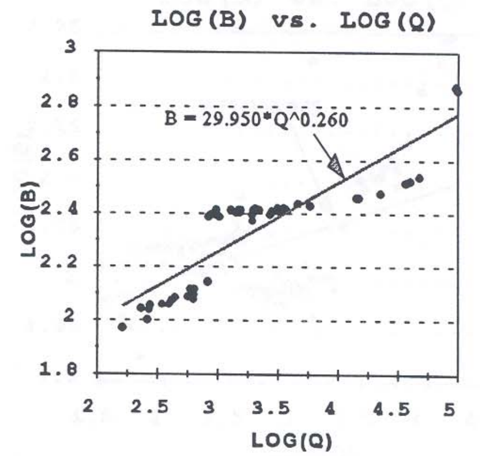
Constant	-0.391108
Std Err of Y Est	0.0981531
R Squared	0.9163473
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.3428195
Std Err of Coef.	0.015272



Station Name: Spring River near Quapaw, Oklahoma
Station ID: 07188000
Period of Record: July, 1987 - June, 1994

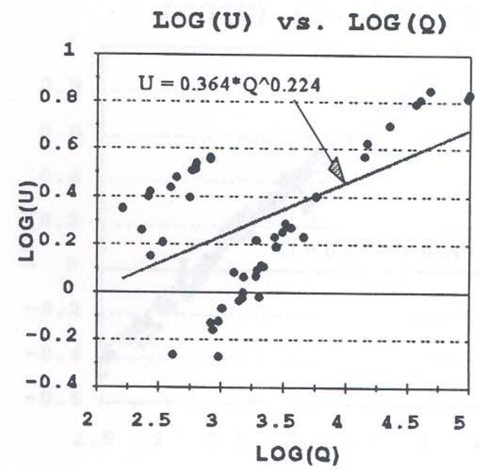
LOG(B) vs. LOG(Q)
Regression Output:

Constant	1.4763952
R Squared	0.772187
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.2599937
Std Err of Coef.	0.0208215



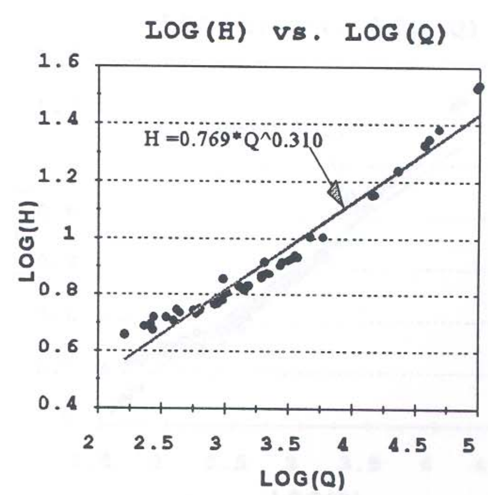
LOG(U) vs. LOG(Q)
Regression Output:

Constant	-0.439324
Std Err of Y Est	0.2579164
R Squared	0.2722146
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.224444
Std Err of Coef.	0.0541097



LOG(H) vs. LOG(Q)
Regression Output:

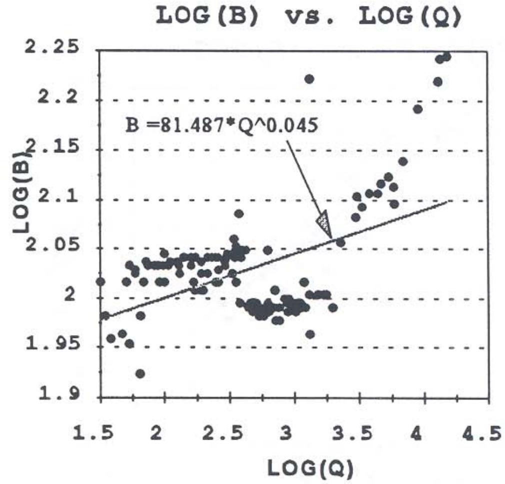
Constant	-0.114111
Std Err of Y Est	0.0446319
R Squared	0.9597853
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.3102523
Std Err of Coef.	0.0093636



Station Name: Spring River near Waco, Missouri
Station ID: 07186000
Period of Record: July, 1987 - August, 1994

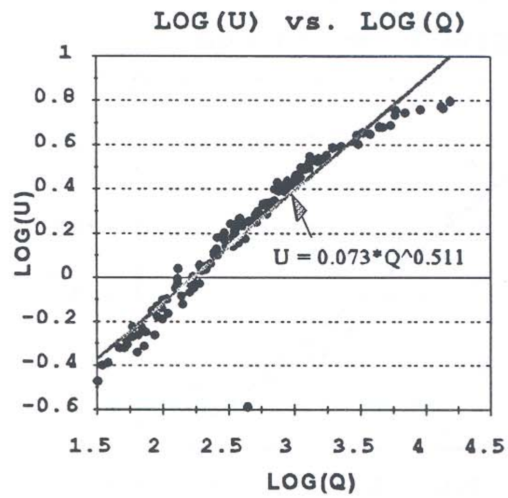
LOG(B) vs. LOG(Q)
Regression Output:

Constant	1.9110863
R Squared	0.2445204
No. of Observations	124
Degrees of Freedom	122
X Coefficient(s)	0.0447126
Std Err of Coef.	0.0071155



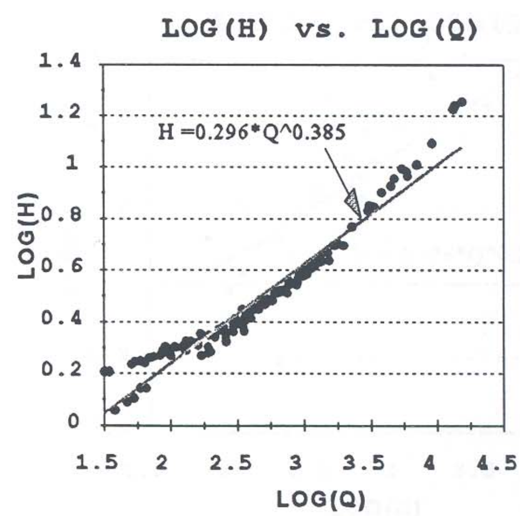
LOG(U) vs. LOG(Q)
Regression Output:

Constant	-1.137545
Std Err of Y Est	0.0944905
R Squared	0.9141472
No. of Observations	124
Degrees of Freedom	122
X Coefficient(s)	0.5107821
Std Err of Coef.	0.0141718



LOG(H) vs. LOG(Q)
Regression Output:

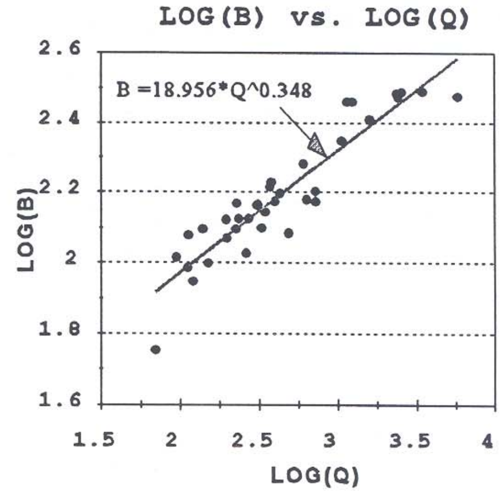
Constant	-0.52911
Std Err of Y Est	0.0572143
R Squared	0.942802
No. of Observations	124
Degrees of Freedom	122
X Coefficient(s)	0.3848055
Std Err of Coef.	0.0085811



Station Name: Elk River Near Tiff City, Missouri
Station ID: 0718900
Period of Record: July 1987 - June 1994

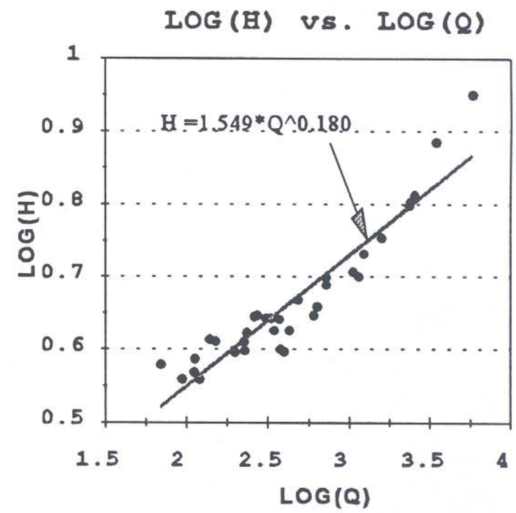
LOG(B) vs. LOG(Q)
Regression Output:

Constant	1.2777423
R Squared	0.8740765
No. of Observations	37
Degrees of Freedom	35
X Coefficient(s)	0.3479106
Std Err of Coef.	0.0223209



LOG(U) vs. LOG(Q)
Regression Output:

Constant	-0.487277
Std Err of Y Est	0.1140527
R Squared	0.5862369
No. of Observations	36
Degrees of Freedom	34
X Coefficient(s)	0.281196
Std Err of Coef.	0.0405144



LOG(H) vs. LOG(Q)
Regression Output:

Constant	0.1901318
Std Err of Y Est	0.0311297
R Squared	0.8861957
No. of Observations	36
Degrees of Freedom	34
X Coefficient(s)	0.1799298
Std Err of Coef.	0.011058