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A Nutrient-Balance Model for Agency Lake, Oregon

prepared for

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by

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Introduction

Agency Lake is a shallow, hyper-eutrophic impoundment located in the Upper Klamath Lake Basin, Oregon (Figure 1). The lake has a surface area of 35.6 km^2 and drainage area of approximately 614 km^2. This report develops water and nutrient balances for Agency Lake using data from an intensive monitoring program conducted by the U.S. Bureau of Reclamation and Klamath Tribes between 1991 and 1993 (USDI, 1993a, 1993b). Flows and nutrient loads at watershed monitoring stations are calculated and compared to identify important contributing areas of the watershed. Mass balances for water, conductivity, total phosphorus, and total nitrogen are developed over monthly and seasonal time scales. Spatial and temporal variations in lake water quality conditions are characterized. Application of empirical eutrophication models developed for reservoirs (Walker, 1987) provides further insights into factors controlling eutrophication in Agency Lake and a limited basis for predicting effectiveness of management strategies designed to improve lake water quality.

Monitoring Program

Watershed and lake monitoring stations operated in 1991-1993 are shown in Figure 2. Time series plots of watershed and lake monitoring data are given in Appendix A. Major tributaries include Wood River, Sevenmile Canal, and Fourmile Canal. Basic features of the watershed and monitoring program are described below.

The major tributaries originate as springs and mountain streams in the southern Cascades, which form the western and northern boundaries of the watershed. The lower portion of each watershed consists of former wetlands which have been diked, drained, ditched, and developed for agricultural use. Approximately 60 km^2 of the Agency Lake watershed was converted from wetland to upland between 1940 and 1989 (USDI, 1993b). Tributary canals supply water for irrigation purposes and accept irrigation return flows and runoff from grazing areas. Site visits in March 1995 revealed evidence of direct surface runoff from grazed areas, barnyards, and animal holding areas into lake tributaries. Other potential nutrient sources in the watershed include oxidation of former wetland soils, runoff from roads, runoff and/or point-source discharges from urban areas (Ft. Klamath) and a fish hatchery.

Watershed delineations shown in Figure 2 have been derived partially from a GIS data base maintained by the Winema National Forest. The remaining delineations have been estimated from maps and other available information. Ungauged areas draining directly into Agency Lake below monitoring points amount to approximately 43 km^2 or 7.3% of the entire watershed; this estimate is uncertain because of difficulties in delineating watersheds in the agricultural areas immediately northwest of the Lake, characterized by its flat topography and intensive water-management activities. These difficulties, combined with the

apparent lack of a complete land-use inventory for the watershed, impose limitations on accuracy of the water-balance and nutrient-balance calculations developed below. Model predictions are fairly insensitive to the assumed delineation of ungauged drainage area, however.

Seven watershed stations were sampled monthly by the USBR during the 1991-1993 study period. Five of these stations (UK100-UK500) are located along the Wood River; these characterize variations in flow and water quality from spring-fed headwaters, through agricultural and wetland areas, and into Agency Lake. Sevenmile Canal (UK600) and Fourmile Canal (UK400) stations characterize drainage from the western and northwestern portions of the watershed. The study period included a dry year (precipitation = 8.7 inches in Water Year 1992) and a wet year (24 inches in Water Year 1993). The long-term-average precipitation is approximately 13.5 inches.

Three lake monitoring stations were sampled biweekly by the Klamath Tribe. As shown in Figure 2, two lake stations are located in Agency Lake (North & South) and one station is located in Klamath Lake. Details on sampling methods and analytical procedures are given in USDI (1993a, 1993b).

Runoff & Nutrient Loads

This section describes the computation of flows and nutrient loads at the tributary monitoring stations. A continuous record of daily flows was provided for one station (UK400 = Wood River at Weed Road). Although continuous stage readings were made at the remaining stations, these data were not available to support the present study. The flow record at the remaining stations consists of instantaneous measurements taken at monthly intervals using a velocity meter.

To provide a basis for mass-balance calculations, a complete daily flow record has been generated for each watershed station using the following procedure:

1. Pair each instantaneous flow measurement with the corresponding daily-mean flow at the Weed Road station.

2. Develop a regression equation relating the station flow to the Weed Road flow.

3. Apply the regression equation to generate a predicted flow for each day in the record.

4. Calculate the residual (observed - predicted) flow on the days with instantaneous flow measurements.

5. Interpolate the residuals over time to generate a residual value for each day in the record.

6. Calculate a daily flow for each day in the record by adding the predicted flow (3) and the interpolated residual (5).

In situations where the correlation between the Weed Road flow and the station flow is high, this procedure tends to track the Weed Road flow (with an appropriate adjustment in scale). In situations where the correlation is weak, this procedure approaches a direct interpolation of the monthly instantaneous flows over time. Estimates derived from this procedure are inferior to direct daily stream flow measurements, provided that adequate stage/discharge relationships can be developed. Accordingly, tributary flows and loadings should be recalculated once a continuous flow record is available for each station. This would be particularly important for Sevenmile Creek, which, based upon watershed characteristics and upon the limited flow and concentration data available, appears to be an important nutrient source.

Based upon application of the FLUX program (Walker, 1987), temporal variations in stream concentrations are relatively low. Concentrations tend to be weakly correlated or uncorrelated with flow. Correlations with season are more pronounced; at lower watershed stations, concentrations tend to be higher during summer months than during winter months. A continuous record of daily mass flux has been generated at each station by interpolating measured concentrations over time and applying the interpolated concentrations to the daily flows. Results are summarized by month, season, and year in Appendix B. Constituents include total phosphorus, ortho phosphorus, total nitrogen, inorganic nitrogen, and conductivity.

Figure 3 shows average flows, fluxes, and flow-weighted-mean concentrations for each station and constituent. These represent average conditions during April through September of each year (1991, 1992, 1993). Year-to-year variations at each station are depicted in Appendix B.

At the Wood River Stations (UK100-UK500), there is a small increase in flow between the most upstream station (UK100 = Dixon Road, April-September mean flow volume = 80 hm^3 = 80 million cubic meters) and the most downstream station (UK500 = Agency Dike, flow = 98.7 hm^3). Inflows from higher order tributaries (Annie Creek, Fort Creek, and Crooked Creek) are not evident in the Wood River flow profile. The net flow contribution from the lower portion of the Wood River watershed is small; this presumably reflects diversions, consumptive use by irrigation, and spatial differences in precipitation and evapotranspiration between the mountain headwaters and the semi-arid lake plain. In contrast, total phosphorus flux increases from 6,511 kg to 14,742 kg and the flow-weighted-mean total phosphorus concentration increases from 81 ppb to 149 ppb between these same two stations. As shown in Figure 3, most of the phosphorus increase occurs in the area between Weed Road (UK400) and Agency Dike (UK500).

Station UK500 is located just upstream of Agency Lake. Given the flat topography and resulting low hydraulic gradient, it is possible that concentrations measured at UK500 are influenced at times by hydraulic exchanges with Agency Lake. Comparisons of water-quality time series at UK500 with time series at Agency Lake stations (Appendix A) do not reveal evidence of this, however. Seasonal increases in total and ortho phosphorus concentrations at UK500 tend to occur 1-2 months earlier than increases at the Lake stations. Furthermore, elevated chlorophyll-a and pH values typical of Agency Lake stations during the summer months were not detected at UK500. Based upon these comparisons, it is assumed that concentrations measured at UK500 were representative of lake inputs from the Wood River watershed.

The flow-weighted-mean phosphorus concentration at the mouth of the Wood River (149 ppb) was similar to that measured at the mouth of Sevenmile Canal (156 ppb). The phosphorus concentration in Fourmile Canal was identical to that measured at headwaters of the Wood River (81 ppb). Station UK700 is located considerably upstream of the lake (Figure 2) and may be more heavily influenced by drainage from eastern mountainous areas than by drainage from the developed lake plain. The difference between 81 ppb and 149-150 ppb is one estimate of anthropogenic impact on stream phosphorus concentrations. Nitrogen concentrations (organic nitrogen, in particular) were much higher at the Sevenmile Canal station (697 ppb) and Fourmile Canal station (462 ppb), as compared with the Wood River Stations (108 to 314 ppb).

Water & Nutrient Balances

In order to construct water balances and nutrient balances for Agency Lake, estimates of contributions from ungauged portions of the watershed are required. Based upon the watershed delineations given in Figure 2, ungauged watersheds amount to 7.3% of the total watershed. These include areas on the west and east side of the lake.

Ungauged flows and loads have been estimated by drainage area proportioning against gauged flows and loads from Sevenmile Canal and Fourmile Canal, based upon proximity. The following equation is used:

$$W_u = W_g A_u / A_g = .283 W_g$$

where,

W_g = gauged flow or load (sum of Fourmile & Sevenmile)

W_u = ungauged flow or load

A_g = gauged drainage area (150.3 km^2)

A_u = ungauged drainage area (42.5 km^2)

This estimation procedure assumes that ungauged watersheds are similar to Fourmile & Sevenmile Canals with respect to land uses, soil types, and other factors determining runoff and nutrient export.

The Agency Lake water balance has been formulated at monthly intervals using the following equation:

External Inflows + Precipitation =

Evaporation + Outflow + Storage Increase

External inflows are derived from the watershed monitoring stations and the estimated ungauged contributions. Precipitation is estimated from regional measurements supplied by USBR. Longterm-average precipitation values have been used for months when direct measurements are missing. Fixed monthly evaporation rates are average pan evaporation rates for 1961-1990, adjusted with a pan coefficient of 0.7. The change-in-storage term is calculated from Upper Klamath Lake elevation records and a capacity vs. elevation table for Agency Lake supplied by USBR.

Outflow is calculated by difference from the other terms, each of which are directly measured or independently estimated. In typical reservoir studies, the accuracy of the water-balance calculations can be checked by comparing observed and predicted outflow rates (Walker, 1987). Direct measurements of Agency Lake outflow would be difficult and are not available, however.

Results of monthly water-balance calculations are summarized in Table 1 and displayed in Figures 4 and 5. Figure 4 shows monthly inflows, outflows, and storage terms. Figure 5 shows lake morphometric and hydrologic features which are significant with respect to nutrient-balance modeling. Generally, variance in outflow is much less pronounced than variance in the inflow. The seasonal inflow cycle (lower in summer, higher in winter) is offset by the seasonal decrease in lake elevation and storage. Mean depth varies from 2.2-2.5 meters in April-May to 0.8-1 meter in October. Hydraulic residence time (computed as the ratio of the average monthly lake volume divided by the net inflow (= external inflow +

precipitation - evaporation)) varies from 90 to 150 days in summer months to 30-40 days in winter months.

Mean depth, hydraulic residence time, and surface overflow rate are important factors regulating nutrient cycling and biological response in reservoirs (Walker, 1985, 1987). Shallow depths tend to promote nutrient recycling from bottom sediments and to promote algal growth by reducing the potential for light limitation. Based upon depth and residence time, low nutrient retention efficiencies are expected. The low surface overflow rate (averaging ~8 m/yr) provides limited dilution of sediment nutrient sources and increases sensitivity to nutrient recycling processes. Summer hydraulic residence times in Agency Lake are well above the 0-14 day range in which flushing rate has been shown to control algal densities (Walker, 1985). The morphometric and hydrologic characteristics of Agency Lake are more or less ideal for promotion of algal growth in response to external or internal sources of nutrients.

Using a similar computational framework, monthly mass balances have been formulated for conductivity, total phosphorus, and total nitrogen (Tables 2-4, Figures 7-15). The mass-balance equation includes an additional term to reflect net retention or loss:

Net Retention = External Inputs + Atmospheric Inputs
- Outputs - Storage Increase

External inputs are derived from the tributary flux calculations described in the previous section. Atmospheric inputs (sum of wetfall and dryfall) are estimated at fixed areal rates of 7 $uS/cm^2*m/yr$ for conductivity, 18 kg/km^2-year for phosphorus, 1080 kg/km^2-year for nitrogen (USEPA, 1975). Outputs are estimated by multiplying the monthly outflow volume times the monthly-average lake concentration. A continuous daily time series has been generated for lake concentration by interpolating lake-mean concentrations (average of North and South stations, Figure 2) between adjacent sampling dates. A corresponding time series of month-end mass storage has been generated by multiplying the month-end concentration times the month-end lake volume. The storage increase term of the mass balance has been calculated as the mass storage at the end of the current month minus the storage at the end of the previous month.

The mass-balance framework ignores diffusive inputs or outputs resulting from hydraulic exchanges between Agency Lake and Upper Klamath Lake. Such exchanges would depend upon exchanges of flow between the two basins, driven by wind and/or elevation differences. Sufficient data are not available to estimate these terms directly. The restricted nature of the channel linking the two lakes and general similarities in water quality between the two lake basins would tend to limit the magnitude and significance of such exchanges. More detailed modeling of both lake basins could provide information on the extent to which the nutrient balances of the two basins are linked by diffusive hydraulic exchanges. Only advective transport from Agency Lake into Upper Klamath Lake is considered in the mass balances formulated here.

The net retention term has been calculated by difference. This term reflects net losses from the water column resulting from sedimentation, atmospheric fixation (nitrogen), nutrient releases from bottom sediments, and the cumulative effects of errors or omissions in the other mass-balance terms. The net retention term is positive during periods when sedimentation or other removal processes dominate and negative during periods when nutrient releases from bottom sediments, atmospheric fixation, or other internal nutrient sources dominate.

Tables 2-4 summarize mass-balance results for each term, on monthly, seasonal, and yearly-average time scales. Monthly series are displayed in Figures 7, 10, 13 for conductivity, total phosphorus, and total nitrogen, respectively. Seasonal series (September-March and April-September of each Water Year) are displayed in Figures 8, 11, and 14. Cumulative mass balances (running sum of monthly input, output, storage, and retention terms starting in April 1991 and ending in October 1993) are shown in Figures 9, 12, and 15; these elucidate the relative magnitudes of each mass-balance term over long time scales.

The conductivity balance has been formulated to provide a means of testing the water-balance and mass-balance framework. If conductivity is assumed to be proportional to the concentration of conservative ions, the net retention term of the mass balance should average close to zero. One limitation of using conductivity for checking the water balance is that it can be influenced by non-conservative ions (such as nitrate, sulfate, phosphate), it is temperature-dependent, and the field-measured values for conductivity are probably less precise than laboratory analyses for conservative ions. While chloride or sodium balances would be preferred for this purpose, the required tributary and lake concentration measurements are not available for these constituents. Because conductivity "concentration" units are in uS/cm^2, mass balance terms have units of uS/cm^2 x hm^3. The relative magnitudes of the terms are of concern, however, rather than the absolute values or units.

Reasonable conductivity balances are established for April-September of each year. Results for 1991 are relatively uncertain because of the scarcity of lake conductivity measurements. The net retention term ranges from 1.4% to 5.7% of the total inputs. Conductivity balances are less satisfactory during winter periods; net retention amounts to -15.5% of the external inputs between October 1991 and March 1992 and -57.0% of the total inputs between October 1992 and March 1993. These negative values may reflect low sampling intensity or additional conductivity sources during winter months. The relatively large excursion in Winter

92-93 is traced to high conductivity readings at the Agency South station on two sampling dates. Further analyses suggest a positive correlation between the monthly retention term for conductivity and lake temperature. It is possible that the poor conductivity balance during winter months is an artifact of the temperature-correction factor inherent in the conductivity measurements. Despite possible problems with the mass balance during winter months, the summer conductivity balances are consistent with reasonable representations of the lake's water balance. More definitive evaluation of potential problems during the winter months would be derived from more intensive winter sampling of the lake stations and construction of chloride or sodium balances in place of conductivity balances.

Phosphorus balances (Figures 10-12) indicate that outputs approximately equaled inputs over the two complete water years studied (1992 and 1993). Seasonal mean total phosphorus concentrations in Agency Lake ranged from 60 to 130 ppb in winter and from 140 to 240 ppb in summer. Over Water Years 1992-1993, the net retention term of the phosphorus balance amounted to 0.6% of the total inputs. Periods of significant positive and negative phosphorus retention are apparent in the monthly (Figure 10) and seasonal (Figure 11) balances. The rapid doubling in lake phosphorus concentration which occurred in early summer of each year reflected periods of negative phosphorus retention, especially in July 1991, June 1992, and July 1993. Phosphorus retention during these months ranged from approximately -10,000 to -20,000 kg/month, as compared with the average external phosphorus load of approximately 3,000 kg/month. Expressed per unit area of lake sediment, these negative retention rates corresponded to phosphorus release rates ranging from 9 to 18 mg/m^2-day during these extreme months. As indicated in Figure 10, these high rates were not sustained throughout the growing season.

Periods of markedly negative phosphorus retention rates most likely reflect phosphorus recycling from lake bottom sediments triggered by photosynthetically-induced increases in pH. Figure 16 shows that monthly phosphorus retention rates are negatively correlated with monthly-average lake pH and chlorophyll-a levels in Agency Lake. The three months with the most negative retention rates (highest apparent internal loading rates) corresponded to months with the highest pH levels. Retention rates tended to be positive in late summer during the declining phase of the seasonal algal bloom. Overlaying the pH and chlorophyll-a time series (Figure 16) suggests that an increase of one log unit in chlorophyll-a was generally accompanied by an increase of one pH unit, except for an anomalous period in late summer 1992, when high pH levels were measured, despite extremely low chlorophyll-a concentrations.

Chemical mechanisms for release of iron-bound phosphorus from lake bottom sediments during periods of high pH have been documented (Stumm and Leckie, 1970) and are thought to be important in Upper Klamath Lake (Klamath

Tribe, 1994). In hardwater lakes, release of iron-bound phosphorus at high pH is typically offset by precipitation of insoluble calcium phosphates (Golterman, 1982). Calcium concentrations averaged 5-7 mg/liter at tributary stations, but were not measured at lake stations. Apparently, calcium levels in the moderately soft waters of Agency Lake are insufficient to control release of iron-bound phosphorus at high pH. This mechanism promotes recycling of phosphorus previously deposited to lake bottom sediments during winter and late summer periods, when positive retention rates are apparent. The recycling occurs during early summer when light and temperature levels are most conducive to algal blooms.

The nitrogen balance (Table 4, Figures 13-15) indicates that Agency Lake is a net source of nitrogen over short and long time scales. Mean total nitrogen concentrations in Agency Lake ranged from 400-500 ppb in winter to 1000-1300 ppb in summer. Over Water Years 1992-1993, the net retention term of the nitrogen balance amounted to -102% if the external inputs. In other words, the external and internal sources of nitrogen were approximately equal. The apparent internal nitrogen source probably reflects fixation of atmospheric nitrogen by bluegreen algae (USDI,1993ab, Barbiero & Kann, 1994). Average summer and winter retention rates correspond to areal fixation rates of 18.2 and 2.2 mg/m^2-day, respectively.

Lake Water Quality

Time series plots of data from three lake monitoring stations (Agency Lake North, Agency Lake South, and Upper Klamath Lake) are included in Appendix A. Box plots depict seasonal (Figure 17), annual (Figure 18), and spatial variations (Figure 19) in lake water quality.

Seasonal variations in nutrient concentrations and chlorophyll-a are pronounced. Figure 17 summarizes data from Agency North and South grouped into four, three-month seasons (March-May, June-August, September-November, December-February). Maximum concentrations of chlorophyll-a, organic nitrogen, total phosphorus, ortho phosphorus, and total nitrogen were observed during the summer (June-August) season. The ratio of chlorophyll-a to total phosphorus (CHLA/TP) was also highest during this season. The strong seasonality in these response variables reflects seasonal variations in environmental factors (temperature, light) and the apparent mechanistic linkages between chlorophyll-a and internal nutrient sources, as described in the previous section. Further analyses indicate that nutrient concentrations, chlorophyll-a concentrations, and Chl-a/P ratios in May and September were significantly below June-August values. For this reason, modelling efforts in the subsequent section are focused on the June-August period.

Within the June-August period, temporal variations in chlorophyll-a are unusually high in relation to variations observed typically observed in other lakes and reservoirs. The coefficient of variation (standard deviation of natural log) is 1.3, as compared with typical values in the range of 0.4 to 0.7 estimated from regional and nationwide data sets (Smeltzer et al., 1989). The high variability partially reflects the episodic character of algal blooms apparently triggered by sediment phosphorus releases (Figure 16). Difficulties associated with sampling algal flakes may also contribute to high variability in Agency Lake chlorophyll-a measurements.

Year-to-year variations are shown in Figure 18, based upon June-August samples from Agency Lake stations. Yearly means and standard errors are listed in Table 5. Following the algorithm included in the PROFILE program for reduction of reservoir water quality data (Walker, 1987), yearly means have been computed by first averaging across stations on each sampling date and subsequently averaging across dates within each year. Chlorophyll-a data from Agency South included one extremely high value (986 ppb on 6/17/92); this is more than three times the next highest value recorded at this station and more than four times the value recorded at Agency North on the same date. When this value is included, the three-year-average chlorophyll-a is 97 ppb and the standard error is 27 ppb. When this value is replaced with the chlorophyll-a concentration measured at Agency North on the same date (195 ppb), the three-year-average decreases to 78 ppb and the standard error decreases to 13 ppb. It is possible that the unusually high value reflects difficulties in collecting representative samples in waters containing large algal flakes. Given the high influence of this single sample on the long-term mean and standard error, the latter summary values (mean = 78 ppb, standard error = 13 ppb) are assumed to represent the average chlorophyll-a response.

Based upon paired t-tests, significant differences in yearly means are indicated only in the case of water depth and ortho phosphorus. Both depth and ortho phosphorus concentration were significantly lower during the 1992 drought year. Significant differences in yearly means are not indicated for the primary measures of trophic response (total phosphorus, total nitrogen, chlorophyll-a, or transparency). Accordingly, modeling efforts in the subsequent section focus on average conditions (between June and August) for all three years.

Spatial variations (June-August) are summarized in Figure 19. Stations are arranged in a north-to-south direction (Agency North, Agency South, Klamath Lake); this follows the major flow axis. Spatial variations are most pronounced in the case of Total N/P ratio and inorganic N/P ratio, both of which increase from north to south. These reflect weaker increasing gradients in nitrogen species and decreasing gradients in phosphorus species. The chlorophyll-a/phosphorus ratio in Agency Lake (median ~.2) is significantly lower than that observed in Upper Klamath Lake (median ~.4). This may reflect a greater influence of nitrogen limitation on algal growth in Agency Lake, as indicated by lower Total and Inorganic N/P ratios. Because of the N/P and Chl-a/P gradients, a single phosphorus/chlorophyll-a ratio (or regression) would not be sufficient to describe spatial variations in chlorophyll-a response across both lakes. Significant differences between Agency North and South stations are apparent only in the case of the Total N/P ratio. Otherwise, spatial variations within Agency Lake are not considered strong enough to warrant a spatially-segmented model.

Based upon the spatial and temporal variations described above, modeling efforts in the subsequent section are focused on predicting Agency Lake responses averaged across stations, years, and months between June and August. Table 6 compares average trophic state indicators in Agency Lake with the distributions of values in 40 Corps of Engineer (CE) reservoirs used in developing the empirical models applied below. Appendix C (extracted from Walker, 1987) describes the diagnostic variables listed in Table 6.

By all measures, Agency Lake is highly eutrophic. Values for chlorophyll-a, organic nitrogen, the first two principle components of reservoir response measurements (PC-1 & PC-2) are all above the CE reservoir range. The Inorganic N/P ratio is below the CE reservoir range; this suggests Agency Lake is more strongly nitrogen limited than any of the reservoirs in the CE data set. Other diagnostic variables indicate that light limitation is not important in Agency Lake, primarily because of its shallow depth and dominance by flake-forming algae, which absorb less light per unit chlorophyll than algal types with smaller cells. Despite the low N/P ratio, the average Chl-a/P ratio (0.31) is in the 67th percentile of CE reservoir values. The shallow depth, nitrogen fixation, and phosphorus recycling mechanisms apparently support a high algal response to phosphorus, despite the potential growth-limiting effects of nitrogen.

Average morphometric and hydrologic features are within the range of the CE reservoir data set (Table 6). As expected, Agency lake is at the low end with respect to mean depth (8th percentile) and surface overflow rate (4th percentile). These characteristics are conducive to nutrient recycling and a high algal response. Lakes and reservoirs with low surface overflow rates are more susceptible to internal nutrient recycling (Walker, 1987). Internal nutrient sources (releases from bottom sediments) are typically expressed on an areal basis (mg/m^2-yr). Dividing the areal release rate by the surface overflow rate (areal water load, m/yr) provides a measure of the potential impact of internal recycling on water-column concentration (mg/m^3 or ppb). At a given recycling rate, this impact is inversely proportional to overflow rate. Thus, the importance of internal sources identified in the previous section is consistent with Agency Lake's morphometric and hydrologic characteristics.

BATHTUB Model Network

The following sections apply empirical models previously developed for evaluating eutrophication problems in Corps of Engineer reservoirs (Walker, 1985, 1987) to data from Agency Lake. The models are derived from the BATHTUB program (Walker, 1987), but are implemented here in a spreadsheet format (adaptation of CNET.WK1, Walker, 1990). The structure of the model network is shown in Figure 20. Equations are summarized in Table 7. This effort provides quantitative perspectives on trophic state and controlling factors in Agency Lake. To a limited extent, modeling also provides a basis for predicting potential water-quality responses to changes in external nutrient loadings, pool elevations, and/or measures designed to reduce internal nutrient recycling.

The BATHTUB model network (Figure 20) contains two categories of models: nutrient-balance models and trophic response models. Trophic response models relate observed or predicted nutrient concentrations to other measures of trophic state (chlorophyll-a, transparency, organic nitrogen, etc.). Nutrient-balance models predict lake nutrient concentrations based upon external loads, morphometry, and hydrology. Each model category is discussed below.

Trophic Response Models

Table 8 summarizes the results of applying empirical models predicting chlorophyll-a, transparency, and other measures of trophic response based upon observed nutrient concentrations and other driving variables. Five alternative equations for predicting mean chlorophyll-a are tested (Chlorophyll-a Models 1-5, see Appendix C). Based upon error statistics derived from the CE reservoir data set and the uncertainty in the observed mean chlorophyll-a, predictions of the first four models (71 - 81 ppb) are not significantly different from the observed mean (78 $\pm$ 14 ppb). Model 5 (exponential P/ Chl-a relationship) substantially over-predicts chlorophyll-a in Agency Lake, probably because of its low N/P ratio and relatively high phosphorus concentrations.

Chlorophyll-a model (Model 1) predicts chlorophyll-a based upon total phosphorus, total nitrogen, non-algal turbidity, mixed layer depth, and hydraulic residence time. This model was designed to account for potential effects of algal growth limitation by phosphorus, nitrogen, light, and/or flushing rate. Applied to the CE reservoir data set, errors are independent of nutrient concentrations, N/P ratios, hydraulic residence time, and indicators of light limitation (turbidity, mixed layer depth, etc.). Because it is the most general formulation, Model 1 has been selected for application to Agency Lake. Following the control pathways shown in Figure 20, predictions of other trophic response variables (transparency, organic nitrogen, Total P - Ortho P, principle components) are driven by predicted chlorophyll-a concentrations.

Further testing against data from individual stations (Agency North, Agency South, Upper Klamath Lake) indicates that error distributions are independent of station only for the chlorophyll-a models which account for nitrogen limitation (Models 1 and 3). When any of the remaining chlorophyll-a models are calibrated to predict chlorophyll-a levels in Agency Lake, they under-predict chlorophyll-a levels in Upper Klamath Lake. This is consistent with the north-to-south increasing gradient in N/P and Chl-a/P ratios (Figure 19). This further suggests that algal populations in Agency Lake are sensitive to both phosphorus and nitrogen, despite the observed nitrogen fixation.

All three transparency models under-predict the observed mean Secchi Depth by more than a factor of two. This is probably related to the importance of flake-forming bluegreen algae (USDI,1993ab), which cause less light attenuation per unit of chlorophyll than other algal types. The transparency model represents the inverse of transparency as a linear function of chlorophyll-a. Based upon CE reservoir data, the slope of this relationship was originally calibrated to 0.025 m^2/mg. This slope is also a parameter in chlorophyll-a Models 1 & 2; lower values will increase algal response to high nutrient concentrations by decreasing self-shading effects. Experience in other applications of the models indicates that a downward adjustment of this slope is frequently necessary in lakes and reservoirs dominated by large-celled bluegreen algae (Heiskary & Walker, 1995; Walker & Havens, 1995).

Table 9 summarizes results after calibration of the model network to Agency Lake response measurements. The primary calibration is downward adjustment of chlorophyll-a/Secchi slope from 0.025 to 0.012 m^2/mg. As discussed above, this is justified based upon type of algae found in Agency Lake. With this adjustment, the observed and predicted transparency values are in agreement; predicted chlorophyll-a concentrations for the two models which consider light limitation (1 and 2) increase to 90 and 135 ppb, respectively. The secondary calibration is the application of a scale factor (0.87) to the predicted chlorophyll-a concentration (Model 1). Based upon the fact that the observed and predicted chlorophyll-a concentrations are not significantly different without calibration, this relatively minor adjustment is not necessary. With the adjustment, observed and predicted chlorophyll-a concentrations are numerically equal.

The remaining response models predict organic nitrogen and non-ortho phosphorus based upon predicted chlorophyll-a and non-algal turbidity. These variables reflect "utilized" nutrient forms; in the absence of high humic or inorganic turbidity levels, they are good surrogates for chlorophyll-a. The remaining equations predict the first two principle components of reservoir response measurements (chlorophyll-a, transparency, organic nitrogen, and composite nutrient concentration). Since observed and predicted values are not significantly different for any of these models, no recalibrations have been performed.

With the above adjustments, the model network provides a basis for predicting relationships among trophic state indicators in Agency Lake. Of primary interest is the relationship between mean chlorophyll-a concentration and total phosphorus concentration. In a predictive mode, one difficulty is that predicted chlorophyll-a also depends upon total nitrogen concentration. Prediction of nitrogen concentrations using an empirical nutrient loading model is not feasible in Agency Lake because of the apparent importance of nitrogen fixation.

Figure 21 shows predicted mean chlorophyll-a concentrations as a function of total phosphorus for two alternative assumptions regarding nitrogen behavior. Under the first assumption, total nitrogen is constant at the 1991-1993 mean (1816 ppb) and independent of phosphorus. Under the second assumption, the model term which reflects nitrogen limitation (Total N - 150) / Total P is fixed at the 1991-1993 mean (6.5); i.e., nitrogen levels are assumed to vary approximately in proportion to phosphorus levels. As total phosphorus concentrations decrease, the first assumption results in a nonlinear response; this reflects a transition from co-limitation by nitrogen and phosphorus to limitation by phosphorus alone. The second assumption results in a linear chlorophyll-a/phosphorus response. Repeating this exercise using chlorophyll-a Model 3 yields essentially equivalent results. Because nitrogen fixation cannot be reliably modeled/predicted, it is difficult to determine which of the above assumptions is most appropriate for modeling chlorophyll-a response to phosphorus in Agency Lake. The following concepts seem to support the second assumption, however:

(1) Given the watershed nutrient sources, any control program designed to reduce external phosphorus loads would also reduce external nitrogen loads.

(2) If it is assumed that algal populations are ultimately controlled by phosphorus because of the facility for nitrogen fixation, one would expect the amount nitrogen fixation to decrease with phosphorus concentration.

Because of these factors, results for the second assumption are emphasized, although results for both assumptions are presented.

Correlations between phosphorus and chlorophyll-a using data from the entire growing season (May thru September) have been developed for the entire Upper Klamath Lake system (Klamath Tribe,1994). Seasonal effects are evident in phosphorus concentrations, chlorophyll-a concentrations, and chlorophyll-a/phosphorus ratio (Figure 17). All three values are significantly lower in May and September, as compared with June thru August. Some of the apparent correlation between phosphorus and chlorophyll-a in the May-September data reflects seasonal variations, as opposed to a mechanistic linkage between phosphorus and chlorophyll-a. For this reason, such correlations should not be used to predict chlorophyll-a response to changes in average phosphorus concentration.

To supplement response predictions based upon the BATHTUB model network, site-specific models predicting algal bloom frequency as a function of total phosphorus concentration have been developed using Agency Lake data (Figure 22). These are based upon cross-tabulation of paired chlorophyll-a and phosphorus concentrations measured at Agency Lake stations between June and August (Heiskary & Walker, 1988; Walker & Havens, 1995). To develop the relationships, 40 paired samples collected between 1991 and 1993 have been sorted based upon increasing phosphorus concentration and bloom frequencies (% of chlorophyll-a > 30 ppb and > 60 ppb) have been computed from each successive set of 10 samples (samples 1-10, 2-11, 3-12, etc.. 31-40). This results in four independent sample sets (samples 1-10, 11-20, 21-30, 31-40). The computed bloom frequencies have been regressed against the mean phosphorus concentration in each sample set. Figure 22 indicates strong linear correlations between total phosphorus and bloom frequency for both bloom criteria. These results further suggest a linear chlorophyll-a/phosphorus response in Agency Lake, consistent with a fixed N/P ratio (Figure 21).

Nutrient Balance Models

Nutrient-balance models predict lake nutrient concentrations based upon external nutrient loadings, morphometric factors, and hydrologic factors. A fundamental assumption in this type of model is that trophic response is controlled by external nutrient inputs, reservoir morphometry, and reservoir hydrology. Mass-balance calculations described in a previous section indicate that internal sources or recycling of nutrients triggered episodically by biological and chemical mechanisms are important in Agency Lake. A second assumption is that reservoir trophic state is at equilibrium or steady-state with respect to external nutrient inputs over time scales ranging from 6 months (growing season) to a year. Pronounced temporal variations in nutrient retention rates, lake nutrient concentrations, chlorophyll-a concentrations suggest that if an "equilibrium" condition exists in Agency Lake, it is a very dynamic one. A further difficulty is that empirical models are generally designed to predict response to phosphorus loading, whereas algal populations in Agency Lake appear to be limited by nitrogen and nitrogen levels are supplemented by nitrogen fixation.

Conditions in Agency Lake are far from ideal for application of empirical nutrient loading models. To the extent that they are based upon the fundamental principle of mass balance, however, loading models can be used to place bounds on reservoir response, given certain assumptions. Modeling objectives, assumptions, methods, and results are described below.

It is assumed that the objective of nutrient-balance modeling is to predict lake response to potential management strategies. Three potential management strategies are considered:

(1) Decrease in External Nutrient Loading. Spatial variations in flow-weighted-mean nutrient concentrations and loads at tributary monitoring stations (Figure 3) suggest anthropogenic impacts. These impacts might be at least partially offset by implementation of agricultural best management practices and/or other source-control measures. One approximate measure of anthropogenic impact is the difference between the combined flow-weighted-mean phosphorus concentration of 144 ppb for the inflows to Agency Lake, as compared with the 81 ppb concentration measured at the most upstream station on the Wood River and at Fourmile Creek (April-September values, 1991-1993, Table 3). Estimation of anthropogenic impacts on flow (and nutrient load) would require much more intensive monitoring, detailed analysis, and modeling of watershed hydrology. Accordingly, flows are assumed to be fixed and the model is applied to predict response to a 44% reduction in average inflow concentration (144 to 81 ppb) and external phosphorus load (23.8 to 13.3 metric tons. Results provide (a) estimates of reservoir conditions in the absence of anthropogenic phosphorus inputs; and (b) estimates of potential responses to watershed management or other measures designed to reduce external nutrient load. Design and modeling of specific watershed management measures is beyond the scope of this report.

(2) Increase in Water Elevation. Mean depth declines seasonally from ~2.4 to ~1 meter (Figure 6). Shallow depths are conducive to nutrient recycling and promote algal growth; increases in water level have been suggested as an appropriate measure for improving water quality in Upper Klamath and Agency Lakes (Klamath Tribe, 1994). As indicated in Figure 20, water depth is a factor is predicting nutrient retention and in predicting algal response to nutrients. A hypothetical increase of 30% in the average April-September pool volume and mean depth is simulated to provide indications of depth sensitivity. This corresponds approximately to maintaining typical spring pool elevations throughout the summer (Figure 6).

(3) Reduction of Internal Phosphorus Recycling. Mass-balance calculations indicate that internal recycling of phosphorus is important, particularly during early summer months. Theoretically, there are several potential mechanisms which would cause internal recycling to decrease in response to a decrease in external load and/or an increase

in water level. Treatment of sediments with alum or lime might also be effective in reducing phosphorus recycling (Cooke et al. ,1993). The model network is not designed for simulating mechanisms determining the effectiveness of these control methods; however, it can be used to predict, by mass-balance, lake response to assumed reductions in internal recycling. To place bounds on this effect, the model network is run with and without an internal recycling term initially calibrated to the 1991-1993 lake data.

The above cases have been represented in a matrix of 3 "Methods" and 4 "Scenarios". The Methods are different representations or models of phosphorus retention in Agency Lake:

(1) **Method A - Uncalibrated / "Typical Reservoir".** Response is predicted using a phosphorus retention model originally calibrated to CE reservoir data (Table 7) using low, median, and high estimates for sedimentation rate (90% confidence interval). This represents the expected response of a "typical" reservoir with phosphorus retention predicted based upon inflow Total P concentration, inflow Ortho P/Total P ratio, mean depth, and hydraulic residence time. In this case, phosphorus retention and recycling would be typical of other reservoirs with similar inflow concentrations, morphometry, and hydrology. This method substantially under-predicts phosphorus levels in Agency Lake because it does not account for the unusually high rates of internal recycling. From a management perspective, Method A provides an indication of reservoir response if chemical treatment or other manipulations (increases in pool level, reduction in external load) were effective in substantially reducing internal phosphorus recycling.

(2) **Method B - Calibrated using Sedimentation and Internal Loading Terms.** The phosphorus retention model is calibrated to predict the observed seasonal mean phosphorus concentration in Agency Lake (mean = 255 ppb, standard error = 29 ppb). Calibration is achieved by setting the sedimentation term to zero (treating external phosphorus loads as conservative in the lake) and specifying an additional "internal" phosphorus source of 1.78 mg/m^2-day (calibrated value). These terms are held fixed in simulating the Scenarios described below.

(3) **Method C - Calibrated using a Constant Scale Factor.** A scale factor of 2.51 is applied to the phosphorus concentration predicted by Method 1, so that the predicted concentration matches the observed concentration of 255 ppb. This assumes that the "typical" reservoir response is amplified by a constant factor which reflects internal loading or other unspecified mechanisms. The factor is held fixed in simulating the Scenarios described below.

Methods B and C represent the two methods which are available in BATHTUB for calibrating the phosphorus retention model to data from a specific reservoir. These represent alternative assumptions; lack of modeling studies documenting modelled responses to changes nutrient loading precludes identification of the "best" calibration procedure. Results discussed below are insensitive to these assumptions (i.e. results for Methods B and C are similar).

Four Scenarios represent different management strategies in a factorial design:

(1) **Scenario 1** - Existing Conditions (1991-1993 average)

(2) **Scenario 2** - 44% decrease in external phosphorus load

(3) **Scenario 3** - 30% increase average pool volume

(4) **Scenario 4** - 44% decrease in external phosphorus load and 30% increase in average pool volume

Table 10 summarizes flow and nutrient inputs for the modeled period (April-September, 1991-1993 average). Model inputs and outputs for each Method and Scenario are listed in Table 11. Figure 23 shows predicted phosphorus, mean chlorophyll-a, and bloom frequencies.

Discussion

Differences between the uncalibrated (Method A) and calibrated (Methods B,C) account for most of the variance among predictions. This reflects the strong influence of internal phosphorus recycling on the trophic state of Agency Lake. Under 1991-1993 conditions (Scenario 1), Method A predicts a mean total phosphorus concentration of 102 ppb (90% confidence interval = 81 to 122 ppb) and mean chlorophyll-a concentration of 30 ppb (90 % c.i. = 23 to 37 ppb). These are estimates of "typical" responses of a reservoir with external nutrient loadings, hydrology, and morphometry identical to those measured in 1991-1993. The importance of internal phosphorus recycling is indicated by comparing these predictions with the 1991-1993 observed values or with results predicted by the calibrated models (Total P = 255 ppb, Mean Chlorophyll-a = 78 ppb). Generally, predictions using calibration Methods B and C are similar for all four Scenarios.

Scenario 2 predicts lake conditions with a 44% reduction in external phosphorus load. This is intended to reflect lake conditions in the absence of anthropogenic phosphorus loads, using the concentration at Dixon Road (81 ppb) as an estimate of unimpacted lake inflow concentration. Method A predicts a mean phosphorus concentration of 67 ppb (90% c.i. = 55 to 77 ppb) and mean chlorophyll-a concentration of 18 ppb (90% c.i. = 14 to 22 ppb) in the absence of excessive internal recycling. This suggests that Agency Lake was eutrophic under natural or unimpacted conditions, but chlorophyll-a concentrations were below the classical hyper-eutrophic boundary (25-30 ppb, NALMS, 1988). Methods B and C predict much higher phosphorus levels (168-180 ppb) and chlorophyll-a levels well into the hypereutrophic range (70-72 ppb). This suggests a naturally hypereutrophic state, if phosphorus recycling rates were also high before watershed development occurred. Similarly, if a 44% reduction in external phosphorus loads were accomplished and if the current recycling rates were to continue, a decrease in trophic state from hypereutrophic to eutrophic would not be expected.

Results for Scenarios 3 and 4 suggest that a 30% increase in volume (depth) would result in relatively small decreases in phosphorus and chlorophyll-a concentrations. As for Scenarios 1 and 2, differences between Methods A and B/C are pronounced.

Based upon these results, excessive internal recycling is the primary factor driving hypereutrophic conditions in Agency Lake. It would be a mistake to conclude, however, that implementation of watershed nutrient controls or raising pool elevation would not have significant beneficial impacts. It is possible, if not likely, that decreases in external load or increases in depth would cause a decrease in internal phosphorus recycling, via the following mechanisms:

(1) Higher pool levels would decrease wind-induced turbulence at the sediment-water interface and thereby decrease sediment resuspension and other vertical phosphorus fluxes controlled by transport processes. Because Agency Lake is at the lower end of the CE model development data set with respect to depth (Table 6), these mechanisms may not be reflected in empirical phosphorus retention model.

(2) Strong correlations among pH, chlorophyll-a, and phosphorus releases from bottom sediments (Figure 16) suggest that recycling is enhanced by high photosynthesis rates. Conversely, recycling would be expected to decrease in response to a decrease in algal productivity. This important feedback loop is not represented in the model.

(3) A portion of the recycled phosphorus may enter the lake during runoff events in the form of particulates rich in available phosphorus (characteristic of runoff from animal holding pens, for example). These materials may settle on the lake bottom and release nutrients to the water column following decomposition. Potential benefits of

reducing these particulate inputs (in both winter and summer months) are not reflected in the model.

None of the above mechanisms are directly reflected in model predictions using calibration Methods B and C. With reductions in external load and/or increases in pool level, these mechanisms may cause a drift towards predictions generated by Method A. Direct modeling of these mechanisms is not possible with existing models, but may be feasible with substantial additional data-collection and modeling effort. Such an effort would dynamic modeling of water-column and sediment compartments at a time step no longer than one month.

The positive feedback loop inherent in the phosphorus recycling mechanism (i.e., phosphorus --> algae --> high pH --> more phosphorus --> more algae, etc.) poses an important chicken-or-egg type question. Once it is operating, this mechanism accelerates Agency Lake algal booms in early summer. Periods of negative phosphorus retention are associated with pH levels above ~9.4 and chlorophyll-a concentrations above ~40 ppb. It is possible, if not likely, that initiation of this process requires elevated lake phosphorus concentrations in Spring. Lake phosphorus concentrations must be high enough at the start of the growing season to generate the initial algal bloom which triggers phosphorus releases from bottom sediments and further accelerates the bloom during summer. This (albeit hypothetical) sequence of events may be important to understanding the linkage between the trophic state of Agency Lake and external nutrient inputs.

As a consequence of linkages between external and internal nutrient sources discussed above, algal populations in Agency Lake may be more sensitive to external loads than predicted by the model. This is further supported by observed differences in response between 1992 (dry year) and 1993 (wet year):

	1992	1993
Net Inflow (hm^3)	96	206
External P Load (mtons)	18.6	34.9
P Retention (mtons)	.8	-5.7
Lake P - April (ppb)	82	133
Mean Chl-a (ppb)	66	86
Frequency > 60 ppb	43%	58%
Frequency > 100 ppb	29%	43%

The lower external phosphorus load in 1992 was accompanied by a less internal recycling (more retention, 0.8 vs. -5.7 mtons) and a lower April phosphorus concentration. Although mean chlorophyll-a concentrations were not statistically different, algal blooms in the relatively dry summer of 1992 were less pronounced and shorter than those observed in the relatively wet summer of 1993 (see time series plots in Appendix A). These yearly differences cannot be successfully predicted with the existing model network, probably because of the network does not include the mechanistic linkages or feedback loops discussed above.

As discussed above, approximately 44% of the external load (Scenario 2) is attributed to anthropogenic impacts. On an annual basis, this corresponds to an anthropogenic load of 23 metric tons. This is a relatively small quantity relative to the phosphorus contained in animal waste generated in the watershed each year. The cattle population is estimated to exceed 75,000 (Kann, J., Personal Communication, 1995). At a phosphorus-equivalent of 17.6 kg/animal/year (Omernik, 1978), the cattle population generates more than 1,320 metric tons of phosphorus per year. The anthropogenic load reaching the lake (23 metric tons) amounts to less than 2% of the phosphorus contained in animal waste. Apparently, most of phosphorus in animal waste is retained in watershed soils or exported as crops. The fact that a small percentage of the animal waste is equivalent to the entire anthropogenic load reaching the lake reflects the potential sensitivity of the lake to agricultural practices. Even if adequate protection measures existed on most of the grazing lands, the load from only a few locations with inadequate protection measures could account for most of the anthropogenic impact. Examples of such locations would include holding areas or farmsteads discharging runoff directly into major tributaries and unfenced range lands allowing cattle access to streams. From a control perspective, this situation is desirable because it suggests that high percentage of the existing anthropogenic load might be controlled by applying control measures to relatively few source areas. Such areas could be identified in watershed inspections and areal photos.

Limitations in the data should also be considered in interpreting model results. The major limitation is the lack of continuous flow data at the mouth of each tributary. Although low variance in the concentration data suggests that the monthly sampling frequency is adequate for calculating loads, this could be misleading if significant loading events occurred between sampling dates. The estimated average phosphorus load from Sevenmile canal (~6 metric tons in April-September, 1991-1993) is ultimately based upon only 7 paired instantaneous flows and grab samples. More intensive flow and concentration data are needed to develop more reliable load estimates. Automated sampling equipment may be needed to capture loads generated by pumping events. Direct monitoring of runoff from the ungauged area on the west side of the lake below the Fourmile Canal station (Figure 2) is also recommended.

Given the above data limitations, it is possible external loads have been under-estimated. Phosphorus retention/recycling has been estimated by difference from lake inputs, outflows, and storage terms. If external loads have be under-estimated, the relative importance of internal nutrient recycling would be diminished and the potential benefits of external load reductions would be greater than those estimated above.

Conclusions & Recommendations

1. Based upon its morphometric and hydrologic features, Agency Lake is an ideal environment for algal growth.

2. Based upon phosphorus, chlorophyll-a, organic nitrogen, and other measures of trophic state, Agency Lake is hypereutrophic.

3. Nutrient mass-balance calculations indicate that there is no net phosphorus retention in Agency Lake on an annual-average basis. Internal sources of nitrogen approximately equal external sources on an annual-average basis.

4. Substantially negative retention rates are indicated for both phosphorus and nitrogen during the growing season. Negative phosphorus retention rates are highly correlated with pH and chlorophyll-a. These tend to occur in the early summer and are likely to reflect release of iron-bound phosphorus from lake bottom sediments during periods of photosynthetically-elevated pH. Negative nitrogen retention rates are likely to reflect fixation of atmospheric nitrogen by bluegreen algae.

5. Based upon the observed low nitrogen/phosphorus ratios in the water column, algae populations appear to be limited by nitrogen. Because of the high rates of nitrogen fixation, however, nitrogen concentrations are self-regulating and phosphorus is likely to be the ultimate limiting nutrient. Empirical trophic response models developed for Corps of Engineer (CE) reservoirs indicate an approximately linear chlorophyll-a/phosphorus response. This is further supported by linear relationships between summer phosphorus concentration and algal bloom frequency developed from Agency Lake data. Because of the shallow depth and dominance by flake-forming algae, light limitation is unimportant.

6. Application of empirical trophic response models to Agency Lake indicates that relationships between observed nutrient concenrations and measures of trophic response (chlorophyll-a, transparency, organic nitrogen, total P - ortho P) are consistent with data from CE reservoirs. As a consequence of dominance by flake-forming algae, downward adjustment of the model coefficient representing light extinction per unit of chlorophyll-a was necessary to calibrate the model network to Agency Lake.

7. Based upon comparison of flow-weighted-mean phosphorus concentrations measured at various watershed monitoring stations, a increase in lake inflow concentration from 81 ppb to 144 ppb (44%) is one estimate of anthropogenic impact on Agency Lake.

8. Because of the importance of internal nutrient recycling and role of nitrogen limitation, empirical nutrient loading models can be used in a limited way to evaluate benefits of nutrient management, water-level management, or other water quality control measures. Potential linkages between external and internal sources are not reflected in existing empirical models. For this reason, projections have been made for a range of assumed internal recycling rates.

9. The model has been used to predict lake response to various management scenarios, including existing conditions, a 44% reduction in external phosphorus load, and 30% increase in average summer volume and mean depth. A high sensitivity to internal recycling rates is indicated for all scenarios. Without anthropogenic loads (44% reduction), chlorophyll-a levels would range from eutrophic to hypereutrophic, depending upon whether the existing high rates of phosphorus recycling are maintained. A 30% increase in volume/depth would result in relatively small improvements. Actual improvements in water quality resulting from these scenarios may be substantially greater than those predicted by the model because the model does not directly simulate mechanisms linking the external and internal nutrient sources.

10. The modeling concept is useful for examining lake monitoring data in light of empirical relationships developed from other reservoir data sets. This provides useful insights on factors controlling eutrophication under existing conditions. Diagnostic insights gained through mass-balance calculations (model independent) are also useful.

11. In a predictive mode, the modeling effort is limited by (a) the extreme conditions in Agency Lake relative to the CE model development data set (shallow depth, high internal cycling rates, high chlorophyll-a concentrations, extreme nitrogen limitation) (b) the requirement for substantial recalibration of the phosphorus retention model; (c) lack of an independent data set (from a different time period, for example) to test the phosphorus calibration; and (d) the wide divergence of responses predicted for different assumptions regarding phosphorus recycling and nitrogen responses. For these reasons, model predictions are not definitive and should be interpreted cautiously.

12. The estimated anthropogenic phosphorus load corresponds to less than 2% of the phosphorus contained in waste from the watershed's cattle population. This suggests that targeting controls in potent source areas may be effective in reducing lake loads. Based upon watershed reconnaissance, potent source areas would include animal holding areas adjacent to streams and unfenced range adjacent to streams.

13. The low intensity of flow and concentration measurements at tributary stations is the major data limitation possibly influencing the mass-balance calculations and model results. More intensive data collection is recommended in the future, if more accurate modeling results are needed or if the data are to be used for identifying important nutrient source areas. More accurate watershed delineations and land use inventories would also be useful.

14. Refinements to the mass balances and model calibrations could be developed within the constraints of historical data and other ongoing monitoring programs. Expansion of the model scope to include the entire Upper Klamath basin and additional years of monitoring data (1989-1994 vs. 1991-1993 analyzed here) would provide an improved basis for calibrating the trophic response models, evaluation of interactions between Upper Klamath and Agency Lakes, and a means for testing water budgets, based upon comparison of observed and predicted lake outflows.

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List of Figures

Figure 1
Regional Map

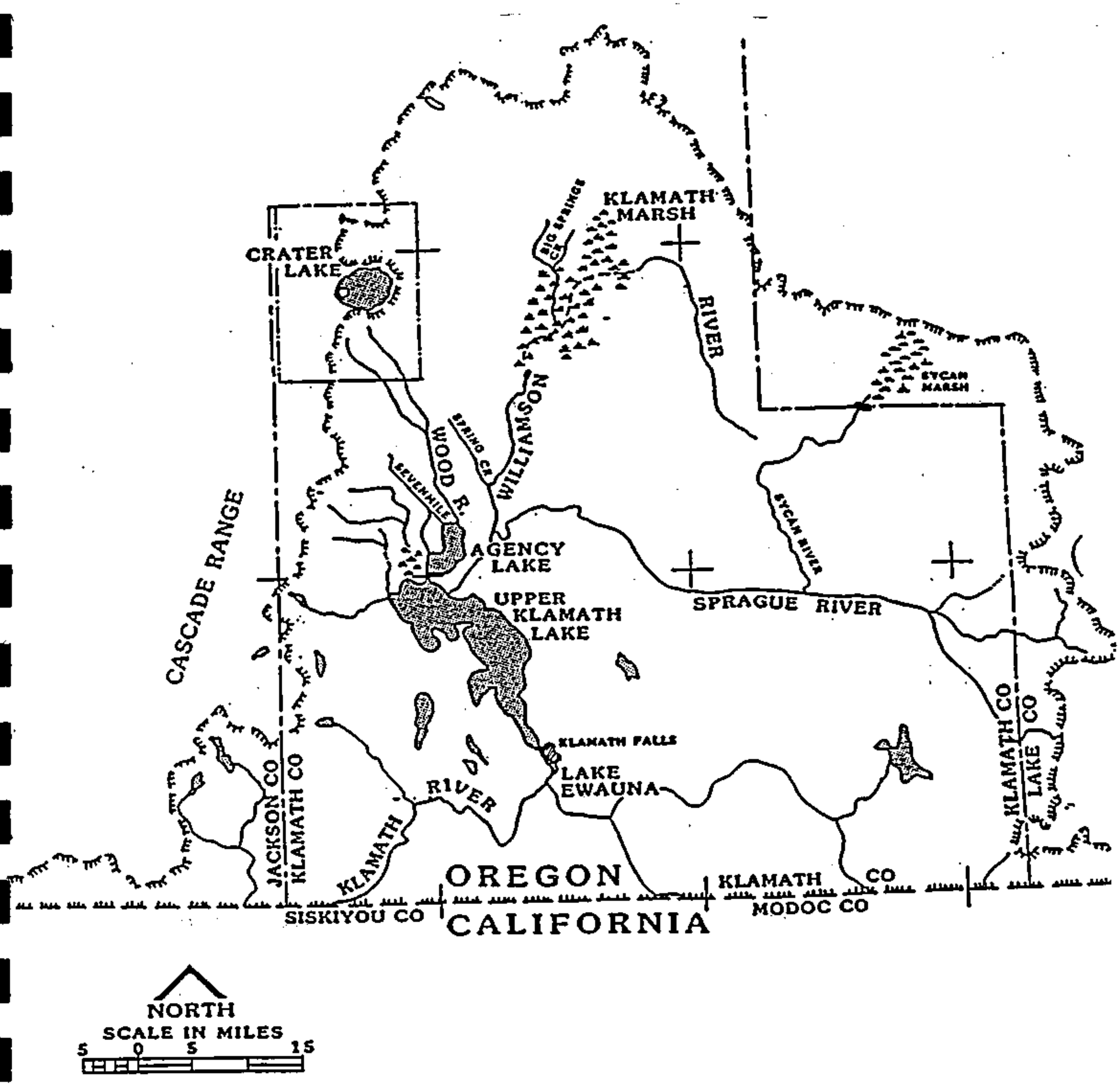
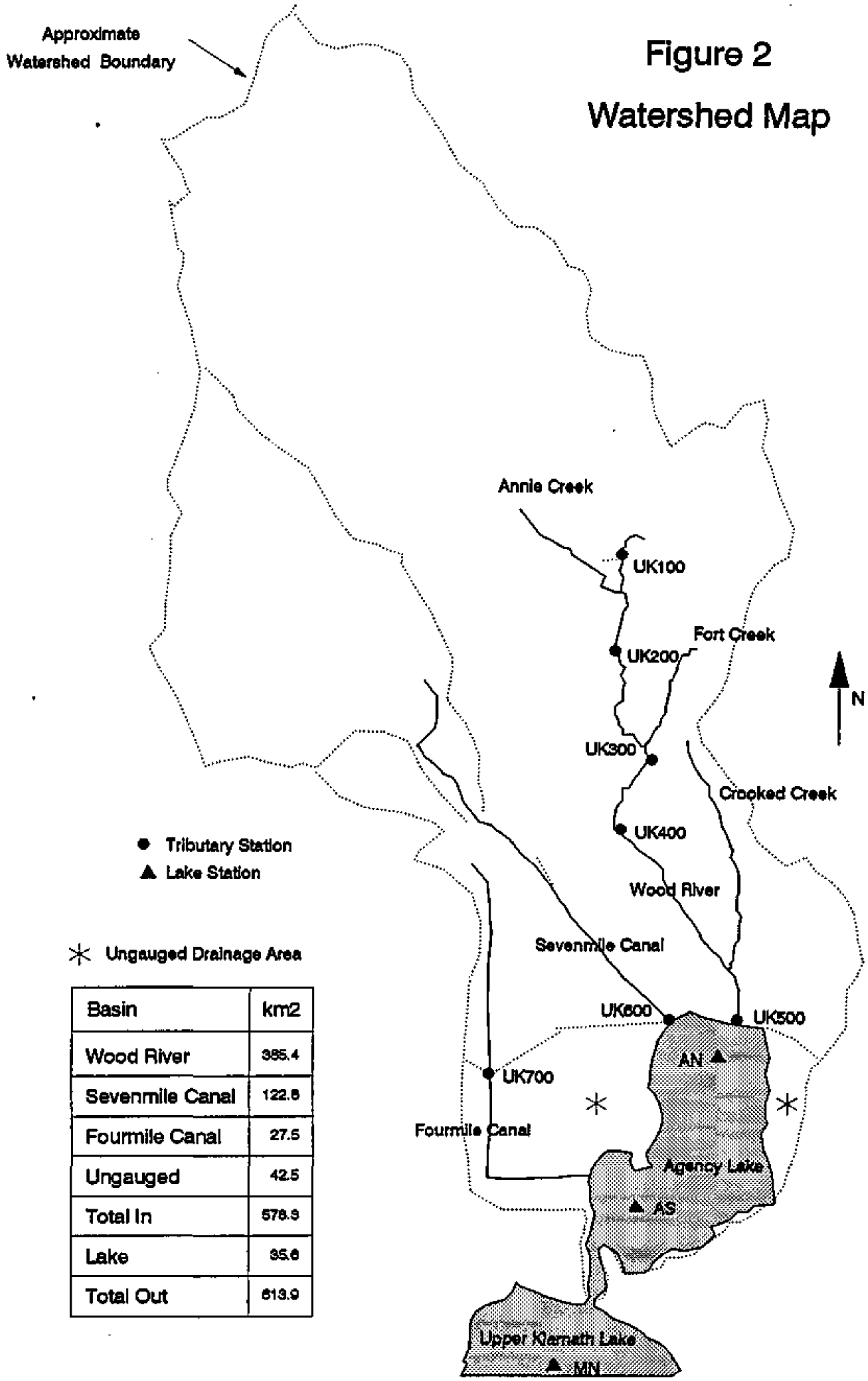


Figure 2
Watershed Map



Basin	km2
Wood River	385.4
Sevenmile Canal	122.6
Fourmile Canal	27.5
Ungauged	42.5
Total In	578.3
Lake	35.6
Total Out	613.9

Figure 3
Average Flows, Fluxes, & Flow–Weighted–Mean Concentrations
April–September, 1991–1993

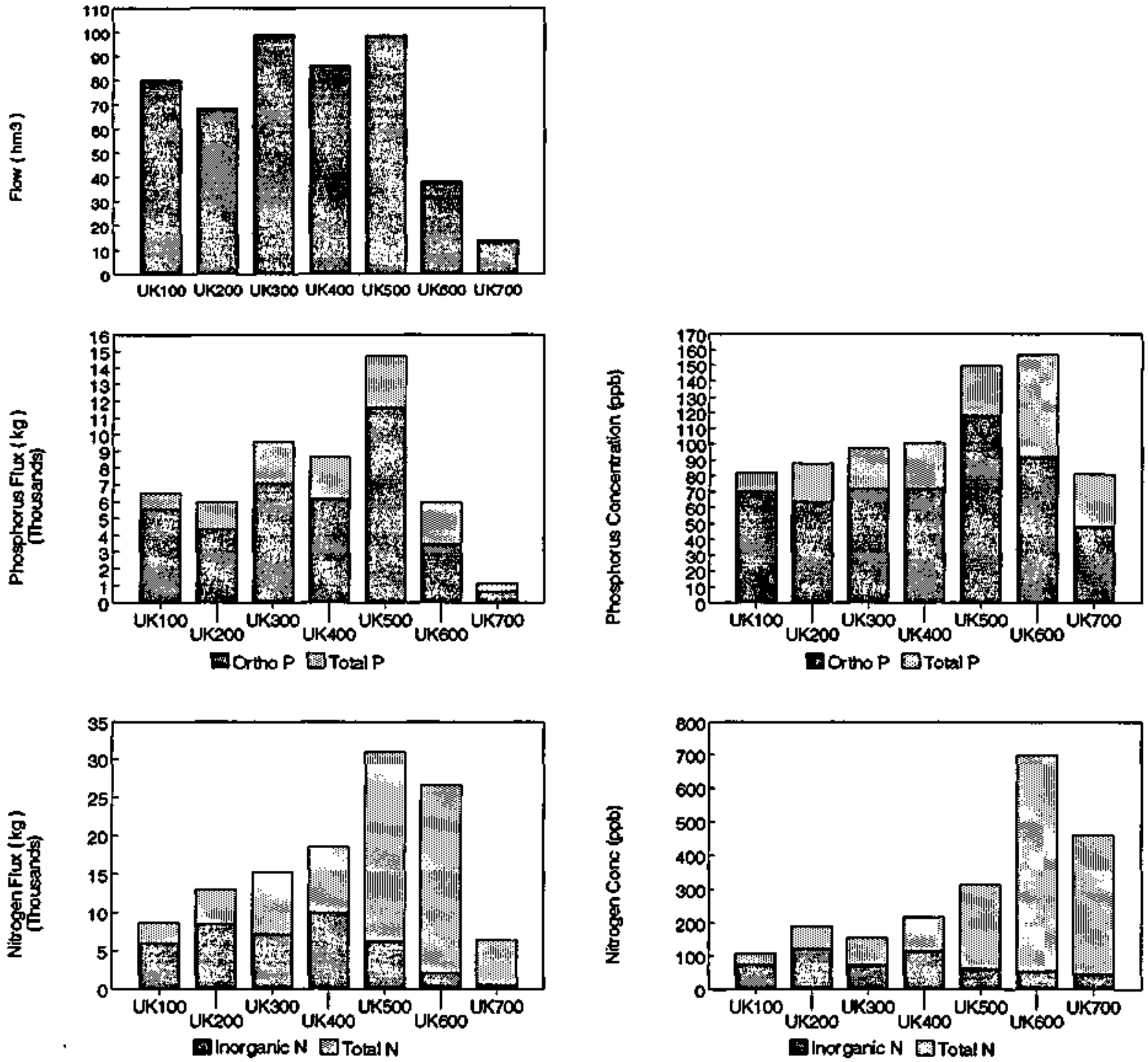
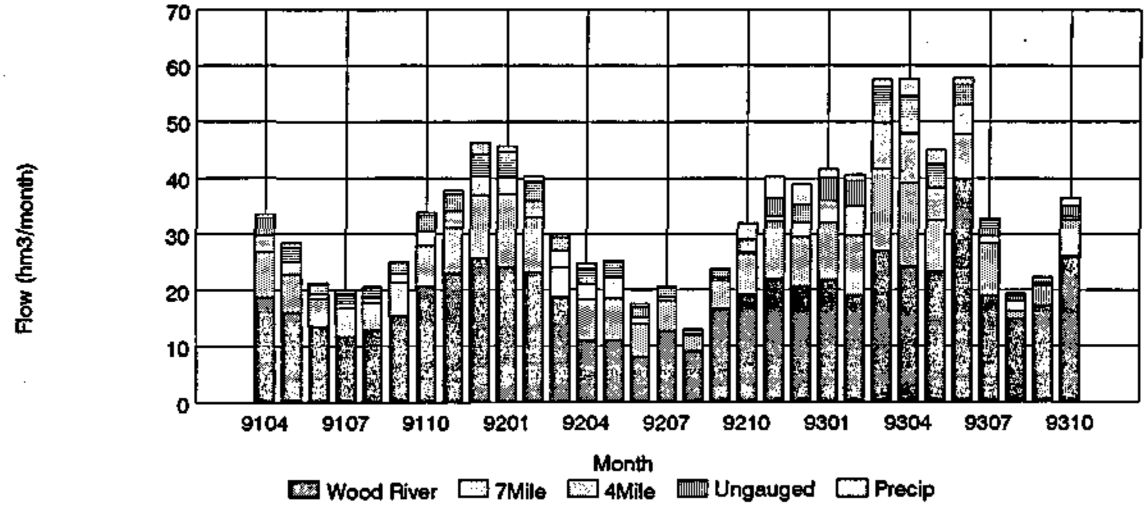
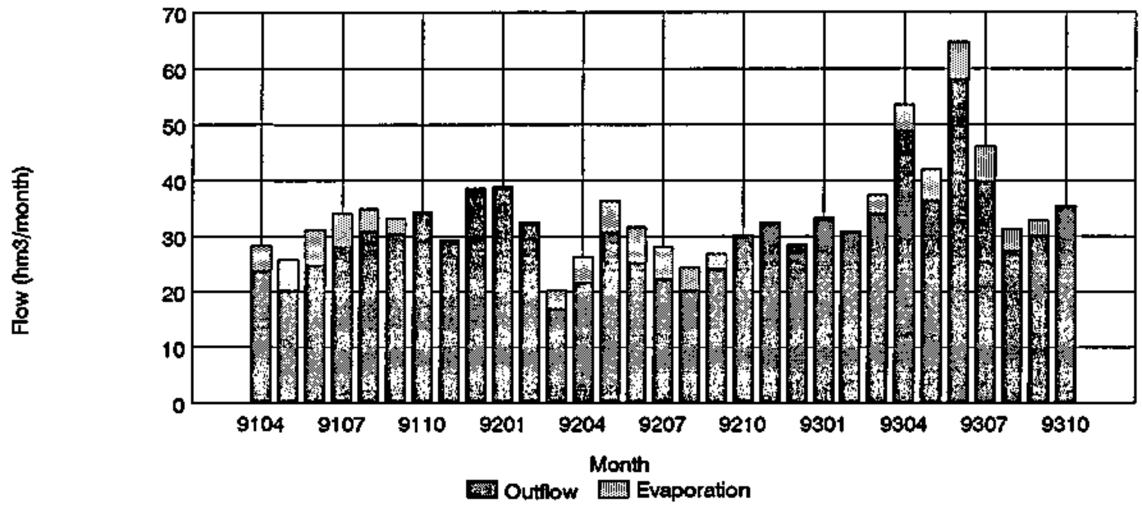


Figure 4
Monthly Water Balance





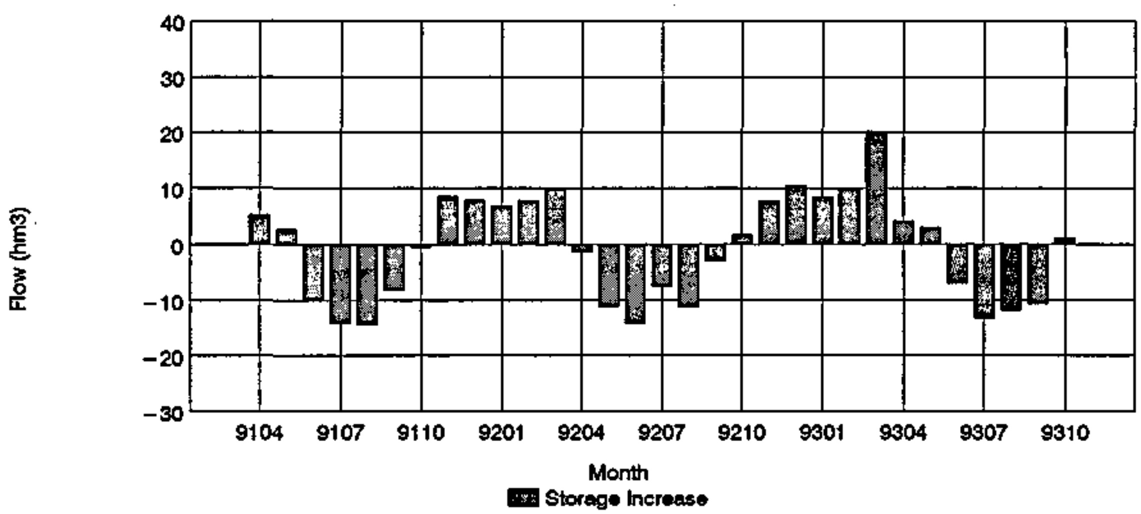
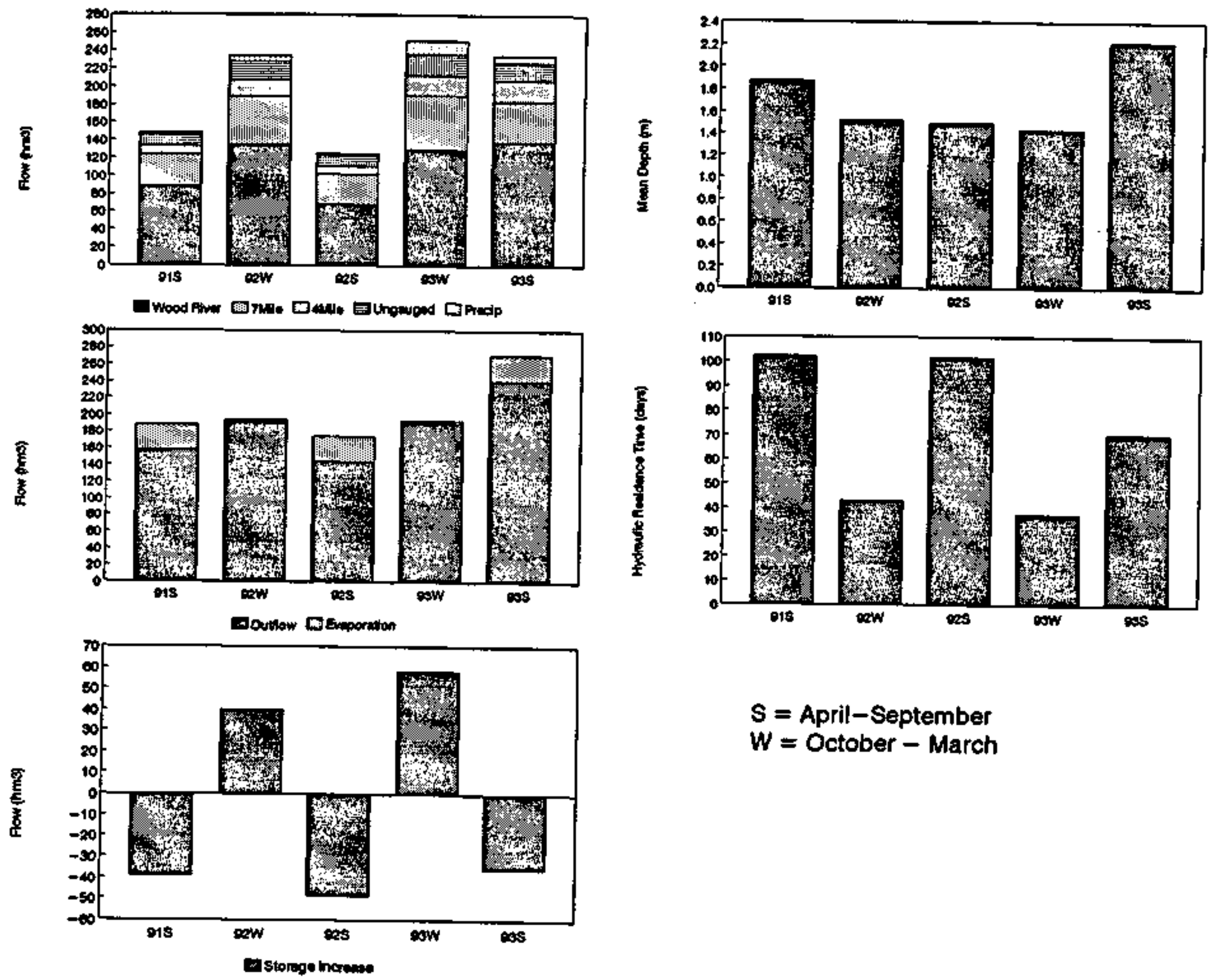


Figure 5
Seasonal Water Balance



S = April–September
W = October – March

Figure 6
Monthly Inflow, Outflow, and Morphometry

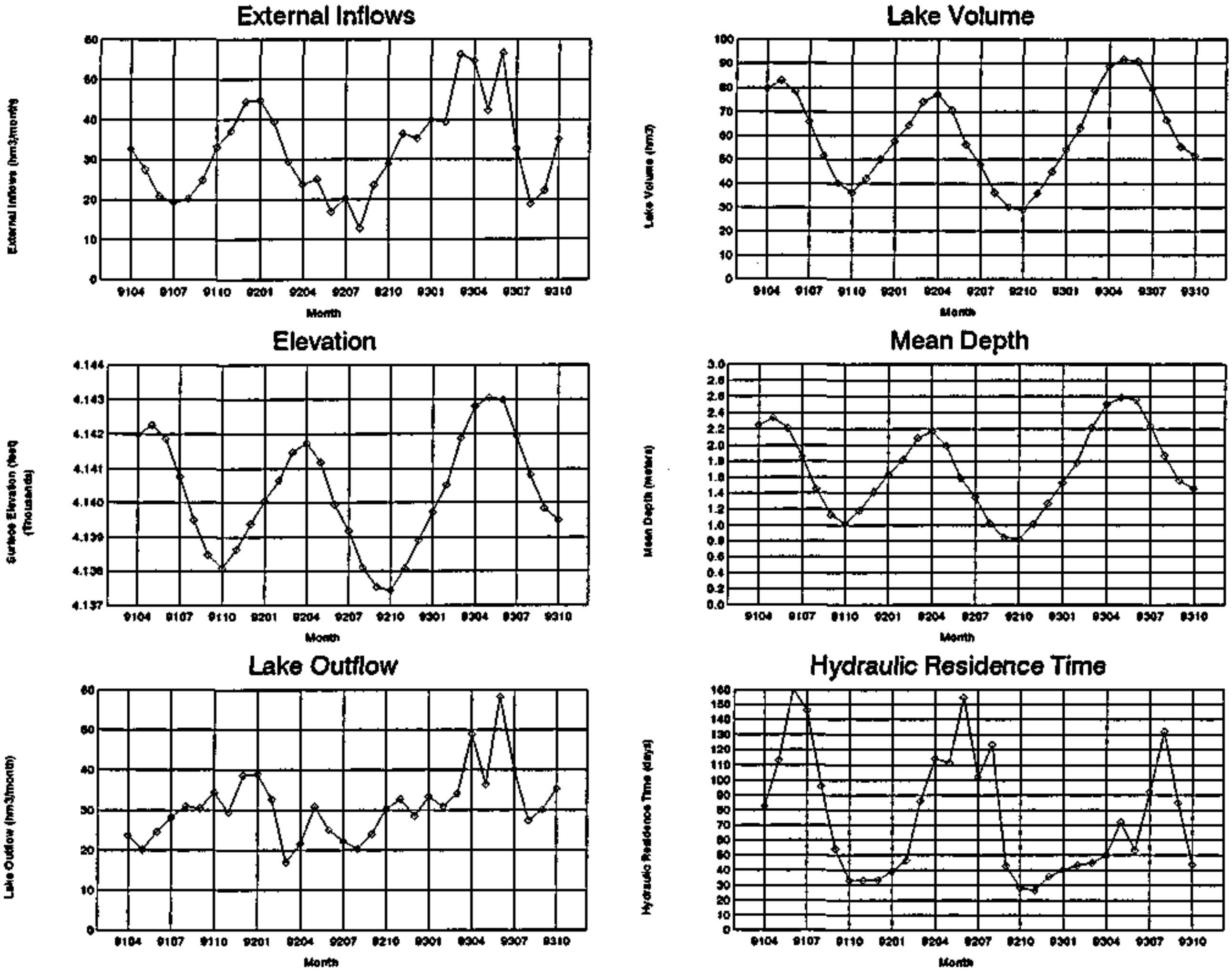
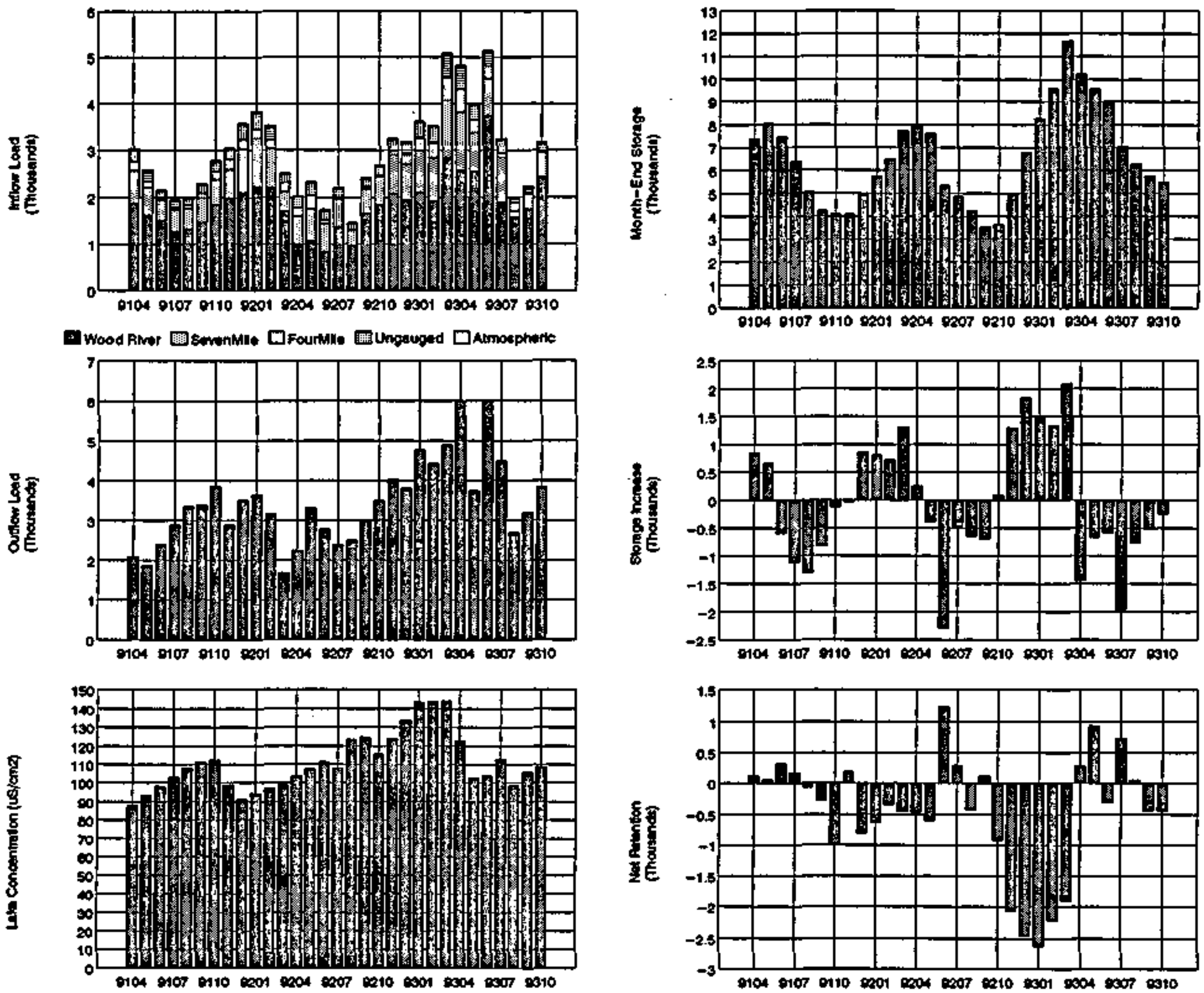


Figure 7
Monthly Mass Balance

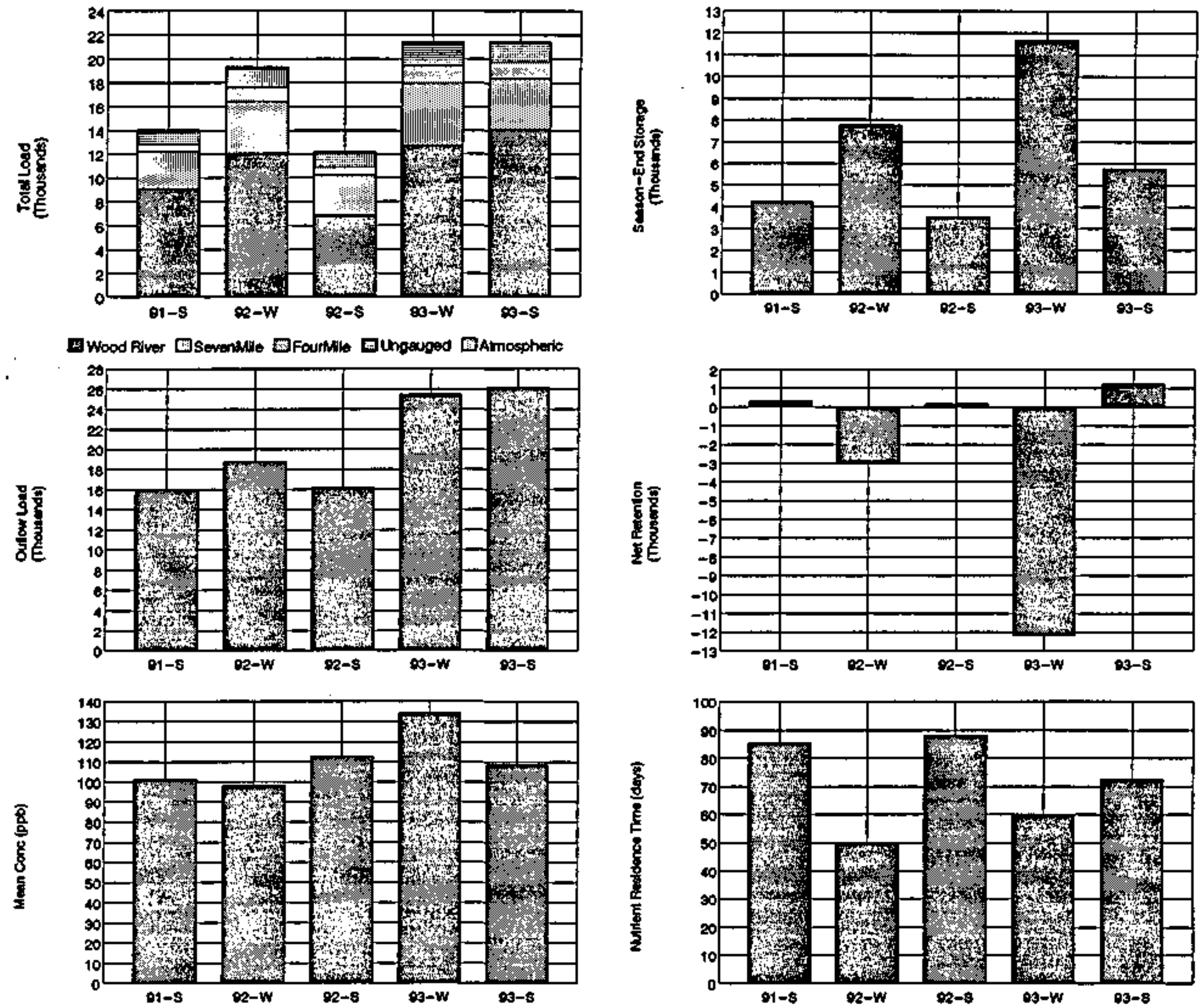
Variable: Conductivity



Mass Balance Terms in uS/cm2 * hm3

Figure 8
Seasonal Mass Balance

Variable: Conductivity



Mass Balance Terms in uS/cm2 * hm3

S = April-Sept, W = Oct-March

Figure 9
Cumulative Mass Balance

Variable: Conductivity

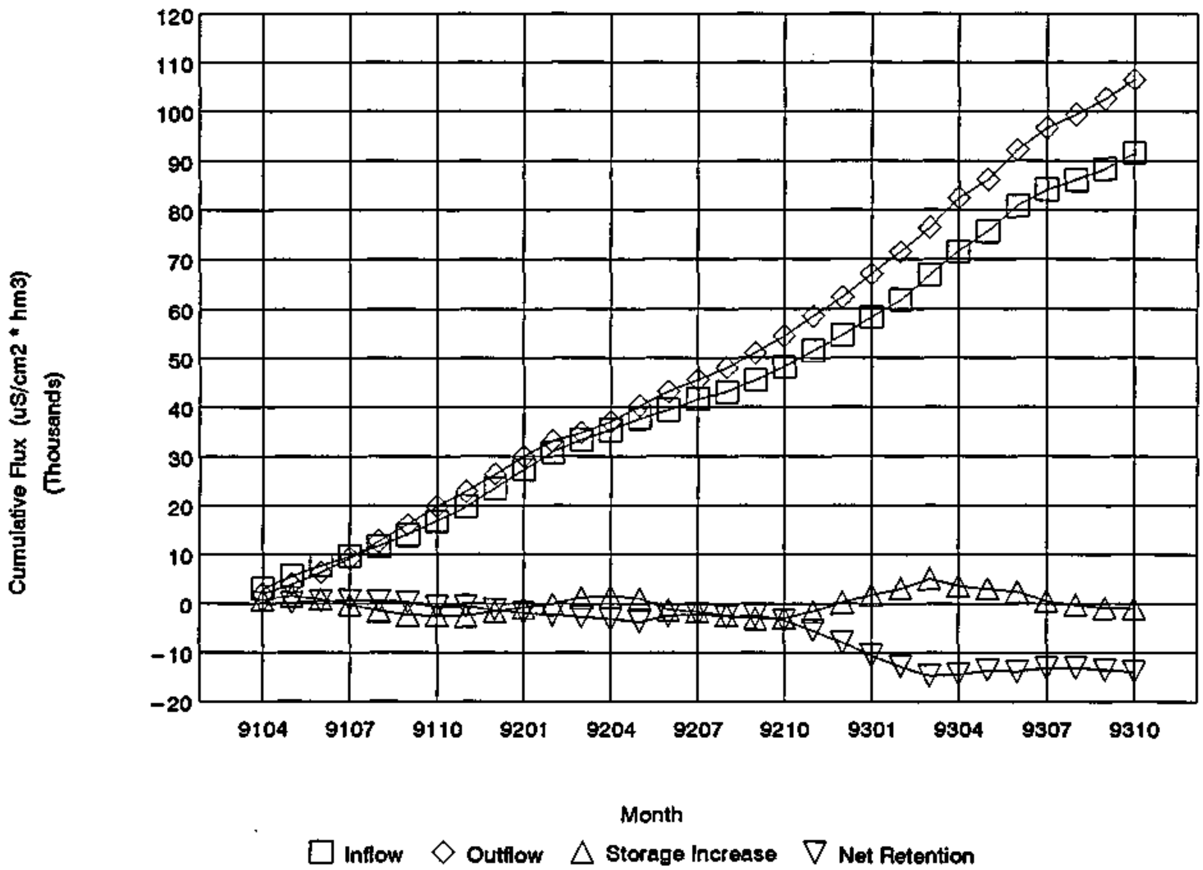
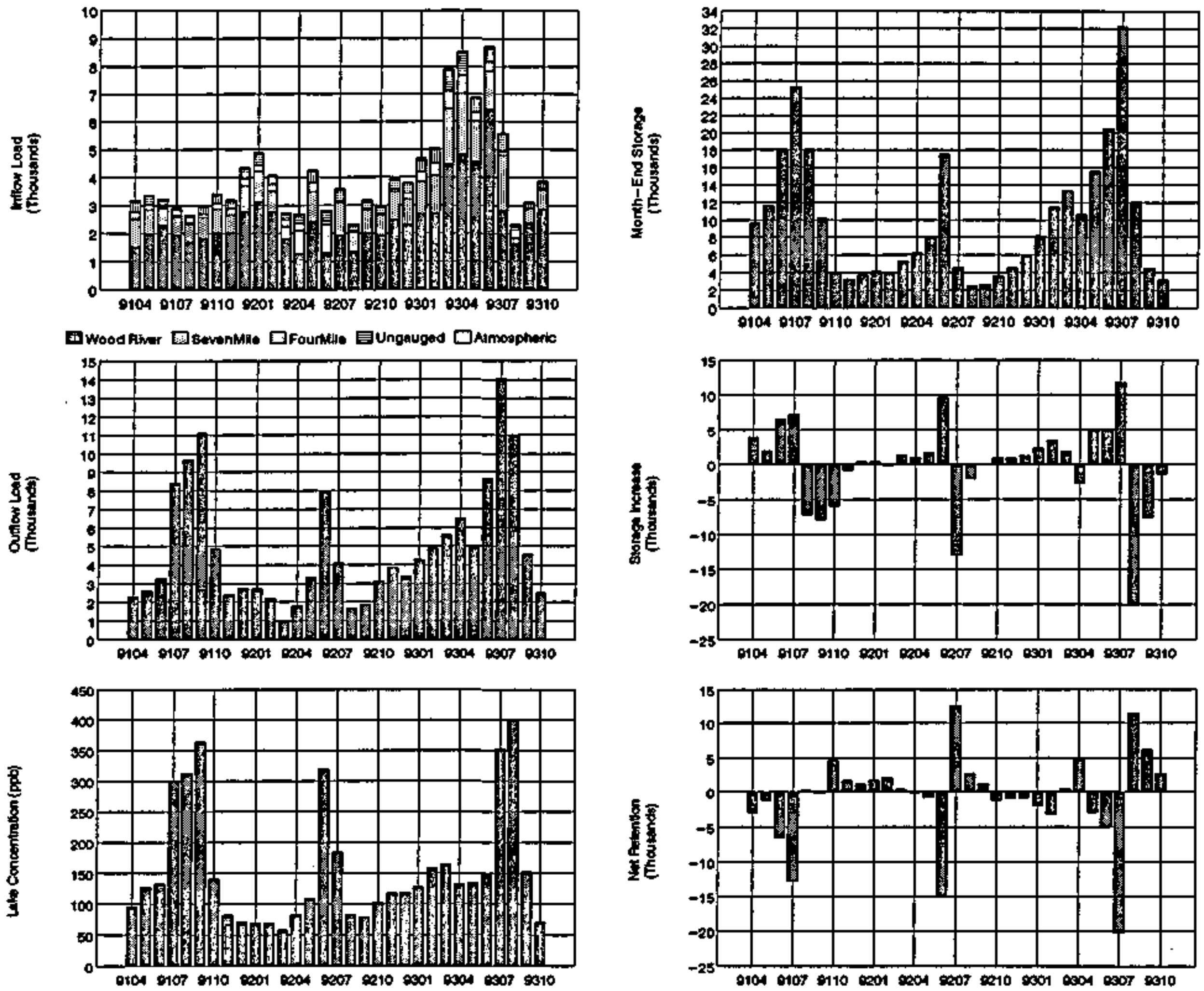


Figure 10
Monthly Mass Balance

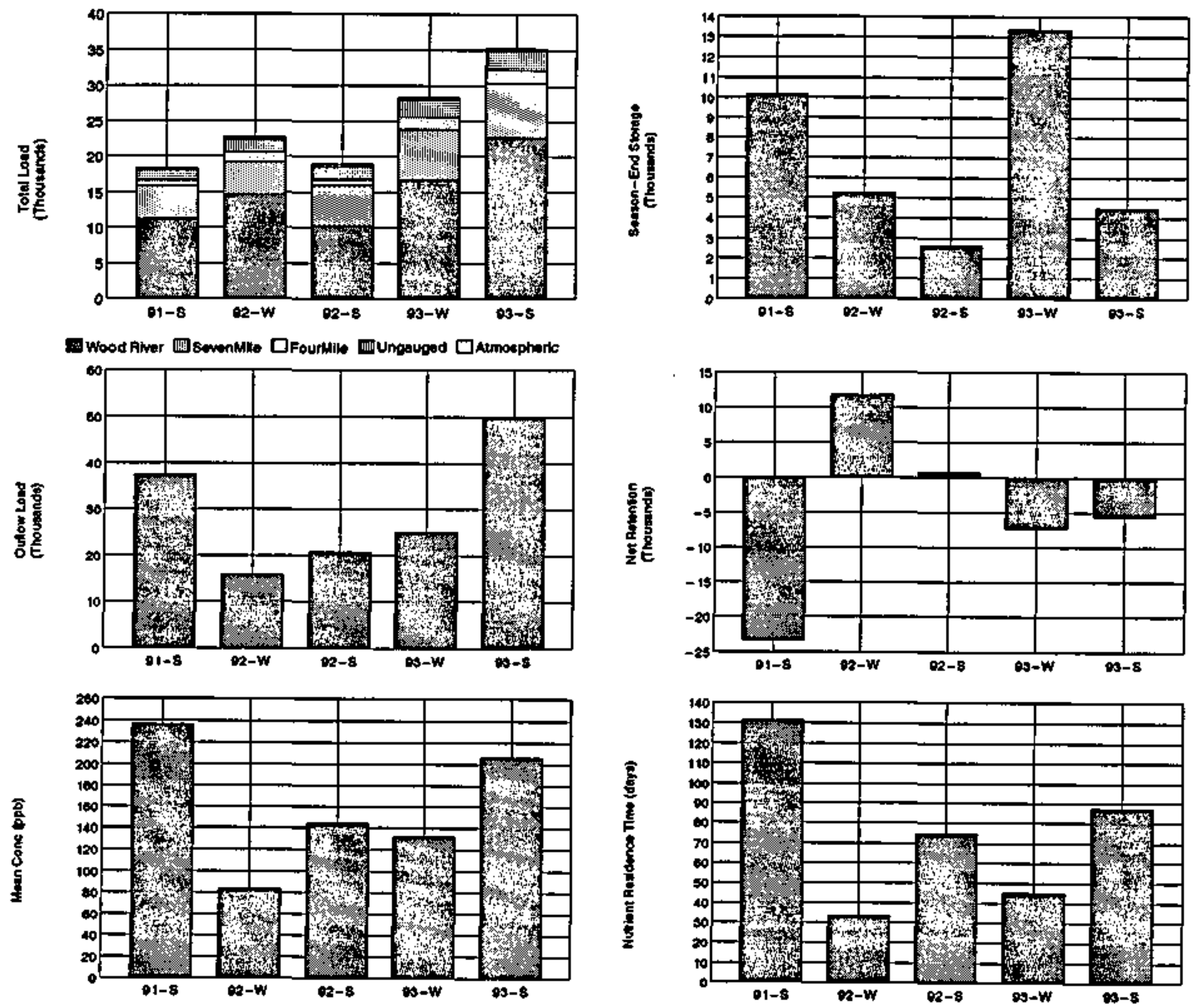
Variable: Total Phosphorus



Mass Balance Terms in Kg/Month

Figure 11
Seasonal Mass Balance

Variable: Total Phosphorus



Mass-Balance Terms in Kg S = April-Sept, W = Oct-March

Figure 12
Cumulative Mass Balance

Variable: Total Phosphorus

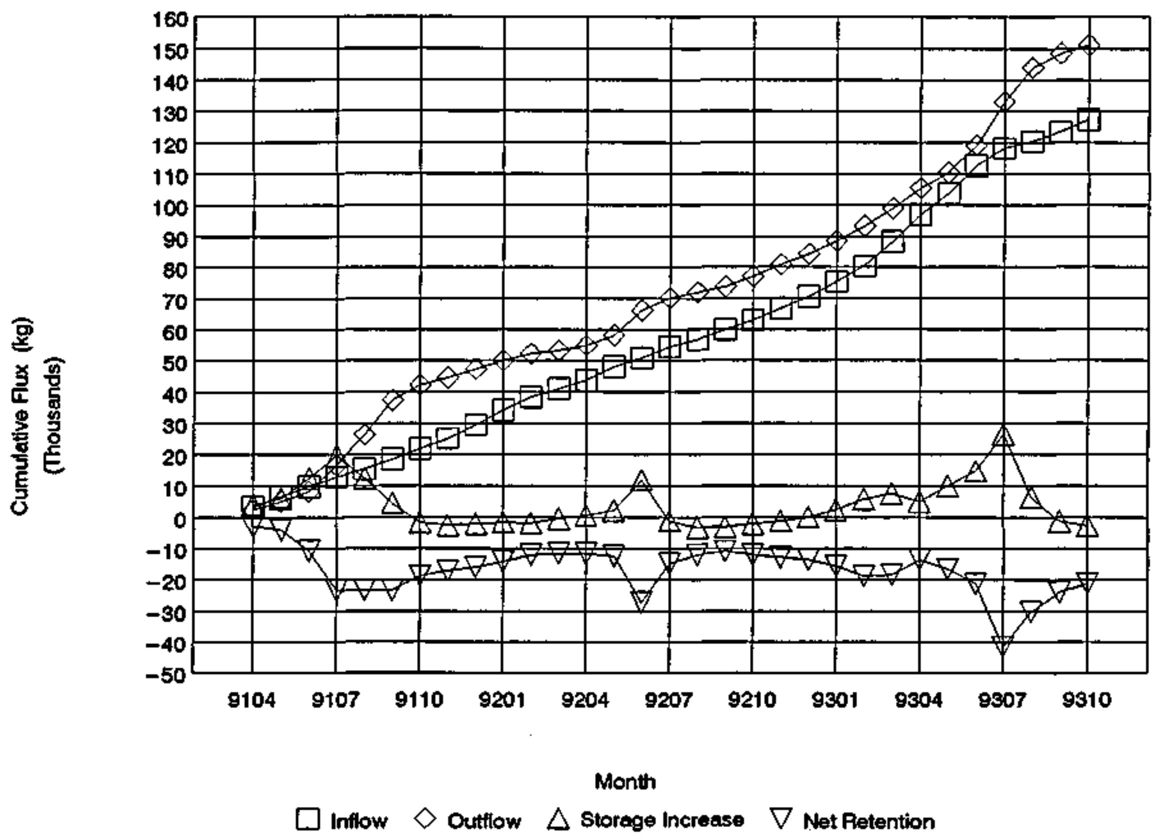
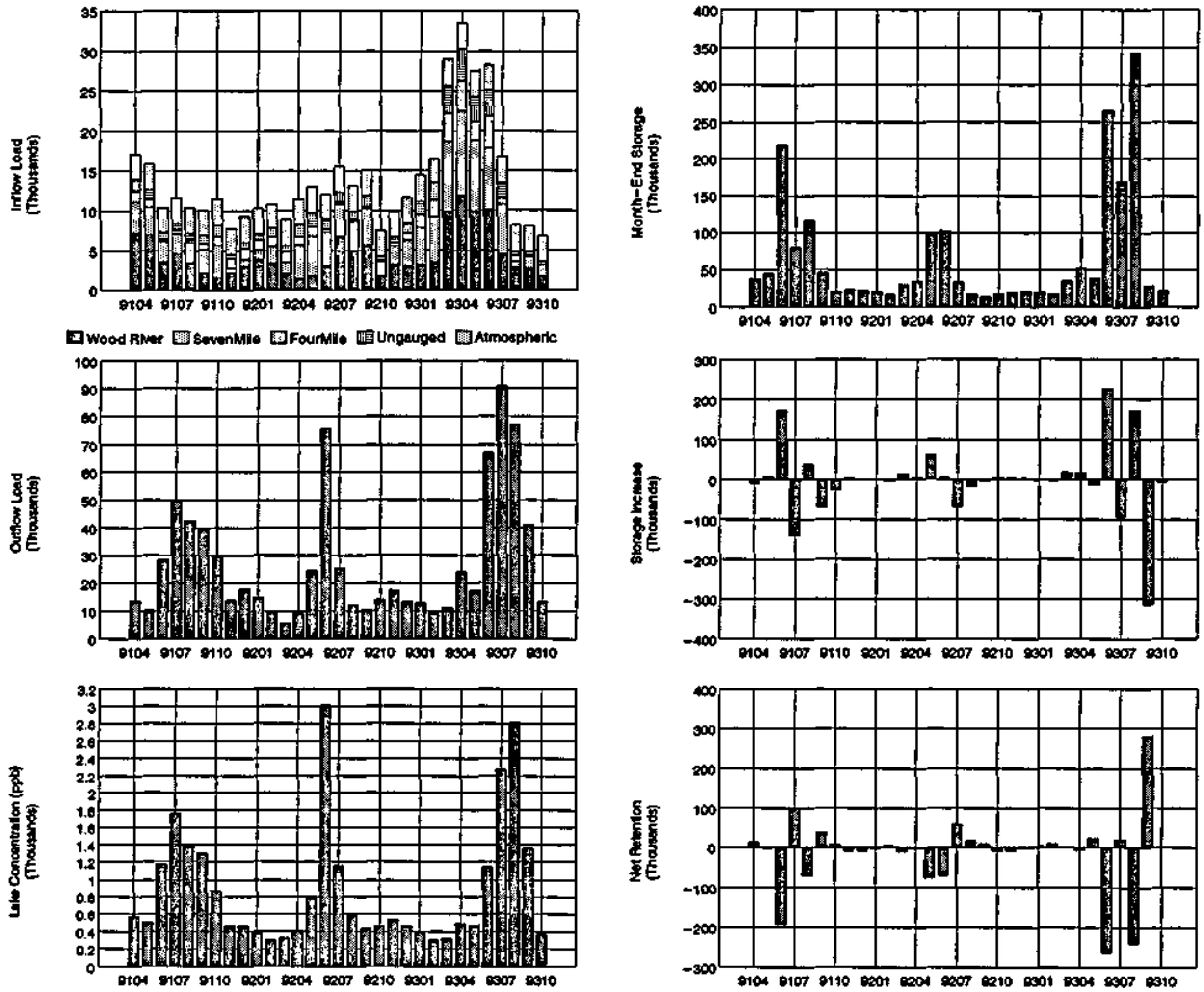


Figure 13
Monthly Mass Balance

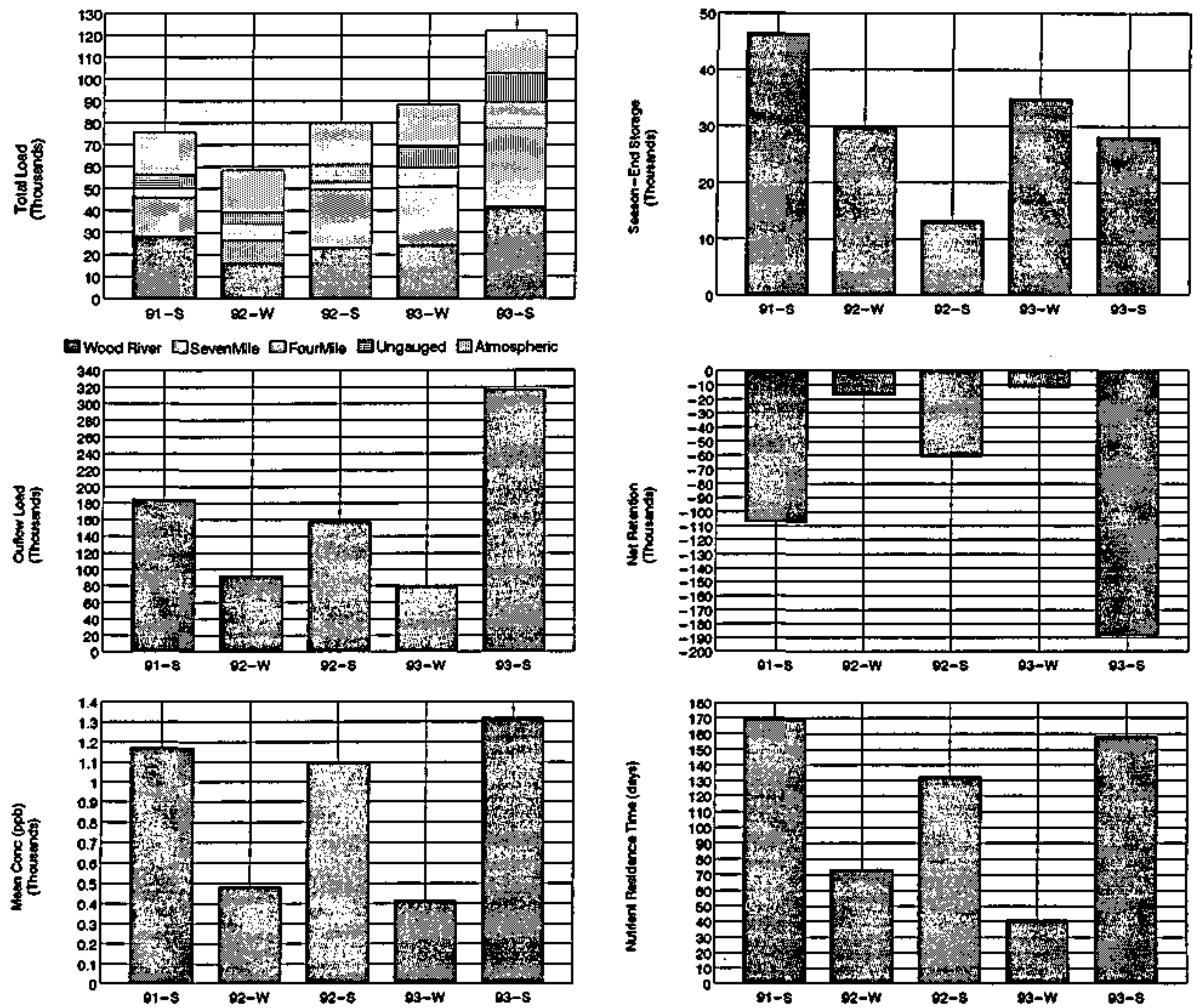
Variable: Total Nitrogen



Mass Balance Terms in Kg/Month

Figure 14
Seasonal Mass Balance

Variable: Total Nitrogen



Mass-Balance Terms in Kg S = April-Sept, W = Oct-March

Figure 15
Cumulative Mass Balance

Variable: Total Nitrogen

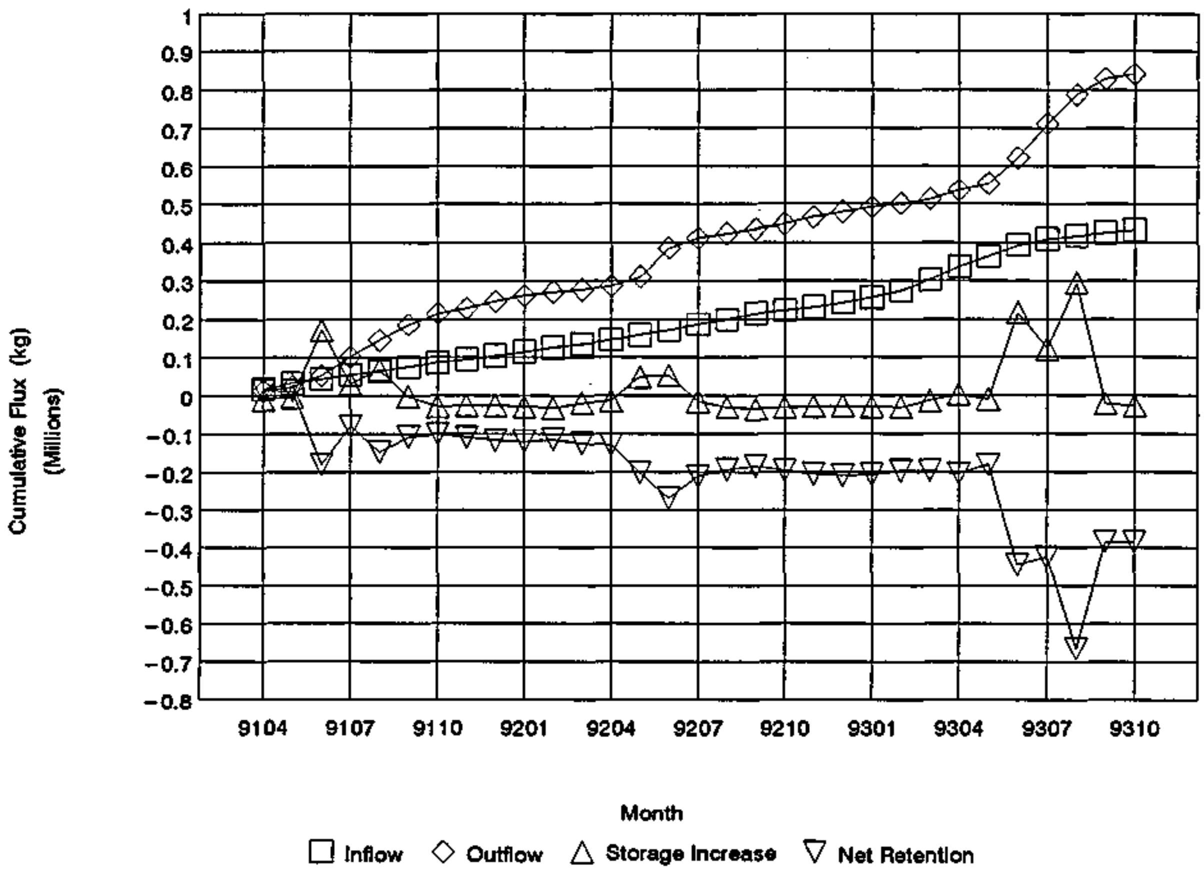
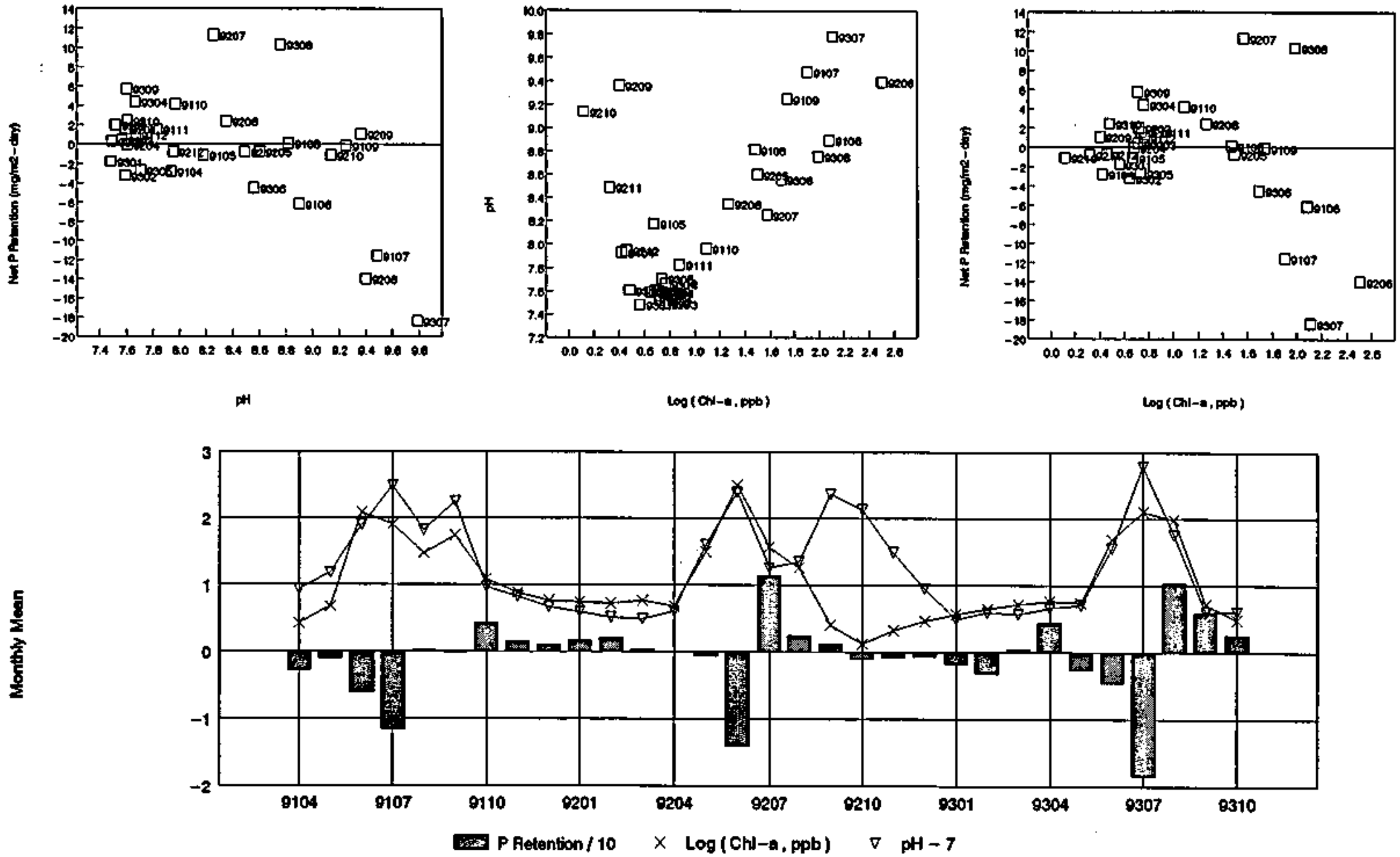


Figure 16
Monthly P Retention, pH, & Chlorophyll-a



Total P Retention Units mg/m2-day

Positive = Net Flux to Sediments, Negative = Net Flux From Sediments

Figure 17
Seasonal Variations in Trophic State Indicators
1 = Mar-May, 2 = June-Aug, 3 = Sept-Nov, 4 = Dec-Feb

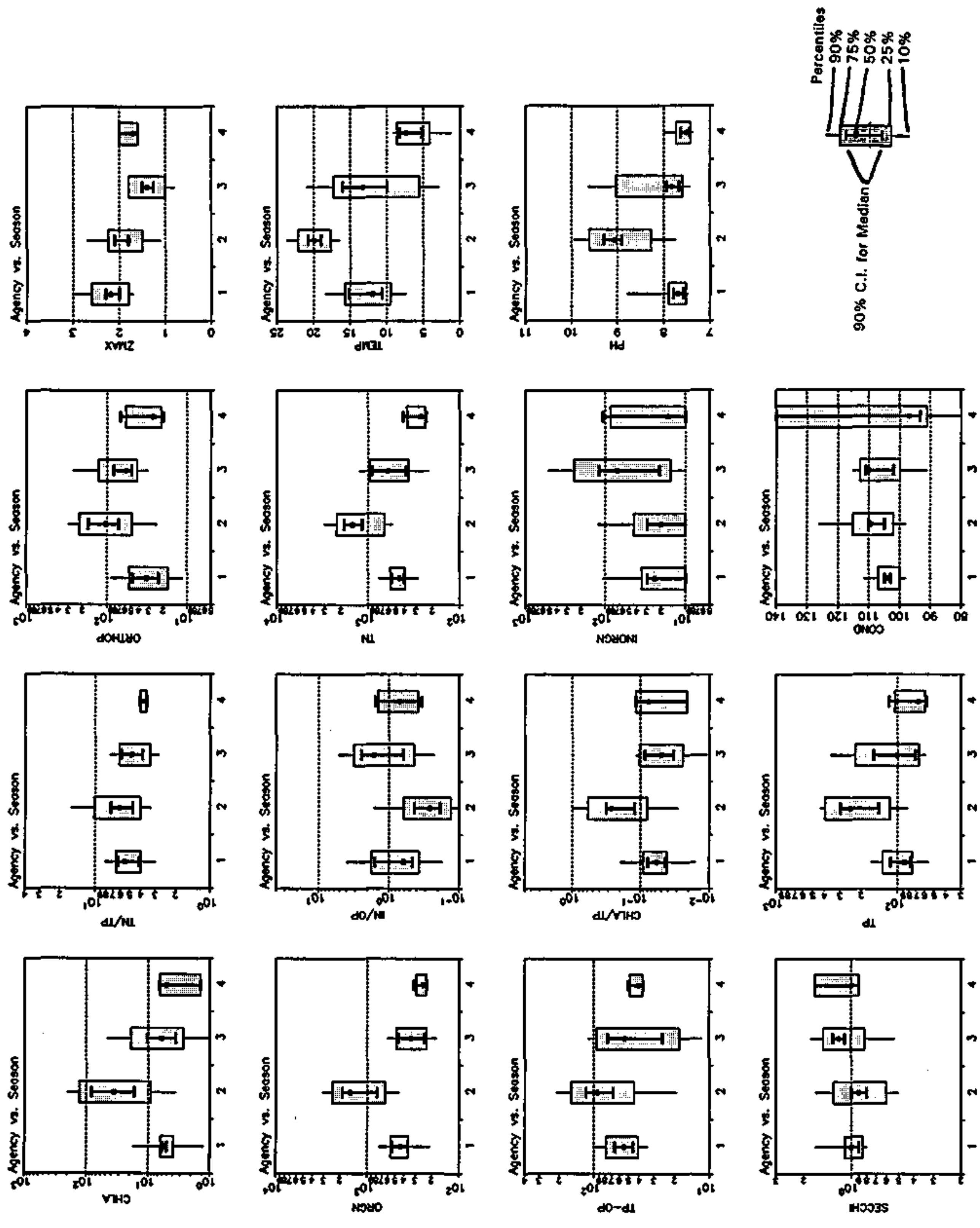


Figure 18
Annual Variations in Trophic State Indicators
June-August Samples
1=1991, 2=1992, 3=1993

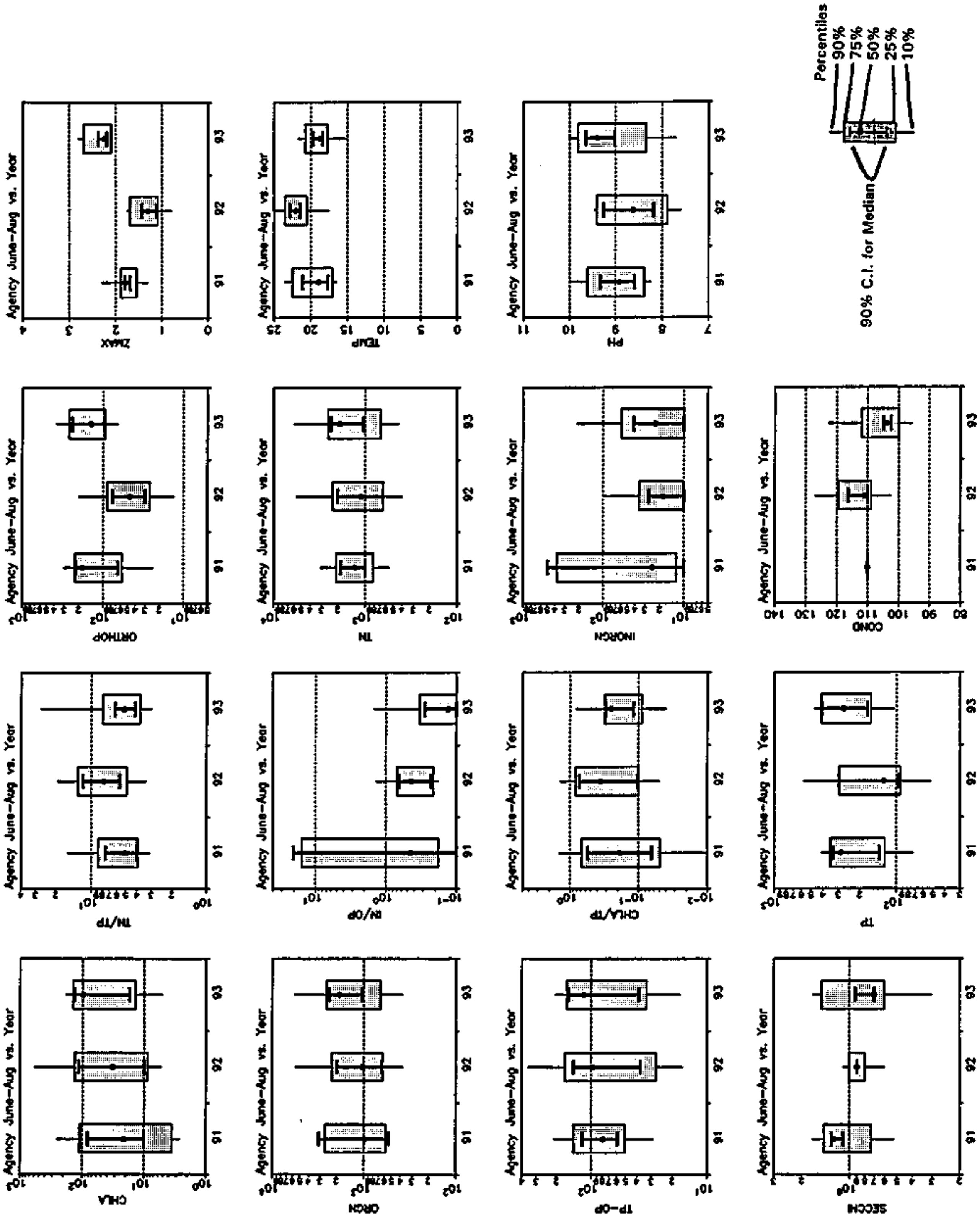


Figure 19
Spatial Variations in Trophic State Indicators
June-August Samples, 1991-1993
1=Agency North, 2=Agency South, 3=Upper Klamath Lake

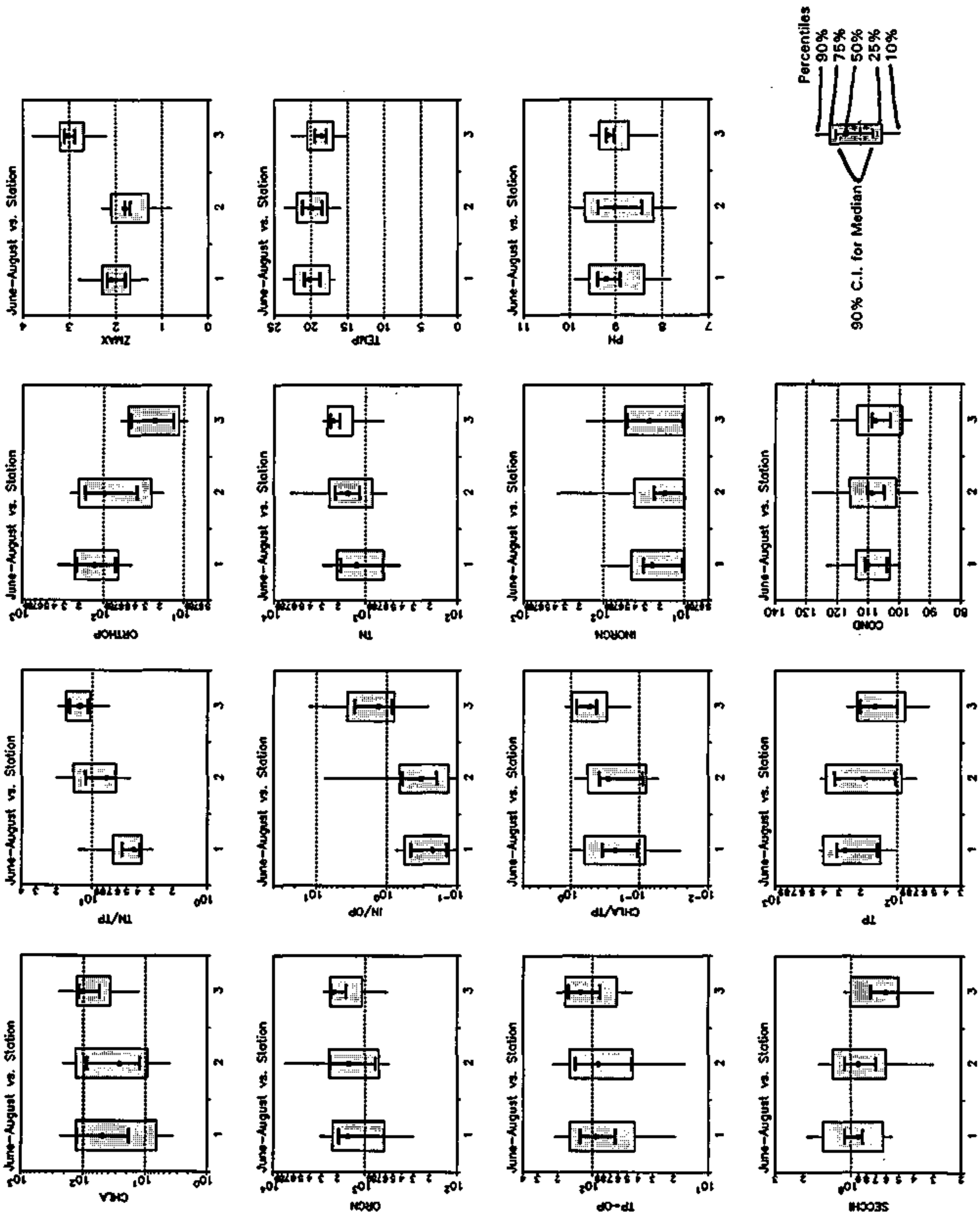


Figure 20
BATHTUB Empirical Model Network
(Walker, 1987)

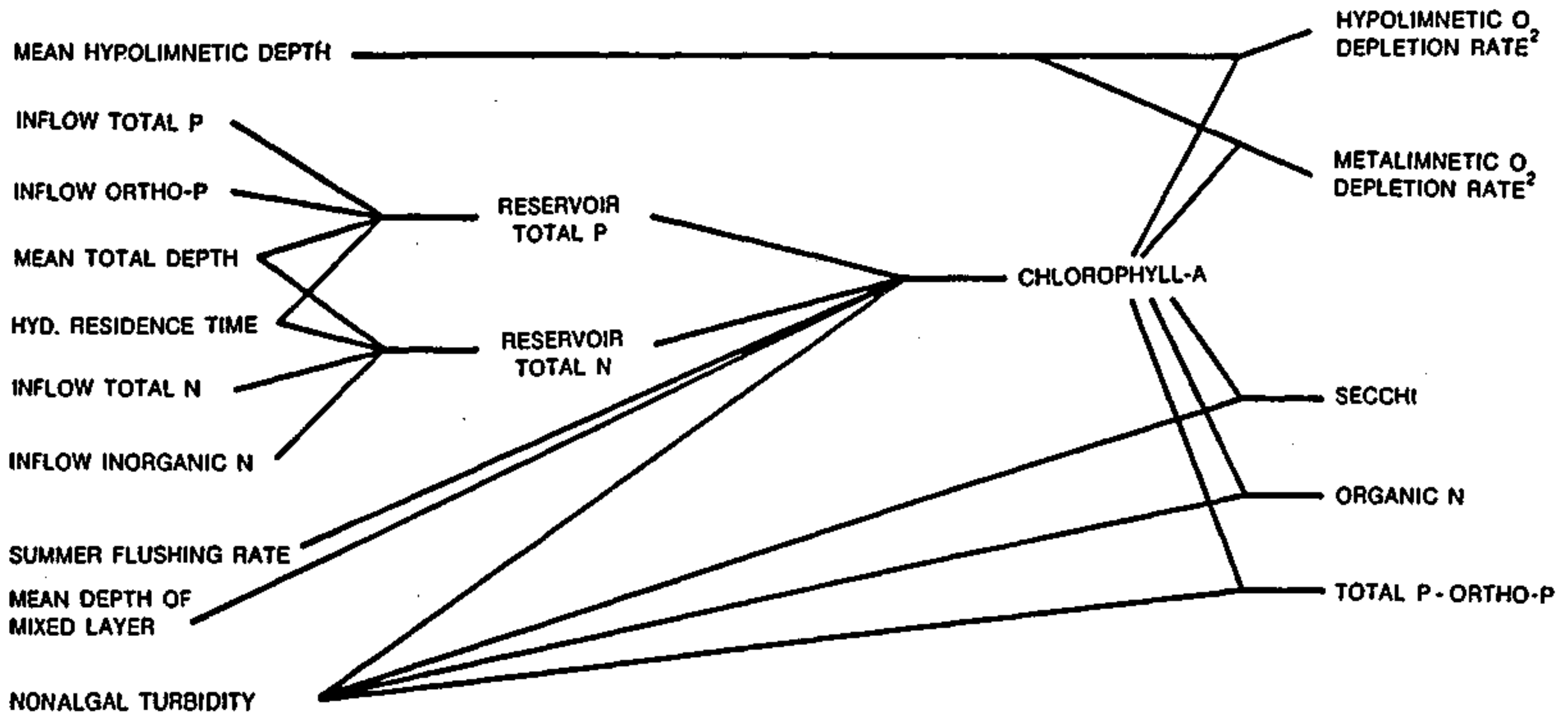
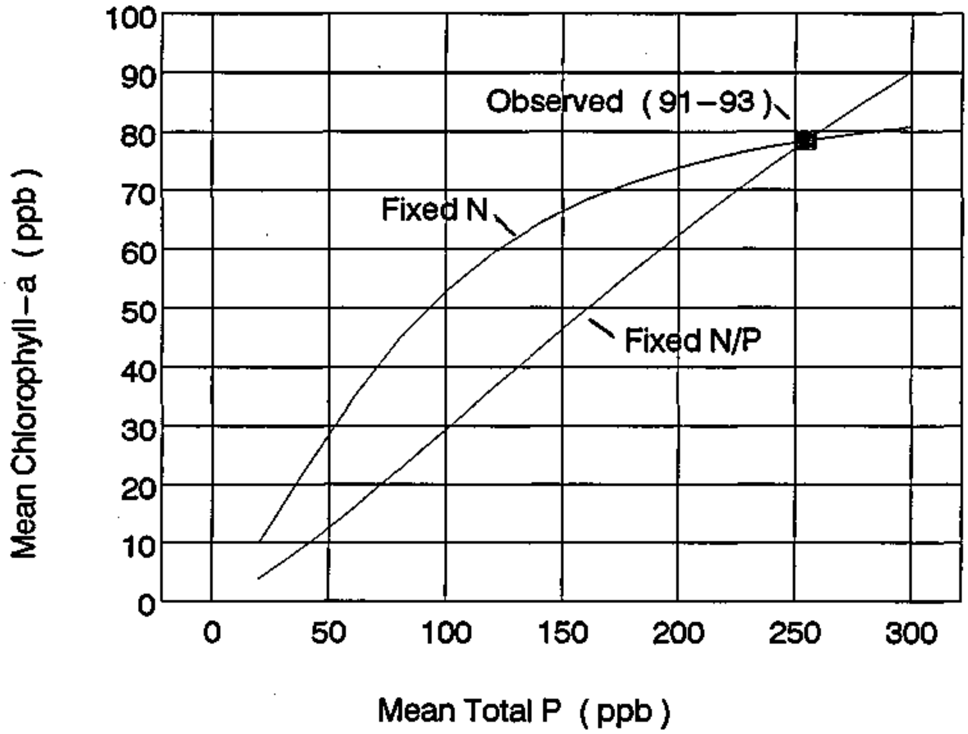


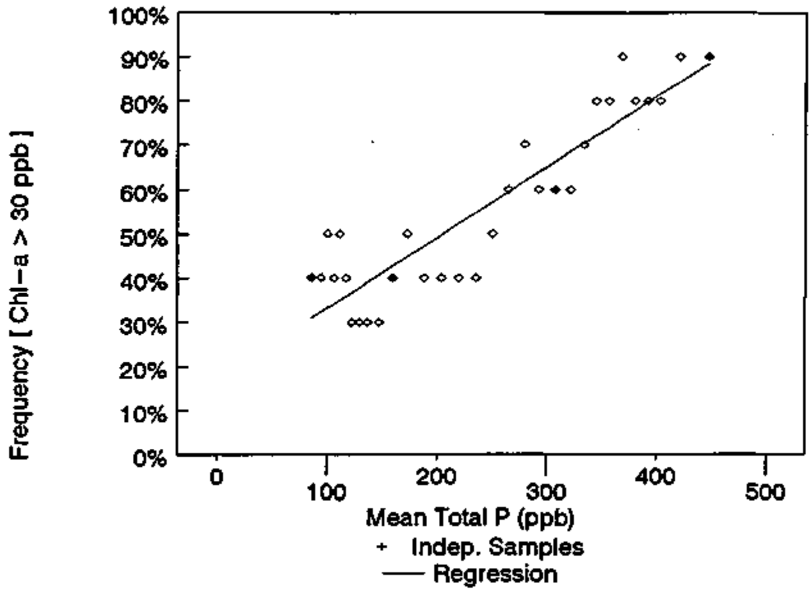
Figure 21
Predicted Chlorophyll Response to Total Phosphorus



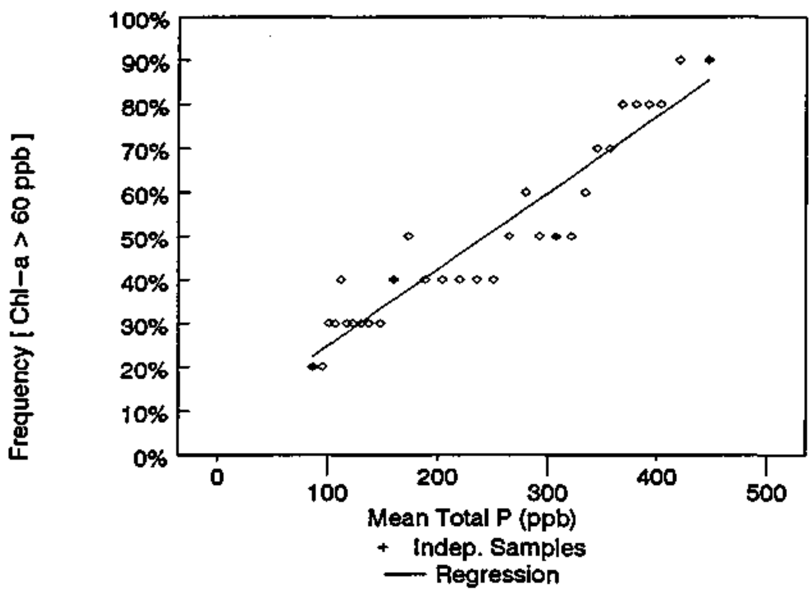
Basis: BATHTUB Chlorophyll–a Model 1
Coefficients:

Total P	255	ppb	Calibration
Total N	1816	ppb	Calibration
Chl–a	78.4	ppb	Calibration
(N–150)/P	6.5		
b	0.012	m2/mg	
a	0.11	1/m	
Zmix	1.86	m	
T	0.24	yrs	
Calib Factor	0.87	–	

Figure 23
Phosphorus / Bloom Frequency Corrlelations
Developed from Agency Lake Data



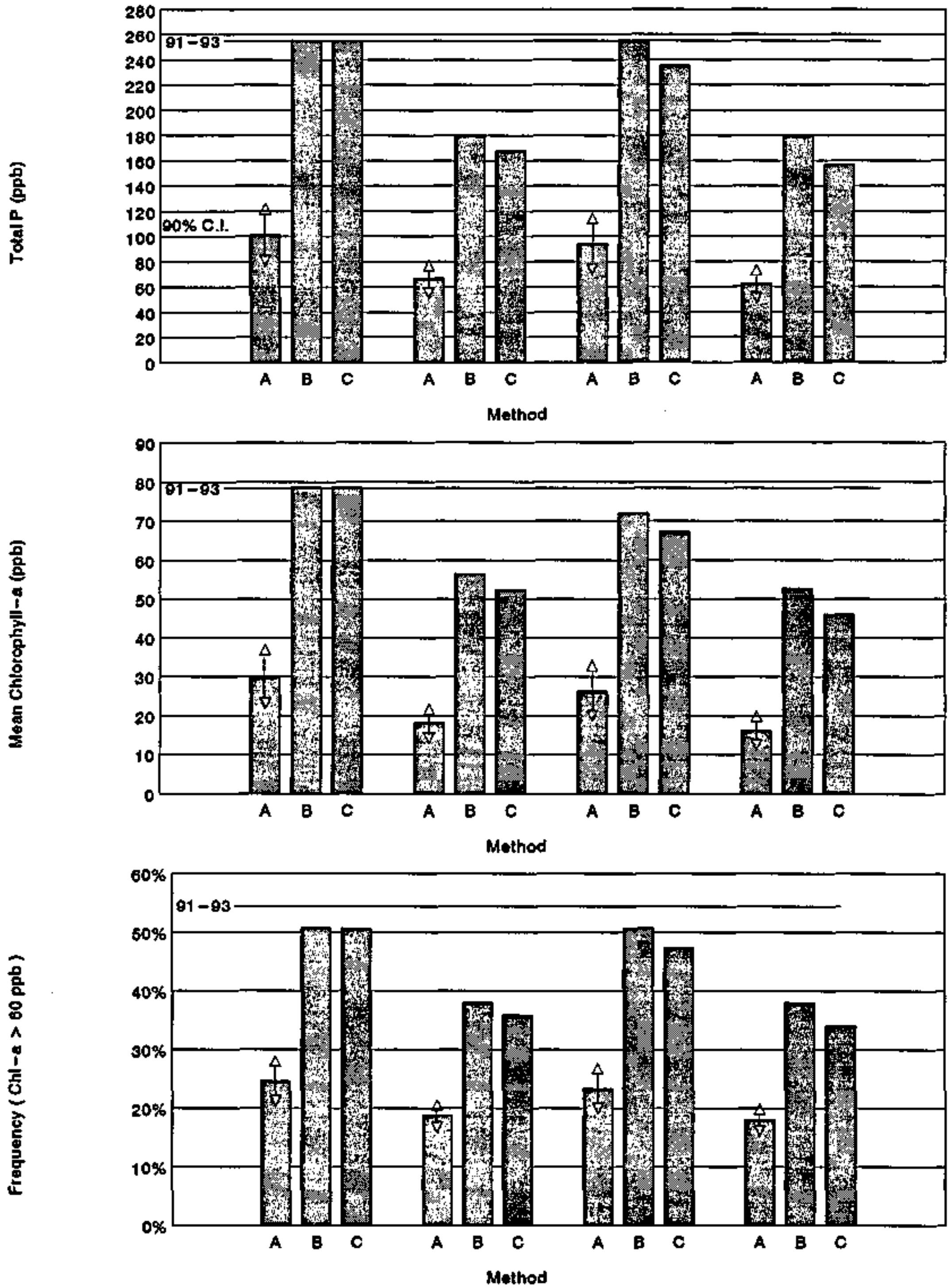
Regression: Y = .1715 + .0015 X
$R2$ = .82, SE = .086



Regression: Y = .0739 + .0017 X
$R2$ = .89, SE = .068

Each Symbol = Average of 10 Samples (+ indicates 10 independent samples)
Paired TP and Chl-a Samples, Agency Lake, North & South Stations, June-August, 1991-1993

Figure 23
Model Results



Scenario:	1	2	3	4
External Load	Existing	−44%	Existing	−44%
Volume/Depth	Existing	Existing	+30%	+30%

List of Tables

Table 1
Monthly & Seasonal Water Balance

Yr-Mo	Elevations (ft) Mean	Elevations (ft) MonthEnd	Volume (hm3) Mean	Volume (hm3) MonthEnd	Mean Depth (m)	Elevation Incr. (m)	Precip m	Evap. m	WoodR AgDike	7Mile	4Mile	Ungaug.	External Inflows	Precip	Evap	Storage Increase	Outflow	Net Inflow	Resid. Time (ds)
									Monthly Water Budget Terms in Million Cubic Meters										
9101																			
9102	4140.1	4140.4	56.3	61.8	1.64														
9103	4141.2	4141.7	71.1	76.5	2.00														
9104	4142.0	4142.2	79.7	81.7	2.24	0.14	0.019	0.130	18.75	7.92	3.02	3.10	32.79	0.66	4.61	5.21	23.65	28.86	62.8
9105	4142.3	4142.4	83.0	84.3	2.34	0.07	0.022	0.158	16.03	6.83	2.16	2.55	27.59	0.78	5.60	2.59	20.17	22.77	113.0
9106	4141.9	4141.5	78.4	74.4	2.21	-0.27	0.008	0.187	13.54	4.88	0.91	1.64	20.98	0.30	6.63	-9.96	24.60	14.64	160.7
9107	4140.8	4140.3	65.9	60.2	1.86	-0.38	0.019	0.171	11.73	5.02	0.92	1.68	19.36	0.69	6.06	-14.12	28.11	13.98	146.1
9108	4139.5	4139.0	51.5	45.8	1.45	-0.39	0.006	0.110	12.87	4.94	0.87	1.64	20.32	0.22	3.90	-14.41	31.05	16.64	96.0
9109	4138.5	4138.2	40.2	37.6	1.13	-0.23	0.001	0.078	15.35	5.91	1.63	2.13	25.03	0.02	2.76	-8.18	30.47	22.28	54.1
9110	4138.1	4138.2	36.1	37.0	1.02	-0.02	0.017	0.000	20.52	7.35	2.54	2.80	33.20	0.60	0.00	-0.64	34.44	33.80	33.1
9111	4138.6	4139.0	41.8	45.5	1.18	0.24	0.019	0.000	22.99	7.98	3.06	3.13	37.16	0.68	0.00	8.49	29.34	37.84	33.1
9112	4139.4	4139.7	50.1	53.3	1.41	0.21	0.057	0.000	25.72	11.19	3.34	4.11	44.37	2.01	0.00	7.83	38.55	46.38	33.5
9201	4140.1	4140.3	57.8	60.1	1.63	0.18	0.025	0.000	24.02	13.10	3.07	4.58	44.77	0.89	0.00	6.80	38.86	45.66	39.2
9202	4140.6	4140.9	64.5	67.9	1.82	0.21	0.025	0.000	23.15	9.77	2.96	3.60	39.47	0.87	0.00	7.75	32.60	40.35	46.4
9203	4141.5	4141.8	74.0	77.7	2.08	0.26	0.013	0.089	18.73	5.30	3.06	2.37	29.45	0.46	3.17	9.78	16.96	26.74	65.8
9204	4141.8	4141.7	77.1	76.3	2.17	-0.04	0.030	0.130	11.10	7.21	2.69	2.80	23.80	1.06	4.61	-1.36	21.61	20.25	114.2
9205	4141.2	4140.7	70.6	65.1	1.99	-0.30	0.001	0.158	11.08	7.34	3.67	3.11	25.20	0.05	5.60	-11.16	30.81	19.65	111.4
9206	4139.9	4139.5	56.4	51.0	1.59	-0.38	0.015	0.187	8.16	5.82	1.08	1.95	17.01	0.54	6.63	-14.17	25.08	10.91	154.9
9207	4139.2	4138.8	47.9	43.4	1.35	-0.21	0.010	0.171	12.73	5.24	0.67	1.67	20.30	0.36	6.06	-7.56	22.16	14.60	101.8
9208	4138.1	4137.7	36.2	32.2	1.02	-0.32	0.002	0.110	9.10	2.71	0.25	0.84	12.90	0.08	3.90	-11.24	20.33	9.09	123.5
9209	4137.5	4137.4	30.2	29.2	0.85	-0.09	0.003	0.078	16.63	4.90	0.59	1.55	23.67	0.09	2.76	-2.97	23.97	21.00	43.1
9210	4137.4	4137.8	29.2	30.8	0.82	0.05	0.081	0.000	19.24	7.19	0.44	2.16	29.04	2.89	0.00	1.63	30.30	31.93	28.4
9211	4138.1	4138.3	35.9	38.5	1.01	0.22	0.109	0.000	21.97	10.20	1.08	3.19	36.45	3.88	0.00	7.69	32.64	40.32	26.7
9212	4138.9	4139.3	44.9	49.0	1.26	0.29	0.104	0.000	20.68	8.74	2.63	3.22	35.26	3.71	0.00	10.44	28.53	38.97	35.7
9301	4139.7	4140.0	54.1	57.3	1.52	0.23	0.046	0.000	21.60	10.04	4.19	4.03	40.05	1.63	0.00	8.34	33.35	41.69	40.2
9302	4140.5	4140.9	63.1	67.1	1.78	0.26	0.033	0.000	19.06	10.63	5.31	4.51	39.51	1.15	0.00	9.79	30.88	40.67	43.5
9303	4141.9	4142.7	76.5	87.2	2.21	0.54	0.034	0.089	27.11	14.49	8.25	6.44	56.28	1.22	3.17	20.17	34.16	54.33	44.8
9304	4142.8	4143.0	88.9	91.4	2.50	0.11	0.086	0.130	24.35	14.72	8.89	6.68	54.64	3.06	4.61	4.13	48.96	53.09	50.2
9305	4143.0	4143.3	91.7	94.4	2.58	0.08	0.072	0.158	23.41	9.07	5.79	4.21	42.48	2.55	5.60	2.99	36.44	39.44	72.1
9306	4143.0	4142.7	90.9	87.4	2.56	-0.19	0.031	0.187	39.96	7.94	5.09	3.69	56.67	1.09	6.63	-7.01	58.14	51.13	53.4
9307	4141.9	4141.5	79.2	74.1	2.23	-0.36	0.004	0.171	19.09	9.36	1.21	2.99	32.66	0.13	6.06	-13.22	39.94	26.72	91.9
9308	4140.8	4140.5	66.4	62.3	1.87	-0.32	0.013	0.110	14.93	1.25	1.95	0.90	19.03	0.46	3.90	-11.85	27.44	15.59	132.1
9309	4139.8	4139.5	55.3	51.8	1.56	-0.28	0.001	0.078	17.27	3.47	0.44	1.11	22.29	0.03	2.76	-10.54	30.09	19.55	64.8
9310	4139.5	4139.6	51.6	52.9	1.45	0.03	0.040	0.000	26.19	6.35	0.59	1.96	35.09	1.43	0.00	1.13	35.40	36.52	43.8
9311	4139.6	4139.7	53.2	53.4	1.50	0.02	0.050	0.000	19.17	5.07	0.73	1.64	26.60	1.78	0.00	0.56	27.81	26.38	56.2
9312	4139.9	4139.9	55.9	56.5	1.58	0.08	0.057	0.000	14.23	5.28	1.48	1.91	22.91	2.01	0.00	3.05	21.87	24.92	69.6
91-S	4140.8	4140.6	66.5	64.0	1.87	-1.05	0.08	0.83	88.28	35.51	9.53	12.75	146.06	2.67	29.56	-38.87	158.04	119.17	102.0
92-W	4139.7	4140.0	54.0	56.9	1.52	1.09	0.16	0.09	135.13	54.68	18.03	20.58	228.43	5.51	3.17	40.01	190.76	230.77	42.9
92-S	4139.6	4139.3	53.1	49.5	1.49	-1.33	0.06	0.83	66.78	33.22	8.94	11.93	122.87	2.18	29.56	-48.46	143.96	95.50	101.7
93-W	4139.4	4139.8	51.0	55.0	1.44	1.59	0.41	0.09	129.86	61.30	21.69	23.54	236.60	14.47	3.17	58.05	189.86	247.91	37.4
93-S	4141.9	4141.7	78.7	78.9	2.22	-0.95	0.21	0.83	139.00	45.81	23.37	19.58	227.77	7.32	29.56	-35.49	241.01	205.52	70.1
Summer	4140.8	4140.5	66.1	63.5	1.86	-1.11	0.11	0.83	98.69	38.18	13.95	14.75	165.57	4.06	29.56	-40.94	181.01	140.06	86.3
Winter	4139.6	4139.9	52.5	55.9	1.48	1.34	0.28	0.09	132.50	57.99	19.96	22.06	232.52	9.99	3.17	49.03	190.31	239.34	40.0
WY-92	4139.7	4139.6	53.6	53.2	1.51	-0.25	0.22	0.92	203.92	87.91	26.97	32.51	351.31	7.69	32.73	-8.46	334.72	326.26	60.1
WY-93	4140.7	4140.8	64.8	65.9	1.63	0.64	0.61	0.92	268.87	107.12	45.27	43.12	464.37	21.79	32.73	22.56	430.87	453.43	52.2
Avg	4140.2	4140.2	59.2	59.6	1.67	0.20	0.42	0.92	236.39	97.51	36.12	37.82	407.84	14.74	32.73	7.05	382.79	389.65	55.5

S = Summer = April-September W = Winter = October-March WY = Water Year = October-September

Table 2
Monthly & Seasonal Mass Balances

Variable: Conductivity

YrMo	External Loads Weed Rd	Agen Dike	7Mile	4Mile	Ungauged	Total	Atmos. Load	End-of-Month Storage Conc	Volume	Mass	Storage Increase	Mean Conc	Outflow Volume	Outflow Load	Net Retention
	*	*	*	*	*	*	*	uS/cm2	hm3	*	*	uS/cm2	hm3	*	*
								86	76.5	6546		83			
9104	2047	1871	701	195	254	3022	20	90	81.7	7391	845	88	23.6	2083	114
9105	1482	1618	605	141	211	2575	21	95	84.3	8052	661	93	20.2	1877	58
9106	742	1496	433	59	139	2127	20	100	74.4	7465	-587	98	24.6	2411	323
9107	729	1281	445	60	143	1928	21	105	60.2	6351	-1113	103	28.1	2895	168
9108	700	1330	437	56	140	1963	21	110	45.8	5051	-1300	108	31.0	3354	-70
9109	1143	1464	523	105	178	2271	20	112	37.6	4228	-823	111	30.5	3391	-277
9110	1556	1841	549	164	202	2757	21	111	37.0	4111	-117	112	34.4	3865	-970
9111	1932	1982	618	198	231	3029	20	90	45.5	4083	-28	99	29.3	2896	182
9112	2049	2103	918	216	321	3559	21	93	53.3	4937	854	91	38.6	3516	-790
9201	2063	2234	1031	199	348	3812	21	95	60.1	5738	800	94	38.9	3655	-622
9202	2026	2213	827	192	288	3520	20	95	67.9	6466	728	97	32.6	3153	-341
9203	1923	1695	430	199	178	2503	21	100	77.7	7766	1300	99	17.0	1674	-450
9204	1526	986	613	181	225	2005	20	105	76.3	8023	257	103	21.6	2233	-465
9205	853	1055	690	292	278	2315	21	117	65.1	7635	-388	108	30.8	3317	-593
9206	356	831	602	87	195	1715	20	105	51.0	5341	-2294	111	25.1	2790	1238
9207	784	1365	589	60	184	2198	21	112	43.4	4874	-467	108	22.2	2393	293
9208	441	968	332	23	100	1423	21	132	32.2	4235	-639	123	20.3	2501	-418
9209	1260	1651	527	52	164	2393	20	122	29.2	3552	-683	124	24.0	2983	114
9210	1562	1842	604	34	180	2661	21	118	30.8	3646	94	116	30.3	3503	-915
9211	2023	2073	823	81	256	3234	20	128	38.5	4935	1290	123	32.8	4027	-2062
9212	2051	1928	778	191	274	3171	21	138	49.0	6773	1838	133	28.5	3807	-2452
9301	2123	2106	882	288	331	3608	21	144	57.3	8257	1484	143	33.3	4780	-2635
9302	1749	1912	917	346	357	3533	19	143	67.1	9597	1340	144	30.9	4434	-2222
9303	2213	2848	1225	508	491	5072	21	134	87.2	11679	2083	144	34.2	4919	-1909
9304	2381	2571	1244	505	495	4816	20	112	91.4	10235	-1444	123	49.0	6001	279
9305	1903	2556	837	275	315	3983	21	101	94.4	9576	-659	103	36.4	3739	924
9306	2036	3756	789	277	301	5122	20	103	87.4	8997	-579	104	58.1	6024	-303
9307	1234	1873	974	92	302	3241	21	95	74.1	7038	-1959	113	39.9	4500	721
9308	1354	1570	132	177	87	1966	21	101	62.3	6282	-756	98	27.4	2694	49
9309	1729	1732	337	36	105	2210	20	111	51.8	5760	-522	106	30.1	3189	-437
9310	2790	2439	506	42	155	3142	21	104	52.9	5516	-244	109	35.4	3851	-444
								86	76.5	6546					
91-S	6843	9060	3144	616	1064	13885	125	112	37.6	4228	-2318	101	158.0	16010	317
92-W	11549	12069	4374	1169	1569	19180	125	100	77.7	7766	3537	98	190.8	18758	-2991
92-S	5220	6856	3352	694	1145	12048	125	122	29.2	3552	-4214	113	144.0	16217	170
93-W	11722	12710	5229	1449	1890	21278	124	134	87.2	11679	8127	134	189.9	25470	-12195
93-S	10636	14058	4313	1361	1606	21337	125	111	51.8	5760	-5919	108	241.0	26148	1233
Summer	7566	9991	3603	890	1272	15757	125	114	39.5	4513	-4150	108	181	19458	573
Winter	11635	12389	4802	1309	1729	20229	125	118	82.4	9722	5832	116	190	22114	-7593
WY 92	16769	18925	7726	1863	2714	31228	250	100	77.7	7766	-676	104	335	34976	-2821
WY 93	22358	26767	9543	2809	3496	42615	249	111	51.8	5760	2206	120	431	51618	-10962
Avg	19563	22846	8634	2336	3105	36922	249	105	64.7	6763	766	113	383	43297	-6892

S = Summer = April-September W = Winter = October-March WY = Water Year = October-September

* Conductivity Mass Units = uS/cm2 x hm3

Table 3
Monthly & Seasonal Mass Balances

Variable: Total Phosphorus

YrMo	External Loads: Weed Rd	Agen Dike	7Mile	4Mile	Ungauged	Total	Atmos. Load	End-of-Month Storage: Conc	Volume	Mass	Storage Increase	Mean Conc	Outflow Volume	Outflow Load	Net Retention
	kg	kg	kg	kg	kg	kg	kg	ppb	hm3	kg	kg	ppb	hm3	kg	kg
								75	76.5	5760		72			
9104	1526	1522	1015	247	357	3141	51	118	81.7	9644	3884	96	23.6	2260	−2953
9105	1241	1975	875	178	298	3326	53	138	84.3	11620	1976	128	20.2	2587	−1184
9106	705	2296	626	74	198	3195	51	244	74.4	18121	6501	134	24.6	3289	−6544
9107	777	1948	643	75	203	2870	53	421	60.2	25356	7235	299	28.1	8404	−12716
9108	766	1704	633	71	199	2607	53	395	45.8	18124	−7232	313	31.0	9713	180
9109	1483	1818	758	133	252	2961	51	270	37.6	10147	−7977	364	30.5	11085	−96
9110	1540	2047	825	207	292	3372	53	111	37.0	4097	−6050	140	34.4	4830	4645
9111	1964	2019	631	250	249	3150	51	71	45.5	3219	−878	82	29.3	2406	1672
9112	2219	2794	901	273	332	4300	53	70	53.3	3723	503	70	38.6	2709	1141
9201	2258	3142	1077	251	376	4845	53	69	60.1	4140	417	69	38.9	2694	1786
9202	1963	2796	716	242	271	4024	49	57	67.9	3888	−252	68	32.6	2218	2107
9203	1776	1806	433	252	194	2686	53	68	77.7	5253	1365	57	17.0	972	403
9204	1517	1279	837	231	302	2648	51	81	76.3	6209	956	82	21.6	1770	−27
9205	843	2413	1063	336	396	4208	53	121	65.1	7891	1682	108	30.8	3326	−746
9206	376	1312	1029	109	322	2772	51	345	51.0	17563	9672	319	25.1	8001	−14850
9207	923	1949	1155	78	349	3530	53	105	43.4	4561	−13002	184	22.2	4088	12497
9208	473	1346	694	28	204	2273	53	78	32.2	2505	−2056	83	20.3	1686	2696
9209	1300	1997	825	61	251	3133	51	90	29.2	2618	113	79	24.0	1890	1181
9210	1615	1951	706	41	212	2910	53	118	30.8	3637	1020	103	30.3	3108	−1165
9211	2157	2513	979	97	304	3893	51	118	38.5	4544	907	118	32.6	3851	−814
9212	2060	2339	882	229	314	3764	53	118	49.0	5776	1232	118	28.5	3367	−781
9301	2114	2704	1141	354	423	4623	53	142	57.3	8152	2376	127	33.3	4249	−1949
9302	2017	2727	1339	435	502	5004	48	172	67.1	11529	3377	158	30.9	4868	−3193
9303	3182	4454	2008	655	754	7870	53	153	87.2	13358	1829	164	34.2	5598	496
9304	3026	4807	2215	659	813	8494	51	117	91.4	10663	−2695	133	49.0	6497	4743
9305	2752	4560	1443	337	504	6844	53	165	94.4	15591	4928	135	36.4	4921	−2952
9306	2731	6470	1392	317	484	8663	51	234	87.4	20441	4850	149	58.1	8670	−4806
9307	1621	2822	1973	134	596	5525	53	434	74.1	32179	11738	353	39.9	14081	−20241
9308	1607	1628	231	272	143	2274	53	194	62.3	12102	−20077	401	27.4	11002	11403
9309	2246	2380	501	45	154	3080	51	87	51.8	4491	−7610	152	30.1	4574	6168
9310	3428	2881	684	44	206	3815	53	59	52.9	3134	−1357	71	35.4	2502	2723
								75	76.5	5760					
91−S	6497	11264	4551	778	1508	18100	312	270	37.6	10147	4388	236	158.0	37337	−23313
92−W	11720	14604	4583	1475	1714	22377	312	68	77.7	5253	−4894	83	190.8	15829	11755
92−S	5433	10296	5603	842	1824	18564	312	90	29.2	2618	−2635	144	144.0	20761	751
93−W	13165	16688	7054	1812	2509	28064	310	153	87.2	13358	10741	132	189.9	25040	−7406
93−S	13984	22667	7755	1764	2694	34880	312	87	51.8	4491	−8867	206	241.0	49745	−5685
Summer	8638	14742	5969	1128	2009	23848	312	146	39.5	5752	−2372	199	181	35948	−9416
Winter	12443	15646	5819	1644	2112	25220	311	113	82.4	9306	2923	107	190	20434	2174
WY 92	17153	24900	10185	2318	3538	40941	624	68	77.7	5253	−7530	109	335	36590	12505
WY 93	27149	39355	14810	3577	5203	62944	623	87	51.8	4491	1874	174	431	74784	−13091
Avg	22151	32127	12497	2947	4371	51943	623	75	64.7	4872	−2828	145	383	55687	−293

S = Summer = April−September W = Winter = October−March WY = Water Year = October−September

Table 4
Monthly & Seasonal Mass Balances

Variable: Total Nitrogen

YrMo	External Loads Weed Rd	Agen Dike	7Mile	4Mile	Ungauged	Total	Atmos. Load	End-of-Month Storage Conc	Volume	Mass	Storage Increase	Mean Conc	Outflow Volume	Outflow Load	Net Retention
	kg	kg	kg	kg	kg	kg	kg	ppb	hm3	kg	kg	ppb	hm3	kg	kg
								629	76.5	48138		464			
9104	10468	7163	3997	1330	1508	13998	3158	470	81.7	38413	-9725	571	23.6	13511	13370
9105	4080	7016	3446	960	1247	12669	3263	538	84.3	45368	6955	505	20.2	10190	-1212
9106	1720	3613	2465	401	811	7291	3158	2947	74.4	219133	173765	1172	24.6	28838	-192155
9107	1193	4590	2534	406	832	8362	3263	1331	60.2	80152	-138981	1770	28.1	49748	100859
9108	990	3460	2493	382	814	7149	3263	2530	45.8	115969	35818	1378	31.0	42768	-68174
9109	1484	2163	2983	716	1047	6909	3158	1234	37.6	46454	-69516	1302	30.5	39663	39920
9110	3702	1642	4032	1118	1457	8249	3263	554	37.0	20493	-25960	875	34.4	30121	7352
9111	6913	2160	557	1349	539	4605	3158	505	45.5	22983	2490	473	29.3	13875	-8603
9112	2522	2993	840	1472	654	5959	3263	424	53.3	22618	-365	463	38.6	17861	-8273
9201	2573	3791	1145	1352	707	6994	3263	343	60.1	20632	-1986	382	38.9	14859	-2615
9202	2869	3384	2128	1300	970	7782	3053	241	67.9	16328	-4303	303	32.6	9880	5258
9203	2089	2093	1377	1333	767	5570	3263	382	77.7	29681	13353	330	17.0	5599	-10119
9204	2213	1445	4156	1139	1498	8238	3158	456	76.3	34820	5138	416	21.6	8983	-2725
9205	895	1741	5071	1143	1759	9714	3263	1496	65.1	97469	62649	794	30.8	24455	-74127
9206	1897	3016	4256	333	1299	8903	3158	2005	51.0	102170	4701	3012	25.1	75559	-68199
9207	9599	6703	4035	328	1235	12300	3263	773	43.4	33555	-68615	1150	22.2	25490	58688
9208	1343	4855	3788	109	1103	9855	3263	543	32.2	17467	-16089	603	20.3	12251	16956
9209	2468	5532	4685	275	1404	11898	3158	452	29.2	13208	-4258	434	24.0	10408	8904
9210	1018	1765	1795	116	541	4218	3263	570	30.8	17571	4363	465	30.3	14094	-10976
9211	1840	3120	2403	330	773	6625	3158	503	38.5	19356	1785	535	32.6	17469	-9471
9212	1936	2969	3219	935	1176	8299	3263	433	49.0	21194	1838	467	28.5	13314	-3591
9301	2173	3208	4553	1605	1743	11109	3263	346	57.3	19846	-1348	390	33.3	13022	2698
9302	2455	3502	5637	2172	2210	13521	2947	263	67.1	17638	-2208	303	30.9	9364	9313
9303	5751	9790	8821	3598	3515	25725	3263	399	87.2	34818	17180	326	34.2	11131	676
9304	5194	11813	10660	3784	4088	30345	3158	574	91.4	52409	17591	490	49.0	23969	-8057
9305	3042	9923	8927	2318	3182	24351	3263	414	94.4	39076	-13333	480	36.4	17506	23441
9306	3428	10071	7759	4011	3331	25173	3158	3030	87.4	264682	225606	1150	58.1	66849	-264124
9307	2148	4522	6240	745	1977	13483	3263	2294	74.1	170031	-94651	2274	39.9	90831	20566
9308	1564	2778	764	834	452	4827	3263	5490	62.3	341987	171956	2805	27.4	76975	-240840
9309	2093	2665	1576	103	475	4819	3158	543	51.8	28124	-313863	1364	30.1	41053	280787
9310	3717	1766	1342	44	392	3545	3263	411	52.9	21711	-6413	376	35.4	13325	-104
								629	76.5	48138					
91-S	19935	28004	17919	4196	6258	56377	19263	1234	37.6	46454	-1685	1169	158.0	184717	-107392
92-W	20668	16063	10078	7924	5095	39160	19263	382	77.7	29681	-16772	483	190.8	92195	-17000
92-S	18414	23292	25991	3327	8297	60906	19263	452	29.2	13208	-16473	1092	144.0	157146	-60504
93-W	15173	24354	26429	8756	9957	69497	19158	399	87.2	34818	21610	413	189.9	78395	-11350
93-S	17468	41772	35926	11795	13505	102998	19263	543	51.8	28124	-6694	1316	241.0	317182	-188227
Summer	18606	31022	26612	6439	9353	73427	19263	740	39.5	29262	-8284	1214	181	219682	-118708
Winter	17921	20209	18254	8340	7526	54328	19211	391	82.4	32250	2419	448	190	85295	-14175
WY 92	39083	39355	36069	11251	13391	100065	38527	382	77.7	29681	-33245	745	335	249341	-77503
WY 93	32641	66126	62355	20551	23462	172495	38422	543	51.8	28124	14916	918	431	395577	-199577
Avg	35862	52741	49212	15901	18427	136280	38474	447	64.7	28903	-9165	842	383	322459	-138540

S = Summer = April-September W = Winter = October-March WY = Water Year = October-September

Table 5
Summary of Agency Lake Water Quality Data
June through August Samples

Year		All		91		92		93		
Variable	Units	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error	
Sampling Dates		23		8		7		8		
Water Depth	meters	1.81	0.11	1.73	0.12	1.29	0.10	2.35	0.08	*
Secchi Depth	meters	0.96	0.09	1.09	0.14	0.85	0.08	0.92	0.19	
Temperature	deg−C	20.18	0.53	19.75	1.00	21.80	0.81	19.20	0.73	
Dissolved Oxygen	ppm	8.90	0.43	9.05	0.62	8.90	0.87	8.76	0.86	
DO Saturation	%	115.7	5.4	117.6	7.6	118.7	10.2	111.0	10.9	
pH	–	8.95	0.16	9.10	0.26	8.62	0.29	9.10	0.30	
Conductivity	us/m2	111	2.3	110	–	115	3.1	107	3.4	
Total Phosphorus	ppb	255	29	263	42	205	68	289	51	
Ortho Phosphorus	ppb	139	21	161	33	68	23	185	39	*
Total P − Ortho P	ppb	111	18	102	17	131	56	104	21	
Total Nitrogen	ppb	1816	278	1559	220	1719	642	2192	611	
Nitrate + Nitrite N	ppb	39	14	77	38	16	10	28	14	
Ammonia N	ppb	28	11	50	34	13	5	24	13	
Inorganic N	ppb	53	18	137	113	29	11	52	27	
Organic N	ppb	1776	274	1524	234	1686	637	2140	592	
Chlorophyll−a	ppb	78.4	13.9	82.6	23.4	65.5	26.9	86.4	25.2	
Freq Chl > 30 ppb	%	63.6%	10.5%	62.5%	18.3%	57.1%	20.2%	71.4%	18.4%	
Freq Chl > 40 ppb	%	59.1%	10.7%	62.5%	18.3%	42.9%	20.2%	71.4%	18.4%	
Freq Chl > 60 ppb	%	54.5%	10.9%	62.5%	18.3%	42.9%	20.2%	57.1%	20.2%	
Freq Chl > 100 ppb	%	40.9%	10.7%	50.0%	18.9%	28.6%	18.4%	42.9%	20.2%	

* Yearly Means are Significantly Different at $p < .05$

Table 6
Agency Lake Response Variables Ranked Against CE Reservoir Data Set

Variable	Units	CE Reservoir Data Set G. Mean	CV	Min	Max	Agency Lake	Rank %
Total P	ppb	48	0.90	10	274	255	95%
Total N	ppb	1002	0.64	243	4306	1816	72%
Compos. Nutrient	ppb	35.7	0.80	6.6	142.2	122	89%
Chlorophyll−a	ppb	9.4	0.77	2.0	63.6	78.4	100%
Secchi Depth	meters	1.08	0.76	0.19	4.55	0.96	45%
Organic N	ppb	474.0	0.51	186.0	1510.0	1776	100%
Total P − Ortho P	ppb	30.0	0.95	4.3	147.5	111	90%
10 ^ (PC−1)	−	245.0	1.31	18.4	2460.4	2763	100%
10 ^ (PC−2)	−	6.4	0.53	1.6	13.4	24.6	100%
(N − 150) / P	−	17.0	0.68	4.7	73.3	6.5	17%
Inorganic N/P	−	29.7	0.99	1.6	127.5	0.4	0%
Non−Algal Turbidity	1/m	0.61	0.88	0.13	5.15	0.11	0%
Mixed Depth * Turbidity	−	3.2	0.78	1.0	17.1	0.19	0%
Mixed Depth / Secchi Depth	−	4.8	0.58	1.5	19.0	1.9	18%
Chl−a * Secchi	mg/m2	10.2	0.71	1.8	30.5	75.0	100%
Chl−a/Total P	−	0.20	0.64	0.04	0.60	0.31	67%
Mean Depth	m	7.59	0.80	1.41	60.26	1.86	8%
Hydraulic Residence Time	yrs	0.16	1.39	0.008	1.74	0.24	65%
Overflow Rate	m/yr	46.77	1.19	4.2	724.4	7.8	4%
Inflow Total P Conc	ppb	109.6	1.01	13.5	446.7	174.8	68%
Inflow Ortho P / Total P	−	0.32	0.51	0.06	0.85	0.72	79%

Agency Lake Values for June−August, 1991−1993

Table 7
BATHTUB Model Network Applied to Agency Lake

Variable Definitions:

a	=	Nonalgal Turbidity (m^{-1})
b	=	Chlorophyll-a / Secchi Slope (m^2/mg)
As	=	Surface Area of Segment (km^2)
B	=	Chlorophyll-a Concentration (mg/m^3)
Bx	=	Nutrient-Potential Chlorophyll-a Concentration (mg/m^3)
Bo	=	Observed Mean Chlorophyll-a (mg/m^3)
Cp	=	Calibration Factor for P Sedimentation Rate
Cb	=	Calibration Factor for Chlorophyll-a
Fot	=	Tributary Ortho-P Load/Tributary Total P Load
G	=	Kinetic Factor Used in Chlorophyll-a Model
Kp	=	Scale Factor for Predicted Total P Concentration
N	=	Reservoir Total Nitrogen Concentration (mg/m^3)
Norg	=	Organic Nitrogen Concentration (mg/m^3)
Nr	=	Dimensionless Second-Order Sedimentation Rate for Phosphorus
P	=	Total Phosphorus Concentration (mg/m^3)
Pi	=	Inflow Total P Concentration (mg/m^3)
PC-1	=	First Principal Component of Response Measurements
PC-2	=	Second Principal Component of Response Measurements
Qs	=	Surface Overflow Rate (m/yr)
S	=	Secchi Depth (m)
So	=	Observed Secchi Depth (m)
T	=	Hydraulic Residence Time (years)
V	=	Mean Volume (hm^3)
Xpn	=	Composite Nutrient Concentration (mg/m^3)
Z	=	Total Depth (m)
Zmix	=	Mean Depth of Mixed Layer (m)
Qnet	=	Net Inflow = External Inflow + Precip - Evap. (hm^3/yr)
Wp	=	External Total P Load (kg/yr)
Wint	=	Net Internal P Recycling Rate (mg/m^2-day)

Calibration Factors:

Phosphorus Retention

Method A - Cp = 1.0, Wint = 0.0, Kp = 1.0

Method B - Cp = 0.0, Wint = 1.78, Kp = 1.0

Method C - Cp = 1.0, Wint = 0.0, Kp = 2.51

Chlorophyll-a Model

b = .012 (from .025)

Cb = 0.87 (from 1.0)

Table 7 (ct)

Model Equations:

Phosphorus Retention (BATHTUB P Model 2):

$$T = V / Qnet$$

$$Qs = Qnet / As$$

$$Pi = Wp / Qnet$$

$$Nr = Cp\ Pi\ T\ 0.056\ Fot^{-1}\ Qs / (Qs + 13.3)$$

$$P = Kp \{ Pi [-1 + (1 + 4\ Nr)^{0.5}]/(2\ Nr) + 365.25\ Wint / Qs \}$$

Chlorophyll-a (BATHTUB Chl-a Model 1):

$$a = 1 / (Bo - b\ So)$$

$$Xpn = [P^{-2} + ((N-150)/12)^{-2}]^{-0.5}$$

$$Bx = Xpn^{1.33} / 4.31$$

$$G = Zmix\ (0.14 + 0.0039 / T)$$

$$B = Cb\ Bx / [(1 + b\ Bx\ G) (1 + G\ a)]$$

Transparency:

$$S = 1 / (a + b\ B)$$

Organic Nitrogen:

$$Norg = 157 + 22.8\ B + 75.3\ a$$

Total P - Ortho P:

$$P - Portho = -4.1 + 1.78\ B + 23.7\ a$$

Principal Components:

$$PC\text{-}1 = 0.554 \log(B) + 0.359 \log(Norg) + 0.583 \log(Xpn) - 0.474 \log(S)$$

$$PC\text{-}2 = 0.689 \log(B) + 0.162 \log(Norg) - 0.205 \log(Xpn) + 0.676 \log(S)$$

Table 8
Application of Empirical Models Relating Observed Nutrient Concentrations in Agency Lake to Measures of Trophic Response
Uncalibrated

Independent Variable	Value	Units	
Total Phosphorus	255	ppb	
Total Nitrogen	1816	ppb	
Mean Depth of Mixed Layer	1.86	m	
Summer Hydraulic Resid. Time	0.236	yrs	
Chlorophyll/Secchi Slope	0.025	m2/mg	* Calibrated
Chl-a Calibration Factor	1	-	* Calibrated
Non-Algal Turbidity	0.08	1/m	

Dependent Variable	Model	Indep Variables	Predicted	CV(E)	Observed	CV(M)	T1	T2
Chlorophyll-a	1	P,N,Light,Flushing	67.3	0.35	78.4	0.177	0.44	0.86
Chlorophyll-a	2	P,Light, Flushing	80.0	0.35	78.4	0.177	-0.06	-0.12
Chlorophyll-a	3	P,N	81.0	0.39	78.4	0.177	-0.08	-0.19
Chlorophyll-a	4	P, Linear	71.4	0.47	78.4	0.177	0.20	0.52
Chlorophyll-a	5	P, Exponential	264.5	0.47	78.4	0.177	-2.59	-6.85
Chlorophyll-a (Used)	1	P,N,Light,Flushing	67.3	0.39	78.4	0.177	0.39	0.86
Secchi	1	Chl-a, Turbidity	0.57	0.28	0.96	0.090	1.86	5.80
Secchi	2	P,N	0.36	0.29	0.96	0.090	3.33	10.73
Secchi	3	P	0.26	0.29	0.96	0.090	4.44	14.32
Organic N		Chl-a, Turbidity	1697	0.25	1776	0.154	0.18	0.29
Total P - Ortho P		Chl-a, Turbidity	116	0.37	111	0.160	-0.13	-0.29
First Princ. Comp.		All	3199	0.35	2763	0.150	-0.42	-0.98
Second Princ. Comp.		All	15.4	0.31	24.6	0.142	1.50	3.27

Model equations developed from CE reservoir data set, given in Walker (1987), See Appendix C
t-statistics comparing observed & predicted concentrations:
T1 considering error typical of CE reservoir data set (CV(E)) Sum (T^2) = 6.10 46.23
T2 considering measurement error in observed mean (CV(M))
Observed Values are for June-August, 1991-1993
Secchi, Organic N, TP-OP Models Use Chlorophyll-a Predicted from Chl-a Model 3
First & Second Principle Components Computed from Chl-a, Secchi, Organic N, & Composite Nutrient Conc.

Table 9
Application of Empirical Models Relating Observed Nutrient Concentrations in Agency Lake to Measures of Trophic Response
Calibrated

Independent Variable	Value	Units	
Total Phosphorus	255	ppb	
Total Nitrogen	1816	ppb	
Mean Depth of Mixed Layer	1.86	m	
Summer Hydraulic Resid. Time	0.236	yrs	
Chlorophyll/Secchi Slope	0.012	m2/mg	* Calibrated
Chl-a Calibration Factor	0.87	-	* Calibrated
Non-Algal Turbidity	0.11	1/m	

Dependent Variable	Model	Indep Variables	Predicted	CV(E)	Observed	CV(M)	T1	T2
Chlorophyll-a	1	P,N,Light,Flushing	90.4	0.35	78.4	0.177	-0.41	-0.80
Chlorophyll-a	2	P,Light, Flushing	135.4	0.35	78.4	0.177	-1.56	-3.08
Chlorophyll-a	3	P,N	81.0	0.39	78.4	0.177	-0.08	-0.19
Chlorophyll-a	4	P, Linear	71.4	0.47	78.4	0.177	0.20	0.52
Chlorophyll-a	5	P, Exponential	264.5	0.47	78.4	0.177	-2.59	-6.85
Chlorophyll-a (Used)	1	P,N,Light,Flushing	78.6	0.39	78.4	0.177	-0.01	-0.02
Secchi	1	Chl-a, Turbidity	0.95	0.28	0.96	0.090	0.01	0.03
Secchi	2	P,N	0.36	0.29	0.96	0.090	3.33	10.73
Secchi	3	P	0.26	0.29	0.96	0.090	4.44	14.32
Organic N		Chl-a, Turbidity	1957	0.25	1776	0.154	-0.39	-0.63
Total P - Ortho P		Chl-a, Turbidity	136	0.37	111	0.160	-0.55	-1.27
First Princ. Comp.		All	2869	0.35	2763	0.150	-0.11	-0.25
Second Princ. Comp.		All	25.0	0.31	24.6	0.142	-0.05	-0.11

Model equations developed from CE reservoir data set, given in Walker (1987), See Appendix C
t-statistics comparing observed & predicted concentrations:

T1 considering error typical of CE reservoir data set (CV(E)) Sum (T^2) = 0.47 2.10

T2 considering measurement error in observed mean (CV(M))

Observed Values are for June-August, 1991-1993

Secchi, Organic N, TP-OP Models Use Chlorophyll-a Predicted from Chl-a Model 3

First & Second Principle Components Computed from Chl-a, Secchi, Organic N, & Composite Nutrient Conc.

Table 10
Water & Nutrient Inflows Used in Modeling
April–September, 1991–1993 Average

		Total P		Ortho P		Total N		Inorganic N	
	Flow	Load	Conc	Load	Conc	Load	Conc	Load	Conc
Term	hm3	kg	ppb	kg	ppb	kg	ppb	kg	ppb
Tributary Stations									
UK100	80.0	6511	81	5613	70	8604	108	6027	75
UK200	68.3	5985	88	4374	64	13046	191	8519	125
UK300	98.9	9607	97	7116	72	15315	155	7252	73
UK400	85.8	8638	101	6175	72	18606	217	9999	117
UK500	98.7	14742	149	11667	118	31022	314	6290	64
UK600	38.2	5969	156	3497	92	26612	697	2135	56
UK700	13.9	1128	81	668	48	6439	462	664	48
Lake Inflows									
Wood River	98.7	14742	149	11667	118	31022	314	6290	64
Sevenmile Canal	38.2	5969	156	3497	92	26612	697	2135	56
Fourmile Canal	13.9	1128	81	668	48	6439	462	664	48
Ungauged	14.8	2009	136	1178.6	80	9353	634	792	54
Total External	165.6	23848	144	17011	103	73427	443	9880	60
Precipitation	4.1	312	77	312	77	19263	4749	19263	4749
Evaporation	29.6								
Net Inflow	140.1	24160	172	17323	124	92690	662	29144	208

Table 11
Model Inputs & Results

Case	–		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
External Load	–		1991–1993					Reduced 44%					Reduced 44%					Reduced 44%				
Volume & Depth	–		1991–1993					1991–1993					Increased 30%					Increased 30%				
Scenario	–		1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4
Method	–	Observ	A	A (Low)	A (High)	B	C	A	A (Low)	A (High)	B	C	A	A (Low)	A (High)	B	C	A	A (Low)	A (High)	B	C
Net Inflow Volume	hm3		140.1	140.1	140.1	140.0	140.0	140.0	140.1	140.1	140.0	140.0	140.0	140.1	140.1	140.0	140.0	140.0	140.1	140.1	140.0	140.0
External P Load	kg		23848	23848	23848	23848	23848	13355	13355	13355	13355	13355	23848	23848	23848	23848	23848	13355	13355	13355	13355	13355
Atmospheric P Load	kg		312	312	312	312	312	312	312	312	312	312	312	312	312	312	312	312	312	312	312	312
Total P Load	kg		24160	24160	24160	24160	24160	13667	13667	13667	13667	13667	24160	24160	24160	24160	24160	13667	13667	13667	13667	13667
Mean Volume	hm3		66.1	66.1	66.1	66.1	66.1	66.1	66.1	66.1	66.1	66.1	85.9	85.9	85.9	85.9	85.9	85.9	85.9	85.9	85.9	85.9
Inflow Ortho P/Total P			0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Sed. Rate Calibration			1.00	0.50	2.00	0.00	1.00	1.00	0.50	2.00	0.00	1.00	1.00	0.50	2.00	0.00	1.00	1.00	0.50	2.00	0.00	1.00
P Scale Factor			1.00	1.00	1.00	1.00	2.51	1.00	1.00	1.00	1.00	2.51	1.00	1.00	1.00	1.00	2.51	1.00	1.00	1.00	1.00	2.51
Internal Recycle	mg/m2–d		0.00	0.00	0.00	1.78	0.00	0.00	0.00	0.00	1.78	0.00	0.00	0.00	0.00	1.78	0.00	0.00	0.00	0.00	1.78	0.00
Inflow P Conc	ppb		172.5	172.5	172.5	172.5	172.5	97.6	97.6	97.6	97.6	97.6	172.5	172.5	172.5	172.5	172.5	97.6	97.6	97.6	97.6	97.6
Mean Depth	m		1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Overflow Rate	m/yr		7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85
Residence Time	yrs		0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Lake Total P	ppb	255	102	122	81	255	255	67	77	55	180	168	94	114	74	255	235	63	73	51	180	157
Chl–a : Fixed (N–150)/P Assumption																						
Lake Total N		1816	813	944	681	1818	1815	587	654	512	1328	1246	763	896	634	1818	1687	559	630	483	1328	1176
Compos. Nutrient Conc.	ppb	121.9	48.5	58.1	38.9	122.1	121.8	31.9	36.9	26.5	86.2	80.2	44.8	54.6	35.4	122.1	112.5	29.9	35.1	24.4	86.2	75.1
Chlorophyll–a	ppb	78.4	30.0	36.9	23.1	78.9	78.7	18.2	21.7	14.4	56.5	52.4	26.4	32.9	20.0	72.0	67.2	16.3	19.8	12.7	52.8	46.0
Non–Algal Turbidity	1/m	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Secchi Depth	m	0.96	2.17	1.84	2.65	0.95	0.96	3.13	2.77	3.66	1.28	1.37	2.40	2.02	2.93	1.04	1.10	3.37	2.95	3.95	1.36	1.53
Organic N	ppb	1776	849	1007	691	1963	1959	579	658	493	1452	1359	765	914	621	1806	1697	537	616	454	1367	1214
Total P – Ortho P	ppb	111	52	64	39	139	138	31	37	24	99	92	45	57	34	126	118	27	34	21	92	80
PC–1	–	3.44	2.69	2.85	2.50	3.46	3.46	2.33	2.46	2.17	3.18	3.12	2.61	2.77	2.41	3.41	3.35	2.26	2.40	2.09	3.14	3.03
PC–2	–	1.39	1.37	1.38	1.36	1.40	1.40	1.34	1.35	1.32	1.40	1.39	1.36	1.37	1.35	1.39	1.39	1.33	1.35	1.31	1.39	1.39
Chl–a : Fixed Nitrogen Assumption																						
Lake Total N	ppb	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1818	1816	1816	1816	1816	1816	1816	1816
Compos. Nutrient Conc	ppb	121.9	81.9	91.5	70.2	122.0	121.9	60.2	67.4	51.4	110.0	106.9	77.7	88.2	65.4	122.0	119.6	57.0	64.9	47.9	110.0	104.0
Chlorophyll–a	ppb	78.4	53.6	59.9	45.5	78.8	78.8	38.4	43.5	32.1	71.7	69.8	47.6	53.9	39.9	71.9	70.6	34.5	39.6	28.4	65.9	62.7
Algal Bloom Frequencies																						
Freq (Chl–a > 30 ppb)	%	64%	32%	35%	29%	55%	55%	27%	29%	25%	44%	42%	31%	34%	28%	55%	52%	27%	28%	25%	44%	41%
Freq (Chl–a > 60 ppb)	%	55%	25%	28%	21%	51%	51%	19%	20%	17%	38%	36%	23%	27%	20%	51%	47%	18%	20%	16%	38%	34%

Method	Description
A	CE Model Network, Without Calibration to Agency Lake – Best Estimate
A (low)	CE Model Network, Without Calibration to Agency Lake – Low Estimate of Sedimentation Rate
A (high)	CE Model Network, Without Calibration to Agency Lake – High Estimate of Sedimentation Rate
B	P Retention Model Calibrated Using Sedimentation Rate & Internal Recycle
C	P Retention Model Calibrated Using Constant Scale Factor for Concentration

Appendix A - Time Series Plots

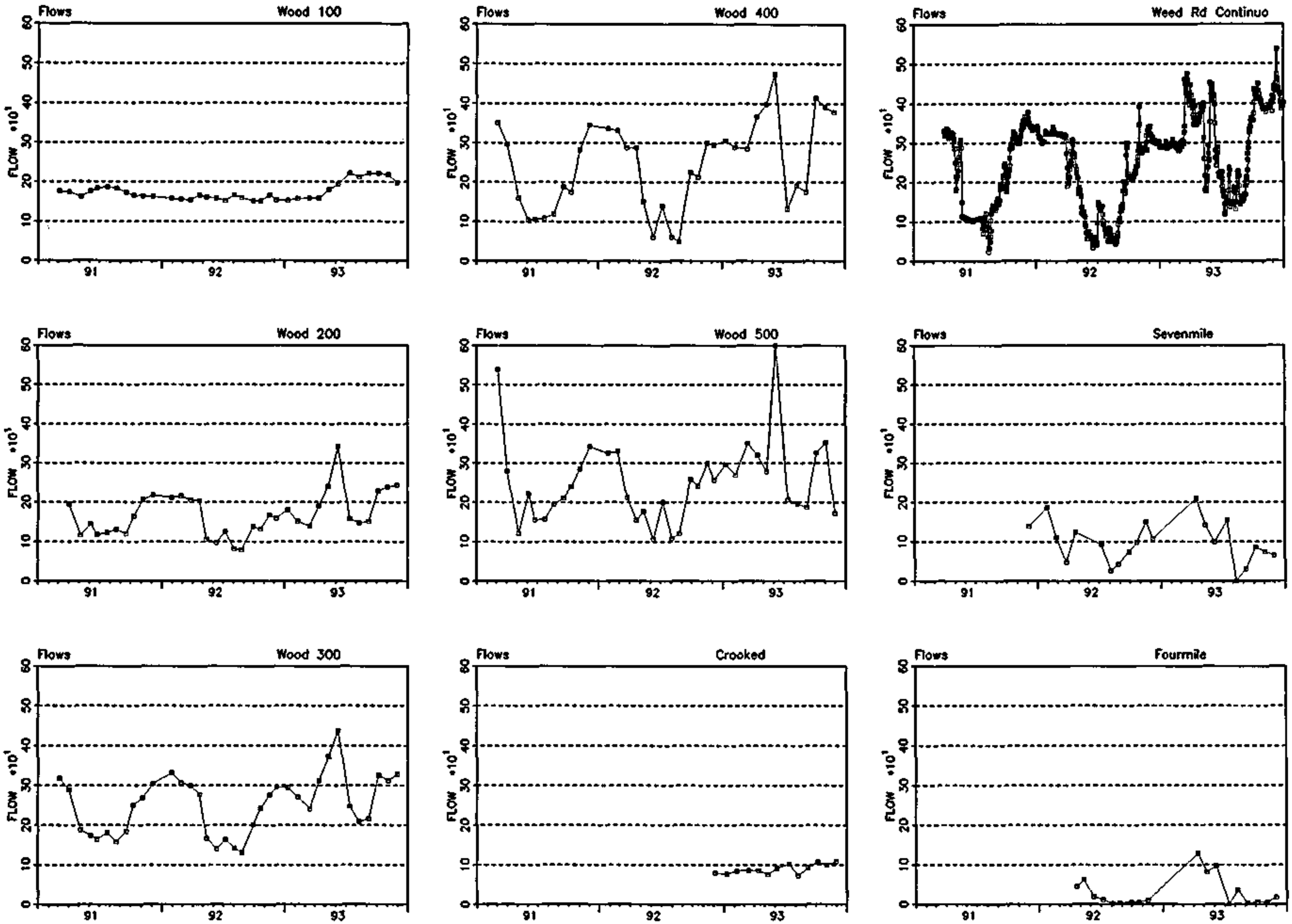
Tributary Flows

River & Lake Stations

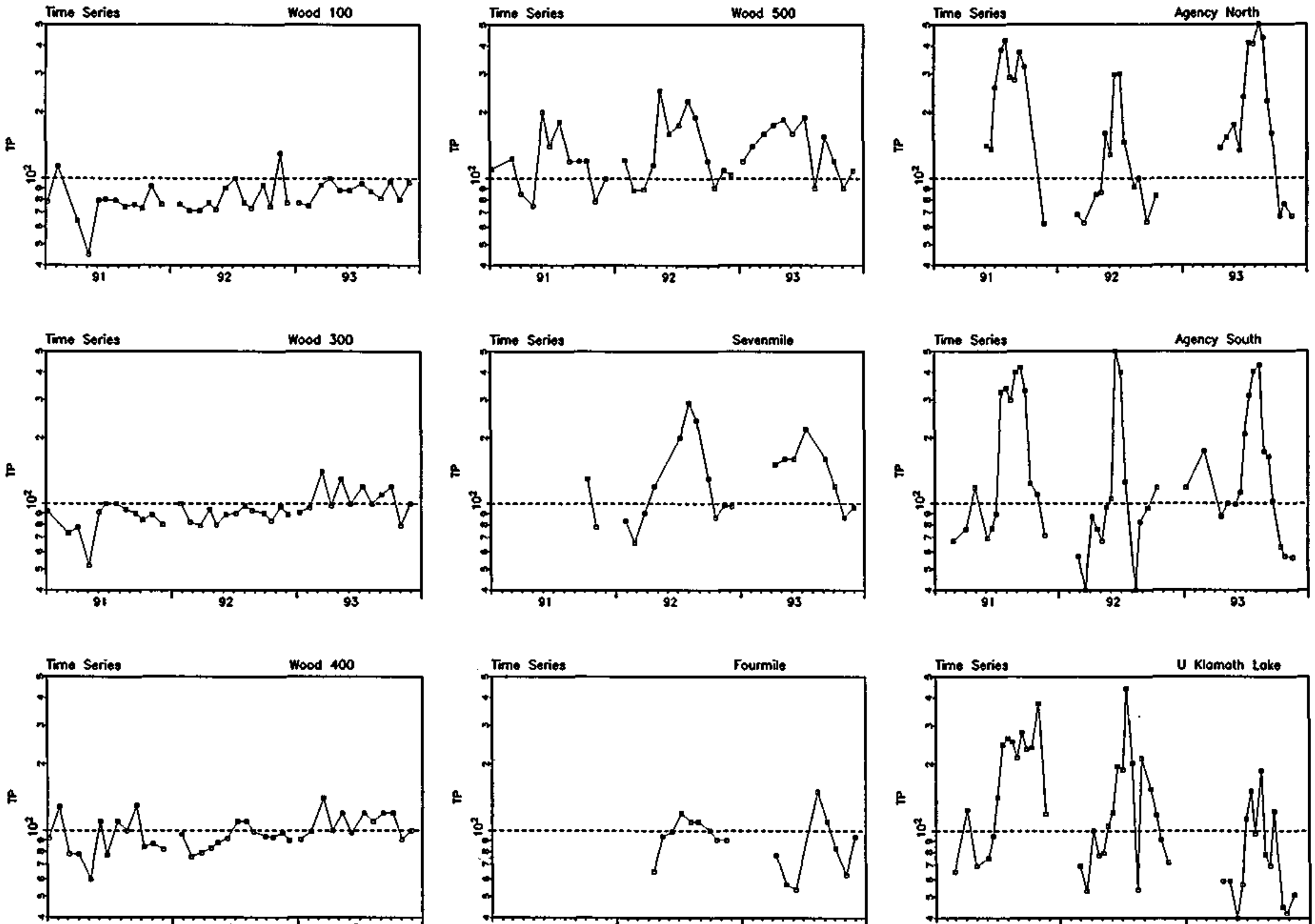
- Total Phosphorus (ppb)
- Ortho Phosphorus (ppb)
- Total Nitrogen (ppb)
- Inorganic Nitrogen (ppb)
- Conductivity (uS/cm^2)
- Temperature (deg-c)
- Dissolved Oxygen (ppm)
- pH

Agency Lake Stations

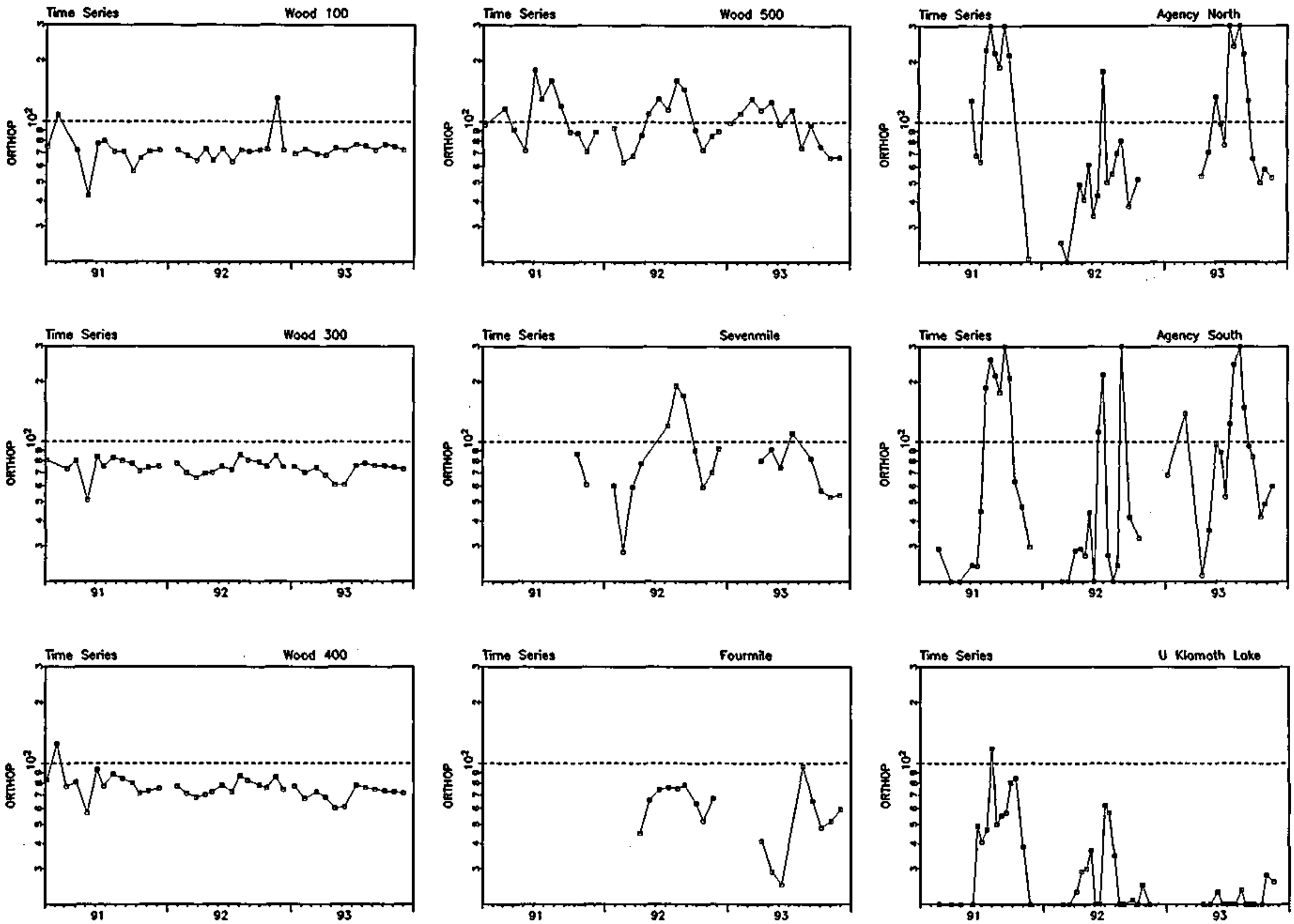
Agency & Upper Klamath Lake Stations



Flows
Wood 100
Wood 400
Weed Rd Continuo
Wood 200
Wood 500
Sevenmile
Wood 300
Crooked
Fourmile
FLOW *10¹
0
10
20
30
40
50
60
91
92
93



Time Series
Wood 100
Wood 500
Agency North
Wood 300
Sevenmile
Agency South
Wood 400
Fourmile
U Klamath Lake
TP
10^2
91
92
93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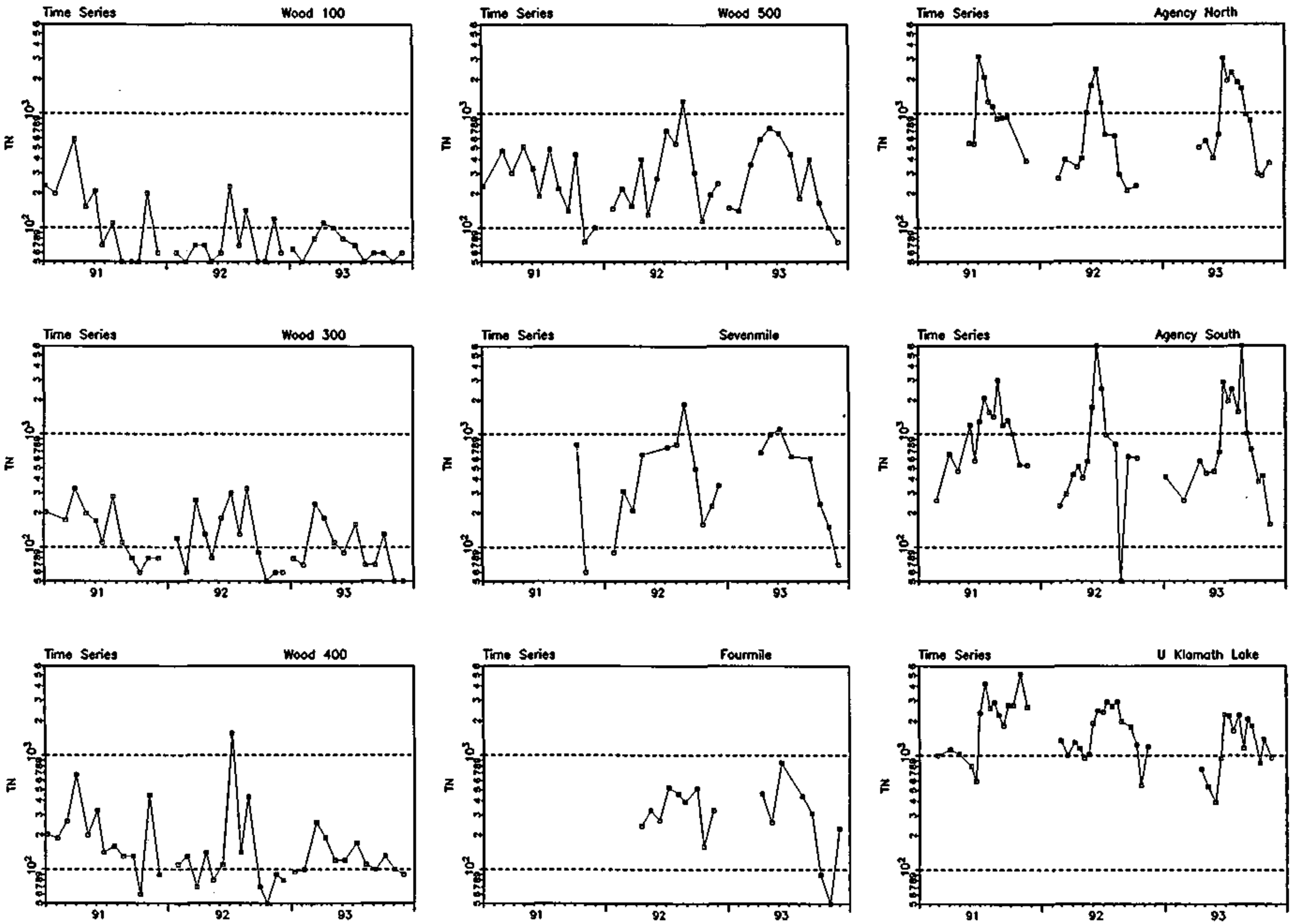
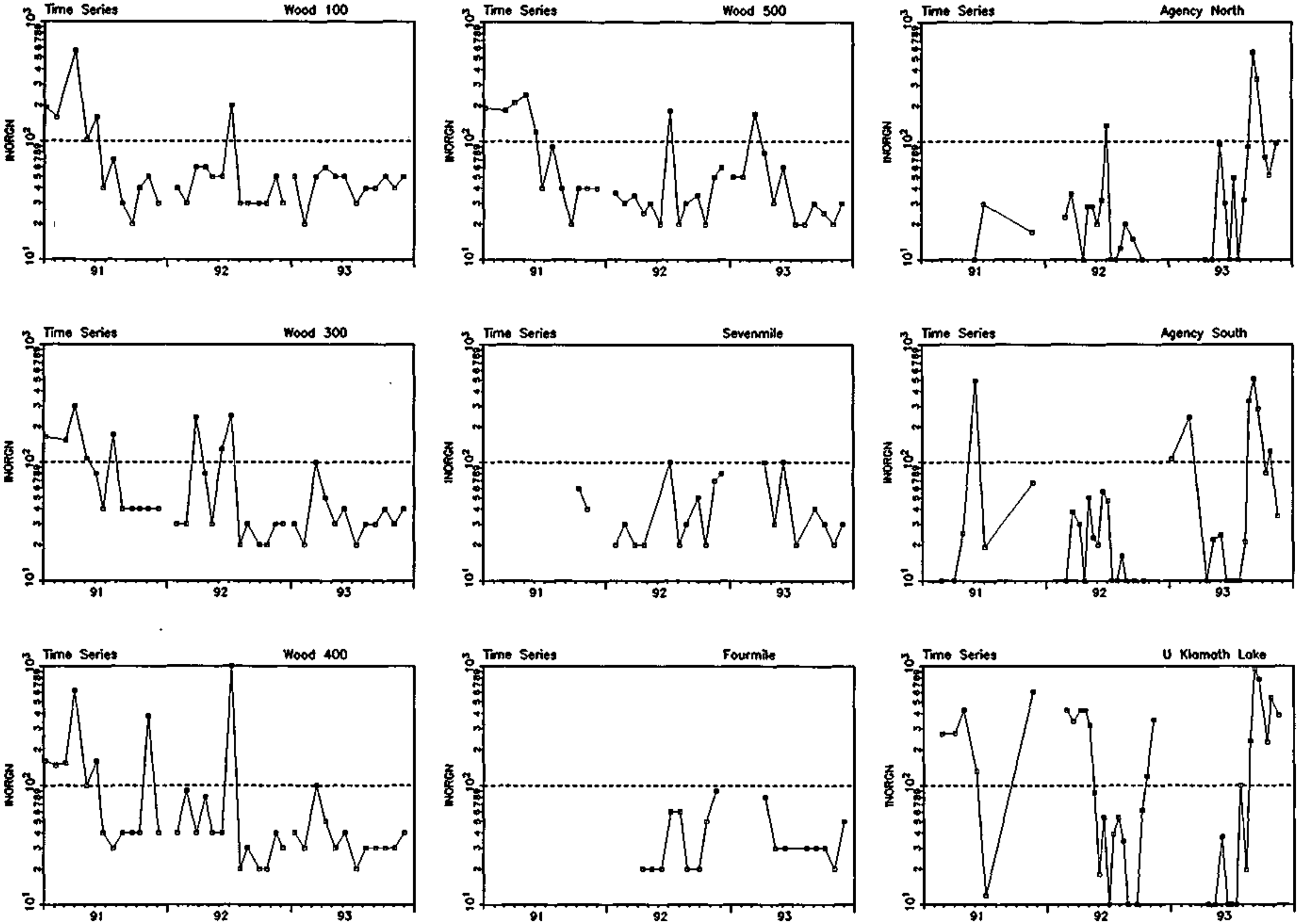
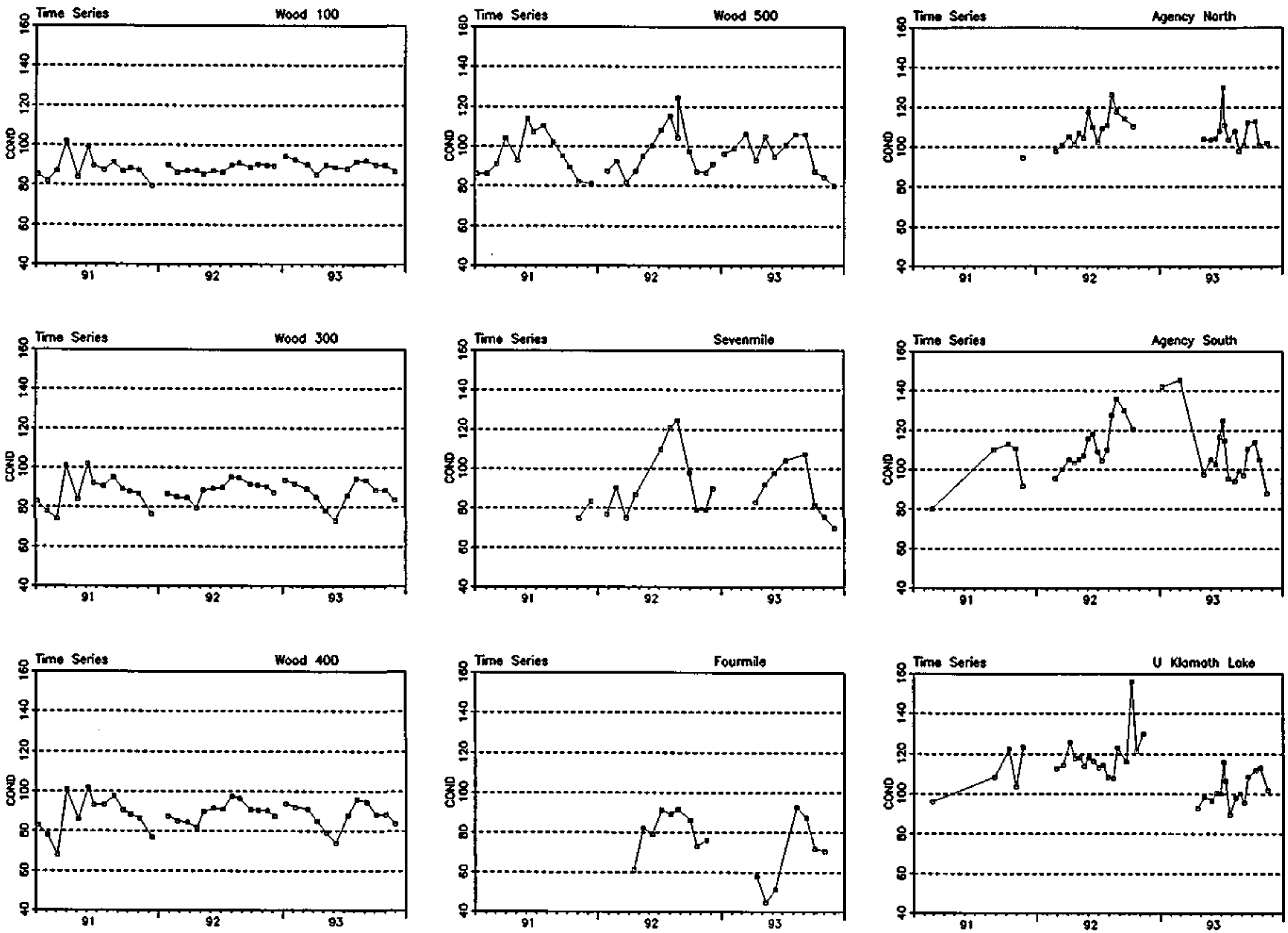
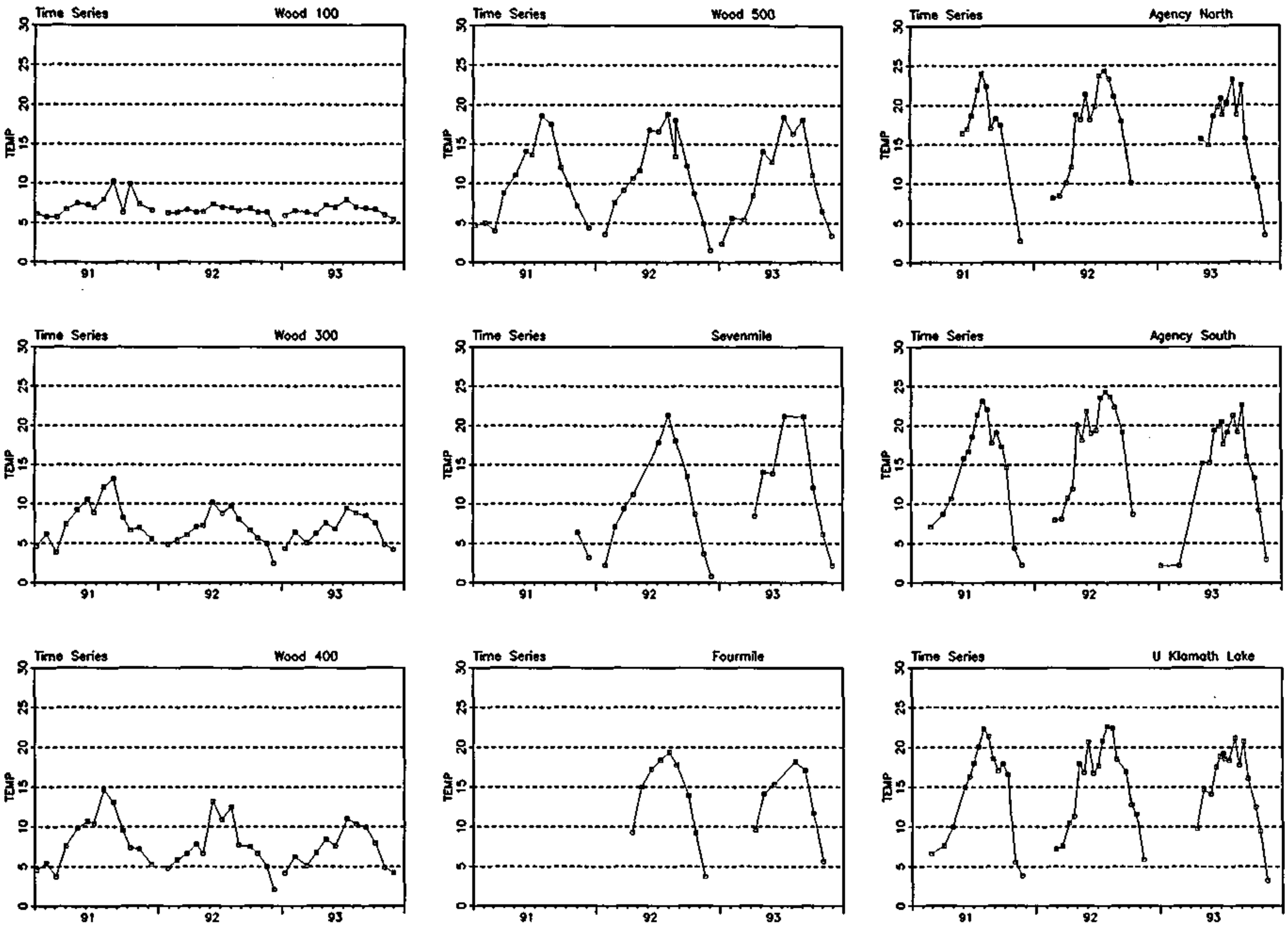
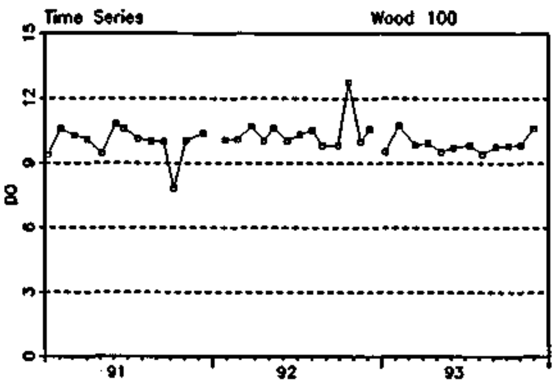
Wood 100
Time Series
Wood 500
Time Series
Agency North
Time Series
Wood 300
Time Series
Sevenmile
Time Series
Agency South
Time Series
Wood 400
Time Series
Fourmile
Time Series
U Klamath Lake
ORTHOP
10^2
91
92
93

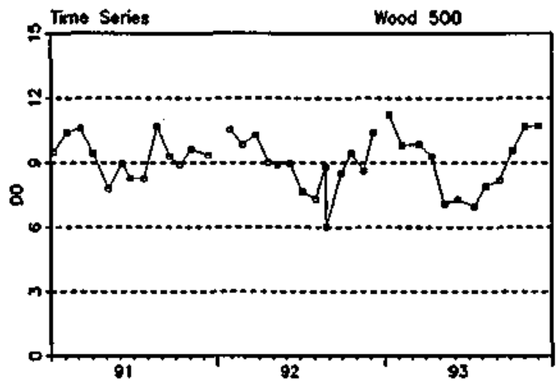

Time Series
Wood 100
Time Series
Wood 500
Time Series
Agency North
Time Series
Wood 300
Time Series
Sevenmile
Time Series
Agency South
Time Series
Wood 400
Time Series
Fourmile
Time Series
U Klamath Lake
TN
91
92
93

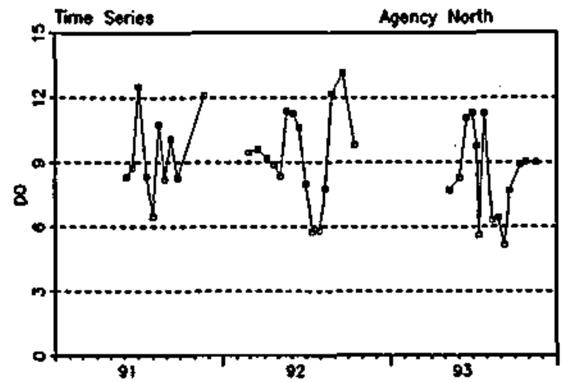

Time Series
Wood 100
Time Series
Wood 500
Time Series
Agency North
Time Series
Wood 300
Time Series
Sevenmile
Time Series
Agency South
Time Series
Wood 400
Time Series
Fourmile
Time Series
U Klamath Lake
INORGN
TNORGN
10^1
10^2
10^3
91
92
93

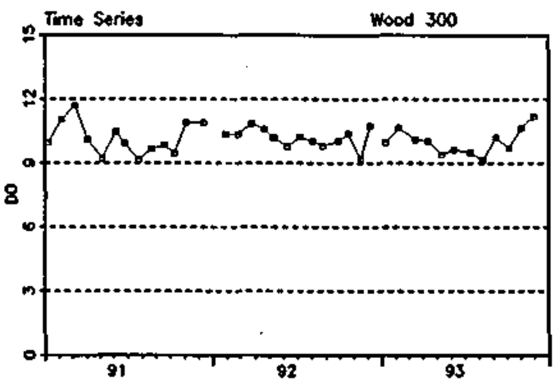

Time Series
Wood 100
Wood 500
Agency North
Wood 300
Sevenmile
Agency South
Wood 400
Fourmile
U Klamath Lake
COND
40
60
80
100
120
140
160
91
92
93

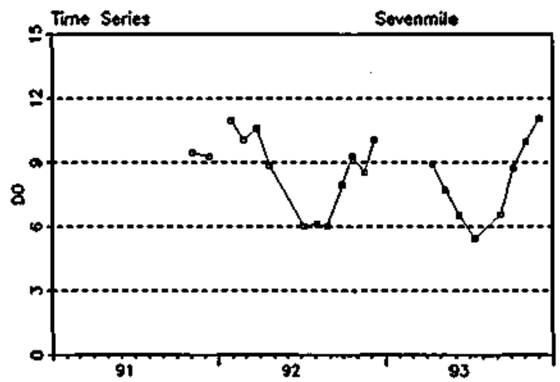

Time Series
Wood 100
Time Series
Wood 500
Time Series
Agency North
Time Series
Wood 300
Time Series
Sevenmile
Time Series
Agency South
Time Series
Wood 400
Time Series
Fourmile
Time Series
U Klamath Lake
TEMP
0
5
10
15
20
25
30
91
92
93

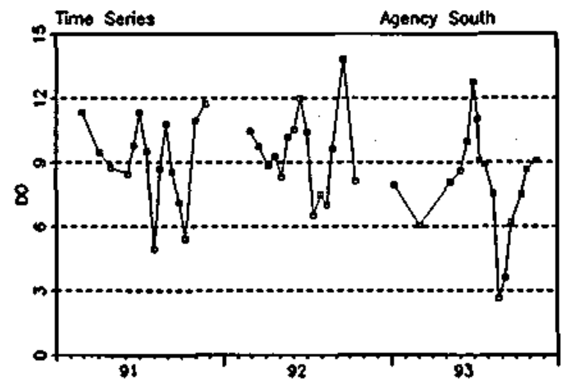

Time Series
Wood 100
DO
0
3
6
9
12
15
91
92
93

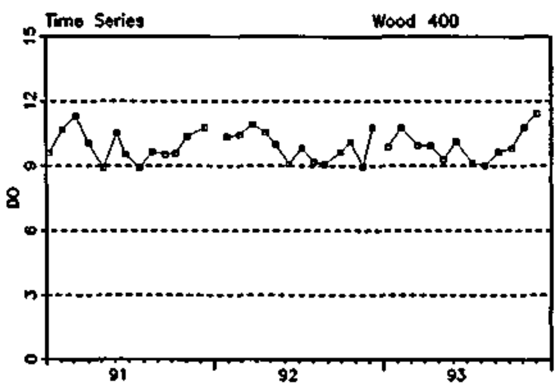

Time Series
Wood 500
DO
0
3
6
9
12
15
91
92
93

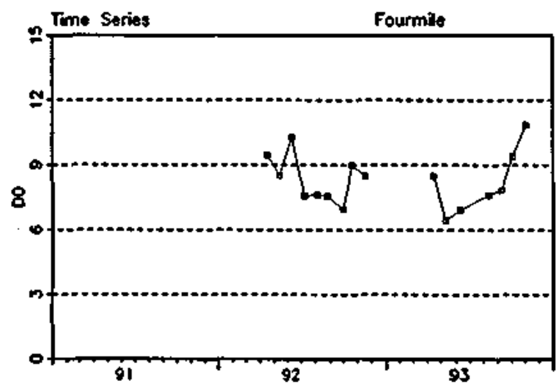

Time Series
Agency North
DO
0
3
6
9
12
15
91
92
93

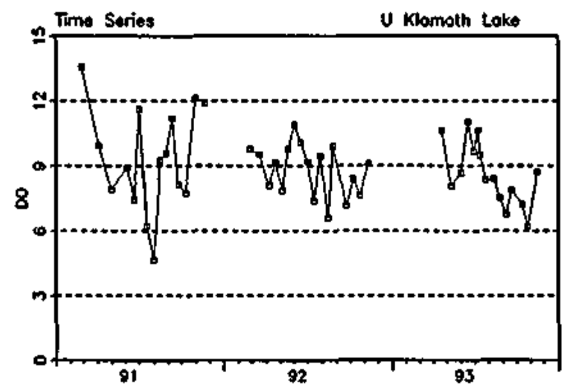

Time Series
Wood 300
DO
0
3
6
9
12
15
91
92
93

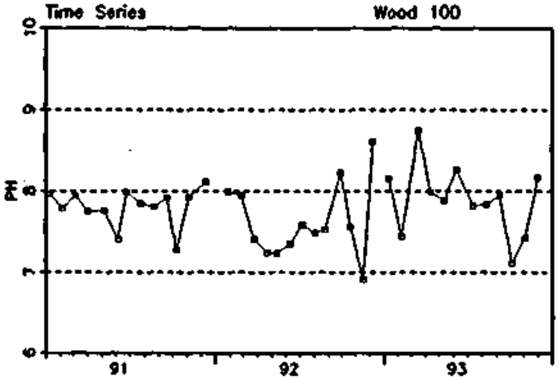

Time Series
Sevenmile
DO
0
3
6
9
12
15
91
92
93

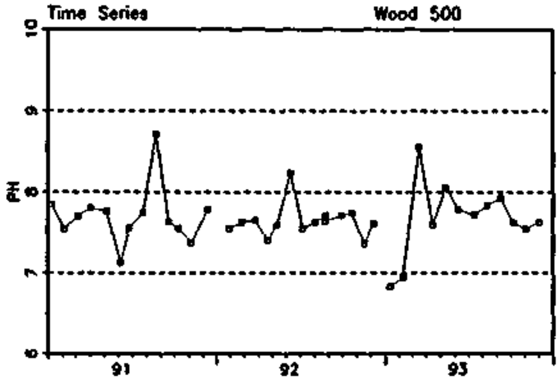

Time Series
Agency South
DO
0
3
6
9
12
15
91
92
93


Time Series
Wood 400
DO
0
3
6
9
12
15
91
92
93


Time Series
Fourmile
DO
0
3
6
9
12
15
91
92
93


Time Series
U Klamath Lake
DO
0
3
6
9
12
15
91
92
93


Time Series
Wood 100
PH
6
7
8
9
10
91
92
93


Time Series
Wood 500
PH
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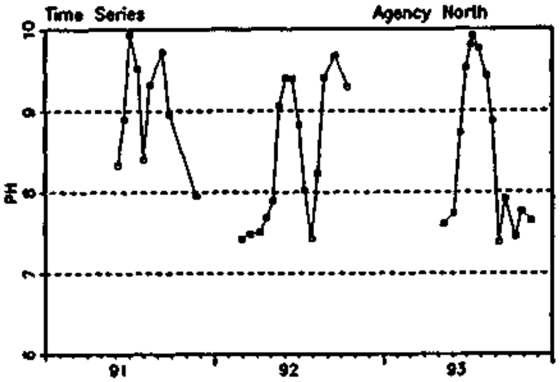
92
93


Time Series
Agency North
PH
6
7
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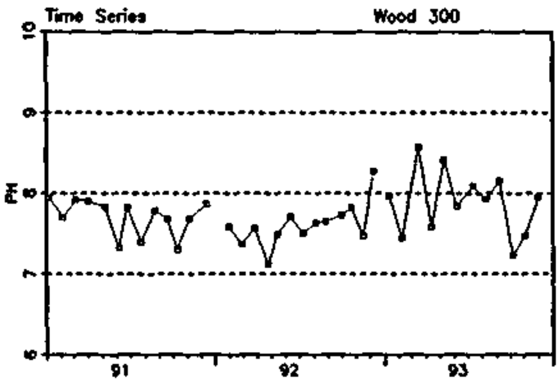
91
92
93


Time Series
Wood 300
PH
6
7
8
9
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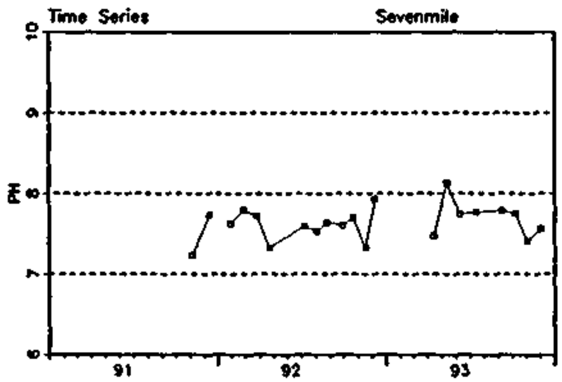
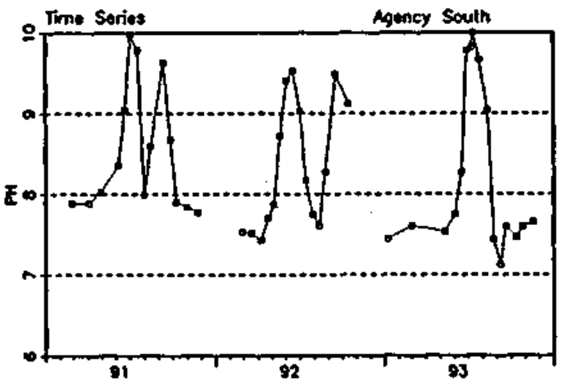
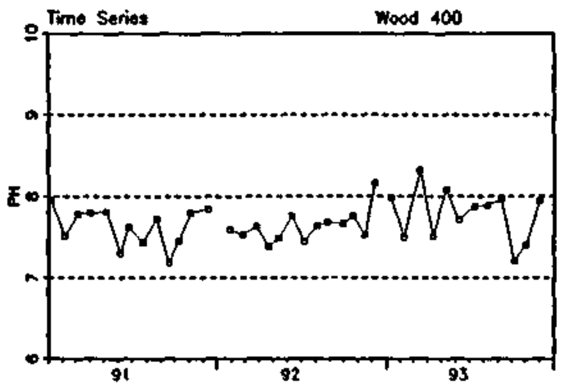
91
92
93


Time Series
Sevenmile
PH
6
7
8
9
10
91
92
93


Time Series
Agency South
PH
6
7
8
9
10
91
92
93


Time Series
Wood 400
PH
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92
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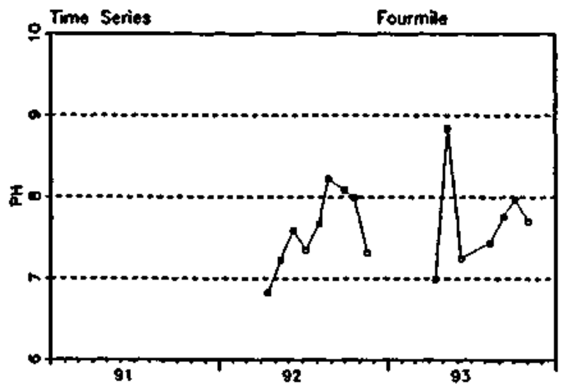
Time Series
Fourmile
PH
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7
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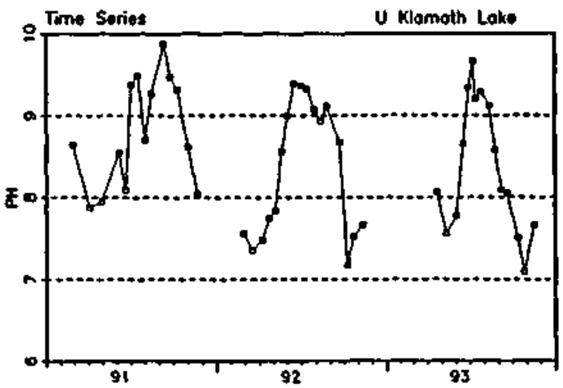
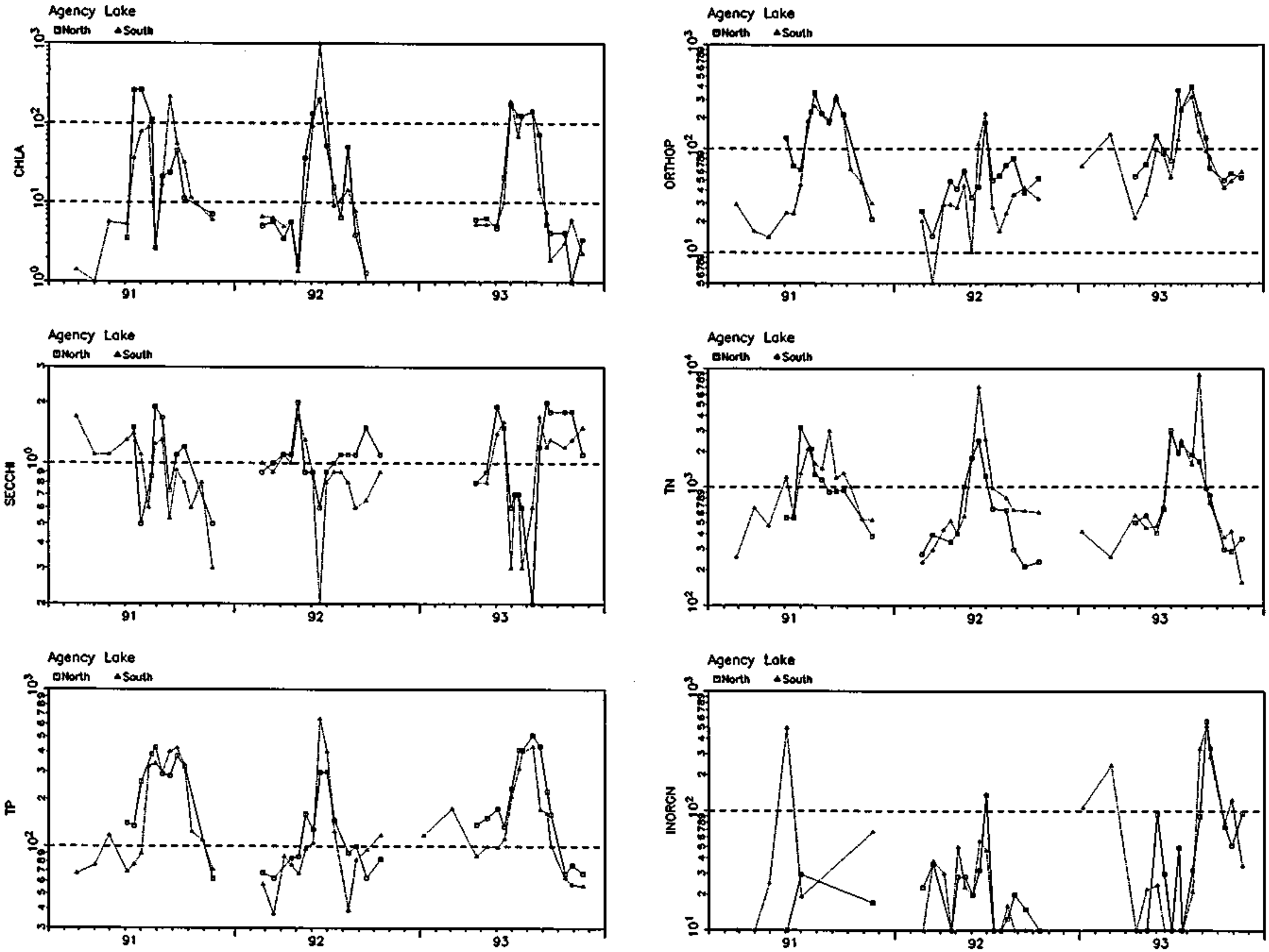
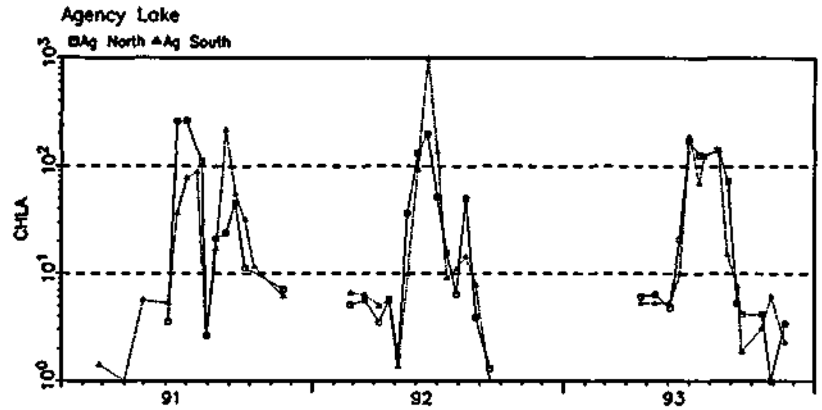
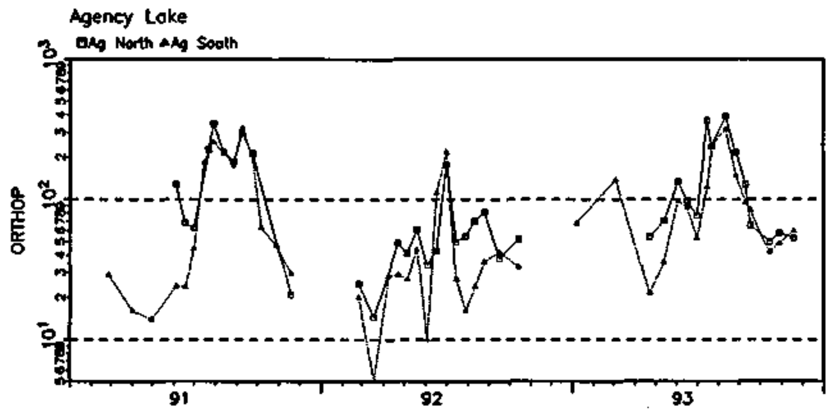
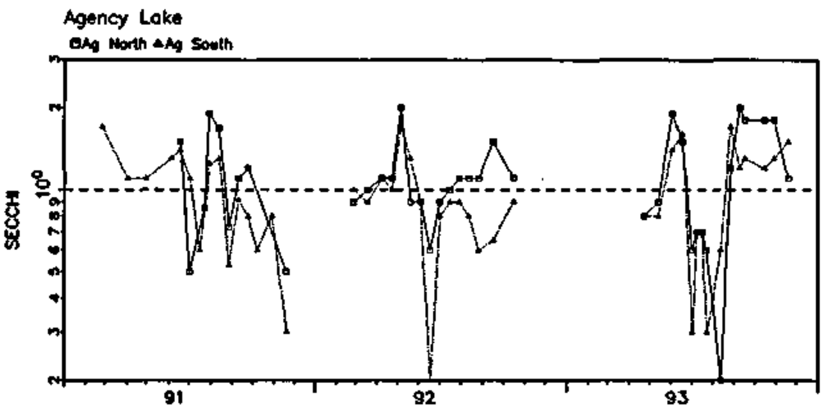
93


Time Series
U Klamath Lake
PH
6
7
8
9
10
91
92
93


Agency Lake
North
South
CHLA
91
92
93
ORTHOP
SECCHI
TN
TP
INORGN


Agency Lake
Ag North Ag South
CHLA
91
92
93


Agency Lake
Ag North Ag South
ORTHOP
91
92
93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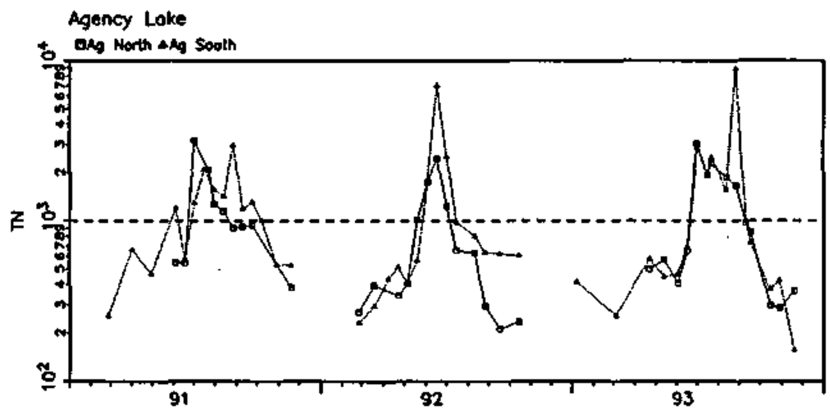
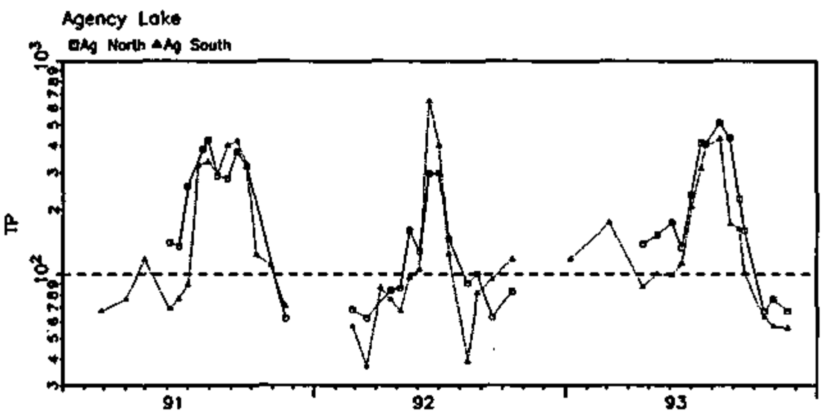
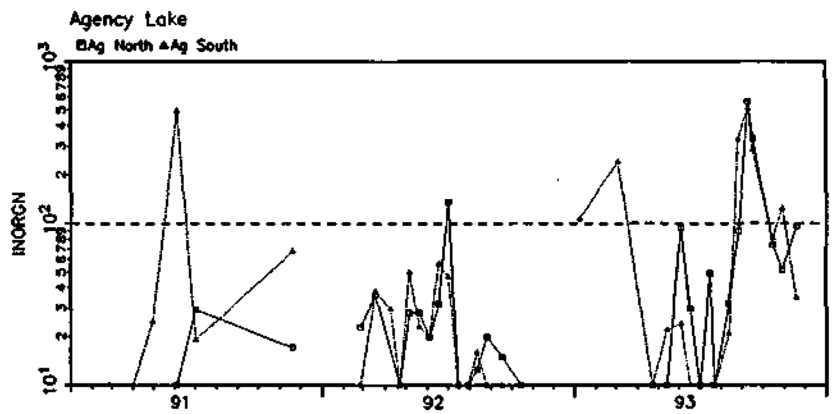
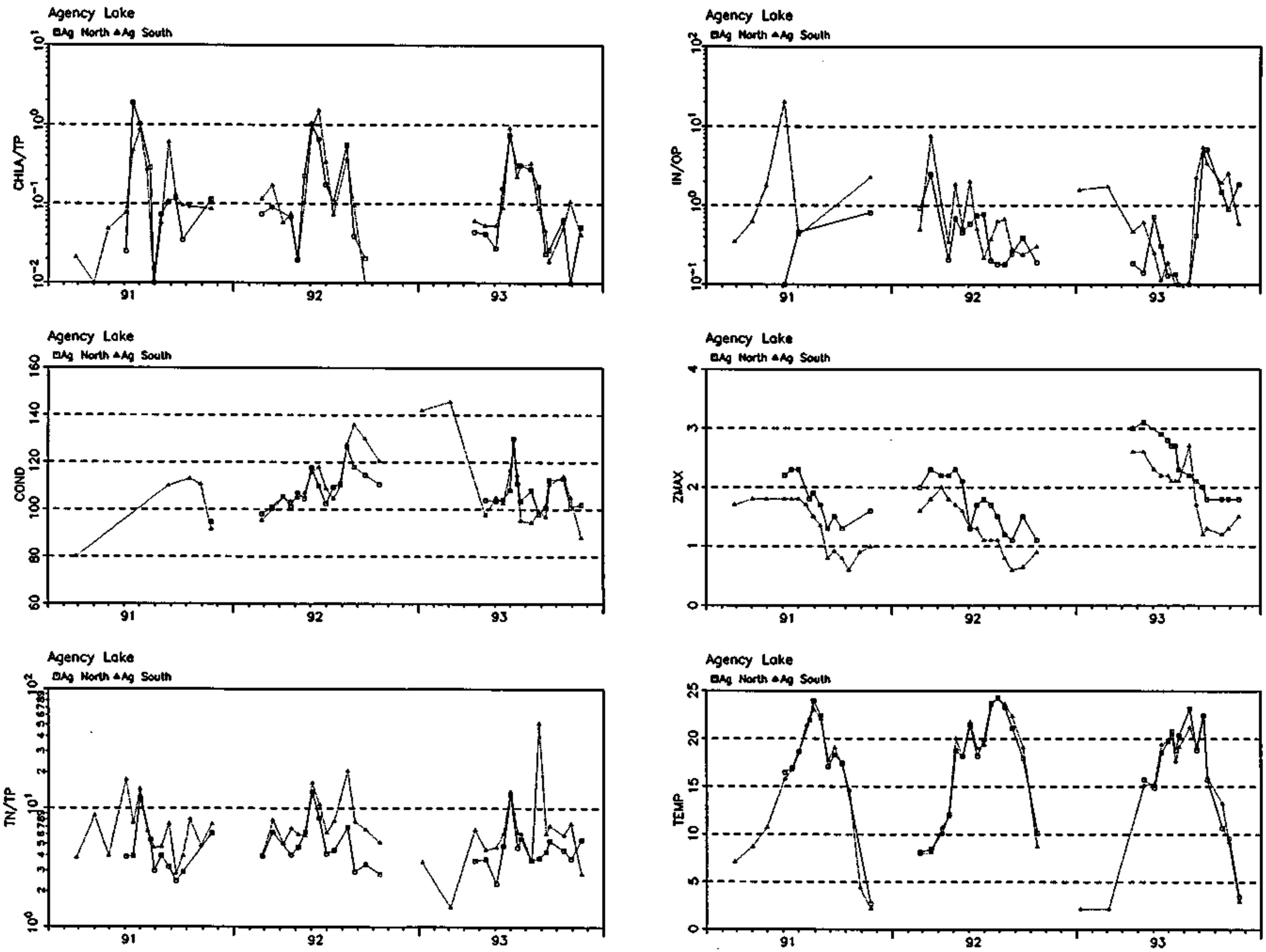
Ag North Ag South
SECCHI
91
92
93


Agency Lake
Ag North Ag South
TN
91
92
93


Agency Lake
Ag North Ag South
TP
91
92
93


Agency Lake
Ag North Ag South
INORGN
91
92
93


Agency Lake
Ag North Ag South
CHLA/TP
IN/OP
COND
ZMAX
TN/TP
TEMP
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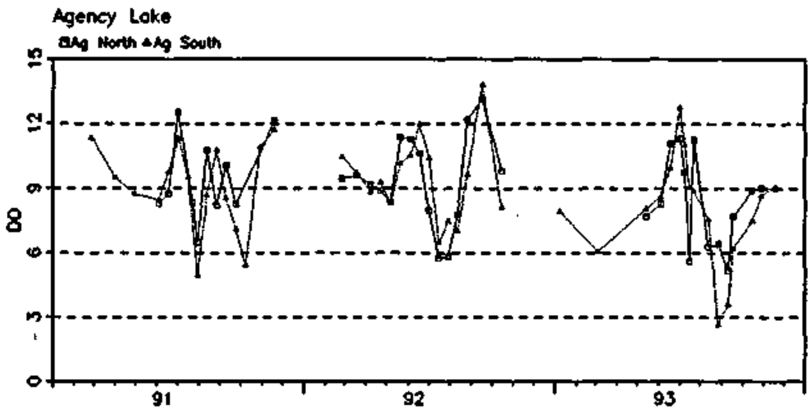
92
93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Ag North Ag South
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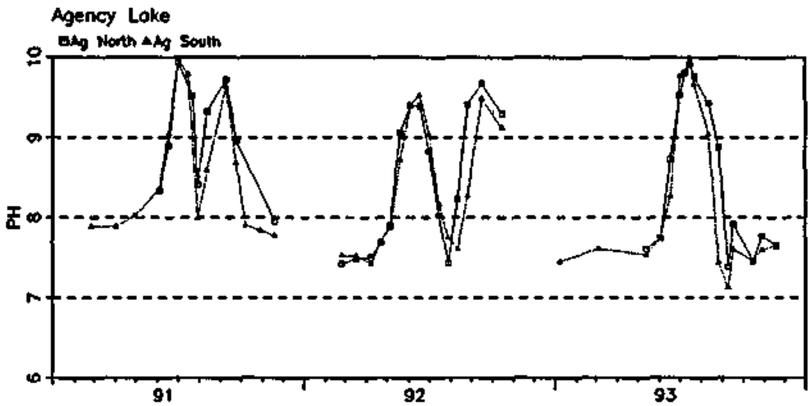
Agency Lake
Ag North Ag South
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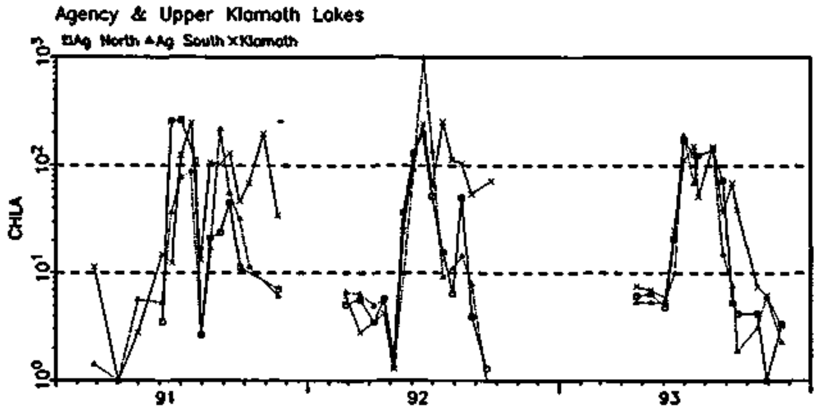
Agency & Upper Klamath Lakes
Ag North Ag South Klamath
CHLA
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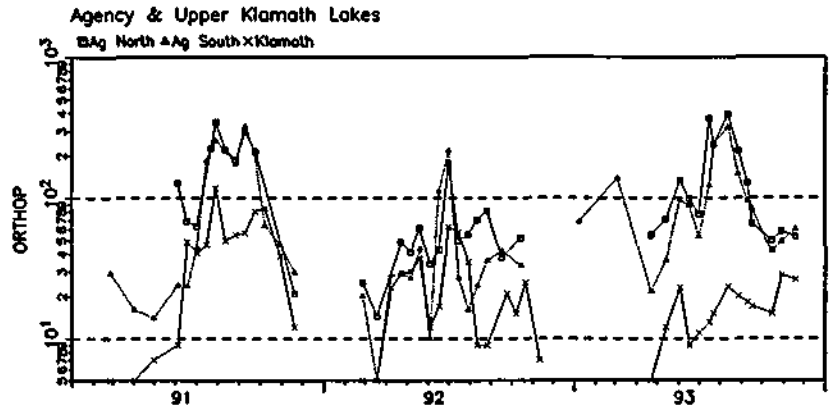
92
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
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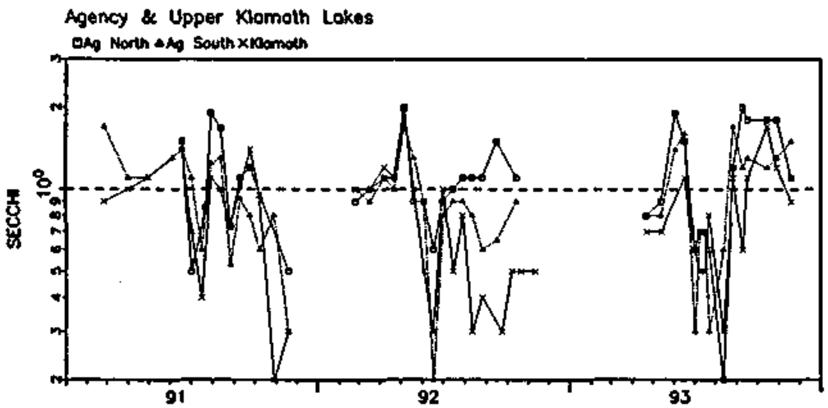
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
SECCHI
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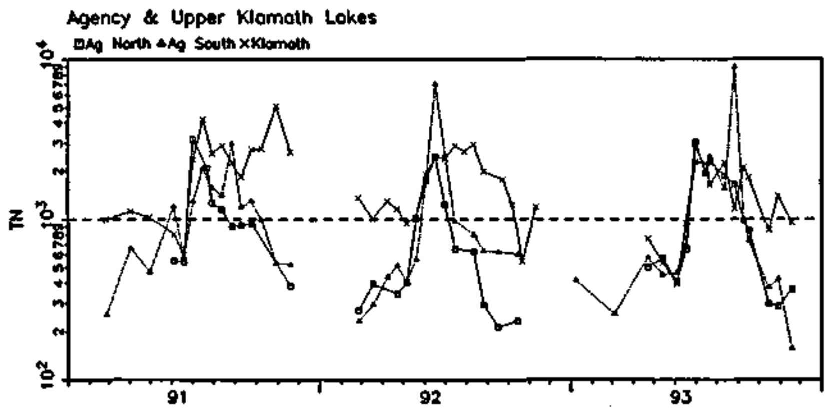
92
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
TN
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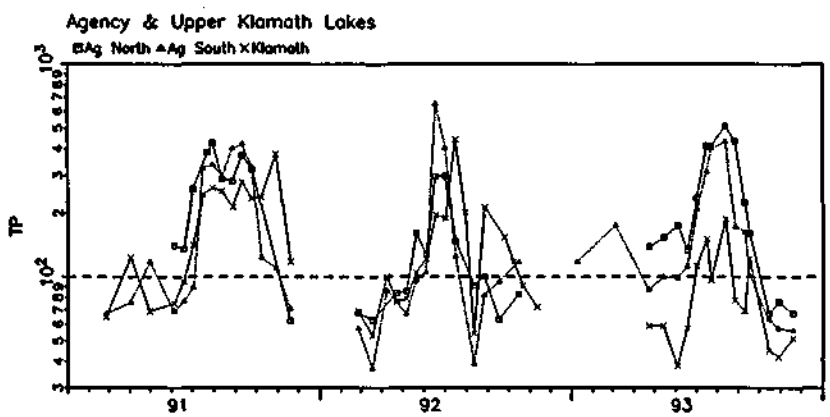
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
TP
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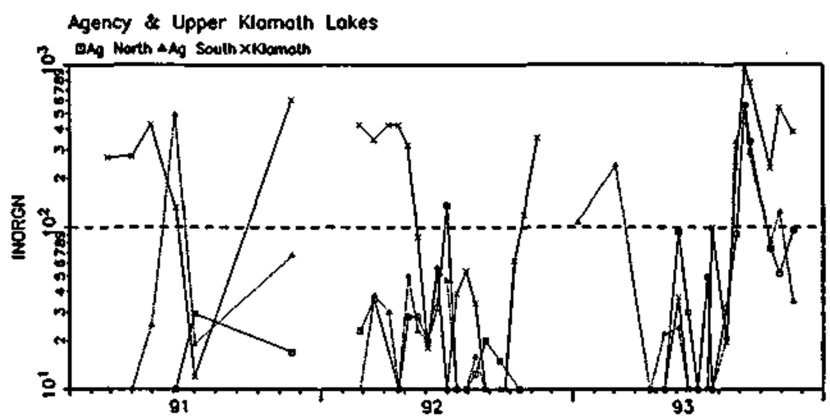
92
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
INORGN
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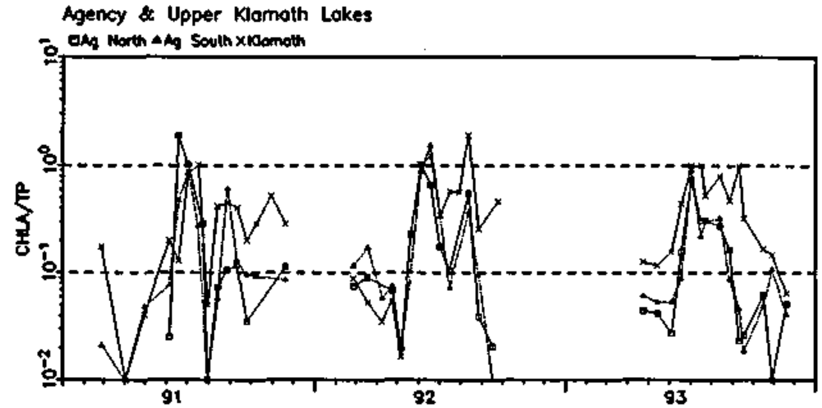
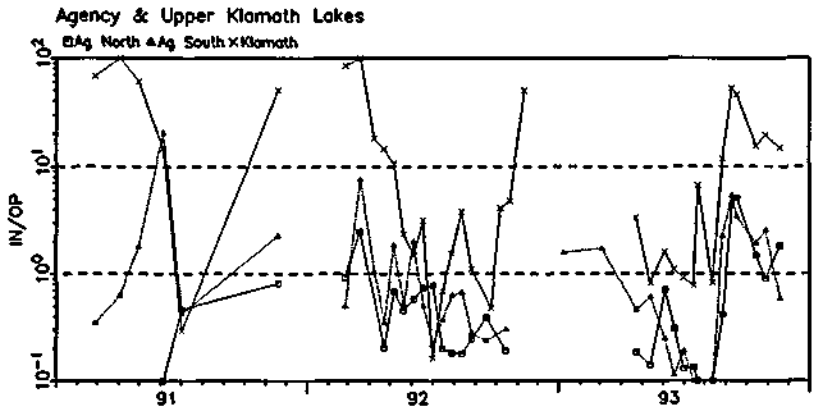
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
CHLA/TP
91
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
IN/OP
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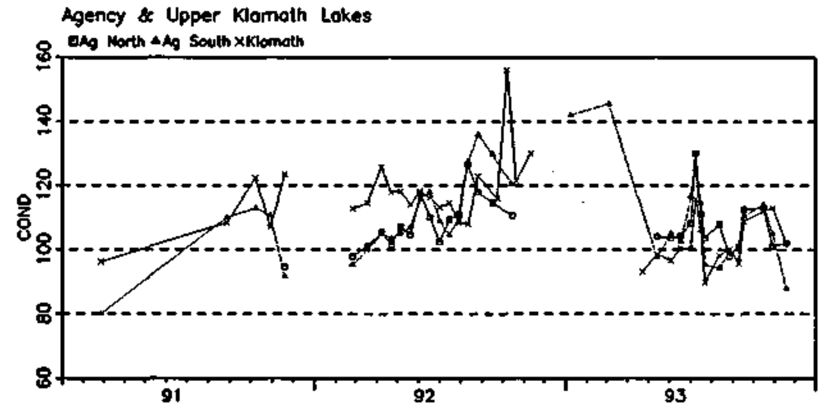
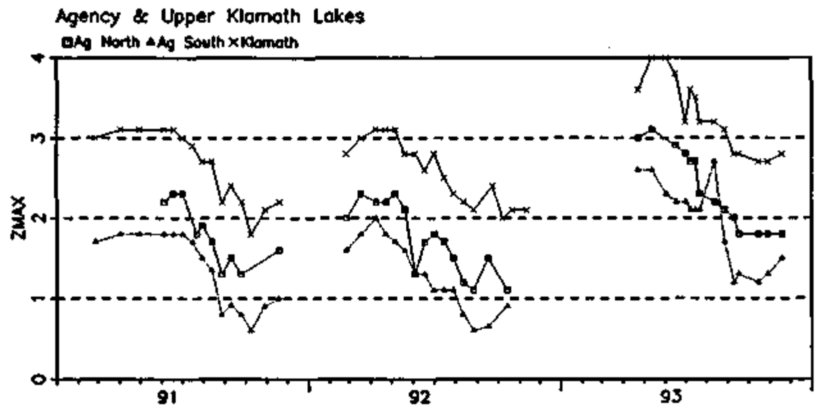
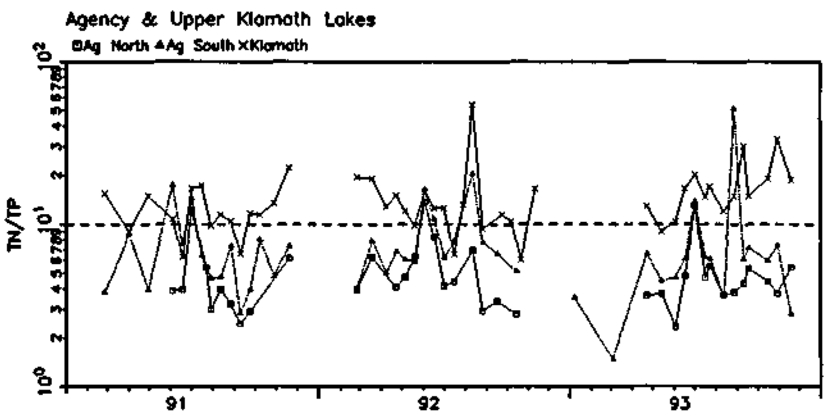
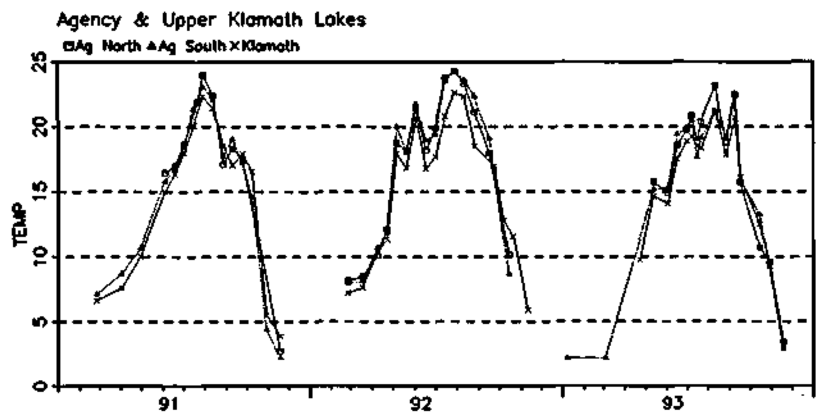
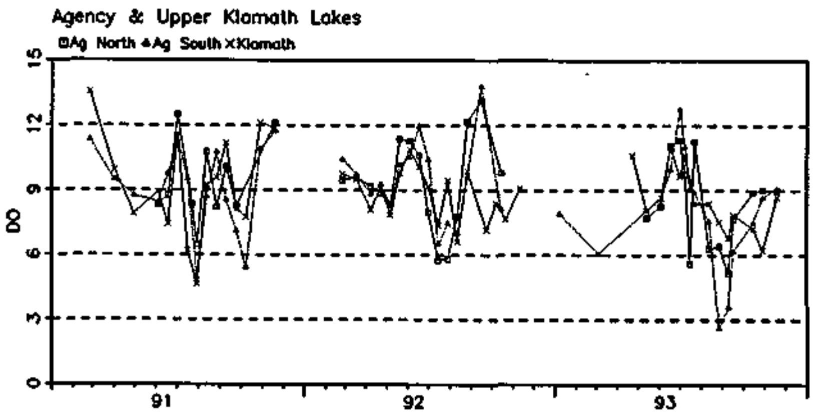
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
COND
91
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
ZMAX
91
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
TN/TP
91
92
93


Agency & Upper Klamath Lakes
□Ag North ▲Ag South ×Klamath
TEMP
91
92
93


Agency & Upper Klamath Lakes
Ag North Ag South Klamath
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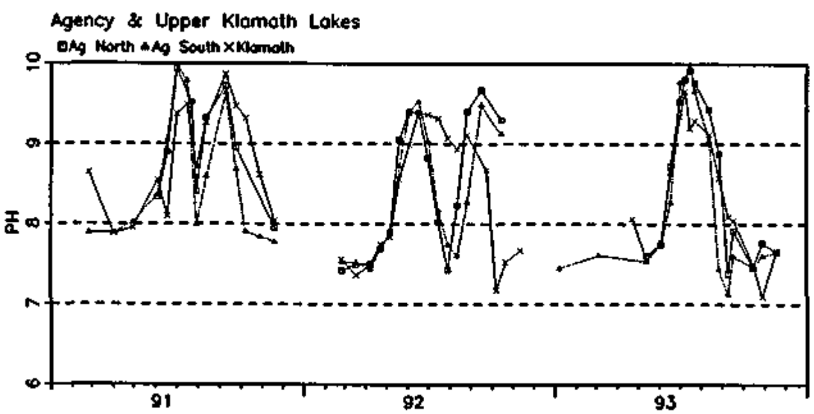
Agency & Upper Klamath Lakes
Ag North Ag South Klamath
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Appendix B - Tributary Flows & Fluxes

UK100 - Dixon Road

UK200 - Ft. Klamath

UK300 - Looseley Road

UK400 - Weed Road

UK500 - Agency Dike

UK600 - Sevenmile Canal

UK700 - Fourmile Canal

Tributary Flows & Fluxes

STATION: UK100 Wood River @ Dixon Road

		Flow-Weighted-Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	12.47	56.5	60.6	417.8	386.0	94.9	705	755	5211	4814	1184
9105	12.75	57.8	56.3	180.1	130.5	89.6	736	717	2295	1663	1142
9106	13.26	79.3	78.7	132.8	93.6	93.7	1051	1043	1760	1242	1243
9107	14.15	79.1	73.7	96.2	59.8	88.2	1119	1042	1360	846	1247
9108	13.92	75.3	70.0	63.8	38.4	90.1	1048	974	888	535	1255
9109	12.73	75.3	60.5	48.6	24.4	87.8	958	770	619	310	1117
9110	12.58	79.1	67.1	90.5	42.1	87.9	995	844	1139	529	1106
9111	12.02	85.6	71.4	144.1	42.1	85.0	1029	857	1732	506	1021
9112	12.34	76.1	72.0	60.9	32.3	81.4	939	889	752	399	1005
9201	12.12	76.0	72.0	59.9	37.7	87.4	921	872	726	457	1059
9202	11.16	72.9	69.4	47.8	34.1	87.8	813	775	533	380	980
9203	11.79	71.2	65.6	60.5	50.5	86.8	839	773	713	595	1023
9204	11.96	75.2	70.1	68.5	59.3	86.9	899	839	820	709	1039
9205	12.19	76.4	66.9	54.2	51.0	85.9	932	816	661	622	1048
9206	11.51	91.8	70.0	104.2	89.4	86.8	1057	806	1199	1029	999
9207	11.96	91.9	66.3	170.9	138.2	87.6	1099	793	2044	1652	1047
9208	12.34	75.4	71.4	107.4	31.2	90.3	930	881	1325	385	1114
9209	11.39	85.2	71.6	85.0	30.0	89.6	970	815	968	342	1020
9210	11.60	83.8	77.1	55.4	31.6	89.9	973	895	643	366	1043
9211	11.92	113.4	112.5	100.2	43.9	89.8	1352	1341	1194	523	1071
9212	11.65	79.3	73.8	63.9	36.1	90.7	924	860	745	421	1058
9301	11.68	76.5	70.1	61.2	41.9	93.8	894	819	715	489	1095
9302	10.79	78.6	72.0	56.5	27.1	92.2	848	777	609	293	995
9303	12.00	92.0	69.3	80.9	48.1	89.7	1104	832	971	577	1077
9304	11.89	97.1	69.2	105.4	57.2	86.4	1155	823	1254	680	1027
9305	13.69	88.7	73.1	95.7	50.6	89.3	1215	1002	1310	693	1222
9306	14.67	89.7	73.3	78.2	45.0	88.6	1316	1075	1147	661	1300
9307	16.54	92.9	76.5	66.8	33.4	88.8	1537	1264	1104	552	1468
9308	16.35	85.9	75.0	53.6	39.5	91.5	1404	1227	877	646	1496
9309	16.26	86.0	73.6	59.7	43.0	91.4	1399	1198	971	700	1487
9310	16.75	90.1	76.1	56.1	46.0	90.2	1510	1275	940	770	1510
9311	15.27	87.6	73.6	54.8	44.8	88.5	1338	1124	836	683	1352
9312	15.00	96.0	72.0	60.0	50.0	86.9	1440	1080	900	750	1304

Seasonal Totals (S = April-September, W = October-March)

91S	79.27	70.9	66.9	153.1	118.7	90.7	5618	5302	12133	9409	7187
92W	72.00	76.9	69.6	77.7	39.8	86.0	5536	5010	5594	2866	6194
92S	71.34	82.5	69.4	98.4	66.4	87.8	5887	4949	7018	4739	6267
93W	69.64	87.5	79.3	70.0	38.3	91.0	6094	5523	4877	2670	6339
93S	89.41	89.8	73.7	74.5	44.0	89.5	8026	6589	6662	3932	8002

Seasonal Averages

Summer	80.01	81.4	70.2	107.5	75.3	89.4	6511	5613	8604	6027	7152
Winter	70.82	82.1	74.4	73.9	39.1	88.5	5815	5267	5235	2768	6266

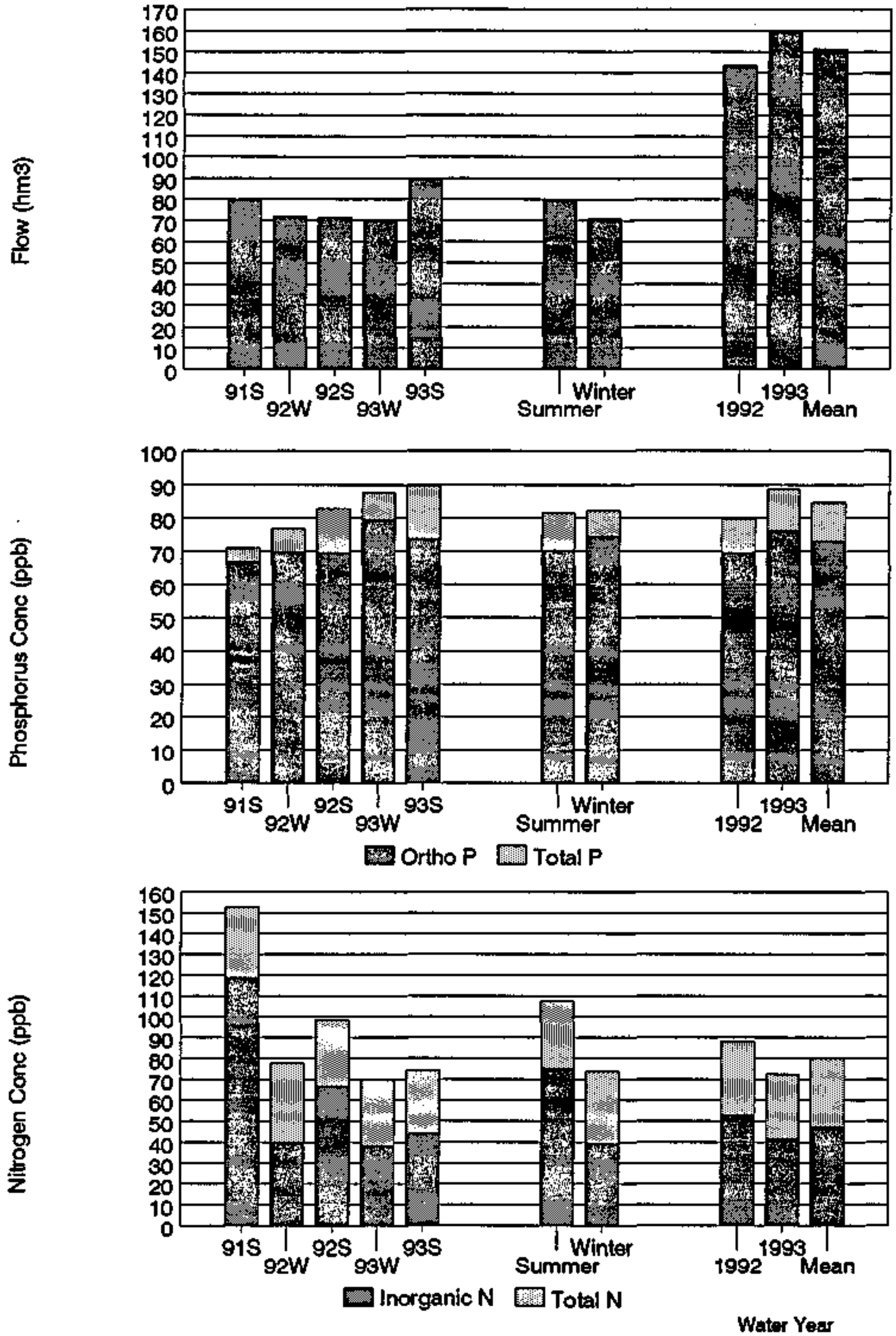
Water Year Totals

1992	143.35	79.7	69.5	88.0	53.1	86.9	11423	9959	12612	7605	12461
1993	159.06	88.8	76.1	72.5	41.5	90.2	14121	12112	11539	6602	14340
Mean	151.20	84.5	73.0	79.9	47.0	88.6	12772	11036	12075	7103	13401

* Conductivity Flux Units = US/CM2 x HM3

Flow & Nutrient Export

Station: UK100 – Wood River @ Dixon Road



S = April–September, W = October–March
Winter = Average of 92W & 93W   Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK200 Wood River @ Ft. Klamath

		Flow-Weighted-Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	13.64	68.4	65.9	1122.8	1079.3	90.3	932	898	15310	14717	1232
9105	11.98	75.2	67.3	187.2	111.8	85.9	901	807	2243	1340	1029
9106	9.52	78.9	74.2	114.3	54.5	91.8	751	707	1088	519	874
9107	9.08	80.2	71.1	110.2	53.5	88.2	728	645	1000	485	800
9108	8.90	88.7	72.3	84.9	32.7	91.7	789	643	755	291	816
9109	9.27	81.8	70.1	79.0	33.8	88.1	759	650	732	313	817
9110	14.08	88.1	68.4	52.6	20.9	85.6	1241	964	741	294	1205
9111	15.81	93.8	68.6	57.8	19.0	80.8	1483	1084	914	300	1278
9112	16.51	74.4	67.6	55.6	22.2	74.7	1229	1116	917	366	1234
9201	15.64	84.6	66.4	94.0	27.8	79.6	1324	1039	1470	434	1245
9202	15.22	79.0	62.2	85.1	37.0	81.0	1202	946	1295	564	1233
9203	15.88	79.6	58.7	417.4	399.7	80.8	1264	932	6626	6345	1283
9204	13.66	78.9	60.5	234.4	195.3	78.5	1078	826	3202	2668	1072
9205	8.04	74.9	64.5	83.9	49.5	85.4	602	519	675	398	687
9206	6.70	78.0	67.5	97.7	66.1	87.7	523	452	655	443	587
9207	8.35	82.0	66.8	117.6	51.7	88.8	685	558	982	432	741
9208	6.29	81.3	72.9	235.8	30.2	91.5	512	459	1484	190	576
9209	9.38	82.7	73.0	125.8	29.0	90.2	776	685	1181	272	847
9210	10.47	79.2	70.6	57.0	29.0	88.3	829	739	597	304	925
9211	12.50	81.9	77.3	85.9	29.0	86.5	1023	967	1073	362	1081
9212	12.75	72.5	67.0	77.7	30.0	84.8	924	854	990	382	1081
9301	13.12	83.3	65.1	110.1	27.8	89.3	1093	855	1444	364	1171
9302	9.94	99.5	59.7	109.6	31.4	86.9	989	594	1090	312	864
9303	12.02	129.0	60.2	181.1	71.3	82.1	1550	723	2177	857	987
9304	14.85	111.2	55.9	178.8	56.2	77.5	1651	829	2654	835	1151
9305	16.78	123.3	50.0	126.4	34.5	70.8	2069	840	2121	579	1189
9306	20.73	89.5	53.0	97.0	37.5	69.4	1856	1099	2011	778	1439
9307	13.37	97.6	61.8	81.6	32.7	77.1	1305	827	1091	437	1031
9308	11.42	89.8	69.0	69.5	36.9	88.8	1026	788	794	421	1014
9309	13.03	77.8	68.4	88.9	33.7	87.6	1013	891	1158	439	1141
9310	18.06	78.4	69.0	122.3	35.9	85.1	1416	1246	2209	648	1538
9311	17.58	89.2	68.0	69.3	39.7	83.0	1567	1196	1218	698	1460
9312	19.26	100.0	67.0	100.0	49.0	80.1	1926	1290	1926	944	1542

Seasonal Totals (S = April-September, W = October-March)

91S	62.38	77.9	69.7	338.7	283.2	89.3	4859	4350	21129	17664	5568
92W	93.14	83.1	65.3	128.4	89.2	80.3	7743	6081	11964	8304	7478
92S	52.44	79.6	66.7	156.0	84.0	86.0	4176	3499	8180	4403	4511
93W	70.80	90.5	66.8	104.1	36.5	86.3	6408	4731	7371	2582	6109
93S	90.17	98.9	58.5	109.0	38.7	77.2	8919	5274	9829	3488	6965

Seasonal Averages

Summer	68.33	87.6	64.0	190.9	124.7	83.1	5985	4374	13046	8519	5681
Winter	81.97	86.3	66.0	117.9	66.4	82.9	7075	5406	9668	5443	6793

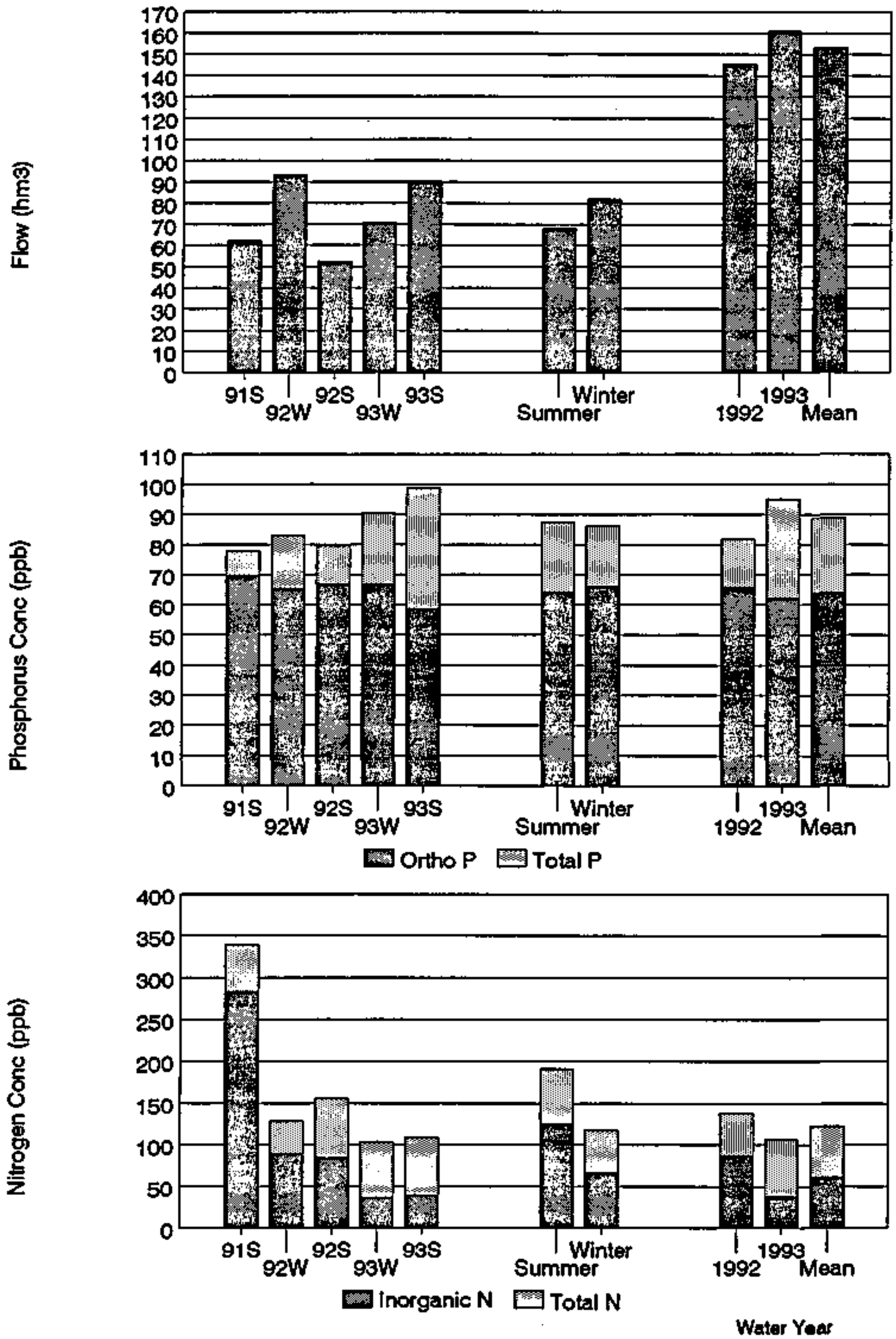
Water Year Totals

1992	145.58	81.9	65.8	138.4	87.3	82.4	11918	9580	20143	12707	11989
1993	160.97	95.2	62.2	106.9	37.7	81.2	15328	10005	17200	6070	13074
Mean	153.27	88.9	63.9	121.8	61.3	81.8	13623	9793	18672	9389	12532

* Conductivity Flux Units = US/CM2 x HM3

Flow & Nutrient Export

Station: UK200 – Wood River @ Ft. Klamath



S = April–September, W = October–March

Winter = Average of 92W & 93W Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK300 Wood River @ Loosely Road

		Flow-Weighted-Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	20.61	67.7	68.6	277.3	223.6	94.3	1396	1413	5716	4610	1944
9105	17.33	65.9	62.9	190.5	101.5	90.3	1142	1090	3301	1759	1565
9106	12.40	95.6	79.1	141.5	61.5	96.7	1185	980	1754	762	1199
9107	13.13	99.8	80.5	224.2	127.3	91.3	1311	1058	2944	1672	1199
9108	11.43	95.0	80.5	146.3	69.7	93.7	1086	920	1672	796	1070
9109	13.74	89.6	77.1	80.9	39.0	89.9	1231	1060	1112	536	1235
9110	20.35	86.0	72.3	67.6	40.0	87.7	1749	1472	1376	814	1784
9111	21.16	85.3	74.4	79.9	40.0	83.7	1806	1574	1690	847	1771
9112	23.61	84.5	75.7	88.9	37.8	78.4	1996	1787	2099	892	1852
9201	23.90	95.5	77.3	110.7	32.2	84.1	2281	1847	2647	770	2011
9202	22.42	88.7	72.9	84.8	32.5	85.7	1989	1636	1902	729	1921
9203	22.82	80.4	67.4	191.6	167.5	84.6	1835	1537	4372	3821	1930
9204	18.97	89.5	68.3	158.2	115.4	81.4	1697	1296	3001	2190	1544
9205	12.24	83.4	70.8	105.0	55.0	87.5	1021	867	1285	673	1071
9206	9.44	88.8	74.0	206.1	156.1	89.5	839	699	1946	1474	844
9207	11.88	92.4	76.4	243.6	175.1	91.5	1098	908	2893	2080	1087
9208	10.51	95.2	83.2	234.3	26.8	95.0	1001	874	2463	282	999
9209	14.09	91.0	79.7	174.6	23.5	92.8	1283	1123	2460	332	1308
9210	17.87	86.1	76.9	61.5	20.9	91.2	1538	1375	1100	373	1631
9211	21.09	93.5	81.9	58.4	28.4	90.1	1972	1726	1230	598	1900
9212	22.61	89.9	75.4	65.2	30.0	89.3	2032	1706	1474	678	2019
9301	21.88	92.0	73.9	76.7	27.7	92.9	2013	1616	1677	606	2033
9302	17.77	103.8	71.0	101.7	35.1	91.4	1846	1261	1807	625	1625
9303	20.51	129.1	72.7	214.5	84.5	88.8	2649	1491	4400	1733	1822
9304	23.97	107.9	67.3	172.7	51.0	84.3	2586	1612	4139	1222	2020
9305	24.71	120.7	61.5	110.1	33.8	77.5	2982	1519	2722	834	1915
9306	27.33	105.4	64.2	105.7	35.4	76.1	2882	1755	2888	967	2079
9307	19.98	114.7	75.2	137.8	23.4	86.4	2292	1502	2753	468	1725
9308	16.29	103.6	77.4	74.5	29.5	93.6	1688	1261	1214	480	1525
9309	18.59	113.1	76.1	90.5	33.4	92.0	2103	1414	1682	621	1710
9310	24.88	103.9	75.2	94.0	35.9	88.9	2585	1871	2339	894	2211
9311	23.29	89.3	73.5	45.0	34.9	86.3	2079	1712	1048	813	2009
9312	25.98	100.0	73.0	50.0	40.0	83.6	2598	1896	1299	1039	2172

Seasonal Totals (S = April–September, W = October–March)

91S	88.64	82.9	73.6	186.1	114.3	92.6	7351	6520	16500	10134	8211
92W	134.26	86.8	73.4	104.9	58.6	83.9	11655	9852	14085	7872	11268
92S	77.13	90.0	74.8	182.1	91.1	88.8	6938	5767	14048	7030	6853
93W	121.73	99.0	75.4	96.0	37.9	90.6	12050	9175	11688	4613	11030
93S	130.88	111.0	69.2	117.7	35.1	83.9	14533	9062	15398	4593	10975

Seasonal Averages

Summer	98.88	97.2	72.0	154.9	73.3	87.8	9607	7116	15315	7252	8680
Winter	128.00	92.6	74.3	100.7	48.8	87.1	11853	9513	12886	6243	11149

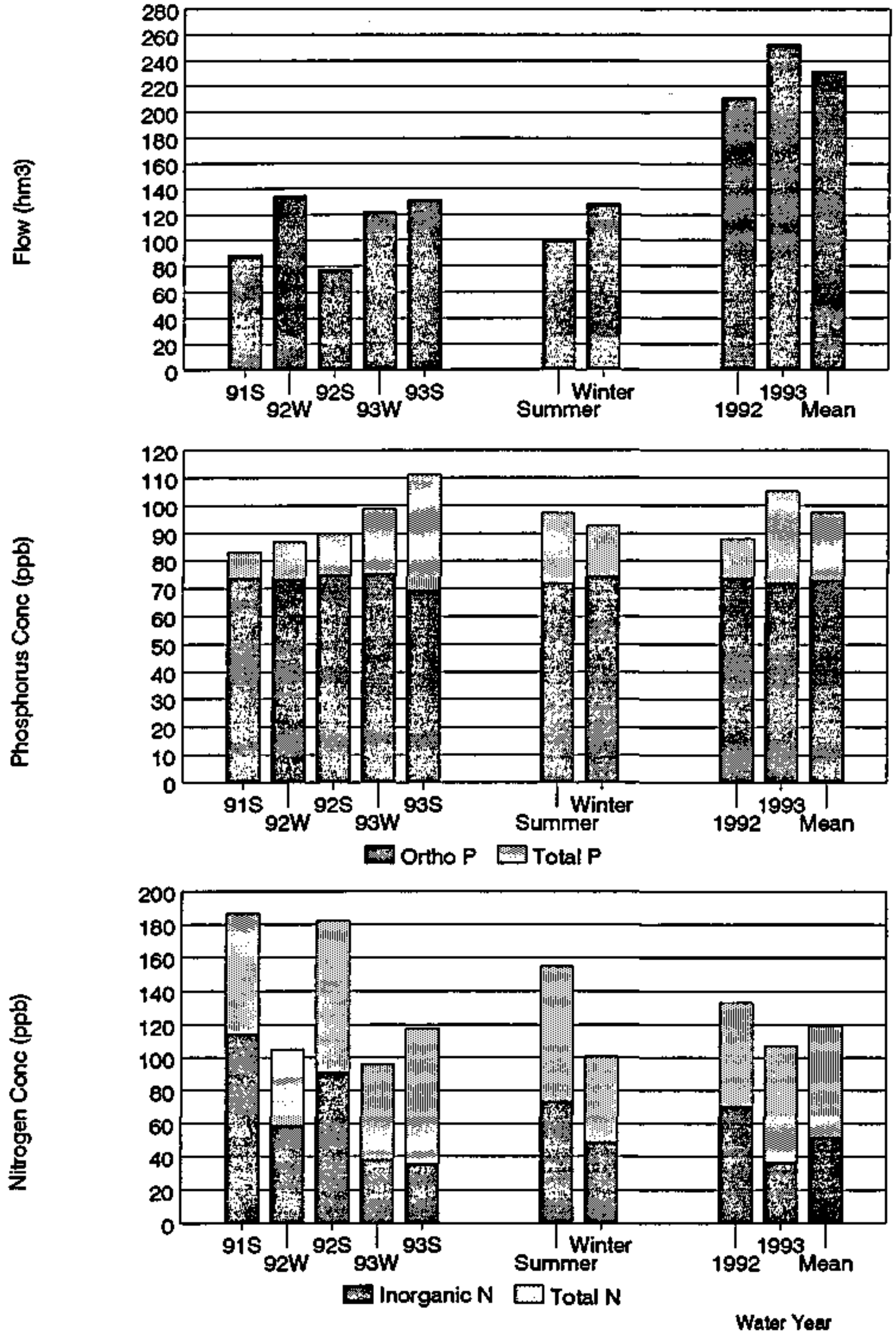
Water Year Totals

1992	211.40	88.0	73.9	133.1	70.5	85.7	18593	15619	28133	14903	18121
1993	252.61	105.2	72.2	107.2	36.4	87.1	26583	18237	27086	9206	22004
Mean	232.00	97.4	73.0	119.0	52.0	86.5	22588	16928	27609	12054	20063

* Conductivity Flux Units = US/CM2 x HM3

Flow & Nutrient Export

Station: UK300 – Wood River @ Loosely Road



S = April–September, W = October–March

Winter = Average of 92W & 93W   Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK400 Wood River @ Weed Road

		Flow–Weighted–Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	21.55	70.8	71.4	485.8	415.5	95.0	1526	1539	10468	8952	2047
9105	16.24	76.4	69.0	251.2	129.0	91.2	1241	1121	4080	2095	1482
9106	7.64	92.3	84.2	225.2	93.4	97.1	705	643	1720	714	742
9107	7.80	99.6	84.5	152.9	33.4	93.5	777	659	1193	260	729
9108	7.29	105.2	84.4	135.9	38.0	96.1	766	615	990	277	700
9109	12.53	118.3	79.1	118.4	39.0	91.2	1483	991	1484	489	1143
9110	17.72	86.9	72.1	208.9	167.4	87.8	1540	1278	3702	2967	1556
9111	23.13	84.9	73.8	298.9	237.5	83.5	1964	1707	6913	5493	1932
9112	26.07	85.1	75.4	96.7	42.2	78.6	2219	1967	2522	1100	2049
9201	24.35	92.7	76.5	105.6	40.4	84.7	2258	1863	2573	983	2063
9202	23.53	83.4	73.2	121.9	71.0	86.1	1963	1722	2869	1670	2026
9203	22.74	78.1	69.0	91.9	57.7	84.6	1776	1570	2089	1313	1923
9204	18.40	82.4	69.7	120.3	68.3	82.9	1517	1282	2213	1258	1526
9205	9.60	87.8	72.5	93.2	45.9	88.9	843	697	895	441	853
9206	3.90	96.5	76.1	486.7	418.1	91.4	376	297	1897	1629	356
9207	8.45	109.3	76.0	1136.5	1054.0	92.8	923	642	9599	8901	784
9208	4.55	104.0	84.1	295.3	35.3	96.9	473	383	1343	161	441
9209	13.61	95.5	79.2	181.4	23.1	92.6	1300	1078	2468	314	1260
9210	17.24	93.7	77.4	59.0	21.7	90.6	1615	1335	1018	375	1562
9211	22.48	96.0	82.6	81.9	35.2	90.0	2157	1856	1840	791	2023
9212	22.95	90.6	75.3	84.4	33.1	89.4	2080	1729	1936	759	2051
9301	22.79	92.8	74.5	95.4	37.2	93.2	2114	1698	2173	847	2123
9302	18.99	106.2	68.4	129.2	43.3	92.1	2017	1299	2455	823	1749
9303	24.52	129.7	70.9	234.5	85.6	90.2	3182	1739	5751	2099	2213
9304	28.15	107.5	67.0	184.5	51.4	84.6	3026	1885	5194	1447	2381
9305	24.24	113.5	60.8	125.5	33.8	78.5	2752	1475	3042	819	1903
9306	26.49	103.1	64.2	129.4	35.8	76.9	2731	1699	3428	948	2036
9307	13.95	116.2	76.2	154.0	23.6	88.4	1621	1063	2148	330	1234
9308	14.21	113.1	75.6	110.1	29.5	95.3	1607	1074	1564	420	1354
9309	18.75	119.8	73.7	111.7	29.0	92.2	2246	1381	2093	544	1729
9310	31.54	108.7	72.6	117.8	29.0	88.5	3428	2291	3717	915	2790
9311	27.90	95.4	71.5	95.2	34.8	86.4	2660	1995	2657	971	2410
9312	30.44	100.0	71.0	90.0	39.0	84.0	3044	2161	2740	1187	2557

Seasonal Totals (S = April–September, W = October–March)

91S	73.04	89.0	76.2	272.9	175.1	93.7	6497	5567	19935	12787	6843
92W	137.55	85.2	73.5	150.3	98.3	84.0	11720	10107	20668	13526	11549
92S	58.50	92.9	74.8	314.8	217.2	89.2	5433	4379	18414	12704	5220
93W	128.97	102.1	74.9	117.7	44.1	90.9	13165	9655	15173	5694	11722
93S	125.79	111.2	68.2	138.9	35.8	84.6	13984	8578	17468	4507	10636

Seasonal Averages

Summer	85.78	100.7	72.0	216.9	116.6	88.2	8638	6175	18606	9999	7566
Winter	133.26	93.4	74.1	134.5	72.1	87.3	12443	9881	17921	9610	11635

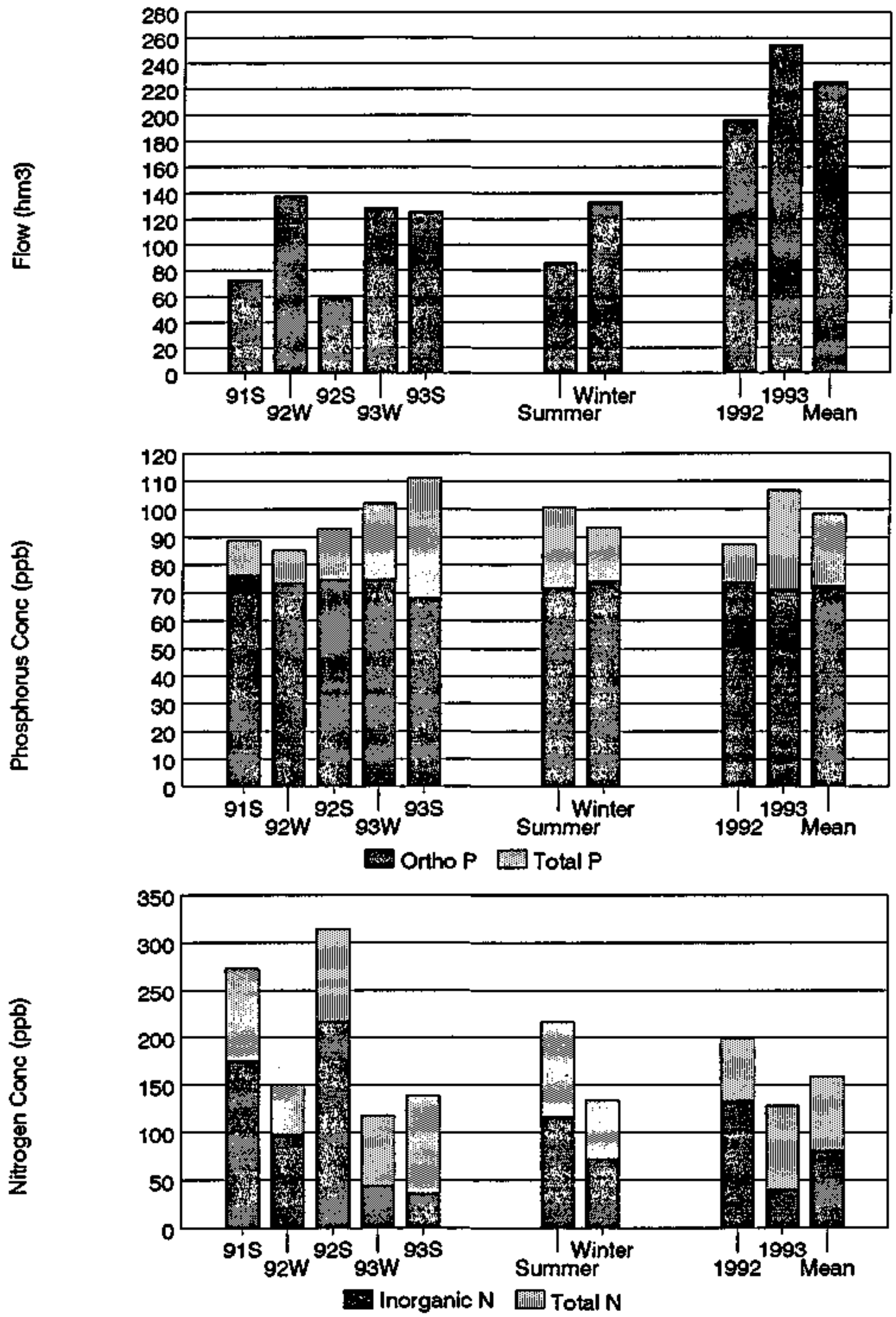
Water Year Totals

1992	196.05	87.5	73.9	199.3	133.8	85.5	17153	14485	39083	26230	16769
1993	254.76	106.6	71.6	128.1	40.0	87.8	27149	18233	32641	10201	22358
Mean	225.41	98.3	72.6	159.1	80.8	86.8	22151	16359	35862	18216	19563

* Conductivity Flux Units = US/CM2 x HM3

Flow & Nutrient Export

Station: UK400 – Wood River @ Weed Road



S = April–September, W = October–March
Winter = Average of 92W & 93W   Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK500 Wood River @ Agency Dike

		Flow-Weighted-Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	18.75	81.2	83.7	381.9	225.1	99.8	1522	1570	7163	4221	1871
9105	16.03	123.2	113.8	437.7	197.0	101.0	1975	1824	7016	3158	1618
9106	13.54	169.6	154.6	266.9	81.7	110.5	2296	2093	3613	1106	1496
9107	11.73	166.0	149.7	391.1	73.3	109.2	1948	1756	4590	861	1281
9108	12.87	132.4	125.5	268.9	48.6	103.3	1704	1615	3460	625	1330
9109	15.35	118.4	93.4	140.9	23.0	95.3	1818	1435	2163	353	1464
9110	20.52	99.8	86.0	80.0	26.9	89.7	2047	1764	1642	552	1841
9111	22.99	87.8	84.9	93.9	39.9	86.2	2019	1952	2160	916	1982
9112	25.72	108.6	93.6	116.4	41.1	81.8	2794	2406	2993	1057	2103
9201	24.02	130.8	105.2	157.8	43.8	93.0	3142	2527	3791	1051	2234
9202	23.15	120.8	102.2	146.2	35.8	95.6	2796	2365	3384	828	2213
9203	18.73	96.4	84.9	111.7	42.3	90.5	1806	1591	2093	793	1695
9204	11.10	115.2	91.3	130.2	34.5	88.9	1279	1013	1445	383	986
9205	11.08	217.9	112.0	157.2	28.1	95.2	2413	1240	1741	312	1055
9206	8.16	160.8	123.5	369.7	88.8	101.9	1312	1007	3016	724	831
9207	12.73	153.1	116.3	526.7	184.7	107.3	1949	1480	6703	2351	1365
9208	9.10	148.0	123.6	533.5	27.0	106.4	1346	1125	4855	246	968
9209	16.63	120.1	101.4	332.7	23.4	99.3	1997	1687	5532	389	1651
9210	19.24	101.4	88.9	91.7	20.8	95.7	1951	1710	1765	401	1842
9211	21.97	114.4	95.9	142.0	29.7	94.4	2513	2108	3120	653	2073
9212	20.68	113.1	91.5	143.6	42.2	93.2	2339	1891	2969	873	1928
9301	21.80	124.1	101.0	147.2	49.5	96.6	2704	2201	3208	1078	2106
9302	19.06	143.1	113.5	183.7	73.6	100.3	2727	2163	3502	1403	1912
9303	27.11	164.3	131.2	361.2	141.9	105.1	4454	3557	9790	3846	2848
9304	24.35	197.4	149.5	485.1	66.7	105.6	4807	3641	11813	1625	2571
9305	23.41	194.8	147.7	423.9	28.9	109.2	4560	3458	9923	676	2556
9306	39.96	161.9	121.5	252.1	20.4	94.0	6470	4857	10071	815	3756
9307	19.09	147.8	112.0	236.9	20.0	98.1	2822	2138	4522	382	1873
9308	14.93	109.0	85.6	186.1	20.0	105.1	1628	1278	2778	299	1570
9309	17.27	137.9	103.4	154.3	20.0	100.3	2380	1786	2665	345	1732
9310	26.19	110.0	88.6	67.4	19.0	93.1	2881	2321	1766	498	2439
9311	19.17	104.9	79.6	51.0	24.2	92.1	2011	1526	977	463	1765
9312	14.23	119.0	79.0	80.0	29.0	90.4	1694	1125	1139	413	1287

Seasonal Totals (S = April–September, W = October–March)

91S	88.28	127.6	116.6	317.2	116.9	102.6	11264	10293	28004	10324	9060
92W	135.13	108.1	93.3	118.9	38.5	89.3	14604	12605	16063	5197	12069
92S	68.78	149.7	109.8	338.6	64.0	99.7	10296	7552	23292	4404	6856
93W	129.86	128.5	105.0	187.5	63.6	97.9	16688	13630	24354	8254	12710
93S	139.00	163.1	123.4	300.5	29.8	101.1	22667	17157	41772	4141	14058

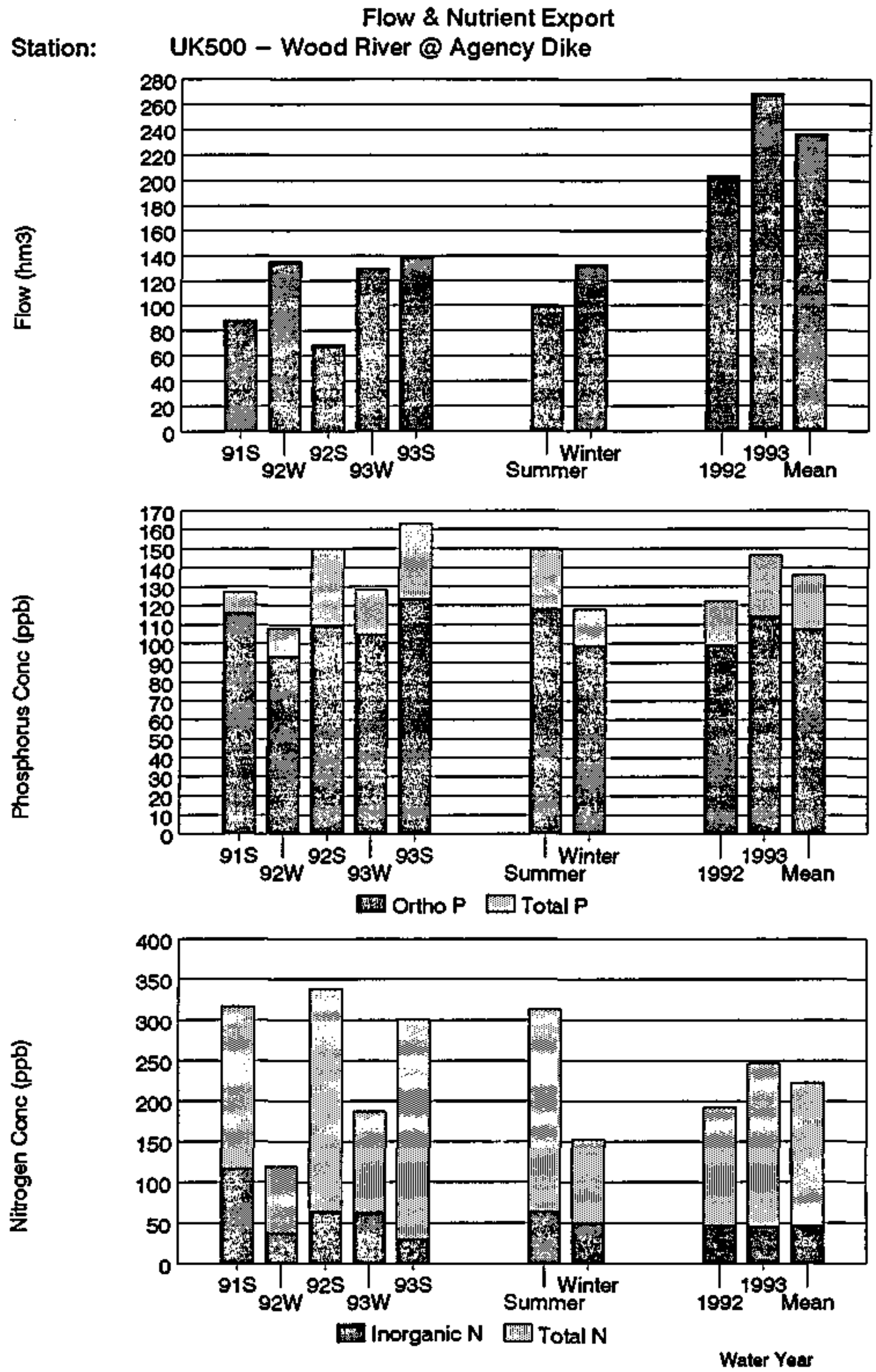
Seasonal Averages

Summer	98.69	149.4	118.2	314.4	63.7	101.2	14742	11667	31022	6290	9991
Winter	132.50	118.1	99.0	152.5	50.8	93.5	15646	13118	20209	6726	12389

Water Year Totals

1992	203.92	122.1	98.8	193.0	47.1	92.8	24900	20157	39355	9602	18925
1993	268.87	146.4	114.5	245.9	46.1	99.6	39355	30787	66126	12395	26767
Mean	236.39	135.9	107.8	223.1	46.5	96.6	32127	25472	52741	10999	22846

* Conductivity Flux Units = US/CM2 x HM3



S = April–September, W = October–March
Winter = Average of 92W & 93W   Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK600 Sevenmile Canal

		Flow-Weighted-Mean Concentrations					Mass Fluxes				
	FLOW	TP	ORTHOP	TN	INORGN	COND	TP	ORTHOP	TN	INORGN	COND
MONTH	HM3	PPB	PPB	PPB	PPB	US/CM2	KG	KG	KG	KG	*
9104	7.92	128.2	81.0	504.7	56.0	88.5	1015	641	3997	444	701
9105	6.83	128.2	81.0	504.7	56.0	88.5	875	553	3446	382	605
9106	4.88	128.2	81.0	504.7	56.0	88.5	626	396	2465	274	433
9107	5.02	128.2	81.0	504.7	56.0	88.5	643	407	2534	281	445
9108	4.94	128.2	81.0	504.7	56.0	88.5	633	400	2493	277	437
9109	5.91	128.2	81.0	504.7	56.0	88.5	758	479	2983	331	523
9110	7.35	112.3	78.2	548.8	53.2	74.8	825	574	4032	391	549
9111	7.98	79.1	61.1	69.8	37.3	77.4	631	487	557	298	618
9112	11.19	80.5	60.5	75.1	30.0	82.1	901	677	840	335	918
9201	13.10	82.2	59.9	87.4	22.9	78.7	1077	785	1145	300	1031
9202	9.77	73.3	41.5	217.9	25.8	84.7	716	406	2128	252	827
9203	5.30	81.7	47.8	259.6	23.8	81.1	433	254	1377	126	430
9204	7.21	116.1	75.3	576.5	21.8	85.1	837	543	4156	157	613
9205	7.34	144.8	91.0	691.0	44.8	94.1	1063	668	5071	329	690
9206	5.82	176.8	107.8	730.9	76.8	103.3	1029	628	4256	447	602
9207	5.24	220.5	136.3	770.5	79.3	112.4	1155	714	4035	415	589
9208	2.71	256.2	175.4	1398.3	27.1	122.5	694	475	3788	73	332
9209	4.90	168.1	117.7	955.1	43.0	107.4	825	578	4685	211	527
9210	7.19	98.2	67.8	249.6	32.2	83.9	706	488	1795	231	604
9211	10.20	95.9	71.3	235.5	63.4	80.7	979	727	2403	646	823
9212	8.74	100.8	90.1	368.2	81.0	89.0	882	788	3219	708	778
9301	10.04	113.6	88.2	453.3	86.3	87.8	1141	886	4553	866	882
9302	10.63	125.9	85.5	530.1	90.9	86.2	1339	909	5637	967	917
9303	14.49	138.6	82.6	608.8	95.7	84.6	2008	1196	8821	1386	1225
9304	14.72	150.5	82.1	724.3	87.9	84.6	2215	1208	10660	1294	1244
9305	9.07	159.1	86.8	984.5	49.5	92.3	1443	787	8927	449	837
9306	7.94	175.2	83.7	977.0	77.3	99.3	1392	665	7759	614	789
9307	9.36	210.7	105.0	666.5	28.0	104.1	1973	983	6240	262	974
9308	1.25	185.6	94.0	612.8	31.5	106.1	231	117	764	39	132
9309	3.47	144.2	72.0	453.6	35.8	96.9	501	250	1576	124	337
9310	6.35	107.6	55.9	211.3	26.3	79.7	684	355	1342	167	506
9311	5.07	90.8	53.5	112.5	24.7	72.9	460	271	570	125	370
9312	5.28	96.0	53.0	70.0	29.0	69.7	507	280	370	153	368

Seasonal Totals (S = April–September, W = October–March)

91S	35.51	128.2	81.0	504.7	56.0	88.5	4551	2875	17919	1988	3144
92W	54.68	83.8	58.2	184.3	31.1	80.0	4583	3182	10078	1701	4374
92S	33.22	168.6	108.5	782.4	49.1	100.9	5603	3605	25991	1633	3352
93W	61.30	115.1	81.5	431.1	78.4	85.3	7054	4995	26429	4805	5229
93S	45.81	169.3	87.5	784.2	60.7	94.2	7755	4011	35926	2783	4313

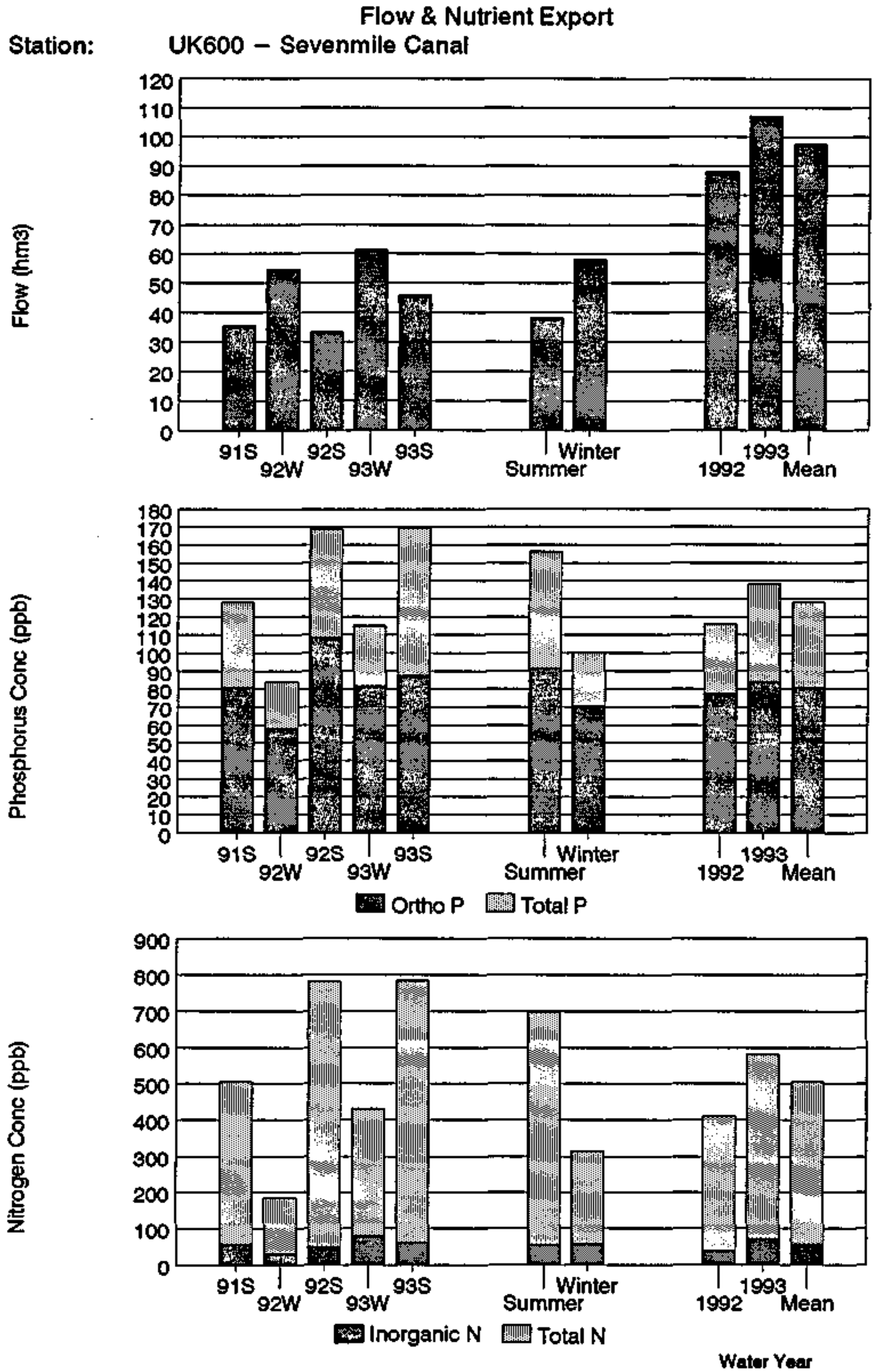
Seasonal Averages

Summer	38.18	156.4	91.6	697.0	55.9	94.4	5969	3497	26612	2135	3603
Winter	57.99	100.3	70.5	314.7	56.1	82.8	5819	4089	18254	3253	4802

Water Year Totals

1992	87.91	115.9	77.2	410.3	37.9	87.9	10185	6788	36069	3334	7726
1993	107.12	138.3	84.1	582.1	70.8	89.1	14810	9006	62355	7588	9543
Mean	97.51	128.2	81.0	504.7	56.0	88.5	12497	7897	49212	5461	8634

* Conductivity Flux Units = US/CM2 x HM3



S = April–September, W = October–March
Winter = Average of 92W & 93W Summer = Average of 91S, 92S, & 93S

Tributary Flows & Fluxes

STATION: UK700 Fourmile Canal

MONTH	FLOW HM3	TP PPB	ORTHOP PPB	TN PPB	INORGN PPB	COND US/CM2	TP KG	ORTHOP KG	TN KG	INORGN KG	COND *
		Flow-Weighted-Mean Concentrations					Mass Fluxes				
9104	3.02	81.6	49.4	440.2	59.8	64.7	247	149	1330	181	195
9105	2.18	81.6	49.4	440.2	59.8	64.7	178	108	960	130	141
9106	0.91	81.6	49.4	440.2	59.8	64.7	74	45	401	55	59
9107	0.92	81.6	49.4	440.2	59.8	64.7	75	46	406	55	60
9108	0.87	81.6	49.4	440.2	59.8	64.7	71	43	382	52	56
9109	1.63	81.6	49.4	440.2	59.8	64.7	133	80	716	97	105
9110	2.54	81.6	49.4	440.2	59.8	64.7	207	125	1118	152	164
9111	3.06	81.6	49.4	440.2	59.8	64.7	250	151	1349	183	198
9112	3.34	81.6	49.4	440.2	59.8	64.7	273	165	1472	200	216
9201	3.07	81.6	49.4	440.1	59.8	64.7	251	152	1352	184	199
9202	2.96	81.8	49.6	439.4	59.8	64.8	242	147	1300	177	192
9203	3.06	82.6	50.5	436.2	59.6	65.3	252	154	1333	182	199
9204	2.69	85.8	53.9	423.4	58.8	67.2	231	145	1139	158	181
9205	3.67	91.7	65.0	311.7	20.0	79.5	336	238	1143	73	292
9206	1.08	101.2	73.4	309.2	25.2	81.0	109	79	333	27	87
9207	0.67	116.7	75.7	491.8	57.2	90.3	78	50	328	38	60
9208	0.25	109.9	76.2	428.6	40.6	90.4	28	19	109	10	23
9209	0.59	103.4	68.1	469.4	20.0	88.2	61	40	275	12	52
9210	0.44	93.0	56.3	262.9	47.4	76.7	41	25	116	21	34
9211	1.08	89.8	63.8	304.7	83.0	75.2	97	69	330	90	81
9212	2.63	87.4	61.8	356.2	88.0	72.6	229	162	935	231	191
9301	4.19	84.7	56.3	383.5	85.9	68.9	354	236	1605	359	288
9302	5.31	82.1	51.1	409.3	83.9	65.3	435	271	2172	445	346
9303	8.25	79.4	45.8	436.1	81.8	61.6	655	378	3598	675	508
9304	8.89	74.1	39.6	425.6	72.2	56.8	659	352	3784	642	505
9305	5.79	58.2	29.3	400.0	34.6	47.4	337	170	2318	200	275
9306	5.09	62.4	31.3	788.5	30.0	54.4	317	159	4011	153	277
9307	1.21	110.4	66.7	613.0	30.0	75.7	134	81	745	36	92
9308	1.95	139.9	88.3	428.0	30.0	90.6	272	172	834	58	177
9309	0.44	102.0	60.3	234.7	29.0	81.9	45	26	103	13	36
9310	0.59	75.1	49.7	75.4	26.0	71.5	44	29	44	15	42
9311	0.73	80.9	56.0	154.0	37.3	70.8	59	41	112	27	51
9312	1.48	94.0	59.0	230.0	50.0	70.8	139	87	340	74	105

Seasonal Totals (S = April-September, W = October-March)

91S	9.53	81.6	49.4	440.2	59.8	64.7	778	471	4196	570	616
92W	18.03	81.8	49.6	439.4	59.8	64.8	1475	895	7924	1078	1169
92S	8.94	94.2	64.0	372.1	35.7	77.7	842	572	3327	319	694
93W	21.89	82.8	52.1	400.0	83.2	66.2	1812	1141	8756	1822	1449
93S	23.37	75.5	41.1	504.6	47.2	58.2	1764	960	11795	1103	1361

Seasonal Averages

Summer	13.95	80.9	47.9	461.6	47.6	63.8	1128	668	6439	664	890
Winter	19.96	82.3	51.0	417.8	72.6	65.6	1644	1018	8340	1450	1309

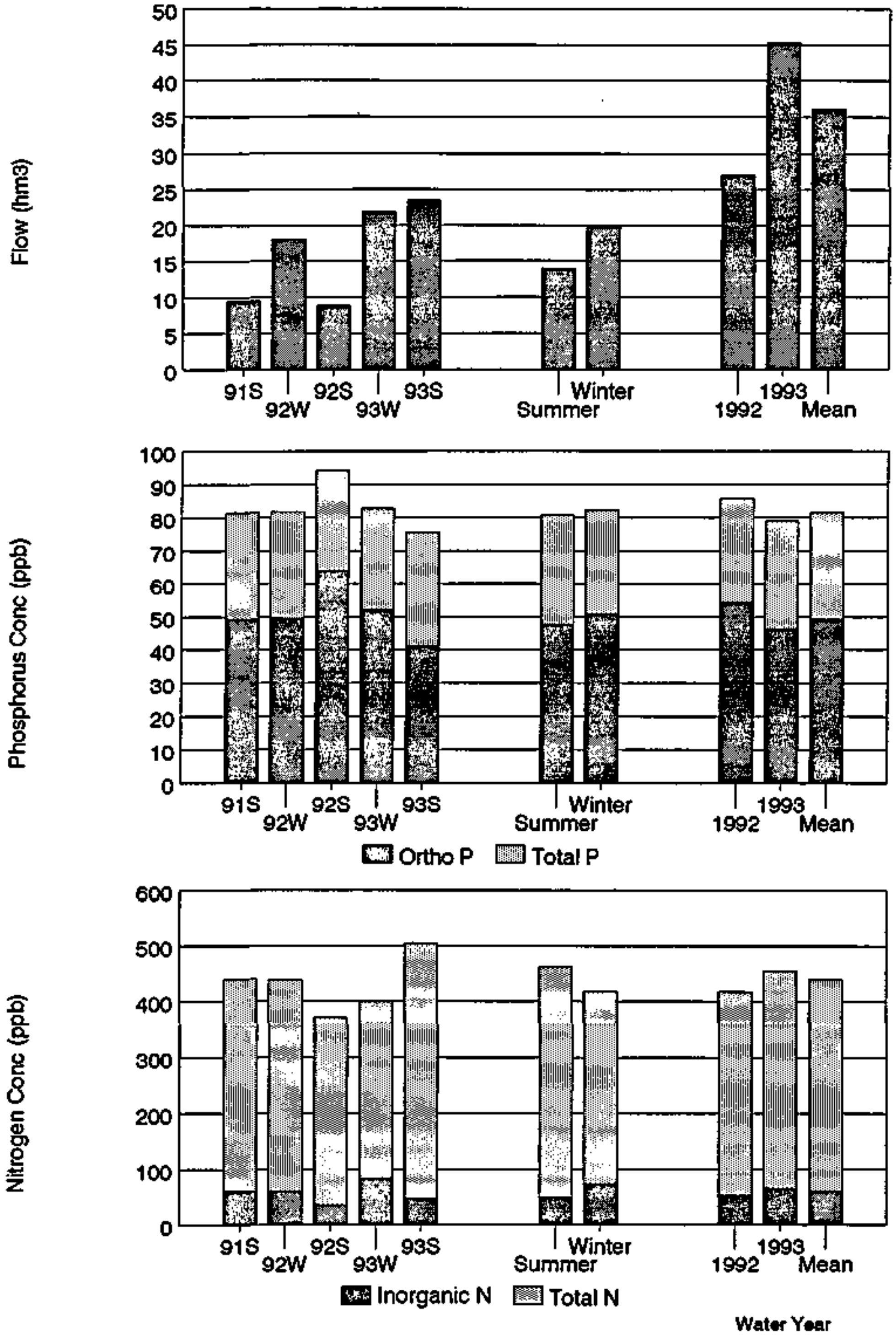
Water Year Totals

1992	26.97	85.9	54.4	417.1	51.8	69.1	2318	1467	11251	1396	1863
1993	45.27	79.0	46.4	454.0	64.6	62.1	3577	2101	20551	2924	2809
Mean	36.12	81.6	49.4	440.2	59.8	64.7	2947	1784	15901	2160	2336

* Conductivity Flux Units = US/CM2 x HM3

Flow & Nutrient Export

Station: UK700 – Fourmile Canal



S = April–September, W = October–March
Winter = Average of 92W & 93W   Summer = Average of 91S, 92S, & 93S

Appendix C - BATHTUB Diagnostic Variables

Copied from Walker (1987)

Table IV-6

Diagnostic Variables and Their Interpretation

Variable	Units	Explanation
TOTAL P	mg/m^3	Total phosphorus concentration CE distribution (MEAN = 48, CV = 0.90, MIN = 9.9, MAX = 274) Measure of nutrient supply under P-limited conditions
TOTAL N	mg/m^3	Total nitrogen concentration CE distribution (MEAN = 1002, CV = 0.64, MIN = 243, MAX = 4306) Measure of nutrient supply under N-limited conditions
C.NUTRIENT	mg/m^3	Composite nutrient concentration CE distribution (MEAN = 36, CV = 0.80, MIN = 6.6, MAX = 142) Measure of nutrient supply independent of N vs. P limitation; equals total P at high nitrogen/phosphorus ratios
CHL-A	mg/m^3	Mean chlorophyll-a concentration CE distribution (MEAN = 9.4, CV = 0.77, MIN = 2, MAX = 64) Measure of algal standing crop based upon photosynthetic pigment
SECCHI	m	Secchi depth CE distribution (MEAN = 1.1, CV = 0.76, MIN = 0.19, MAX = 4.6) Measure of water transparency as influenced by algae and nonalgal turbidity
ORGANIC N	mg/m^3	Organic nitrogen concentration CE distribution (MEAN = 474, CV = 0.51, MIN = 186, MAX = 1510) Portion of nitrogen pool in organic forms; generally correlated with chlorophyll-a concentration

(Continued)

Notes: CE distribution based upon 41 reservoirs used in development and testing of the model network (MEAN, CV = geometric mean and coefficient of variation). Low and high values are typical benchmarks for interpretation.

(Sheet 1 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
TP-ORTHO-P	mg/m^3	Total minus ortho-phosphorus CE distribution (MEAN = 30, CV = 0.95, MIN = 4, MAX = 148) Portion of phosphorus pool in organic/particulate forms; correlated with chlorophyll-a and nonalgal turbidity
HOD-V	mg/m^3-day	Hypolimnetic oxygen depletion rate CE distribution (MEAN = 77, CV = 0.75, MIN = 36, MAX = 443) Rate of oxygen depletion below thermocline; related to organic supply from settling of surface-layer algae, external organic sediment loads, and mean hypolimnetic depth For HOD-V > 100, hypolimnetic oxygen supply depleted within 120 days after onset of stratification
MOD-V	mg/m^3-day	Metalimnetic oxygen depletion rate CE distribution (MEAN = 68, CV = 0.71, MIN = 25, MAX = 286) Rate of oxygen depletion within thermocline; generally more important than HOD-V in deeper reservoirs (i.e., mean hypolimnetic depth >20 m)
ANTILOG PC-1	--	First principal component of reservoir response variables(i.e., chlorophyll-a, Secchi, organic N, composite nutrient) CE distribution (MEAN = 245, CV = 1.3, MIN = 18, MAX = 2,460) Measure of nutrient supply: Low: PC-1 < 50 = low nutrient supply = low eutrophication potential High: PC-1 > 500 = high nutrient supply = high eutrophication potential

(Continued)

(Sheet 2 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
ANTILOG PC-2	--	Second principal component of reservoir response variables (i.e., chlorophyll-a, Secchi, organic N, composite nutrient) CE distribution (MEAN = 6.4, CV = 0.53, MIN = 1.6, MAX = 13.4) Measure of nutrient expression in organic vs. inorganic forms Measure of light-limited productivity: Low: PC-2 < 4 = turbidity-dominated = light-limited = low nutrient response High: PC-2 > 10 = algae-dominated = light unimportant = high nutrient response
(N-150)/P	--	(Total nitrogen - 150)/Total phosphorus ratio CE Distribution (MEAN = 17, CV = 0.68, MIN = 4.7, MAX = 73) Indicator of limiting nutrients based upon total nutrients: Low: (N-150)/P < 10-12 = nitrogen-limited High: (N-150)/P > 12-15 = phosphorus-limited
INORGANIC N/P Ratio	--	Inorganic nitrogen/ortho-phosphorus ratio CE distribution (MEAN = 30, CV = 0.99, MIN = 1.6, MAX = 127) Indicator of limiting nutrient based upon inorganic nutrients: Low: N/P < 7-10 = nitrogen-limited High: N/P > 7-10 = phosphorus-limited
TURBIDITY	1/m	Nonalgal turbidity (1/SECCHI - 0.025 × CHL-A) CE distribution (MEAN = 0.61, CV = 0.88, MIN = 0.13, MAX = 5.2) Inverse Secchi corrected for light extinction by chlorophyll-a Reflects color and inorganic suspended solids

(Continued)

(Sheet 3 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
		Influences algal response to nutrients: Low: Turbidity < 0.4 = low turbidity = allochthonous particulates unimportant = high algal response to nutrients High: Turbidity > 1 = high turbidity = allochthonous particulates unimportant = low algal response to nutrients
ZMIX * TURBIDITY		Mixed-layer depth × turbidity (dimensionless) CE distribution (MEAN = 3.2, CV = 0.78, MIN = 1.0, MAX = 17) Effect of turbidity on mean light intensity in mixed layer: Low: Value < 3 = light availability high = turbidity unimportant = high algal response to nutrients High: Value > 6 = light availability low = turbidity important = low algal response to nutrients
ZMIX/SECCHI		Mixed-layer depth/Secchi depth (dimensionless) CE distribution (MEAN = 4.8, CV = 0.58, MIN = 1.5, MAX = 19) Inversely proportional to mean light intensity in mixed layer for a given surface light intensity: Low: Value < 3 = light availability high = high algal response to nutrients High: Value > 6 = light availability low = low algal response to nutrients

(Continued)

(Sheet 4 of 5)

Table IV-6 (Concluded)

Variable	Units	Explanation
CHL-A * SECCHI		Chlorophyll-a × transparency (mg/m^2) CE distribution (MEAN = 10, CV = 0.71, MIN = 1.8, MAX = 31) Partitioning of light extinction between algae and turbidity Measure of light-limited productivity Correlated with PC-2 (second principal component): Low: Value < 6 = turbidity-dominated = light-limited = low nutrient response High: Value > 16 = algae-dominated = nutrient-limited = high nutrient response
CHL-A/ TOTAL P	--	Mean chlorophyll-a/total P CE distribution (MEAN = 0.20, CV = 0.64, MIN = 0.04, MAX = 0.60) Measure of algal use of phosphorus supply Related to nitrogen-limited and light-limitation factors: Low: Value < 0.13 = low phosphorus response = N, light, or flushing limited High: Value > 0.40 = high phosphorus response = N, light, and flushing unimportant = P limited (e.g., northern lakes)

(Sheet 5 of 5)

Notes:

$TP_{FLOW-WTD}$ < $TP_{A\&G}$

(page 8) 255 Avg.

Summer 140-240

Seasonal

Q-wtd.