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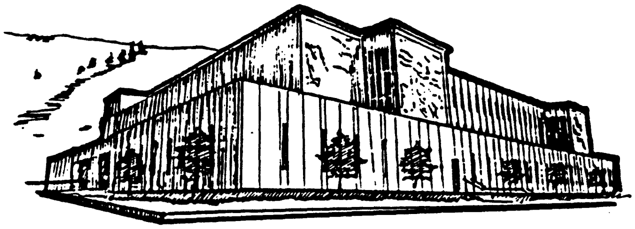

WATER QUALI~~L~~TY BENEFITS OF
THE MISSOULA PHOSPHATE BAN
IN THE CLARK FORK RIVER

By

Perry Berlind

Presented in partial fulfillment of the requirements
for the degree of
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Approved by

Vicki Watson
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Water Quality Benefits of the Missoula Phosphate Ban in the Clark Fork River (72 pp.)

Director: Dr. Vicki Watson VW

Algal accumulation in the Clark Fork River in western Montana has reached levels of nuisance accumulation. Excessive nutrient loads in the river are believed to contribute to the nuisance algal accumulation. Studies on the Clark Fork River have shown that municipal wastewater treatment plants are responsible for much of the nutrient loading to the river. A phosphate detergent ban has been enacted by the City and County of Missoula to reduce nutrient loading to the river. This report analyzes the reductions in algal accumulation expected to result from decreased nutrient loading to the river because of the ban.

The most direct way to measure the benefits of the phosphate detergent ban on the algal accumulation in the river would be to simply compare pre- and post- ban levels of algal accumulation. Limited data exist for this comparison. However, the algal accumulation data collected can not be directly compared because of confounding environmental factors that influence algal accumulation. The pre-ban data were collected in a low flow year and the post-ban data were collected in an average flow year.

A model designed to simulate algal accumulation under differing environmental conditions has been developed to facilitate comparison of pre- and post- ban data. Nutrient concentrations in the Clark Fork River under differing nutrient load conditions have been determined by a nutrient model developed for this project.

Nuisance levels of algal accumulation in the Clark Fork River were shown to be substantially reduced as a result of the decreased loading achieved by the phosphate detergent ban. The largest reductions were found at sites farthest down the river from the Missoula wastewater treatment plant where nutrient levels were farther below saturation.

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CHAPTER 1. INTRODUCTION

The Clark Fork River Basin drains parts of Idaho, British Columbia, and most of western Montana. The water flows through the Clark Fork River into Lake Pend Oreille, and then through the Pend Oreille River into the great Columbia River. The water of the Clark Fork River Basin has been polluted by many industrial, rural, and urban activities. Mining, smelting, logging, paper production, agricultural, and urban wastes have created major water quality problems. The Section 525 amendments to the Clean Water Act in 1987 directed the State of Montana to comprehensively assess the impacts of these activities on the water quality of the basin. Many chemical and physical problems were identified by the Governor's Office Section 525 report (Johnson and Schmidt, 1988). Elevated levels of metals, nutrients, turbidity, and temperature, depleted levels of dissolved oxygen, dewatering, sedimentation, channelization, and hydroelectric dams were found to create major problems. The most significant water quality issues identified by the report result from the presence of heavy metals that have been mobilized in the system by mining activities. Mining and smelting wastes have introduced these metals into the water, sediments, and floodplains of the basin, adversely affecting the quality of the surface and ground water and causing acute and chronic problems for the local aquatic community.

The Governor's Office Section 525 report identified nutrient pollution as the second most significant water quality issue facing the Clark Fork River Basin. Nutrients are put into the system from agricultural runoff, urban and industrial wastewater discharges, and groundwater infiltration. Excess bioavailable nutrients in the Clark Fork River contribute to nuisance levels of algal accumulation and to heavy nutrient loading and changes in the trophic status of Lake Pend Oreille. Nutrient concentrations in most reaches of the Clark Fork River are below levels that saturate maximum algal standing crop (Watson et al, 1990). Therefore, reductions in nutrient levels in the river may result in reductions of algal standing crop.

The City of Missoula has enacted a ban on the sale of phosphate detergents to help curb the amount of phosphorus discharged to the river from the Missoula wastewater treatment plant (WWTP). This report will analyze the realized reductions in algal accumulation achieved as a result of decreased nutrient loading due to the phosphorus detergent ban. In the classic impact study design, the changes in algal accumulation as a result of the ban are determined by measuring algal accumulation above and below the point of nutrient loading both before and after the ban went into effect. However, comparisons between these conditions are confounded by many uncontrolled environmental factors that affect algal growth, such as flow conditions and temperatures for a given year and flow and lighting differences from site-to-site. These problems are only partially resolved by the classic impact study design.

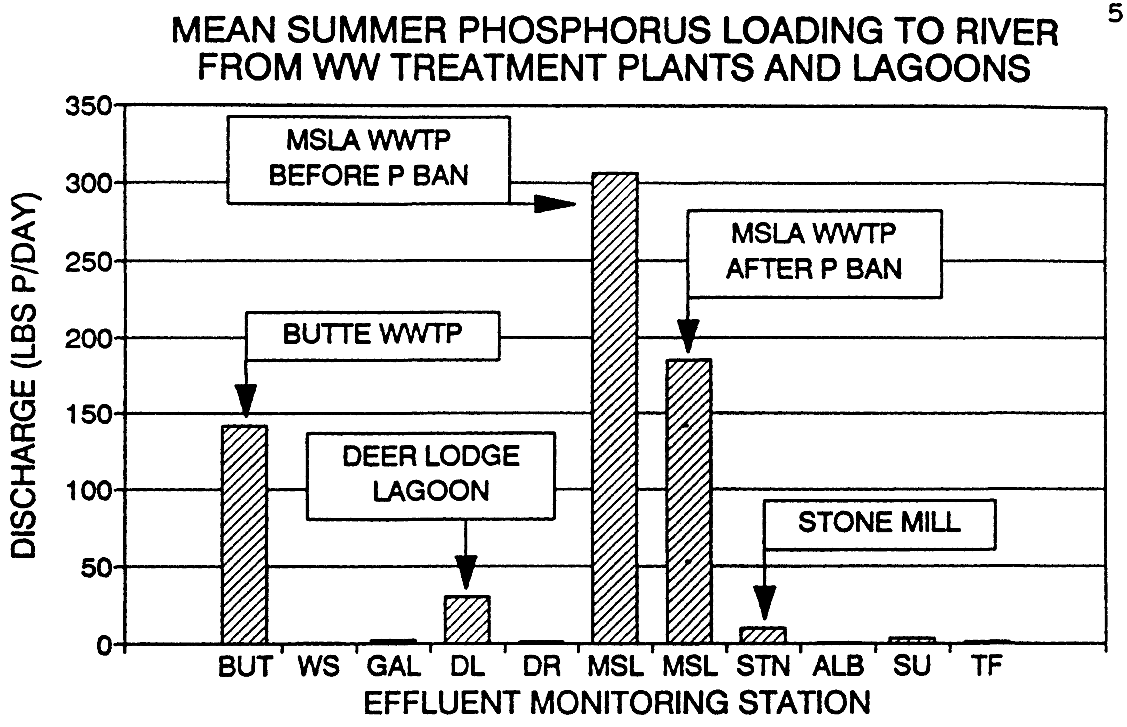
Another approach must be taken to account for these confounding factors and to allow an unbiased evaluation of the effects of the phosphate detergent ban on algal accumulation in the Clark Fork River. A numerical model has been developed to simulate levels of algal accumulation in the Clark Fork River under different nutrient, temperature, and light regimes. This model can be run to test the effects of changes in nutrient concentrations in the river as a result of the phosphate detergent ban. The confounding year-to-year factors are controlled by utilizing a nutrient concentration model developed for the Clark Fork River that estimates river nutrient concentrations from river flows and nutrient loads.

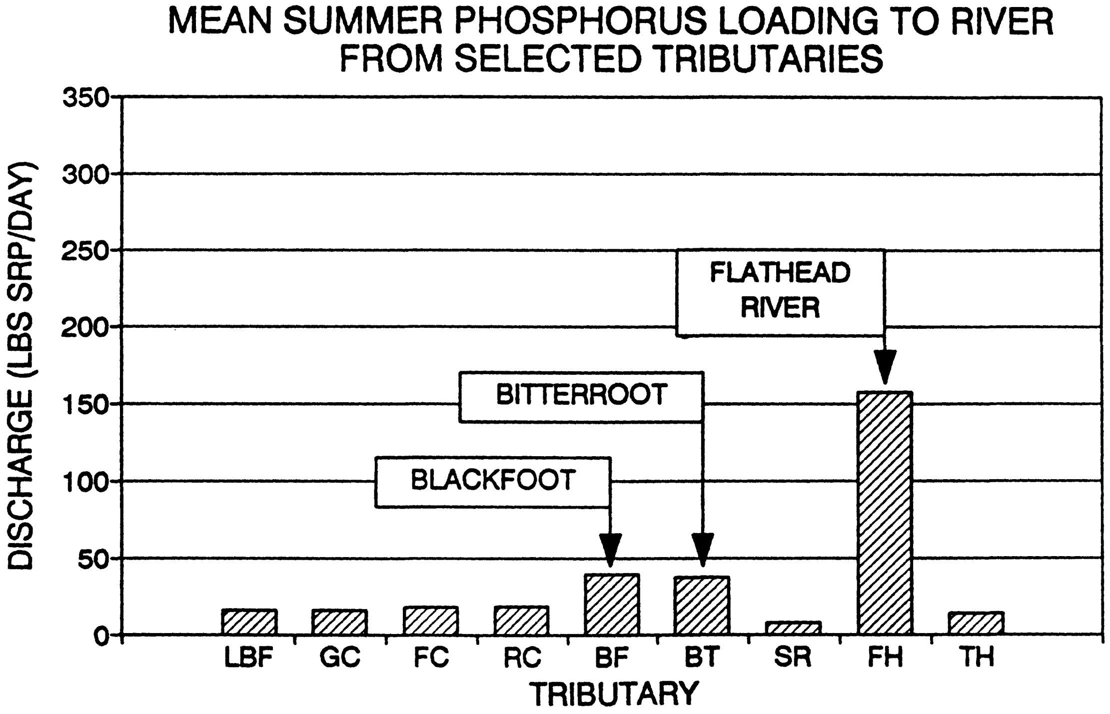
CHAPTER 2. NUTRIENTS IN THE CLARK FORK RIVER

The Section 525 water quality assessment of the Clark Fork River Basin has spawned additional studies designed to address the specific causes and effects of nutrient pollution. The bioavailable forms of the nutrients phosphorus and nitrogen are of concern for eutrophication control and algal management. Bioavailable nitrogen is in the form of nitrate (NO_3^-, nitrite (NO_2^-), and ammonia (NH_3^-), and the sum total of these forms is referred to as total soluble inorganic nitrogen (TSIN or SIN). The bioavailable form of phosphorus is soluble reactive phosphorus (SRP), chemically equivalent to inorganic orthophosphate (PO_4^{3-}).

NUTRIENT SOURCE ASSESSMENT

The Montana Water Quality Bureau has identified the major point and non-point sources of nutrients to the Clark Fork River Basin (Ingman, 1990). The point nutrient sources along the main stem and headwaters of the Clark Fork River include the municipal wastewater discharges from Butte, Warm Springs, Galen, Deer Lodge, Drummond, Missoula, Alberton, Superior, and Thompson Falls. The mean summer phosphorus loading to the river for each of these plants is shown in Figure 1. The Missoula and Butte wastewater treatment plants (WWTP) contribute the greatest loads of bioavailable soluble reactive phosphorus (SRP). The Stone Container pulp mill, which seasonally discharges wastewater pond effluent into the river, has achieved major reductions in phosphorus loading to the





Figures 1 (top) and 2. Mean summer phosphorus loading to the Clark Fork River from selected tributaries and wastewater treatment facilities.

river and has a low average discharge. The main tributary nutrient sources to the Clark Fork River include the Little Blackfoot River, Gold Creek, Flint Creek, Rock Creek, Blackfoot River, Bitterroot River, and the Flathead River. In the middle Clark Fork River, the tributary loadings contribute about one-third of the total nutrient load to the river. In the lower Clark Fork River, the SRP loading is dominated by the Flathead River (Figure 2).

NUTRIENT SAMPLING-METHODS

The Montana Water Quality Bureau began collecting and analyzing Clark Fork River water samples for total and dissolved nutrients in 1988. Grab samples were collected monthly at selected sites along the main stem and tributaries of the Clark Fork River. Main stem samples were collected from the headwaters of the Clark Fork River near Butte to a point nearly 375 river miles downstream, below Cabinet Gorge Reservoir in northeastern Idaho (Figure 3). The 18 station locations (see Table 1) are measured in river miles from Warm Springs. Samples for dissolved nutrients were filtered in the field through a standard 0.45 micron glass filter. Samples were packed on ice after collection and returned to the Montana Department of Health Chemistry Laboratory for analysis. The sample collection and analysis followed standard EPA approved methodology. To ensure the precision and accuracy of the data, strict quality assurance/quality control (QA/QC) protocols were implemented. All collection

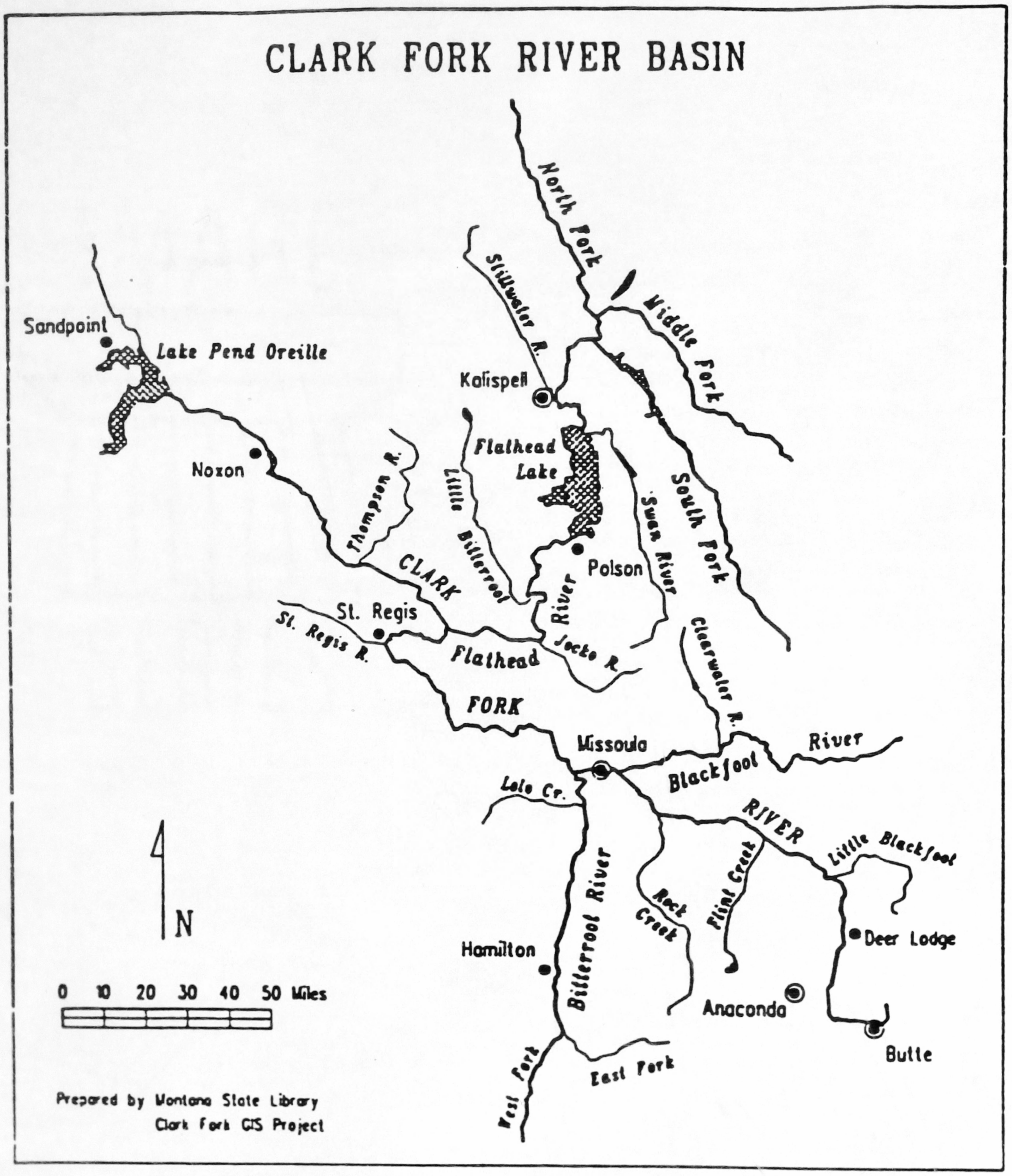


Figure 3. The Clark Fork River Basin.

Table 1. CLARK FORK RIVER MONITORING STATION LEGEND

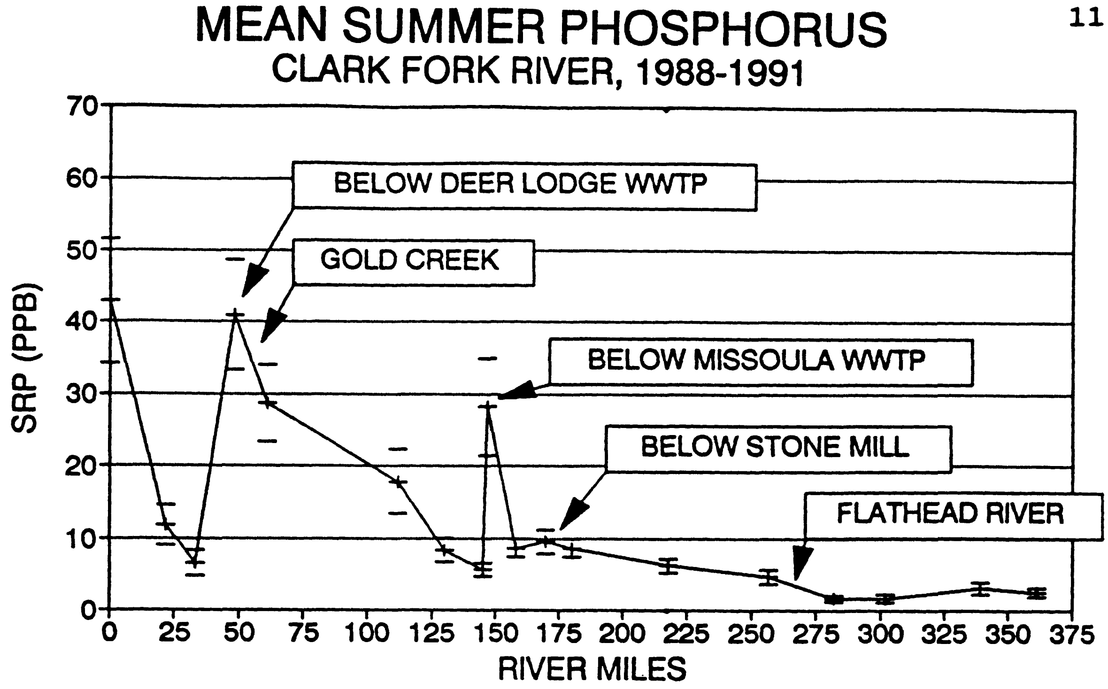
STATION ID	RIVER MILES	STATION DESCRIPTION
WS	0	At Warm Springs, near Anaconda
DM	22	Near Dempsey
DL	33	As river enters Deer Lodge
ALB	48	Above the Little Blackfoot River
GC	61	Below Gold Creek, above Flint Creek
BO	112	Bonita, above Rock Creek
TU	130	Turah, below Rock Creek
AM	145	Above Missoula WWTP
BM	148	Below Missoula WWTP
HB	158	Harper's Bridge, below Bitterroot
HU	170	Huson, below Stone Container Mill
AL	181	Above Alberton
SU	219	At Superior
AF	258	Above Flathead River, near Plains
ATF	283	Above Thompson Falls
BTF	303	Below Thompson Falls
BN	340	Below Noxon Reservoir
BCG	362	Below Cabinet Gorge Reservoir

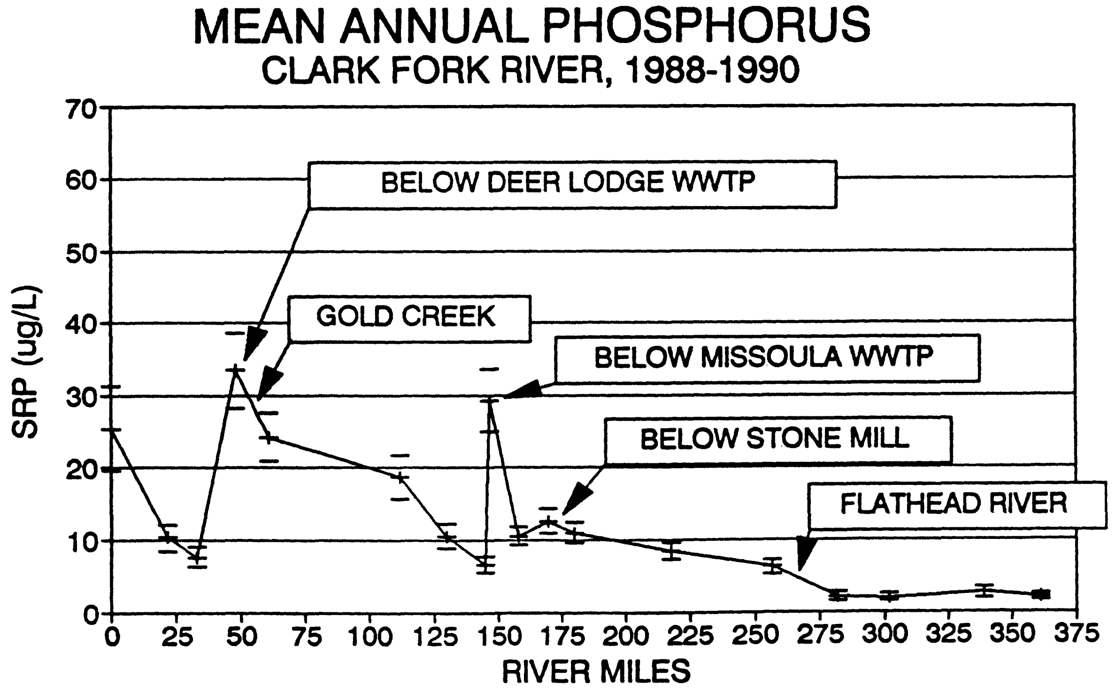
equipment was acid washed and rinsed to prevent sample contamination. Filtered blanks were also collected and analyzed. The state lab uses a QA/QC program of duplicates, spiked samples, known standards, and EPA audit samples to insure the integrity of the data (MDHES, 1974). To complement the state's monthly sampling, the University of Montana began collecting and analyzing biweekly samples during the summers of 1988, 1989, and 1990. Field collection and lab analysis were conducted under the same EPA approved techniques.

NUTRIENT SAMPLING-RESULTS

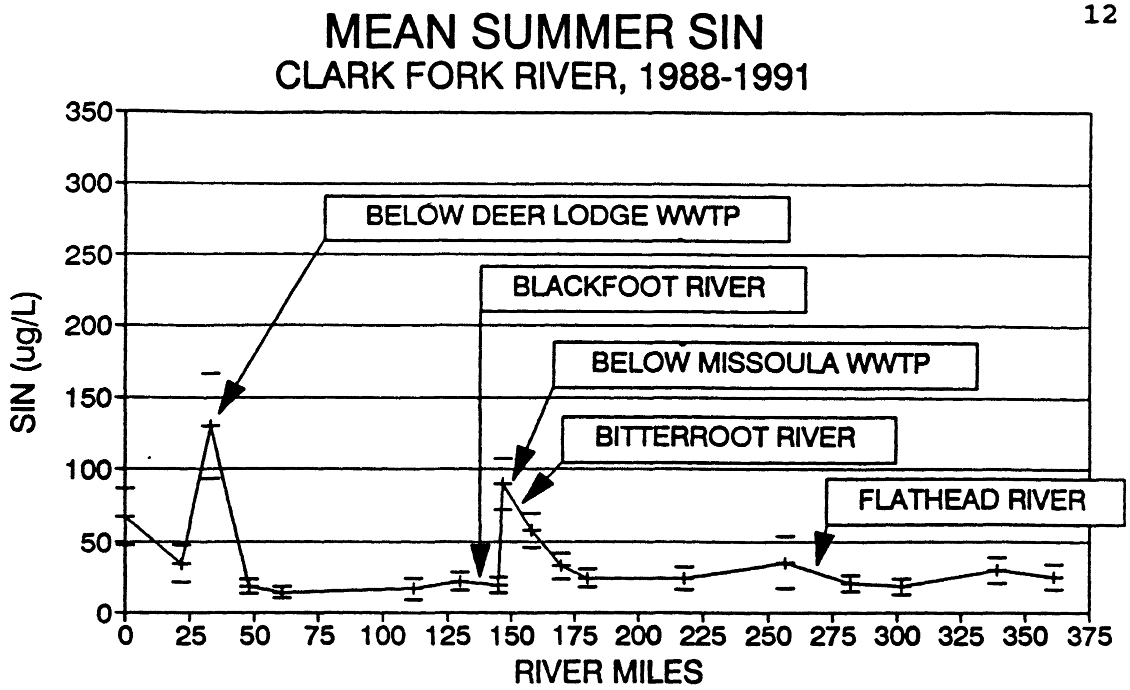
A plot of nutrient concentrations vs. distance down the river displays the dynamics of nutrient levels in the Clark Fork River. Figure 4 shows mean summer SRP levels along the river as averaged over the course of 4 years worth of data. The 95% confidence intervals are also presented to represent the variability of the data. The phosphorus level is near 40 ug/L (PPB) at the Warm Springs monitoring station near Anaconda. This value is high for the Clark Fork, but the actual phosphorus load at this point is low because of the low average flow (100 cfs) at this station. Along the reach of the river below Warm Springs, at the Dempsey and Deer Lodge stations, the SRP concentration has dropped to a value near 10 ug/L. The concentration has dropped because of dilution by nutrient poor water and by biological nutrient uptake by algae. The next station is below the Deer Lodge wastewater lagoon, and the SRP concentration consequently jumps back up to 40 ug/L. The next station is below the confluence with phosphorus rich Gold Creek, and the SRP stays high near 30 ug/L. The SRP levels in the river gradually decrease downstream as the flows increase and more dilution and biological uptake occurs. After the Blackfoot River enters the Clark Fork almost 150 miles downstream from Warm Springs, the SRP concentration has dropped to 7 ug/L at the above Missoula station.

Nutrient levels would gradually decrease downstream from this point if there were no other significant point sources of nutrients. However, effluent from the Missoula wastewater treatment plant enters the river between the above and below Missoula stations, just past the 150 mile mark. At this point, the river's SRP concentration jumps to 30 ug/L. The large jump in concentration at this station represents the loading by the Missoula WWTP. The average annual daily load to the river from the Missoula WWTP is currently 185 lbs total P/day. The SRP concentration drops off downstream from the below Missoula station and stays near 10 ug/L at the Harper's Bridge, Huson, and Alberton stations because of dilution from the Bitterroot River and from algal uptake along this reach. The influence of the Stone mill discharges, located between the Harper's Bridge and Huson stations, is manifested as a small average increase in SRP levels at the Huson station. The lower Clark Fork River is characterized by low nutrient levels and large flows. There is a heavy nutrient load in the

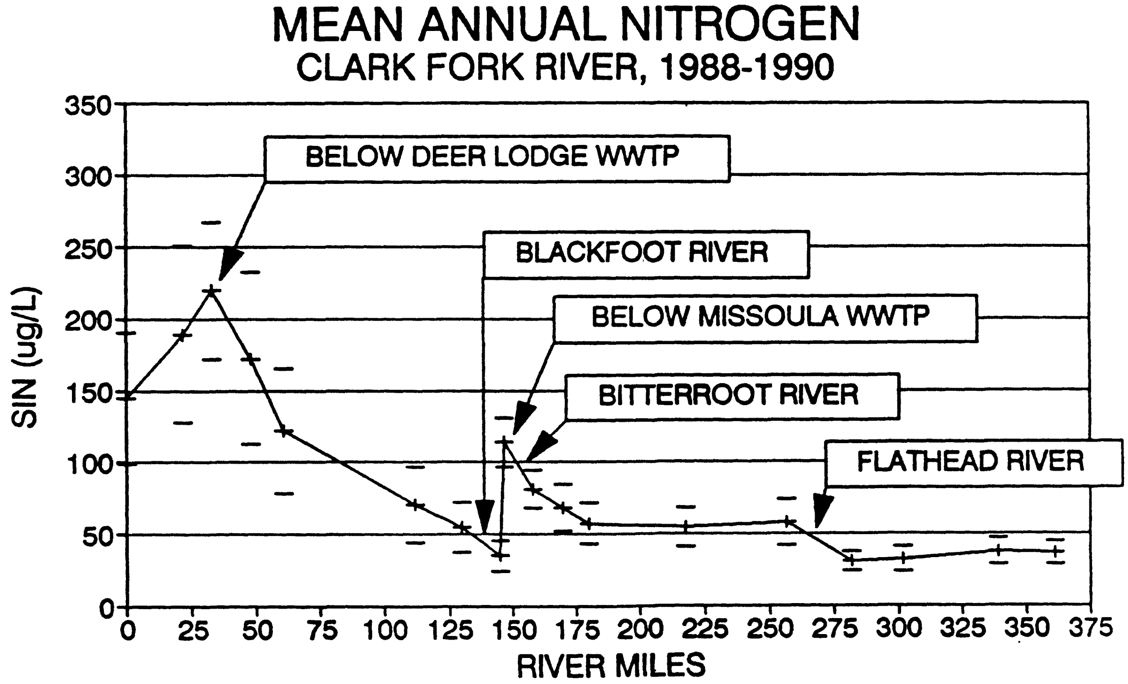




Figures 4 (top) and 5. Mean summer and annual soluble reactive phosphorus (SRP) concentrations in the Clark Fork River.



MEAN SUMMER SIN
CLARK FORK RIVER, 1988-1991



MEAN ANNUAL NITROGEN
CLARK FORK RIVER, 1988-1990

Figures 6 (top) and 7. Mean summer and annual soluble inorganic nitrogen (SIN) concentrations in the Clark Fork River.

lower Clark Fork, defined by the large volume of water flowing towards Lake Pend Oreille.

The bioavailable nitrogen levels in the Clark Fork follow trends similar to that of phosphorus (Figure 6). Total soluble inorganic nitrogen levels peak downstream from wastewater discharges at Butte, Deer Lodge, and Missoula, and then the levels drop off. The nitrogen plots do not show the sustained high nutrient levels below Gold Creek, which is only a significant contributor to the phosphorus load. Nitrogen does not drop as dramatically as does phosphorus below the Bitterroot River because the Bitterroot is relatively high in nitrogen. Annual nutrient levels (Figures 5 and 7) are similar to the summer-only averages.

CHAPTER 3. ALGAL ACCUMULATION IN THE CLARK FORK RIVER

NUISANCE ALGAL ACCUMULATION

Algal accumulation in the Clark Fork River is a natural phenomenon that is beneficial to the local aquatic community. The algae serve as a food source and refuge for aquatic invertebrates, as well as acting as a critical keystone for nutrient cycles. However, like all good things, too much algae can be harmful. Algae levels can be considered a nuisance if the algae interferes with some aspect of recreational, commercial, or natural use of the river. This interference can be purely aesthetic or have some more tangible physical effect. Algae can block agricultural irrigation intakes, clog pumps, and stagnate irrigation channels. Algal mats can prevent recreational boat use and interfere with fishing. Algal accumulation also adversely affects river fisheries by clogging intergravel habitat, controlling the dynamics of local insect communities, and affecting dissolved oxygen (DO) levels.

Various attempts have been made to quantify algal accumulation and to define levels of nuisance algal accumulation. Algal biomass accumulation can be determined by the amount of chlorophyll present over a given area (measured as mg chlorophyll "a"/m^2), or by measuring the amount of ash free dry weight present per area. Nordin (1985) has found algal accumulation levels of less than 50 mg/m^2 to be acceptable aesthetically and for recreational uses. Welch

(1988) has found a biomass range of 100-150 mg chlorophyll/m^2 to represent a critical level for an aesthetic nuisance. This biomass level corresponds to filamentous coverage near 20%. Photographs of Clark Fork River algal research sites have been used to solicit comments on the aesthetic nuisance of attached algae. An informal survey of local citizens found unanimous agreement that biomass levels of 200 mg chlorophyll/m^2 is aesthetically unacceptable, and the majority felt that biomass levels of 100 mg chlorophyll/m^2 are unacceptable (Watson, pers. comm.). Algal accumulation of less than 100 mg chlorophyll/m^2 was not found to affect the local community of aquatic organisms adversely (Nordin, 1985). For this report, algal accumulation in the Clark Fork River that exceeds 100 mg chlorophyll/m^2 will be defined as nuisance accumulation.

ALGAL MONITORING-METHODS

In 1986, the Montana Water Quality Bureau surveyed attached algae levels along the entire length of the Clark Fork from the headwaters near Warm Springs to the Idaho border. This sampling program utilized algae grown on randomly selected natural rock substrates. Numerous algal communities exist in the Clark Fork River. The upper river is dominated by a filamentous green, Cladophora, while the middle and lower river is generally characterized by a mixed community of periphytic diatoms. Algal levels were found to exceed 100 mg chlorophyll/m^2 at many of the upper and middle river sites (Weber, 1988).

Algal accumulation on artificial substrates was monitored during the 1987, 1988, and 1990 summer growing seasons under a program developed by Dr. Vicki Watson at the University of Montana. These data were primarily collected to validate a model designed to simulate algal accumulation in the Clark Fork River. Algal samples were collected on both natural (rocks) and artificial (ceramic tiles or styrofoam) substrates. The substrates were kept at a constant depth of 20-30 cm and in flows near 0.3 m/s. Samples were collected and analyzed for chlorophyll and ash free dry weight in accordance with standard methods. Algal samples were scraped off the substrate, and the chlorophyll extracted with acetone. The samples were then centrifuged and spectrophotometrically analyzed. Ash free dry weight was determined by ashing and weighing the algae samples.

In 1987, unglazed ceramic tiles served as the artificial substrates that were placed in the river at sites above and below the Missoula WWTP, and at sites near Harper's Bridge and Huson, bracketing the Stone mill. Samples were collected and analyzed at the end of the growing season in September. Natural substrates were collected in 1988 at two sites, one further upstream from Missoula near Rock Creek, and the second at the below Missoula site. In the summer of 1990, artificial tile substrates were placed at the same sites as the 1987 substrates, and at four lower river sites, Alberton, Superior, St. Regis, and Plains. The Superior substrates disappeared early in the experiment. Samples were collected weekly at the middle river sites and monthly at the lower river sites from the beginning of July to the end of September. Five to ten replicate samples were collected at each site and the samples were analyzed for chlorophyll and ash free dry weight.

ALGAL MONITORING-RESULTS

The results from the artificial substrate experiments confirm that the greatest levels of algal accumulation occur at sites downstream and closest to the Missoula wastewater treatment plant. Figure 8 shows the mean peak biomass attained at each of the sites as averaged over the course of the summer for each year. Algal accumulation found on the substrates at the above Missoula site are similar for all three years, with an average biomass near 25 mg chlorophyll/m^2. At the below Missoula site, algal accumulation is above the 100 mg chlorophyll/m^2 nuisance criterion all three years. Algal accumulation is highest in 1987 and 1988, low flow, pre- phosphate detergent ban years. 1990 was an average flow, post- ban year, and therefore has lower levels of attached algae. The lower river sites are characterized by low levels of algal accumulation. The variability of the replicate samples is highest at the sites with high levels of algal accumulation. Algal accumulation on the artificial substrates is most uniform at low (< 50 mg chlorophyll/m^2) levels. Algal accumulation data as measured over the course of each summer is presented in Figures 11

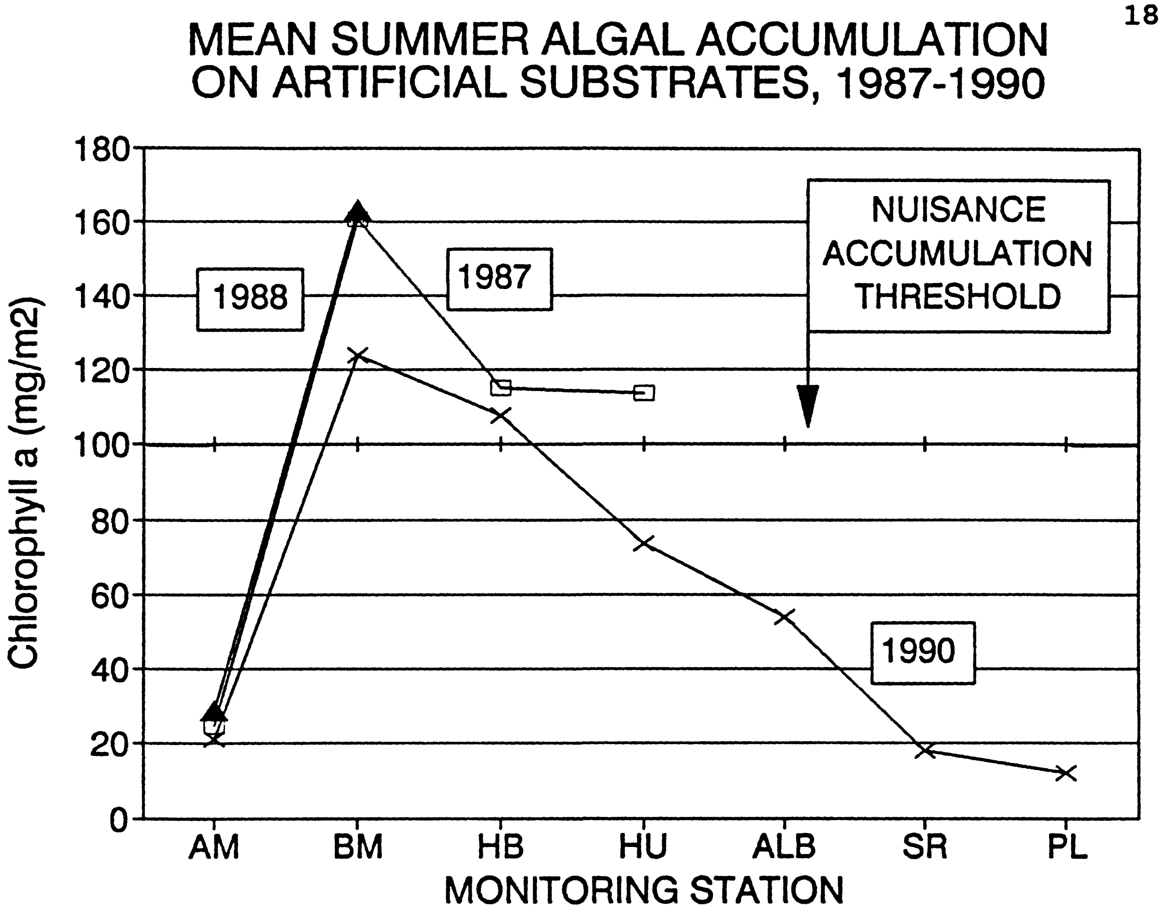


Figure 8. Mean summer algal accumulation as measured on artificial substrates in the Clark Fork River, 1987-1990.

through 18 as part of the algal accumulation model validation runs.

LIMITATIONS OF ALGAL GROWTH AND ACCUMULATION

The rate of algal growth and amount of accumulation in a given year is dependent upon many physical and chemical factors. Algal growth is primarily a function of temperature, light, and nutrient availability. In the Clark Fork River, the algal growing season is roughly limited to May through September, when temperatures and light levels are most favorable. Algal accumulation over time represents the balance between growth rates and algal die-offs and sloughing. Sloughing of the algal biomass occurs as filaments weaken and break away due to scouring high river flows and environmental stress. Environmental stress can occur from toxic discharge events, extreme temperature or flow fluctuations, and from nutrient limitation.

In all natural ecosystems, some combination of factors will limit growth. The most important limiting factor for algal growth and accumulation in the Clark Fork River is nutrient availability. Both nitrogen and phosphorus have been found to be low enough to limit growth and maximum standing crop at different seasons and different locations on the Clark Fork River (Watson et al, 1990).

CHAPTER 4. THE MISSOULA PHOSPHATE DETERGENT BAN

Many communities have adopted bans on phosphate detergents to reduce phosphorus discharges from local wastewater treatment plants. Phosphate detergents were identified as a problem in the Great Lakes states, Europe, and Australia in the late 1960's and early 1970's (DeJung, 1989, Hartwell, 1973, Hartig, 1990). Phosphorus discharges were strongly contributing to the eutrophication of receiving waters. In 1988, a phosphate detergent ban was proposed for Missoula to reduce phosphorus discharges from the Missoula wastewater treatment plant. A reduction in phosphorus discharges from the Missoula plant would prevent violations of the wastewater treatment plant's discharge permit, lower the bioavailable phosphorus load to the Clark Fork River, and allow the City of Missoula the opportunity to annex more homes and expand the city sewer system while remaining in permit compliance.

The County and City of Missoula jointly enacted the Missoula Phosphate Ordinance on November 21, 1988. The ordinance prohibits the sale of any laundry and dishwasher detergents, soaps, bleaches, and water conditioners that contain more than 0.5% phosphorus. This ban pertains to these cleaning products that are sold inside the city limits and within 3 miles of the city (Figure 9). The ban does not cover many outlying communities, including Bonner, Lolo, and Frenchtown, but these areas are covered by the ban de facto.

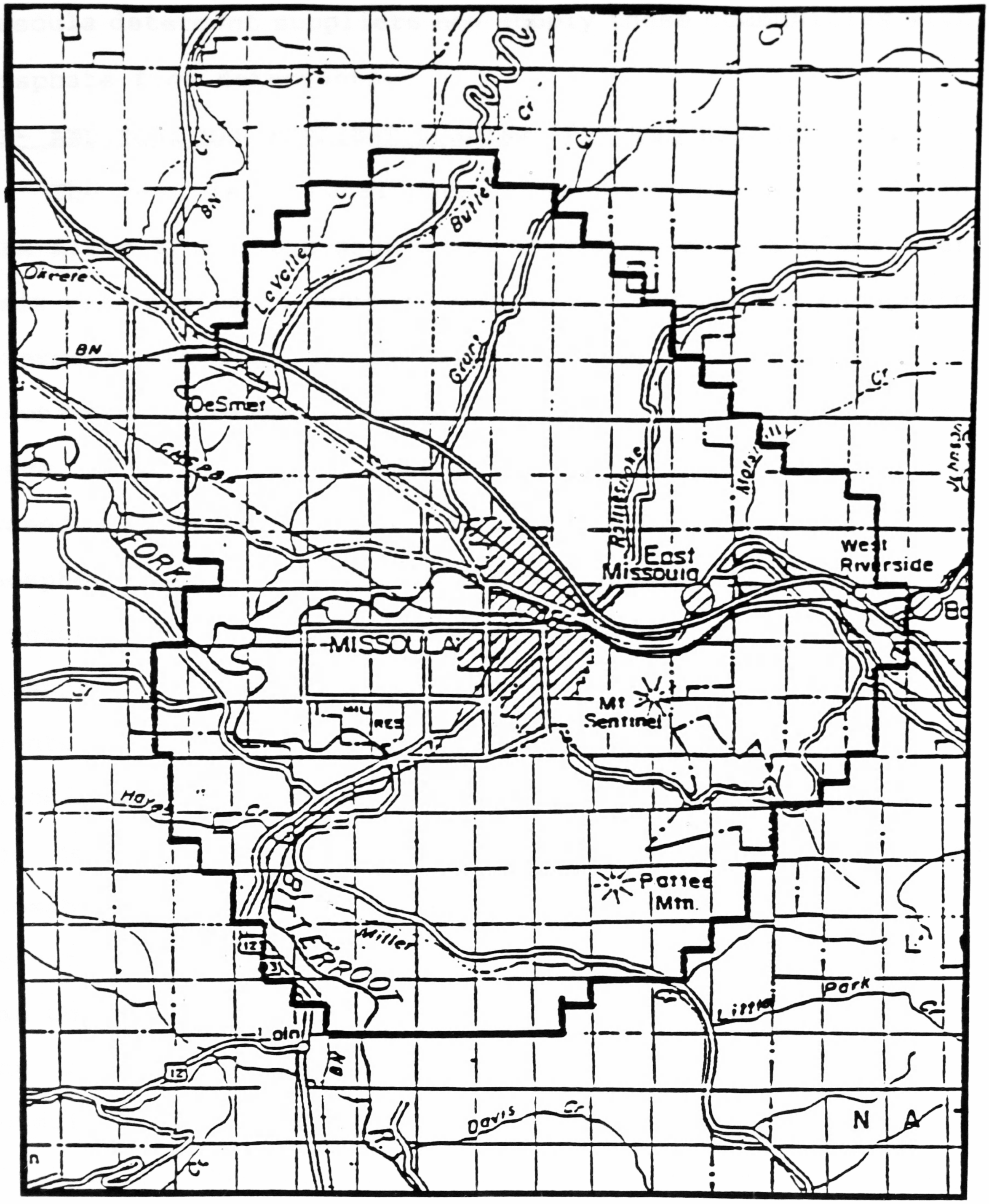


Figure 9. Area affected by the Missoula Phosphate Detergent Ban.

Many residents of these communities shop in Missoula, and Missoula detergent suppliers now supply these communities with phosphate free detergents.

PRE- AND POST BAN NUTRIENT LOADING FROM THE MISSOULA WWTP

The mean daily total phosphorus discharge to the Clark Fork River from the Missoula wastewater treatment plant over a six year period is shown in Figure 10. Before the phosphate detergent ban went in to effect in May, 1989, phosphorus discharges from the plant averaged 306 lbs/day and showed large monthly fluctuations. Monthly average discharges exceeded the plant's NPDES permit level of 375 lbs phosphorus/day on five months out of the six year period. The fluctuations represent changes in the plant's influent phosphorus levels and high phosphorus releases due to upset events occurring within the plant itself. Phosphorus discharges have decreased to an average of 185 lbs/day after the detergent ban was enforced, reflecting the decreased phosphorus load to the plant. This translates to a 40% reduction in annual phosphorus discharges to the river. Post-ban phosphorus discharges remain stable compared to the pre-ban discharge fluctuations. This is in part due to a conscious effort on behalf of the plant operators to avoid plant upsets and run the plant more consistently (Miller, 1991), and in part due to the closing of a Missoula dairy operation that had irregularly introduced phosphorus-rich wastes into the city wastewater system.

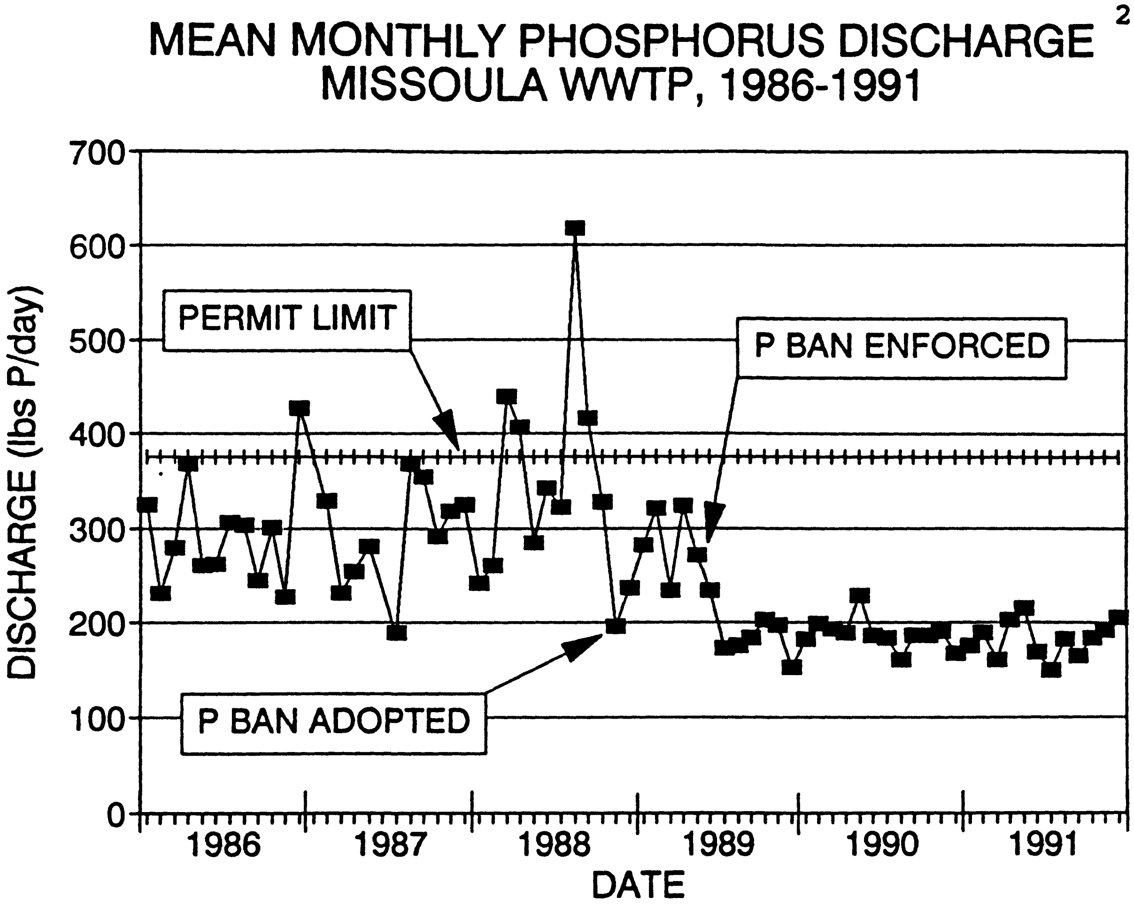


Figure 10. Mean monthly phosphorus discharges from the Missoula Wastewater Treatment Plant to the Clark Fork River, 1986-1991.

Phosphorus discharges from the Missoula wastewater plant could be reduced even further by more expensive and elaborate techniques. Metal ion coagulates such as alum (aluminum sulfate) or ferric chloride could be added to the secondary clarifier of the plant to complex and precipitate out phosphorus (Kerri, 1991). Effluent from the plant could also be land treated in the summertime, completely eliminating the nutrient load to the river.

CHAPTER 5. APPROACH TO ASSESSING THE BENEFITS OF THE BAN

The nutrient load reduction achieved as a result of the phosphate detergent ban has decreased algal accumulation in the Clark Fork River. Comparisons of measured algal accumulation before and after the ban data qualitatively show this to be true (see Figure 8). However, there are a number of confounding environmental factors besides nutrients that affect algal accumulation in the river. Yearly differences in cloud cover, temperatures, grazing, toxic events, and algal sloughing affect algal accumulation. The primary factor controlling algal accumulation is the amount of water discharged through the river channel. The flow controls water temperature, nutrient dilution, and substrate scouring. To normalize these confounding factors, a numerical model that simulates algal accumulation in the Clark Fork River has been developed. Algal accumulation in the river can be simulated under pre- and post- ban nutrient conditions with all other factors held constant. The realized benefits as a result of the phosphate detergent ban can then be quantified as reductions in accumulated algal biomass and as reductions of the frequency of occurrence of nuisance levels of algal accumulation.

The algal accumulation model simulates algal accumulation as a function of nutrient concentration. To normalize the confounding factors that affect nutrient concentrations in a given year, a numerical nutrient concentration model has been developed. This nutrient model predicts what river nutrient concentrations are in the river as a function of nutrient loading and flow. The nutrient model predicts the changes in river nutrient levels as a result of decreased nutrient loading from the phosphate detergent ban by isolating the effects of the ban. The output of the nutrient model is used as the input to the algal accumulation model, and the algal model is then run to assess the benefits of the ban.

CHAPTER 6. THE ALGAL ACCUMULATION MODEL

NATURE OF THE ALGAL ACCUMULATION MODEL

A model designed to simulate algal growth and accumulation in the Clark Fork River was developed by Dr. Vicki Watson at the University of Montana. The model is given average daily light, temperature, and nutrient conditions as inputs, and then predicts total algal biomass accumulation for each day of the growing period. The model begins with a small initial biomass and then estimates the net growth, respiration, and sloughing rates on an hourly basis. The model then adds or subtracts this amount of biomass from the previous estimate of the biomass. This process then continues for each day of the growing period and algal accumulation increases or decreases as conditions demand.

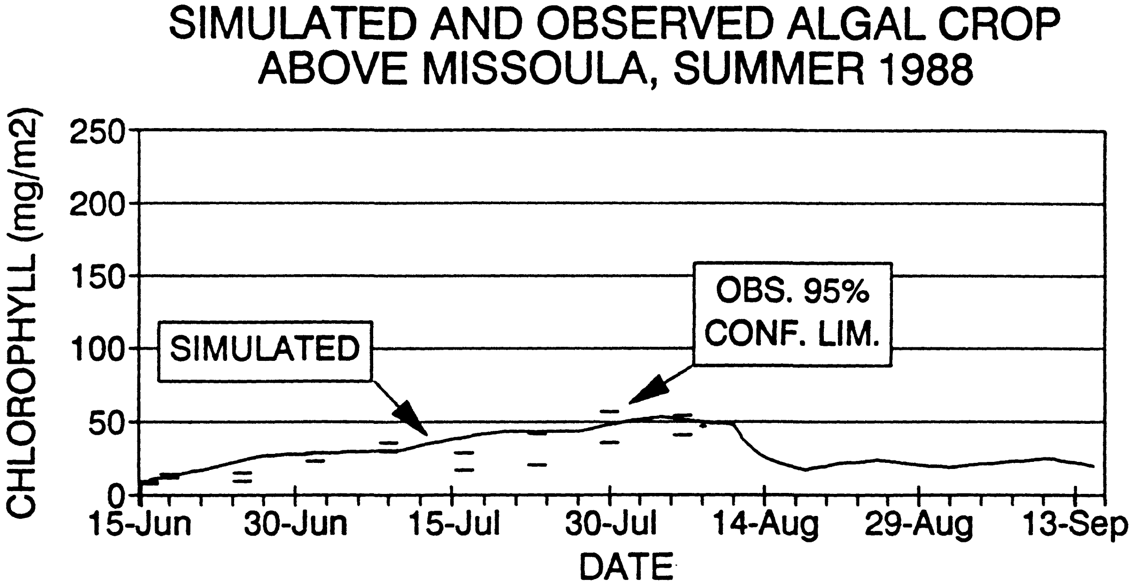
The model is based on a number of simplifying assumptions. Growth limitation is based solely on phosphorus, temperature, and light limitation. Other nutrients are not considered. The model does not consider effects from insect grazing, scouring flows, turbidity, or cloudy weather. The model does a reasonably good job of predicting algal accumulation in the river and the simplifying assumptions do not seem to compromise the data. The kinetics of the model are described in further detail in Appendix A.

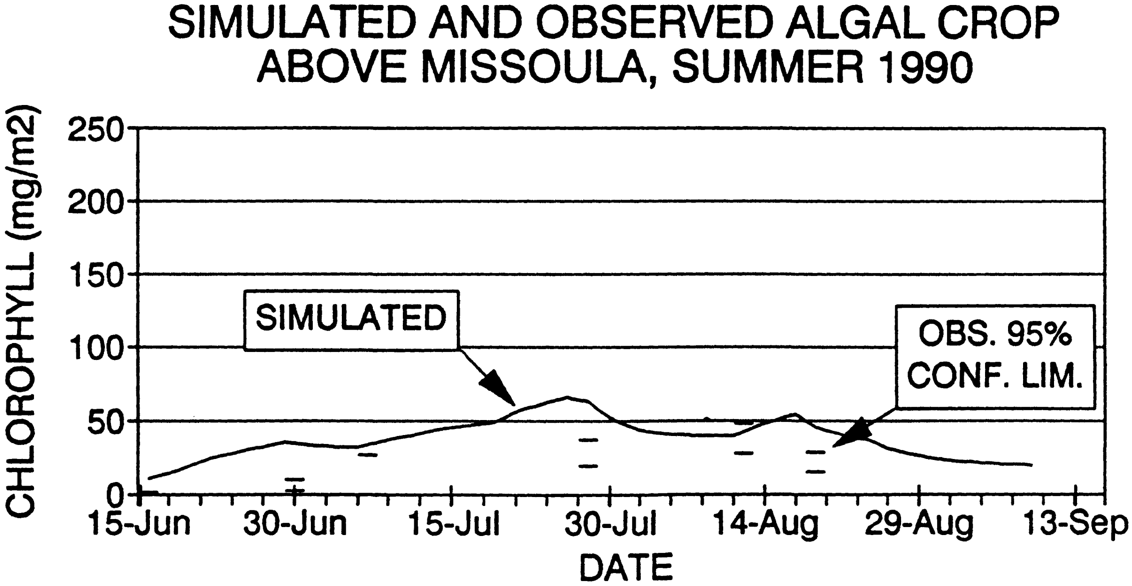
VALIDATION OF THE ALGAL ACCUMULATION MODEL

The model was validated by using field data (phosphorus concentration and water temperature) for the model inputs and comparing the model's simulated levels of algal accumulation to actual measured algal accumulation at each site. Validation data were used from 1988 and 1990 at the above and below Missoula (AM and BM) sites and from 1990 at the Harper's Bridge (HB), Huson (HU), St. Regis (SR) and Plains (PL) sites. Model parameters, such as the growth kinetics and sloughing rates, were adjusted to achieve the best fit of the simulated data to the actual algal accumulation. The model was declared validated when the simulated algal accumulation reasonably matched the observed data on two independent parameters. Model simulations were validated against the peak biomass attained over the course of the growing period and the general growth and sloughing patterns. To facilitate the model validation, the observed and simulated algal accumulation levels were normalized to a 93 day summer growth period, from June 15 to September 15.

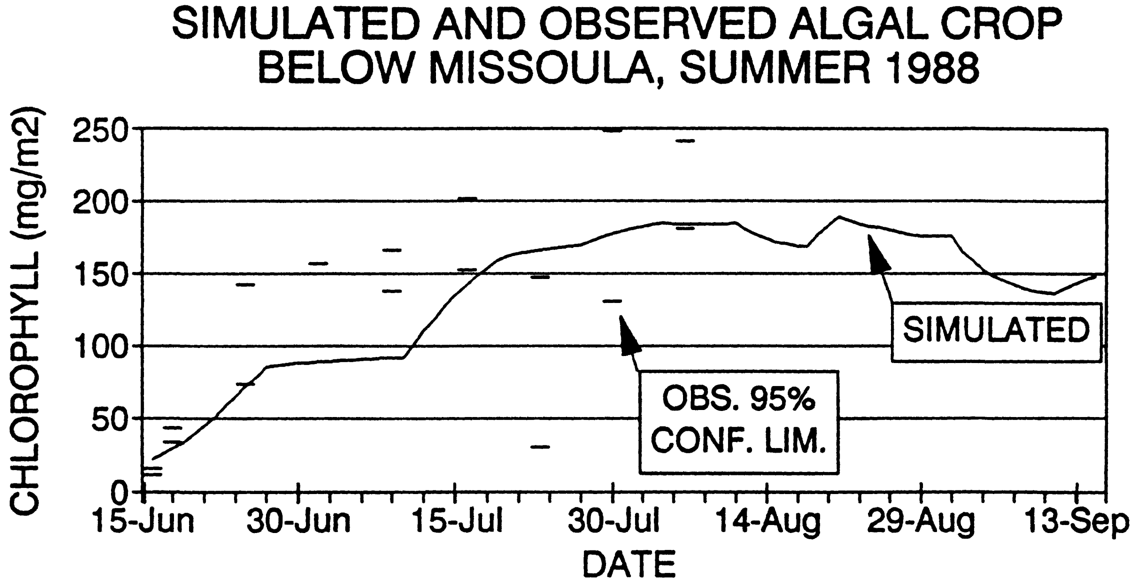
Results from the model validation runs are presented in Figures 11 through 18. The plots show the model simulation and observed algal accumulation for each site over the summer growing season. The observed data, from the artificial substrate experiments, are represented by the 95% confidence interval limits of the measured values. The simulated algal accumulation does a reasonably good job of representing the actual measured algal accumulation at each site, with the exception of the St. Regis site. The simulated and observed data generally both show similar growth and sloughing patterns and the model accurately predicts the peak biomass level attained at the middle river sites. The simulated levels run high for the lower river sites because the observed algal accumulation does not accumulate as fast in the larger river channel as it does in the smaller reaches of the river. The observed data from the below Missoula site exhibit wide confidence intervals and large fluctuations between sampling dates. This is due to uneven algal accumulation on the artificial substrates and unexpected sloughing events. It is difficult to declare the model validated in these conditions. However, the simulated values do pass through many of the observed confidence intervals and appear to reasonably represent the real world.

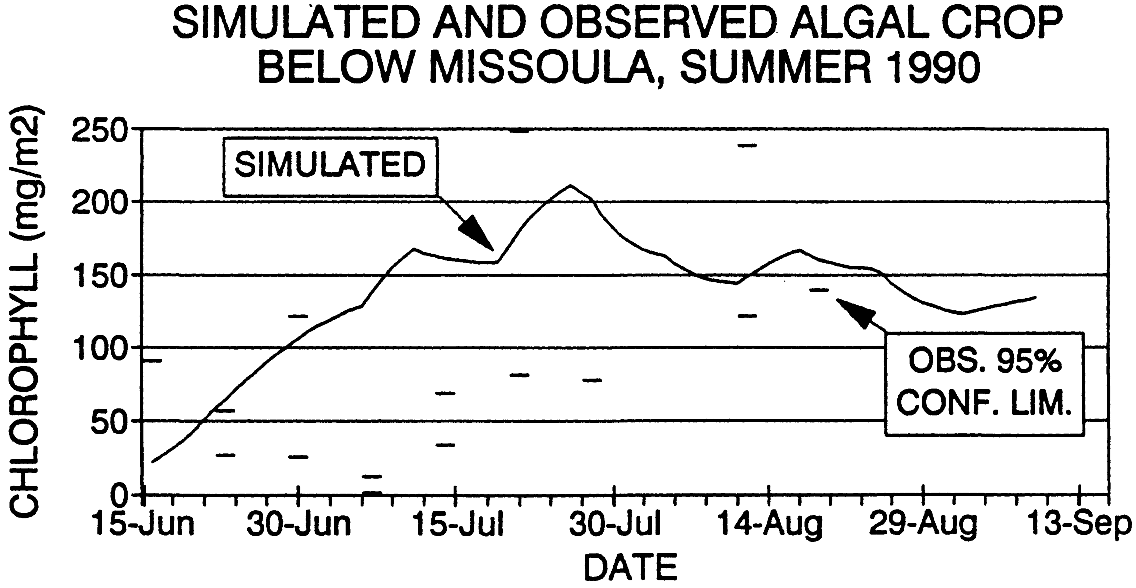
The observed nutrient and temperature data used as inputs to the model were based on biweekly intervals. The observed value was used to represent the temperature and nutrient conditions in the river for that entire period. Light levels were simulated based on typical light levels from this latitude. This simplification decreases model sensitivity by ignoring any small scale and diurnal fluctuations of these parameters. Model prediction could be improved by using more frequently measured input data that would more closely match the actual temperature and nutrient fluctuations seen in the river. Model sensitivity could also be improved by considering other physical parameters, most importantly nitrogen concentrations that are seen in the river.



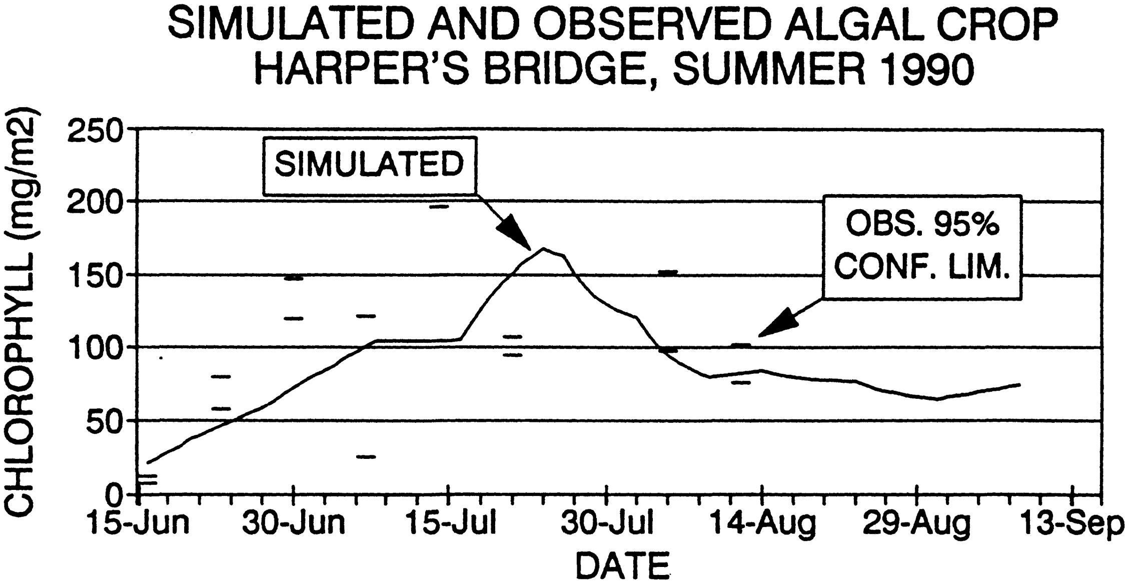


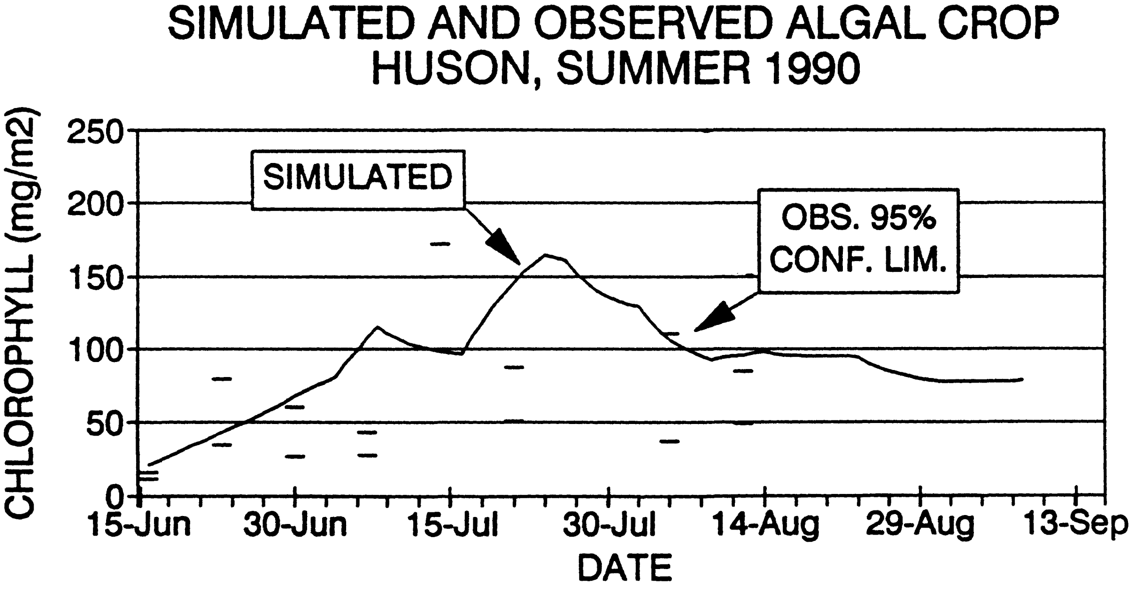
Figures 11 (top) and 12. Validation runs of the algal accumulation model. Simulated and observed algal accumulation in the Clark Fork River.



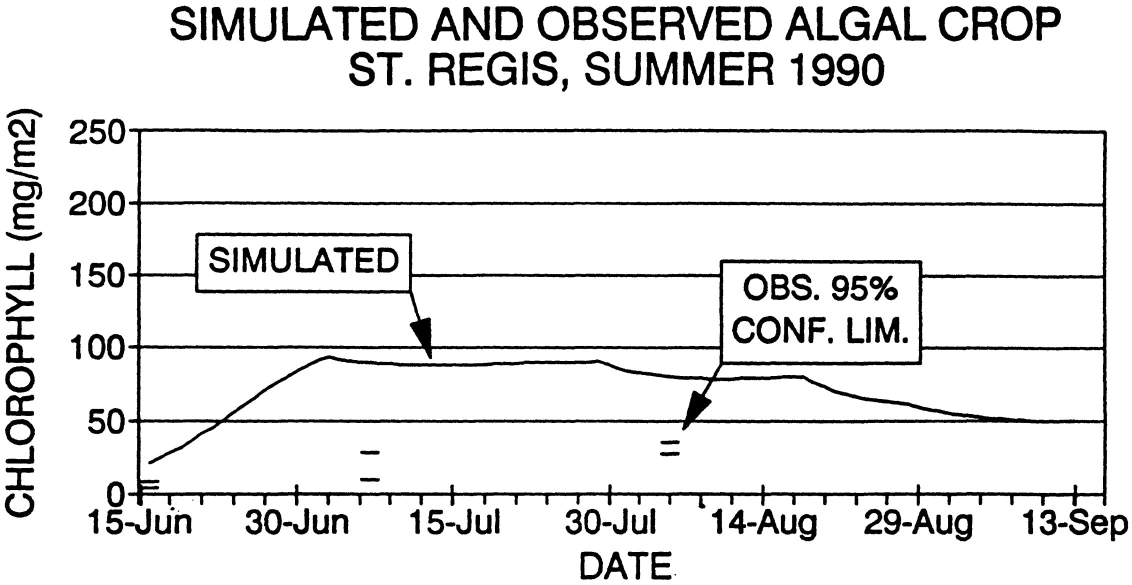


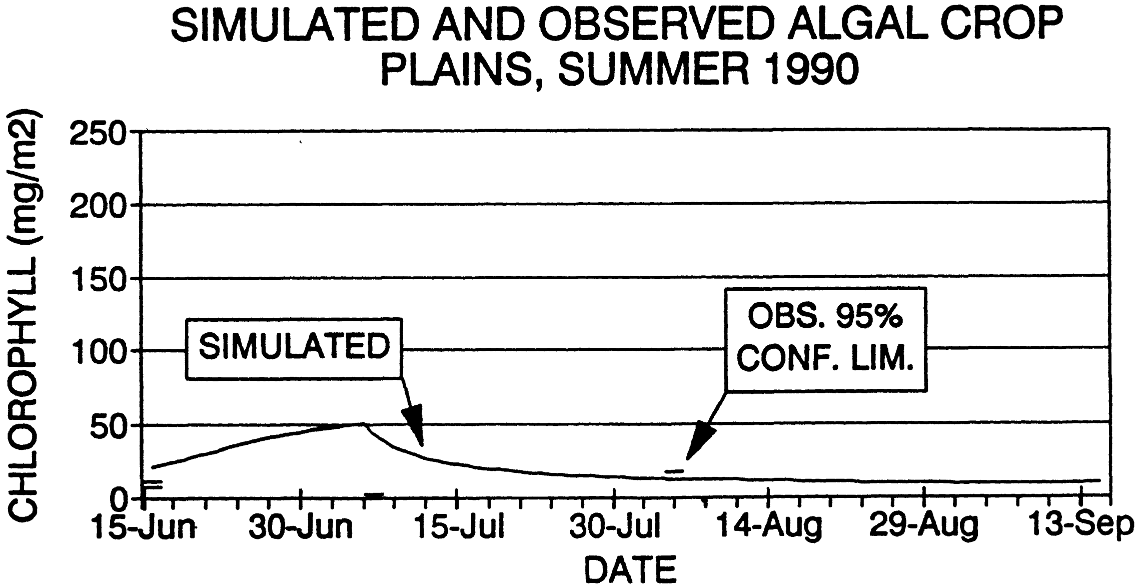
Figures 13 (top) and 14. Validation runs of the algal accumulation model. Simulated and observed algal accumulation in the Clark Fork River.





Figures 15 (top) and 16. Validation runs of the algal accumulation model. Simulated and observed algal accumulation in the Clark Fork River.





Figures 17 (top) and 18. Validation runs of the algal accumulation model. Simulated and observed algal accumulation in the Clark Fork River.

CHAPTER 7. THE CLARK FORK RIVER NUTRIENT MODEL

PURPOSE AND NATURE OF THE NUTRIENT MODEL

A Clark Fork River nutrient model was developed to provide nutrient level input data to the algal accumulation model that is normalized against confounding environmental factors. These inputs will allow valid comparisons of pre- and post- ban algal accumulation by isolating the effects of the phosphate detergent ban. The nutrient model predicts soluble reactive phosphorus concentrations at selected sites on the Clark Fork River for low and average flow conditions. High flow years are not modeled because of the high rates of sloughing and substrate scouring that would be expected to prevent accumulation of nuisance levels of attached algae.

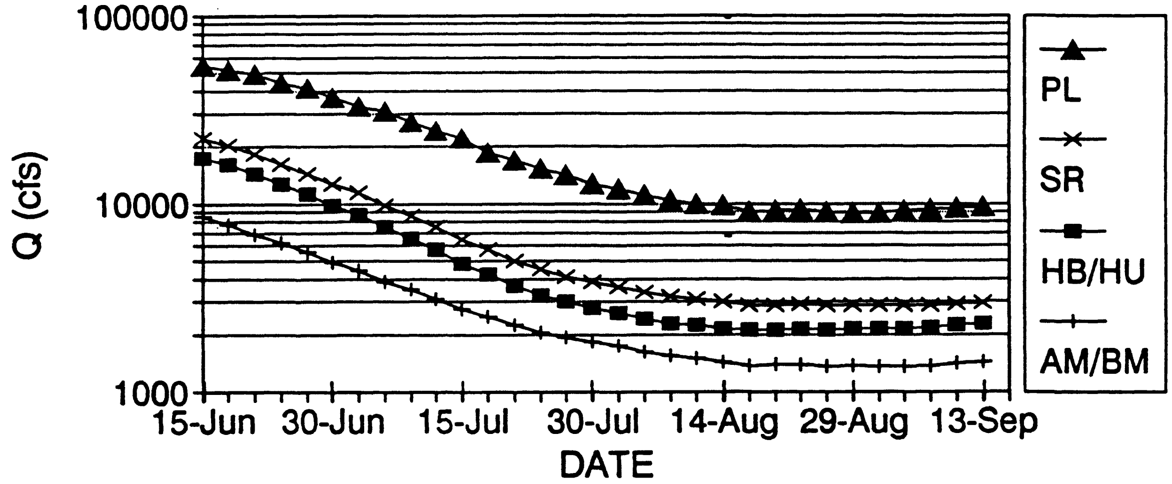
The nutrient model was developed by first defining three basic parameters that control the nutrient levels in the river. These parameters include flow, nutrient loading, and nutrient uptake and retention in the system. The model utilizes standardized flow conditions, a mass-balance approach to nutrients in the river, and empirically derived nutrient retention and uptake factors for each reach of the river. Nutrient levels are predicted for each of the sites where algal accumulation and nutrient data had been previously collected, namely the above and below Missoula sites, Harper's Bridge, Huson, St. Regis, and Plains. The nutrient model was validated with observed nutrient data collected by the Montana Water Quality Bureau and the University of Montana in 1988 and

1990.

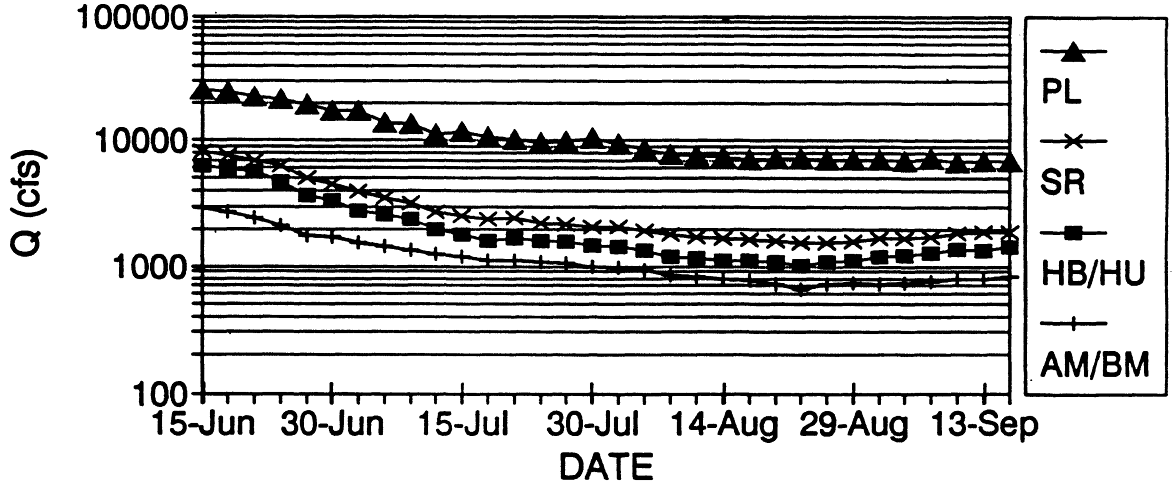
The river's average and low flow conditions were defined from 62 years (1930-1991) of USGS gauging station records. The average flow scenario was defined by the average of the 61 year record available for each station. The 1990 water year was classified as an average flow year because the 1990 station discharge figures are within ten percent of this average. The low flow scenario was defined by the average of the lowest 10% of the flows, with the exclusion of one extremely low flow year. The 1987 and 1988 water years are within this low flow condition. The standardized flow scenarios so obtained are presented in Figures 19 and 20. The major tributaries between the gauging stations include the Bitterroot River between the below Missoula and Harper's Bridge sites, the St. Regis River between Huson and St. Regis, and the Flathead River between St. Regis and Plains.

The mass-balance approach to estimating phosphorus levels in the river begins by utilizing the nutrient concentrations at the above Missoula site from a low flow (1988) and an average flow (1990) year. The nutrient load at this location is known from the flow and nutrient concentration. Phosphorus loading from the Missoula wastewater treatment plant was calculated from the wastewater treatment plant's monthly discharge report (see Figure 10), and.then this load was added into the river. The nutrient concentration at the below Missoula site was then calculated from the known nutrient load

STATION DISCHARGE, CLARK FORK RIVER
AVERAGE FLOW SCENARIO



STATION DISCHARGE, CLARK FORK RIVER
LOW FLOW SCENARIO



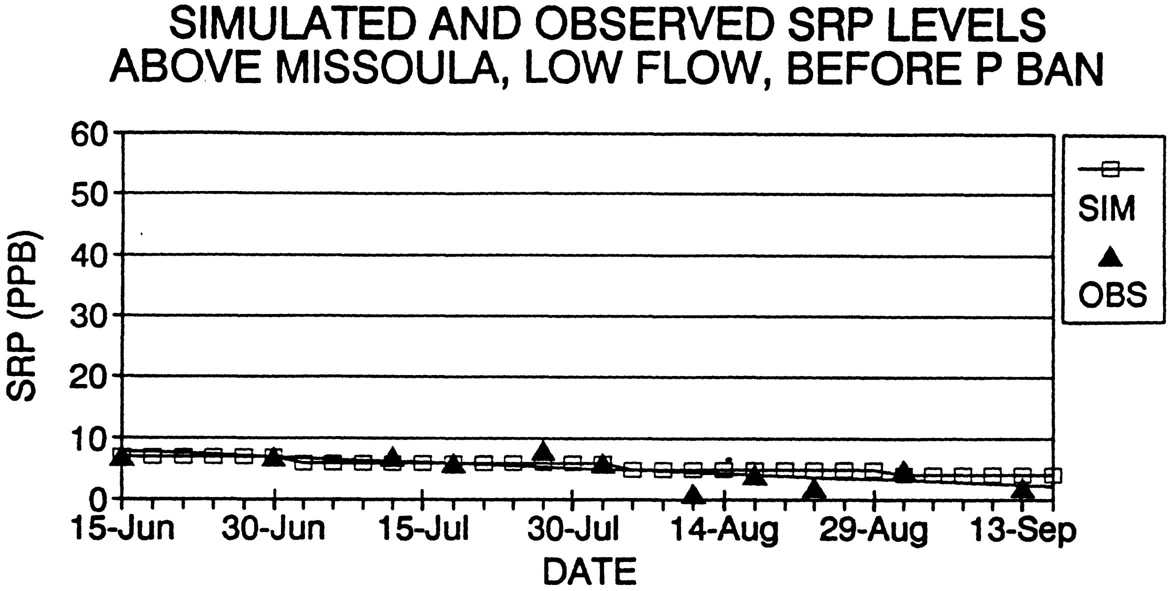
Figures 19 (top) and 20. Clark Fork River station discharge, average and low flow scenarios.

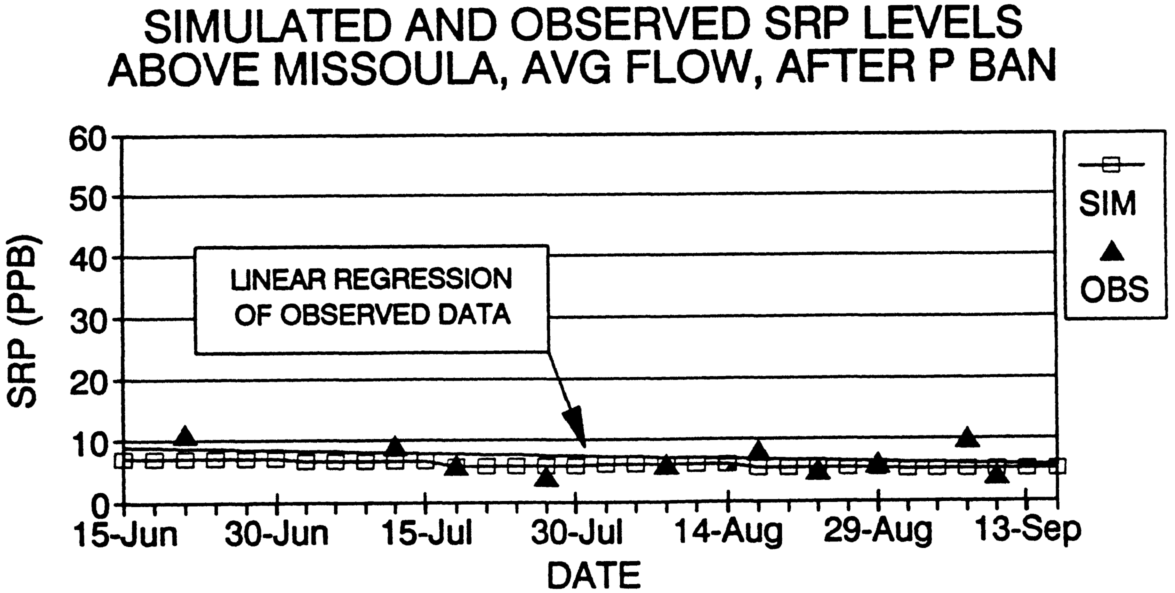
and known river flow. Nutrient loading from tributaries was estimated by averaging nutrient and flow data from pre- and post- ban years, and added in at the appropriate locations. The nutrient load predicted by this conservative approach is greater than nutrient loads actually found in the river, suggesting that there is a net retention of phosphorus in each reach of the river. An algal uptake and retention term was introduced to reduce the excess nutrient load. The amount of phosphorus retained in each reach of the river was determined by empirical measurements of algal retention and uptake from each reach. A linearly increasing percent retention term was applied to each reach of the river over the entire summer growing season. The changing nutrient retention simulates the increasing retention due to increasing algal accumulation over the course of the summer.

VALIDATION OF THE NUTRIENT MODEL

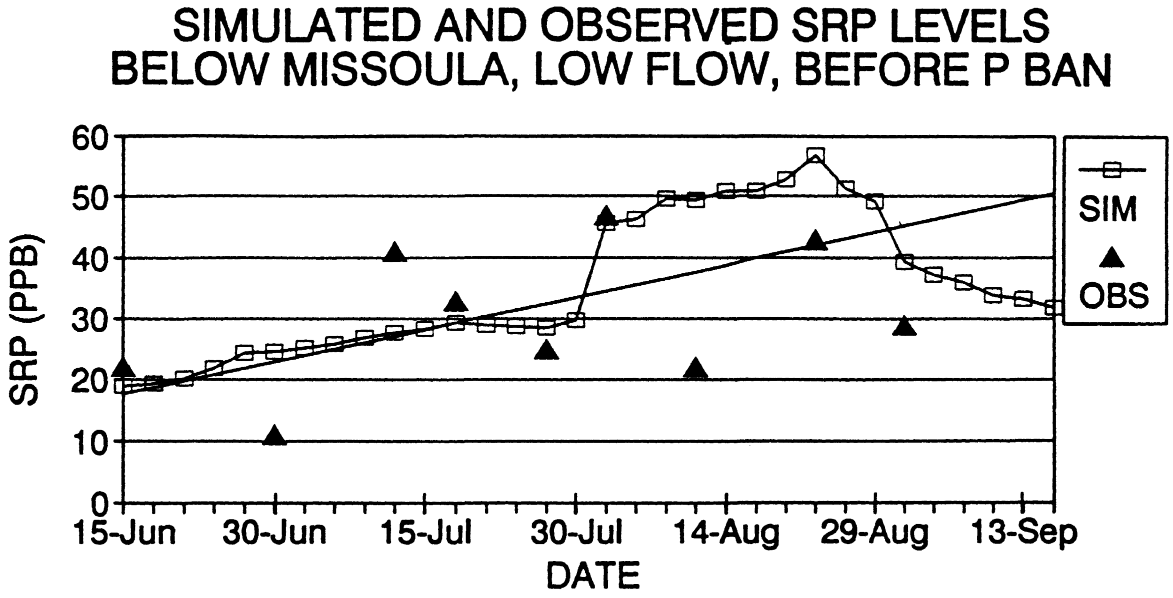
This nutrient concentration model was validated with available observed nutrient data. The model was run under low flow conditions with pre-ban loading and the output compared to observed data from 1988, a low flow, pre-ban year. The model was also run under average flow conditions with post-ban loadings and the results compared with observed data from 1990. The validation runs are presented in Figures 21 through 32. The simulated nutrient concentrations from the model are consistent with the observed data, and the model predicts peak concentrations reasonably well. To facilitate the validation, a "best-fit" least-squares linear regression routine was applied to the observed data and is plotted along with the observed data. The below Missoula site (Figures 23 and 24) is the most difficult to model because of the large fluctuations in observed nutrient concentrations, and the therefore the simulated values are not as close a fit as the other sites. When observed data becomes available, the model should be validated for low flow, post-ban conditions.

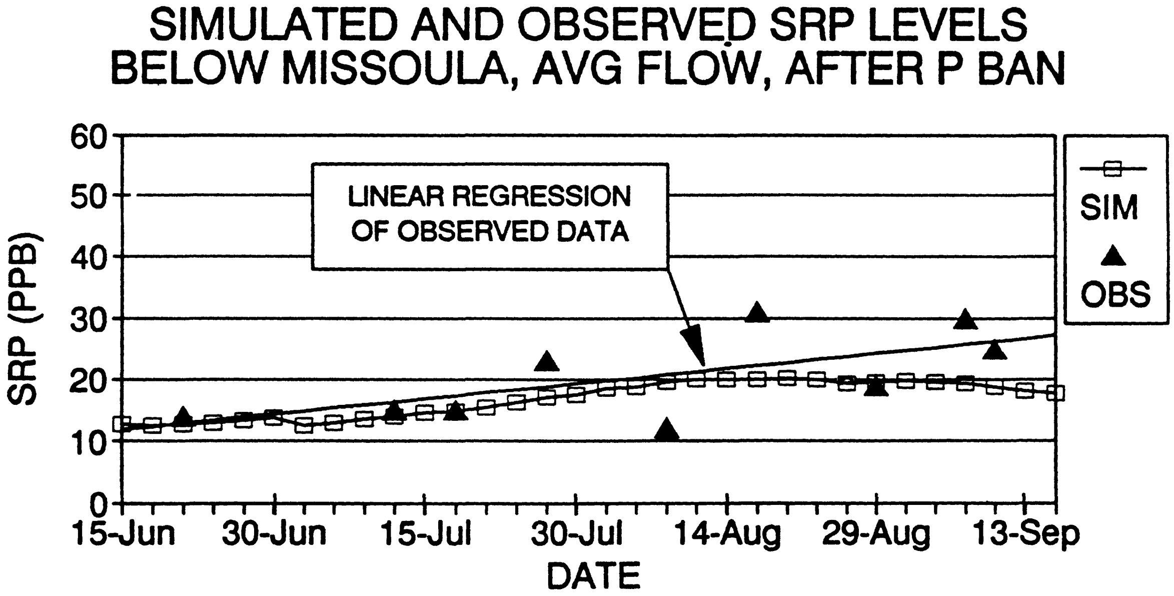
The validated nutrient model was then used to predict changes in instream nutrient concentrations solely as a result of the phosphate detergent ban. The nutrient model was first run for low flow, before the ban conditions. The nutrient loading from the Missoula wastewater treatment plant was then reduced to post-ban levels, and the model was run again. Figures 33 and 34 show the predicted nutrient reductions found in the river under low flow, before and after the ban conditions. The reductions in nutrient concentrations represent the effects of the phosphate detergent ban. The model was also run for average flow, before and after the ban conditions, and the results are presented in Figures 35 and 36. The nutrient model predicts an average 35% reduction in nutrient concentrations for the average flow scenario and an average 43% reduction for the low flow scenario at the below Missoula site. The other middle river sites, Harper's Bridge and Huson see similar reductions in nutrient levels. The lower river sites do not see quite as large a percent reduction in nutrient levels because of the smaller influence of the Missoula wastewater treatment plant nutrient loading at these sites.



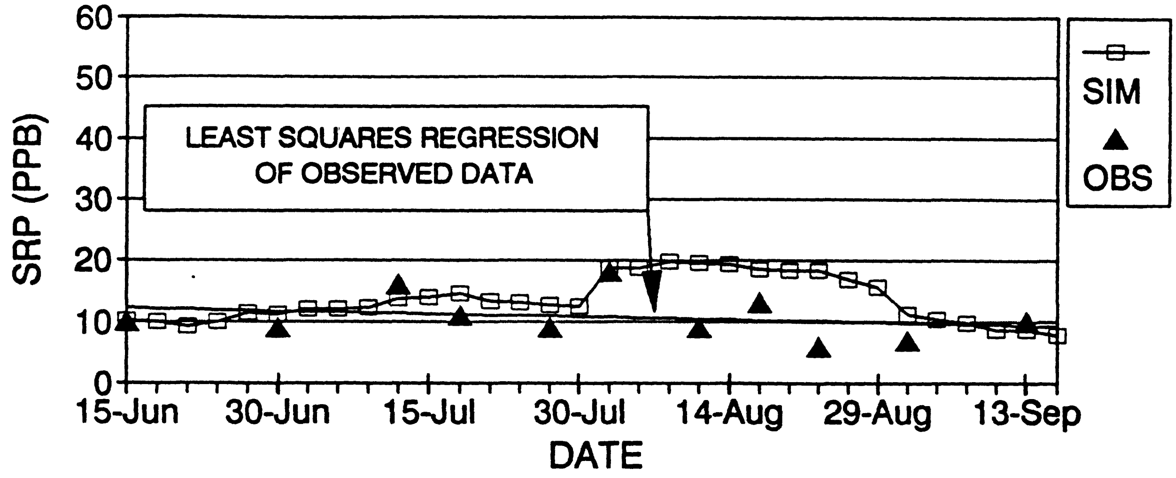


Figures 21 (top) and 22. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.

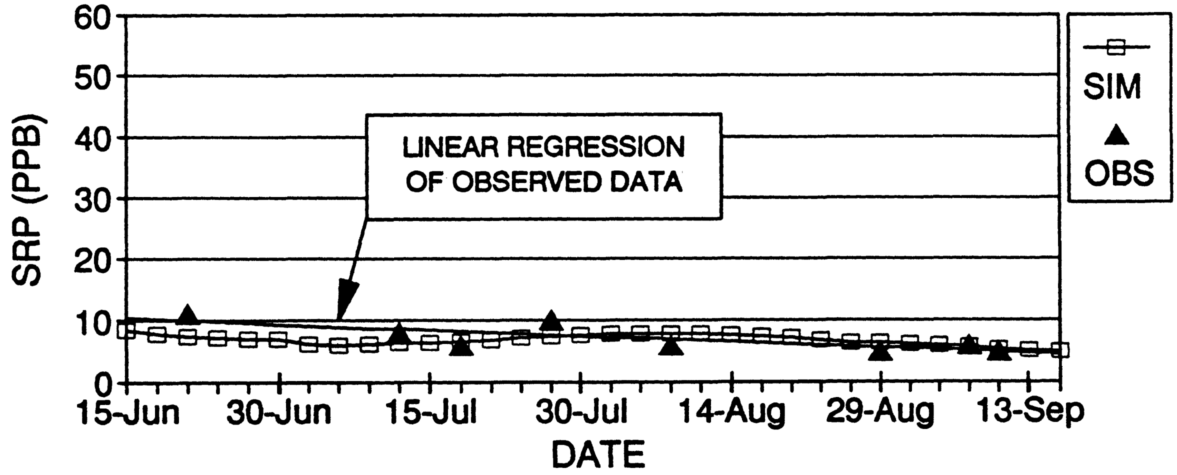




Figures 23 (top) and 24. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.

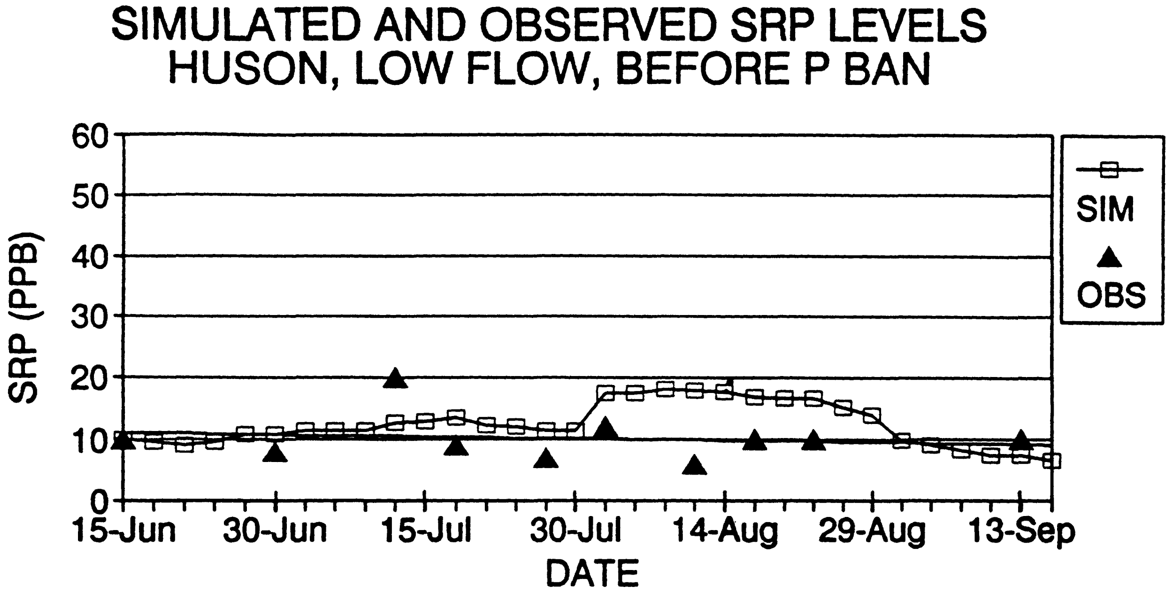


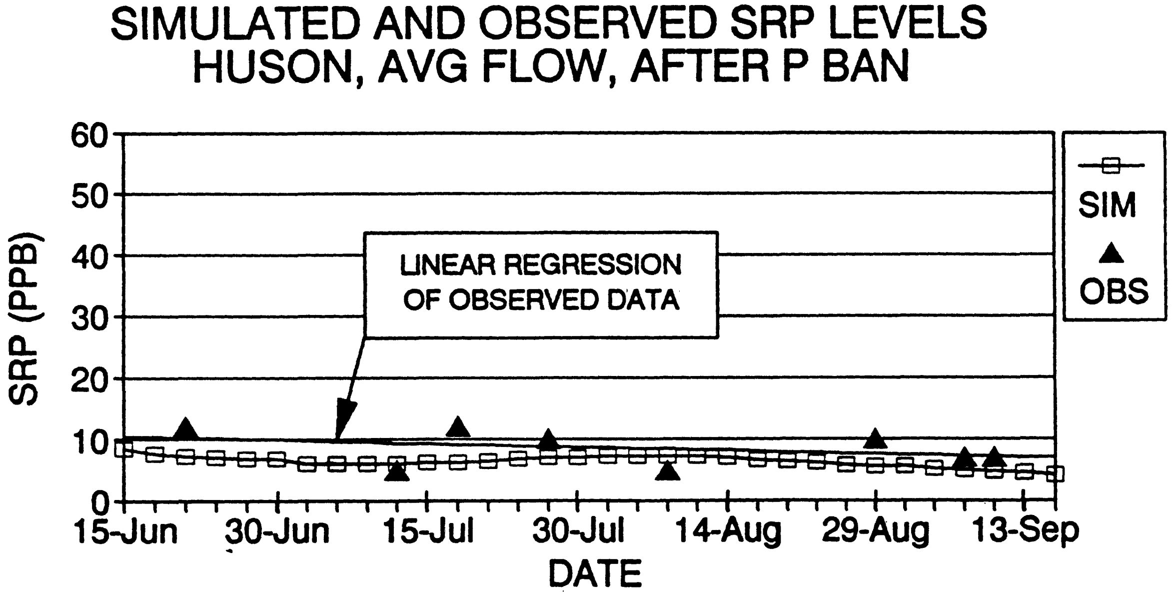
SIMULATED AND OBSERVED SRP LEVELS
HARPER'S BRIDGE, LOW FLOW, BEFORE P BAN



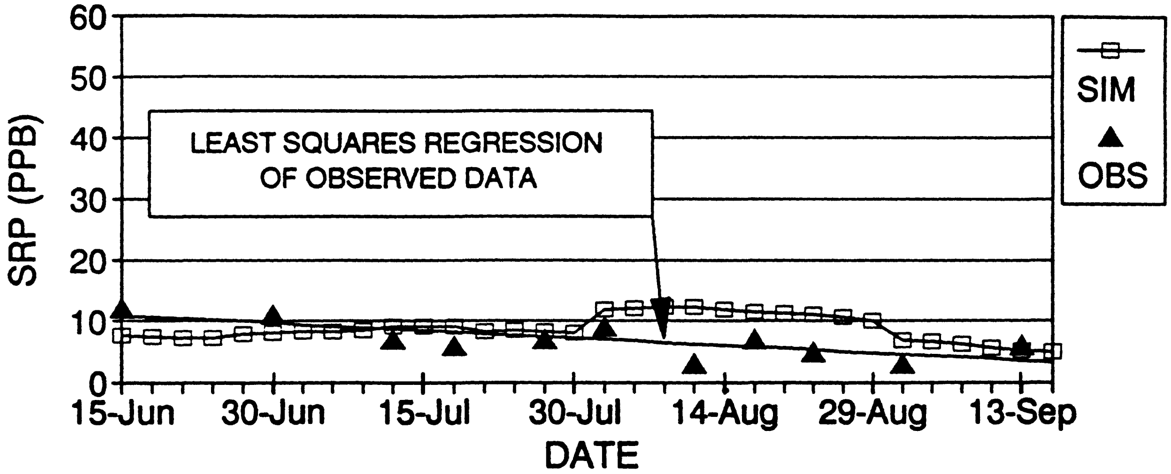
SIMULATED AND OBSERVED SRP LEVELS
HARPER'S BRIDGE, AVG FLOW, AFTER P BAN

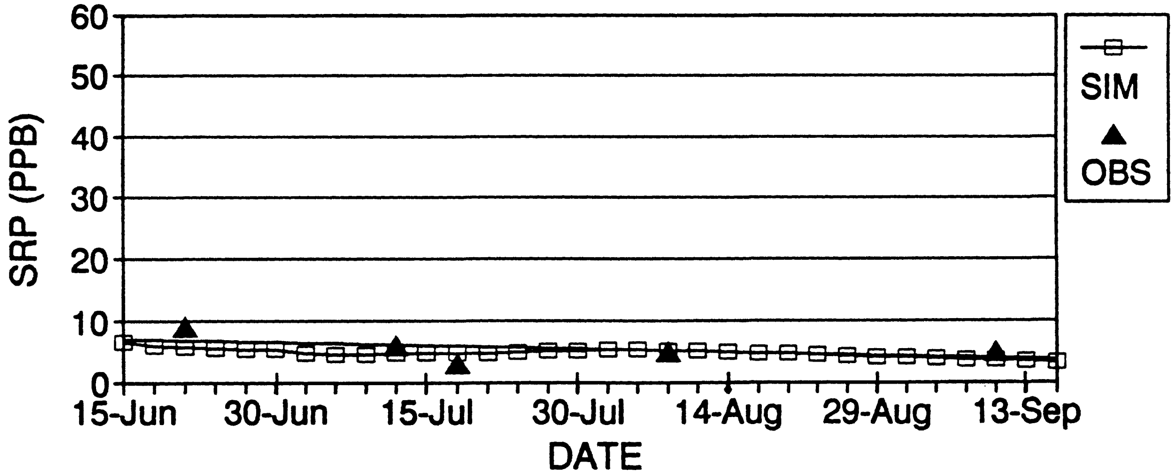
Figures 25 (top) and 26. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.



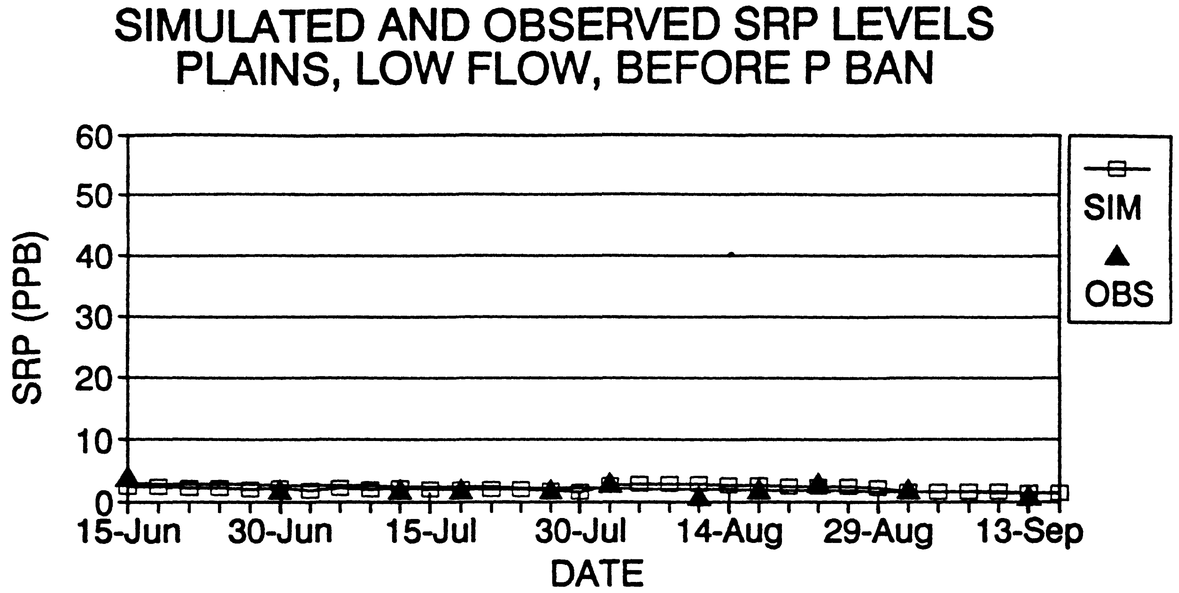


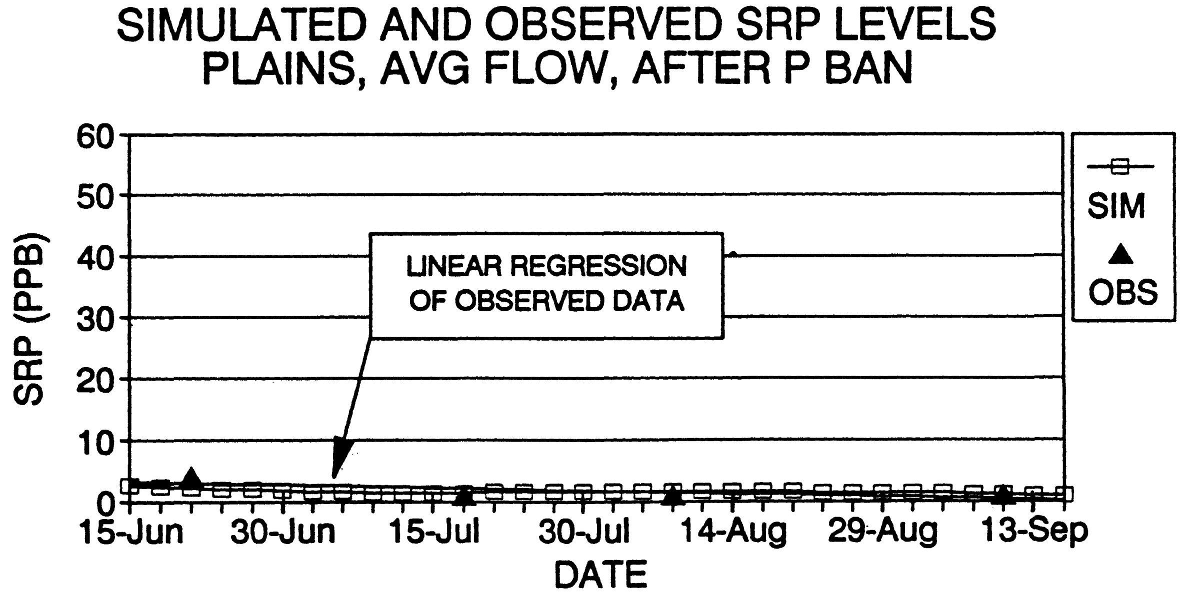
Figures 27 (top) and 28. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.


SIMULATED AND OBSERVED SRP LEVELS
ST. REGIS, LOW FLOW, BEFORE P BAN

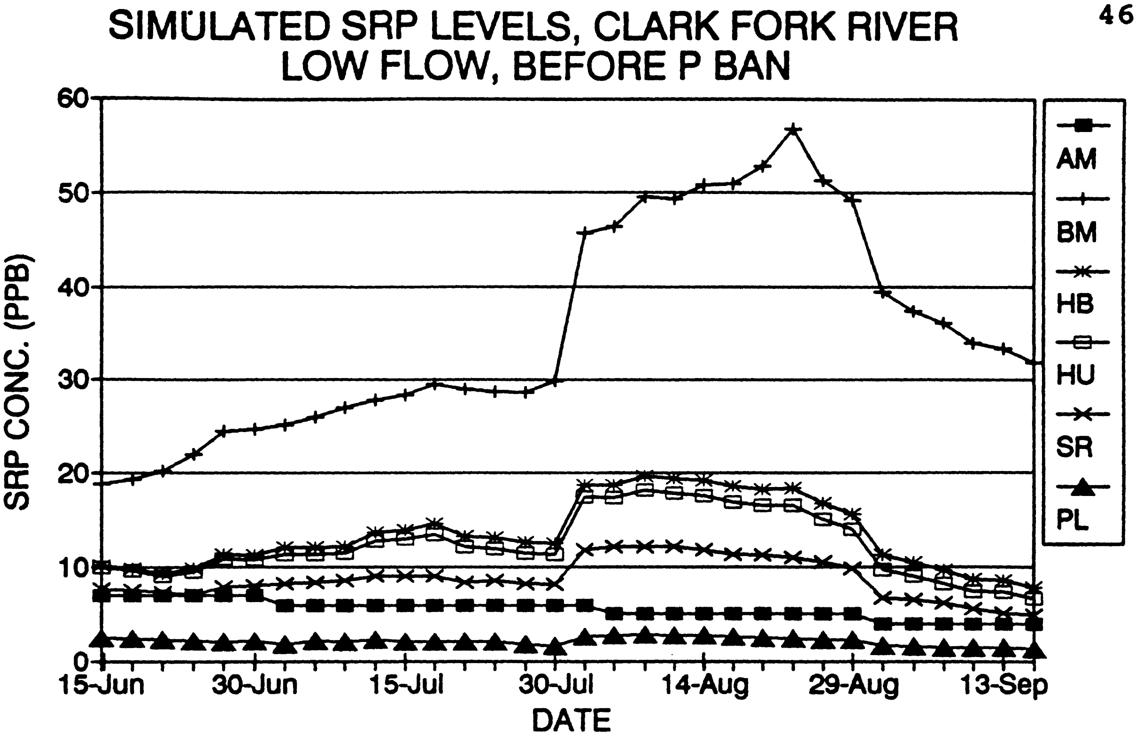

SIMULATED AND OBSERVED SRP LEVELS
ST. REGIS, AVG FLOW, AFTER P BAN

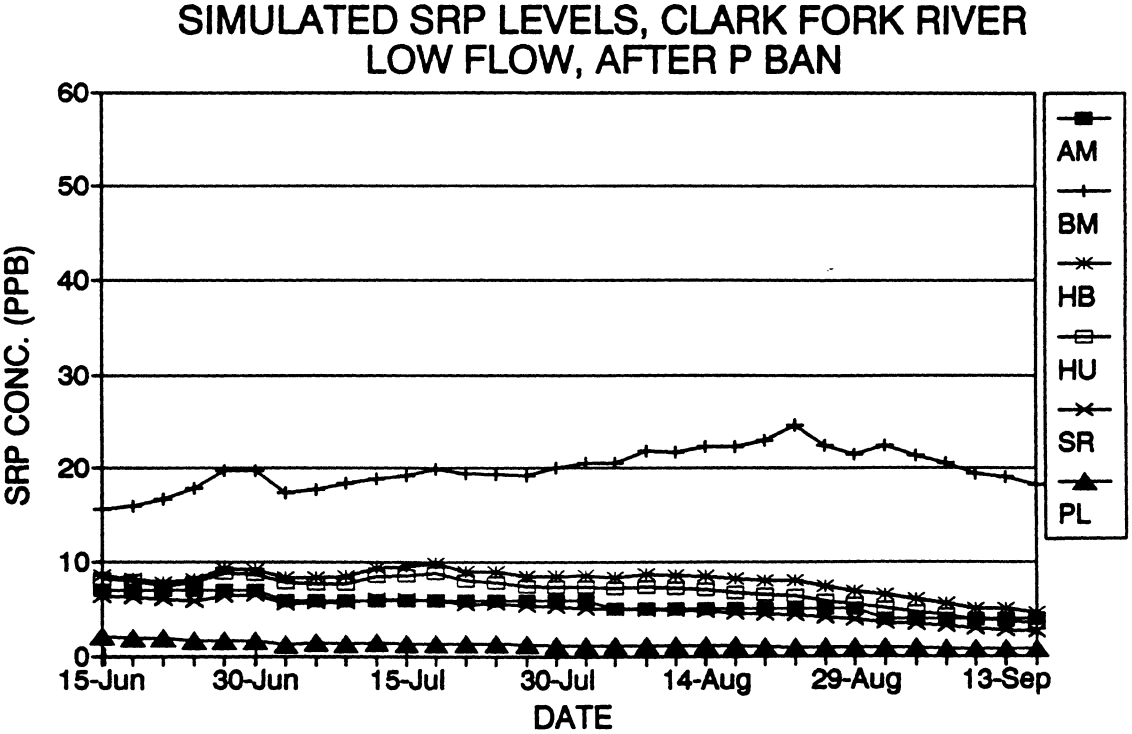
Figures 29 (top) and 30. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.



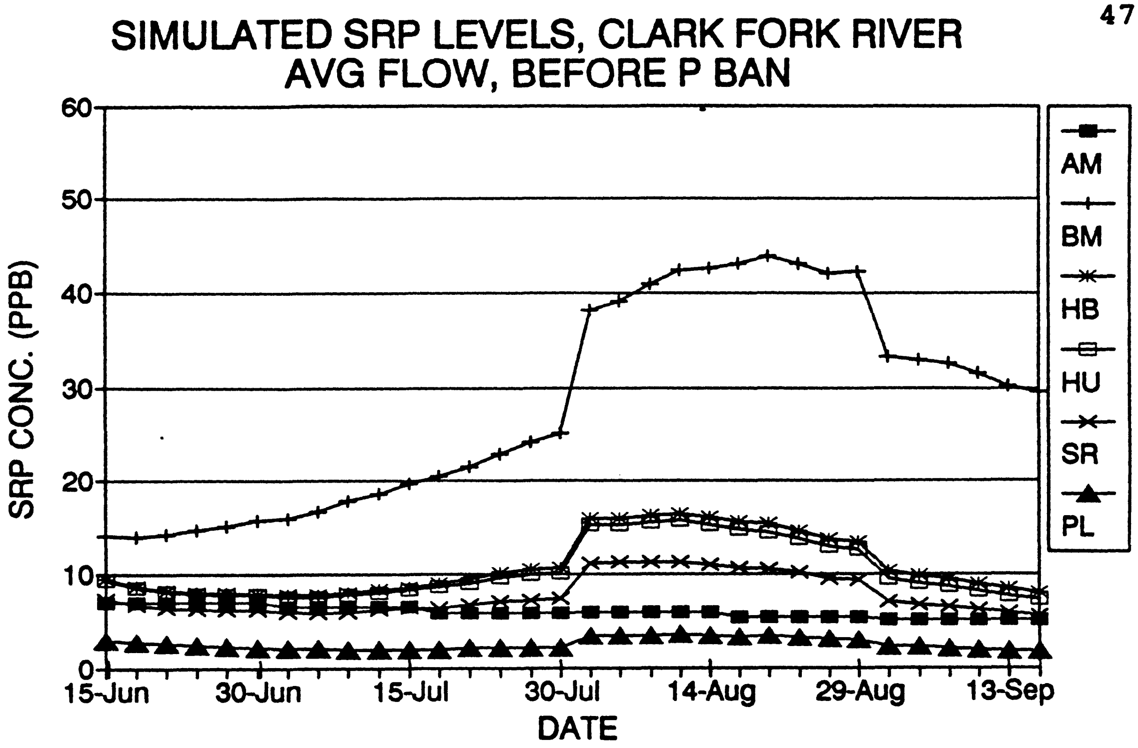


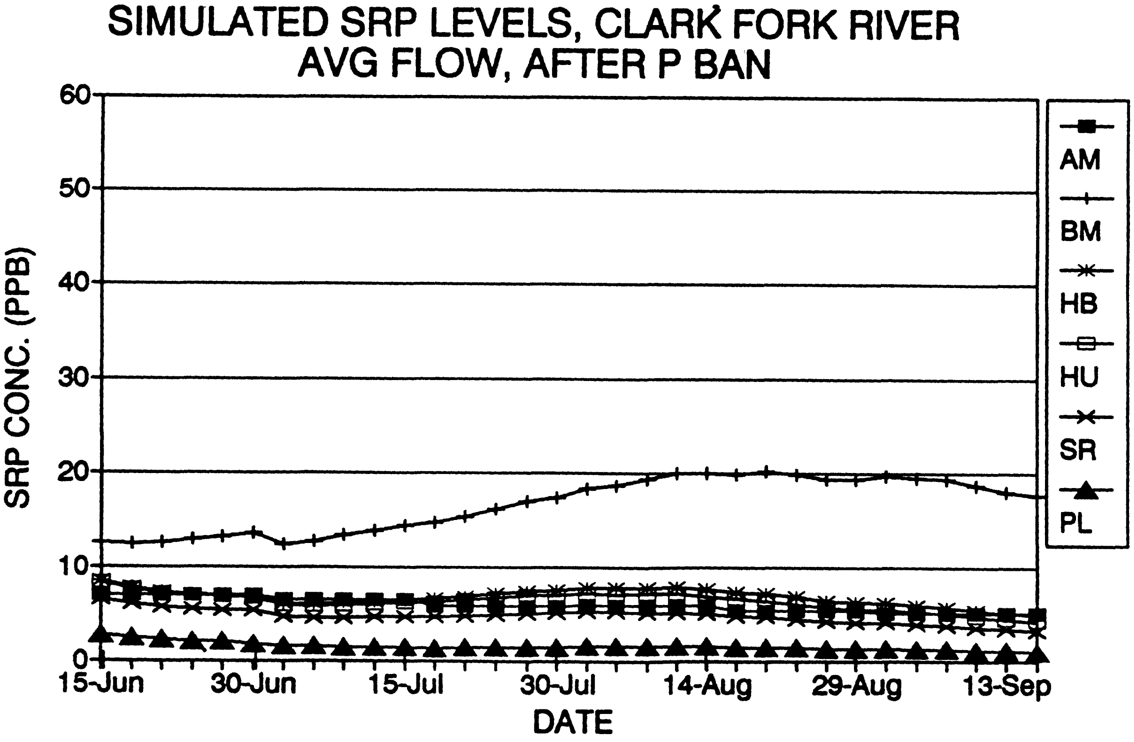
Figures 31 (top) and 32. Validation runs of the nutrient model. Simulated and observed nutrient concentrations in the Clark Fork River.





Figures 33 (top) and 34. Simulated soluble reactive phosphorus (SRP) levels for selected stations in the Clark Fork River, low flow scenario, before and after the Missoula phosphate detergent ban.





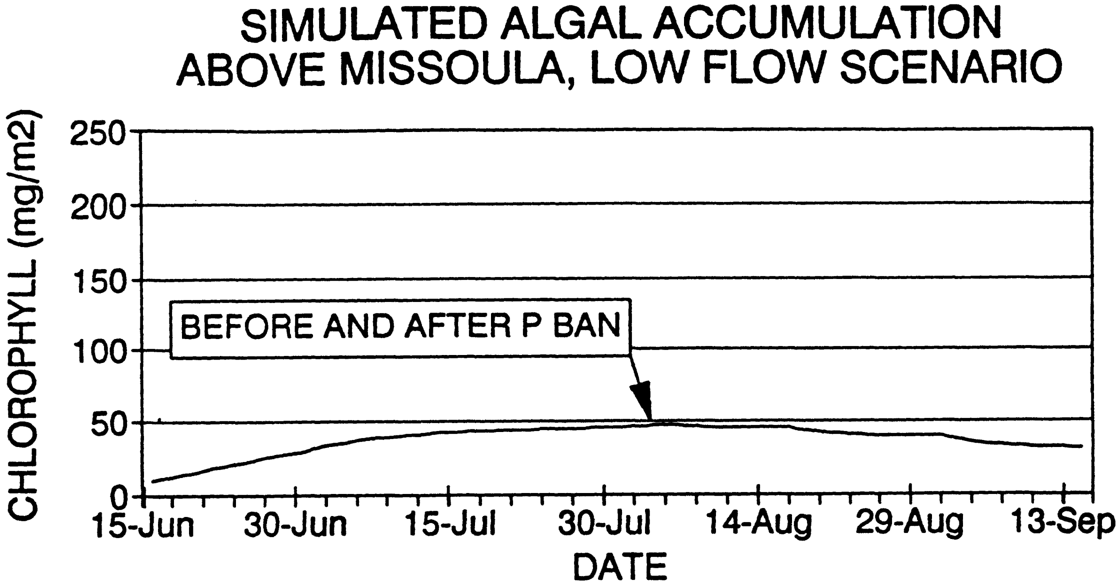
Figures 35 (top) and 36. Simulated soluble reactive phosphorus (SRP) levels for selected stations in the Clark Fork River, average flow scenario, before and after the Missoula phosphate detergent ban.

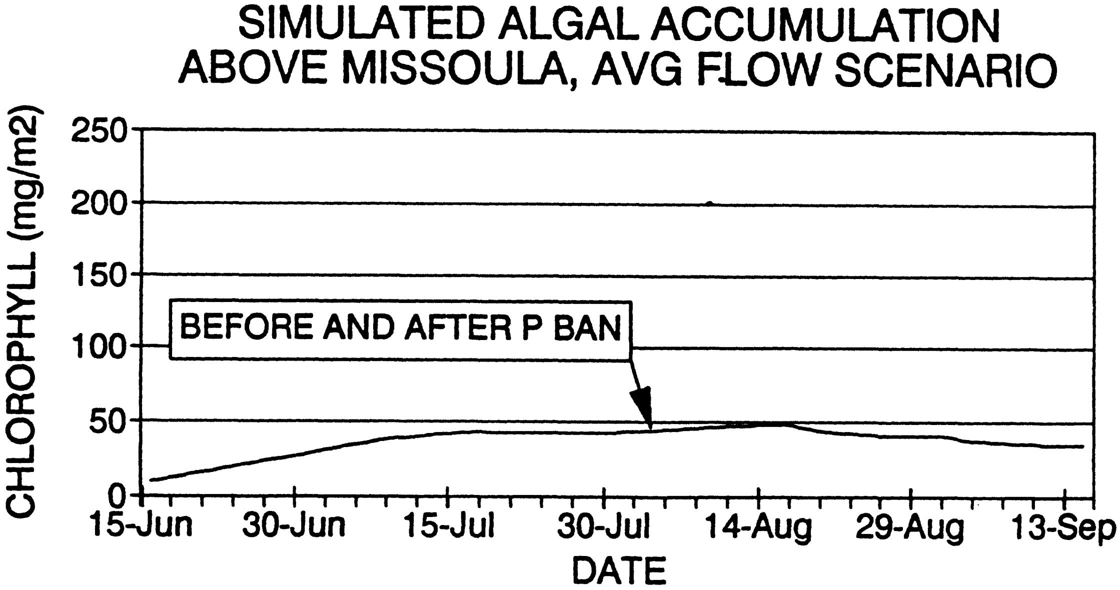
CHAPTER 8. ALGAL RESPONSE TO THE PHOSPHATE DETERGENT BAN

The nutrient model predicts how the nutrient levels in the Clark Fork River have changed since the inception of the Missoula phosphate detergent ban. This information can then be used in the algal accumulation model to predict changes in algal accumulation as a result of the ban. The algal accumulation model was run under the four scenarios of low and average flow conditions, before and after the phosphate detergent ban for each of the six study sites.

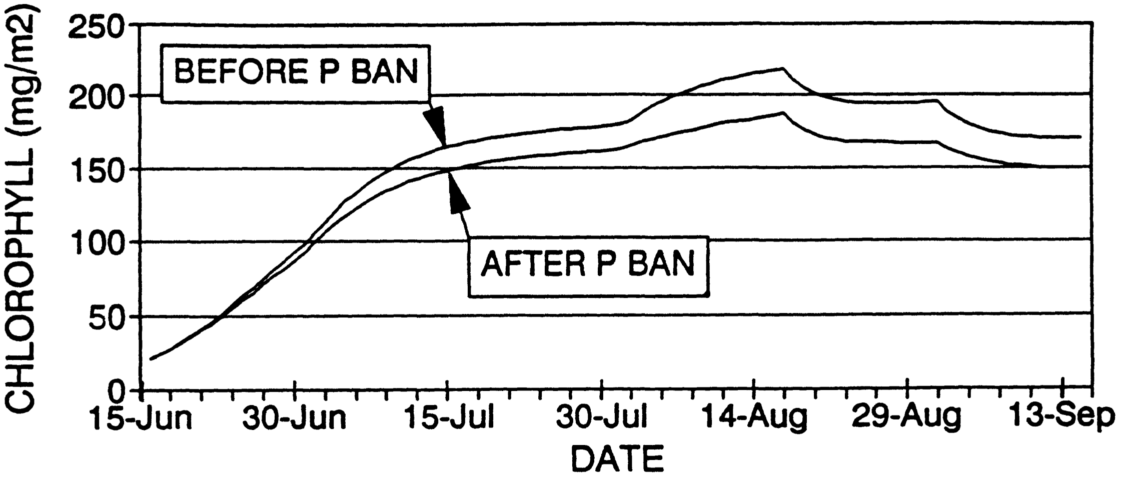
ALGAL RESPONSE-RESULTS

The predicted algal accumulation for each site is presented in Figures 37 through 48. Each figure shows algal accumulation before and after the phosphate detergent ban. The above Missoula site is not affected by phosphorus loading from the Missoula wastewater treatment plant and therefore shows no response to the phosphate detergent ban. The algal accumulation model predicts the highest algal accumulation at the below Missoula site and accumulation decreases downriver from that point. The below Missoula, Harper's Bridge, Huson, and St. Regis sites are characterized by a rapid increase in algal accumulation for the first 20 days of the simulation, followed by a gradual leveling off until mid-summer. Algal accumulation then increases to a peak biomass near mid-August. At this point, algal sloughing becomes greater than accumulation and levels of algal accumulation decline through the rest of the summer. The simulations for the Plains site

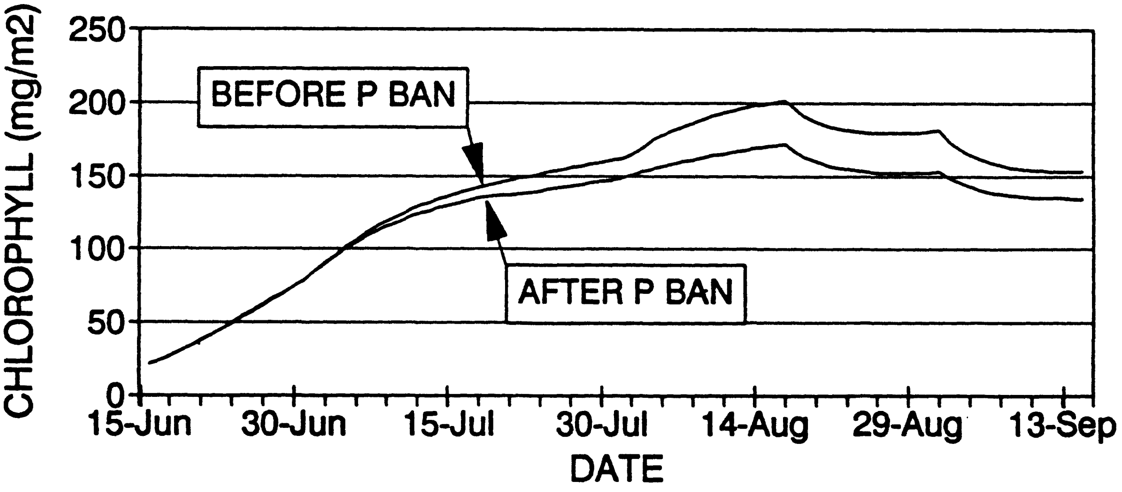




Figures 37 (top) and 38. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.

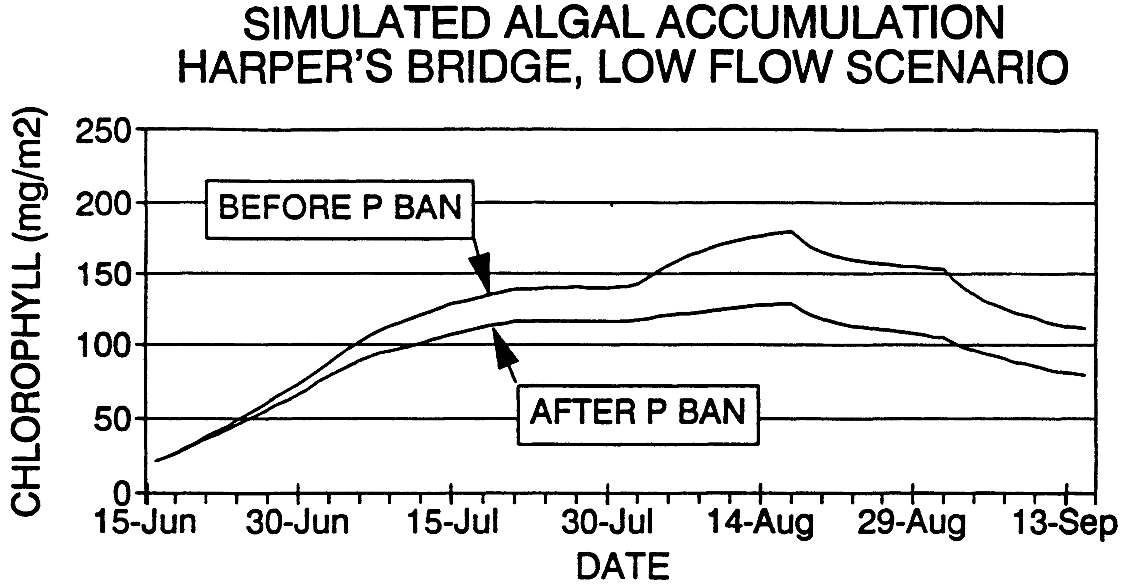


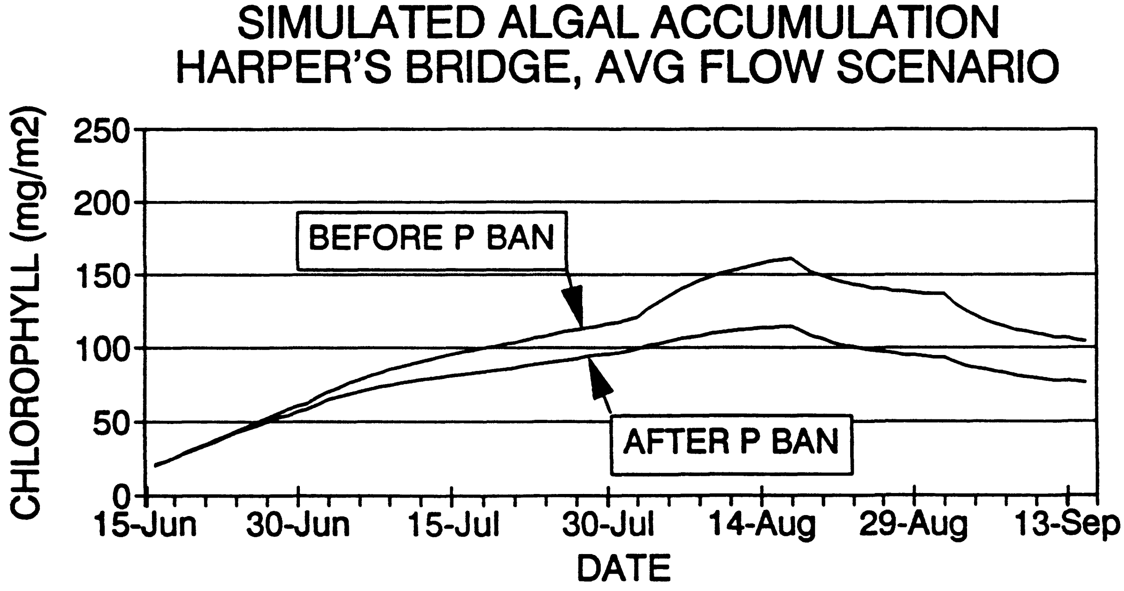
SIMULATED ALGAL ACCUMULATION BELOW MISSOULA, LOW FLOW SCENARIO



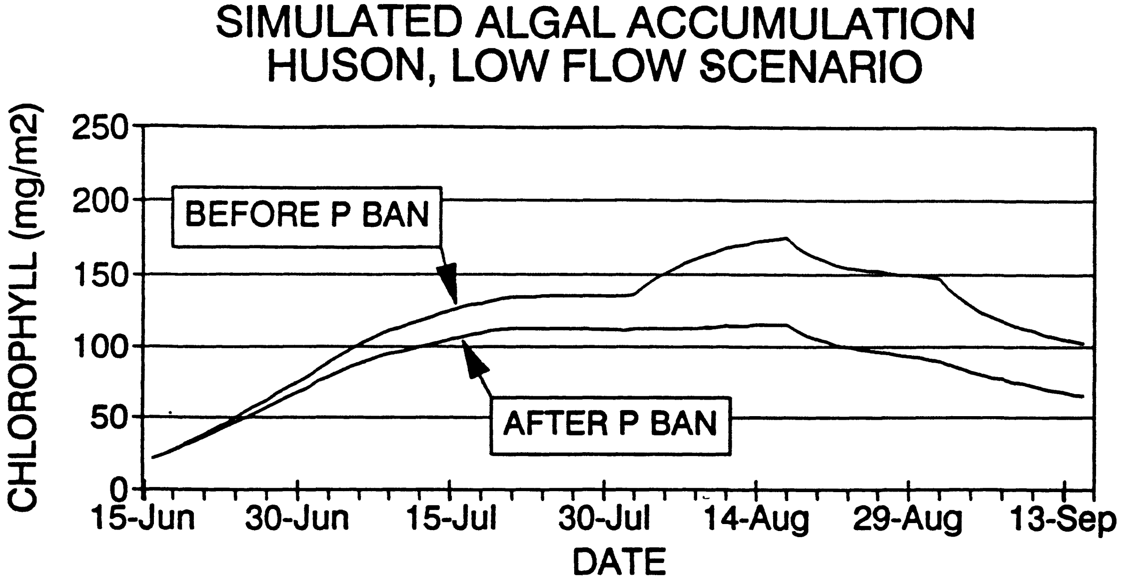
SIMULATED ALGAL ACCUMULATION BELOW MISSOULA, AVG FLOW SCENARIO

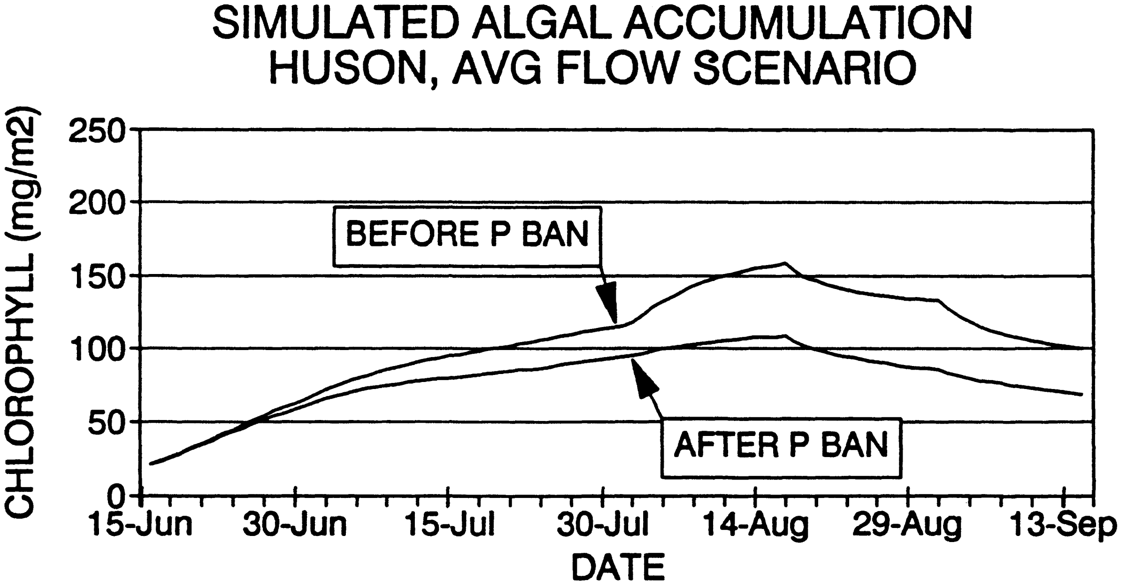
Figures 39 (top) and 40. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.



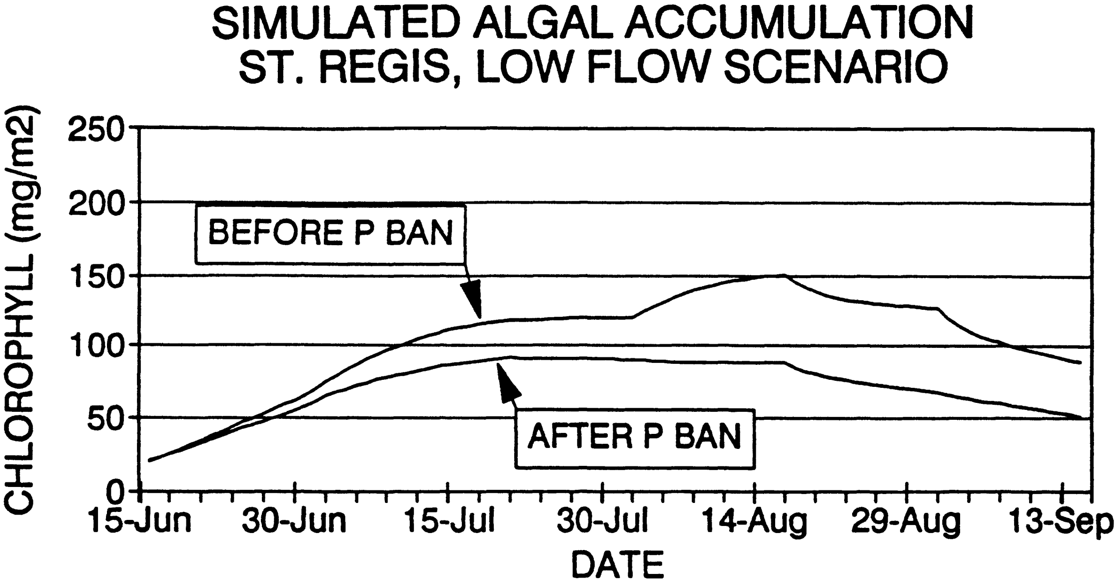


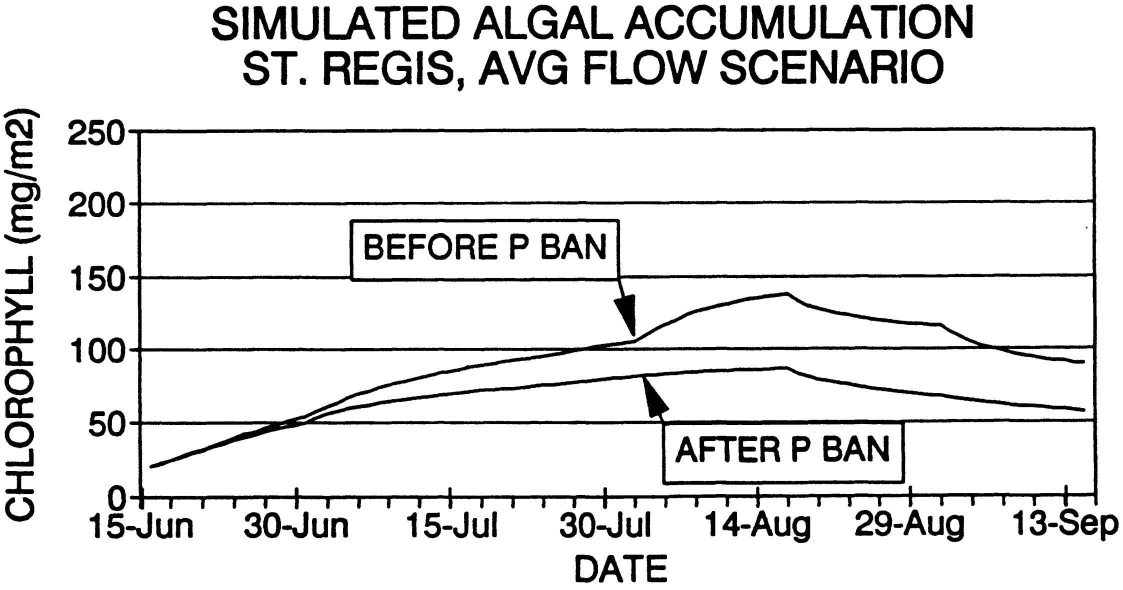
Figures 41 (top) and 42. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.



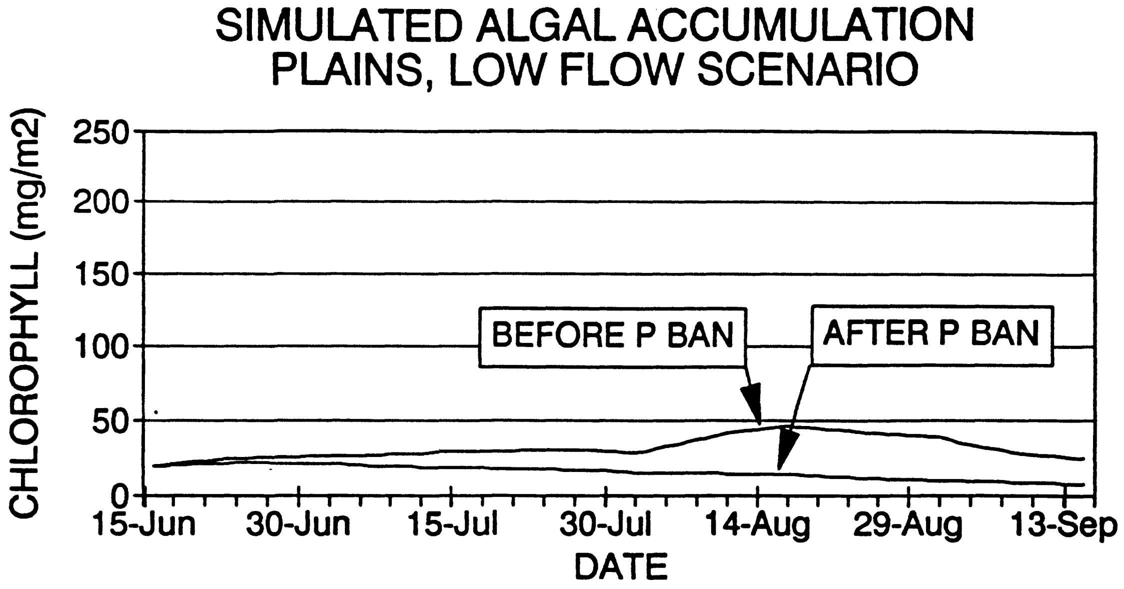


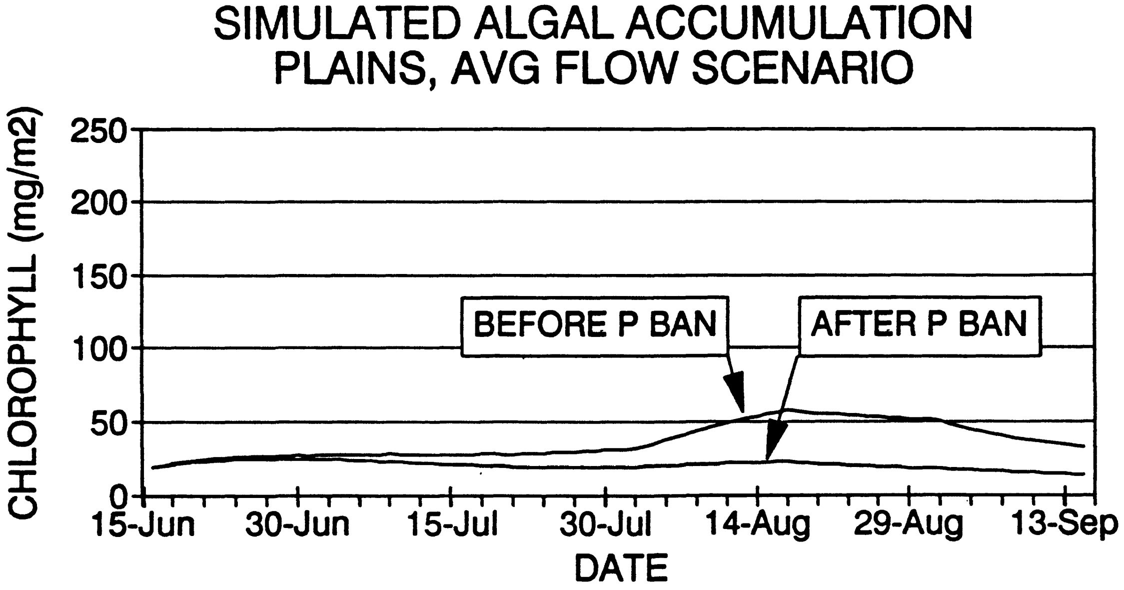
Figures 43 (top) and 44. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.





Figures 45 (top) and 46. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.





Figures 47 (top) and 48. Pre- and post- phosphate detergent ban algal accumulation, Clark Fork River.

are similar to the above Missoula site, with low levels of algal accumulation throughout the summer.

Two approaches were taken to summarize the differences between pre- and post- ban simulations. The first approach compares the peak biomass attained at each site for each pair of pre- and post- ban simulations. The second approach compares the average algal biomass accumulated over the summer before and after the ban for each site. The results from these calculations are presented as percent differences in Table 2.

TABLE 2. PREDICTED CHANGE IN ALGAL ACCUMULATION IN RESPONSE TO MISSOULA PHOSPHATE DETERGENT BAN

SITE	FLOW	% DIFFERENCE IN PEAK BIOMASS BEFORE AND AFTER P BAN	% DIFFERENCE IN TOTAL BIOMASS BEFORE AND AFTER P BAN
AM	AVG	0	0
BM	AVG	16	11
HB	AVG	33	25
HU	AVG	37	27
SR	AVG	46	33
PL	AVG	80	57
AM	LOW	0	0
BM	LOW	15	12
HB	LOW	33	25
HU	LOW	41	29
SR	LOW	49	38
PL	LOW	74	69

The results presented in Table 2 suggest that the greatest differences between pre- and post- ban algal accumulation occur farthest down the river. Nutrient concentrations are farthest from saturation at the lower river sites and therefore exhibit the greatest response to a change in nutrient levels. Most of the reductions in peak and total biomass were slightly greater during low flow conditions. The model predicts a minimum change of 11% in total biomass at the below Missoula site. Variability in the replicate samples from artificial substrates at this site are at this magnitude, hence this 11% does not represent a significant change. The nutrient reductions achieved as a result of the ban do not translate into an equivalent reduction in algal accumulation at the below Missoula site. The nutrient levels are still high enough after the ban that they are not limiting algal growth or accumulation, and nuisance levels of attached algae can still be expected.

The percent difference in total biomass at the Harper's Bridge and Huson sites is near 25%. A predicted reduction of this magnitude should result in a noticeable difference in the river. The model suggests that total algal accumulation at the Plains site will be reduced by 60% to 70%. The nutrient levels at this site were below levels that saturate algal accumulation before the ban. The nutrient reductions achieved by the ban at this site therefore significantly reduce the expected algal accumulation.

The percent difference in peak biomass attained as a result of the phosphate ban at each site follow similar trends as the percent difference in total biomass. The greatest differences occur with increasing distance down river, where nutrient levels are farthest from saturation.

The output of the algal accumulation model can also be used to predict the change in the frequency of occurrence of nuisance algal conditions as a result of the phosphate detergent ban. The percentage of days that algal accumulation exceeded the defined nuisance level of 100 mg chlorophyll/m^2 was calculated for each site. The percent reduction in the number of days of nuisance algal occurrence as a result of the ban was also calculated, and the results are presented in Table 3.

TABLE 3. PREDICTED CHANGE IN FREQUENCY OF OCCURRENCE OF NUISANCE ALGAL CONDITIONS IN RESPONSE TO MISSOULA PHOSPHATE DETERGENT BAN

SITE	FLOW	% OF DAYS ALGAL ACCUMULATION > 100 mg/m2 Chl BEFORE P BAN	% OF DAYS ALGAL ACCUMULATION > 100 mg/m2 Chl AFTER P BAN	% REDUCTION
AM	AVG	0	0	0
BM	AVG	79	79	0
HB	AVG	65	23	65
HU	AVG	63	16	74
SR	AVG	43	0	100
PL	AVG	0	0	0
AM	LOW	0	0	0
BM	LOW	83	81	1
HB	LOW	78	58	26
HU	LOW	78	47	40
SR	LOW	65	0	100
PL	LOW	0	0	0

The results from Table 3 suggest that nuisance levels of algal accumulation were attained before the ban at all sites except for the above Missoula and Plains sites. Nuisance algal conditions are more frequent in low flow years because of the higher nutrient concentrations and temperatures found in the river during low flow conditions. The below Missoula site shows a 79% frequency of days with nuisance algal levels both before and after the phosphate detergent ban, low and average flow conditions. Any slight reductions achieved at this site are not enough to pull algal levels below nuisance conditions.

As a result of the phosphate detergent ban, the frequency of nuisance algal conditions is substantially reduced at the Harper's Bridge, Huson, and St. Regis sites. Harper's Bridge and Huson show reductions of frequency of nuisance algal levels of 65% and 74%, respectively, for the average flow condition. These same sites show reductions of 26% and 40%, respectively, for the low flow condition. Greater reductions occur under the average flow conditions because nutrient levels are lower than the low flow levels, and therefore further from growth saturating levels. The frequency of nuisance levels at the St. Regis site varied from 43-65% of the summer before the ban, but no days of nuisance algal accumulation after the ban.

CHAPTER 9. CONCLUSIONS

Algal accumulation in the Clark Fork River has been predicted to be substantially reduced as a result of the Missoula phosphate detergent ban. The 40% reduction in nutrient loading to the river from the Missoula wastewater treatment plant as a result of the ban has likely resulted in substantial reductions in peak and total algal biomass accumulations. The frequency of occurrence of nuisance algal accumulation has likely been reduced by up to 100% at sites downriver from the Missoula wastewater treatment plant.

Nutrient concentrations in the river just below the Missoula wastewater treatment plant are still high enough after the ban that algal growth and accumulation are not nutrient limited. The greatest benefits were found at the greatest distances downriver from the Missoula wastewater treatment plant. Overall, the reduced nutrient loading as a result of the ban probably resulted in decreased levels of nuisance algal accumulation over a 100 mile stretch of the river, from Harper's Bridge to below Plains.

These conclusions are based on models validated with observed data from the Clark Fork River. These models should continue to be improved through validation of more data collected from post-ban years. Algal accumulation on artificial substrates and nutrient data should continue to be collected for this purpose. These models could also be improved by incorporating considerations for other physical parameters, particularly nitrogen concentrations.

Greater reductions in algal accumulation could be achieved with greater reductions in nutrient loading to the river. Management actions should focus on reducing point source phosphorus discharges even further. The Missoula wastewater treatment plant nutrient discharge is still a contributor to nuisance levels of algal accumulation. The Butte and Deer Lodge nutrient loads have also been decreased as a result of recent phosphorus detergent bans passed in these communities. Management efforts should continue to be directed at reducing these nutrient sources by utilizing more advanced techniques for phosphorus removal in the wastewater treatment plants or by disposing of the effluent on land in the summertime.

APPENDIX A.

Kinetics of the Algal Accumulation Model by Vicki Watson

PERISIM is a program written in IBM BASICA which simulates the accumulation of attached algal biomass on river rocks over time. In its current form the model has been shown to simulate with reasonable accuracy the accumulation of biomass of the mixed diatom community that characterizes the middle and lower Clark Fork River during the summer growing season.

The model simulates attached algal biomass accumulation by estimating the production of new biomass (via photosynthesis) and the loss of biomass (to respiration and sloughing) every hour. Gains in biomass are added to the previous estimate of biomass and the losses subtracted. Thus the mass of algal material gradually increases or decreases depending on whether gains exceed losses or vice versa. That is, the change in biomass over time is simulated by the equation:

Bt = Bt-1 + Bt-1 * (rates of growth -respiration -sloughing)

where Bt = biomass at time t, Bt-1 = biomass at previous point in time. The time step used is one hour.

The ecological processes simulated are algal growth (via photosynthesis), respiration, and sloughing (or loss of biomass due to detaching of algae from the substratum and washing away). Each of these will be discussed separately.

Algal growth has been modeled with varying levels of complexity. While some of the more complex methods are considered to depict nutrient uptake and growth more realistically, some of the simpler methods often produce estimates that are as accurate (or more accurate). In PERISIM, algal growth is a function of available light, nutrients, and temperature. Under optimum conditions of light, nutrients, and temperature, algal biomass increases at a maximum exponential rate (that is, some fraction of the existing biomass is added each day). When any of these factors is less than optimum, the rate of increase is reduced by a specific formula. That is, the growth rate is estimated by:

u = umax * LD * ND * TD

where u is the rate of increase, umax is the maximum rate of increase of which that particular community is capable, and LD, ND, and TD are the light, nutrient, and temperature dependent functions that reduce the maximum rate of increase to that expected under these suboptimum conditions (Lehman et al, 1975).

The light dependence formula is that used by Steele (1964, 1965) which recognizes that photosynthesis increases with light up to a point, then becomes saturated and finally inhibited at higher light levels. This relationship is depicted by the formula:

$$LD = (IZ/IOPT) * \exp(1-IZ/IOPT)$$

where LD is the light dependence of growth, IZ is the light at depth Z in calories/cm2/day, IOPT is the optimum light level. PERISIM estimates the surface light level for that time of year and time of day at the latitude being simulated. The light is then attenuated for the depth being simulated, using the formula:

$$IZ = Io * \exp(-nZ)$$

where Io is the surface light and n is the extinction coefficient.

Obviously, growth exhibits an increasing and decreasing response to temperature over a wide range of temperatures. Temperatures in the Clark Fork rarely exceed the optimum (around 25C for many species), hence growth may be represented as a simple increasing function of temperature by the formula:

TD or temperature dependence of growth = 0.04 * T

where T is the ambient water temperature in centigrade.

The effect of nutrients on algal growth has been modeled in numerous ways. The formula used here is the simple Monod or Michaelis Menten formulation which assumes that algal growth rates can be estimated from ambient available nutrient levels. When estimating accumulation rates of a mixed community this method does as well or better than more complex methods (DiToro, 1981). Nutrient dependence is calculated as:

ND or nutrient dependence of growth = P/(P+Kp)

where P is the concentration of soluble reactive phosphorus (SRP) in ppb in the ambient water and Kp is the half saturation constant or the concentration of P which produces half of the maximum growth rate. Note that when P = Kp then ND is 0.5 and the growth rate is 1/5 of the maximum rate. When P is much > Kp, this term approaches 1 and the growth rate approaches the maximum growth rate. When P is much < Kp, this term approaches zero. However, Kp is very low, 2ppb or less according to most research. Hence, when ambient SRP is low relative to Kp, it is below detection.

Respiration is modeled as a simple function of temperature similar to the temperature dependence of growth:

R or respiration rate = 0.04 * T * Kr

where Kr is the maximum daily respiration rate (0.1/day). This equation produces respiration rates similar to those produced by the equation developed by Graham et al (1982) in which R = 0.151*(0.025T + 0.1).

Sloughing is a function of water velocity, turbulence, and the vigor of the algal community. Artificial stream studies show that following colonization, algal biomass increases at a rapid exponential rate then levels off as losses in biomass come to balance gains. As long as environmental conditions do not change greatly, a dynamic equilibrium biomass is established that seems to be a function of ambient nutrient levels. That is, under higher nutrient levels, algal biomass accumulates to a higher level before levelling off than it does under lower nutrient levels. Based on the work of Bothwell (1989) and Watson (1990), a formula was developed that described this relationship between ambient nutrient level and the maximum biomass sustained at this dynamic equilibrium:

Bmax = 10 + 60 * P/(P+Kb)

where 10 g/m2 is the biomass sustained at P levels below detection level, 60 is the maximum biomass sustained when P saturates standing crop and Kb is the SRP level that produces a standing crop that is about half of the maximum level.

As the biomass at a site approaches the maximum biomass that can be sustained given the nutrient levels there, sloughing increase. This is accomplished by the formula:

Sloughing rate = SLMAX * B/Bmax

where SLMAX is the maximum daily sloughing rate (set at 1/2 the standing crop per day). This approach is similar to that used by Auer and Canale (1980, 1982) except that their Bmax is fixed rather than a function of ambient nutrient levels. Actually Auer and Canale made two uses of Bmax to limit the standing crop of Cladophora. As B approaches Bmax, the growth rate slowed due to shading, nutrient limitation, and waste buildup and the sloughing rate increased. The formulations used were:

growth dependence = 1-(B/Bmax)
sloughing rate = max rate (B/Bmax).

Model Inputs

The model estimates the light levels for each day and hour. The environmental data that the model requires is water quality data, specifically water temperature (in degrees centigrade) and nutrient levels (SRP in ppb). These parameters were measured weekly during the summers of 1988 and 1990 on the Clark Fork. The model requires daily values, and another simple program (PERIFILE) was developed to produce daily water quality input files from the weekly measurements. An initial biomass value must be specified, typically between 1 and 3 g/m2 is used for simulations. For validation runs, the amount of biomass observed on artificial substrates after one week of colonization was used as the initial biomass and the simulation was started on that date. The model also requires the values of the rate constants and other constants in the simulation equations. These are summarized in the accompanying table.

Model Outputs

PERISIM estimates ash free dry weight of attached algae per square meter of river bed for each day of the simulation. Ash free dry weight is then converted to chlorophyll a by a conversion factor (CCF). This factor is 150 for high nutrient sites (below Missoula, Harper's Bridge), 300 for low nutrient sites (above Missoula, Plains), and 200 for moderate nutrient sites (all others).

RATE CONSTANTS AND OTHER PARAMETERS USED IN PERISIM

SYMBOL	VALUE USED	DEFINITION	SOURCE
M	378 cal/cm2/day	mean annual daily light intensity at 45 N latitude	Hutchinson 1975
VAR	249 cal/cm2/day	seasonal variation of light intensity either side of the mean	"
VARDL	4 hrs	seasonal variation of daylength either side of the mean	
N	0.5	extinction coefficient of water	"
MUMAX	1 per day (ie, doubles daily)	maximum growth rate of algae	Watson 1981, 1983 Whitton 1967
KI	10 cal/cm2/day	half saturation constant for light for photosynthesis	Watson 1981, 1983
IOPT	15 cal/cm2/day	optimum light level for photosynthe	"
KPMU	2 ppb	half saturation constant of phospho for algal growth	"
KPB	5 ppb	half saturation constant of phospho for algal standing crop	explained in text
SLMAX	0.5/day	maximum daily sloughing rate similar to 0.3/day used in	Auer & Canale 1980 Auer & Canale 1988
KR	0.1/day	respiration rate coefficient used in $R = 0.04 * KR * T$ produces values similar to $R = .151*(.025 T + .1)$ used by	Watson 1981, 1983 Graham et al. 1982

APPENDIX B.

The Missoula Phosphate Detergent Ordinance

ORDINANCE NO. 2643

AN ORDINANCE PROHIBITING THE SALE OF CERTAIN CLEANING PRODUCTS WITH MORE THAN A TRACE CONTENT OF PHOSPHORUS.

BE IT ORDAINED BY THE CITY COUNCIL OF THE CITY OF MISSOULA THAT TITLE 13 OF THE MISSOULA MUNICIPAL CODE BE AMENDED BY ADDING CHAPTER 13.10, SECTIONS 13.10.010 THROUGH 13.10.080, MISSOULA MUNICIPAL CODE.

Section 1. Chapter 13.10. Phosphorus Content of Wastewater Discharges, of Title 13, Sections 13.10.010 through 13.10.080, Missoula Municipal Code, Public Services, is hereby adopted as follows:

CHAPTER 13.10 PHOSPHORUS CONTENT OF WASTEWATER DISCHARGES.

13.10.010 Legislative Intent and Purpose

The intent and purpose of this chapter shall be to:

(a) Set forth regulations, prohibitions and requirements pertaining to phosphorus compounds for direct and indirect discharges into the City wastewater collection and treatment system enabling the City to better attempt to comply with the Montana Pollution Discharge Elimination System Permit.

(b) Generally protect the health, safety, and welfare of residents of the city and downstream users of the Clark Fork River with respect to quality of water available to them.

(c) Prescribe powers and duties of the City of Missoula and the City/County Health Department to be exercised within their jurisdictional area within the city limits and within three miles of the city limits.

13.10.020 Definitions

(a) "Chemical water conditioner" means a water softening chemical or other substance containing phosphorus which is intended to treat water for use in machines for washing laundry.

(b) "Commercial establishment" means any premises used for the purpose of carrying on or exercising any trade, business, profession, vocation, or commercial or charitable activity, including but not limited to laundries, hotels, motels, and food or restaurant establishments.

(c) "Household cleaning product" means any product including but not limited to soaps, detergents, laundry bleaches, and laundry additives used for domestic or commercial cleaning purposes, including but not limited to the cleaning of fabrics, dishes, food utensils, and household and commercial premises. Household cleaning product does not mean foods, drugs, cosmetics, or personal care items such as toothpaste, shampoo, or hand soap.

(d) "Person" means any individual, proprietor of a commercial establishment, corporation, municipality, the state or any department, agency, or subdivision of the state, and any partnership, unincorporated association, or other legal entity.

(e) "Phosphorus" means elemental phosphorus.

(f) "Trace quantity" means an incidental amount of phosphorus which is not part of the household cleaning product formulation, and is present only as a consequence of manufacturing, and does not exceed 0.5% of the content of the product by weight expressed as elemental phosphorus.

13.10.030 <u>Application of Chapter</u>

The provisions of this chapter shall be enforced by the City and the City/County Health Department and will apply to persons engaged in the sale or commercial distribution of products that have as their substantive content prohibited phosphorus compounds within the City of Missoula and within 3 miles of the Missoula City Limits.

13.10.040 <u>Prohibited Phosphorus Compounds</u>

(a) No household or commercial cleaning product shall be distributed, sold, offered, or exposed for sale within the City of Missoula or within 3 miles of the city limits if it contains phosphorus in concentrations in excess of a trace quantity, except as provided in this chapter, except that no dish washing detergent may be distributed, sold, offered, or exposed for sale if it contains phosphorus in excess of 8.7% by weight expressed as elemental phosphorus.

(b) No chemical water conditioner or softener which contains more that 20% phosphorus by weight may be distributed, sold, offered, or exposed for sale within the city limits or within 3 miles of the city limits.

13.10.050 <u>Exceptions</u>

The following cleaning agents and other products containing phosphorus are exempt from the provisions of this ordinance:

(a) Those used in food or beverage processing.

(b) Those used for industrial processes or for cleaning food and beverage processing equipment, medical or surgical equipment, or dairy equipment; and

(c) Those existing stocks of phosphorus cleaning products and water conditioners which are offered for sale within the City of Missoula and within 3 miles of the Missoula City limits, for a period of six months after adoption of this ordinance.

13.10.060 <u>Labeling</u>

None of the products listed below shall be offered for sale unless the item is clearly labeled with the percent elemental phosphorus content to the nearest one tenth of one percent accuracy, except that products which contain a trace quantity may be labeled "contains no phosphorus", "contains no phosphates", or similar labeling which makes a clear statement that phosphorus is not present in the product.

Products requiring labeling:

1. Powdered or liquid laundry detergents and soaps.
2. Powdered laundry bleaches.
3. Powdered laundry chemical water conditioners.
4. Powdered laundry pre-soak products.
5. Powdered and liquid automatic dishwasher detergents and soaps.

13.10.070 Penalty

A person involved in the sale or commercial distribution of any phosphorus compound prohibited by this chapter who is unaware of the provisions of this chapter, shall for a first offense of this chapter be notified of such noncompliance by either the City or by the Missoula City/County Health Department and shall be given 10 days from receipt of such notice to comply with the provisions of this chapter. Failure to comply with this chapter following this 10 day period shall be a misdemeanor. A minimum fine of $50.00 shall be imposed for each violation of this chapter. The maximum penalty that may be imposed shall be $500.00 and no imprisonment may be imposed. Each day a violation exists shall constitute a separate and independent violation of this chapter.

13.10.080 Annual Report

On or before the 1st day of August of each year the Public Works Director and the City/County Health Department shall prepare a summary of the reports transmitted to State and Federal agencies during the previous twelve month period as required by the Montana Pollution Discharge Elimination System permit issued to the City of Missoula under date of August 1, 1988. The said summary shall be submitted to the Mayor and the City Council on or before the 15th day of August of each year.

Section 2. Severability.

If any section, subsection, sentence, clause, phrase or word of this ordinance is for any reason held to be invalid, such decision shall not affect the validity of the remaining portions of this ordinance.

Codification Instructions

This ordinance shall be codified as 13.10.010 through 13.10.070 of Title 13.

Passed by a ____

Approved by the Mayor this ______ day of _________________, 1988.

ATTEST: APPROVED:

_________________________ _________________________

City Clerk Mayor

(SEAL)

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