IMPACTS OF PROPOSED WASTEWATER DIVERSION ON EUTROPHICATION AND RELATED WATER QUALITY CONDITIONS IN THE ILLINOIS RIVER, OKLAHOMA

prepared for

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SUMMARY

The Illinois River is a unique and highly-valued resource in Oklahoma, as reflected by its designations as a Scenic River and cold-water fishery. Over the past decade, phosphorus and chlorophyll-a (algal pigment) concentrations have increased by factors of two to three in Lake Frances and Tenkiller Ferry Reservoir and are currently found within ranges considered "hypereutrophic", or excessively enriched. The associated increases in dissolved and particulate organic materials have led to violations in standards for dissolved oxygen, turbidity, and aesthetics at several locations in and below these impoundments. It is also likely that excessive levels of algal-derived organic material in Lake Frances are responsible for the 20% violation frequency of the trihalomethane standard observed at the Siloam Springs water supply. This degradation has serious implications for aquatic life, recreational uses, aesthetic qualities, water supplies, and public health.

Mass balance calculations indicate that phosphorus loadings from point sources in Arkansas are transported over long distances and have significant effects on Lake Frances, Tenkiller Ferry Reservoir, and the intervening river segments. Currently, sewage effluent from Arkansas point sources accounts for at least 16% of the flow leaving Lake Frances under the seven-day-average, two-year-frequency, low-flow conditions (7-Q-2) to which Oklahoma water quality standards apply. The proposed Fayetteville discharge would increase the effluent percentage to 23%. Under median summer flows, the effluent percentage would increase from 9% to 14%. Existing point and nonpoint nutrient loadings have already consumed the basin's capacity to assimilate nutrient loadings without causing nuisance algal growths. The watershed is simply too small to handle effluent volumes of the existing and proposed magnitudes without violating the standards, unless nutrient removal can be accomplished down to the levels of existing nonpoint sources in the basin (roughly .15 mg/liter Total P and 2.5 mg/liter Total N).

Because of its nutrient contributions, the proposed sewage diversion from Fayetteville will increase the spatial and temporal violation frequencies of the following water quality standards applicable to the Illinois River Basin (Oklahoma Water Resources Board, 1982):

(1) **nutrients**: "not to exceed levels which result in man-induced eutrophication problems"

(2) **dissolved oxygen**: minimum 6 mg/l in stream segments
minimum 5 mg/l in lake surface waters

(3) **turbidity**: maximum 10 NTU

(4) **solids (suspended and/or settleable)**: "maintained so as to be essentially free of floating debris, bottom deposits, scum, foam, and other materials, including suspended solids of a persistent nature, from other than a natural source"

In addition, the nutrient enrichment and other changes in Illinois River water quality which would result from the Fayetteville discharge would be in direct violation of Oklahoma's Anti-Degradation Policy for its Scenic Rivers.

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INTRODUCTION

I have prepared this testimony at the request of the Office of the Attorney General, State of Oklahoma, with the following objectives:

(1) to review data on eutrophication and related water quality conditions in Illinois River basin;
(2) to evaluate the potential impacts of the proposed wastewater diversion from Fayetteville, Arkansas, on water quality conditions in the basin;
(3) to determine whether Oklahoma water quality standards related to eutrophication will be violated as a result of the diversion.

My qualifications (details provided separately) include fifteen years experience in the development and application of predictive techniques for surface water quality, with an emphasis on stream, lake, and reservoir eutrophication problems. I recently completed a seven-year research project for the Office of the Chief, U.S. Army Corps of Engineers. This project involved the compilation and analysis of a nationwide data base on reservoir quality, which included information from Tenkiller Ferry Reservoir, Beaver Reservoir, and several others in Oklahoma and Arkansas (Walker,1981). The data base was used to develop and test empirical techniques for predicting eutrophication and related water quality conditions in impoundments (Walker,1982,1984b,1985). Several of the techniques which were developed under the above research project have been applied to the relatively large volume of water quality and hydrologic data available for the Illinois River Basin in order to develop a technical basis for evaluating the impacts of the proposed Fayetteville discharge. Results are described below.

DATA SOURCES

The following evaluations are based partially upon review of water quality and hydrologic data retrieved from EPA's STORET data base.

Relevant stations and time periods are summarized in Table 1. A station map is shown in Figure 1. Stations along the Illinois mainstem have been renumbered in downstream order ("I01" above Clear Creek in Arkansas to "I16" just above the river mouth in Oklahoma).

The data include samples taken in 1985 and 1986 under the recent EPA/AR/OK Illinois River Basin Study, as well as results from intensive surveys of Tenkiller Ferry Reservoir conducted by the Corps of Engineers, Tulsa District, in 1986. Appendix A displays summaries of water quality data from various longterm monitoring stations as a function of flow regime. These summaries are referenced at various locations in the discussion below.

Survey reports on Lake Frances (USEPA,1977a;Threlkeld,1983), Tenkiller Ferry Reservoir (USEPA,1977b), and the Upper Illinois Basin (Oklahoma State Board of Health,1976; Terry et al.,1982; Roberts/Schornick & Assoc.,1984; Gakstatter and Katko,1986) have also been reviewed. Aerial and ground reconnaissance of the watershed have provided useful perspectives on terrain, land uses, river characteristics, and reservoir characteristics.

BASIN CHARACTERISTICS

As illustrated in Figure 2, the Illinois River flows approximately 160 miles from Northwest Arkansas, through Northeast Oklahoma, to the Arkansas River. The main river channel has a relatively uniform gradient of approximately 5 ft/mile. Tributary and headwater slopes are higher (10-22 ft/mile). With the exception of two reservoir segments (Frances and Tenkiller), flow velocities along the mainstem in Oklahoma are relatively high. Tommy Fain (pers. comm.,1986), a ranger with the Oklahoma Scenic River Commission, indicates that high velocities pose a hazard to recreational users below Lake Frances and are responsible for occasional drownings, even during relatively low-flow periods.

Under an extreme low flow of 52 cfs at the USGS gauge in Watts (USGS Station Number 07195500, 7-Q-2 = 82 cfs, mean flow = 578 cfs), the average velocity is .84 ft/sec or 14 miles/day (Daryl Walters, USGS, Tulsa, pers. com., 1986). At this rate, the time-of-travel between Lake Frances and Tenkiller Ferry would be on the order of 5 days and much lower under typical flows. The basin slope and flow velocity, combined with the low mean hydraulic retention time of Lake Frances (< 2 days) are conducive to downstream transport of nutrient discharges from the upper watershed, particularly over long time scales. The result is that Tenkiller Ferry Reservoir is the most likely receptacle for nutrients discharged from the upper watershed.

Because of geologic and climatologic factors, the Illinois River has high water quality potential in relation to other areas of the state. Moving west from the Mississippi River, mean precipitation is above 48 in/yr throughout most of Arkansas, begins to drop rapidly at the Oklahoma border, and reaches 16 inches/yr in western Oklahoma. Associated with this gradient in precipitation are gradients in natural vegetation (forested->grassland->desert shrub) and increases in watershed sediment yield (250->800 tons/mi2-yr) (Langbein and Schumm,1958). As a result of these gradients, streams in the eastern end of the state, particularly including the Illinois River, have the lowest natural suspended solids levels and highest potential aesthetic appeal. The existing and proposed future discharge of nutrients to these waters jeopardize this unique resource by promoting excessive levels of algal growth in various stream and reservoir segments.

Generally, water quality surveys conducted to date have not detected extensive growth of algae or periphyton in stream channels, but algae have been found in abundant quantities in reservoir segments (Gakstatter and Katko,1986). Large diurnal swings in dissolved oxygen, which reflect photosynthesis and respiration by algae or periphyton, have been detected in stream segments below Lake Frances, however. The existing data base is limited because intensive surveys of the river below Lake Frances have not been performed under summer, low-flow conditions which are most conducive to algal growth. Photographic evidence (Pigg,1986) suggests that significant algal densities are found in river reaches below Lake Frances and that these densities have increased in recent years.

Based upon basin hydraulic and morphometric characteristics and upon data analyses discussed below, Lake Frances and Tenkiller Ferry Reservoir are the two segments which are most vulnerable to eutrophication problems. While phosphorus uptake, deposition, and/or adsorption may occur in stream segments under low-flow conditions, these processes would be reversed under high-flow, scouring conditions. Algae generated within the two impoundments are transported to downstream river segments and lead to violations in Oklahoma's water quality standards, as described below.

LONGTERM TRENDS

Significant increases in phosphorus concentrations have been observed at mainstem river stations over the past decade or so (Figure 3). Some of the concentration changes can be explained by variations in hydrologic conditions. Because of the importance of point-source phosphorus discharges in the upper basin, stream concentrations tend to be higher above Lake Frances during low-flow years (e.g., 1980). Comparing years of similar mean flows, however, indicates that the average phosphorus concentration at the inflow to Lake Frances has roughly doubled over the ten-year period (e.g., 1975 vs. 1985). Photographs taken by Jimmy Pigg (1986) of the Oklahoma State Health Department demonstrate that increases in algal densities and noticeable decreases in aesthetic qualities occurred over roughly the same time period at Round Hollow below Lake Frances.

Figure 4 illustrates that the observed increases in stream phosphorus levels have been accompanied by substantial increases in chlorophyll-a concentrations in Lake Frances and Tenkiller Ferry Reservoir, based upon comparison of average concentrations detected by the EPA National Eutrophication Survey (1974-1975) with those derived from the recent EPA/OK/AR/COE basin study (1985-1986).

Chlorophyll-a, an algal photosynthetic pigment, is the most direct and practical measure of algal density. The following system is commonly used to classify lakes and reservoirs into trophic states based upon mean chlorophyll-a concentrations (Reckhow and Chapra,1983):

"Oligotrophic"	< 4 ppb
"Mesotrophic"	4 - 10 ppb
"Eutrophic"	10-25 ppb
"Hypereutrophic"	> 25 ppb

As shown in Figure 4, chlorophyll-a concentrations in Lake Frances and Tenkiller Ferry Reservoir increased two to three fold over the ten-year period. Based upon the 1986 data, Lake Frances and the upper end of Tenkiller would be classified as "hypereutrophic", the highest and most productive trophic state category. Such conditions are generally characterized by excessive quantities of algal-derived, soluble and particulate organic material, occasional scums and floating mats, and obnoxious taste and odors. Large fluctuations in dissolved oxygen levels occur on a daily basis because of photosynthesis and respiration processes. Periods of sustained oxygen depletion and resulting fish kills may occur following periodic die-off of algal blooms. Such conditions are stressful to aquatic life and can severely impair aesthetics and water uses (recreation, water supply) (Walmsley, 1984).

As demonstrated below, algal growth in Lake Frances increases significantly under low flows and is limited by hydraulic residence time under average to high flows. Flows on the dates of sampling by the EPA National Eutrophication Survey in 1974 were high in relation to those experienced during the summer 1985-6 surveys. Hydrologic factors may partially explain the observed differences in chlorophyll-a between the 1974-5 and 1985-6 time periods in Lake Frances. The increases in phosphorus concentrations cannot be explained based upon hydrologic factors, however.

Because of its relatively long hydraulic residence time, changes in Tenkiller cannot be explained by short-term flow variations. The coincident nitrate decreases and phosphorus increases in Tenkiller suggest that eutrophication has been accelerated due to increased point-source nutrient loadings. Relative to algal cell requirements (typically 7 parts nitrogen to 1 part phosphorus), point sources tend to be rich in phosphorus and non-point sources tend to be rich in nitrogen, particularly in this watershed because of the apparent significance of nitrate loadings resulting from land application of animal wastes (Gakstatter and Katko,1986). The ratio of nitrate nitrogen to ortho phosphorus decreased from 20 to 6 at the near-dam station over this time period. This decrease indicates that Tenkiller has been driven towards a nitrogen-limited condition, which is undesirable for reasons discussed below.

The decrease in N/P ratio further aggravates the problem of nutrient enrichment because it promotes the growth of nitrogen-fixing bluegreen algae which tend to be more objectionable to water users (scum formation, odor, taste). Because they have the unique capability to derive nitrogen supplies from the atmosphere, bluegreens have competitive advantage over other algal types under nitrogen-limited conditions.

Because their cells are relatively large and/or toxic, bluegreens are generally less susceptible to predation by zooplankton than are other algal types. As a result, bluegreen productivity tends to create an excessive organic load which is processed by decomposer organisms (bacteria and fungi) and leads to oxygen depletion. Other, less undesirable algal types (diatoms, greens) are grazed by zooplankton and thereby supply the food chain which leads to fish production.

Certain species of bluegreens (including Anabaena, Aphanizomenon, Microcystis, and others) are known to produce potent neurotoxins and livertoxins which cause disease and death of livestock and other animals that drink from algae-infested water. Indirect evidence indicates that one or more of these toxins are responsible for certain cases of human gastroenteritis and dermatitis from municipal and recreational water supplies which have been studied elsewhere (Carmichael,1986).

Aphanizomenon, a notorious problem bluegreen, was found at the upper end of Tenkiller during the 1985 (Gakstatter and Katko,1986). In contrast, the 1974 EPA survey found that Tenkiller algal populations were dominated by diatoms and Aphanizomenon was not detected. Aphanizomenon is notorious for causing taste and odor problems in water supplies, which are numerous along Tenkiller Ferry Reservoir.

Gakstsatter and Katko (1986) observed no floating mats or clumps of bluegreens during their one-day sampling program on Lake Tenkiller in 1985. The chlorophyll-a concentrations detected in their survey, however, (1.7 - 12 ppb), were much lower than average values detected in the extensive biweekly surveys conducted by the Corps of Engineers (COE) in 1986 (10 - 35 ppb).

Floating algal mats and scums were noted during the COE 1986 water quality surveys, particularly at the upper end of the lake (Steve Nolen, Corps of Engineers, Tulsa, pers. com. 1987). Accumulations of algal mats along shorelines in Tenkiller and "pea soup" conditions have drawn numerous complaints from marina operators and recreational users. According to Mr. Nolen, an aquatic biologist and lifelong resident of the area, it is generally considered by area residents and lake users that water quality has deteriorated significantly in recent years. For example, because of its exceptional clarity, Lake Tenkiller was once the most popular spot for skin diving in the state. Its popularity has decreased dramatically in recent years, however, with the concommitant increases in algal densities and reductions in water clarity (Steve Nolen, Corps of Engineers, Tulsa, pers.comm., 1987).

The observed increases in phosphorus and chlorophyll-a concentrations, reductions in N/P ratio, development of nuisance bluegreen algal populations, development of surface scums and mats, and resulting adverse impacts on lake beneficial uses are all likely attributed to increased point-source loadings. These changes constitute violations of Oklahoma's nutrient standard 4.10(c), which prohibits nutrient levels or shifts in N/P ratio resulting in "man-induced eutrophication" (Oklahoma Water Resources Board,1982).

As suggested by its position at the bottom of the watershed (Figure 2) and high flow velocities, Tenkiller is the ultimate receptacle for phosphorus discharges from the watershed. Mass-balance calculations described below indicate that most of the phosphorus discharged from point sources in the basin reaches Tenkiller. Because of its relatively long hydraulic residence time (averaging 250 days), low non-algal-turbidity levels, and high non-point nitrogen loadings, Tenkiller is particularly susceptible to phosphorus loadings from point and non-point sources in the watershed. Reduction of these sources is critically needed to reverse the significant water quality deterioration which has been experienced in recent years.

PHOSPHORUS TRANSPORT CALCULATIONS

Figure 5 displays stream total phosphorus concentrations as a function of flow at three stations: Near Siloam Springs (above Lake Frances), Watts (below Lake Frances), Tahlequah (above Tenkiller Ferry). Above Lake Frances, phosphorus decreases with increasing flow, for flows below the mean annual value. This reflects dilution of upstream point source discharges and indicates that significant transport of those discharges to Lake Frances occurs. At flows above the mean annual value, runoff and streambed scouring mechanisms begin to dominate and concentration tends to increase slightly with flow. At the Watts and Tahlequah stations, the low-flow dilution mechanism is less apparent, but still present. Phosphorus deposition occurring in Lake Frances and the stream channel under low flow conditions tends to obscure the dilution mechanism at downstream stations. At high flows, however, much of this material is transported downstream, as reflected by the increasing concentrations.

Phosphorus transport calculations have been performed using data from each of the three stream stations discussed above. Given intermittent grab-sample concentration data, the flows at the times (or days) of sampling, and the continuous flow record for each station, the problem is to estimate the total quantity or flux of material past the station over a given time period. Since phosphorus concentration cannot be considered independent of flow (Figure 5), averaging the concentration independently of flow will yield invalid results.

FLUX, a computer program developed for the Army Corps of Engineers (Walker,1984b,1986a), has been used for these calculations. The program employs a variety of techniques for calculation of loading, estimation of confidence limits, display of data, and optimization of monitoring program designs. Basically, the approach is to divide the samples into strata or groups based upon flow regime, calculate loadings separately for each stratum, and then combine the estimates across strata, weighting according to frequency of occurrence.

Such calculations usually show that long-term loading estimates are relatively sensitive to samples taken under high flow regimes and insensitive to samples taken under low flows. The sampling programs at these stations have generally been periodic, as opposed to flow-weighted. A greater emphasis on sampling of high flow regimes would provide an improved basis for loading computations. The FLUX program is designed to make most efficient use of available data and to develop unbiased loading estimates, regardless of sampling strategy, however.

To provide a reasonably broad coverage of flow regimes, the calculations have been performed using all samples taken between October 1981 and September 1986. These samples have been mapped onto the continuous daily flow record for October 1981 through March 1986 (the latest available). Where missing, flows at the upstream station (near Siloam Springs, above Lake Frances) have been estimated from the flow record at Watts based upon drainage area ratio. Results of calculations are summarized in Table 2. Over this time period, flows averaged near normal.

Interpretation of the loading estimates is facilitated by mass balance calculations. The watershed has been segmented as shown in Figure 6. Flow and phosphorus loading estimates have been developed for each segment by adding the point and nonpoint loading estimates. Point source loading estimates have been developed from various data sources, (see Table 5, below). Nonpoint loadings have been estimated by applying the average runoff rate during the 1981-1986 sampling period (.36 meters/year) to an average estimated runoff concentration.

Based upon review of monitoring data from nonpoint-source watersheds in the basin (e.g., Illinois River above Mud Creek, Clear Creek, Baron Fork, and Caney Creek), average runoff concentrations of 100 and 150 ppb have been assumed for Oklahoma and Arkansas portions of the watershed, respectively. The higher value for Arkansas is consistent with a higher intensity of land uses (62% agricultural, 8% urban, 30% forested in Arkansas (Arkansas Soil and Water Conservation Commission,1979) vs. 38%, 3%, and 59%, respectively, in Oklahoma (Oklahoma Dept. of Pollution Control,1976)) and with my impressions regarding land use intensities derived from aerial reconnaissance of the watershed in November 1986.

Loadings calculated for each watershed have been summed moving downstream to Lake Tenkiller. Phosphorus retention in Lake Frances has been estimated using an empirical model developed from Corps of Engineer reservoir data (Walker,1985). Results of the phosphorus routing calculations are displayed in Figure 7. The 90% confidence limits for the loading past each station are shown in relation to predicted phosphorus concentration profiles due to nonpoint and total (point+nonpoint) loadings. The predicted total concentration profile is within the confidence ranges of the loadings calculated from monitoring data at each of the three stations.

These results suggest that point and nonpoint discharges from the upper basin are transported downstream to Tenkiller Ferry. Although some transformation (from soluble to particulate) and intermittent deposition/scouring may occur in the stream channel and in Lake Frances, total phosphorus is transported over long distances and times, particularly in a basin with this type of elevation profile (Figure 2) and without major seasonal flood plains (Lee et al.,1985). Based upon these results, impacts on both Lake Frances and Tenkiller Ferry Reservoir should be considered in evaluating the proposed Fayetteville discharge.

CORPS OF ENGINEER 1986 SURVEY OF TENKILLER FERRY RESERVOIR

As discussed above, conditions in Tenkiller Ferry have deteriorated significantly over the past decade or so. This section summarizes results from the survey conducted by the Corps of Engineers in 1986, in conjunction with the EPA/AR/OK Illinois Basin Study. The cooperation of Steve Nolen of the Corps of Engineer Tulsa district in supplying these data is acknowledged.

The reservoirs was sampled biweekly in profile at each of 14 sampling stations identified in Figure 8. Figure 9 summarizes average, mixed-layer (0-12 ft) mean concentrations for October-September 1986 samples. The cross-hatched areas indicate the 67% confidence limits for the mean value (mean +/- 1 standard error). Stations are numbered in increasing order moving upstream from the dam.

Consistent with data from other reservoirs with similar morphometry and loading distributions (Walker,1985), significant longitudinal water quality gradients are found in Tenkiller Ferry. Stations closer to the inflow tend to have higher nutrient, chlorophyll-a, and turbidity levels, and lower transparency. Based upon temperature, ortho phosphorus, BOD, and chlorophyll-a values, Station 14 is clearly in the river above the reservoir, as opposed to the reservoir itself. Levels of ortho phosphorus drop off suddenly (from 120 to 20 ppb), once the river enters the reservoir below Station 14; this primarily reflects algal uptake and longitudinal transport mechanisms (advection and dispersion). Turbidity measurements indicate that Oklahoma's water quality standard (10 NTU) is violated at upper reservoir stations due to a combination of high algal densities (in the hypereutrophic range) and inorganic suspended solids.

Figure 10 displays dissolved oxygen variations in the surface layer of the reservoir. All stations show a tendency towards supersaturation during the daytime, which reflects intense algal photosynthesis. At the upper reservoir stations, oxygen concentrations reached 6 ppm above saturation. Based upon the levels of chlorophyll-a (exceeding 30 ppb), large diurnal fluctuations in oxygen are likely. The lower limits of oxygen levels (i.e. early morning values following nighttime respiration) are unknown because diurnal sampling was not conducted. Oxygen concentrations below 5 ppm (the Oklahoma standard for lake surface waters) were detected at three stations.

The dissolved oxygen situation deteriorates significantly when variations with depth are considered (Figures 11 and 12). Vertical temperature and oxygen profiles from the near-dam station (01) are displayed over the April-October 1986 period. Anaerobic conditions develop at 70 feet of depth in mid-late June and extend until turnover in October. Note that the maximum depth of the reservoir is about 150 feet, but the measurements only extend to the 70-foot level. It is possible that anaerobic conditions develop earlier at the bottom.

The rate of oxygen depletion below the thermocline reflects the sedimentation and decay of organic material entering from the watershed and generated in the mixed layer ~~are~~ as a result of algal productivity. In a eutrophic reservoir with a relatively long hydraulic residence time, such as Tenkiller, the latter source of oxygen demand is likely to dominate. Based upon oxygen and temperature profiles at the near-dam station (Figure 12), the rate of oxygen depletion below the thermocline is estimated to be 1222 mg/m^2-day. Figure 13 shows the relationship between hypolimnetic oxygen depletion rate and mixed-layer chlorophyll-a concentrations for other Corps of Engineer reservoirs (Walker,1985). In 1986, the oxygen depletion rate and chlorophyll-a concentration in Tenkiller were at the upper limits of those observed in other Corps reservoirs. This reflects an extreme degree of eutrophication.

OXYGEN VIOLATIONS AT LONGTERM MONITORING STATIONS

There is evidence that oxygen depletion in Tenkiller Ferry, generated as a result of excessive nutrient loadings and algal productivity, is transported to the Lower Illinois River downstream of the dam, where it leads to violations of the 6 mg/liter standard. Figure 14 displays oxygen and temperature data from four longterm Illinois River stations for the 1975-1986 period. Average concentrations and violation frequencies have been calculated and displayed as a function of month.

The temperature data show that the water is warmed by an average of 3-4 deg-C as is passes through Lake Frances (upstream I04 vs. downstream I06 and I12). Exposure of the fertile waters to solar radiation in Lake Frances increases water temperature and provides the energy to support abundant algal growth, when residence times are adequate. Water temperatures below Tenkiller Ferry (I16) are 4-6 deg-C cooler than the upstream river during summer months because of the hypolimnetic (bottom-water) discharge from the dam.

As a result of the hypolimnetic discharge, oxygen violations are much more frequent below the reservoir than at upstream river stations. Violations upstream of Lake Frances (Station I04 Near Siloam Springs) are relatively infrequent (less than 10% for all months). This station is located above stream reaches which are conducive to algal growth, despite high nutrient levels. Violation frequencies at Watts and Tahlequah are at intermediate levels and peak at 25-30% of the samples during May. During July, August, and September (when oxygen is depleted in the bottom waters of Tenkiller), the standard is violated more than 50% of the time. This situation is especially significant because the Lower Illinois below Tenkiller is designated as a trout fishery (Oklahoma Water Resources Board,1982).

The actual violation frequencies at all stations may be greater than those indicated in Figure 14 because the data do not reflect diel variations. The greater dissolved oxygen violation frequencies at stations below Lake Frances partially reflect the effects of nutrient loading and excessive oxygen demands generated through photosynthesis by algae and periphyton. Decreases (not increases) in point and nonpoint nutrient sources in the basin are needed to bring the river and reservoir segments into compliance with Oklahoma's water quality standards and designated uses.

ILLINOIS RIVER IN AND BELOW LAKE FRANCES

The impacts of nutrients on Lake Frances (and on the Illinois River downstream of Lake Frances) depend strongly upon flow regime and season. Hydraulic residence times on the order of 1-2 weeks are generally required for full algal response to nutrients in reservoir environments (Walker,1985). Under mean flows (578 cfs at Watts), Lake Frances has a hydraulic residence time of approximately 1.8 days, based upon a lake volume of 2.8 hm^3 reported by Threlkeld(1983), and the opportunity for development of significant algal biomass is limited. Under low flows, however, residence time increases (e.g., to 12 days for 7-Q-2 of 82 cfs at Watts). Given adequate residence time, the lake's shallow depth (mean 1.2 meters), and the abundant supplies of available nutrients contributed primarily by upstream points sources (particularly under low-flow conditions), Lake Frances is an ideal environment for algal growth.

The impacts of residence time on algal productivity in Lake Frances are strongly reflected in the data summaries displayed in Appendix A. As flow regimes decrease from medium to low, water quality conditions in Lake Frances (as reflected by the data summaries from the USGS station at Watts just downstream of the lake) respond in a way which is consistent with increasing algal productivity. These responses include significant increases in chlorophyll-a, organic nitrogen, total kjeldahl nitrogen, biochemical oxygen demand (which partially reflects algal respiration), and frequency of dissolved oxygen violations (D.O.< 6 mg/liter). Again, the calculated frequencies of oxygen violations (15% at Watts under low-flow conditions) are based upon daytime (generally, afternoon) grab samples and likely underestimate actual violation frequencies calculated from diel sampling. Nitrate concentrations also decrease at low flows due to increased algal uptake. Similar changes are noted when one compares the stations upstream and downstream of Lake Frances under low and mean flow regimes.

Under low to mean flows, turbidity levels are significantly higher in Lake Frances than in the upstream river. The elevated turbidity levels are caused by a combination of inorganic suspended solids (resuspended bottom sediments) and algal cells. Based upon seasonal comparisons, Gakstatter and Katko (1986) concluded that the algal-related component is not insignificant and that the elevated turbidity levels may be sensitive to upstream nutrient discharges. Since algal cells are particulates and scatter light, there is no scenario in which an increase in nutrients and algal counts would not cause an increase in turbidity, regardless of background turbidity levels due to inorganic suspended solids.

During the low-flow sampling survey conducted by Threlkeld(1983), (mean flow at Watts = 158 cfs, minimum flow = 95 cfs) turbidity exceeded Oklahoma's water quality standard (10 NTU) in all 30 samples collected in and below the lake between July and September of 1982, but in none of the 5 samples collected above the lake during the same time period. Maximum turbidity levels exceeded 40 NTU and chlorophyll-a levels reached 115 ppb. Generally, turbidity and chlorophyll-a levels were lower during the EPA intensive survey in August of 1985 (mean flow at Watts = 258 cfs, minimum flow = 200 cfs), but violations of the turbidity standard were still detected in and below the lake (Gakstatter and Katko,1986).

Because of the lake's shallow mean depth (1.2 m), light extinction by inorganic suspended solids in Lake Frances is insufficient to cause light limitation of algal growth . Based upon empirical studies of data from Corps of Engineer reservoirs (Walker,1984a,1985), the ratio of Secchi Depth to mixed layer depth is generally less than .2 in reservoirs where light-limitation is a significant factor influencing chlorophyll-a responses to nutrients. In the case of Lake Frances, this ratio averages about 0.5. Thus, light limitation is not likely to be a major factor.

Threlkeld (1983) pointed out the sensitivity of algal growth in Lake Frances to residence time and the relationship between increasing chlorophyll-a concentration and increasing nitrate assimilation (inflow-outflow) in the reservoir. Although nitrogen and phosphorus are generally available at levels in excess of algal growth requirements under most flow regimes, nitrate levels tend to decrease significantly under low summer flows. Threlkeld suggested that nitrogen is most likely to be the limiting nutrient in Lake Frances under low-flow conditions. Based upon an earlier survey, the Oklahoma State Department of Health (1976) also concluded that algal growth in Lake Frances was potentially nitrogen-limited.

Figure 15 displays nitrate, ortho phosphorus, and chlorophyll-a concentrations in Lake Frances and in the downstream river as a function of runoff rate (discharge/watershed area). Nitrate tends to be depleted at low flows due to algal uptake in the reservoir. Ortho phosphorus, however, remains at elevated concentrations (100-200 ppb) under low flows. Additional sampling under low flows (approaching 7-Q-2) would provide improved data for assessing limiting factors and lake conditions under extreme flow conditions.

Based upon these data, Threlkeld's assessment that nitrogen is the limiting nutrient in Lake Frances under low-flow conditions seems to be correct. Peak algal biomass under low-flow conditions may be limited by nitrogen loadings to the reservoir. This evaluation is especially significant in light of the increases in nitrogen loading which would result from the proposed Fayetteville diversion, as evaluated further below.

The effects of algal production in Lake Frances are transported to the downstream river. As noted by Gakstatter and Katko (1986), algae and turbidity levels tend to decrease below Lake Frances as a result of dilution and/or sedimentation mechanisms. Figures 16-18 display mean river profiles for August 1985 and 1986, based upon data from the EPA/AR/OK Illinois Basin study. Stations are arranged in downstream order (see Figure 1 for locations). Significant increases in algae and related water quality components (organic nitrogen, kjeldahl nitrogen, turbidity) are apparent as the river enters Lake Frances. Water quality improves downstream of the lake.

Conditions were apparently much more severe during August 1986, as compared with August 1985, the period of the intensive survey by Gakstatter and Katko. During August 1986, eutrophic waters (Chlorophyll-a > 10 ppb) extended as far downstream as Chewey, approximately 20 miles below the dam. Consistent with the discussion above, removals of nitrate and ammonia nitrogen in Lake Frances were also more evident during August 1986 period, when algal populations were at much higher levels. It is possible that the heavy rains and high flows experienced during the August 1985 survey may have resulted in lower residence times in Lake Frances and lower algal growth. Because of this, conclusions regarding lake and river dynamics and condition should not be drawn exclusively from the August 1985 intensive survey.

Additional intensive studies, under low-flow conditions, would provide improved bases for evaluating the system.

Monitoring of diurnal oxygen variations provides useful information photosynthesis and respiration and is essential to determining compliance with dissolved oxygen standards in streams with elevated nutrient and algal levels. Figures 19 and 20 display diel variations monitored at several locations along the Illinois River during August of 1985. Consistent with the chlorophyll-a and related water quality profiles, diel oxygen variations were less significant at stations above Lake Frances (approximately 1-1.5 mg/liter), as compared with stations below (2.5-4.5 mg/liter). This reflects increased photosyntheses and respiration by algae and/or periphyton in the river below the lake. Violations of the 6 mg/liter standard were also detected during the early morning hours at two stations (Above Flint Creek and East of Chewey). The frequency and severity of oxygen violations were probably much higher in August 1986, based upon much higher algal levels (Figures 16-18). Unfortunately, diel studies were not performed during that period.

The diel swings and daytime super-saturation indicate that significant photosynthesis occurs in the river downstream of the lake, despite the fact that algal concentrations decrease moving downstream. Apparently, the rate of algal removal (possibly due to sedimentation or predation) exceeds the rate of production in downstream reaches. Survey results generally suggest that algal problems and related aesthetic problems in the river below Lake Frances are primarily the result of algae generated in the lake and transported downstream. These conclusions are subject to the important data limitation that the river below the Lake Frances has not been intensively studied under low-flow conditions.

MODELING IMPACTS OF FAYETTEVILLE DIVERSION ON LAKE FRANCES

Calculations have been performed to evaluate the potential impacts of the proposed Fayetteville diversion on nutrient levels and algal growth in Lake Frances. Projections have been made for a total of 18 cases involving combinations of the following:

(1) flow regime (7-Q-2, low, mean);
(2) upstream discharges (existing, with P controls, none);
(3) Fayetteville discharge (without, with);

Predictions without and with the Fayetteville discharge are summarized in Tables 3 and 4, respectively. For each case, the calculations involve formulation of water and mass balances on the lake and prediction of water quality conditions, expressed in terms of the following:

(1) total phosphorus concentration;
(2) total nitrogen concentration;
(3) nitrogen-to-phosphorus ratio = "(TN-150)/TP"
    = indicator of limiting nutrient;
(4) potential chlorophyll-a = algal growth potential associated with the nutrient concentrations
    = chlorophyll-a which would develop at long residence times and optimal light intensities;
(5) mean chlorophyll-a = predicted algal concentrations when effects of nutrient levels, residence time, and turbidity are considered;
(6) secchi depth = water column transparency, as influenced by algal and non-algal turbidity.

Calculations of nutrient retention in the lake and responses of chlorophyll-a and Secchi depth are based upon empirical models developed from reservoir data (Walker,1984b,1985). These models have been developed from and extensively tested against reservoir data from several areas of the country, including Lake Keystone on the Arkansas River in Oklahoma and Beaver Reservoir on the White River in Arkansas. The chlorophyll-a response model is designed to account for potential effects of algal growth limitation by phosphorus, nitrogen, turbidity, and flushing rate.

Estimates of existing point sources have been developed from various sources, as detailed in Table 5. Estimates of non-point source concentrations and loadings from the watershed above Lake Frances are based upon review of monitoring data (vs. flow regime) from watersheds in the basin not strongly impacted by point sources (Caney Creek, Baron Fork, Illinois River above Mud Creek, Clear Creek). 80–150 ppb Threlkeld Ballard=60 Ill.@ Savoy 510 ppb.

Results of the calculations are displayed in Figure 21. For each flow regime and variable, six bars are shown: (1) and (2), predicted values without and with the Fayetteville discharge under existing point-source loadings; (3) and (4), predicted values without and with the Fayetteville discharge, assuming reduction of existing point-source discharges in the basin to 1 mg/liter total phosphorus; (5) and (6), predicted values without and with the Fayetteville discharge, with upstream nonpoint loadings only. Circles indicate observed mean values under low and mean flows, as derived from the data summaries in Appendix A. Comparisons of observed and predicted values for each variable indicate that the empirical models employed for estimating nutrient retention and algal responses are applicable to the system.

For each scenario, addition of the Fayetteville discharge to the existing point and nonpoint loadings would cause increases in nutrient and chlorophyll-a concentrations and reductions in transparency. The changes in mean chlorophyll-a and transparency are relatively small due to the excessive magnitudes of the existing point-source loadings and low hydraulic residence time, which limits the ability of the algae to consume the abundant nutrient supply in Lake Frances (but not in Tenkiller). Changes in "potential chlorophyll-a", which might be found, for example, in shallow, backwater areas isolated from the main river flow through or downstream of the reservoir, are more substantial. Percentage increases in nutrients and mean chlorophyll-a and reductions in transparency due to the Fayetteville discharge are greater under conditions involving improved treatment or elimination of other point sources.

Under each scenario, changes resulting from the Fayetteville discharge constitute violations of Oklahoma's nutrient standard which prohibits man-induced eutrophication. The increases in algal density attributed to the Fayetteville discharge would also increase the violation frequencies of other water quality standards related to algal growth, including turbidity, aesthetics, and dissolved oxygen. Because standards are violated under existing conditions, the river is "water-quality limited" and any percentage increase in violation frequency is unacceptable.

The ratio (TN-150)/TP is an indicator of the relative importance of nitrogen (low values) vs. phosphorus (high values) as factors limiting algal growth. As shown in Figure 21, the model predicts a shift in limiting nutrient from nitrogen to phosphorus with the implementation of point-source phosphorus controls in the basin. Despite substantial reductions in phosphorus concentrations associated with basinwide phosphorus controls, the predicted responses of mean chlorophyll-a are relatively small. Phosphorus concentrations in Lake Frances under low flows would still be high enough (150-200 ppb) to support abundant algal growth, even with basinwide effluent reductions to 1 mg/liter Total P. This reflects the fact the natural dilution capacity of the watershed under low flows is too small in relation to the high volume of existing point-source discharges and low volume (nutrient trapping efficiency) of Lake Frances. For example, under 7-Q-2, sewage effluent accounts for 16% of the river flow through Lake Frances and 71% of the total phosphorus loading at an effluent concentration of 1 mg/liter (Table 3).

With complete elimination of point sources from basin, mean chlorophyll-a concentration in Lake Frances under 7-Q-2 flows would be reduced to 25 ppb, as compared with 69 ppb under existing loading conditions. Phosphorus removal to concentrations below 1 mg/liter and/or diversion of existing waste loadings out of the basin would be required to cause substantial improvements in Lake Frances. Despite these results, phosphorus removal to 1 mg/liter for major point sources is recommended for the purpose of improving/protecting Tenkiller Ferry Reservoir.

The watershed has inadequate dilution capacity to handle the existing point-source discharges, even with phosphorus removal. Figure 22 shows the cumulative frequency distribution of river composition at Watts, expressed as percent of the flow comprised of effluent, based upon analysis of the June-September monthly flow record between 1974 and 1985 and the total upstream point-source discharge under present conditions (10.4 mgd, Table 5). The projected impact of a 6.1 mgd Fayetteville discharge on the frequency curve is also shown.

Under existing conditions, effluent accounts for at least 10% of the flow through Lake Frances during 45% of summer months. With the addition of Fayetteville, effluent would account for at least 10% of the flow during 60% of the summer months. Under existing conditions, effluent accounts for at least 20% of the river flow during 9% of summer months. With the addition of Fayetteville, effluent would account for at least 20% of the flow during 27% of the summer months. Both curves in Figure 22 would shift further to the right with future development upstream.

At the lowest monthly mean flow recorded between 1974 and 1985 (39 cfs or 25.2 mgd, August 1980), effluent accounted for 41% of the river flow. These high percentages are especially disturbing in view of the fact that sewage treatment efficiency upstream has not been particularly impressive (e.g., average and maximum effluent BOD-5 from Rogers in 1985-1986 were 56 mg/liter and 110 mg/liter, respectively, based upon STORET data). I wonder how awareness of these statistics might influence the enthusiasm of weekend floaters or the thirst of Siloam

Spring residents during the summer. The observed degradation of the river and reservoirs, as discussed above, is no surprise when the high effluent percentages are considered.

To supplement the above, additional evaluations of the Fayetteville discharge impacts on Lake Frances are being performed using QUAL-2, a model which has been designed for simulation of algal growth and dissolved oxygen impacts in rivers and shallow impoundments (Walker,1983b; VanBenscoten and Walker,1984; Brown and Barnwell,1985). Preliminary results of these modeling studies confirm nitrogen limitation under 7-Q-2 conditions in Lake Frances and indicate that, for existing point-source discharges in the watershed, nitrogen loading from Fayetteville would increase peak algal biomass and increase the extent of dissolved oxygen violation downstream of Lake Frances due to algal respiration and diurnal variations.

BASIN-WIDE MASS BALANCE CALCULATIONS

Tables 5, 6, and 7 document mass-balance calculations which have been performed for the Illinois River Basin above and below Lake Frances for average, dry, and wet hydrologic years, respectively. Flow volumes and nutrient loadings (ortho phosphorus, total phosphorus, and total nitrogen) from point and nonpoint sources in the basin are quantified. Percentage increases due to the Fayetteville discharge have also been calculated and displayed in Figure 23. Annual nutrient retention in Lake Frances is relatively insignificant (averaging 10% for phosphorus and 6% for nitrogen). Because of this, the calculated total nutrient loadings to the basin would be similar to those reaching Tenkiller Ferry Reservoir. Calculated loadings of ortho phosphorus do not necessarily reach Tenkiller Ferry Reservoir, however, because some would be converted to particulate phosphorus during transport.

Subsequently recycled.

Expressed on a percentage basis, impacts of the Fayetteville discharge on nutrient loadings to each reservoir would be higher during drier years. The runoff rate for water year 1981 (4 inches/yr or .1 meters/yr) has been used as an example of a dry hydrologic year. Under this condition, the Fayetteville discharge would increase the annual loadings of total phosphorus and nitrogen to Lake Frances by 6.7% and 11.0%, respectively, vs. 4.7% and 8.2% under average flows. Total phosphorus and nitrogen loadings to Tenkiller Ferry Reservoir would increase by 9.3% and 10.4%, respectively, during a dry year and by 2.8% and 9.3% during an average year. Regardless of their precise magnitudes, these increases are unacceptable in view of the fact that Oklahoma's water quality standards are already being violated due to excessive nutrient enrichment.

Table 8 compares loading estimates under existing conditions with estimates developed previously based upon 1974-1975 monitoring data collected by the EPA National Eutrophication Survey (1977a,b). The EPA/NES calculated loadings to Lake Frances and to Tenkiller Ferry for an "average hydrologic year" (basin runoff=.3 m/yr). Using the same EPA/NES data set, Walker(1982) calculated loadings to Tenkiller Ferry for 1974-1975, when runoff was relatively high (.6 m/yr). The loading estimates for existing conditions in Table 8 are based upon the same methodology employed in Tables 5-7, with runoff rates adjusted in each case to conform to the 1974-1975 estimates. The comparisons indicate 6-21% increases in nitrogen loading, as compared with 96-135% increases in phosphorus loading over this period. These results are generally consistent with the observed increased eutrophication in the reservoir and river segments discussed previously and further suggest that point sources have been primarily responsible for these increases.

CONCLUSIONS: IMPACTS OF DIVERSION ON OKLAHOMA WATER QUALITY STANDARDS

The addition of nutrient loadings from Fayetteville would cause increases in nutrient and algal concentrations in Lake Frances, the Scenic River below Lake Frances, and in Tenkiller Ferry Reservoir. The monitoring data reviewed above indicate that these segments are already severely impacted by nutrient loadings from the upper watershed. The watershed is simply too small to provide sufficient dilution of the existing point-source discharges, especially given the presence of Lake Frances, which acts as an algal culturing vessel and supplies abundant quantities of organic material to the downstream river. Further increases in nutrient and algal levels attributed to the "man-induced" Fayetteville discharge would constitute a violation of Oklahoma's nutrient standard (4.10(c)). Increases in observed violation frequencies for dissolved oxygen (4.11(a)) and turbidity (4.10(b)) would also be expected.

Another standard directly related to algal growth is 4.10(d) Solids (Suspended and/or Settleable). "Floating debris, bottom deposits, scum, and foam" are all characteristic of eutrophic waters and are probable contributors to the historically observed decreases in the aesthetic qualities of the river below Lake Frances. Mass-balance calculations indicate that the nuisance algal scums and mats observed in Tenkiller primarily result from excessive point-source nutrient loadings. The scenic and recreational values of this resource are in jeopardy due to past and proposed future increases in nutrient loading.

There are numerous water supply withdrawals in Oklahoma from Lake Frances, Tenkiller Ferry Reservoir, and the intervening river. Potential water supply impacts related to eutrophication include taste and odor, interferences with water treatment processes (filter clogging, coagulation, flocculation), and increased chlorine demand (Bernhardt,1980; Walker,1983a). Such interferences can have significant economic effects on water supplies in terms of chemical and energy costs. Violations of the standard for Taste and Odor (4.10(e)) may also occur as a result of increased nutrient enrichment.

Health risks associated with generation of trihalomethanes (THM's) and other chlorinated organic compounds (Johnson and Jensen,1986) should also be considered in evaluating the implications of further nutrient enrichment on water supplies in the basin. Algae are known to be potent precursors of trihalomethanes (THM's), which are formed when organic materials in water supplies react with chlorine added for disinfection purposes (Oliver and Shindler,1980; Dorin,1980). Chloroform, the dominant THM, has been shown to be carcinogenic (National Academy of Science,1977). Empirical studies have shown that indices of eutrophication (phosphorus, chlorophyll-a) are correlated with reservoir organic carbon and finished-water THM levels (Walker,1983a,1986b).

Quarterly samples from the Siloam Springs water supply (which withdraws from Lake Frances) indicate a THM range of 41 to 111 ppb for the 1983-1986 period. The existing EPA maximum contaminant level of 100 ppb was exceeded in 20% of the samples. It is possible, if not likely, that Oklahoma water supplies in the Illinois River (in particular, Watts, which also withdraws water from Lake Frances) also experience THM levels above 100 ppb. No THM data are available from these supplies, however, because EPA regulations do not require THM monitoring in supplies serving less than 10,000 people. Although about 15,000 people drink water withdrawn from Tenkiller Ferry Reservoir, they are distributed over 26 individual supplies. Because of the somewhat arbitrary sampling requirements established the EPA, these people are not protected from cancer risks associated with THM's under existing regulations. For a given treatment process, such risks increase significantly (roughly in proportion to) the level of organic material in the source water supply.

Revisions of the existing drinking waters regulations under development by the EPA may involve more stringent THM controls, especially in view of the fact that the existing maximum contaminant level of 100 ppb corresponds to a cancer risk of approximately 2 deaths/10,0000 (National Academy of Science,1977), which is much higher than the risk level at which other toxic contaminants are regulated. West Germany, for example, has a THM standard of 25 ppb (Dorin,1980). Further increases in algal-derived organic material may increase health risks associated with THM's and increase water treatment costs required for compliance with future regulations.

Mass-balance calculations described above show that increases in nutrient and algal concentrations would result from diversion of the Fayetteville discharge into the Illinois River basin. These increases would constitute a change in water quality which is in direct violation of Oklahoma's Anti-Degradation Policy for designated Scenic Rivers (Section 3, Oklahoma Water Resource Board, 1982).

The above factors should be considered, in addition to the values of the Illinois River as a unique scenic and recreational resource for Oklahoma, in evaluating impacts of the proposed diversion and in developing an effective longterm management program for point and nonpoint nutrient sources in the watershed.

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TABLES

Table 1
Stations Codes and Descriptions

STORET STATION INDEX

AGENCY CODE	STATION CODES PRIMARY	SECONDARY	DESCRIPTION	SEQ
11coetul	oka0164		tenkiller res	TK01
11coetul	oka0165		tenkiller res	TK02
11coetul	oka0166		tenkiller res	TK03
11coetul	oka0167		tenkiller res	TK04
11coetul	oka0168		tenkiller res	TK05
11coetul	oka0169		tenkiller res	TK06
11coetul	oka0170		tenkiller res	TK07
11coetul	oka0171		tenkiller res	TK08
11coetul	oka0172		tenkiller res	TK09
11coetul	oka0173		tenkiller res	TK10
11coetul	oka0174		tenkiller res	TK11
11coetul	oka0175		tenkiller res	TK12
11coetul	oka0176		tenkiller res	TK13
11coetul	oka0177		tenkiller res	TK14
21okoshd	217002x3z202	sr05	lake francis dam	I05
21okoshd	sr1		below frances sg 1955	
21okoshd	sr2		above flint creek	I07
21okoshd	sr3		east of chewey	I08
21okoshd	sr4		west of chewey	I09
21okoshd	sr45		combs bridge	I10
21okoshd	sr5		above tahlequah gs 1965	I11
21okoshd	217000x9z204	sr63	sequoyah ab baron fork	I13
21okoshd	217007x8z202	sr65	horseshoe bend	I14
21okoshd	21700z203	sr75	caney creek above tk	T06
21okoshd	21700a6x10z204	07198000	ill at highway 64 bridge	I13
21okoshd	21700da6x7z301	07196500	il near tahlequah	I12
21okoshd	sr67		tenkiller .25 mi ab caney	
21okoshd	sr02	fr02	lake frances upper end	
21okoshd	sr03	fr03	lake frances middle	
21okoshd	sr04	fr04	lake frances	
21okoshd	srgrif01		greenleaf nursery discharge	
21okoshd	srmwn01		midwestern nursery upper disch	
21okoshd	srmwn02		midwestern nursery lower	
21okoshd	sr72		tenkiller caney creek arm	
21okoshd	sr68		tenkiller off chicken creek ramp	
21okoshd	sr69		tenkiller dam area	
21okoshd	illgw01		dripping springs	
21okoshd	illgw02		dripping springs	
21okoshd	illgw03		black fox hollow springs	
21okoshd	21700c1x2z2	07195500	illinois river nr watts	I06
21okoshd	21703z200	07196000	flint creek near kansas	T04
21okoshd	21707z302	07197000	baron fork at eldon	T05
21okoshd	s21701		tahlequah stp	
1116apcc	050010	ark06a	ill nr siloam springs	I04
1116apcc	050134	ark40	ill nr savoy	I02
1116apcc	050135	ark41	osage creek nr elm spr	
1116apcc	050011	ark04a	flint ck nr w siloam spr	
1116apcc	050219	ir2	ill r nr pedro ark	I03
1116apcc	050220	ir3	clear crk at savoy ark	T02
1116apcc	050221	ir4	illinois r nr viney grove	I01
1116apcc	050222	ir5	osage ck at logan	T03
1116apcc	050223	ir6	muddy fork nr savoy	T01
1116apcc	050005	ark05	sager crk nr siloam sp	
1116apcc	050007	ark07	baron fork at dutch mills	
efar1	ar0020273		siloam springs stp	
efar1	ar0033553		rogers stp	
efar1	ar0022063		springdale stp	
11epanes	401301		tenkiller	
11epanes	401302		tenkiller	
11epanes	401303		tenkiller	
11epanes	401304		tenkiller	
11epanes	4013a1		tenkiller outflow	
11epanes	4013a2		tenkiller inflow	
11epanes	4013b1		pine branch	
11epanes	4013c1		barron fork	
11epanes	4013xa		tahlequah stp	
11epanes	400801		lake frances	
11epanes	400802		lake frances	
11epanes	400803		lake frances	
11epanes	4008a1		frances outflow	
11epanes	4008a2		frances inflow	
11epanes	4008b1		ballard creek	
11epanes	4008xa		stillwater stp	

Table 2 /5
Results of Phosphorus Trayport Calculations

Station		Siloam Spr	Watts	Tahlequah
USGS Code		07195400	07195500	07196500
Drainage Area	mi^2	509	635	959
Mean Annual Flow	cfs	450	561	867
October 1981-March 1986:		.88	.88	.90
Mean Flow	cfs	496	619	983
Mean Flow	hm^3/yr	442	551	875
Total P Load	kg/yr	162975	193952	212625
Flow-Weighted Conc.	ppb	369	352	243
Coef. of Variation *		0.08	0.08	0.09
Number of Samples		60	83	82

* Standard Error of Estimate / Mean

1976-81				
$\bar{Q}_{all}$	hm^3/yr	256	320	484
$\bar{c}$	ppb	258	~~224~~ 234	113
Flux	kg/yr	66,054	~~89,935~~ 71,786	54725
cV	—	.046	~~.49~~ .067	.06
n_s	—	65	65	37

Baron Fk ~102 ppb

Table 3
Lake Frances Mass-Balance / Eutrophication-Response Calculations Without Fayetteville Discharge

LAKE FRANCES MASS-BALANCE / EUTROPHICATION RESPONSE CALCULATIONS WITHOUT FAYETTEVILLE DISCHARGE

CASE		1	2	3	4	5	6	7	8	9
HYDROLOGIC CONDITION		7-Q-2	LOW	MEAN	7-Q-2	LOW	MEAN	7-Q-2	LOW	MEAN
FAYETTEVILLE		no	no	no	no	no	no	no	no	no
OTHER POINT SOURCES		exist	exist	exist	p=1000	p=1000	p=1000	no	no	no
NONPOINT SOURCE CHARACTERISTICS										
Runoff	m/yr	0.045	0.1	0.32	0.045	0.1	0.32	0.045	0.1	0.32
Nonpoint Total P	ppb	80	100	150	80	100	150	80	100	150
Nonpoint Ortho P	ppb	40	50	75	40	50	75	40	50	75
Nonpoint Total N	ppb	1000	1600	2500	1000	1600	2500	1000	1600	2500
Non-Algal Turbidity	1/m	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
POINT SOURCE CHARACTERISTICS										
Existing Flow	hm3/yr	14.44	14.44	14.44	14.44	14.44	14.44			
Total P	ppb	4966	4966	4966	1000	1000	1000			
Ortho P	ppb	4128	4128	4128	900	900	900			
Total N	ppb	17201	17201	17201	17201	17201	17201			
Fayetteville Flow	hm3/yr									
Total P	ppb									
Ortho P	ppb									
Total N	ppb									
WATER BALANCE	HM3/YR									
Precipitation Flow	hm3/yr	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
NonPoint Flow		73.91	164.24	525.57	73.91	164.24	525.57	73.91	164.24	525.57
Point Flow		14.44	14.44	14.44	14.44	14.44	14.44	0.00	0.00	0.00
Fayetteville Flow		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Inflow		90.96	181.29	542.62	90.96	181.29	542.62	76.52	166.85	528.18
Evaporation		4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Outflow		86.89	177.22	538.55	86.89	177.22	538.55	72.45	162.78	524.11
PHOSPHORUS BALANCE	KG/YR									
Precipitation Load		69	69	69	69	69	69	69	69	69
NonPoint Load		5913	16424	78835	5913	16424	78835	5913	16424	78835
Point Load		71709	71709	71709	14440	14440	14440	0	0	0
Fayetteville Load		0	0	0	0	0	0	0	0	0
Total Load		77691	88282	150614	20422	30933	93345	5982	16493	78905
Sedimentation		34761	23169	14308	4766	4344	6760	1030	2061	5723
Outflow		42930	65034	136306	15656	26590	86584	4952	14432	73182
NITROGEN BALANCE	KG/YR									
Precipitation Load		4620	4620	4620	4620	4620	4620	4620	4620	4620
NonPoint Load		73908	262784	1313920	73908	262784	1313920	73908	262784	1313920
Point Load		248382	248382	248382	248382	248382	248382	0	0	0
Fayetteville Load		0	0	0	0	0	0	0	0	0
Total Load		326910	515786	1566922	326910	515786	1566922	78528	267404	1318540
Sedimentation		82700	71627	90893	82700	71627	90893	9270	25080	68749
Outflow		244210	444159	1476030	244210	444159	1476030	69258	242324	1249791
RESPONSE CALCULATIONS										
Residence Time	yrs	0.0319	0.0156	0.0051	0.0319	0.0156	0.0051	0.0383	0.0170	0.0053
Inflow P Conc	ppb	894	498	280	235	175	173	83	101	151
1-Rp		0.553	0.737	0.905	0.767	0.860	0.928	0.828	0.875	0.927
Inflow N Conc	ppb	3762	2910	2910	3762	2910	2910	1084	1643	2516
1-Rn		0.747	0.861	0.942	0.747	0.861	0.942	0.882	0.906	0.948
Total Phosphorus	ppb	494	367	253	180	150	161	68	89	140
Total Nitrogen	ppb	2810	2506	2741	2810	2506	2741	956	1489	2385
Potential Chl-a	ppb	271	220	205	164	134	149	40	65	123
Mean Chlorophyll-a	ppb	69.1	42.0	13.7	57.5	35.6	13.0	25.1	26.3	12.8
Secchi	ppb	0.40	0.49	0.65	0.45	0.53	0.66	0.70	0.60	0.66
(N-150)/P		5.4	6.4	10.2	14.0	15.7	16.1	11.0	15.1	16.0

Constant Factors: Watershed Area = 1642.4 km2, Precipitation = 1.13 m/yr, Evaporation = 1.76 m/yr
Atmospheric P Load = 30 kg/km2-yr, Atmospheric N Load = 2000 kg/km2-yr
Reservoir Mean Depth = 1.8 m, Area = 2.31 km2

Table 4
Lake Frances Mass-Balance / Eutrophication-Response Calculations With Fayetteville Discharge

LAKE FRANCES MASS-BALANCE / EUTROPHICATION RESPONSE CALCULATIONS WITH FAYETTEVILLE DISCHARGE

CASE		10	11	12	13	14	15	16	17	18
HYDROLOGIC CONDITION		7-Q-2	LOW	MEAN	7-Q-2	LOW	MEAN	7-Q-2	LOW	MEAN
FAYETTEVILLE		yes	yes	yes	yes	yes	yes	yes	yes	yes
OTHER POINT SOURCES		exist	exist	exist	p=1000	p=1000	p=1000	no	no	no
NONPOINT SOURCE CHARACTERISTICS										
Runoff	m/yr	0.045	0.1	0.32	0.045	0.1	0.32	0.045	0.1	0.32
Nonpoint Total P	ppb	80	100	150	80	100	150	80	100	150
Nonpoint Ortho P	ppb	40	50	75	40	50	75	40	50	75
Nonpoint Total N	ppb	1000	1600	2500	1000	1600	2500	1000	1600	2500
Non-Algal Turbidity	1/m	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
POINT SOURCE CHARACTERISTICS										
Existing Flow	hm3/yr	14.44	14.44	14.44	14.44	14.44	14.44			
Total P	ppb	4966	4966	4966	1000	1000	1000			
Ortho P	ppb	4120	4120	4120	900	900	900			
Total N	ppb	17201	17201	17201	17201	17201	17201			
Fayetteville Flow	hm3/yr	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
Total P	ppb	1000	1000	1000	1000	1000	1000	1000	1000	1000
Ortho P	ppb	900	900	900	900	900	900	900	900	900
Total N	ppb	13150	13150	13150	13150	13150	13150	13150	13150	13150
WATER BALANCE	HM3/YR									
Precipitation Flow	hm3/yr	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
NonPoint Flow		73.91	164.24	525.57	73.91	164.24	525.57	73.91	164.24	525.57
Point Flow		14.44	14.44	14.44	14.44	14.44	14.44	0.00	0.00	0.00
Fayetteville Flow		8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
Total Inflow		99.40	189.73	551.06	99.40	189.73	551.06	84.96	175.29	536.62
Evaporation		4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Outflow		95.33	185.66	546.99	95.33	185.66	546.99	80.89	171.22	532.55
PHOSPHORUS BALANCE	KG/YR									
Precipitation Load		69	69	69	69	69	69	69	69	69
NonPoint Load		5913	16424	78835	5913	16424	78835	5913	16424	78835
Point Load		71709	71709	71709	14440	14440	14440	0	0	0
Fayetteville Load		8440	8440	8440	8440	8440	8440	8440	8440	8440
Total Load		86131	96642	159054	28862	39373	101785	14422	24933	87345
Sedimentation		37501	25242	15171	7336	5913	7419	3043	3311	6313
Outflow		48630	71400	143883	21526	33460	94365	11379	21623	81032
NITROGEN BALANCE	KG/YR									
Precipitation Load		4620	4620	4620	4620	4620	4620	4620	4620	4620
NonPoint Load		73908	262784	1313920	73908	262784	1313920	73908	262784	1313920
Point Load		248382	248382	248382	248382	248382	248382	0	0	0
Fayetteville Load		110986	110986	110986	110986	110986	110986	110986	110986	110986
Total Load		437896	626772	1677908	437896	626772	1677908	189514	378390	1429526
Sedimentation		118911	94199	100655	118911	94199	100655	36851	43494	77916
Outflow		318985	532573	1577253	318985	532573	1577253	152663	334896	1351610
RESPONSE CALCULATIONS										
Residence Time	yrs	0.0291	0.0149	0.0051	0.0291	0.0149	0.0051	0.0343	0.0162	0.0052
Inflow P Conc	ppb	903	521	291	303	212	186	178	146	164
1-Rp		0.565	0.739	0.905	0.746	0.850	0.927	0.789	0.867	0.928
Inflow N Conc	ppb	4593	3376	3068	4593	3376	3068	2343	2210	2684
1-Rn		0.728	0.850	0.940	0.728	0.850	0.940	0.806	0.885	0.945
Total Phosphorus	ppb	510	385	263	226	180	173	141	126	152
Total Nitrogen	ppb	3346	2868	2883	3346	2868	2883	1887	1956	2538
Potential Chl-a	ppb	332	250	210	219	168	162	107	101	136
Mean Chlorophyll-a	ppb	70.5	42.4	13.6	61.9	37.5	12.9	47.5	32.2	12.9
Secchi	ppb	0.39	0.49	0.65	0.43	0.52	0.66	0.50	0.55	0.66
(N-150)/P		6.3	7.1	10.4	14.2	15.1	15.8	12.3	14.3	15.7

Constant Factors: Watershed Area = 1642.4 km2, Precipitation = 1.13 m/yr, Evaporation = 1.76 m/yr
Atmospheric P Load = 30 kg/km2-yr, Atmospheric N Load = 2000 kg/km2-yr
Reservoir Mean Depth = 1.8 m, Area = 2.31 km2

Table 5
Basinwide Mass Balance Calculations - Average Year

6.0

WATER AND MASS BALANCE CALCULATIONS ILLINOIS RIVER ABOVE TENKILLER DAM AVERAGE HYDROLOGIC YEAR

POINT SOURCE DISCHARGES

TREATMENT PLANT	STATE	FLOW mgd	FLOW hm3/yr	STP CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	STP LOADS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr	
Prarie Grove	AR	0.24 a	0.33	3975	4750	16000 e	1319	1576	5310	
Springdale	AR	6.70 a	9.26	4200 6.2	4800 6.9	16200 d	38913	44472	150093	23600
Rogers	AR	3.50 a	4.84	4000 6.1	5300 7.3	19200 d	19360	25652	92926	24600
Watts	OK	0.07 b	0.10	3975	4750	16000 e	385	460	1549	
Siloam Spring	AR	2.40 a	3.32	3900 4.6	~~4700~~	18000 e d	12943	15598	59738	17160
Gentry City	AR	0.21 a	0.29	3975	4750	16000 e	1154	1379	4646	11,100
Tahlequah	OK	2.60 c	3.71	~~3800~~ 4.0	4200	~~10500 d~~	14083	15565	38913	
Lincoln City	AR	0.41 a	0.57	3975	4750	16000 e	2254	2693	9071	
Westville	OK	0.10 c	0.14	3975	4750	16000 e	550	657	2213	
Indian Nations	OK	0.05 c	0.07	3975	4750	16000 e	275	320	1106	
Sequoyah	OK	0.04 b	0.05	3975	4750	16000 e	192	230	774	
Stillwell	OK	0.24 c	0.33	3975	4750	16000 e	1319	1576	5310	
Stillwell Cannery	OK	0.12 c	0.17	3975	4750	16000 e	660	788	2655	
TOTALS		16.76	23.17	4031	4790	16155	93406	110975	374385	
TOTALS	AR	13.46	18.61	4080	4909	17208	75943	91371	321785	
TOTALS	OK	3.29	4.56	3833	4303	11527	17463	19605	52520	
TOTALS above Lake Frances		10.44	14.44	4120	4966	17201	59592	71700	248329	
TOTALS below Lake Frances		6.31	8.73	3872	4498	14426	33815	39276	125976	
Fayetteville		6.10 f	8.44	900	1000	13150 f	7596	8440	110986	

Runoff Rate = 0.32 m/yr

NONPOINT CALCULATIONS	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Above Frances	1644	526.08	75	150	2500 g	39456	78912	1315200
Below Frances	2526	808.32	50	100	1666 g	40416	80832	1346661
Total	4170	1334.40	60	120	1995	79872	159744	2661861

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	540.52	183	279	2893	99048	150612	1563529
Below Frances	2526	817.05	91	147	1802	74231	120108	1472637
Total	4170	1357.57	128	199	2236	173278	270719	3036166

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	548.96	194	290	3050	106644	159052	1674515
Below Frances	2526	817.05	91	147	1802	74231	120108	1472637
Total	4170	1366.01	132	204	2304	180874	279159	3147152

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	1.56	6.01	3.98	5.45	7.67	5.60	7.10
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	0.62	3.74	2.40	3.02	4.38	3.12	3.66

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - Oklahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, UESPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed
f - phosphorus from Fayetteville discharge permit;
nitrogen = median value for plants practicing phosphorus removal (USEPA,1974)
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

Table 6
Basinwide Mass Balance Calculations - Dry Year

WATER AND MASS BALANCE CALCULATIONS ILLINOIS RIVER ABOVE TENKILLER DAM DRY HYDROLOGIC YEAR

POINT SOURCE DISCHARGES			STP CONCENTRATIONS				STP LOADS		
TREATMENT PLANT	STATE	FLOW mgd	FLOW hm3/yr	ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Prarie Grove	AR	0.24 a	0.33	3975	4750	16000 e	1319	1576	5310
Springdale	AR	6.70 a	9.26	4200	4800	16200 d	38913	44472	150093
Rogers	AR	3.50 a	4.84	4000	5300	19200 d	19360	25652	92926
Watts	OK	0.07 b	0.10	3975	4750	16000 e	385	460	1549
Siloam Spring	AR	2.40 a	3.32	3900	4700	18000 d	12943	15598	59730
Gentry City	AR	0.21 a	0.29	3975	4750	16000 e	1154	1379	4646
Tahlequah	OK	2.68 c	3.71	3800	4200	10500 d	14083	15565	38913
Lincoln City	AR	0.41 a	0.57	3975	4750	16000 e	2254	2693	9071
Westville	OK	0.10 c	0.14	3975	4750	16000 e	550	657	2213
Indian Nations	OK	0.05 c	0.07	3975	4750	16000 e	275	328	1106
Sequoyah	OK	0.04 b	0.05	3975	4750	16000 e	192	230	774
Stillwell	OK	0.24 c	0.33	3975	4750	16000 e	1319	1576	5310
Stillwell Cannery	OK	0.12 c	0.17	3975	4750	16000 e	660	788	2655
TOTALS		16.76	23.17	4031	4790	16155	93406	110975	374305
TOTALS	AR	13.46	18.61	4080	4909	17288	75943	91371	321785
TOTALS	OK	3.29	4.56	3833	4303	11527	17463	19605	52520
TOTALS above Lake Frances		10.44	14.44	4128	4966	17201	59592	71700	248329
TOTALS below Lake Frances		6.31	8.73	3872	4498	14426	33815	39276	125976
Fayetteville		6.10 f	8.44	900	1000	13150 f	7596	8440	110986

Runoff Rate = 0.1 m/yr

NONPOINT CALCULATIONS	WATERSHED AREA Km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P Kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Above Frances	1644	164.40	75	150	2500 g	12330	24660	411000
Below Frances	2526	252.60	50	100	1666 g	12630	25260	420832
Total	4170	417.00	60	120	1995	24960	49920	831832

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	178.84	402	539	3687	71922	96360	659329
Below Frances	2526	261.33	178	247	2092	46445	64536	546808
Total	4170	440.17	269	366	2740	118366	160895	1206137

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	187.28	425	560	4113	79518	104800	770315
Below Frances	2526	261.33	178	247	2092	46445	64536	546808
Total	4170	448.61	281	377	2936	125962	169335	1317123

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	4.72	5.50	3.86	11.57	10.56	8.76	16.83
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	1.92	4.42	3.27	7.15	6.42	5.25	9.20

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - OKlahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, UESPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed
f - phosphorus from Fayetteville discharge permit;
nitrogen = median value for plants practicing phosphorus removal (USEPA,1974)
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

Table 7
Basinwide Mass Balance Calculations - Wet Year

WATER AND MASS BALANCE CALCULATIONS ILLINOIS RIVER ABOVE TENKILLER DAM WET HYDROLOGIC YEAR

POINT SOURCE DISCHARGES			STP CONCENTRATIONS				STP LOADS		
		FLOW	FLOW	ORTHO P	TOTAL P	TOTAL N	ORTHO P	TOTAL P	TOTAL N
TREATMENT PLANT	STATE	mgd	hm3/yr	ppb	ppb	ppb	kg/yr	kg/yr	kg/yr
Prarie Grove	AR	0.24 a	0.33	3975	4750	16000 e	1319	1576	5310
Springdale	AR	6.70 a	9.26	4200	4800	16200 d	38913	44472	150093
Rogers	AR	3.50 a	4.84	4000	5300	19200 d	19360	25652	92926
Watts	OK	0.07 b	0.10	3975	4750	16000 e	385	460	1549
Siloam Spring	AR	2.40 a	3.32	3900	4700	18000 d	12943	15598	59738
Gentry City	AR	0.21 a	0.29	3975	4750	16000 e	1154	1379	4646
Tahlequah	OK	2.68 c	3.71	3800	4200	10500 d	14083	15565	38913
Lincoln City	AR	0.41 a	0.57	3975	4750	16000 e	2254	2693	9071
Westville	OK	0.10 c	0.14	3975	4750	16000 e	550	657	2213
Indian Nations	OK	0.05 c	0.07	3975	4750	16000 e	275	328	1106
Sequoyah	OK	0.04 b	0.05	3975	4750	16000 e	192	230	774
Stillwell	OK	0.24 c	0.33	3975	4750	16000 e	1319	1576	5310
Stillwell Cannery	OK	0.12 c	0.17	3975	4750	16000 e	660	788	2655
TOTALS		16.76	23.17	4031	4790	16155	93406	110975	374305
TOTALS	AR	13.46	18.61	4080	4909	17288	75943	91371	321785
TOTALS	OK	3.29	4.56	3833	4303	11527	17463	19605	52520
TOTALS above Lake Frances		10.44	14.44	4128	4966	17201	59592	71700	248329
TOTALS below Lake Frances		6.31	8.73	3872	4498	14426	33815	39276	125976
Fayetteville		6.10 f	8.44	900	1000	13150 f	7596	8440	110986

Runoff Rate = 0.73 m/yr

NONPOINT CALCULATIONS	WATERSHED		FLOW-WEIGHTED CONCENTRATIONS				LOADINGS	
	AREA	FLOW	ORTHO P	TOTAL P	TOTAL N	ORTHO P	TOTAL P	TOTAL N
	km2	hm3/yr	ppb	ppb	ppb	kg/yr	kg/yr	kg/yr
Above Frances	1644	1200.12	75	150	2500 g	90009	180018	3000300
Below Frances	2526	1843.98	50	100	1666 g	92199	184398	3072071
Total	4170	3044.10	60	120	1995	182208	364416	6072371

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	1214.56	123	207	2675	149601	251718	3248629
Below Frances	2526	1852.71	68	121	1726	126014	223674	3198047
Total	4170	3067.27	90	155	2102	275614	475391	6446676

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	1223.00	129	213	2747	157197	260158	3359615
Below Frances	2526	1852.71	68	121	1726	126014	223674	3198047
Total	4170	3075.71	92	157	2132	283210	483831	6557662

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	0.69	4.35	2.64	2.70	5.00	3.35	3.42
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	0.28	2.47	1.50	1.44	2.76	1.78	1.72

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - OKlahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, UESPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed
f - phosphorus from Fayetteville discharge permit;
nitrogen = median value for plants practicing phosphorus removal (USEPA,1974)
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

Table 8
Comparisons of Loading Estimates
Existing Conditions vs. 1974-75

COMPARISON OF LOADING ESTIMATES EXISTING CONDITIONS VS. 1974-1975

	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P Kg/yr	TOTAL P Kg/yr	TOTAL N Kg/yr
EPA NATIONAL EUTROPHICATION SURVEY LOADING ESTIMATES (1974-1975) LOADS TO LAKE FRANCES								
Runoff Rate= .306 m/yr (Normalized)								
Existing	1644	517.50	100	284	2910	97322	147159	1505989
1974-1975	1644	519.00		163	2559		84780	1328000
% Increase	0.00	-0.29		74.08	13.73		73.58	13.40
EPA NATIONAL EUTROPHICATION SURVEY LOADING ESTIMATES (1974-1975) TOTAL LOADS TO BASIN								
Runoff Rate= .306 m/yr (Normalized)								
Existing	4170	1299.19	131	203	2247	169784	263731	2919710
1974-1975	4170	1298		98	2200		127290	2855190
% Increase	0.00	0.09		107.00	2.17		107.19	2.26
WALKER (1982) LOADING ESTIMATES (1974-1975) LOADS TO TENKILLER FERRY RESERVOIR								
Runoff Rate = .6 m/yr (Sampled Conditions)								
Existing	4170	2525.17	96	163	2125	243166	418495	5365295
1974-75	4170	2510.00	53	91	1903	133800	227680	4776940
% Increase	0.00	0.60	80.54	79.21	11.64	81.63	80.29	12.32

FIGURES

FIGURES (CT.)

Figure 1
Station Map

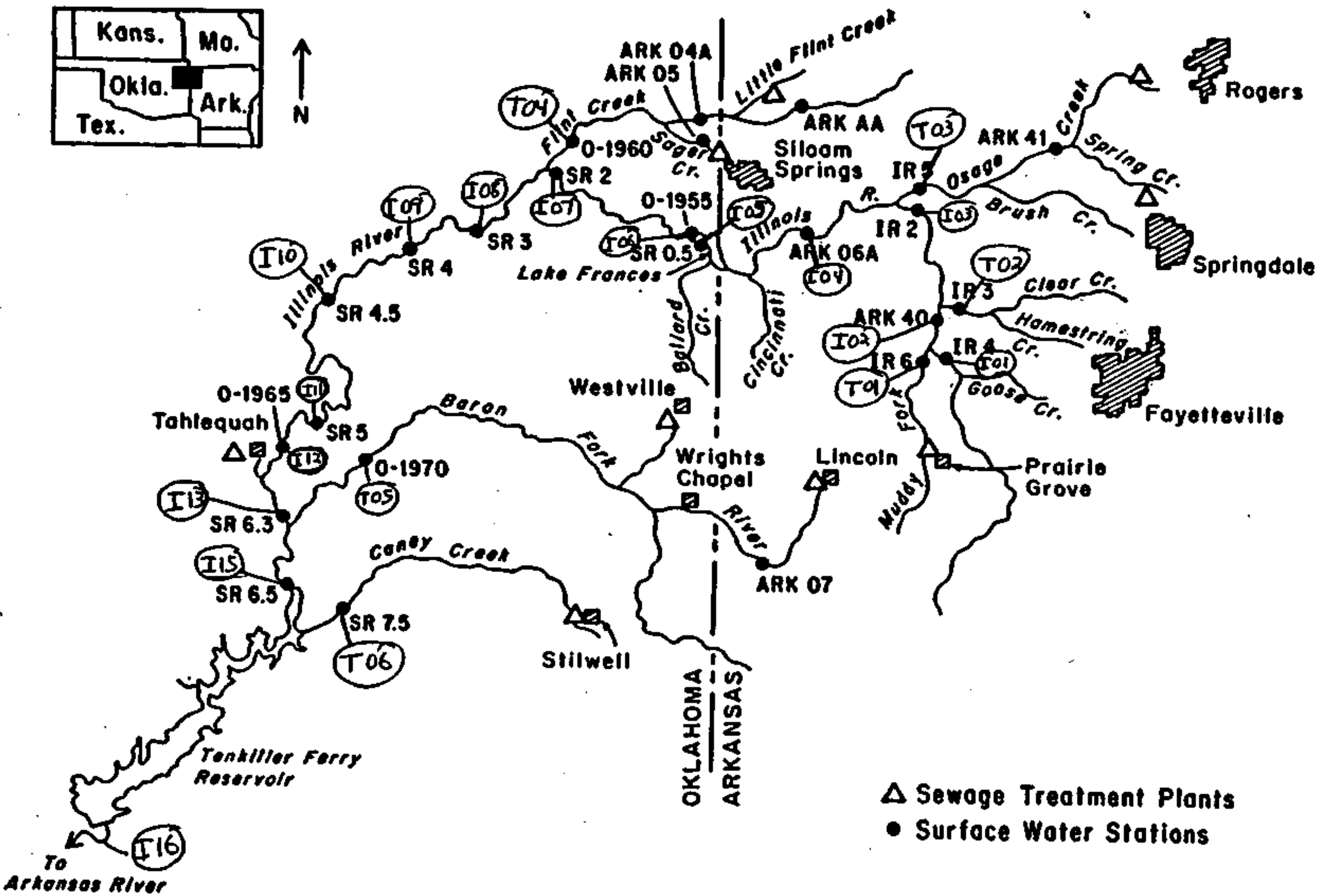


Figure 2
Illinois River Basin Elevation Profile

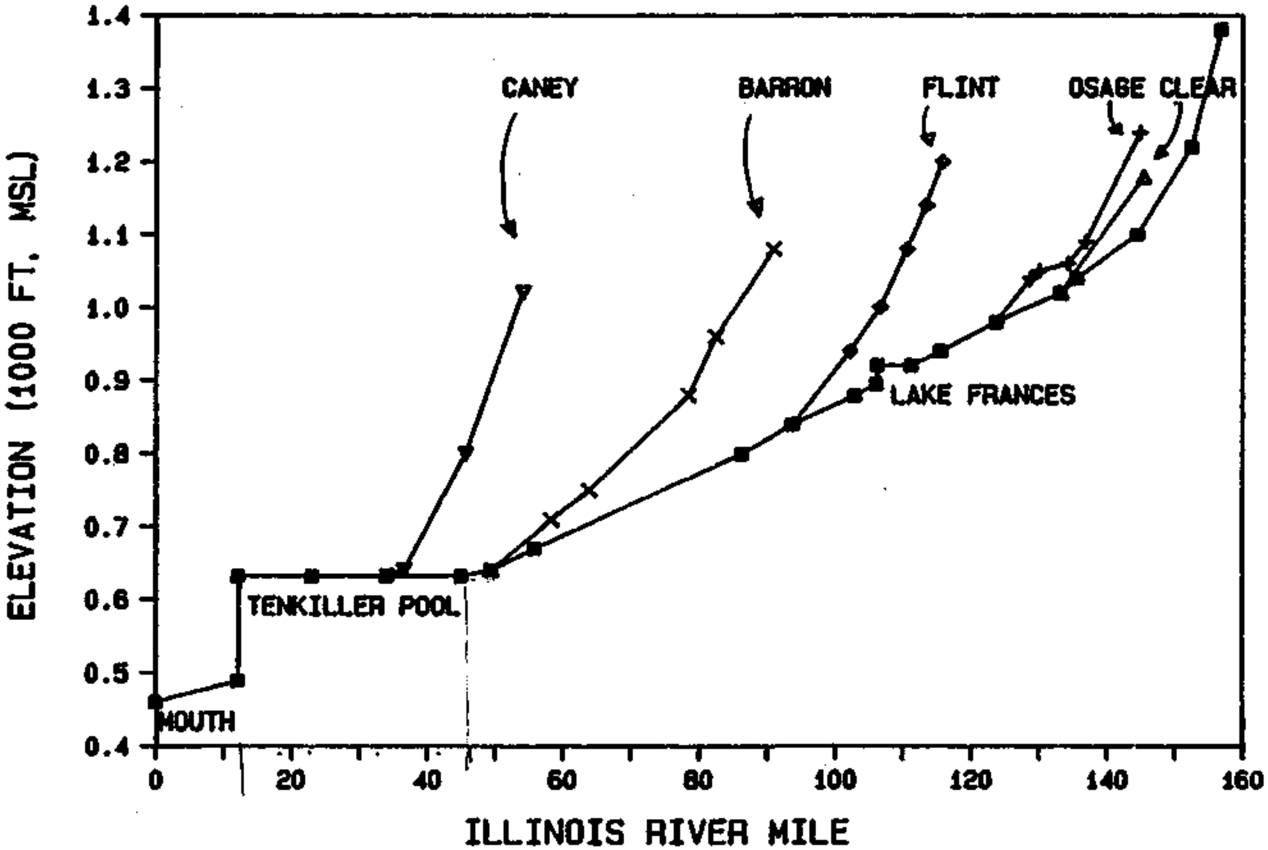
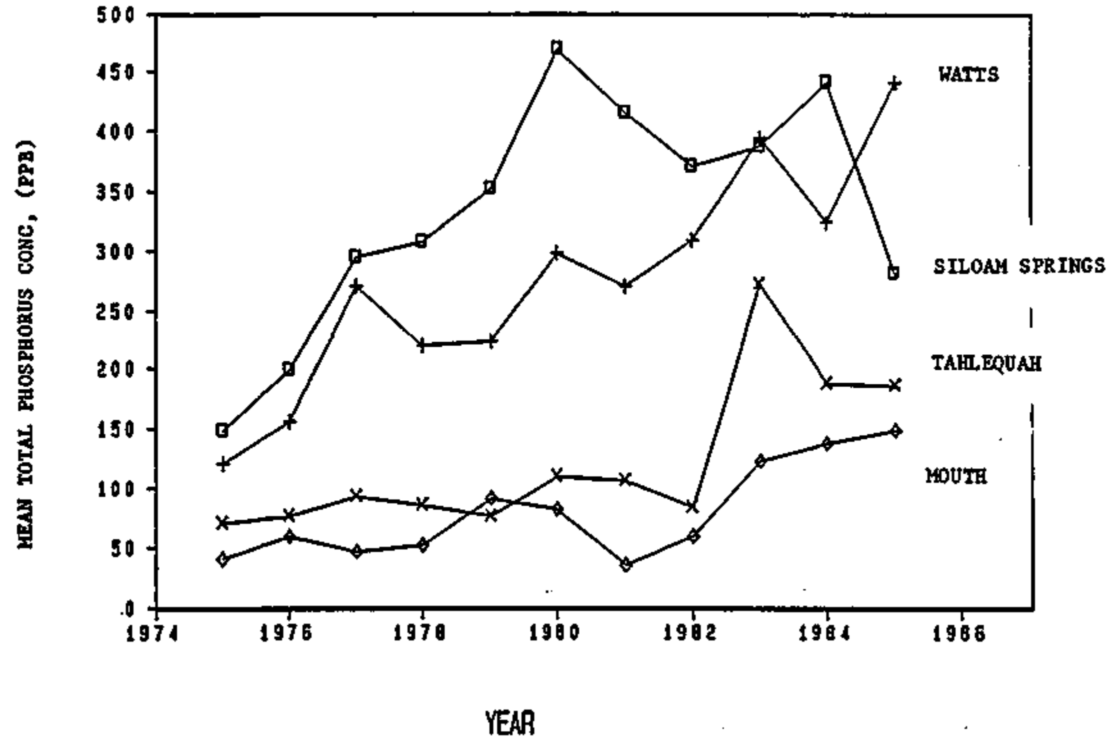


Figure 3
Time Series of Annual Mean Phosphorus Concentrations
and Flows at Illinois River Stations



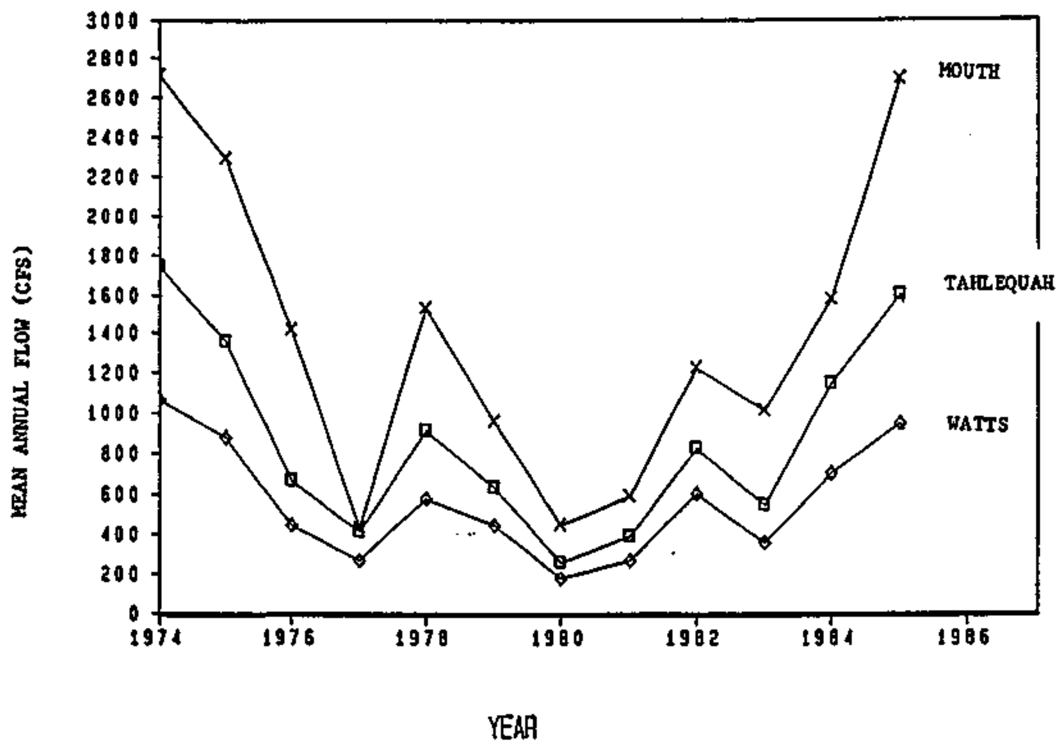


Figure 4
Comparison of Mean Nutrient and Chlorophyll-a Concentrations
1974-5 vs. 1985-6

Left Bar = EPA National Eutrophication Survey, 1974-1975
Right Bar = EPA/Arkansas/Oklahoma Illinois River Study, 1985-1986
Tenkiller Data (TK-U,M,L,D) from Corps of Engineers

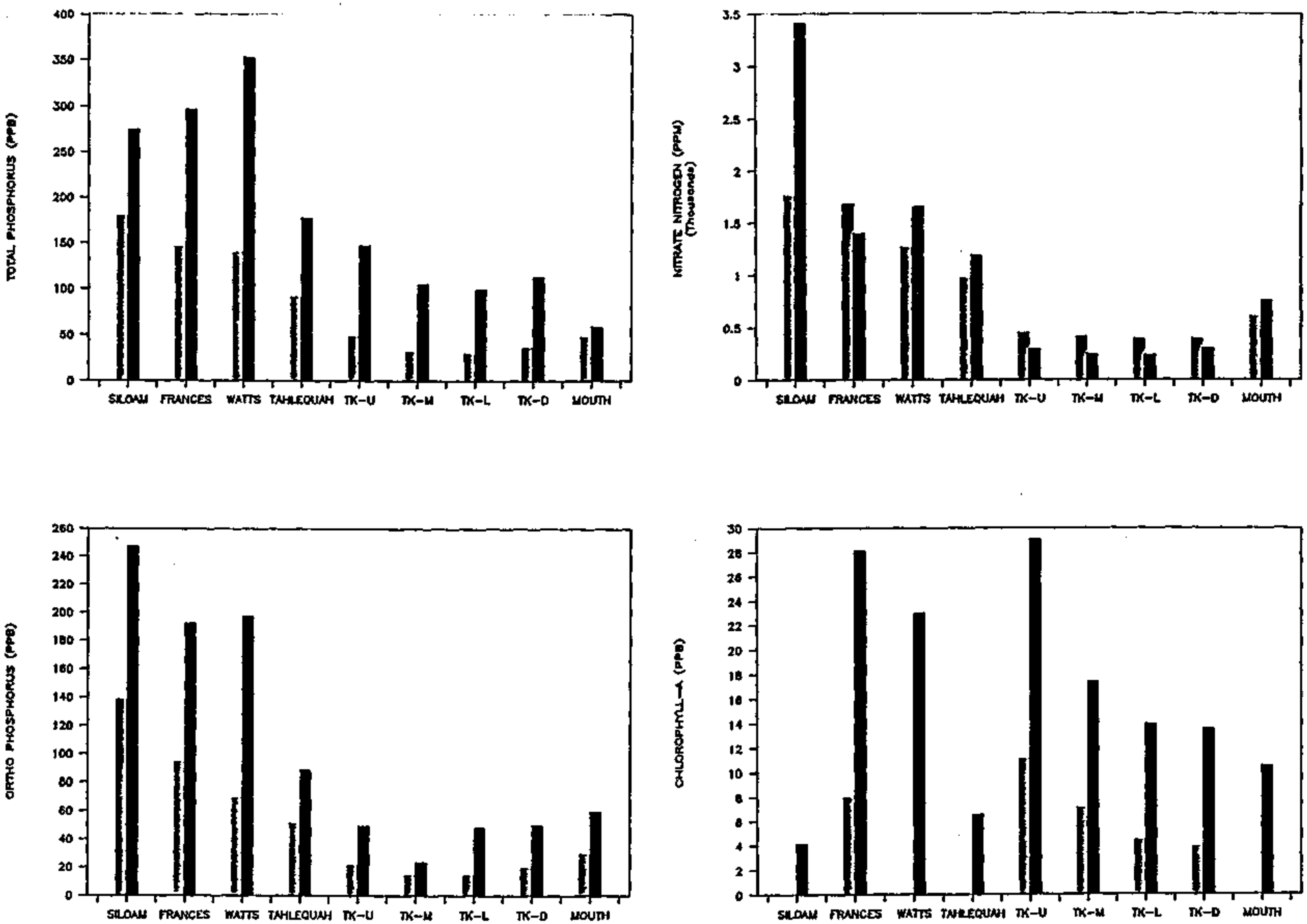


Figure 5
Relationships between Total Phosphorus Concentration and Flow at Three Illinois River Stations
1982-1986

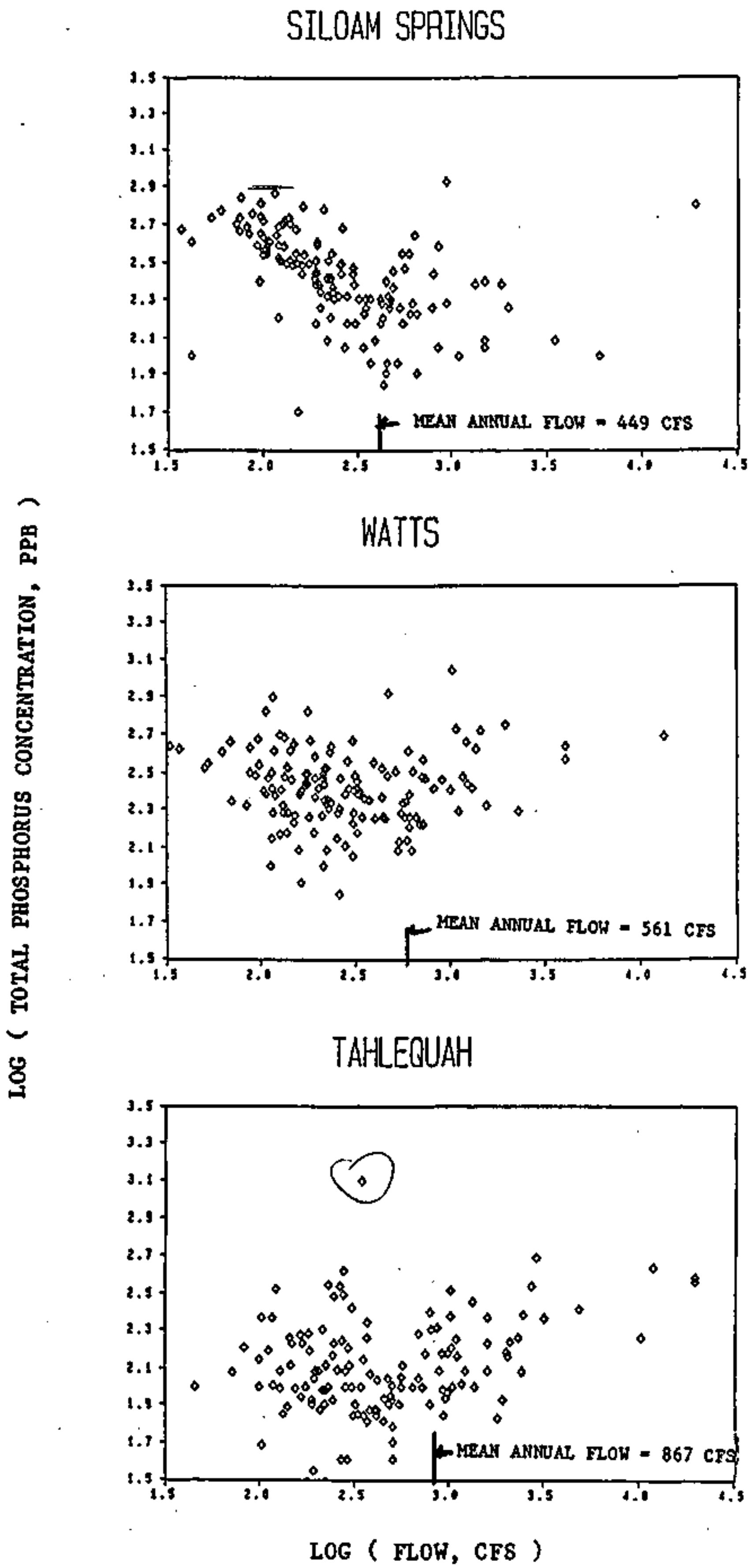


Figure 6
Watershed Segmentation Used for Phosphorus Transport Calculations

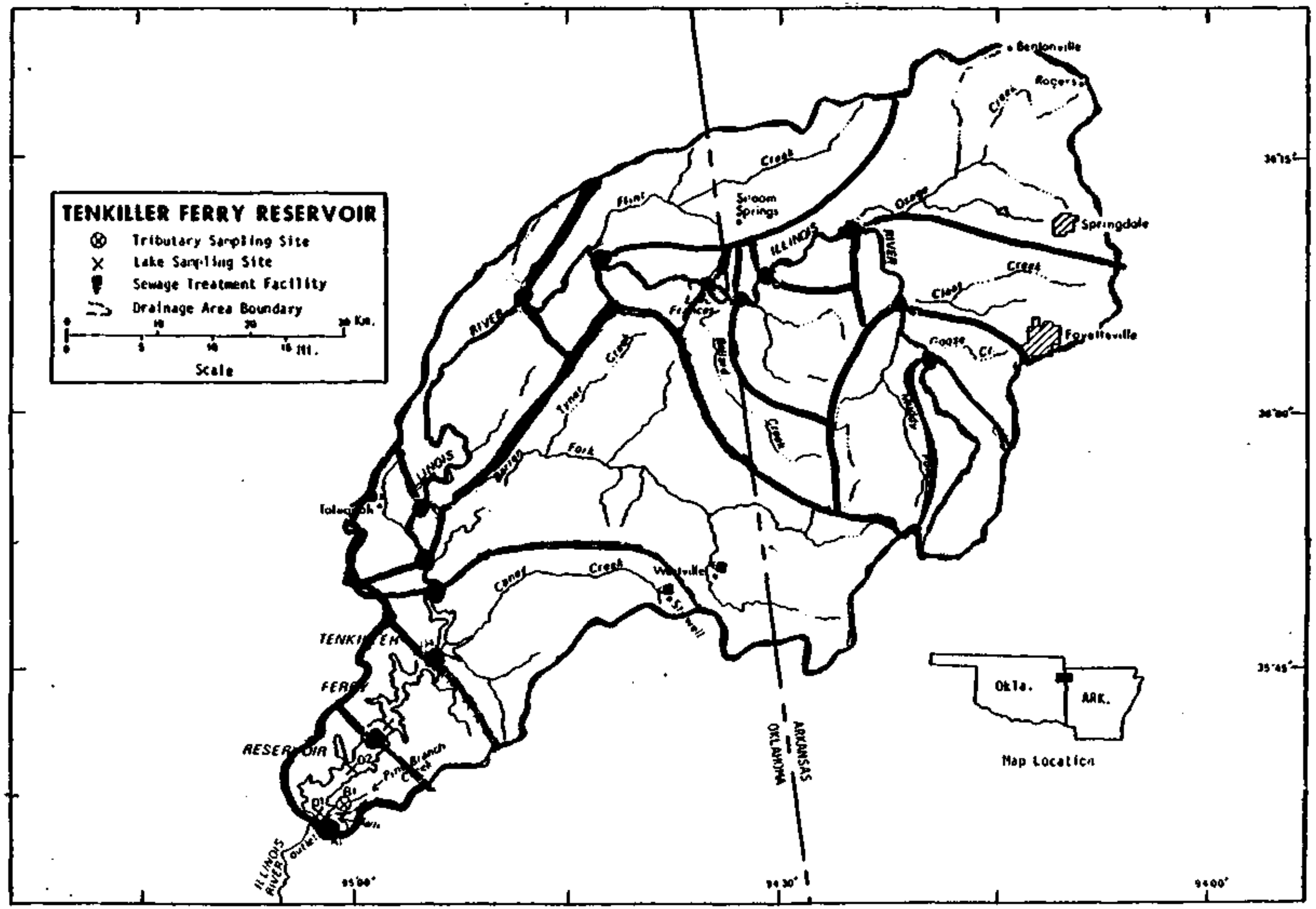
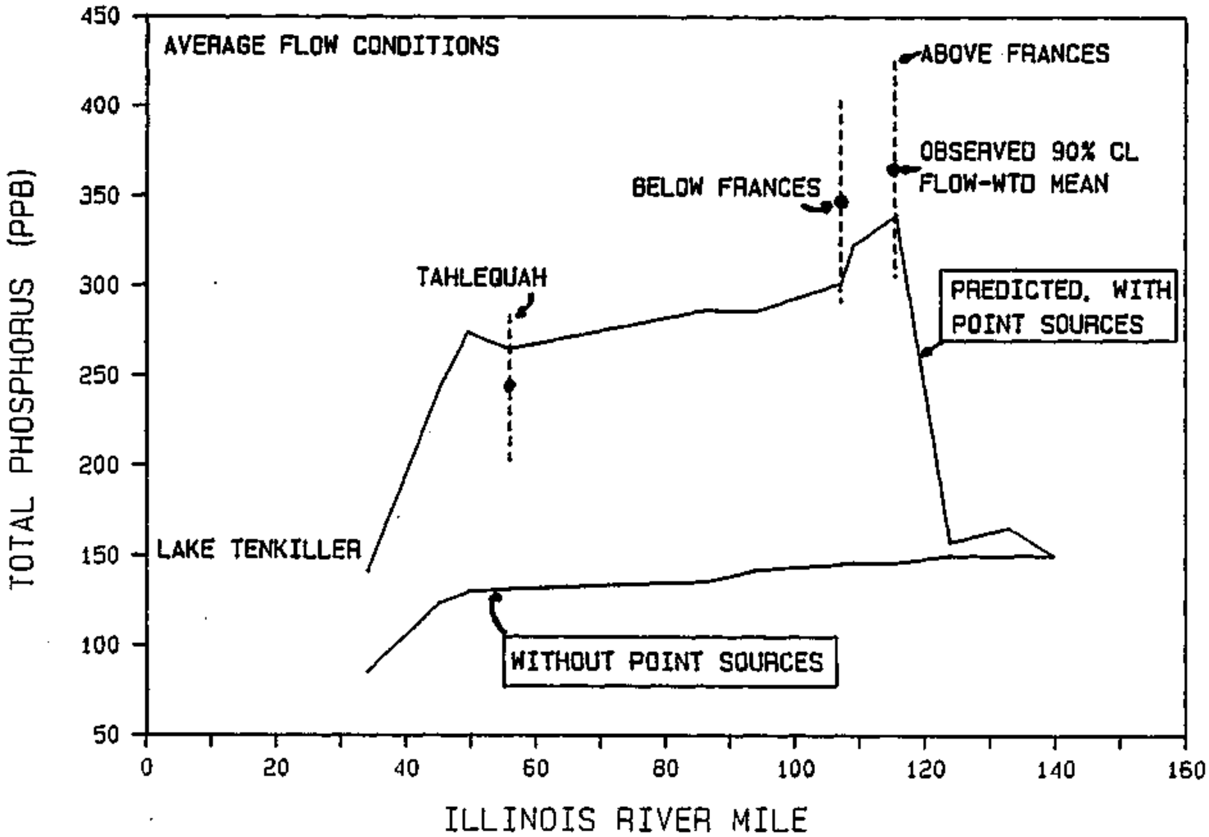


Figure 7
Observed and Predicted Downstream Transport of Total Phosphorus in the Illinois River Basin Average 1982-1986 Conditions



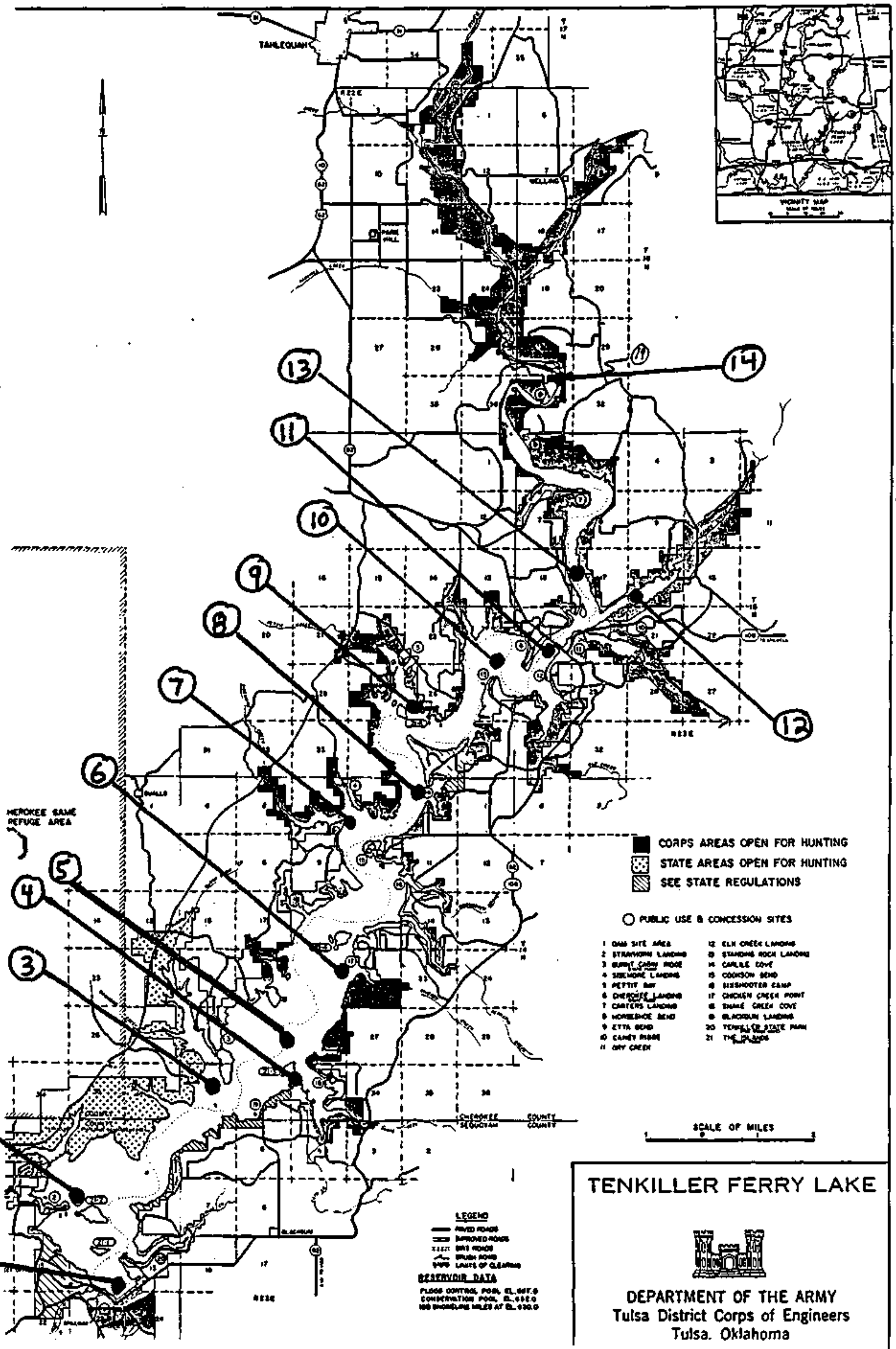
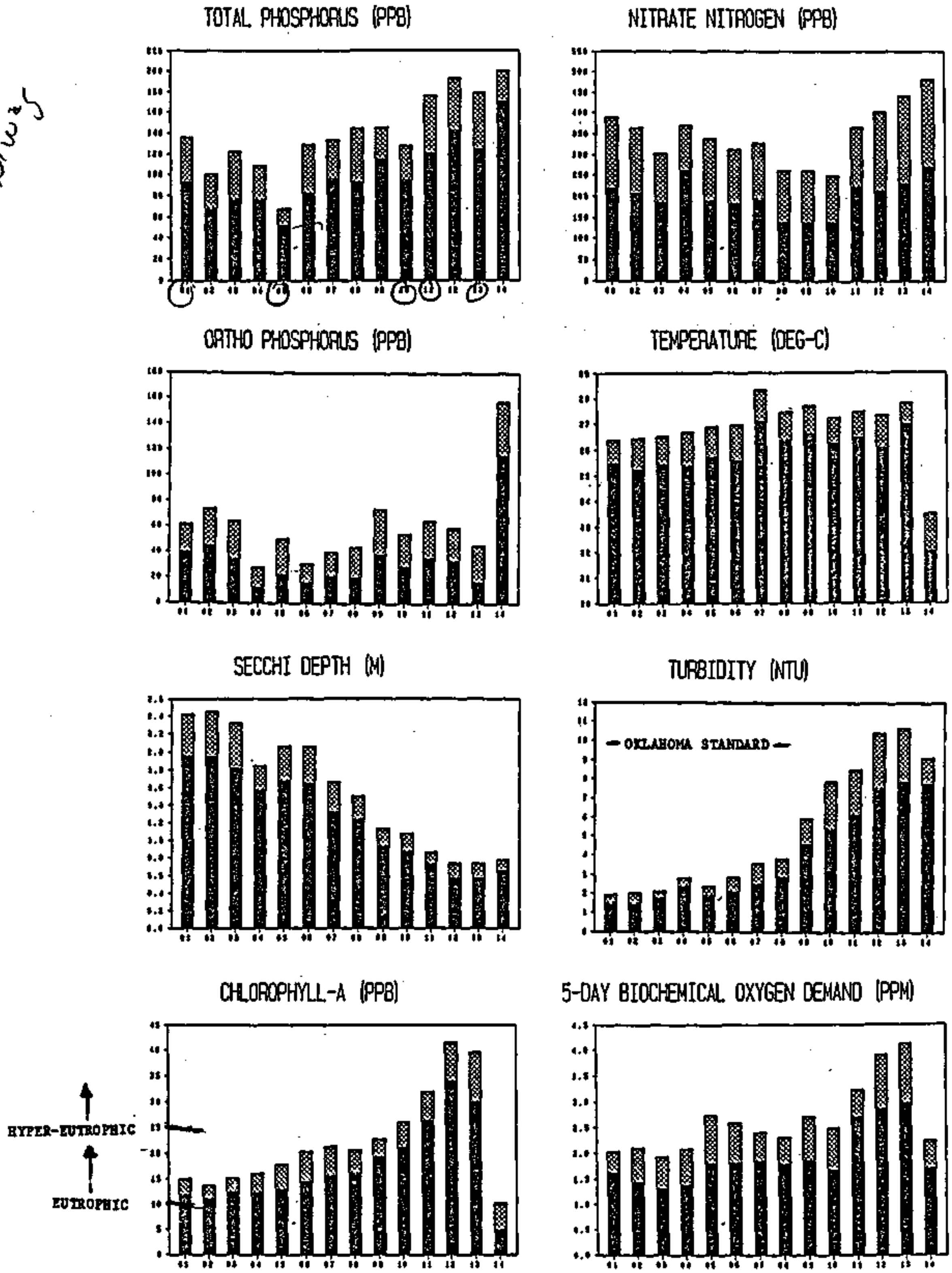


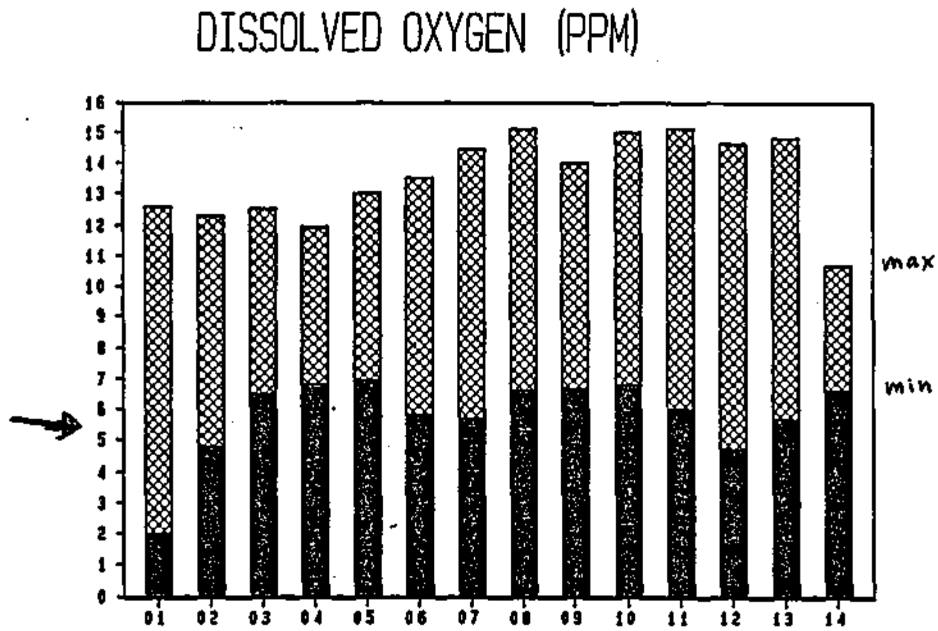
Figure 8
Station Locations
Tenkiller Ferry Reservoir
Corps of Engineer 1986 Survey

Figure 9
Mean Concentrations - Tenkiller Ferry Reservoir
Surface Layer (0-12 ft), April-September 1986
Stations Identified in Figure 8.



mean ±1se

Figure 10
Mixed-Layer Dissolved Oxygen Variations
Tenkiller Ferry Reservoir 1986



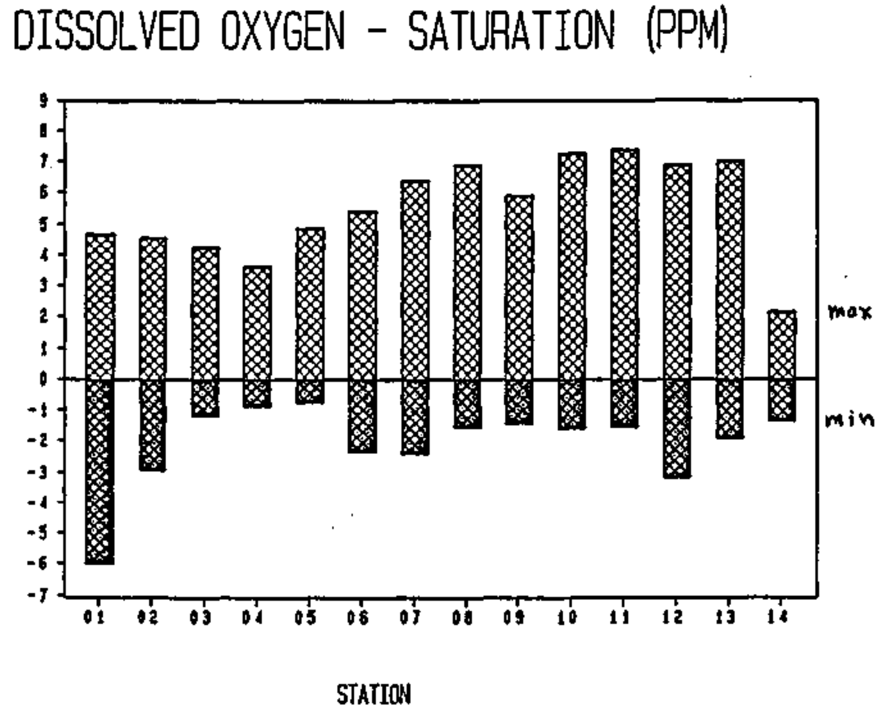


Figure 11
Dissolved Oxygen and Temperature Contours
Tenkiller Ferry Reservoir 1986
Near Dam Station (01)

DATE (MONTH-DAY), 1986

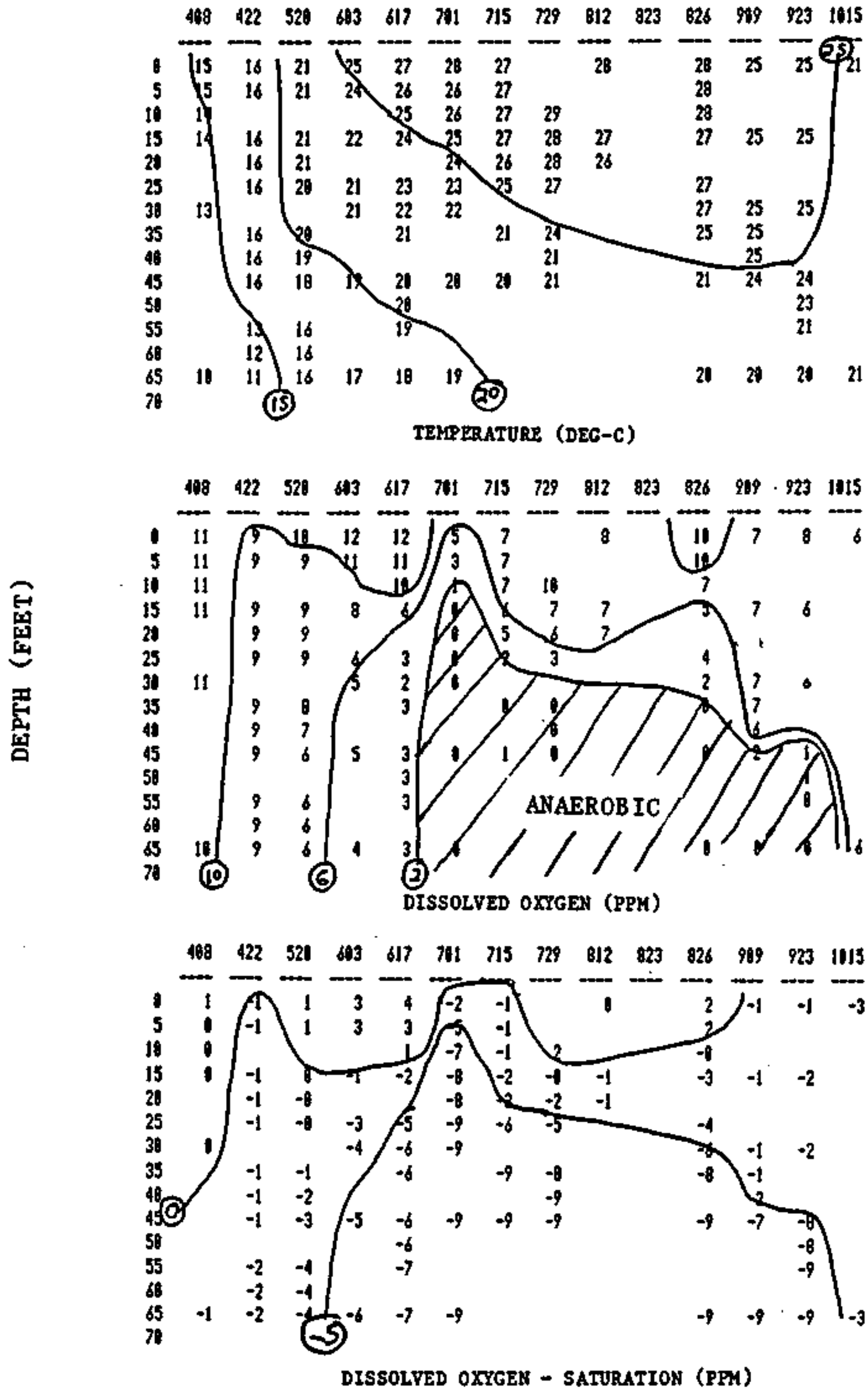


Figure 12
Dissolved Oxygen and Temperature Profiles
Tenkiller Ferry Reservoir 1986
Near Dam Station (01)

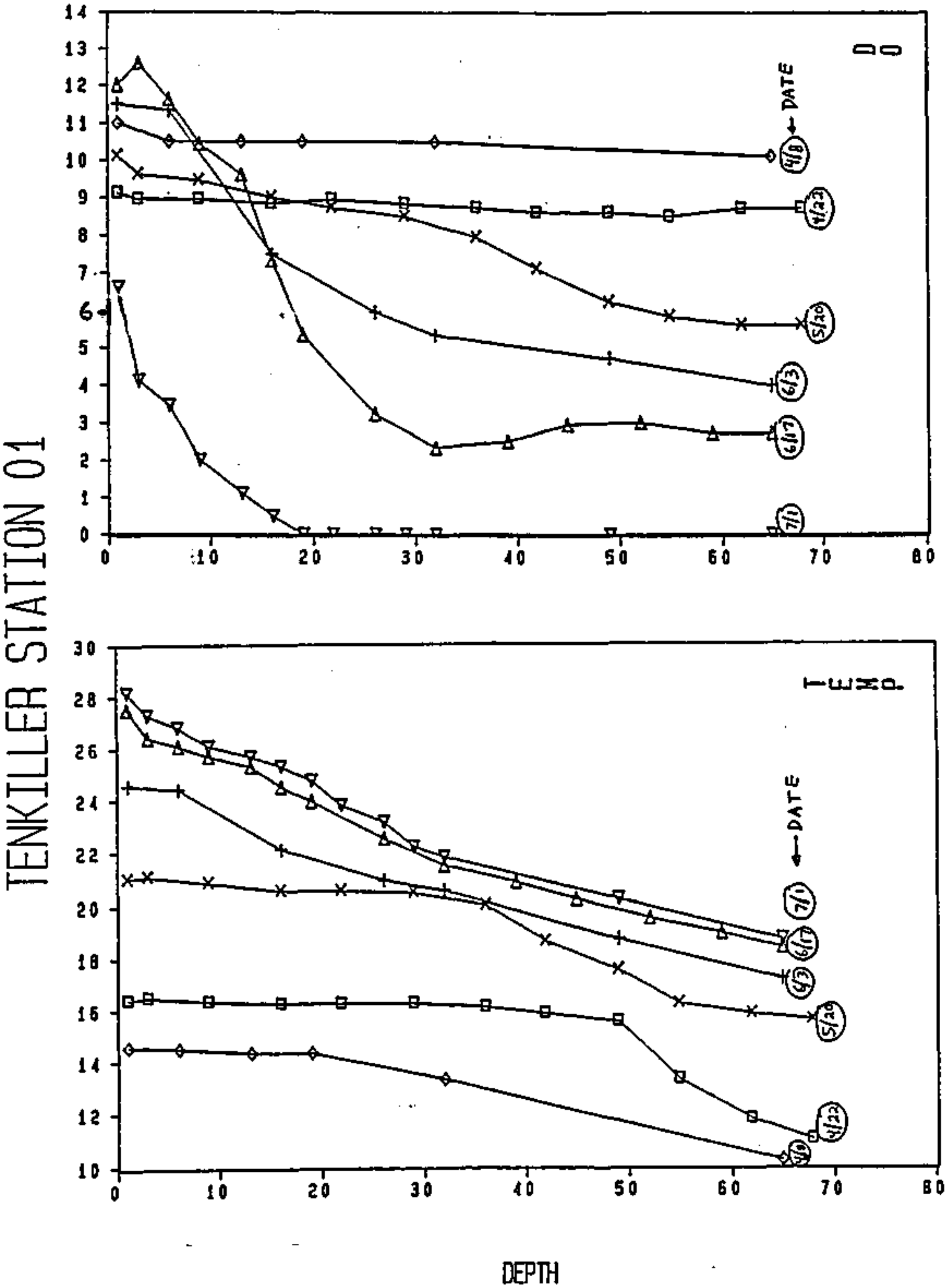
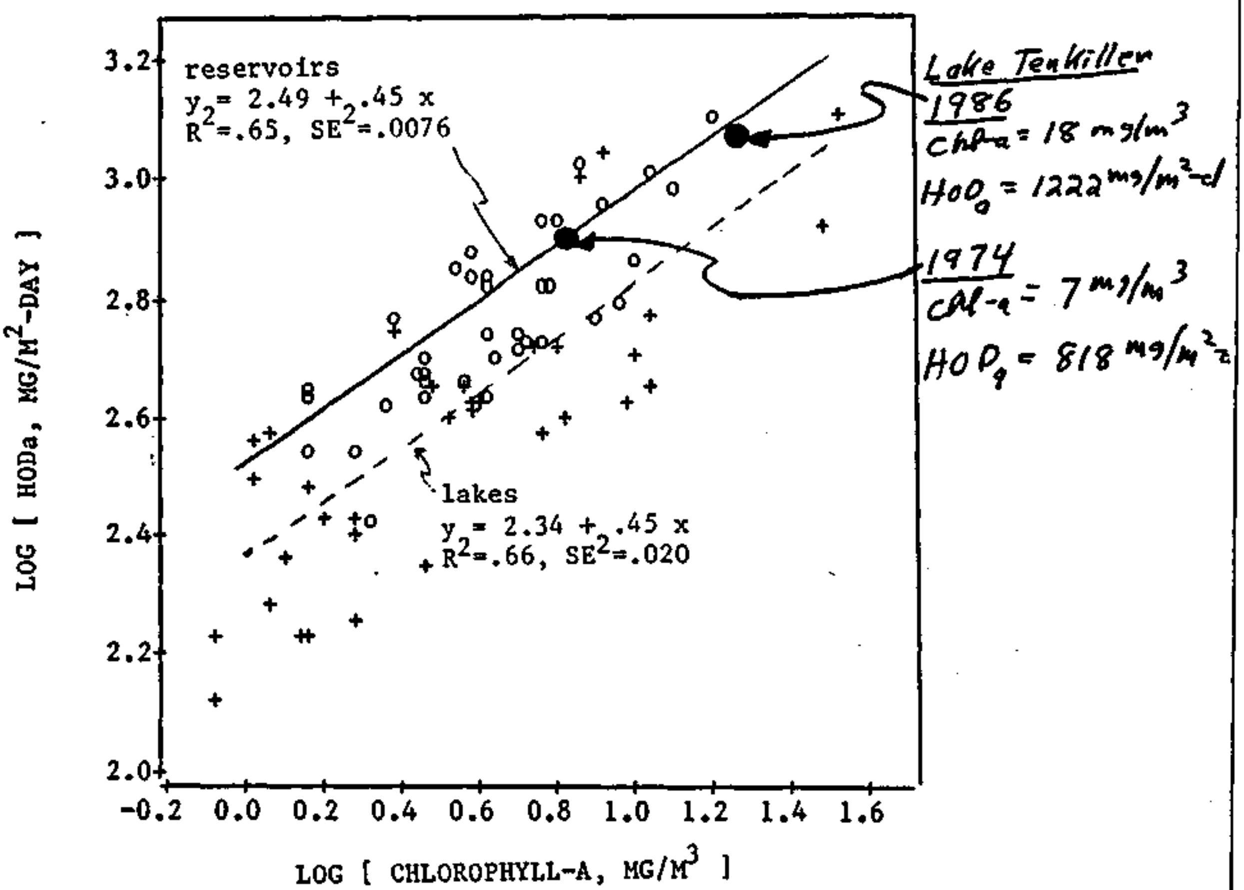


Figure 13
Relationship Between Areal Hypolimnetic Oxygen Depletion Rate
and Mean Mixed-Layer Chlorophyll-a Concentrations
Corps of Engineers Reservoirs
(Walker, 1985)



Symbols:
o = CE Reservoir
+ = Natural Lake, Zh > 2 m

Figure 14
Monthly Variations in Oxygen and Temperature at Longerm Monitoring
Stations on the Illinois River, 1975-1986

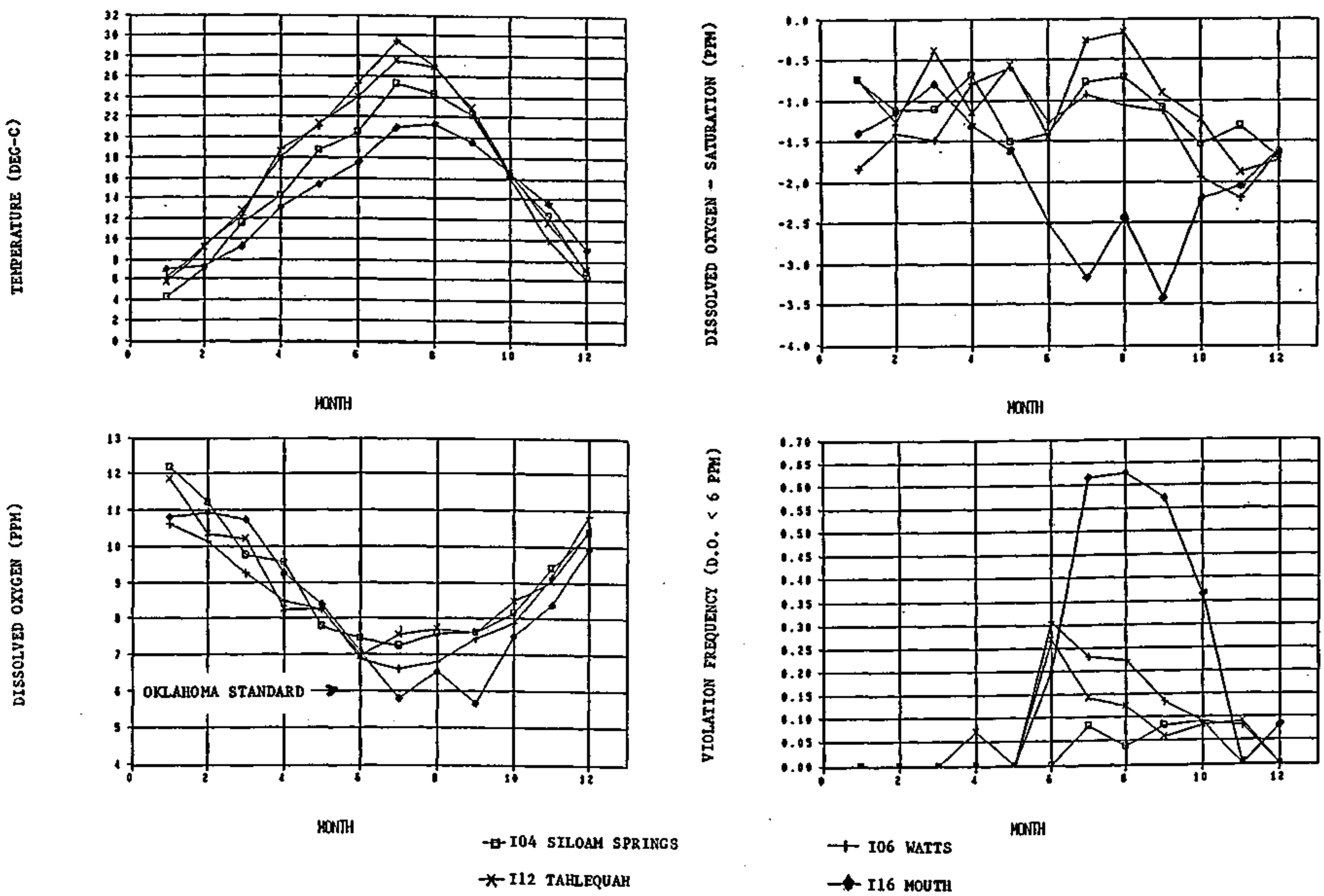
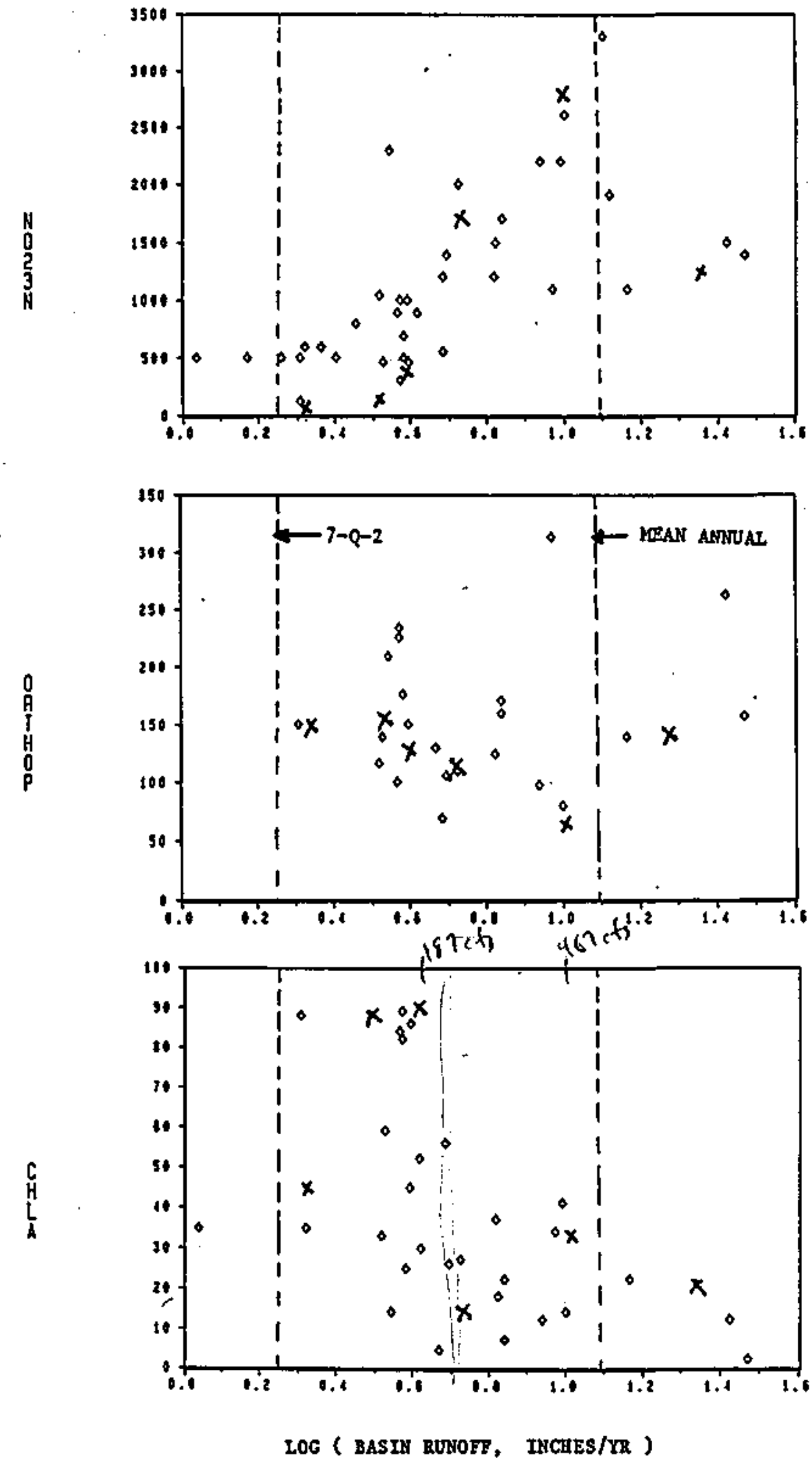


Figure 15
Available Nutrient and Chlorophyll-a Concentrations vs. Watershed Runoff Below Lake Frances



◊ ILLINOIS RIVER BELOW LAKE FRANCES

X LAKE FRANCES NEAR-DAM STATION (Threlkeld,1983)

Figure 16
Spatial Profiles - Illinois River Stations
Chlorophyll-a (ppb), Turbidity (NTU), and Secchi Depth (m)
August 1985 vs. August 1986 Means

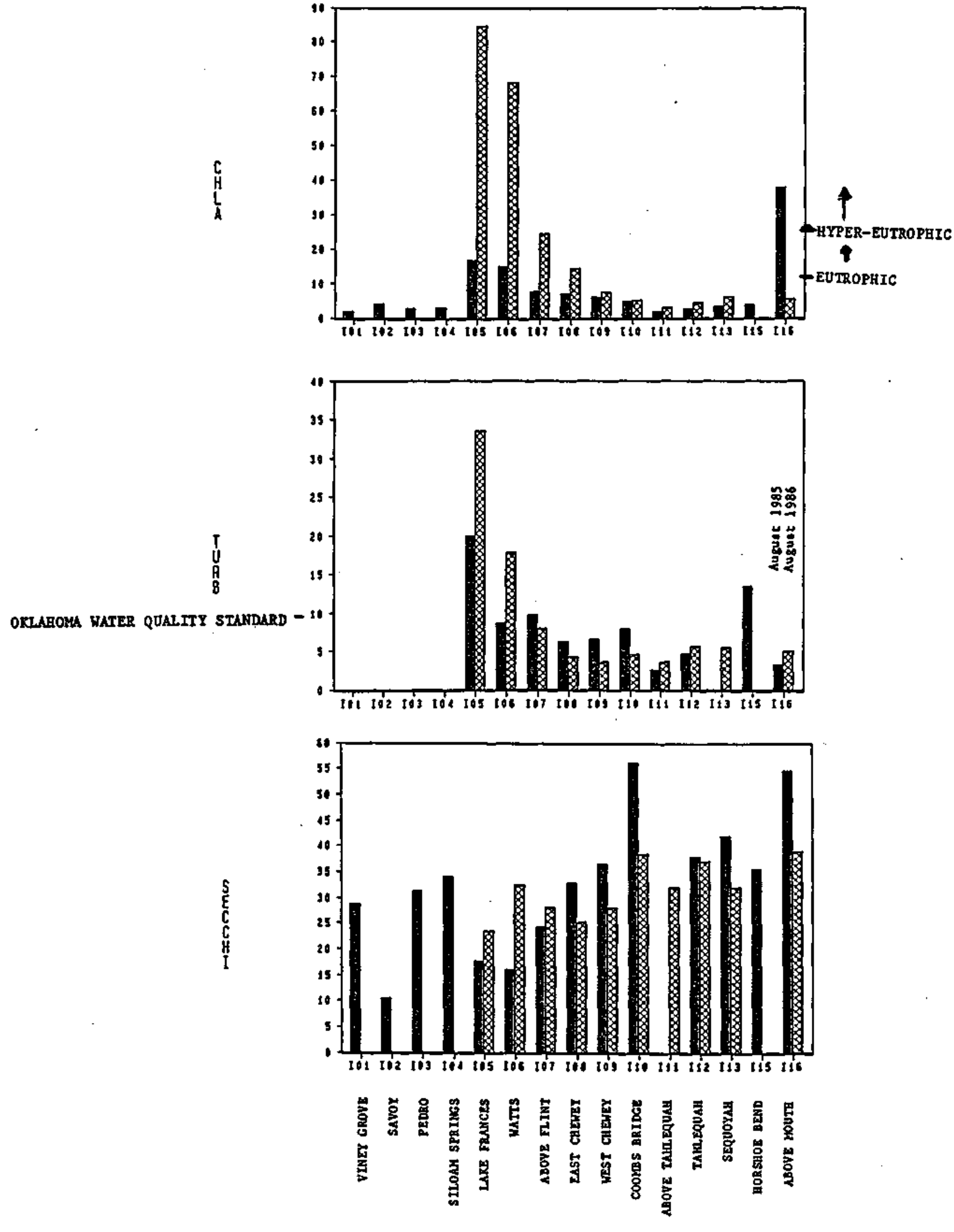


Figure 17
Spatial Profiles - Illinois River Stations
Nitrite+Nitrate, Ammonia, Kjeldahl Nitrogen (ppb)
August 1985 vs. August 1986 Means

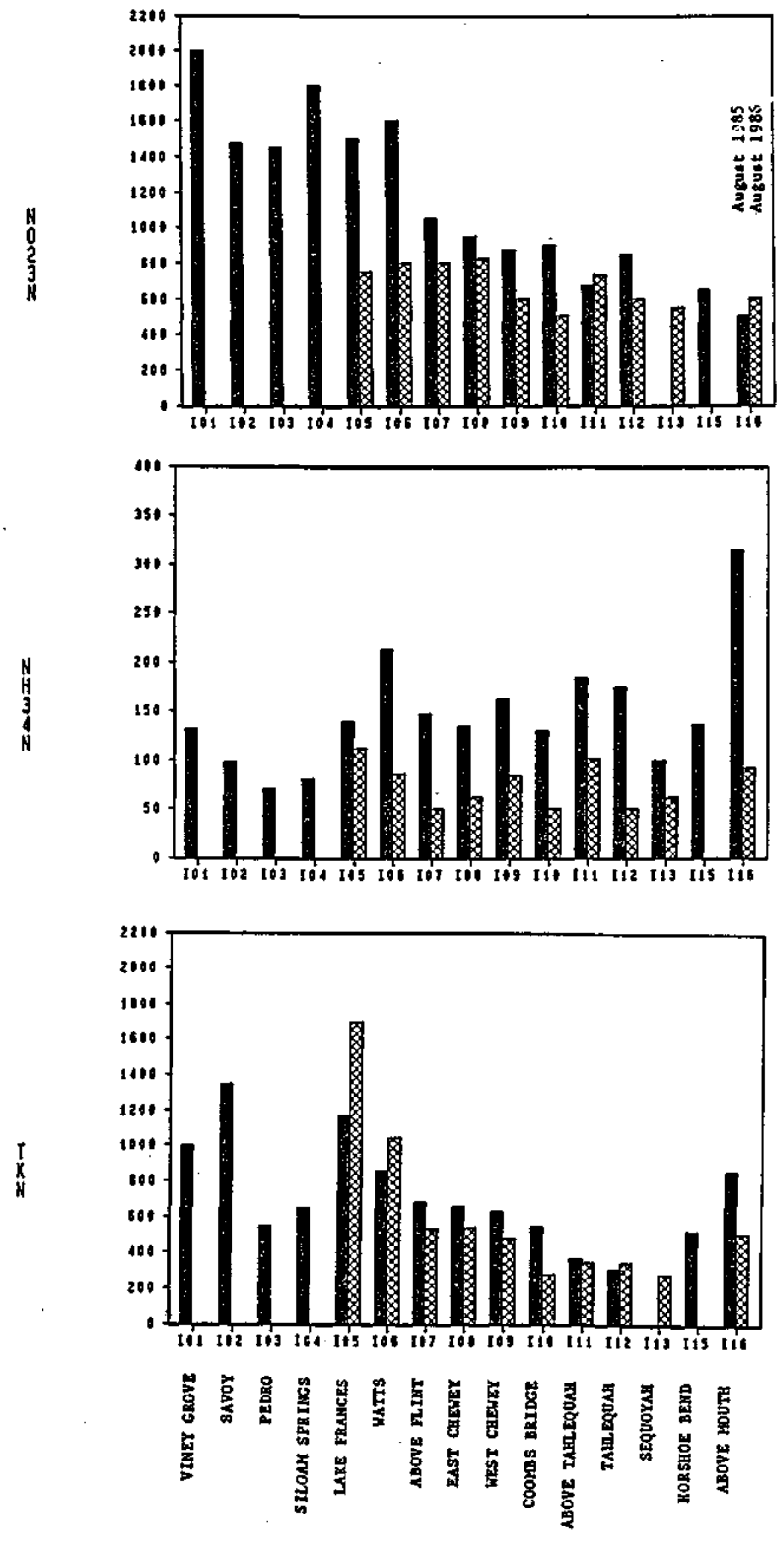


Figure 18
Spatial Profiles - Illinois River Stations
Total Phosphorus, Ortho Phosphorus, Organic Nitrogen (ppb)
August 1985 vs. August 1986 Means

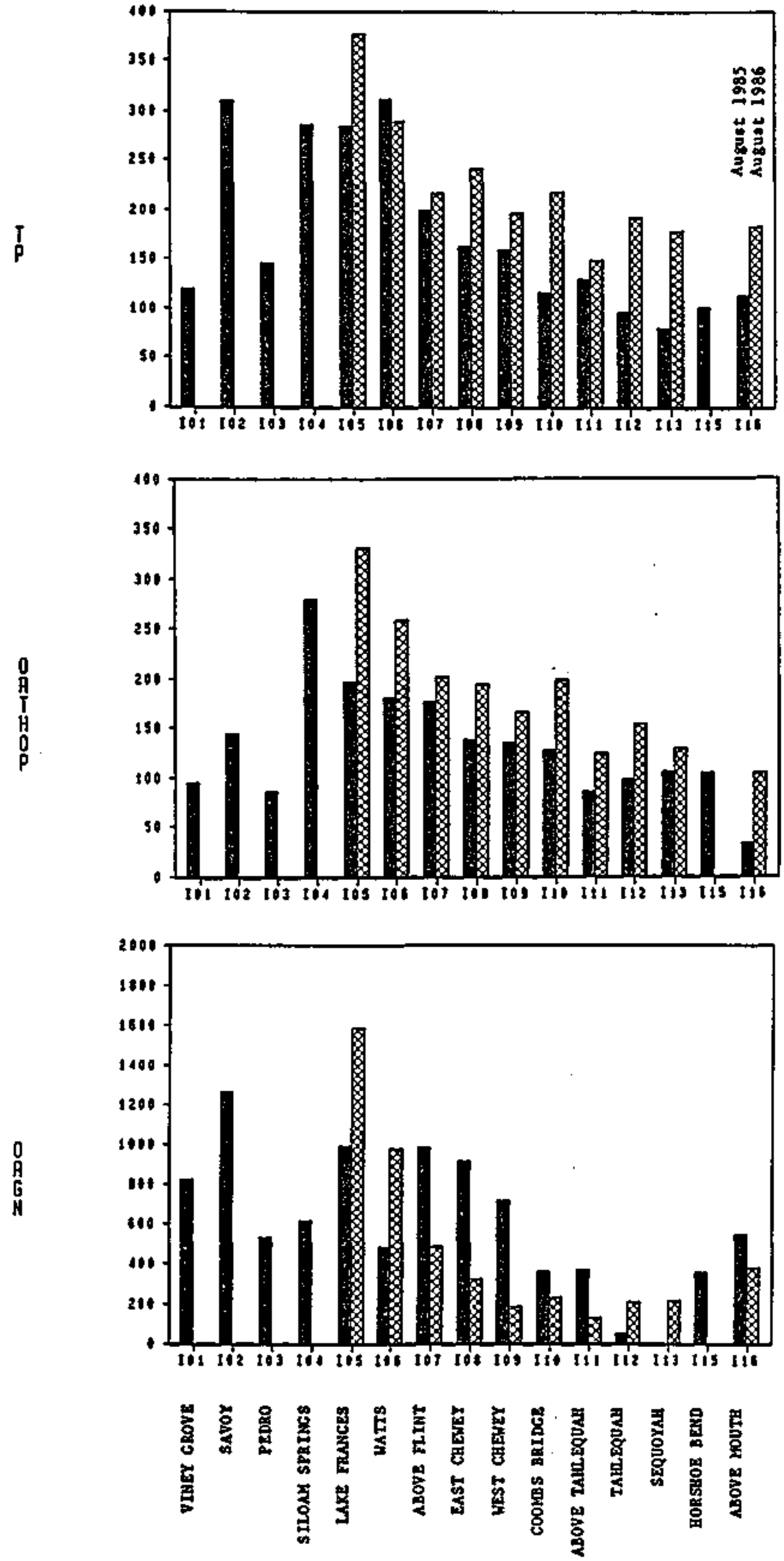
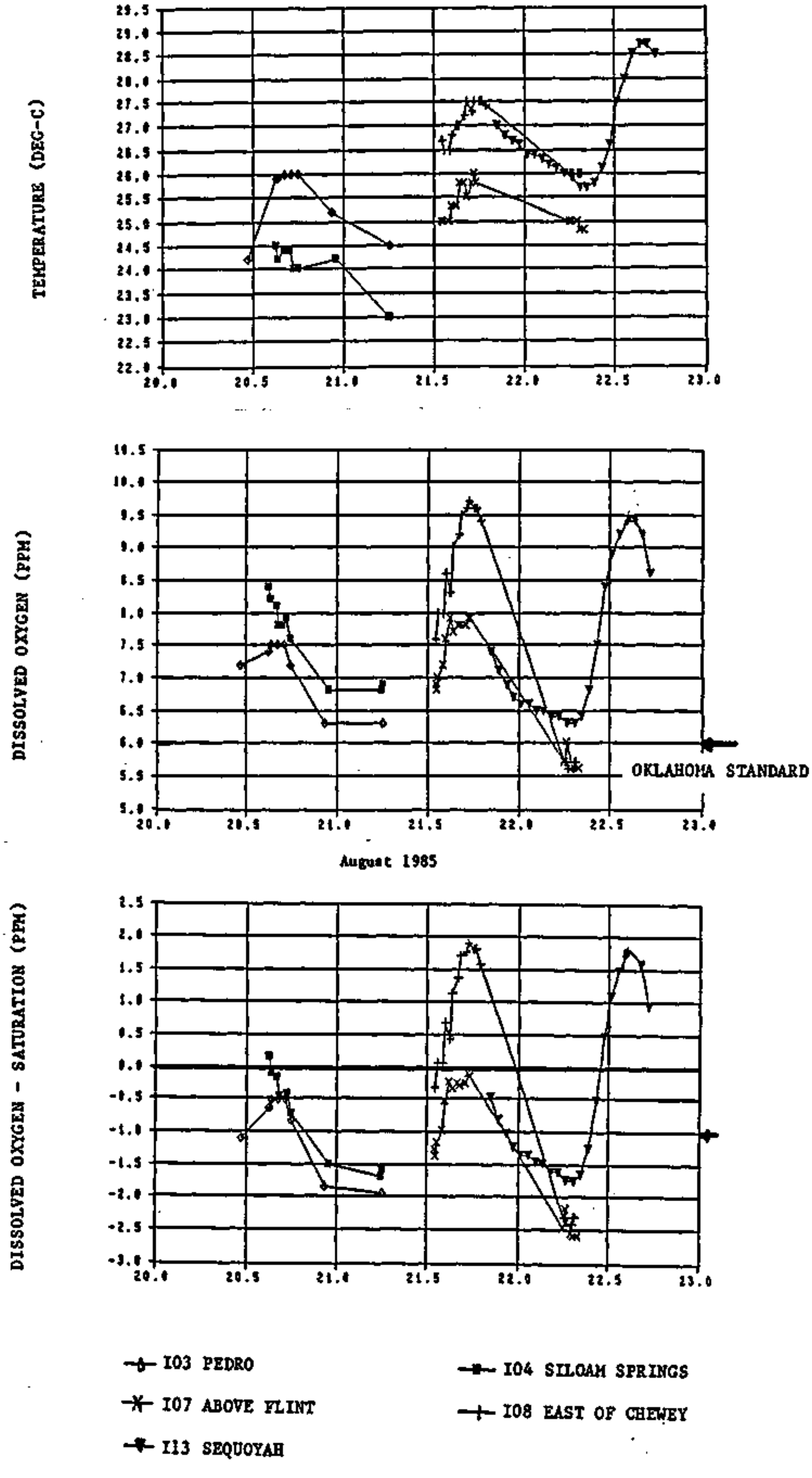
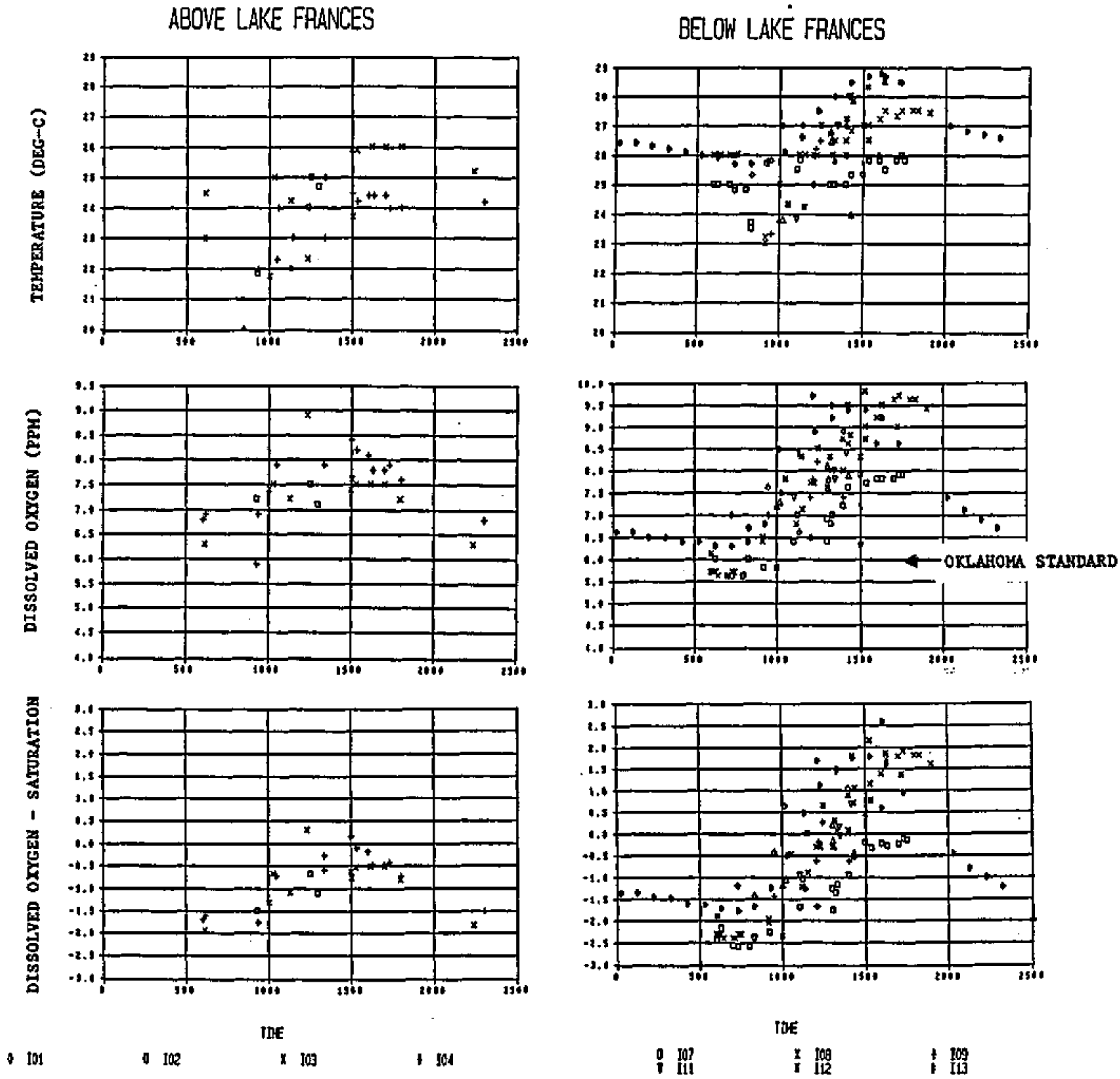


Figure 19
Diurnal Variations in Stream Oxygen Concentrations
August 1985
Stations Separate



6 mg/l
1 mg/l Deficit
≤ 8 hours

Figure 20
Diurnal Variations in Stream Oxygen Concentrations
August 1985
Stations Combined



I01 VINEY GROVE

I02 SAVOY

I03 PEDRO

I04 SILOAM SPRINGS

I07 ABOVE FLINT

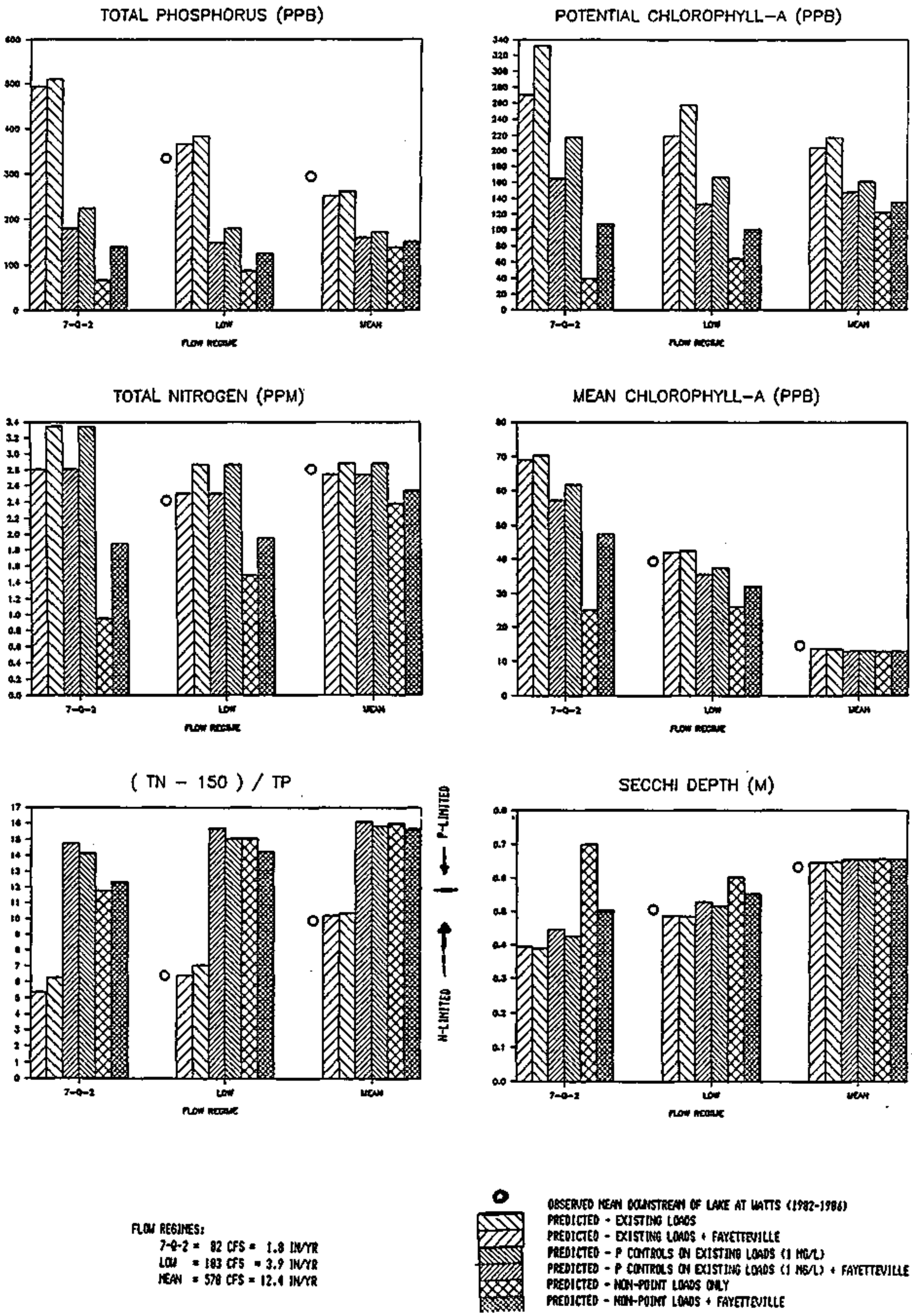
I08 EAST CHEWEY

I09 WEST CHEWEY

I11 ABOVE TAHLEQUAH

I13 SEQUOYAH

Figure 21
Predicted Impacts of Fayetteville Discharge on Nutrient, Algae, and Transparency Levels in Lake Frances



FLOW REGIMES:
7-Q-2 = 82 CFS = 1.8 IN/YR
LOW = 183 CFS = 3.9 IN/YR
MEAN = 578 CFS = 12.4 IN/YR

Figure 22

Composition of Streamflow at Watts

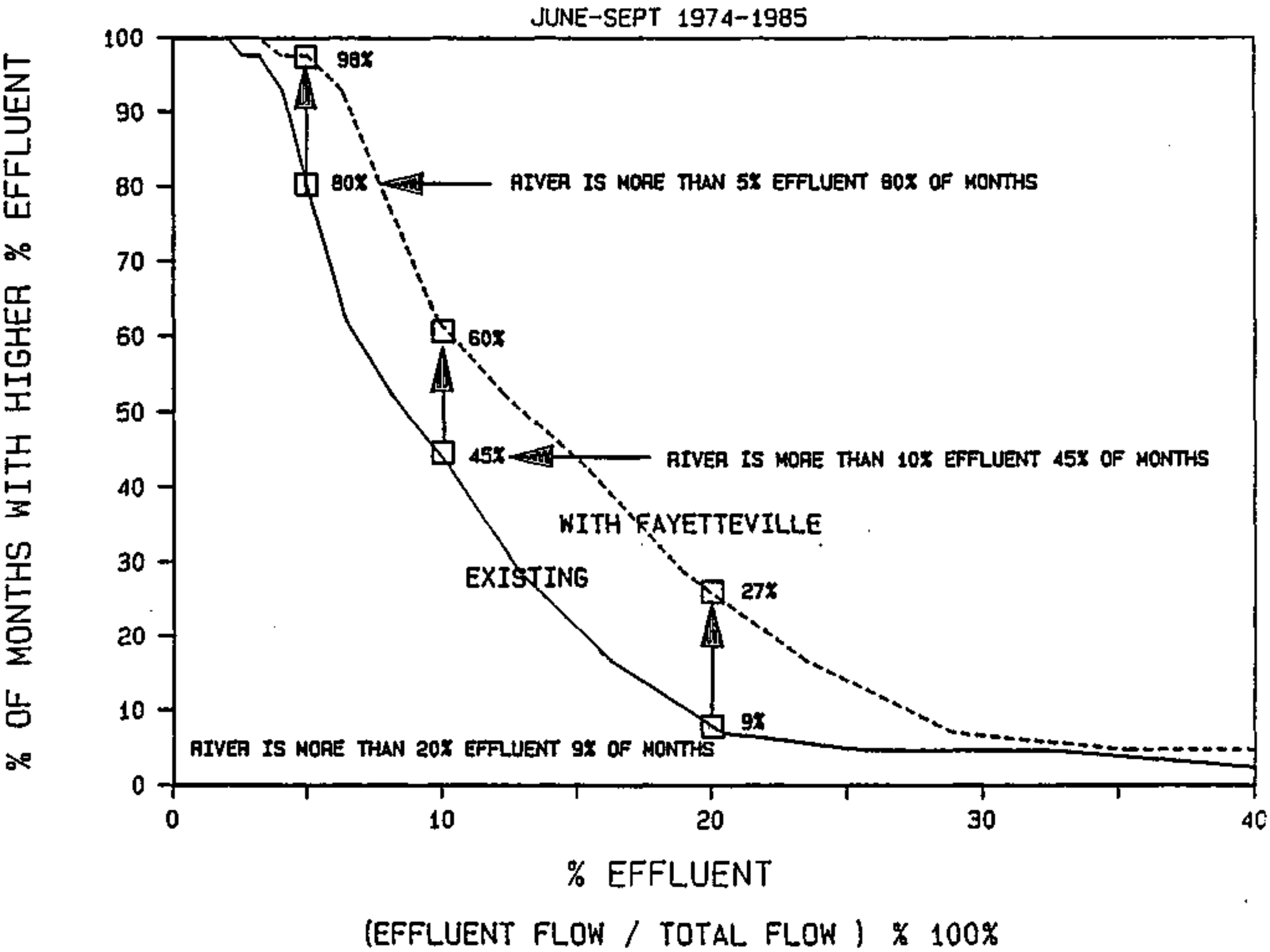
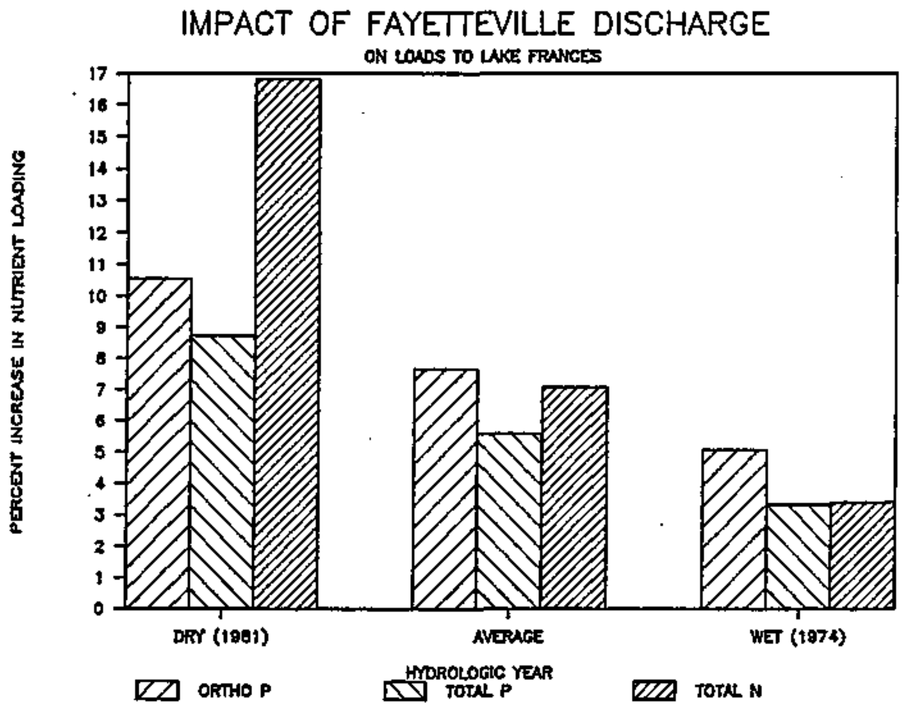
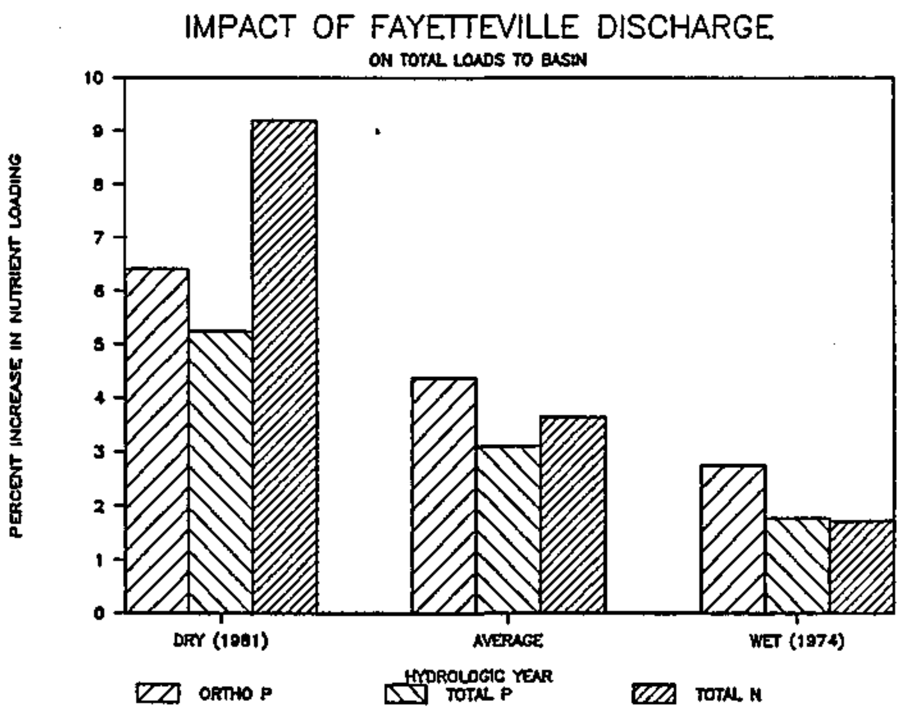


Figure 23
Percentage Increases in Nutrient Loading to the Illinois River Basin
Resulting from Proposed Fayetteville Discharge





APPENDIX A

Mean Concentrations by Station and Flow Regime

Illinois River Long-Term Monitoring Stations
October 1981 - September 1986

SS = Illinois River above Lake Frances (I04)
WA = Illinois River, USGS Station Near Watts, Below Frances (I06)
FC = Flint Creek Near Kansas (T04)
TQ = Illinois River, USGS Station Near Tahlequah (I12)
BF = Baron Fork Near Eldon (T05)
GO = Illinois River, USGS Station Near Gore, Below Tenkiller (I16)

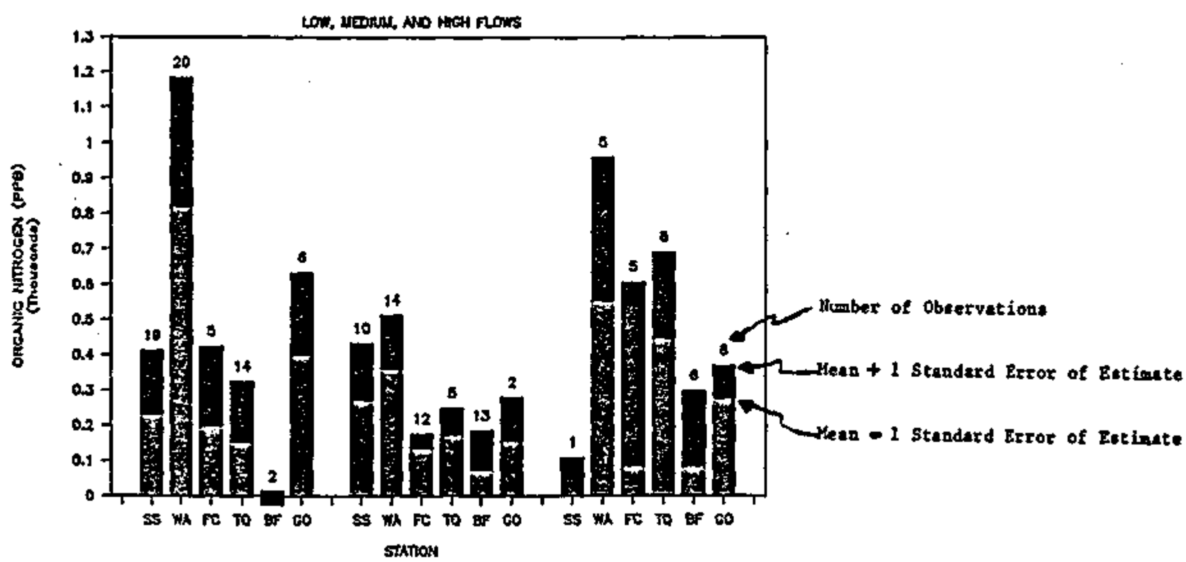
Station Locations and Data Sources Identified in Figure 1 and Table 1

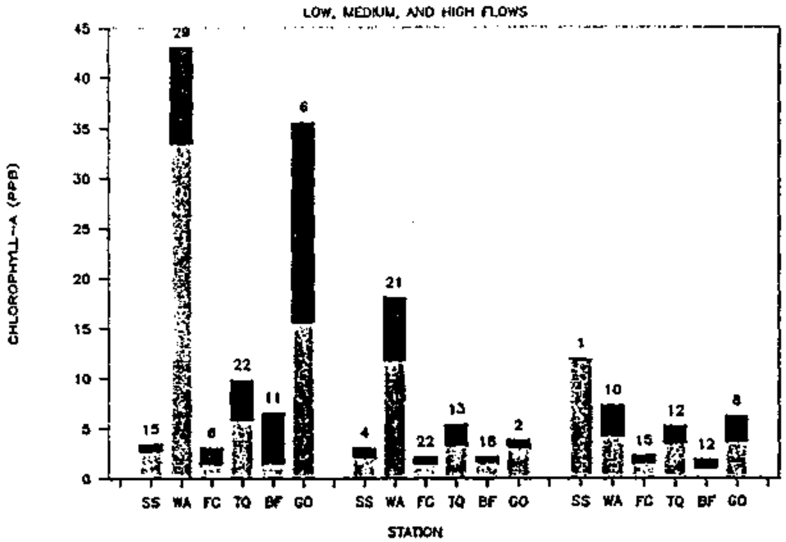
Stations SS and WA supplemented with data from EPA Clean Lakes Study, 1981-1982, Above and Below Lake Frances, (Threlkeld, 1983)

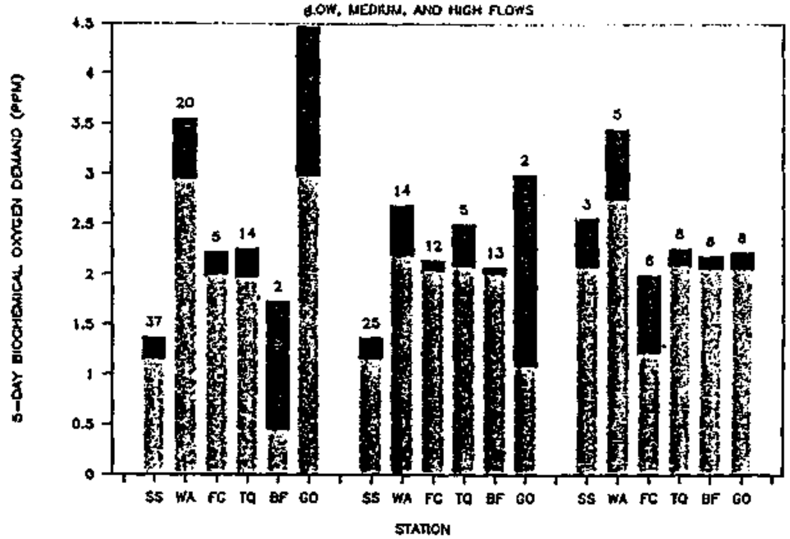
Flow Regime	Unit Runoff (cfs/mi^2)	Frequency * (% of Daily Mean Values)
Low	< .45	48.2%
Medium	>= .45, < 1.8	38.9%
High	>= 1.8	12.9%

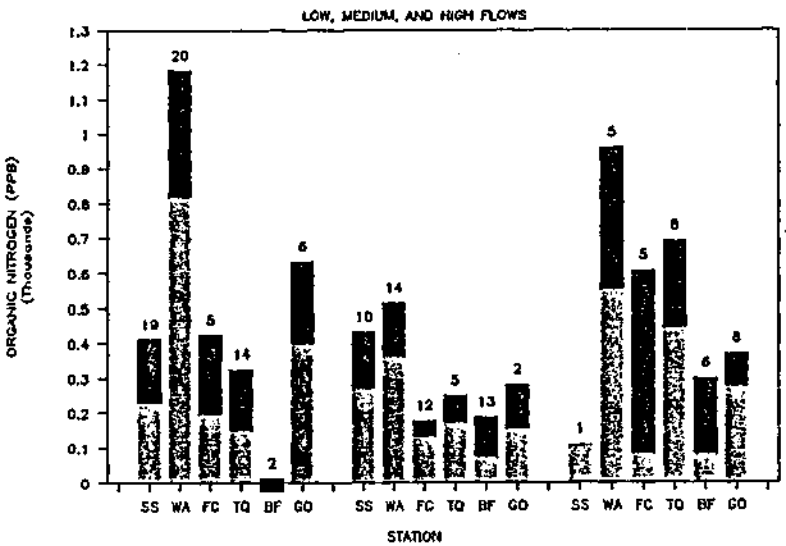
* Frequencies Based upon October 1981 - March 1986 Flow Record

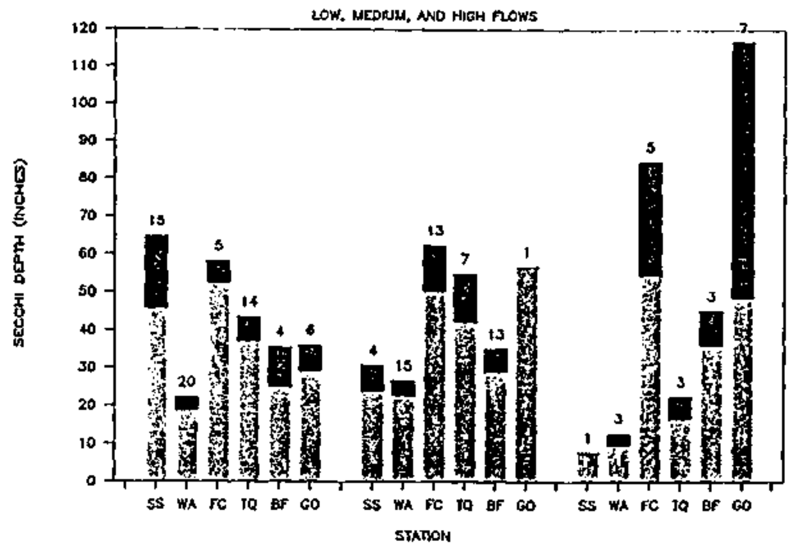
Mean Annual Discharge at Tahlequah = 867 cfs = .90 cfs/mi^2

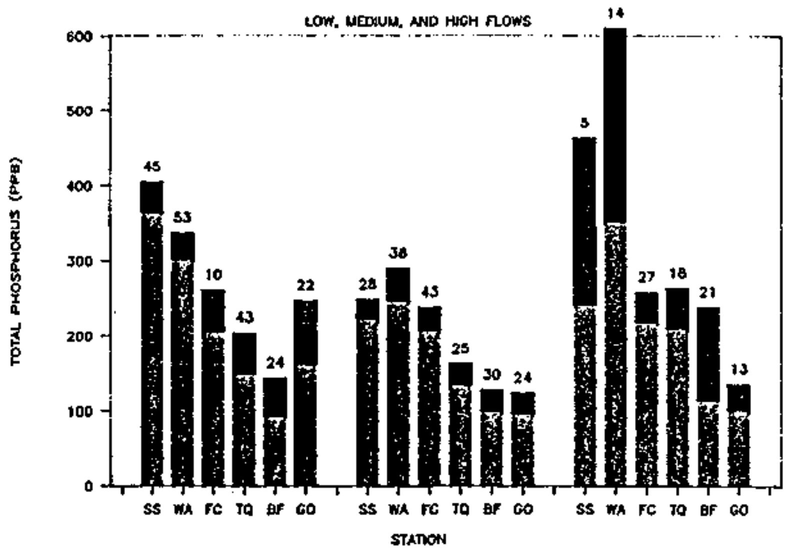


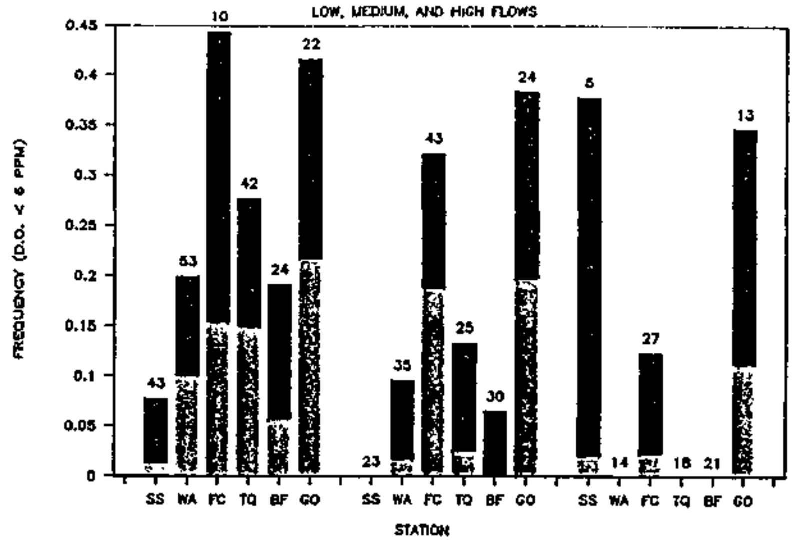

LOW, MEDIUM, AND HIGH FLOWS
CHLOROPHYLL-A (PPB)
SS WA FC TQ BF GO SS WA FC TQ BF GO SS WA FC TQ BF GO
STATION

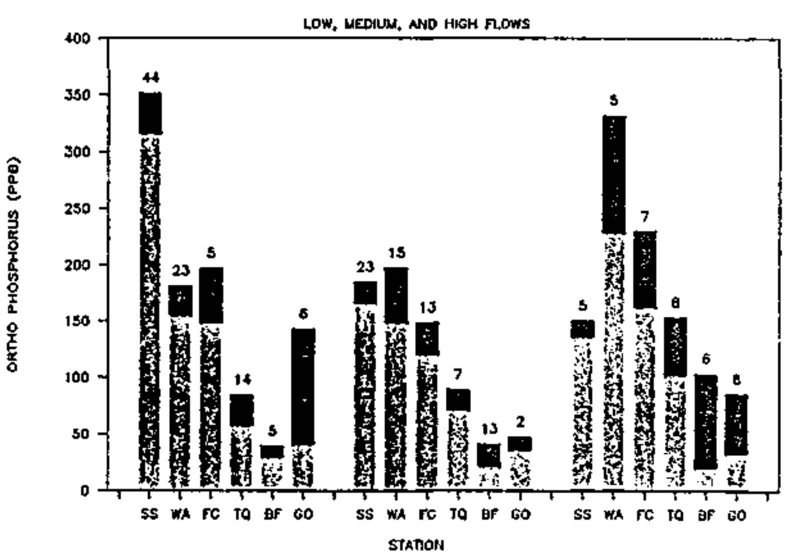

LOW, MEDIUM, AND HIGH FLOWS
5-DAY BIOCHEMICAL OXYGEN DEMAND (PPM)
SS WA FC TQ BF GO SS WA FC TQ BF GO SS WA FC TQ BF GO
STATION

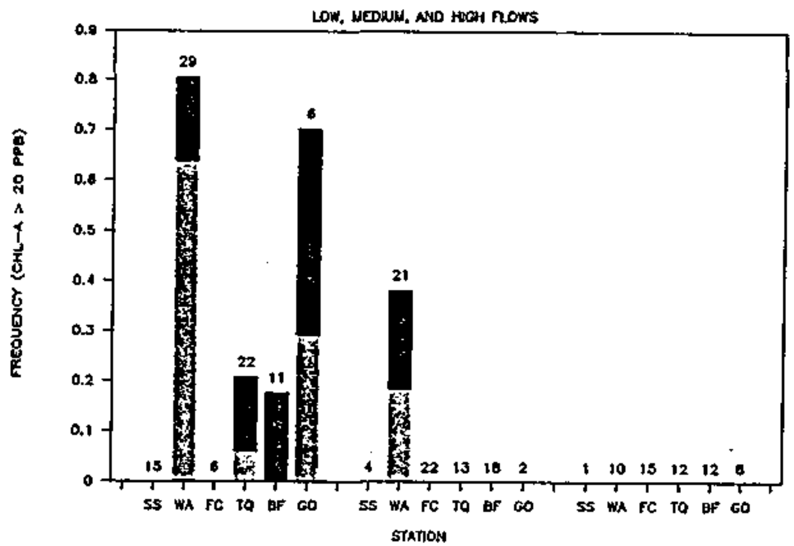

LOW, MEDIUM, AND HIGH FLOWS
ORGANIC NITROGEN (PPB)
(Thousands)
SS WA FC TQ BF GO SS WA FC TQ BF GO SS WA FC TQ BF GO
STATION


LOW, MEDIUM, AND HIGH FLOWS
SECCHI DEPTH (INCHES)
SS WA FC TQ BF GO SS WA FC TQ BF GO SS WA FC TQ BF GO
STATION

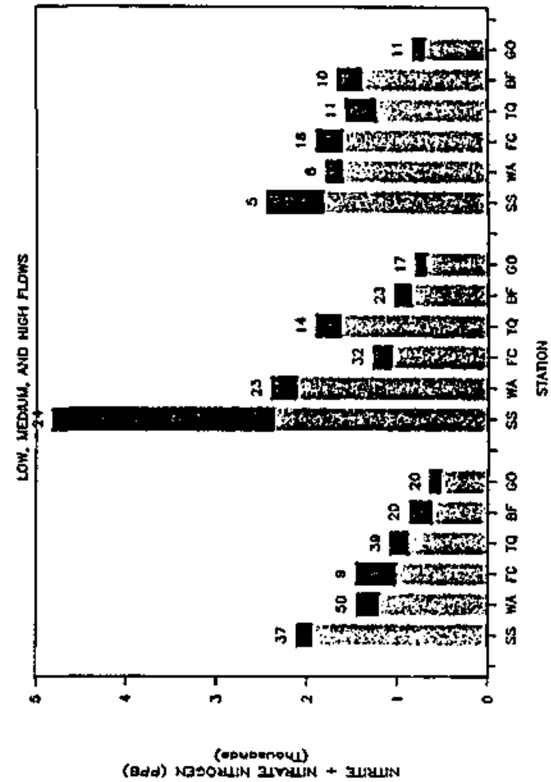

LOW, MEDIUM, AND HIGH FLOWS
TOTAL PHOSPHORUS (PPB)
STATION
SS WA FC TQ BF GO

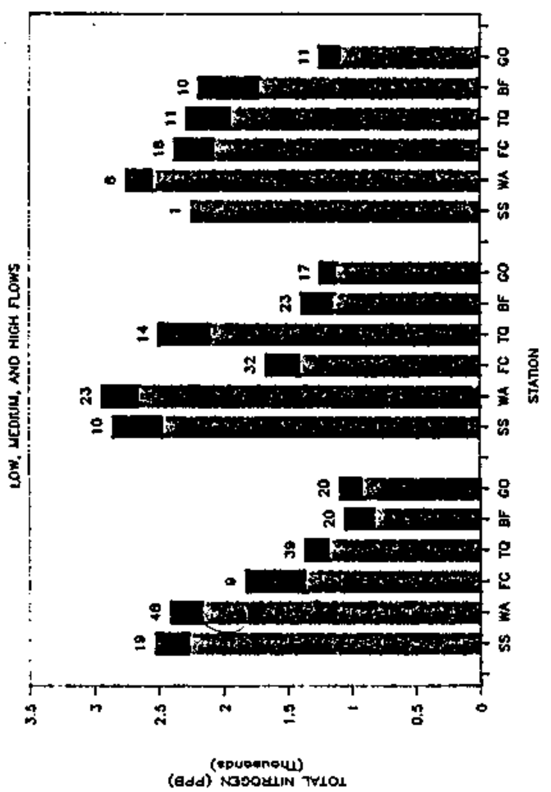

LOW, MEDIUM, AND HIGH FLOWS
FREQUENCY (D.O. < 6 PPM)
STATION
SS WA FC TQ BF GO

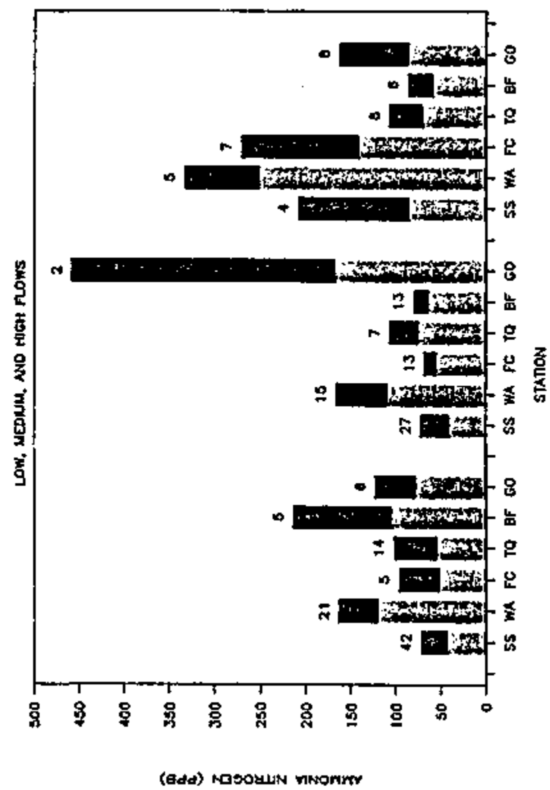

LOW, MEDIUM, AND HIGH FLOWS
ORTHO PHOSPHORUS (PPB)
STATION
SS WA FC TQ BF GO

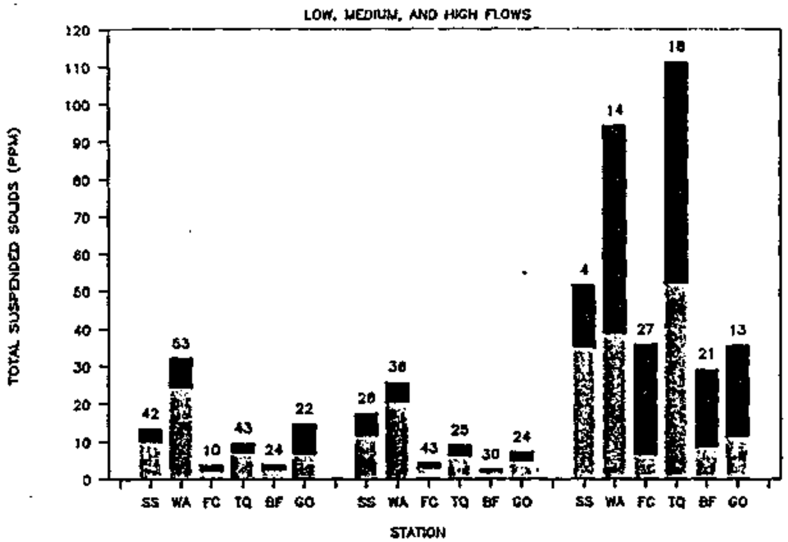

LOW, MEDIUM, AND HIGH FLOWS
FREQUENCY (CHL-A > 20 PPB)
STATION
SS WA FC TQ BF GO

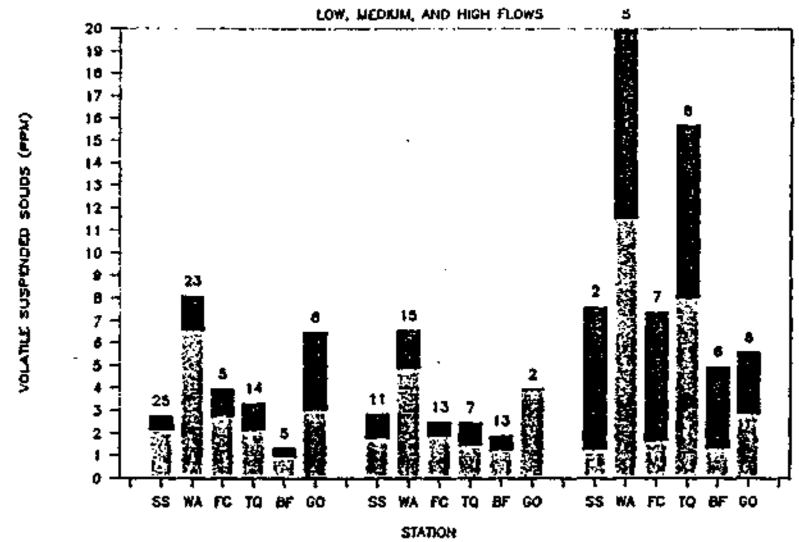

TOTAL KJELDAHL NITROGEN (PPB)
(Thousands)
LOW, MEDIUM, AND HIGH FLOWS
STATION

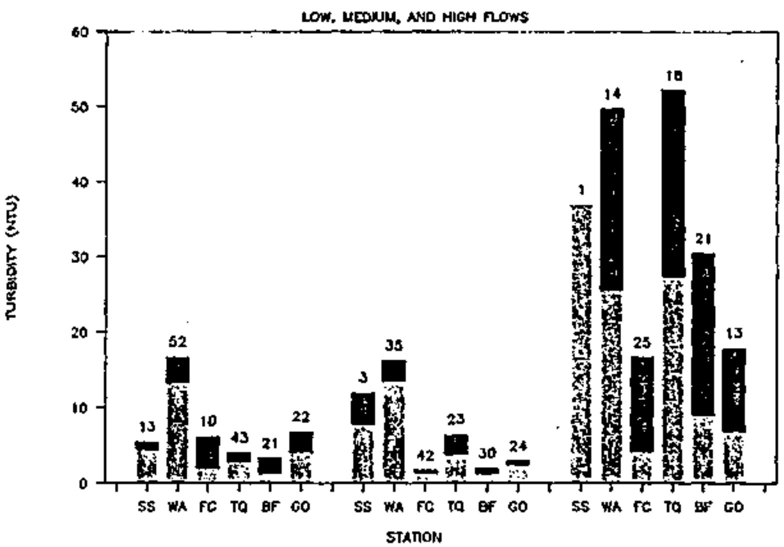

NITRITE + NITRATE NITROGEN (PPB)
(Thousands)
LOW, MEDIUM, AND HIGH FLOWS
STATION

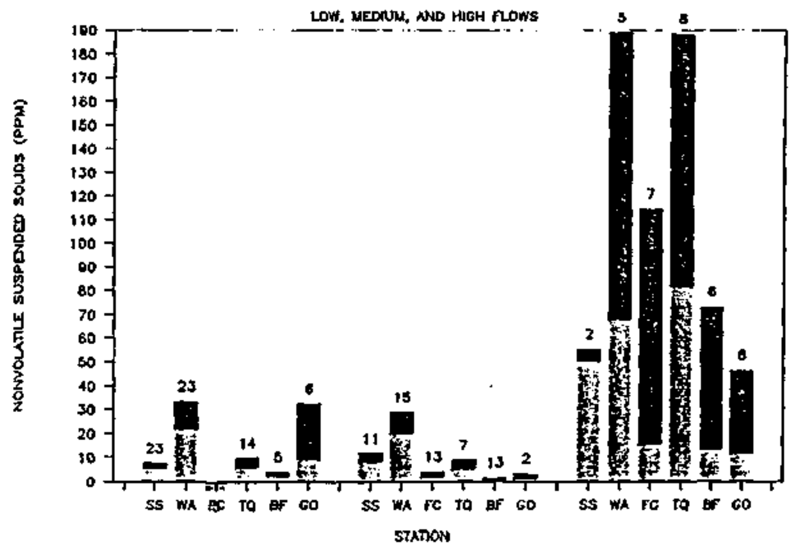

TOTAL NITROGEN (PPB)
(Thousands)
LOW, MEDIUM, AND HIGH FLOWS
STATION


AMMONIA NITROGEN (PPB)
LOW, MEDIUM, AND HIGH FLOWS
STATION


LOW, MEDIUM, AND HIGH FLOWS
TOTAL SUSPENDED SOLIDS (PPM)
0
10
20
30
40
50
60
70
80
90
100
110
120
42
63
10
43
24
22
28
38
43
25
30
24
4
14
27
18
21
13
SS WA FC TQ BF GO
SS WA FC TQ BF GO
SS WA FC TQ BF GO
STATION


LOW, MEDIUM, AND HIGH FLOWS
VOLATILE SUSPENDED SOLIDS (PPM)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
25
23
5
14
5
8
11
15
13
7
13
2
2
5
7
8
6
8
SS WA FC TQ BF GO
SS WA FC TQ BF GO
SS WA FC TQ BF GO
STATION


LOW, MEDIUM, AND HIGH FLOWS
TURBIDITY (NTU)
0
10
20
30
40
50
60
13
52
10
43
21
22
3
35
42
23
30
24
1
14
25
18
21
13
SS WA FC TQ BF GO
SS WA FC TQ BF GO
SS WA FC TQ BF GO
STATION


LOW, MEDIUM, AND HIGH FLOWS
NONVOLATILE SUSPENDED SOLIDS (PPM)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
23
23
14
5
6
11
15
13
7
13
2
2
5
7
8
6
6
SS WA FC TQ BF GO
SS WA FC TQ BF GO
SS WA FC TQ BF GO
STATION

WW

IMPACTS OF PROPOSED WASTEWATER DIVERSION ON EUTROPHICATION AND RELATED WATER QUALITY CONDITIONS IN THE ILLINOIS RIVER, OKLAHOMA

AMENDED TESTIMONY

prepared for

State of Oklahoma
Office of Attorney General
112 State Capitol
Oklahoma City, Oklahoma 73105

by

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
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February 1987

In reviewing mass-balance calculations contained in my previously submitted testimony, I have discovered an error in the sewage effluent nutrient levels used to construct mass balances (Tables 3-8). In transferring measured concentrations for Springdale, Rogers, Siloam Springs, and Tahlequah from one spreadsheet to another, I had mistakenly copied mean values for August 1985 (period of the EPA intensive survey), instead of mean, 1985-1986 values. Direct measurements of total nitrogen concentrations in the Fayetteville discharge have also been located (USEPA,1977). Corrected Tables 3-8 and dependent Figures 21 and 23 and page 24 are attached. These small numeric changes do not influence conclusions stated in my testimony.

REFERENCE

U.S. Environmental Protection Agency, "Report on Beaver, Table Rock, and Bull Shoals Reservoirs", Working Paper No. 480, National Eutrophication Survey, Corvallis Environmental Research Laboratory, February 1977.

Table 3
Lake Frances Mass-Balance / Eutrophication-Response Calculations
Without Fayetteville Discharge

LAKE FRANCES MASS-BALANCES / EUTROPHICATION RESPONSE CALCULATIONS WITHOUT FAYETTEVILLE DISCHARGE

CASE		1	2	3	4	5	6	7	8	9
HYDROLOGIC CONDITION		7-0-2	LOW	MEAN	7-0-2	LOW	MEAN	7-0-2	LOW	MEAN
FAYETTEVILLE		no	no	no	no	no	no	no	no	no
OTHER POINT SOURCES		exist	exist	exist	p=1000	p=1000	p=1000	no	no	no
NONPOINT SOURCE CHARACTERISTICS										
Runoff	m/yr	0.045	0.1	0.32	0.045	0.1	0.32	0.045	0.1	0.32
Nonpoint Total P	ppb	80	100	150	80	100	150	80	100	150
Nonpoint Ortho P	ppb	40	50	75	40	50	75	40	50	75
Nonpoint Total N	ppb	1000	1600	2500	1000	1600	2500	1000	1600	2500
Non-Algal Turbidity	1/m	0.8	1	1.2	0.8	1	1.2	0.8	1	1.2
POINT SOURCE CHARACTERISTICS										
Existing Flow	hm3/yr	14.4	14.4	14.4	14.4	14.4	14.4			
Total P	ppb	7018	7018	7018	1000	1000	1000			
Ortho P	ppb	6147	6147	6147	900	900	900			
Total N	ppb	23846	23846	23846	23846	23846	23846			
Fayetteville Flow	hm3/yr									
Total P	ppb									
Ortho P	ppb									
Total N	ppb									
WATER BALANCE	HM3/YR									
Precipitation Flow		2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
NonPoint Flow		73.91	164.24	525.57	73.91	164.24	525.57	73.91	164.24	525.57
Point Flow		14.40	14.40	14.40	14.40	14.40	14.40	0.00	0.00	0.00
Fayetteville Flow		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Inflow		90.92	181.25	542.58	90.92	181.25	542.58	76.52	166.85	528.18
Evaporation		4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Outflow		86.85	177.18	538.51	86.85	177.18	538.51	72.45	162.78	524.11
PHOSPHORUS BALANCE	(KG/YR									
Precipitation Load		69	69	69	69	69	69	69	69	69
NonPoint Load		5913	16424	78835	5913	16424	78835	5913	16424	78835
Point Load		101859	101859	101859	14400	14400	14400			
Fayetteville Load										
Total Load		107841	117553	179964	20382	30893	93385	5982	16493	78985
Sedimentation		52642	34946	18558	4754	4336	6757	1030	2061	5723
Outflow		54400	82607	161406	15628	26557	86547	4952	14432	73182
NITROGEN BALANCE	KG/YR									
Precipitation Load		4620	4620	4620	4620	4620	4620	4620	4620	4620
NonPoint Load		73908	262784	1313920	73908	262784	1313920	73908	262784	1313920
Point Load		343382	343382	343382	343382	343382	343382			
Fayetteville Load										
Total Load		421910	610786	1661922	421910	610786	1661922	78528	267404	1318540
Sedimentation		123548	96189	101587	123548	96189	101587	9270	25080	68749
Outflow		298363	514598	1560335	298363	514598	1560335	69258	242324	1249791
RESPONSE CALCULATIONS										
Residence Time	yrs	0.0319	0.0156	0.0051	0.0319	0.0156	0.0051	0.0383	0.0170	0.0053
Inflow P Conc	ppb	1232	663	334	235	174	173	83	101	151
1-Rp		0.508	0.703	0.897	0.767	0.860	0.928	0.828	0.875	0.927
Inflow N Conc	ppb	4858	3447	3086	4858	3447	3086	1084	1643	2516
1-Rn		0.707	0.843	0.939	0.707	0.843	0.939	0.882	0.906	0.948
Total Phosphorus	ppb	626	466	300	180	150	161	68	89	140
Total Nitrogen	ppb	3435	2904	2897	3435	2904	2897	956	1409	2385
Potential Chla	ppb	360	277	235	182	143	153	40	65	123
Mean Chlorophyll-a	ppb	75.1	44.6	14.0	59.9	36.5	13.0	25.1	26.3	12.8
Secchi	ppb	0.37	0.47	0.65	0.44	0.52	0.66	0.70	0.60	0.66
(N-150)/P	ppb	5.2	5.9	9.2	18.3	18.4	17.1	11.8	15.1	16.0

Constant Factors: Watershed Area = 1642.4 km2, Precipitation = 1.13 m/yr, Evaporation = 1.76 m/yr
Atmospheric P Load = 30 kg/km2-yr, Atmospheric N Load = 2000 kg/km2-yr.
Reservoir Mean Depth = 1.2 m, Area = 2.31 km2

CORRECTED 2/6/8

Table 4
Lake Frances Mass-Balance / Eutrophication-Response Calculations
With Fayetteville Discharge

LAKE FRANCES MASS-BALANCES / EUTROPHICATION RESPONSE CALCULATIONS WITH FAYETTEVILLE DISCHARGE

CASE		10	11	12	13	14	15	16	17	18
HYDROLOGIC CONDITION		7-0-2	LOW	MEAN	7-0-2	LOW	MEAN	7-0-2	LOW	MEAN
FAYETTEVILLE		yes	yes	yes	yes	yes	yes	yes	yes	yes
OTHER POINT SOURCES		exist	exist	exist	p=1000	p=1000	p=1000	no	no	no
NONPOINT SOURCE CHARACTERISTICS										
Runoff	m/yr	0.045	0.1	0.32	0.045	0.1	0.32	0.045	0.1	0.32
Nonpoint Total P	ppb	80	100	150	80	100	150	80	100	150
Nonpoint Ortho P	ppb	40	50	75	40	50	75	40	50	75
Nonpoint Total N	ppb	1000	1600	2500	1000	1600	2500	1000	1600	2500
Non-Algal Turbidity	1/m	0.8	1	1.2	0.8	1	1.2	0.8	1	1.2
POINT SOURCE CHARACTERISTICS										
Existing Flow	hm3/yr	14.4	14.4	14.4	14.4	14.4	14.4			
Total P	ppb	7018	7018	7018	1000	1000	1000			
Ortho P	ppb	6147	6147	6147	900	900	900			
Total N	ppb	23846	23846	23846	23846	23846	23846			
Fayetteville Flow	hm3/yr	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
Total P	ppb	1000	1000	1000	1000	1000	1000	1000	1000	1000
Ortho P	ppb	900	900	900	900	900	900	900	900	900
Total N	ppb	16125	16125	16125	16125	16125	16125	16125	16125	16125
WATER BALANCE	HM3/YR									
Precipitation Flow		2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
NonPoint Flow		73.91	164.24	525.57	73.91	164.24	525.57	73.91	164.24	525.57
Point Flow		14.40	14.40	14.40	14.40	14.40	14.40	0.00	0.00	0.00
Fayetteville Flow		8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
Total Inflow		99.36	189.69	551.02	99.36	189.69	551.02	84.96	175.29	536.62
Evaporation		4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Outflow		95.29	185.62	546.95	95.29	185.62	546.95	80.89	171.22	532.55
PHOSPHORUS BALANCE	(KG/YR									
Precipitation Load		69	69	69	69	69	69	69	69	69
NonPoint Load		5913	16424	78835	5913	16424	78835	5913	16424	78835
Point Load		101059	101059	101059	14400	14400	14400	0	0	0
Fayetteville Load		8440	8440	8440	8440	8440	8440	8440	8440	8440
Total Load		115481	125993	188404	28822	39333	101745	14422	24933	87345
Sedimentation		55043	36984	19487	7324	5906	7416	3043	3311	6313
Outflow		60439	89009	168917	21498	33428	94328	11379	21623	81032
NITROGEN BALANCE	KG/YR									
Precipitation Load		4620	4620	4620	4620	4620	4620	4620	4620	4620
NonPoint Load		73900	262784	1313920	73900	262784	1313920	73900	262784	1313920
Point Load		343382	343382	343382	343382	343382	343382			
Fayetteville Load		136095	136095	136095	136095	136095	136095	136095	136095	136095
Total Load		558005	746881	1798017	558005	746881	1798017	214623	403499	1454635
Sedimentation		173190	127474	114669	173190	127474	114669	45321	48792	80531
Outflow		384815	619408	1683349	384815	619408	1683349	169302	354707	1374104
RESPONSE CALCULATIONS										
Residence Time	yrs	0.0291	0.0149	0.0051	0.0291	0.0149	0.0051	0.0343	0.0162	0.0052
Inflow P Conc	ppb	1212	679	344	302	212	186	178	146	164
1-Rp		0.523	0.706	0.897	0.746	0.850	0.927	0.789	0.867	0.928
Inflow N Conc	ppb	5856	4024	3287	5856	4024	3287	2653	2357	2731
1-Rn		0.690	0.829	0.936	0.690	0.829	0.936	0.789	0.879	0.945
Total Phosphorus	ppb	634	480	309	226	180	172	141	126	152
Total Nitrogen	ppb	4038	3337	3078	4038	3337	3078	2093	2072	2580
Potential Chla	ppb	434	325	252	241	180	167	115	105	130
Mean Chlorophyll-a	ppb	75.2	44.7	13.8	64.0	38.4	13.0	49.3	32.7	12.9
Secchi	ppb	0.37	0.47	0.65	0.42	0.51	0.66	0.49	0.55	0.66
(N-150)/P	ppb	6.1	6.6	9.5	17.2	17.7	17.0	13.8	15.2	16.0

Constant Factors: Watershed Area = 1642.4 km2, Precipitation = 1.13 m/yr, Evaporation = 1.76 m/yr
Atmospheric P Load = 30 kg/km2-yr, Atmospheric N Load = 2000 kg/km2-yr
Reservoir Mean Depth = 1.2 m, Area = 2.31 km2

CORRECTED 2/6/8?

Table 5
Basinwide Mass Balance Calculations - Average Year

WATER AND MASS BALANCE CALCULATIONS ILLINOIS RIVER ABOVE TENKILLER DAM AVERAGE HYDROLOGIC YEAR

POINT SOURCE DISCHARGES				STP CONCENTRATIONS			STP LOADS		
TREATMENT PLANT	STATE	FLOW mgd	FLOW hm3/yr	ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Prarie Grove	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Springdale	AR	6.70 a	9.26	6200	6900	23600 d	57443	63928	218654
Rogers	AR	3.50 a	4.84	6100	7300	24600 d	29523	35331	119062
Watts	OK	0.07 b	0.10	5225	6100	19115 e	506	590	1850
Siloam Spring	AR	2.40 a	3.32	4600	6000	17160 d	15266	19913	56951
Gentry City	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Tahlequah	OK	2.69 c	3.71	4000	4200	11100 d	14824	15565	41137
Lincoln City	AR	0.41 a	0.57	5225	6100	19115 e	2962	3458	10837
Westville	OK	0.10 c	0.14	5225	6100	19115 e	723	844	2643
Indian Nations	OK	0.05 c	0.07	5225	6100	19115 e	361	422	1322
Sequoyah	OK	0.04 b	0.05	5225	6100	19115 e	253	295	925
Stillwell	OK	0.24 c	0.33	5225	6100	19115 e	1734	2024	6344
Stillwell Cannery	OK	0.12 c	0.17	5225	6100	19115 e	867	1012	3172
TOTALS		16.73	23.13	5513	6353	20495	127497	146927	473998
TOTALS	AR	13.43	18.57	5820	6794	22433	108230	126174	416605
TOTALS	OK	3.30	4.56	4229	4555	12596	19268	20753	57393
TOTALS above Lake Frances		10.41	14.40	6147	7018	23846	88484	101031	343266
TOTALS below Lake Frances		6.32	8.73	4468	5256	14971	39014	45896	130732
Fayetteville		6.10 f	8.44	900	1000	16125 f	7596	8440	136095

Runoff Rate = 0.32 m/yr

NONPOINT CALCULATIONS	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Above Frances	1644	526.08	75	150	2500 g	39456	78912	1315200
Below Frances	2526	808.32	50	100	1666 g	40416	80832	1346661
Total	4170	1334.40	60	120	1995	79872	159744	2661861

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	540.48	237	333	3069	127940	179943	1658466
Below Frances	2526	817.05	97	155	1808	79430	126728	1477393
Total	4170	1357.53	153	226	2310	207369	306671	3135859

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	548.92	247	343	3269	135536	188383	1794561
Below Frances	2526	817.05	97	155	1808	79430	126728	1477393
Total	4170	1365.97	157	231	2395	214965	315111	3271954

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	1.56	4.31	3.08	6.54	5.94	4.69	8.21
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	0.62	3.02	2.12	3.70	3.66	2.75	4.34

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - Oklahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, USEPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed, based upon average conc of sampled sources (d)
f - phosphorus from Fayetteville discharge permit;
average total n in fayetteville discharge; epa nat. eutro. survey, 1975
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

EPA Permit 8395 kg/yr

EPA / Champagne 301 lb/d = 49,939 kg/yr

Threshold = 71,500 kg

APPCAE 6 %

CORRECTED 2/6/87

Table 6
Basinwide Mass Balance Calculations - Dry Year

WATER AND MASS BALANCE CALCULATIONS   ILLINOIS RIVER ABOVE TENKILLER DAM   DRY   HYDROLOGIC YEAR

POINT SOURCE DISCHARGES				STP CONCENTRATIONS			STP LOADS		
TREATMENT PLANT	STATE	FLOW mgd	FLOW hm3/yr	ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Prarie Grove	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Springdale	AR	6.70 a	9.26	6200	6900	23600 d	57443	63928	218654
Rogers	AR	3.50 a	4.84	6100	7300	24600 d	29523	35331	119862
Watts	OK	0.07 b	0.10	5225	6100	19115 e	506	590	1850
Siloam Spring	AR	2.40 a	3.32	4600	6000	17160 d	15266	19913	56951
Gentry City	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Tahlequah	OK	2.68 c	3.71	4000	4200	11100 d	14824	15565	41137
Lincoln City	AR	0.41 a	0.57	5225	6100	19115 e	2962	3458	10837
Westville	OK	0.10 c	0.14	5225	6100	19115 e	723	844	2643
Indian Nations	OK	0.05 c	0.07	5225	6100	19115 e	361	422	1322
Sequoyah	OK	0.04 b	0.05	5225	6100	19115 e	253	295	925
Stillwell	OK	0.24 c	0.33	5225	6100	19115 e	1734	2024	6344
Stillwell Cannery	OK	0.12 c	0.17	5225	6100	19115 e	867	1012	3172
TOTALS		16.73	23.13	5513	6353	20495	127497	146927	473998
TOTALS	AR	13.43	18.57	5828	6794	22433	108230	126174	416605
TOTALS	OK	3.30	4.56	4229	4555	12596	19268	20753	57393
TOTALS above Lake Frances		10.41	14.40	6147	7010	23846	88484	101031	343266
TOTALS below Lake Frances		6.32	8.73	4468	5256	14971	39014	45896	130732
Fayetteville		6.10 f	8.44	900	1000	16125 f	7596	8440	136095

Runoff Rate = 0.1 m/yr

NONPOINT CALCULATIONS	WATERSHED		FLOW-WEIGHTED CONCENTRATIONS			LOADINGS		
	AREA km2	FLOW hm3/yr	ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Above Frances	1644	164.40	75	150	2500 g	12330	24660	411000
Below Frances	2526	252.60	50	100	1666 g	12630	25260	420832
Total	4170	417.00	60	120	1995	24960	49920	831832

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	178.80	564	703	4219	100814	125691	754266
Below Frances	2526	261.33	198	272	2111	51644	71156	551563
Total	4170	440.13	346	447	2967	152457	196847	1305830

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	187.24	579	716	4755	108410	134131	890361
Below Frances	2526	261.33	198	272	2111	51644	71156	551563
Total	4170	448.57	357	458	3215	160053	205287	1441925

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	4.72	2.69	1.90	12.72	7.53	6.71	18.04
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	1.92	3.01	2.33	8.34	4.98	4.29	10.42

ADPC+E 6%

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - Oklahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, USEPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed, based upon average conc of sampled sources (d)
f - phosphorus from Fayetteville discharge permit;
average total n in fayetteville discharge; epa nat. eutro. survey, 1975
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

CORRECTED 2/6/87

Table 7
Basinwide Mass Balance Calculations - Wet Year

WATER AND MASS BALANCE CALCULATIONS ILLINOIS RIVER ABOVE TENKILLER DAM WET HYDROLOGIC YEAR

POINT SOURCE DISCHARGES

TREATMENT PLANT	STATE	FLOW mgd	FLOW hm3/yr	STP CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	STP LOADS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Prarie Grove	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Springdale	AR	6.70 a	9.26	6200	6900	23600 d	57443	63928	210654
Rogers	AR	3.50 a	4.84	6100	7300	24600 d	29523	35331	119062
Watts	OK	0.07 b	0.10	5225	6100	19115 e	506	590	1850
Siloam Spring	AR	2.40 a	3.32	4600	6000	17160 d	15266	19913	56951
Gentry City	AR	0.21 a	0.29	5225	6100	19115 e	1517	1771	5551
Tahlequah	OK	2.68 c	3.71	4000	4200	11100 d	14824	15565	41137
Lincoln City	AR	0.41 a	0.57	5225	6100	19115 e	2962	3458	10837
Westville	OK	0.10 c	0.14	5225	6100	19115 e	723	844	2643
Indian Nations	OK	0.05 c	0.07	5225	6100	19115 e	361	422	1322
Sequoyah	OK	0.04 b	0.05	5225	6100	19115 e	253	295	925
Stillwell	OK	0.24 c	0.33	5225	6100	19115 e	1734	2024	6344
Stillwell Cannery	OK	0.12 c	0.17	5225	6100	19115 e	867	1012	3172
TOTALS		16.73	23.13	5513	6353	20495	127497	146927	473998
TOTALS	AR	13.43	18.57	5828	6794	22433	108230	126174	416605
TOTALS	OK	3.30	4.56	4229	4555	12596	19268	20753	57393
TOTALS above Lake Frances		10.41	14.40	6147	7018	23046	88484	101031	343266
TOTALS below Lake Frances		6.32	8.73	4460	5256	14971	39014	45896	130732
Fayetteville		6.10 f	8.44	900	1000	16125 f	7596	8440	136095

Runoff Rate = 0.73 m/yr

NONPOINT CALCULATIONS	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Above Frances	1644	1200.12	75	150	2500 g	90009	180018	3000300
Below Frances	2526	1843.90	50	100	1666 g	92199	184390	3072071
Total	4170	3044.10	60	120	1995	182208	364416	6072371

TOTAL LOADINGS WITHOUT FAYETTEVILLE

Above Frances	1644	1214.52	147	231	2753	170493	281849	3343566
Below Frances	2526	1852.71	71	124	1729	131213	230294	3202802
Total	4170	3067.23	101	167	2134	309705	511343	6546369

TOTAL LOADINGS WITH FAYETTEVILLE

Above Frances	1644	1222.96	152	237	2845	186089	289489	3479661
Below Frances	2526	1852.71	71	124	1729	131213	230294	3202802
Total	4170	3075.67	103	169	2173	317301	519783	6682464

PERCENT INCREASE DUE TO FAYETTEVILLE

Above Frances	0	0.69	3.54	2.29	3.35	4.26	3.00	4.07
Below Frances	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0	0.28	2.17	1.37	1.80	2.45	1.65	2.08

a - Martin Maner, Ark DPCE, 1986 STP Flows
b - Oklahoma 208 Projection for 1985
c - Total Phosphorus Loading Estimate to the Ill. River Basin, USEPA, Sept 1984
d - annual means, illinois river survey, storet, 1985-1986
e - assumed, based upon average conc of sampled sources (d)
f - phosphorus from Fayetteville discharge permit;
average total n in fayetteville discharge; epa nat. eutro. survey, 1975
g - based upon review of monitoring data from non-point-source watersheds in basin
and higher density of urban and agricultural land uses in arkansas vs. oklahoma portions

CORRECTED 2/6/87

Table 8
Comparisons of Loading Estimates
Existing Conditions vs. 1974-75

COMPARISON OF LOADING ESTIMATES EXISTING CONDITIONS VS. 1974-1975

EPA NATIONAL EUTROPHICATION SURVEY LOADING ESTIMATES (1974-1975) LOADS TO LAKE FRANCES
Runoff Rate= .306 m/yr (Normalized)

	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Existing	1644	517.5	244	341	3094	126213	176491	1600926
1974-1975	1644	519.0		163	2559		84780	1328000
% Increase	0.00	-0.30		108.79	20.91		108.17	20.55

EPA NATIONAL EUTROPHICATION SURVEY LOADING ESTIMATES (1974-1975) TOTAL LOADS TO BASIN
Runoff Rate= .306 m/yr (Normalized)

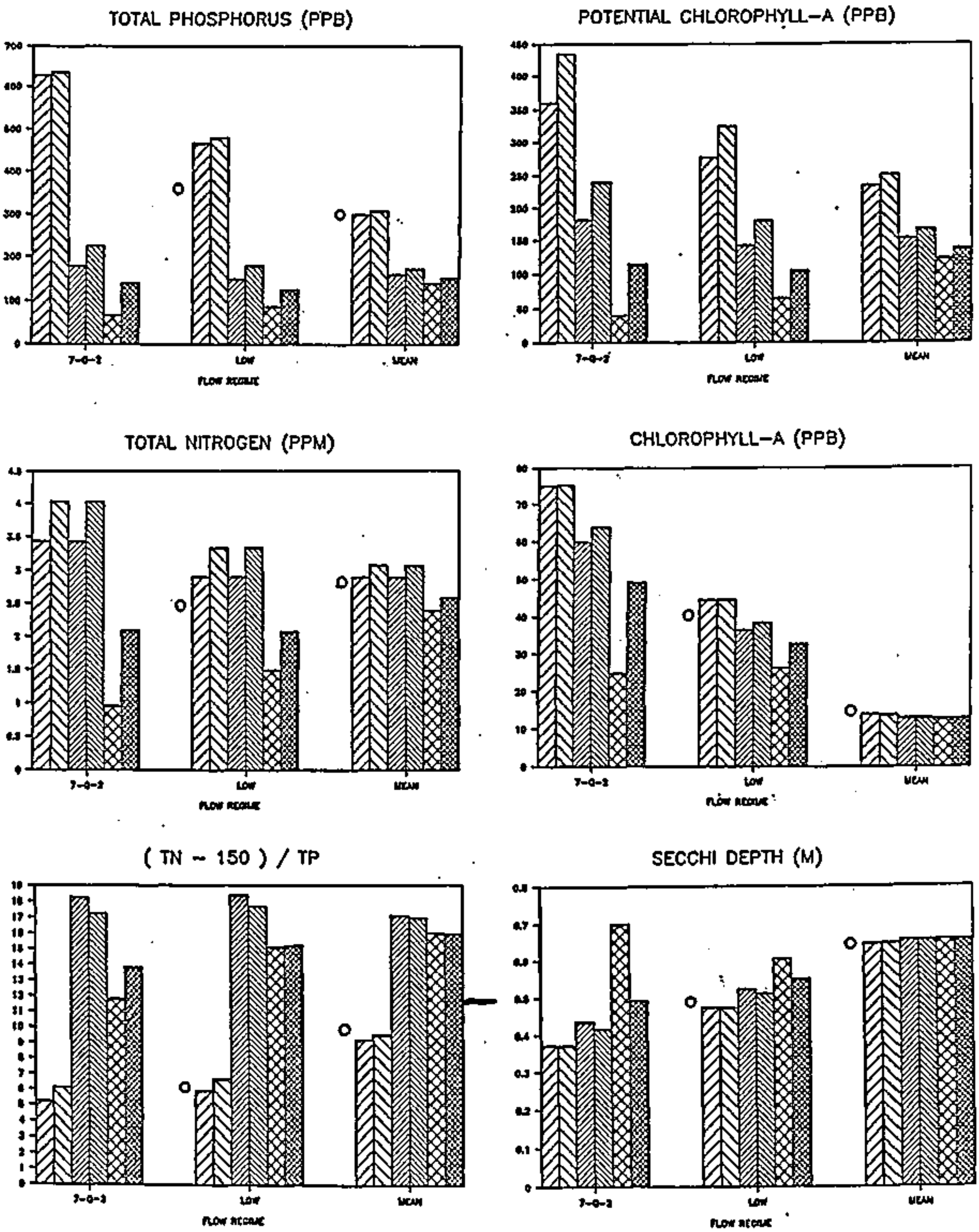
	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Existing	4170	1299.1	157	231	2324	203875	299682	3019403
1974-1975	4170	1298.0		98	2200		127290	2855190
% Increase	0.00	0.09		135.22	5.66		135.43	5.75

WALKER (1982) LOADING ESTIMATES (1974-1975) LOADS TO TENKILLER FERRY RESERVOIR
Runoff Rate = .6 m/yr (Sampled Conditions)

	WATERSHED AREA km2	FLOW hm3/yr	FLOW-WEIGHTED CONCENTRATIONS ORTHO P ppb	TOTAL P ppb	TOTAL N ppb	LOADINGS ORTHO P kg/yr	TOTAL P kg/yr	TOTAL N kg/yr
Existing	4170	2525.1	110	177	2164	277257	446447	5464988
1974-75	4170	2510.0	53	91	1903	133880	227680	4776940
% Increase	0.00	0.60	105.85	94.91	13.72	107.09	96.09	14.40

CORRECTED 2/6/87

Figure 21
Predicted Impacts of Fayetteville Discharge on Nutrient, Algae, and Transparency Levels in Lake Frances



Freq < %

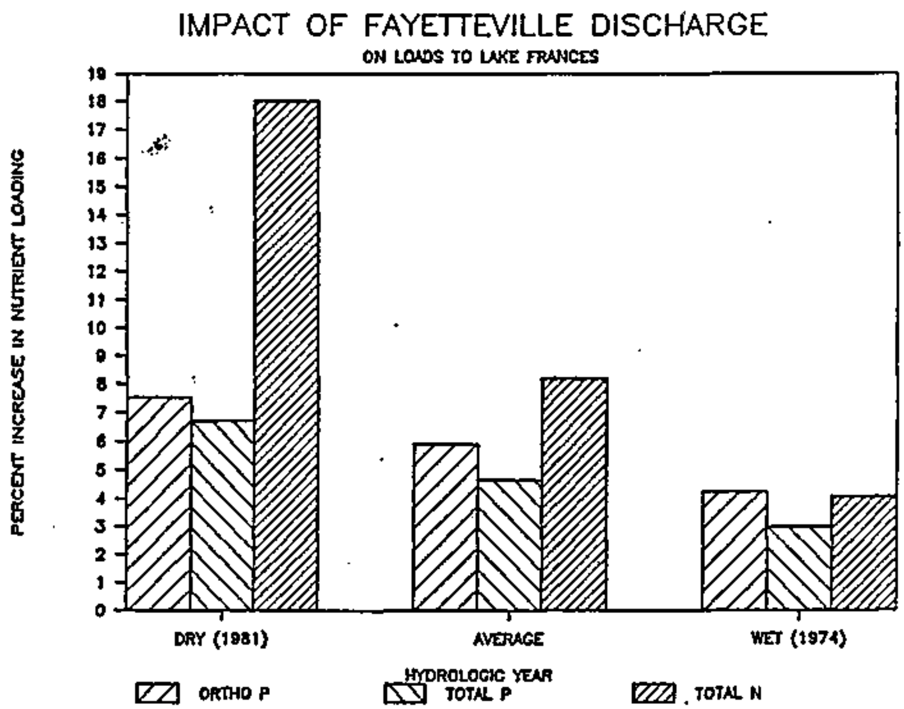
FLOW REGIMES:
7-Q-2 = 82 CFS = 1.8 IN/YR
LOW = 183 CFS = 3.9 IN/YR
MEAN = 578 CFS = 12.4 IN/YR

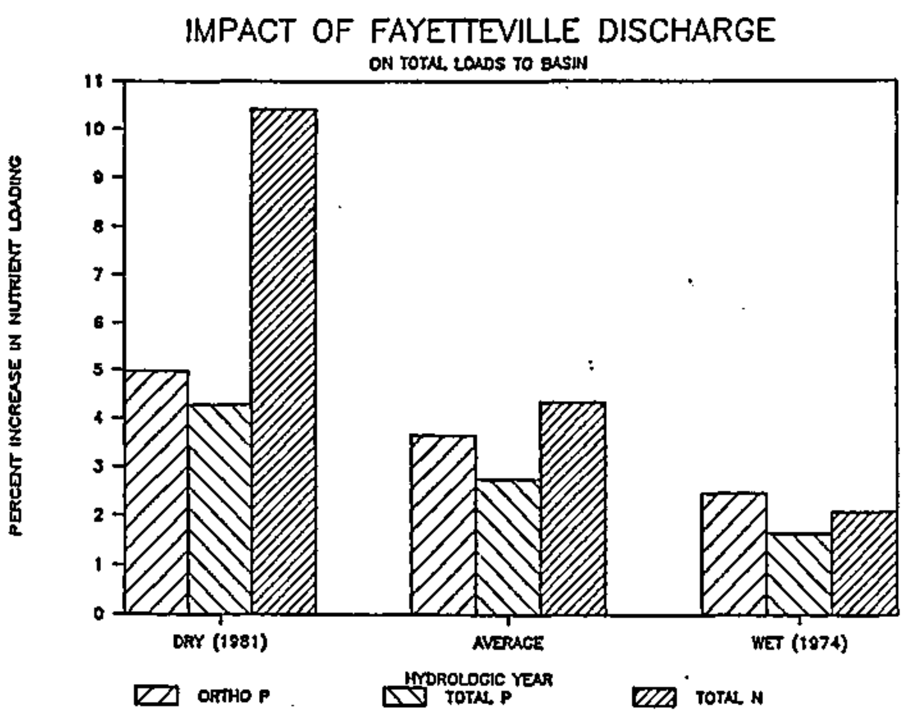
cfs/mi²
.13
.29
.91

O OBSERVED MEAN DOWNSTREAM OF LAKE AT WATTS (1982-1986)
PREDICTED - EXISTING LOADS
PREDICTED - EXISTING LOADS + FAYETTEVILLE
PREDICTED - P CONTROLS ON EXISTING LOADS (1 MG/L)
PREDICTED - P CONTROLS ON EXISTING LOADS (1 MG/L) + FAYETTEVILLE
PREDICTED - NON-POINT LOADS ONLY
PREDICTED - NON-POINT LOADS + FAYETTEVILLE

CORRECTED 2/4/87

Figure 23
Percentage Increases in Nutrient Loading to the Illinois River Basin Resulting from Proposed Fayetteville Discharge





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meters/yr) has been used as an example of a dry hydrologic year. Under this condition, the Fayetteville discharge would increase the annual loadings of total phosphorus and nitrogen to Lake Frances by 6.7% and 18.0%, respectively, vs. 4.7% and 8.2% under average flows. Total phosphorus and nitrogen loadings to Tenkiller Ferry Reservoir would increase by 4.3% and 10.4%, respectively, during a dry year and by 2.8% and 4.3% during an average year. Regardless of their precise magnitudes, these increases are unacceptable in view of the fact that Oklahoma's water quality standards are already being violated due to excessive nutrient enrichment.

Table 8 compares loading estimates under existing conditions with estimates developed previously based upon 1974-1975 monitoring data collected by the EPA National Eutrophication Survey (1977a,b). The EPA/NES calculated loadings to Lake Frances and to Tenkiller Ferry for an "average hydrologic year" (basin runoff=.3 m/yr). Using the same EPA/NES data set, Walker(1982) calculated loadings to Tenkiller Ferry for 1974-1975, when runoff was relatively high (.6 m/yr). The loading estimates for existing conditions in Table 8 are based upon the same methodology employed in Tables 5-7, with runoff rates adjusted in each case to conform to the 1974-1975 estimates. The comparisons indicate 6-21% increases in nitrogen loading, as compared with 96-135% increases in phosphorus loading over this period. These results are generally consistent with the observed increased eutrophication in the reservoir and river segments discussed previously and further suggest that point sources have been primarily responsible for these increases.

CONCLUSIONS: IMPACTS OF DIVERSION ON OKLAHOMA WATER QUALITY STANDARDS

The addition of nutrient loadings from Fayetteville would cause increases in nutrient and algal concentrations in Lake Frances, the Scenic River below Lake Frances, and in Tenkiller Ferry Reservoir. The monitoring data reviewed above indicate that these segments are already severely impacted by nutrient loadings from the upper watershed. The watershed is simply too small to provide sufficient dilution of the

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IMPACTS OF PROPOSED WASTEWATER DIVERSION ON EUTROPHICATION AND RELATED WATER QUALITY CONDITIONS IN THE ILLINOIS RIVER, OKLAHOMA

REBUTTAL TESTIMONY

prepared for

State of Oklahoma
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1. **Assimilation of Phosphorus Load above Lake Frances.**

Dr. Blanz (Page 8) indicates that 70-75% of the phosphorus currently being added to the river is being assimilated before it reaches Lake Frances and Oklahoma. Supporting data, assumptions, and calculations are absent from his testimony.

This statement conflicts with results of detailed mass balances described in my testimony (Walker,1987,pp. 8-11, Figure 7), which show that most point and nonpoint phosphorus loadings discharged into the Illinois River and its tributaries in Arkansas are not assimilated in the upper river reaches, but are transported to Lake Frances and, eventually, to Lake Tenkiller.

Over long time scales, phosphorus is unlikely to be trapped or removed in stream segments, except under special circumstances (e.g., seasonal overflows onto large flood plains leading to nutrient deposition and/or uptake up by terrestrial plants). Organic materials (BOD) can be removed from the water column by microbial decay or by sedimentation. Phosphorus may be cycled between inorganic and organic forms, but it does not "decay" and can only be removed from the system by sedimentation. While some algal uptake and deposition may occur in the stream channel on an intermittent basis, deposited materials are scoured and transported downstream during high-flow events. Generally, longterm accumulation of phosphorus can occur only in impoundments or lakes where bottom sediments are isolated from scouring velocities. Based upon application of a phosphorus retention model developed for reservoirs (Walker,1985), deposition of 70-75% of the point-source loading above Lake Frances would require an impoundment with at least 4 times the volume of Lake Frances. Such an impoundment does not exist on the River above Lake Frances.

Stream surveys (Threlkeld,1983, Gakstatter and Katko 1986, Chlorophyll-a plot Page A-2, Walker,1987) indicate that little algal or periphyton growth occurs in the river above Lake Frances, even under low-flow conditions. This further decreases the probability that significant phosphorus retention occurs above Frances.

2. Unequal Distribution of Study Effort between White and Illinois Rivers.

The proposed diversion would involve a 50/50 split between the Illinois River and White River Basins. It is clear from the testimonies of Mr. Bondy and Dr. Blanz that the levels of technical effort (monitoring, modeling) which have been expended in evaluating the water quality impacts in each basin are far from equal. The White River has been emphasized. Projections of water quality impacts on Clear Creek, Mud Creek, and Illinois River are subjective, uncertain, and unacceptable.

Mr. Bondy (p. 1) indicates that "the ADPC&E analysis was an **uncalibrated** (emphasis mine) D.O. model based upon a dye study performed on Mud Creek and Clear Creek just below Mud Creek, and upon literature based model kinetics". "Literature based model kinetics" means that model coefficients have been selected from wide ranges of feasible values. This approach is very subjective and risky. It is acceptable only for preliminary impact analyses. Final impact analyses used to support wastewater management decisions of this magnitude should be based upon models which have been calibrated and verified with site-specific field data on the relevant water quality parameters.

did he consider organic N?

Mr. Bondy's testimony focuses exclusively on oxygen and does not address the more important issue of phosphorus, the effects of which are transported over much longer distances and time scales, as compared with carbonaceous or nitrogenous biochemical oxygen demand.

3. Ecological Carrying Capacity.

Dr. Blanz, in discussing the rationale for spit flow, states (p. 4): "It was the Department's position that waste generated in one basin should not be transferred to another, rather the ecological carrying capacity of each basin should naturally dictate the ultimate loading and, therefore, growth and land use in that basin."

This approach to wastewater management is constrained by required compliance with water quality standards. Observed violations of Oklahoma's water quality standards for the Illinois River indicate that the "ecological carrying capacity" of the basin has already been exceeded. These violations result primarily from Arkansas point-source discharges, which account for 16% of the flow and 94% of the phosphorus loading leaving Lake Frances under summer low-flow conditions (Walker,1987).

According to Dr. Blanz's rationale, then, the "ultimate loading, growth, and land use" have **already** been exceeded. This should put a stopper on the proposed Fayetteville discharge, as well as on any future growth in the basin, unless Dr. Blanz's definitions of "basin" and "ecological carrying capacity" do not cross state boundaries.

4. Phosphorus Loading Calculations.

Mr. Champagne presents phosphorus loading calculations for various sources in the Illinois River Basin. On Page 2, he states "Data from a [USGS] report was sufficient to justify an existing total phosphorus concentration of 8.7 mg/liter for Springdale. A 10 mg/liter concentration of total phosphorus was assumed for all other facilities, based upon what is typically found in secondary treatment effluent."

In my opinion, the assumed 10 mg/liter effluent concentration is unreasonably high and serves to diminish the relative contribution of the Fayetteville discharge. Total phosphorus concentrations in secondary effluents rarely exceed 10 mg/liter. In a survey of 347 secondary treatment plants conducted by the EPA in 1972-1973, the median effluent total phosphorus concentration was 6.1 mg/liter. Median concentrations exceeded 10 mg/liter in only 11% of the plants (USEPA,1974).

Direct monitoring of STP effluents indicate the following mean concentrations (1985-1986, STORET data):

Springdale	6.9 mg/liter
Rogers	7.3 "
Siloam Springs	6.0 "
Tahlequah	4.2 "

These recent data (not available at the time of Mr. Champagne's calculations) indicate that 10 mg/liter is not "typical" of wastewater effluents in the basin and thus that the relative impact of the Fayetteville discharge would be greater than indicated by Mr. Champagne's calculations and pie charts.

5. **Loose Linkage to Basinwide Phosphorus Controls.**

Mr. Champagne also refers to "projected" reductions in phosphorus discharges from other sources in the basin (p. 2-3): "**assuming** (emphasis added) that the projected levels of treatment for the other discharges were implemented, the net overall effect would be the significant reduction of pollutants, including phosphorus".

It is inappropriate and risky to predicate evaluation or issuance of the Fayetteville discharge permit on assumed reductions from other point sources in the basin. As stated by Mr. Champagne (p.3.), these reductions have yet to be defined or implemented, pending outcome of the Illinois River Basin Study. In this light, this whole process of considering the Fayetteville discharge permit and its impacts on Oklahoma's water quality standards for the Illinois River is premature.

increase in nitrogen loads.

6. **No Adverse Environmental Impact.**

Dr. Thompson (p.3): "In my opinion, the small amount of added phosphorus from the Fayetteville WWTP will have no adverse environmental impact."

As a result of excessive phosphorus inputs and resulting eutrophication, Oklahoma's stream standards for nutrients, dissolved oxygen, turbidity and aesthetics are violated on occasion from the state line to the river mouth under existing conditions. The river and reservoirs are already water-quality limited. Any further increases in nutrient loadings will increase the spatial and temporal violation frequencies and further impair water uses.

The added discharge from Fayetteville appears "small" only because it is being heaped on top of an excessive existing loading. Because the standards are already being violated due to excessive nutrient discharges, any avoidable increase in nutrient loading, regardless of magnitude, is unacceptable and inconsistent with fundamental water quality management policies outlined in the Clean Water Act. illegal

Monitoring data summarized in my direct testimony clearly indicate that water quality conditions in Lake Frances, Lake Tenkiller, and the intervening river have deteriorated significantly over the past decade as a result of increased nutrient loadings. In a recent conversation with Bill Roach (an Oklahoma resident and skin diver who has owned a vacation home on the lower end of Lake Tenkiller since 1967), I obtained additional historical perspectives. Mr. Roach described the lake as "crystal clear" during the early and mid 1970's. A "marked increase in algae" occurred sometime between 1978 and 1982. Clarity has been reduced to the point where "you can't see 2 feet into the water" during critical summer periods. Mr. Roach has found that clarity is somewhat greater during the fall after peak algal growths have died off. Because of his interest in skin diving, he has adjusted his vacation schedule accordingly and now seldom visits the lake during the summer.

He also mentioned that the deterioration in water quality was accompanied by marked reductions in the log perch population. Once abundant in the lake, this exotic fish is now rarely spotted by skin divers. This account is consistent with trends in the monitoring data and demonstrates use impairment and possible ecological impacts. Addition of the Fayetteville discharge would cause further degradation.

7. Comprehensive Evaluation of Alternatives.

Mr. Champagne, in his Enclosure #2 ("A Reconsideration in Response to: Senate Report 98-506..."), describes four alternatives which were considered (pp. 3-4). Alternatives 3 and 4 (diversions to Arkansas River) were rejected because they were "not cost-effective". Land treatment options are not described.

Dr. Blanz relates that the city has gone against the recommendations of at least four highly respected environmental consulting firms before arriving at the current "cost-effective" and "ecological" solution.

The terms "cost-effective" or "not cost-effective" are only relevant to alternatives which accomplish the stated objective: compliance with water quality standards. Based upon mass balances for an average hydrologic year (Walker,1987,Table 5), phosphorus removal (1 mg/liter) from all point sources in the basin would cause a 40% reduction in loading to Lake Tenkiller. Nearly proportionate reductions in average phosphorus and algal concentrations would be expected. Figure 21 demonstrates that, even with phosphorus removal down to 1 mg/liter, Lake Frances and the river below it will still be eutrophic under low and 7-Q-2 summer flows. Oklahoma water quality standards would still be violated, although at a reduced frequency. This reflects the low dilution capacity of the watershed and nitrogen-limited condition of Lake Frances.

P => .2 mg/l

Based upon these considerations, schemes involving diversion of effluents out of the basin and/or land application seem to be the only alternatives which would bring the Illinois River into compliance with water quality standards. These measures deserve further consideration.

8. 7-Day Permit Levels vs. 30-Day Permit Levels.

Mr. Leonard summarizes effluent permit conditions (Pages 2-3).

The permit specifies a maximum 7-day-average phosphorus concentration of 2 mg/liter and a maximum 30-day average concentration of 1 mg/liter. My mass balance calculations (Tables 4-7) are based upon the 30-day value. Because of the low hydraulic residence time of Lake Frances, conditions in the lake and downstream river would respond to changes in inflow concentrations on a weekly time scale. Thus, the projected increases in phosphorus concentrations due to the Fayetteville discharge could be twice those described in my testimony (Tables 4-7, Figures 21 and 23) and still be in compliance with the permit.

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Threlkeld, S.T., "Lake Frances Phase I Diagnostic/Feasibility Study", prepared for U.S. Environmental Protection Agency, Grant No. S-006284-01-0, 1983.

U.S. Environmental Protection Agency, "Nitrogen and Phosphorus in Wastewater Effluents", Working Paper No. 22, National Eutrophication Survey, Corvallis Environmental Research Laboratory, July 1974.

Walker, W.W., Jr., "Empirical Methods for Predicting Eutrophication in Impoundments, Report 3: Model Refinements", prepared for Chief of Engineers, U.S. Army, USAE Waterways Experiment Station, Vicksburg, Mississippi, Technical Report E-81-9, March 1985.

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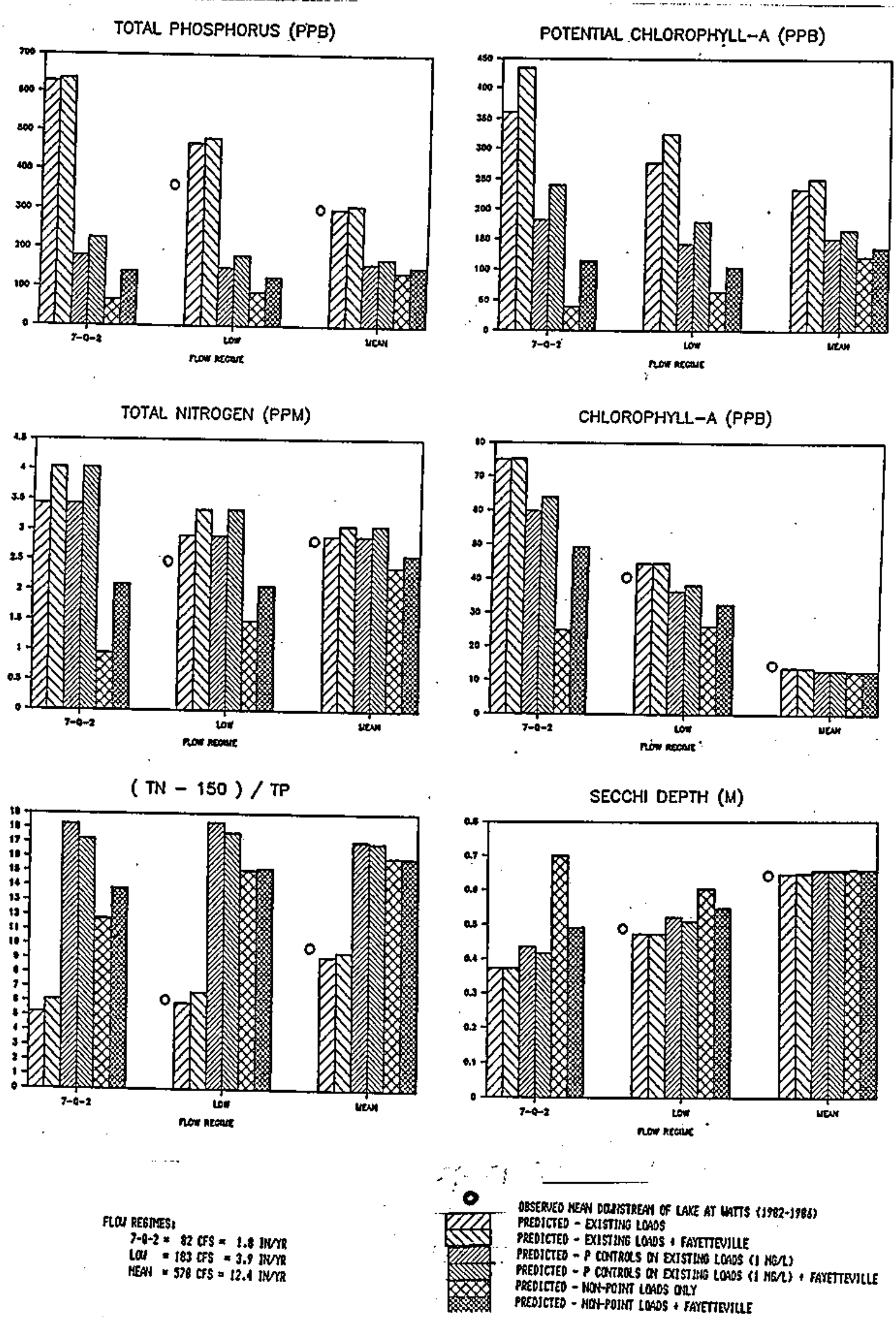
Figure 21
Predicted Impacts of Fayetteville Discharge on Nutrient, Algae, and Transparency Levels in Lake Frances



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drier years. The runoff rate for water year 1981 (4 inches/yr or .1 meters/yr) has been used as an example of a dry hydrologic year. Under this condition, the Fayetteville discharge would increase the annual loadings of total phosphorus and nitrogen to Lake Frances by 6.7% and 18.0%, respectively, vs. 4.7% and 8.2% under average flows. Total phosphorus and nitrogen loadings to Tenkiller Ferry Reservoir would increase by 4.3% and 10.4%, respectively, during a dry year and by 2.8% and 4.3% during an average year. Regardless of their precise magnitudes, these increases are unacceptable in view of the fact that Oklahoma's water quality standards are already being violated due to excessive nutrient enrichment.

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