EVALUATION OF THE BENEFITS OF NUTRIENT REDUCTIONS ON ALGAL LEVELS IN THE CLARK FORK RIVER

FINAL REPORT

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BY

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EXECUTIVE SUMMARY

Attached algae in the Clark Fork River exceed aesthetic nuisance levels set by British Columbia and interfere with recreation. Algal respiratory demands contribute to night time violations of Montana water quality standards for dissolved oxygen. In an effort to control algal levels by controlling nutrient loading, the city of Missoula banned phosphate-based laundry detergents, reducing P loading from this major point source almost 50%.

To evaluate the benefits of this ban, a study of river algae accumulation was conducted. It was not possible to base this evaluation on a comparison of preban and postban algal levels because preban data were from a low flow year while post ban data were from an average flow year. In addition preban data included only one site above the point source (insufficient site replication), and the three down stream sites had nutrient levels that approached or exceeded the point that saturates algal standing crop. Little improvement was expected at these sites; most improvement was expected further downstream where reduction in lower nutrient levels should result in greater reductions in algae. No preban data were available for these sites.

Hence the evaluation was accomplished by using a computer model that simulates the accumulation of attached algae over the summer. The model accurately predicted the accumulation of algae measured on artificial substrates at four sites before the ban and 7 sites after the ban. Then this validated model was used to predict the accumulation of algae at several sites downstream of the point source under preban and postban loading for both average flow and 10 year low flow years. Reductions in algae levels were expressed as the percent reduction in the peak biomass and the cumulative biomass simulated over the summer.

Under average flow conditions, the model predicted that the P ban would effect a 6 to 38 % reduction in peak and mean algal biomass, depending on the site. Under low flow conditions, the predicted reductions were slightly greater--9 to 48 %. As expected, greater reductions occurred further downstream. Assuming the study sites are representative of the reaches they bracket, the P ban produced at least a 25% reduction in algal levels over 110 river miles. During low flow years, the ban was predicted to effect at least a 40% reduction in 100 river miles.

British Columbia has set 100 mg/m2 of chlorophyll a as the level of attached algae that represents an aesthetic nuisance. Assuming for the moment that this level represents a criterion for algae, peak summer levels in the Clark Fork exceed this criterion from the headwaters down to the confluence with the Flathead. Peak levels predicted by the model exceed 100 mg/m2 both before and after the ban. However, <u>mean</u> summer levels from Harper's Bridge to St. Regis exceed 100 mg/m2 before the ban and drop below this level after the ban in average years. In low flow years only

Harper's Bridge and Huson move from above the criterion to below it. Under all scenarios, the site just below the sewage plant exceeds the criterion, and the Plains site is below the criterion. If the Harper's Bridge, Huson and St. Regis sites are representative of the reaches they bracket and the reach down to the Flathead, the P ban reduced the mean summer chlorophyll level below this nuisance criterion for 100 miles of river.

Given the role of attached algae in dissolved oxygen violations and its possible role in foaming, such reductions would certainly be ecologically significant. Would such reductions produce a change in algal levels or foaming that casual observers could perceive? This is unlikely. Algal levels are tremendously variable from rock to rock within a site. So differences between sites and years can only be perceived with very costly labor intensive sampling programs. And the differences between sites and years could be due to factors other than nutrients. Paying such a cost to prove the benefits of the P ban in each site and year is not justified.

Like rivers, people show a lot of variability. We all know people who died of lung disease who did not smoke, and smokers who did not die of lung disease. However, by compiling health and mortality data from thousands of people, it was possible to determine that there is a significant relationship between smoking and lung disease. This relationship is used to predict the increased risk of lung disease from various levels of exposure to smoking. Based on this relationship, warnings are issued against smoking, and smoking is banned in areas where it would affect other people. We do not require proof that every person who smokes will get lung disease before protecting people from the risk associated with smoking.

Artificial stream studies have quantified the relationship between nutrient and attached algae levels. This relationship was incorporated into a realistic, well validated model that was used to predict how river algal levels will likely respond to various exposures to nutrients. Based on these predictions, the Missoula P ban has greatly reduced the river's risk of producing nuisance algae levels and the attendant water quality problems. The benefit to cost ratio of this managment action is quite high.

The only management action that could rival the P ban in its potential effect would be much more costly--land treatment of the Missoula sewage in the summer time. If all these nutrients were retained on the land, the resulting reduction in P and N loads to the river would be enormous. The sites downstream of the sewage plant might be expected to approach the site above the sewage plant in nutrient and algal levels. Nutrients brought in by the Bitterroot River and the pulp mill would result in some increase in algae, but summer algal levels would be drastically reduced. These reductions would further benefit chemical water quality (and could be predicted using the model used in this study); however, the potential impacts on the fishery of this reduction in food base should be addressed also.

NUTRIENT LIMITATION IN THE UPPER CLARK FORK

EXECUTIVE SUMMARY

The upper Clark Fork exhibits massive growths of the filamentous green alga *Cladophora* that interferes with fishing and contributes to violations of the state DO standard. To evaluate what nutrient reductions would be required to reduce *Cladophora* levels significantly, *Cladophora* growth potential was assessed at several sites on the river that exhibit different nutrient levels.

Cladophora requires more than a year to develop massive growths on new substrates. Germinating zoospores must first establish a holdfast and then grow upright filaments. The upright filaments often break off, particularly over winter, and new filaments grow from the holdfast in subsequent years. With each year the growths appear more massive. To study the limitation of massive growths in one growing season, rocks already well colonized with *Cladophora* and just beginning the new year's growth of filaments were collected from two sites. These rocks were then transplanted to four other sites that differed in their levels of soluble inorganic P and N. The four sites and their nutrient levels were:

	Median (and range) of SRP (ppb)	Median (and range) of Nitrate (ppb)	N:P
Warm Springs:	40 (20-90)	15 (<10-40)	0.375
Deer Lodge:	5 (3-22)	80 (4-150)	16
Gold Creek:	27 (11-37)	<10 (<10-30)	<0.37
Bear Creek:	37 (16-46)	<10 (<10)	<0.27

In mid July, rocks were placed at similar depths and water velocities and checked weekly when water samples were collected. Half the rocks were harvested after one month and half after a second month. Algal levels were expressed as chlorophyll a and ash free dry weight (AFDW) per unit area.

In August, chlorophyll levels were slightly correlated with median SRP and nitrate (slightly better with nitrate). In September, neither nutrient showed any correlation with chlorophyll levels. In August, AFDW showed no significant differences between sites, and in September, AFDW differences were not correlated with median nutrient levels.

The ratio of N:P at these sites suggests that N is more likely to limit algal growth than P at three sites (Warm Springs, Gold Creek and Bear Creek) while P should be more limiting at Deer Lodge. However, massive growths accumulated at Deer Lodge, Gold Creek and Bear Creek but not at Warm Springs. The lack of massive accumulations at Warm Springs may have been caused by heavier grazing or by limitation by toxic metals or a shortage of some trace element.

Hence, nutrient levels in the upper river appear to be sufficiently high long enough that other factors account for much of the variation in algal levels.

These results suggest that it may be necessary to reduce the median nutrient concentrations below the 5ppb SRP observed at Deer Lodge and below the nitrate detection limit (10 ppb) observed at Gold Creek and Bear Creek before really significant reductions in Cladophora levels are observed. A careful assessment of point source contributions is necessary to determine whether this would be possible by controlling point sources alone.

It should be noted that Cladophora can store excess nutrients during short periods of high nutrient levels to last through fairly long periods of low nutrient levels. Hence if all the sites had a few short periods of high nutrient levels, the difference in the typical levels at these sites may not be that relevant. Such short periods of high nutrient levels might not be picked up even in weekly sampling. In addition, nutrient levels in June might determine algal levels for the rest of the summer. It may be that controlling these short periods of high nutrient levels would result in reductions in algal levels at those sites that typically have fairly low nutrient levels. Again, a careful assessment of point source contributions may reveal whether this is possible by controlling point sources only.

It may be that the most important factors controlling Cladophora accumulations in some Montana rivers is the frequency and duration of spring scouring flows and the hardness of the water. The middle Clark Fork has nutrient levels as high or higher than the upper river (although the N:P ratios are not so low) but is not characterized generally by massive Cladophora growths (though the alga is present). The Middle Clark Fork water is softer and has higher flows that last until later in the spring/summer. Increased reductions in flows associated with withdrawal of water from the river will increase hardness and decrease scouring flows (particularly toward the end of the high flow season). This may allow the Cladophora problem to move downstream. In recent years I have observed that certain growths of Cladophora in the middle river have become more massive, but this may be natural variation.

INTRODUCTION

Attached algae communities in the Clark Fork River sometimes reach levels that interfere with beneficial uses of the river. Nutrient addition experiments carried out in streamside artificial streams have identified the levels of nitrogen and phosphorus that saturate attached algae standing crop in these waters. Most reaches of the Clark Fork most of the time are below the nutrient levels that saturate standing crop, hence reductions in nutrient levels may reduce attached algae levels in the river (Watson et al. in press).

Recently, the City of Missoula enacted a ban on the sale of laundry detergents containing a significant amount of phosphate. Since that time the soluble reactive phosphorus (SRP) load from the Missoula sewage plant has been reduced almost 50%. In recent years the Frenchtown pulp mill dramatically reduced P loading (and N loading to a lesser extent). This reduction, along with the greater dilution by higher river flows, likely resulted in lower instream SRP levels in 1990 when compared to the drought years that preceded the ban. The effect of such a change in loading on river biota is often evaluated by comparing biotic response above and below the point of loading both before and after the change takes place. This is the classic impact study design. Simple upstream-downstream comparisons are confounded by the fact that the sites may differ for many factors besides the one under study. Simple before-after comparisons are confounded by year-to-year differences in many uncontrolled factors. Even with the combined upstream-downstream before-after design, it is difficult to evaluate the benefits of a single action when numerous other factors change over time and space as well. In addition, benefits may not occur immediately downstream or immediately in time.

In the case of the effect of the Missoula phosphate ban, some limited 'before the ban' algal accumulation data exists. Algal accumulation on artificial substrates was measured above and below the sewage plant and the pulp mill in 1987 and above and below the sewage plant in 1988. However, the three sites below the sewage plant have such high nutrient levels that nutrients may still be <u>near</u> levels that saturate standing crop even <u>after</u> the ban. Changes in nutrient levels near the point of saturation have a small effect on algal growth rates which is detectable in a controlled laboratory situation but are unlikely to be detectable when measured under field conditions with their greater sources of variation. The greatest benefits of the ban are likely to accrue further down river where nutrient levels are lower. Here changes in algae levels may be great enough to measure; however, there is no preban data for these sites.

Another approach provides a better means of quantifying the effects of the P ban on algal levels in the Clark Fork. A model of attached algae accumulation developed by Watson has been validated for the middle Clark Fork River using instream nutrient and algae levels measured in 1988 and 1990. The model was then used to predict accumulation of algal standing crop in different parts of the river under both average flow and low flow conditions given the SRP loads produced by the Missoula Sewage Plant before and after the P ban.

ALGAL ACCUMULATION IN THE MIDDLE & LOWER CLARK FORK, 1987 & 1990

The primary purpose of monitoring algal accumulation on artificial substrates was to obtain data that could be used to validate the algal accumulation model. Some limited evaluations of the artificial substrate data are made below.

Methods--Artificial substrates identical to those used in the summer of 1987 (unglazed ceramic tiles) and similar to those used in 1988 (styrofoam beadboard) were placed in the Clark Fork at the same sites monitored in 1987: above and below the Missoula waste water treatment plant WWTP (Russel Street and Schmidt site) and above and below the mill (Bioassay shack and Ken Cyr's land at Huson). In addition substrates were placed at several sites farther downriver (Alberton, Superior, St. Regis, and Plains--the Superior substrates were vandalized soon after placement). Substrates were kept between 20-30 cm deep and in water flowing 0.3 m/s +/- 0.1m/s. Middle river substrates were sampled weekly and lower river substrates monthly from early July until the end of September. Five to 10 replicate samples were collected each time. Water samples were collected at the same time and analyzed for soluble reactive P and for soluble inorganic nitrogen (unless the WQB was sampling at that time). Algal material on the substrates was analyzed for chlorophyll a and for ash free dry weight according to Standard Methods (1985).

Results--Substrates placed upstream of the Missoula WWTP showed fairly similar behavior in all three years (Figures, 1, 2, 3--chlorophll levels were somewhat higher in 1988, a severe drought year). The site below the Missoula WWTP reached similar peak levels in all three years but certainly grew more slowly at the beginning of the summer in 1990. The SRP and nitrate levels were lower earlier in the summer and rose in late August and early September, probably contributing to the rapid increase in accumulation during that period. The stations above and below the mill showed a rapid increase in biomass early in the summer (and actually outstripped the below Missoula site early on) but levels dropped off later in the summer. In early summer, these sites had higher nitrate levels than the below Missoula site, but later these nitrate levels dropped below those at the below Missoula site (see nutrient data in Appendix N). Low N levels and the drop in algal standing crop observed in early summer at the below Missoula site may have been caused by some high flows in upper river tributaries which were somewhat damped out by groundwater inflows and Bitterroot River inputs at the sites bracketing the mill. Generally, algal standing crops at the sites bracketing the mill were similar in 1990 and 1987 with the exception of the last sampling below the mill which was much lower in 1990 than in 1987.

There is no preban data for the sites from Alberton down, but after the ban the Alberton algal levels were similar to the below mill levels (just a bit lower), and the St. Regis levels were similar to the above Missoula levels. The algal accumulation levels at Plains (not shown in these figures; see next section) were lower still. Hence these sites demonstrate that lower accumulation levels are associated with the lower nutrient levels that characterize these sites.

Conclusions--To facilitate comparing the maximum algal accumulation levels attained in 1987, 1988 and 1990, the last three to four samplings of the summer were averaged (Figure 4). Sites are referred to by number on graphs: 1,2--above and below the Missoula STP; 3,4--above and below the mill; 5--Alberton; 6--St. Regis; 7--Plains. Again the site above the STP had similar biomass in all years with 1988 a little higher. The site below the mill accumulated significantly less chlorophyll in 1990, while the site above the mill accumulated significantly less AFDW.

EVALUATION OF BENEFITS OF THE P BAN THROUGH USE OF AN ALGAE MODEL

Nature of the Algae Accumulation Model

The model used in this study is described in detail in Appendix M. The following is a short conceptual description.

The algal accumulation model was developed to simulate the accumulation of attached algae on the bed of a river. The model allows algal biomass to 'grow' as a function of temperature, light and nutrient level. Biomass is lost to respiration and sloughing. The algal growth and respiration functions are fairly typical formulations used in the literature. A maximum growth rate (taken from the literature) measured under optimal conditions of light, temperature and nutrient levels is reduced in proportion to the difference between optimal conditions and the actual ambient conditions. Respiration is handled in a similar fashion but is a function of temperature only.

The above portions of the model could be used to simulate algal growth in a lake as well as a river. In order to consider the accumulation of attached algae in a river, the model must also consider sloughing (the detachment and washing away of the algae). Sloughing has been modeled in a number of ways, from having a fixed sloughing rate to having sloughing increase as algal biomass approaches a level considered to be the maximum biomass that can be supported by the conditions at the site under study. Generally, this maximum biomass is set at the maximum value ever observed in the system under study. In the model used here, an improvement on the latter approach was used.

Studies of attached algae in artificial streams show that when attached algae is allowed to colonize and grow on a bare surface, it accumulates rapidly at first, then the rate of accumulation slows and approaches zero. The processes of loss come to balance the processes that add to the biomass and an equilibrium biomass is reached. This equilibrium biomass is a function of nutrient concentration. That is, the higher the nutrient concentration the longer the algae will increase in biomass before accumulation levels off. Hence the maximum biomass that can be sustained is a function of nutrient level. The artificial stream studies of Bothwell and Watson were used to develop a function that predicts maximum biomass from soluble reactive phosphorus (SRP) levels. Hence the maximum biomass that a site can support is changing over time as a function of ambient SRP concentration. And again as the algal biomass levels estimated by the model approach the maximum level that can be supported, sloughing increases.

So in a nutshell, the model is given as input an initial low level of biomass, and then is given on an hourly basis the light, temperature and nutrient conditions at a particular site on the river. Every hour, the model estimates the growth, respiration and sloughing rates as described above and adds or subtracts an appropriate amount of biomass from its previous estimate of the biomass. Thus algal biomass gradually increases or decreases depending on whether current conditions cause gains to exceed losses or <u>vice versa</u>.

<u>Validation of the Model</u>

To validate a simulation model one must have several independent sets of validation data. Validation data is a combination of both the input data the model requires (in this case, light, temperature and nutrient data) and the ouput data the model produces (algal biomass levels over the summer). In 1988 and 1990 both SRP and algal accumulation rates were measured at several sites on the Clark Fork. (In 1987 algal accumulation rates were measured but SRP was not, and in 1989 SRP was measured but algal accumulation rates were not).

The model was used to simulate algal accumulation at two sites in 1988 (above and below the Missoula sewage treatment plant or STP) and at 7 sites in 1990 (above and below the STP, above and below the pulp mill and at Alberton, below St. Regis and at Plains). The results of these validation runs appear in Figures 5 to 12. In all of these figures the model simulation results appear as a line. The horizontal markers represent the 95% confidence interval of the measured algal levels on artificial substrates in the river. The line produced by the model does not pass through every 95% confidence interval, but taken all together, the model does a good job of predicting the differences in algal levels between these sites and the general pattern of algal accumulation over the growing season.

<u>Estimating Nutrient Levels Under Different Loading & Flow Scenarios</u>

To evaluate the benefits of the phosphate ban, it seemed most reasonable to use the algae model to predict algal accumulation rates under the nutrient conditions one would expect under the following 4 scenarios:

Average flow conditions with P loadings before and after ban
Low flow conditions with P loadings before and after ban

In order to estimate the SRP levels that would be expected under these conditions, it was necessary to develop a simple nutrient model for the river. This model estimates the nutrient concentration at each station by dividing the total loads added to the upstream reach by the flows at the station in question. In other words:

$$\text{SRP @ DOWN} = \frac{\text{(SRP*Flow @ UP + SRP*Flow of Trib or Eff)}}{\text{(combined Flow of UP and Trib or Eff)}}$$

Where SRP is the concentration of SRP at downstream (DOWN) or upstream stations (UP) or in tributaries (Trib) or effluents (Eff); Flow is the volume of water passing a point per unit time.

Flow data were provided by the USGS office in Helena and included the long term average flows for these sites and the 10th percentile low flows (only 10% of flows are lower than these). Sewage plant loading is based on data available from the plant (data from preban years were averaged as were post ban data). Inriver SRP concentrations measured at the above Missoula site and in the Bitterroot and Flathead rivers were also averaged for preban and post ban years.

This approach has a number of sources of error. It assumes we have a good estimate of the loads and the flows of each reach. It also assumes that phosphorus is conservative which it is not. Phosphorus may be taken up or released by the algae in each reach at any given time. Hence the downstream concentrations may be greater or lesser than would be predicted by this strictly conservative approach.

During the summer, nutrient levels along the river are generally lower than predicted by this conservative model. This is to be expected since algae are taking up nutrients from the water. The percent of the incoming nutrient load retained in each reach over several summers of available data was determined, and this retained load was subtracted before estimating the concentration below the reach. The above approach produced the nutrient levels summarized in Figures 13 to 16.

<u>Algal Accumulation Under Four Nutrient Scenarios</u>

The above nutrient levels were used to produce four experimental simulations for each of the following sites: above and below the WWTP, above and below the mill, at St. Regis and Plains. Results of these simulations appear in figures 17 to 22. Each figure shows the results of two simulations--before and after the P ban. Each site and each flow regime is depicted on a different figure.

Conclusions

To permit quick comparisons between pre and post ban simulations, differences between these simulations were summarized in a single number. First, the peak algal biomass of the summer was noted for each pair of simulations, and the percent reduction between these peaks was noted. In addition, the mean summer algal biomass was determined, and the percent reduction between pre and post ban means was calculated (Table 1).

Generally, greater % differences are exhibited farther down the river where nutrient levels are lower. The farther the nutrient level is below saturation, the greater is the effect of a nutrient loading reduction. In addition, algal differences are generally greater in lower flow years than in average flow years because the instream nutrient concentration change from pre to post ban loading is greater in low flow years. One exception is the site just below the Missoula WWTP. In low flow years the nutrient concentrations both before and after the ban are so near saturation that the reduction has less of an effect.

British Columbia has set 100 mg/m2 of chlorophyll a as the level of attached algae that represents an aesthetic nuisance. Assuming for the moment that this level represents a criterion for algae, observed summer levels in the Clark Fork exceeded this criterion from the headwaters down to the confluence with the Flathead before the ban (Water Quality Bureau data). Peak levels predicted by the model exceed 100 mg/m2 before and after the ban. However, predicted mean summer levels from Harper's Bridge to St. Regis exceed this level before the ban and drop below it after the ban in average flow years. In low flow years, only the mean biomass at Harper's & Huson move from above the criterion to below it. Under all scenarios, the site below the WWTP exceeds the criterion, and the Plains site is below it. If the Harper's to St. Regis sites are representative of the reaches they bracket and the reach down to the Flathead, the P ban reduced mean summer chlorophyll below this criterion for 100 miles of river (Table 2).

ACKNOWLEDGEMENTS

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REFERENCES

APHA. 1985. Standard Methods for the examination of water and waste water. 16 th edition.

Watson, V. J., P. Berlind, L. Bahls. in press. Control of algal standing crop by P and N in the Clark Fork River. Clark Fork River Symposium, Montana Academy of Science, April, 1990.

TABLE 1. PREDICTED REDUCTION IN ALGAL ACCUMULATION IN RESPONSE TO THE MISSOULA PHOSPHATE DETERGENT BAN

FLOW	SITE	RIVER MILES FROM ABV MSL	PEAK SUMMER BIOMASS (mg CHL a/m2) BEFORE P BAN	AFTER P BAN	% REDUCED	MEAN SUMMER BIOMASS (mg CHL a/m2) BEFORE P BAN	AFTER P BAN	% REDUCED
AVERAGE	ABV MSL	0	50	50	0	40	40	0
	BEL MSL	2	220	190	14	152	139	9
	ABV MILL	13	160	150	6	117	88	25
	BEL MILL	25	190	160	16	123	92	25
	ST. REGIS	89	140	130	7	112	80	29
	PLAINS	122	80	50	38	66	41	38
LOW	ABV MSL	0	50	50	0	34	34	0
	BEL MSL	2	230	210	9	154	138	10
	ABV MILL	13	180	150	17	106	69	35
	BEL MILL	25	200	170	15	103	60	42
	ST. REGIS	89	170	130	24	85	44	48
	PLAINS	122	70	40	43	36	20	44

TABLE 2. PREDICTED REDUCTION IN FREQUENCY OF OCCURRENCE OF NUISANCE ALGAL CONDITIONS IN RESPONSE TO THE MISSOULA PHOSPHATE DETERGENT BAN

FLOW	SITE	RIVER MILES BELOW ABV MSL	% OF DAYS ALGAL LEVELS > 100 mg/m2 CHL BEFORE P BAN	AFTER PBAN	% REDUCTION IN FREQUENCY OF EXCEEDANCES OF CHL CRITERIA
AVERAGE	ABV MSL	0	0	0	0
	BEL MSL	2	79	79	0
	ABV MILL	13	65	23	65
	BEL MILL	25	63	16	75
	ST. REGIS	89	43	0	100
	PLAINS	122	0	0	0
LOW	ABV MSL	0	0	0	0
	BEL MSL	2	83	81	2
	ABV MILL	13	78	58	29
	BEL MILL	25	78	47	50
	ST. REGIS	89	65	0	200
	PLAINS	122	0	0	0

LIST OF FIGURES

OBSERVED ATTACHED ALGAL BIOMASS ACCUMULATION, MIDDLE CLARK FORK:

FIG 1. ash free dry weight accumulation (AFDW), 1987 & 1990
FIG 2. chlorophyll a accumulation, 1987 & 1990
FIG 3. chlorophyll a accumulation, 1988
FIG 4. late summer averages, chlorophyll and AFDW, 1987-1990

VALIDATION RUNS OF THE ALGAL ACCUMULATION MODEL
(COMPARISON OF SIMULATED AND OBSERVED ALGAL LEVELS)

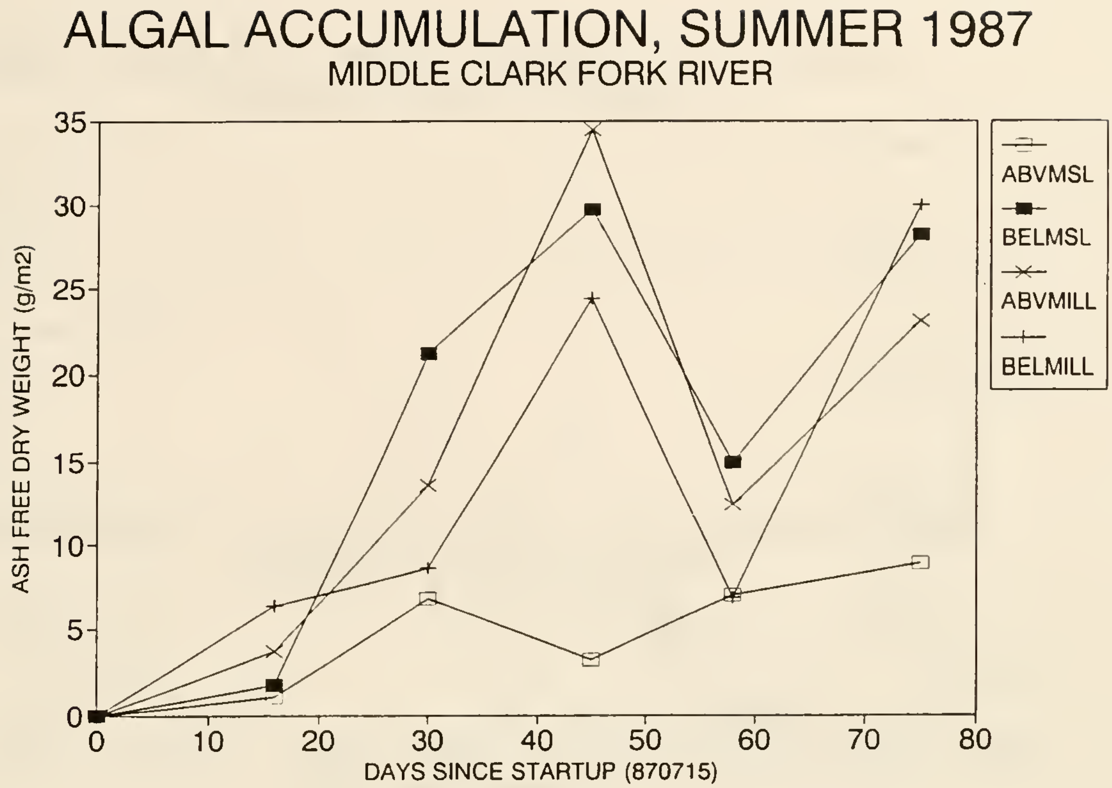
FIG 5. chlorophyll a, above & below Missoula WWTP, 1988
FIG 6. chlorophyll a, above & below Missoula WWTP, 1990
FIG 7. ash free dry weight, above & below Missoula WWTP, 1990
FIG 8. chlorophyll, above & below mill (Harper Br. & Huson), 1990
FIG 9. ash free dry weight, above & below mill, 1990
FIG 10. chlorophyll & ash free dry weight, Alberton, 1990
FIG 11. chlorophyll, St. Regis & Plains, 1990
FIG 12. ash free dry weight, St. Regis & Plains, 1990

MODEL SIMULATIONS OF SOLUBLE REACTIVE PHOSPHORUS LEVELS AT SIX SITES ON THE RIVER FOR 2 FLOW SCENARIOS AND 2 LOADING SCENARIOS
SITES ARE: AM & BM = ABOVE AND BELOW MISSOULA WWTP;
HB & HU = ABOVE AND BELOW PULP MILL (HARPER'S BRIDGE & HUSON);
SR = ST. REGIS; PL = PLAINS.

FIG 13. AVERAGE FLOW, BEFORE BAN
FIG 14. AVERAGE FLOW, AFTER BAN
FIG 15. LOW FLOW, BEFORE BAN
FIG 16. LOW FLOW, AFTER BAN

ALGAL MODEL SIMULATIONS OF ALGAL BIOMASS BEFORE AND AFTER P BAN FOR AVERAGE AND LOW FLOW CONDITIONS:

FIG 17. ABOVE MISSOULA
FIG 18. BELOW MISSOULA
FIG 19. ABOVE MILL (HARPER'S BRIDGE)
FIG 20. BELOW MILL (HUSON)
FIG 21. ST. REGIS
FIG 22. PLAINS


ALGAL ACCUMULATION, SUMMER 1987
MIDDLE CLARK FORK RIVER
ASH FREE DRY WEIGHT (g/m2)
DAYS SINCE STARTUP (870715)
ABVMSL
BELMSL
ABVMILL
BELMILL

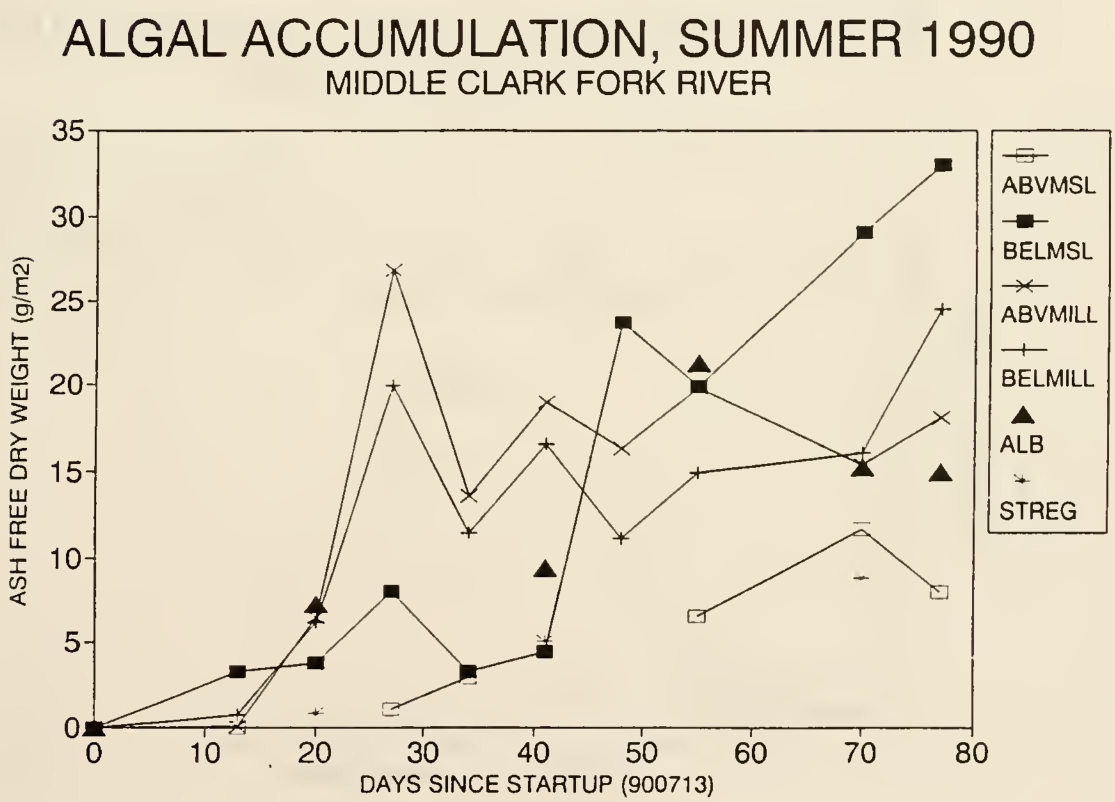
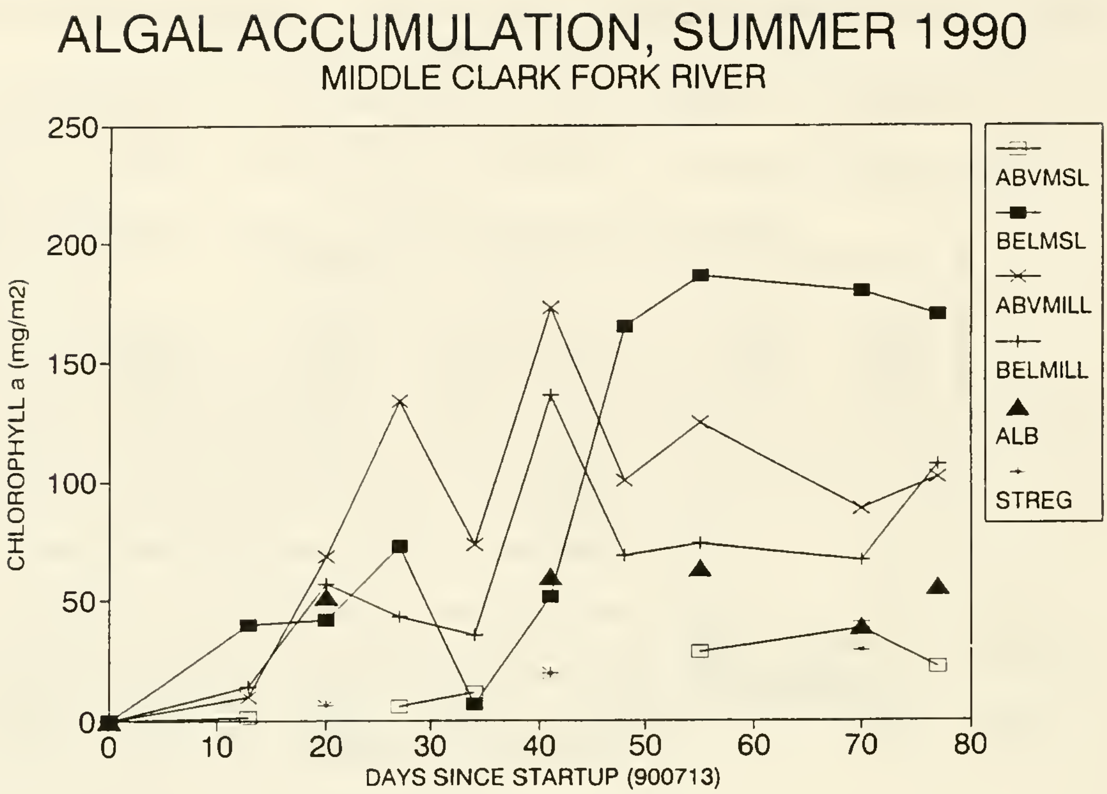

ALGAL ACCUMULATION, SUMMER 1990
MIDDLE CLARK FORK RIVER
ASH FREE DRY WEIGHT (g/m2)
DAYS SINCE STARTUP (900713)
ABVMSL
BELMSL
ABVMILL
BELMILL
ALB
STREG

FIGURE 1


ALGAL ACCUMULATION, SUMMER 1990
MIDDLE CLARK FORK RIVER
CHLOROPHYLL a (mg/m2)
DAYS SINCE STARTUP (900713)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
ABVMSL
BELMSL
ABVMILL
BELMILL
ALB
STREG

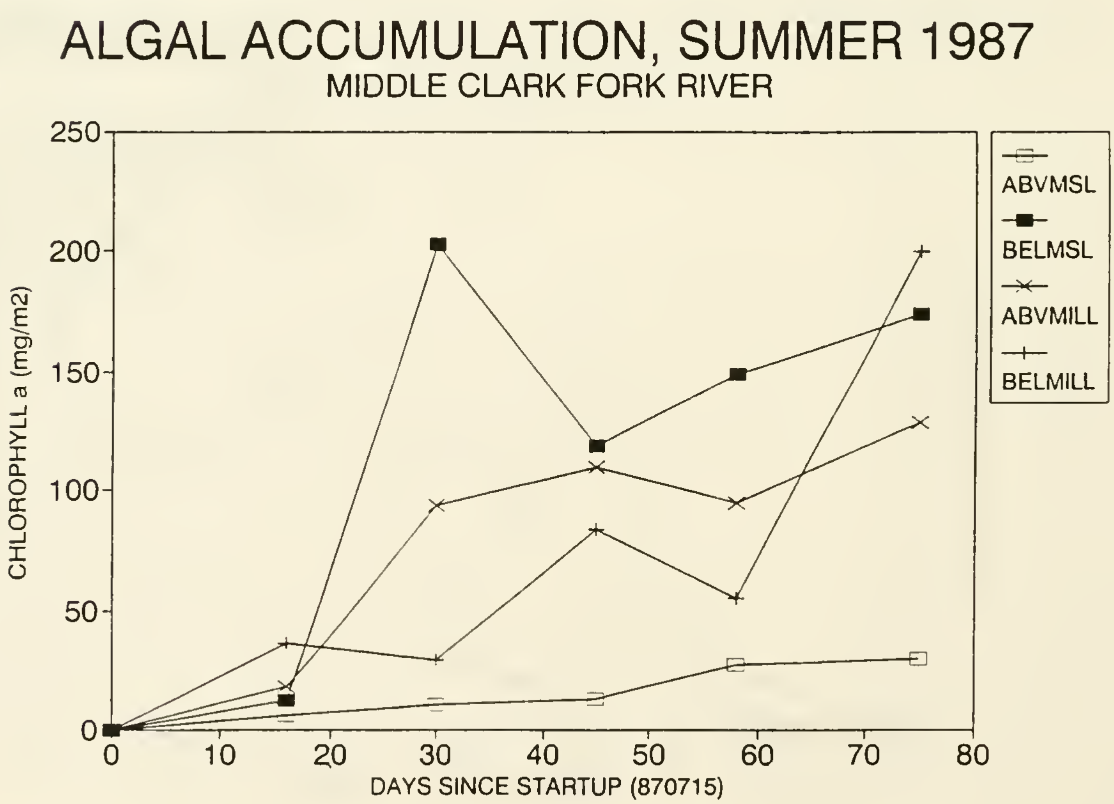

ALGAL ACCUMULATION, SUMMER 1987
MIDDLE CLARK FORK RIVER
CHLOROPHYLL a (mg/m2)
DAYS SINCE STARTUP (870715)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
ABVMSL
BELMSL
ABVMILL
BELMILL

FIGURE 2

ALGAL ACCUMULATION, SUMMER 1988

MIDDLE CLARK FORK RIVER

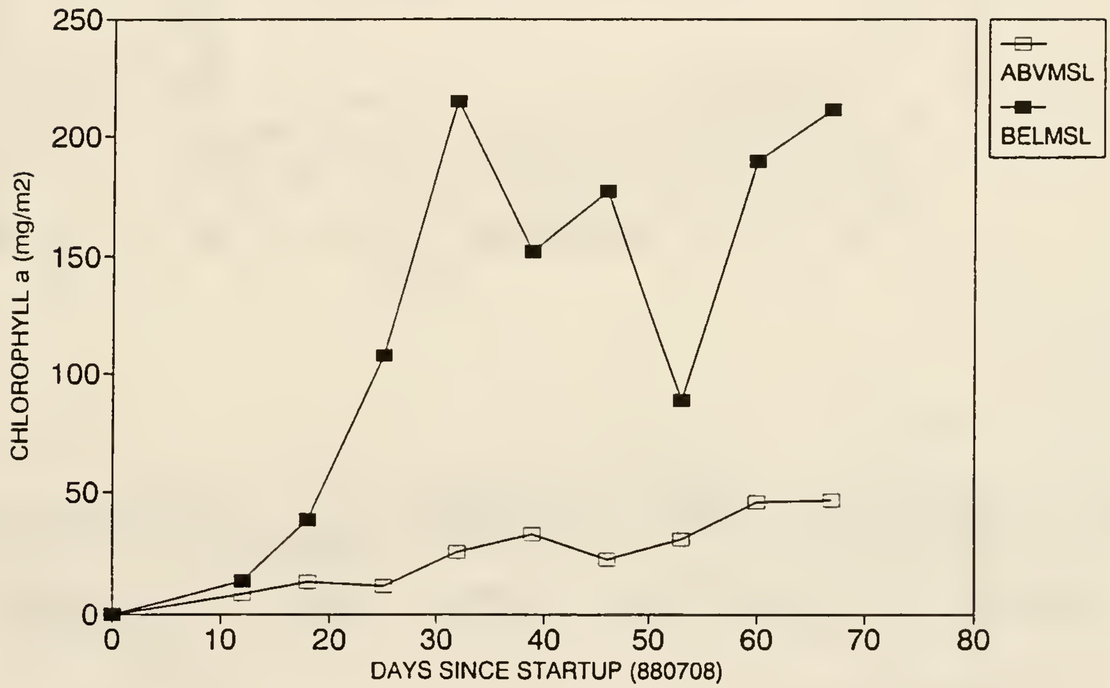
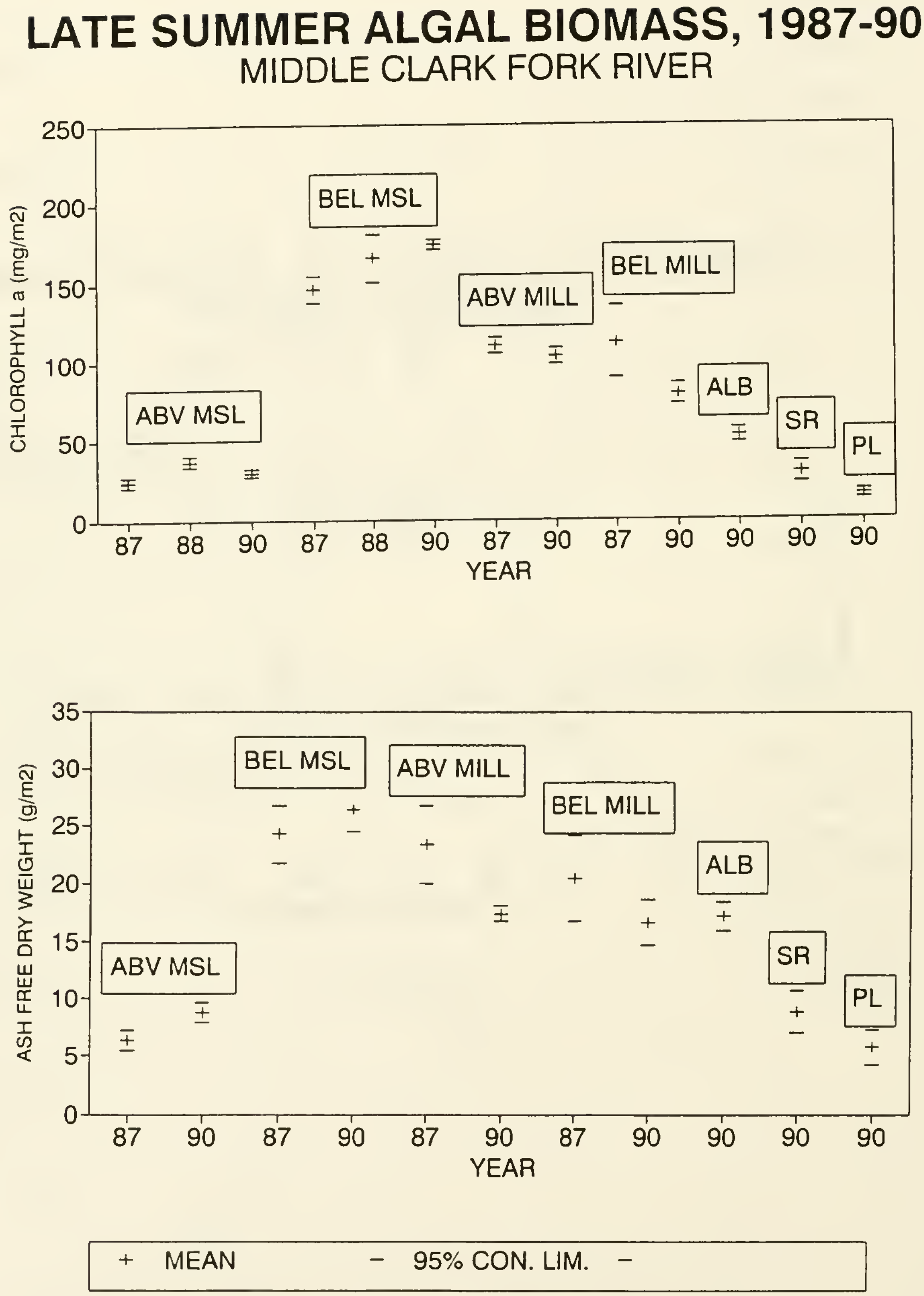


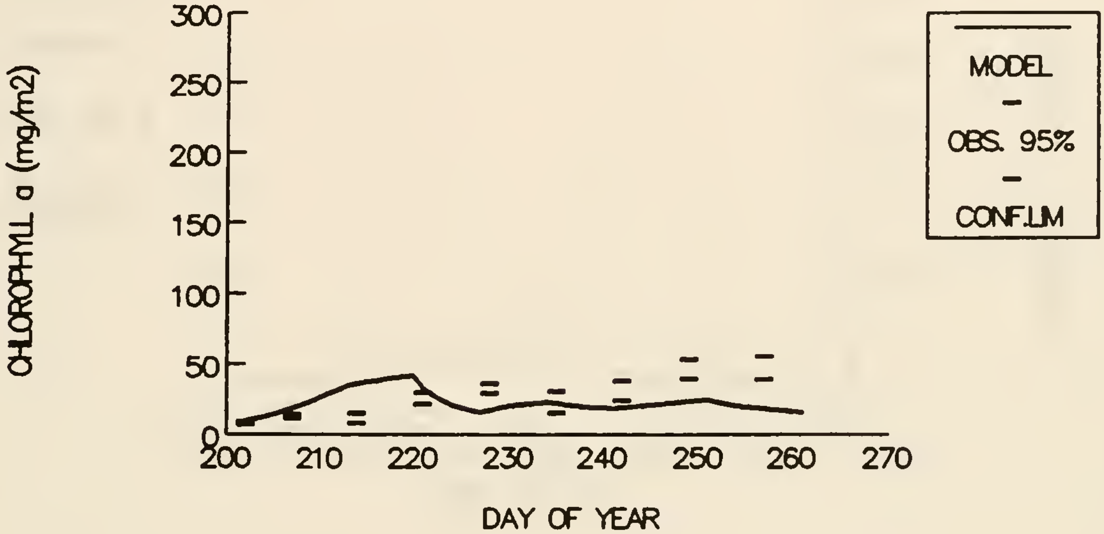
FIGURE 3

FIGURE 4



LATE SUMMER ALGAL BIOMASS, 1987-90
MIDDLE CLARK FORK RIVER
CHLOROPHYLL a (mg/m2)
0
50
100
150
200
250
ABV MSL
BEL MSL
ABV MILL
BEL MILL
ALB
SR
PL
87 88 90 87 88 90 87 90 87 90 90 90 90
YEAR
ASH FREE DRY WEIGHT (g/m2)
0
5
10
15
20
25
30
35
ABV MSL
BEL MSL
ABV MILL
BEL MILL
ALB
SR
PL
87 90 87 90 87 90 87 90 90 90 90
YEAR
+ MEAN
– 95% CON. LIM. –

SIMULATION OF ALGAL STANDING CROP ABOVE MSL STP, SUMMER 1988



SIMULATION OF ALGAL STANDING CROP BELOW MSL STP, SUMMER 1988

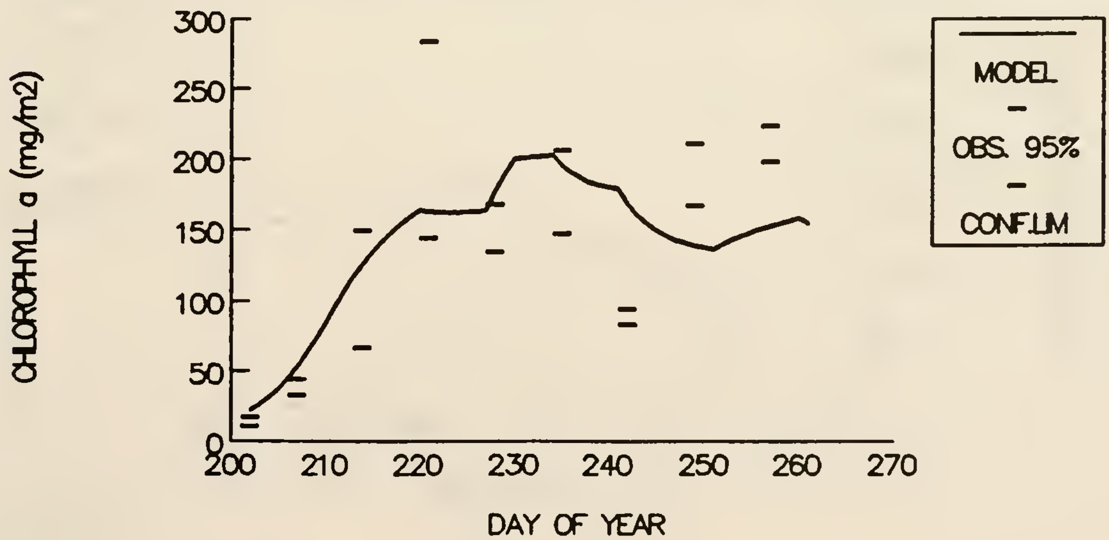
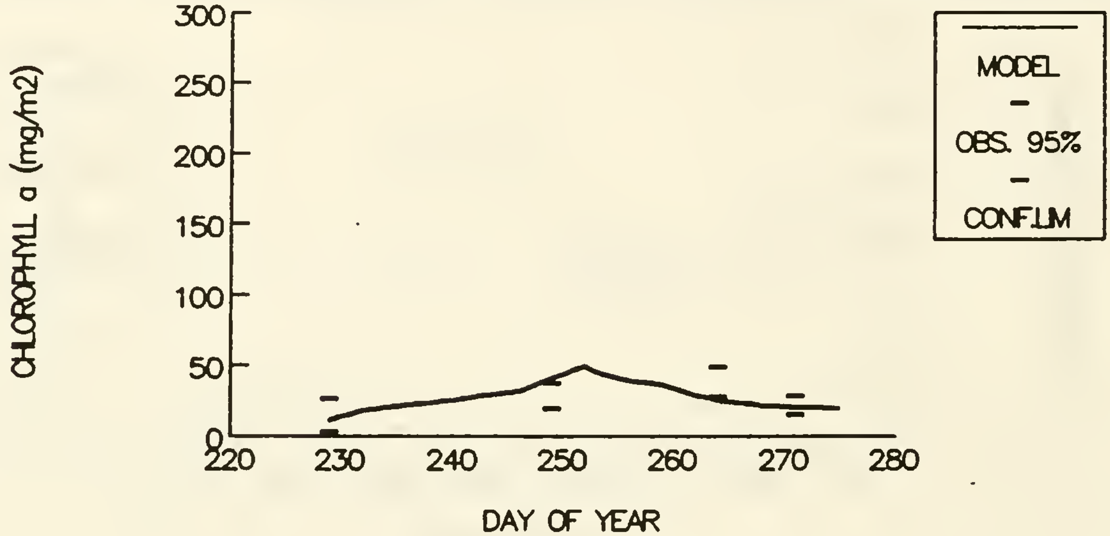


Figure 5

SIMULATION OF ALGAL STANDING CROP ABOVE MSL STP, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP BELOW MSL STP, SUMMER 1990

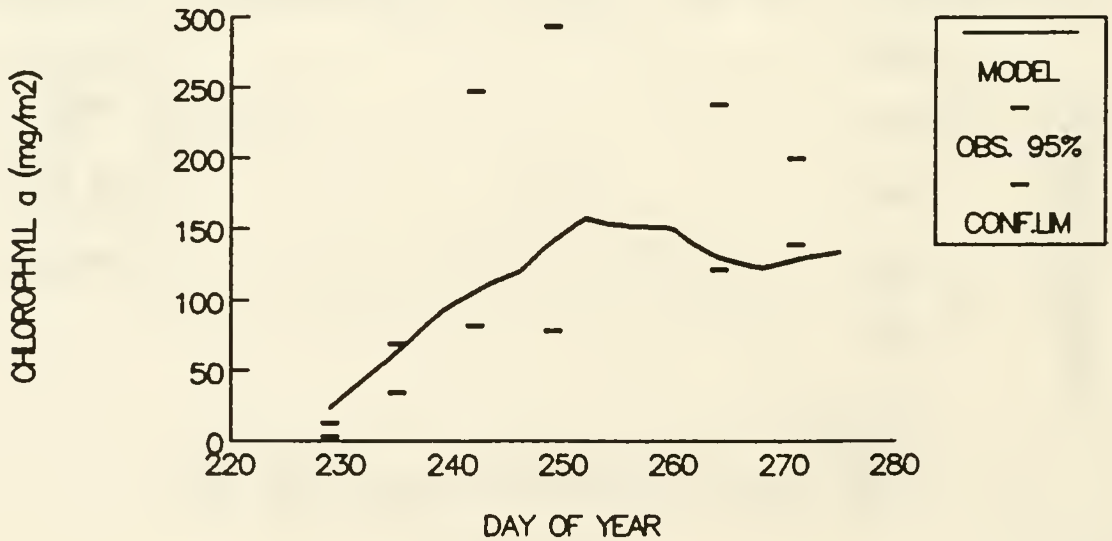
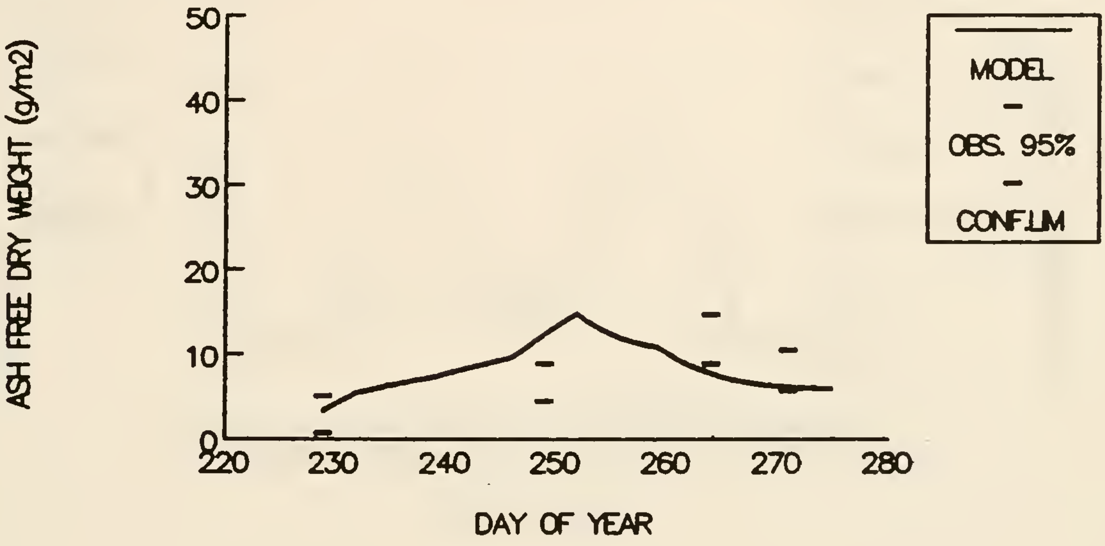


Figure 6

SIMULATION OF ALGAL STANDING CROP ABOVE MSL STP, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP BELOW MSL STP, SUMMER 1990

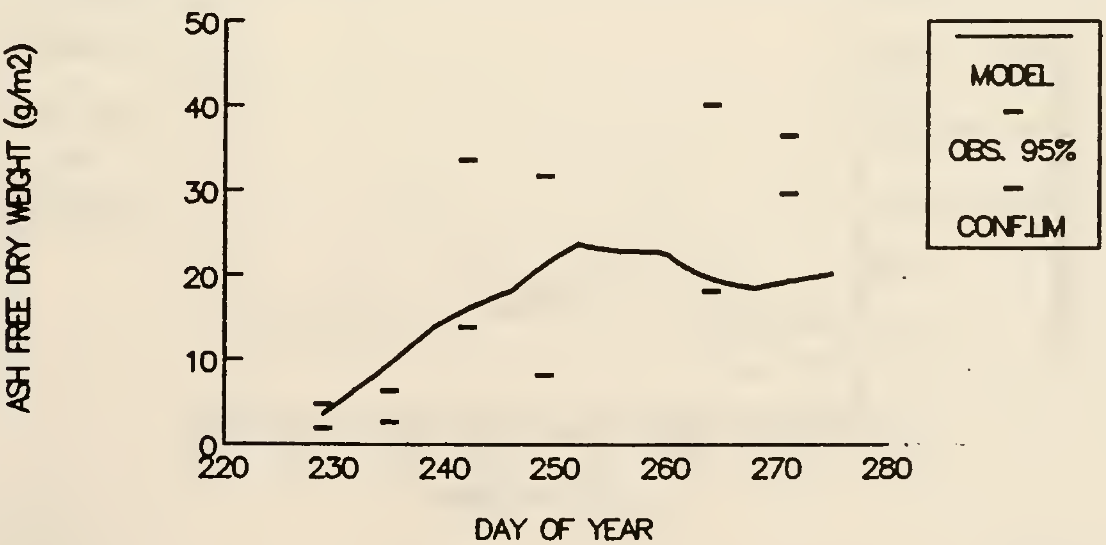
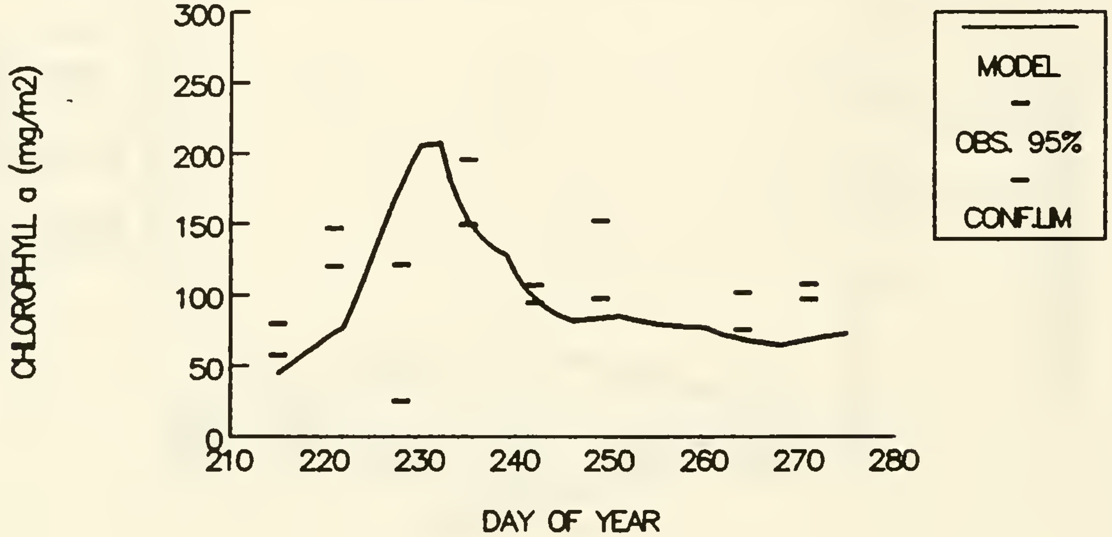


Figure 7

SIMULATION OF ALGAL STANDING CROP AT HARPER BRIDGE, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP AT HUSON, SUMMER 1990

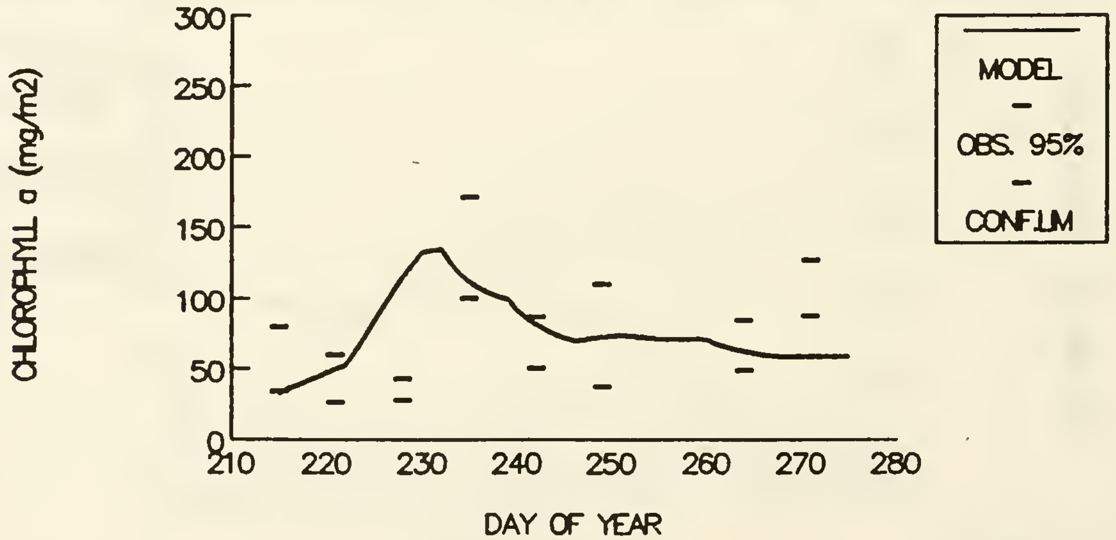
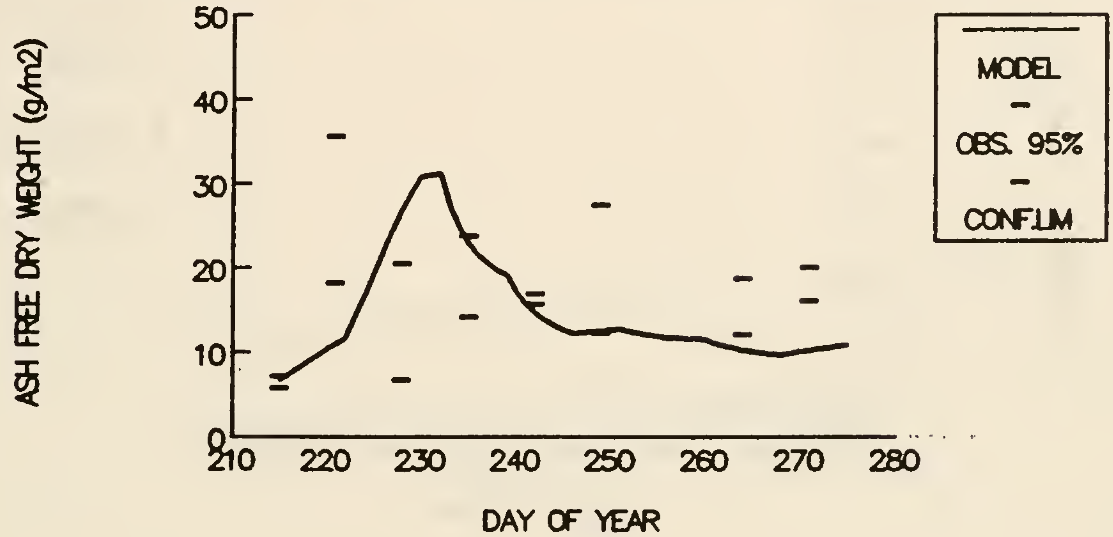


Figure 8

SIMULATION OF ALGAL STANDING CROP AT HARPER BRIDGE, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP AT HUSON, SUMMER 1990

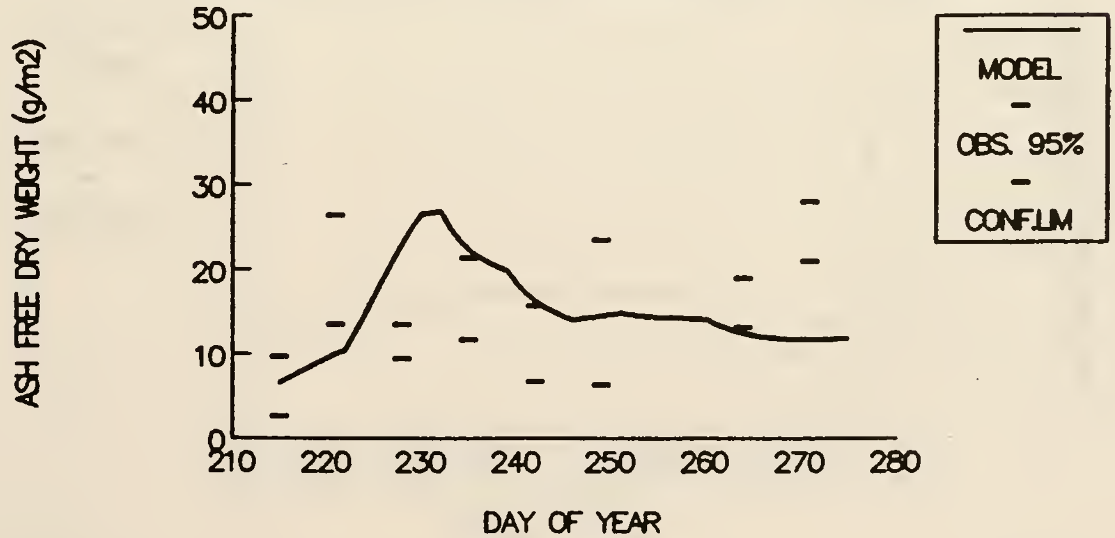
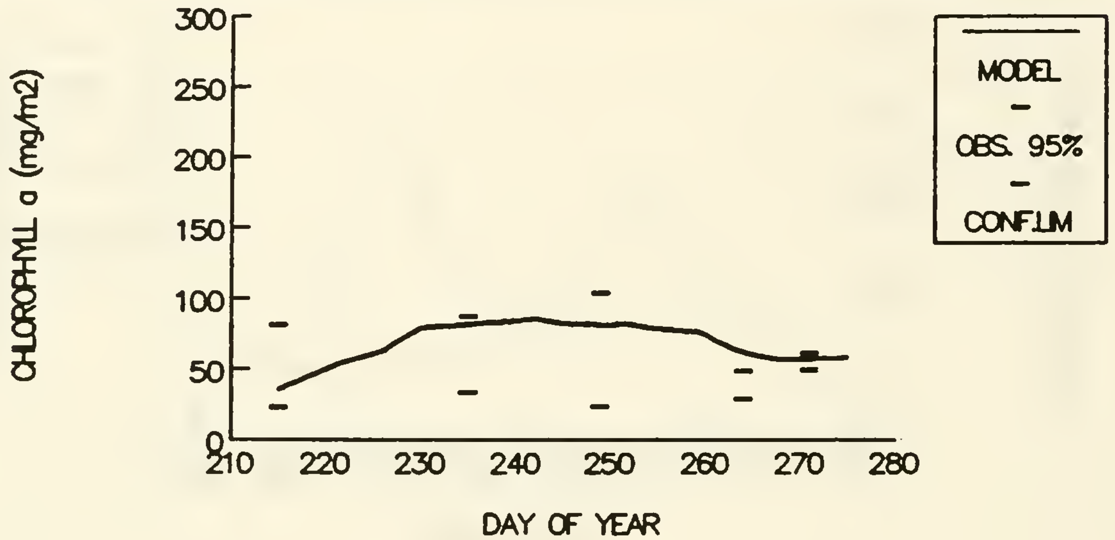


Figure 9

SIMULATION OF ALGAL STANDING CROP AT ALBERTON, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP AT ALBERTON, SUMMER 1990

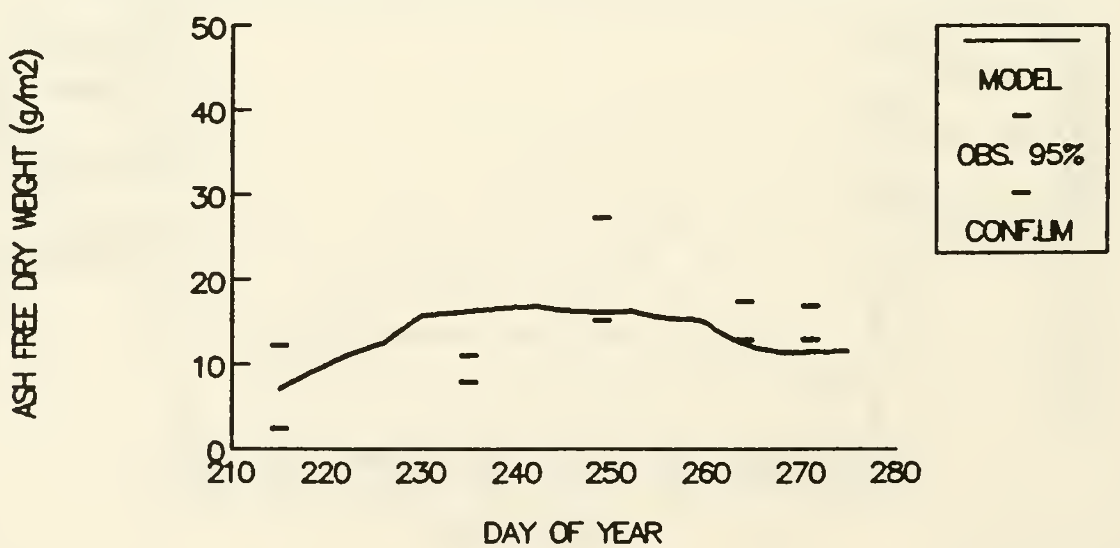
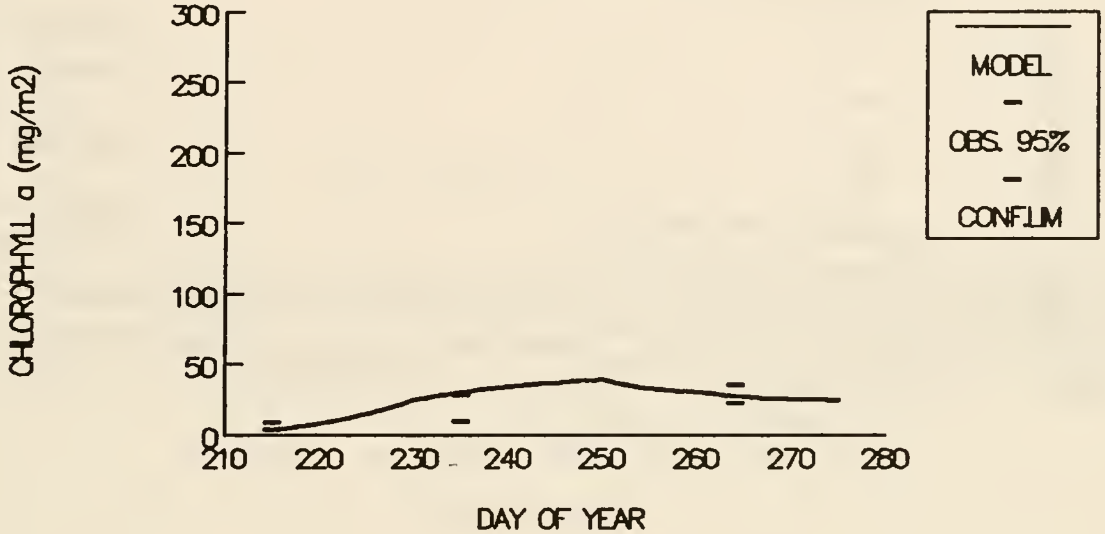


Figure 10

SIMULATION OF ALGAL STANDING CROP BELOW ST. REGIS, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP PLAINS, SUMMER 1990

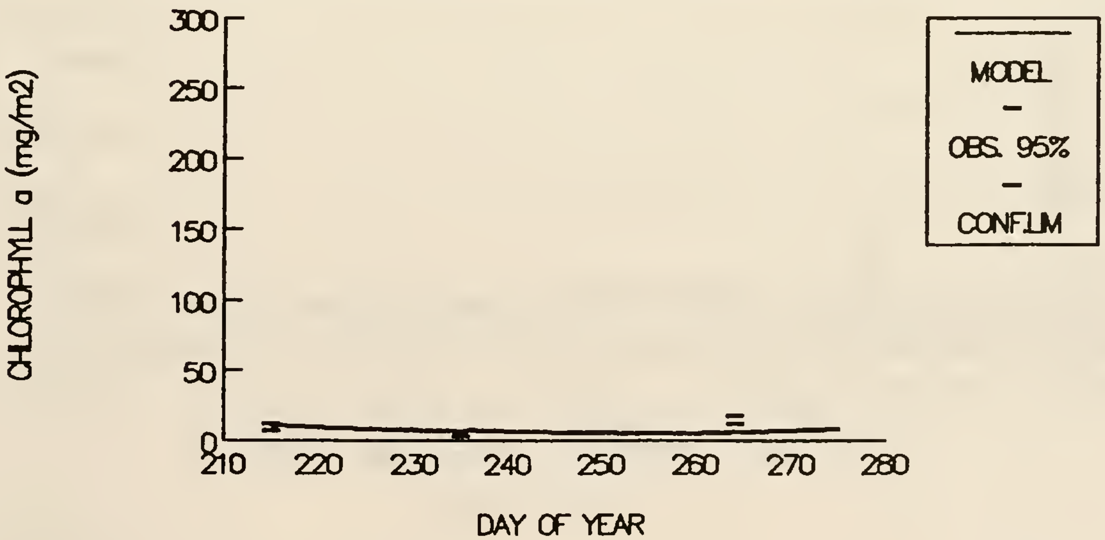
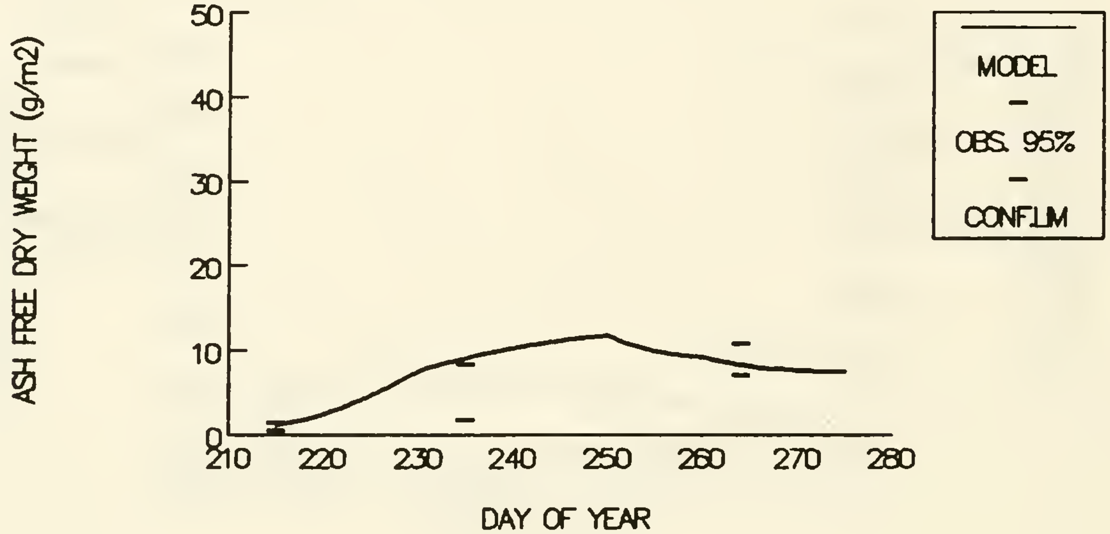


Figure 11

SIMULATION OF ALGAL STANDING CROP BELOW ST. REGIS, SUMMER 1990



SIMULATION OF ALGAL STANDING CROP PLAINS, SUMMER 1990

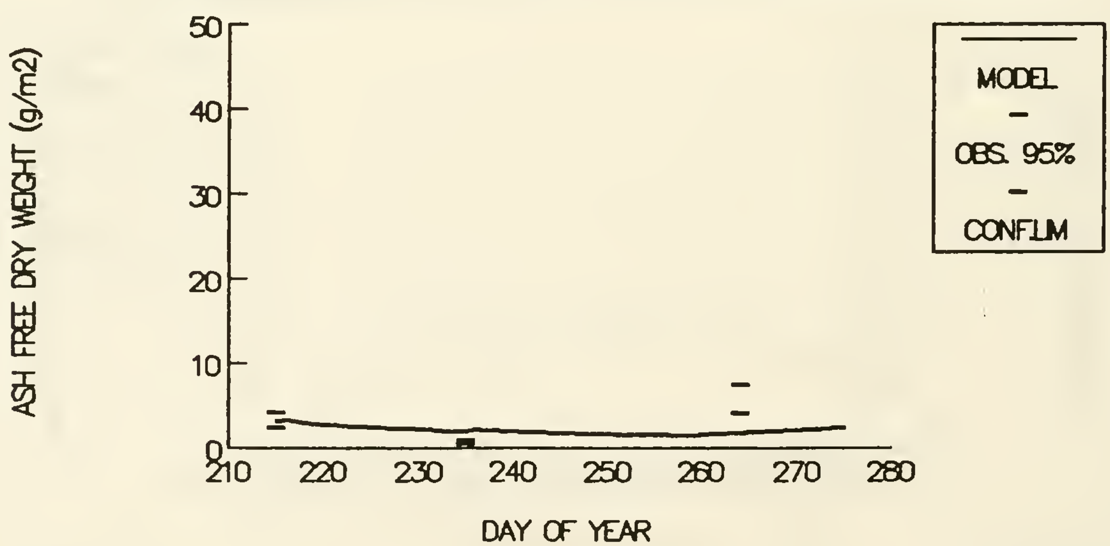


Figure 12

FIGURE 13

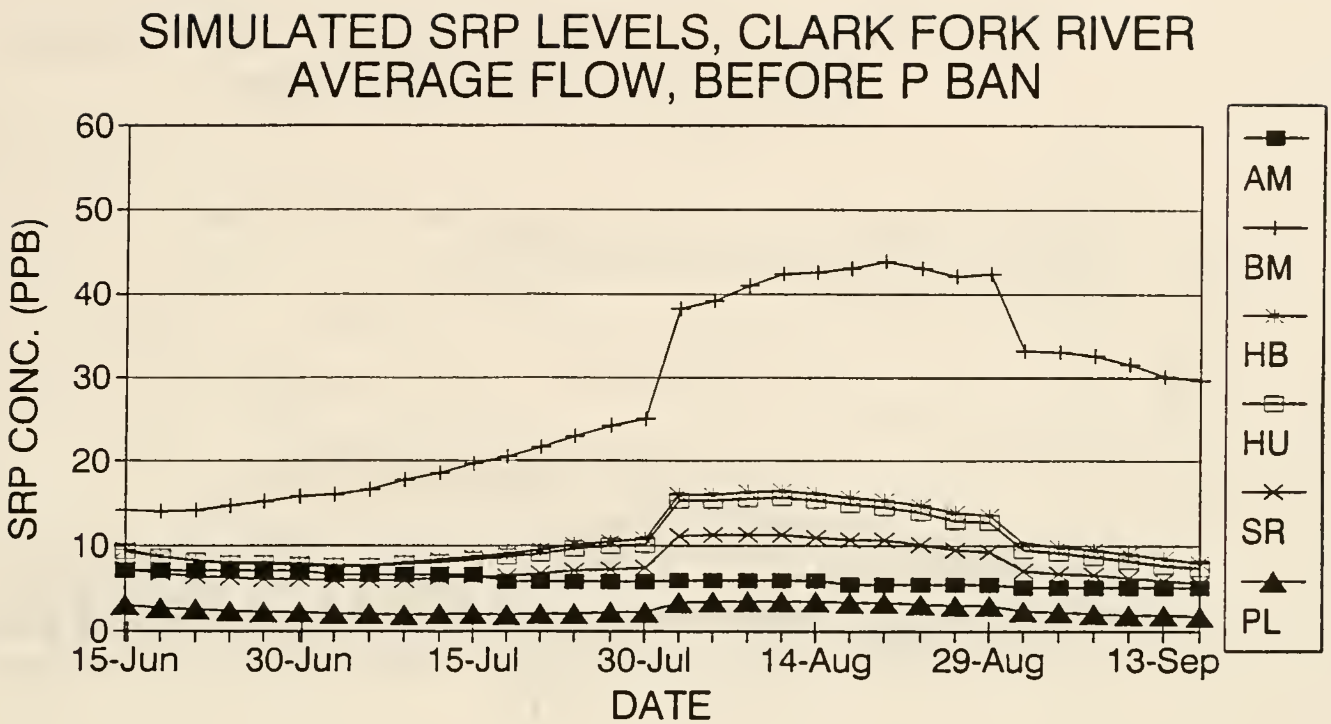


FIGURE 14

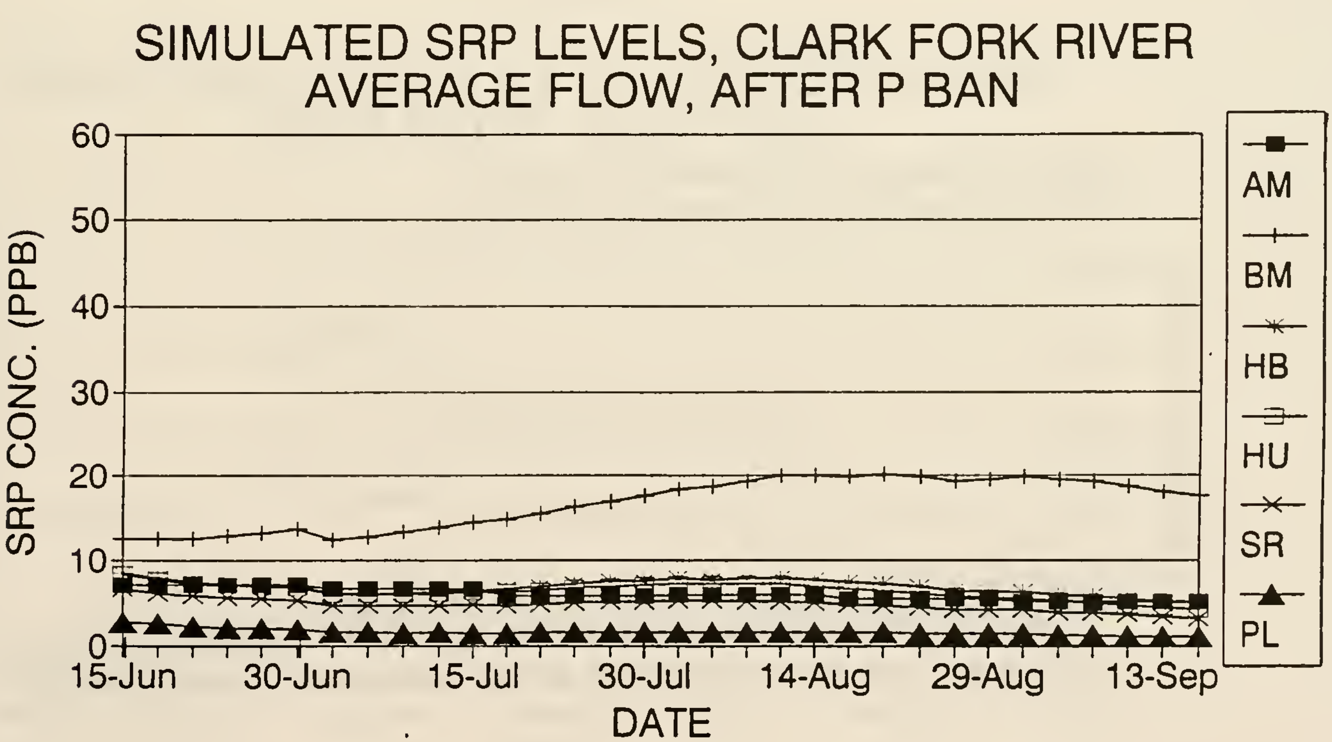


FIGURE 15

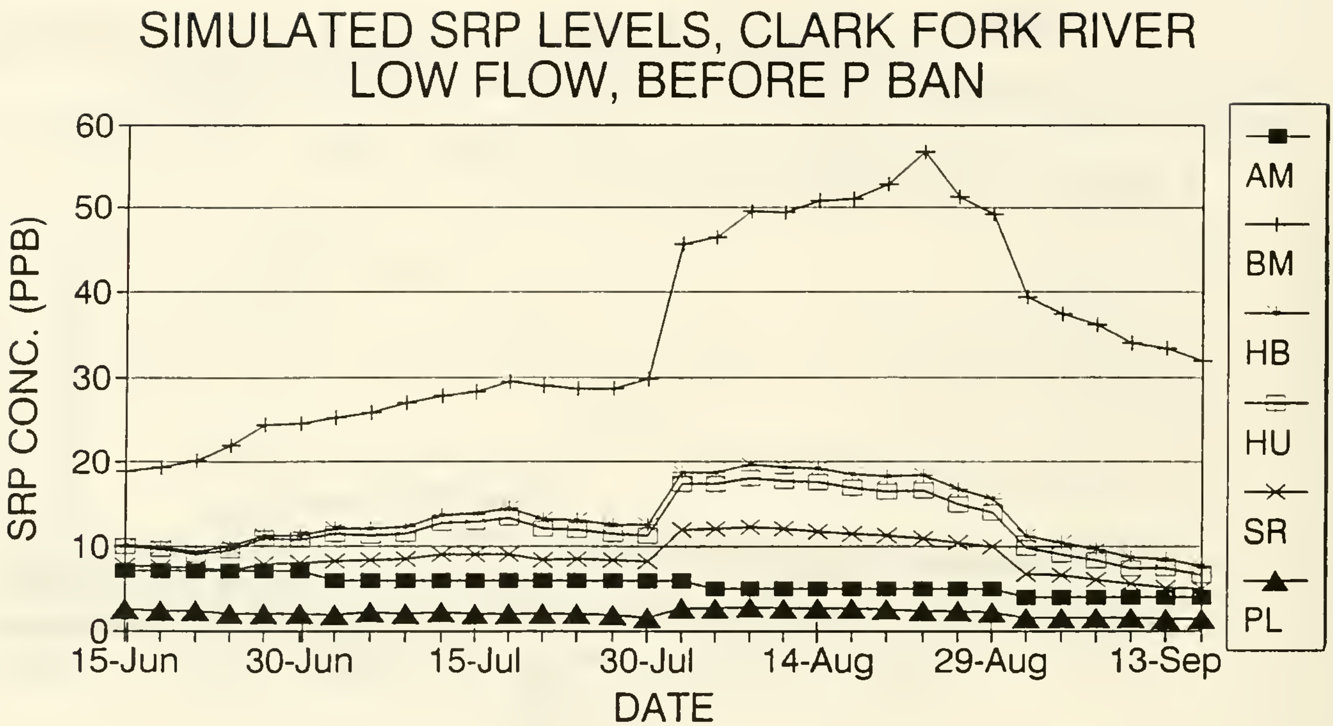


FIGURE 16

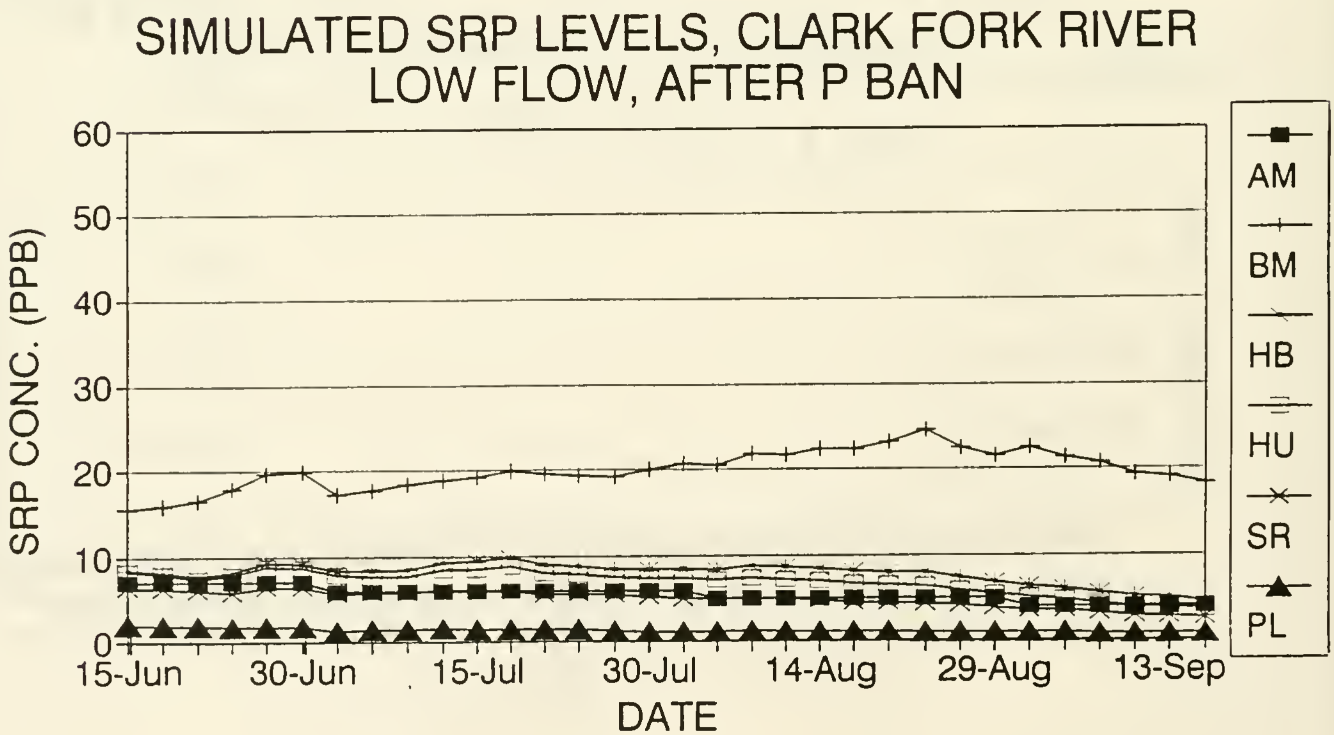
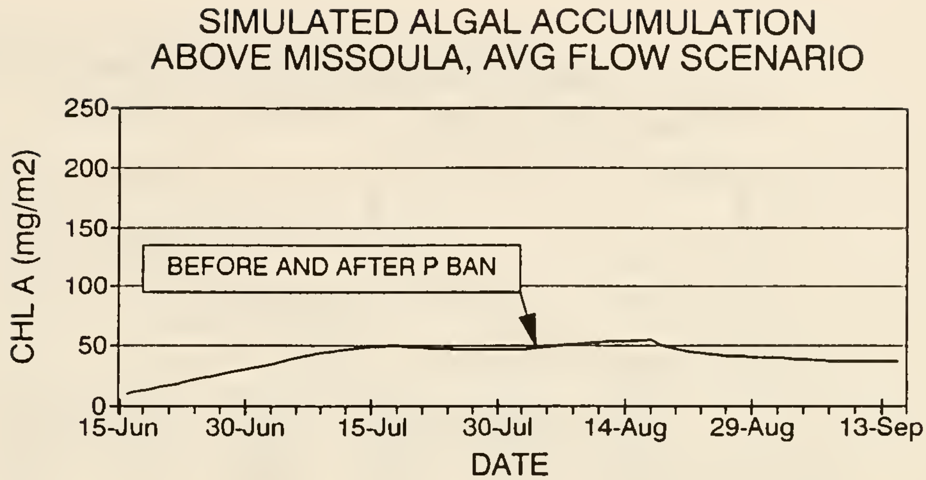


FIGURE 17


SIMULATED ALGAL ACCUMULATION
ABOVE MISSOULA, AVG FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE AND AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

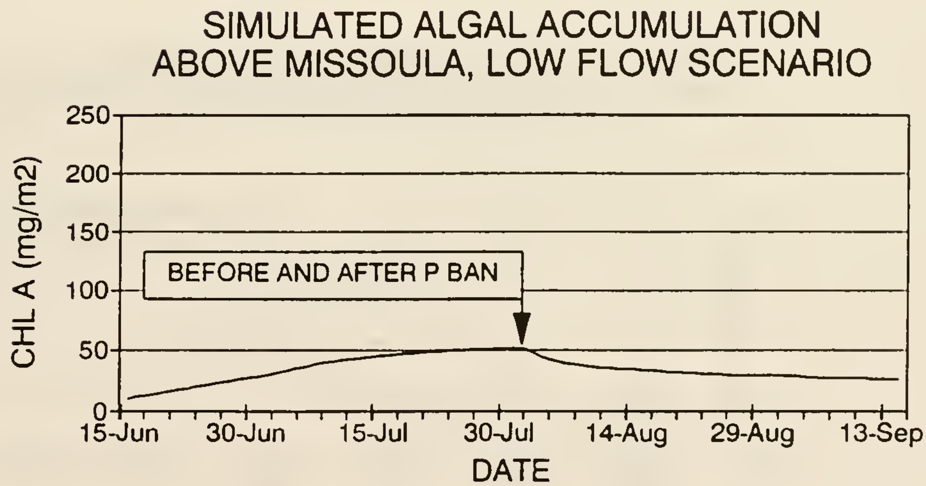
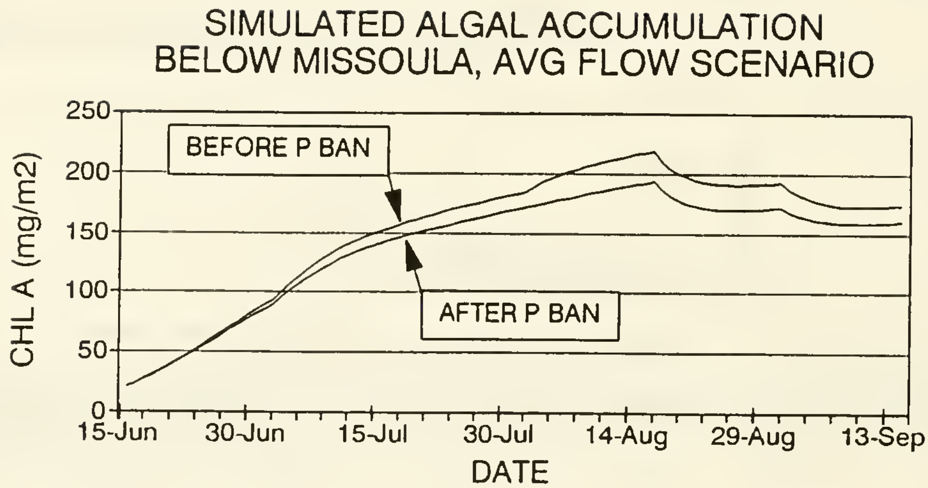
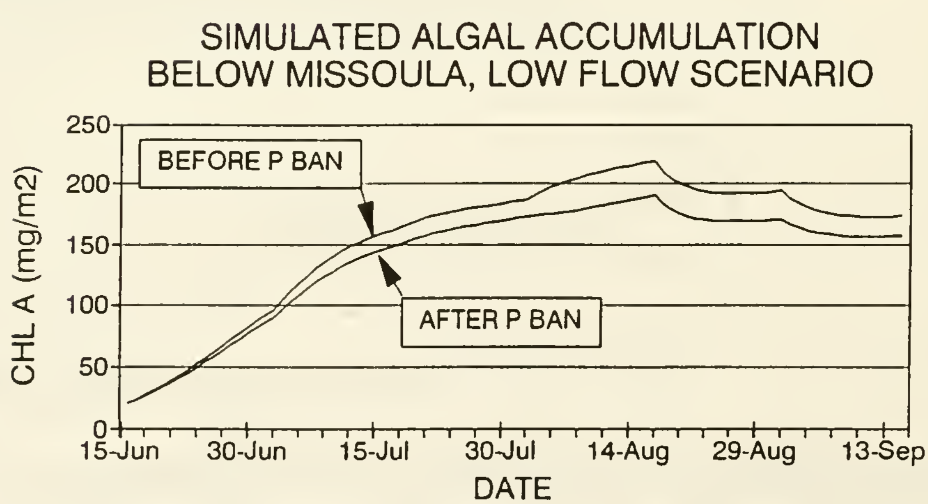

SIMULATED ALGAL ACCUMULATION
ABOVE MISSOULA, LOW FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE AND AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

FIGURE 18

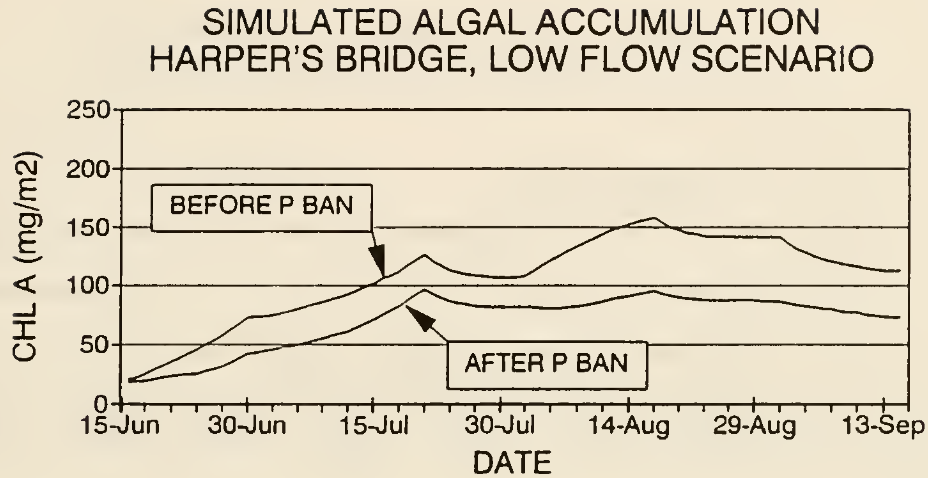


SIMULATED ALGAL ACCUMULATION
BELOW MISSOULA, AVG FLOW SCENARIO
250
200
150
100
50
0
CHL A (mg/m2)
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE



SIMULATED ALGAL ACCUMULATION
BELOW MISSOULA, LOW FLOW SCENARIO
250
200
150
100
50
0
CHL A (mg/m2)
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

FIGURE 19


SIMULATED ALGAL ACCUMULATION
HARPER'S BRIDGE, LOW FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

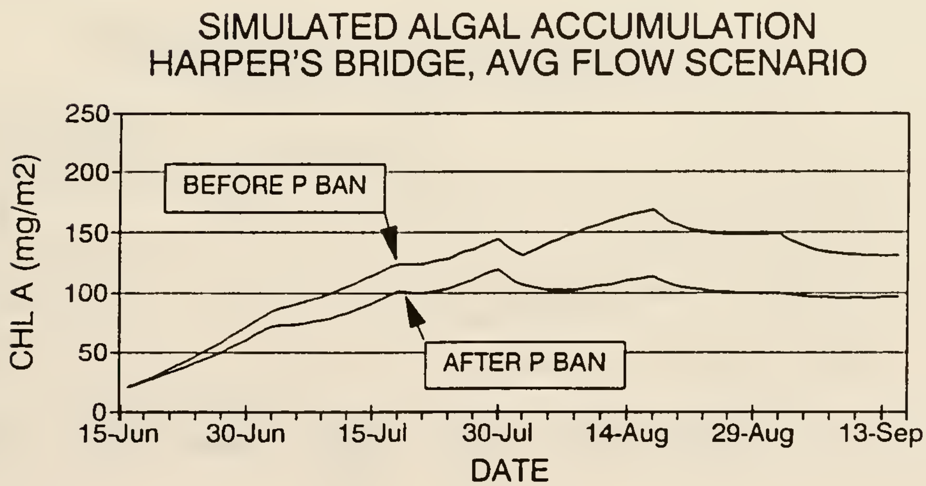
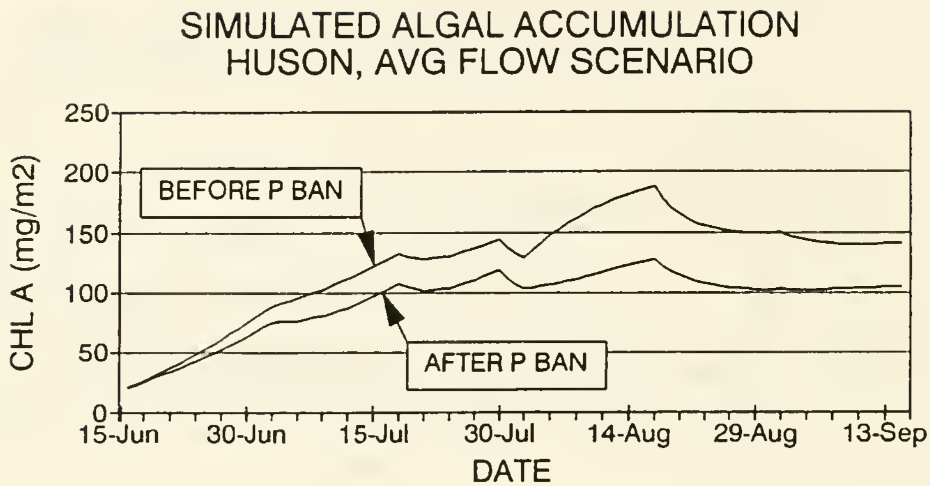
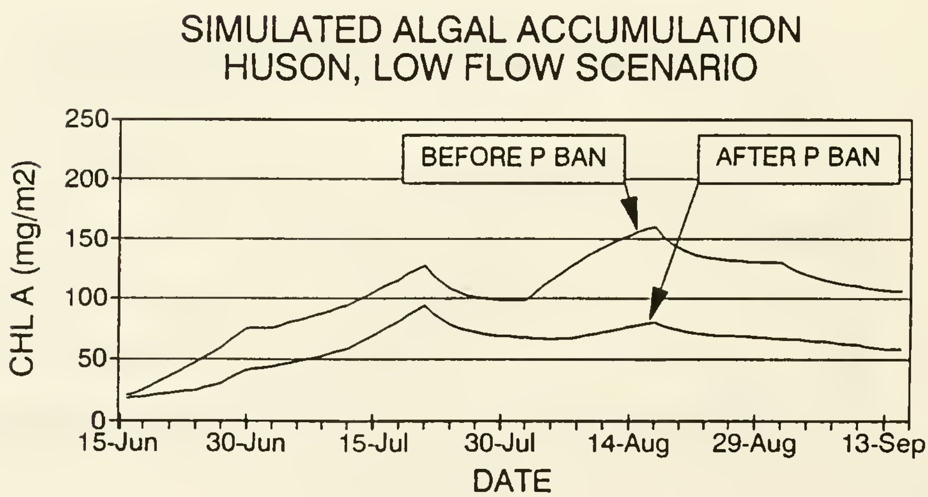

SIMULATED ALGAL ACCUMULATION
HARPER'S BRIDGE, AVG FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

FIGURE 20

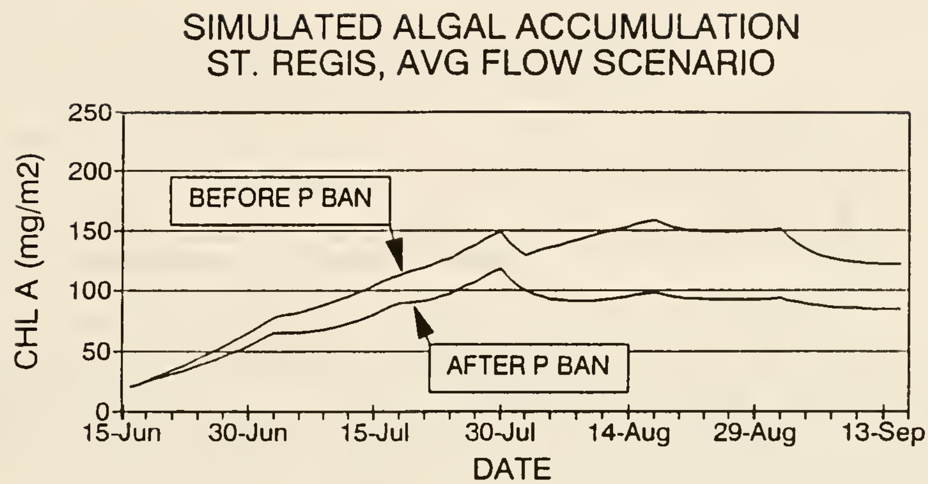


SIMULATED ALGAL ACCUMULATION
HUSON, AVG FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE



SIMULATED ALGAL ACCUMULATION
HUSON, LOW FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

FIGURE 21


SIMULATED ALGAL ACCUMULATION
ST. REGIS, AVG FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

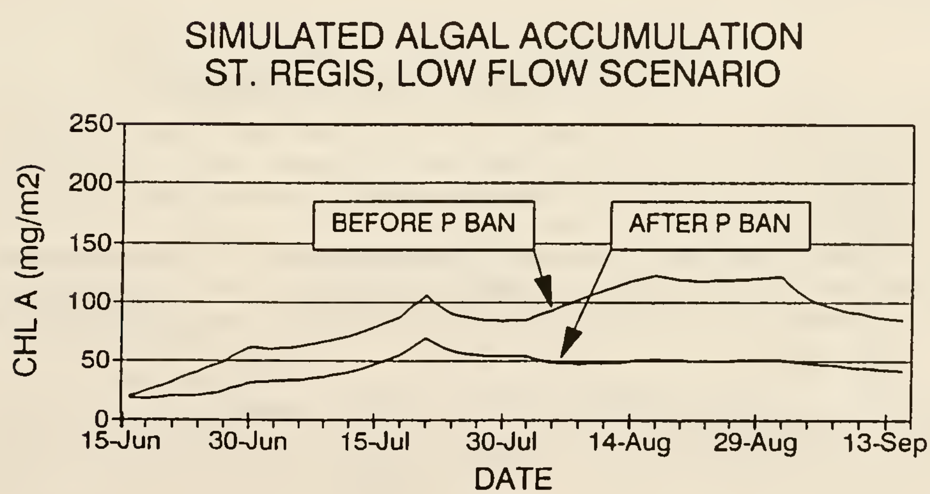
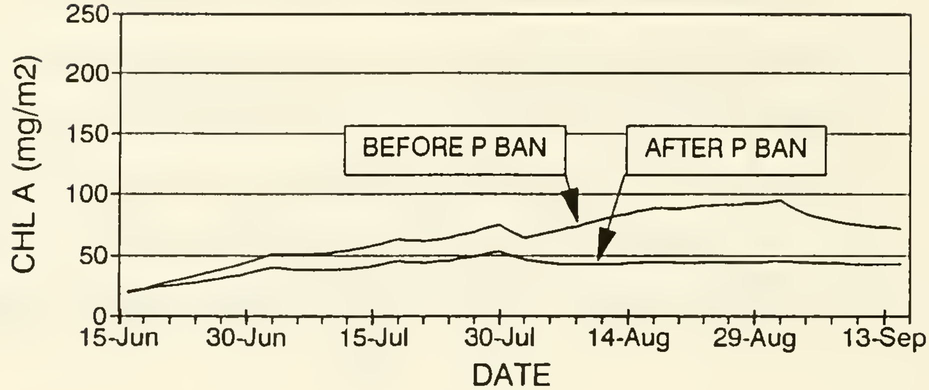
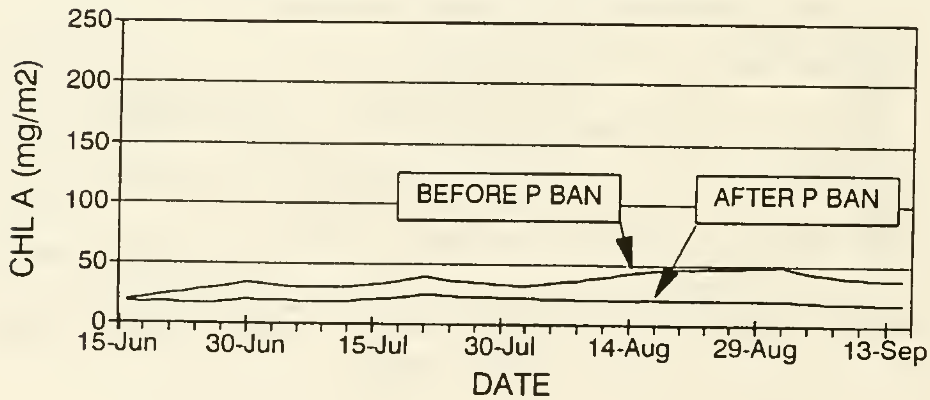

SIMULATED ALGAL ACCUMULATION
ST. REGIS, LOW FLOW SCENARIO
CHL A (mg/m2)
250
200
150
100
50
0
BEFORE P BAN
AFTER P BAN
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
DATE

FIGURE 22

SIMULATED ALGAL ACCUMULATION
PLAINS, AVG FLOW SCENARIO



SIMULATED ALGAL ACCUMULATION
PLAINS, LOW FLOW SCENARIO



APPENDIX N--NUTRIENT SAMPLING ON THE CLARK FORK RIVER, SUMMER 1990

METHODOLOGY

Between July 11 and October 2, 1990, water was sampled weekly at 12 sites on the upper and middle Clark Fork and bimonthly from 5 sites on the lower river (site locations in Table 1). Samples were not collected during the weeks when the Montana Water Quality Bureau was conducting its monthly sampling.

Sampling procedures followed EPA guidelines, including acid washing of all equipment that came in contact with samples. Immediately after collection, samples were filtered in the field through 0.45 um membrane filters. Samples were transported on ice to the lab (within 8 hours of collection) and then frozen until thawed by microwave just before analysis. Filtered samples were analyzed in the PI's lab at the University of Montana for soluble reactive phosphorus or SRP (EPA 365.2--colorimetric ascorbic acid) and for nitrate (EPA 353.3--colorimetric, manual cadmium reduction). Samples were analyzed for ammonia at the Freshwater Laboratory of the UM Yellow Bay Station.

The limit of quantification (or LOQ) of SRP is 2.5 ug/l +/- 10% or 10 ug/l +/- 5%. The LOQ of nitrate is 10 ug/l +/- 20% or 30 ug/l +/-5%. EPA QA samples were run with each batch of analyses and were always within 95% of their accepted values. Like the river samples, these EPA QA samples were frozen and thawed before analysis, indicating that this method of handling did not substantially alter the nutrient levels in the samples. Field blanks showed no measureable contamination.

Table 2 contains the summer nutrient sampling data, including that collected by WQB.

RESULTS

SRP--Figure 1N shows the maximum, minimum and median SRP values from July to October, 1990, at each site. The mainstem shows increases in SRP downstream of the Deer Lodge sewage lagoons, Gold Creek, Flint Creek and the Missoula sewage plant. Values at any one site vary 2 to 5 fold over time.

Figure 2N shows weekly SRP values at Warm Springs (WS) and Deer Lodge (DL). The wide ranging values at WS may have resulted from the reclamation work being done on the ponds and creek channel. The rise in SRP at DL on 8/21 and 8/28 occurred during high summer flows following heavy rains. On 8/21 the river at DL was extremely muddy (channel bottom could not be seen in 6 inces of water). Deer Lodge and the Bear Creek site (below Flint Creek and Drummond) were noticeably more muddy than other sites on 8/21. The river was somewhat clearer on 8/28, but the flow continued to be high.

Fig. 3N shows weekly SRP values at 5 upper river sites that were sampled by this project as well as by WQB. DL, Beavertail (BVT), and Turah (TU) all increased suddenly on 8/21, but sites above the Little Blackfoot (ALBF) and below Gold Creek (GC) did not. ALBF and GC decreased over time from the end of July to the end of September. This trend may be the result of some combination of algal depletion, changes in flow or in the Deer Lodge lagoon discharge.

Figure 4N provides a more detailed look at the stretch of river between the confluence with the Little Blackfoot and Rock Creek. This project sampled two additional sites not regularly sampled by WQB: between the Little Blackfoot and Gold Creek (BLBF) and near Bear Creek (BC) which is below Flint Creek. BLBF closely follows the trend at GC mentioned earlier. The slight increase in SRP from BLBF to GC shows the influence of Gold Creek when the creek's concentration exceeded 100 ug/l SRP and its flow was greater than 15 cfs. After 8/21 the Clark Fork's flow increases about 20% (USGS data) and Gold Creek flow decreases by 50% (J. Carey, unpubl. data). The SRP values at the BC and BVT sites were well above upstream sites after mid August. USGS data indicate that Flint Creek was high from late July to late August and may help explain these high SRP values.

Figure 5N shows flow and SRP over time at GC. Flows alone cannot explain the decrease in SRP levels over the summer at this site.

Figure 6N shows weekly SRP values at 5 middle river sites (ABVSTP, BELSTP, ABVMILL, BELMILL, and ALB). The first three sites downstream of the Missoula STP showed increases in SRP in mid August. The extremely high value (70 ppb) for the above the mill site seems unlikely, but an increase at these sites at that time was corroborated by the periphyton data. Before mid August algae were accumulating very slowly at all three sites. Then in mid August all three sites showed a dramatic increase in accumulation rates, followed by a decrease in algal standing crops when nutrient levels dropped the following week. Then the site below the STP exhibited rapid accumulation again as its nutrient levels remained high while the sites above and below the mill leveled off at more modest algae levels in keeping with their modest nutrient levels.

NITRATE--Figure 7N shows maximum, minimum and median values of nitrate from Warm Springs to Plains. Nitrate was generally at or below detection except at Deer Lodge, below Missoula STP, below the Bitterroot (ABVMILL) and below the mill (BELMILL). Figure 8N shows weekly nitrate at WS, DL, and ALBF. At Deer Lodge, nitrate levels are inversely related to flows (Figure 9N), supporting the hypothesis that most of this nitrate originates in groundwater. The two outliers are 8/21 and 8/28, the days of high, turbid flow.

Figure 10N shows nitrate levels in the middle river over the summer. Nitrate above Missoula's STP were at or below detection. Nitrate levels were much higher below the STP and were sometimes higher still at below the Bitterroot (ABVMILL). However, when ammonia values were added to nitrates, the site below the STP always had the highest soluble inorganic N levels (Figure 11N). The site below the mill showed considerable variation which was not detected by the WQB monthly sampling. The WQB sampling site below the mill is a bit farther downstream than the site used by this study.

TABLE 1. IDENTIFICATION OF SAMPLING SITES

SYMBOL	NAME		LOCATION
WS	Warm Springs	**	0.5 miles below Warm Springs Bridge
DL	Deer Lodge	**	Business I90 bridge, south of town
ALBF	Above Little Blackfoot	**	Three miles east of Garrison
BLBF	Below Little Blackfoot		One mile west of Pat's Place
GC	Gold Creek	**	USGS station below Gold Creek
DR	Drummond		Campground below railroad bridge
BC	Bear Creek		BLM access 3 miles upstream of bridge at Bear Creek
BVT	Beavertail	*	Beavertail campground (near WQB's Bonita site)
TU	Turah	*	Turah fishing access (WQB samples at bridge just downstream)
BF	Blackfoot River	*	0.5 miles above mouth (WQB site is USGS station 5.6 mi NE of Bonner)
ABVSTP or AM	Above Missoula STP	**	below Russell Street bridge
BELSTP or BM	Below Missoula STP	**	Shuffield site
ABVMILL or HB	Above pulp mill	*	At mill's bioassay shack (WQB site at Harper Bridge--HB)
BELMILL or HU	Below pulp mill	*	Ken Cyr's land at Huson (HU) (WQB site downstream of RR bridge)
ALB	Alberton	*	1 mile upstream of Petty Creek (WQB site just upstream of creek)
SU	Superior	**	Bridge in downtown Superior
AFH	Above Flathead River	*	3 miles downstream of St. Regis (WQB site at Hwy 200 bridge just above confluence)
FH	Flathead River	*	Flathead River near Hwy 200 mile 88 (WQB site near reservation boundary)
BFH or PL	Below Flathead River	*	Across river from Plains fairgrounds (WQB site above Thompson Falls Reservoir)

** Sample site same as WQB site
* Sample site near or in same river reach as WQB site, so expected to have similar water quality

TABLE 2. CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990

DATE	Site		Air T	H2O T	pH	SRP	NO3
07/11/90	WS		35	24	8.4	0.045	0.04
07/17/90	WS	WQB				0.053	0.03
07/24/90	WS		21.0	19.0	8.1	0.058	0.02
08/01/90	WS		20.0	18.0	7.6	0.040	0.01
08/06/90	WS	WQB				0.030	0.01
08/14/90	WS		30.0	22.5	7.8	0.092	0.02
08/21/90	WS		18.0	16.5	8.5	0.067	0.01
08/28/90	WS		19.0	15.0	9.0	0.019	< 0.01
09/06/90	WS		25.0	18.0	9.0	0.044	< 0.01
09/12/90	WS	WQB				0.040	0.01
09/17/90	WS		16.5	15.0	8.6	0.043	< 0.01
10/02/90	WS		9.5	11.0	8.45	0.044	0.02
07/11/90	DL		31	22	7.8	0.015	0.03
07/18/90	DL	WQB				0.005	0.10
07/24/90	DL		21.5	17.5	7.9	0.013	0.11
08/01/90	DL		28.0	17.0	6.3	0.008	0.13
08/07/90	DL	WQB				0.006	0.12
08/14/90	DL		30.0	20.0	7.6	0.006	0.08
08/21/90	DL		20.0	16.0	8.2	0.019	0.09
08/28/90	DL		23.0	14.0	8.2	0.022	0.06
09/06/90	DL		26.0	16.5	8.4	0.008	0.04
09/11/90	DL	WQB				0.003	0.04
09/17/90	DL		21.0	14.0	8.4	0.003	0.05
10/02/90	DL		9.5	10.0	8.2	0.004	0.15
07/11/90	ALBF		33	23	7.7	0.050	< 0.01
07/18/90	ALBF	WQB				0.068	0.03
07/24/90	ALBF		20.0	15.0	8.3	0.060	< 0.01
08/01/90	ALBF		18.0	15.0	7.2	0.052	< 0.01
08/07/90	ALBF	WQB				0.047	< 0.005
08/14/90	ALBF		27.0	19.0	7.8	0.045	< 0.01
08/21/90	ALBF		17.0	14.0	8.5	0.034	0.03
08/28/90	ALBF		15.0	13.0	8.2	0.024	< 0.01
09/06/90	ALBF		23.0	15.0	8.2	0.019	< 0.01
09/11/90	ALBF	WQB				0.012	< 0.005
09/17/90	ALBF		15.0	12.0	8.0	0.013	< 0.01
10/02/90	ALBF		7.0	9.5	8.5	0.014	< 0.01

TABLE 2. CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990 (cont)

DATE	Site		Air T	H2O T	pH	SRP	NO3
07/11/90	BLBF		33	23	7.75	0.033	< 0.01
07/24/90	BLBF		22.0	18.0	8.1	0.034	< 0.01
08/01/90	BLBF		27.0	18.0	8.1	0.030	< 0.01
08/14/90	BLBF		32.0	21.0	7.7	0.024	< 0.01
08/21/90	BLBF		20.0	16.5	8.5	0.024	0.01
08/28/90	BLBF		23.0	16.5	8.5	0.020	< 0.01
09/06/90	BLBF		28.0	18.0	8.50	0.017	< 0.01
09/17/90	BLBF		19.0	15.0	8.6	0.014	< 0.01
10/02/90	BLBF		7.0	9.5	8.5	0.014	< 0.01
07/11/90	GC		35	23	7.65	0.031	< 0.01
07/18/90	GC	WQB				0.034	< 0.01
07/24/90	GC		22.5	18.5	8.0	0.037	< 0.01
08/01/90	GC		27.0	19.0	7.7	0.032	< 0.01
08/07/90	GC	WQB				0.029	< 0.01
08/14/90	GC		33.0	21.0	8.1	0.026	< 0.01
08/21/90	GC		21.5	17.0	8.6	0.026	< 0.01
08/28/90	GC		23.0	17.5	8.7	0.020	< 0.01
09/06/90	GC		27.0	19.0	8.70	0.018	< 0.01
09/12/90	GC	WQB				0.011	0.03
09/17/90	GC		19.5	16.0	8.8	0.013	< 0.01
10/02/90	GC		9.0	9.5	8.6	0.014	< 0.01
07/11/90	DR		34	23	7.5	0.038	< 0.01
10/02/90	DR		7.5	9.5	8.5	0.021	< 0.01
07/24/90	BC		23.0	19.0	8.1	0.037	< 0.01
08/01/90	BC		31.0	21.0	7.6	0.037	< 0.01
08/14/90	BC		37.0	24.0	8.0	0.043	< 0.01
08/21/90	BC		26.0	17.5	8.5	0.046	< 0.01
08/28/90	BC		28.0	18.5	8.6	0.043	< 0.01
09/06/90	BC		29.0	19.5	8.60	0.030	< 0.01
09/17/90	BC		23.0	17.0	8.8	0.021	< 0.01
10/02/90	BC		10.5	9.8	8.55	0.016	< 0.01

TABLE 2. CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990 (cont)

DATE	Site		Air T	H2O T	pH	SRP		NO3
07/11/90	BVT		34	24	7.6	0.024	<	0.01
07/17/90	BONITA	WQB				0.016	<	0.01
07/24/90	BVT		22.0	19.0	8.3	0.020	<	0.01
08/01/90	BVT		29.0	21.5	7.9	0.017	<	0.01
08/05/90	BONITA	WQB				0.009	<	0.01
08/14/90	BVT		28.0	18.0	7.4	0.007	<	0.01
08/21/90	BVT		23.0	18.0	8.5	0.039		0.02
08/28/90	BVT		25.0	19.0	8.5	0.032	<	0.01
09/06/90	BVT		29.0	20.0	8.70	0.022	<	0.01
09/10/90	BONITA	WQB				0.016	<	0.01
09/17/90	BVT		21.0	17.0	8.8	0.009	<	0.01
10/02/90	BVT		10.5	11.5	8.55	0.007	<	0.01
07/11/90	TU		34	22.5	7.6	0.011	<	0.01
07/17/90	TU	WQB				0.006	<	0.01
07/24/90	TU		18.0	17.0	8.1	0.005	<	0.01
08/01/90	TU		31.0	20.0	7.7	0.008	<	0.01
08/14/90	TU		38.0	24.0	8.3	0.005	<	0.01
08/05/90	TU	WQB				0.006		0.03
08/21/90	TU		21.0	18.0	8.5	0.009		0.02
08/28/90	TU		28.0	18.0	8.6	0.016	<	0.01
09/06/90	TU		31.0	19.5	8.70	0.010	<	0.01
09/10/90	TU	WQB				0.007	<	0.01
09/17/90	TU		20.0	16.0	8.8	0.005		0.02
10/02/90	TU		10.0	11.0	8.7	0.004	<	0.01
07/12/90	BF		34	21	7.9	0.002	<	0.01
07/17/90	BF	WQB				0.002	<	0.01
07/24/90	BF		18.0	17.0	8.1	0.010	<	0.01
08/01/90	BF		31.0	19.0	7.6	0.002	<	0.01
08/05/90	BF	WQB				0.002		0.01
08/14/90	BF		37.0	22.0	7.8	0.003		0.01
08/21/90	BF		23.0	17.0	8.6	0.036		0.02
08/28/90	BF		29.0	17.5	8.6	0.002	<	0.01
09/06/90	BF		32.5	19.5	8.60	0.005	<	0.01
09/10/90	BF	WQB				0.001	<	0.01
09/17/90	BF		19.5	15.0	8.7	0.002	<	0.01
10/02/90	BF		10.0	9.0	8.6	0.001	<	0.01

TABLE 2. CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990 (cont)

DATE	Site		Air T	H2O T	pH	SRP	NO3
07/12/90	ABVSTP			20	7.8	0.009	< 0.01
07/17/90	ABVSTP	WQB				0.006	< 0.01
07/26/90	ABVSTP		19.0	17.0	7.4	0.004	< 0.01
07/31/90	ABVSTP		21.0	20.0	7.7	0.006	< 0.01
08/05/90	ABVSTP	WQB				0.006	< 0.01
08/16/90	ABVSTP		33.0	23.0	7.7	0.008	0.01
08/23/90	ABVSTP		21.0	17.0	8.5	0.005	0.01
08/30/90	ABVSTP		23.0	17.0	8.5	0.006	< 0.01
09/06/90	ABVSTP			20.0	8.50	0.010	< 0.01
09/10/90	ABVSTP	WQB				0.004	< 0.01
09/21/90	ABVSTP		10.5	13.5	8.7	0.003	< 0.01
09/28/90	ABVSTP			15.0		0.003	< 0.01
07/12/90	BELSTP			20.5	7.7	0.015	0.05
07/17/90	BELSTP	WQB				0.015	0.05
07/26/90	BELSTP		15.0	16.0	7.6	0.023	0.04
07/31/90	BELSTP		23.0	21.0	7.7	0.024	0.04
08/05/90	BELSTP	WQB				0.012	0.04
08/16/90	BELSTP		35.0	22.0	7.8	0.031	0.05
08/23/90	BELSTP		21.0	18.0	8.4	0.026	0.03
08/30/90	BELSTP		18.0	17.0	8.4	0.019	0.02
09/06/90	BELSTP			19.0	8.65	0.030	0.03
09/10/90	BELSTP	WQB				0.025	0.09
09/21/90	BELSTP		15.0	14.0	8.7	0.028	0.07
09/28/90	BELSTP			16.0	8.2	0.033	0.05
07/12/90	ABVMILL		31		8	0.008	0.02
07/17/90	ABVMILL	WQB				0.006	0.02
07/26/90	ABVMILL		17.0	17.0	7.3	0.010	0.03
07/31/90	ABVMILL		23.0	21.0	7.6	0.008	0.05
08/05/90	ABVMILL	WQB				0.006	0.05
08/16/90	ABVMILL		31.0	22.0	7.6	0.073	0.05
08/23/90	ABVMILL		26.0	17.0	8.5	0.011	0.05
08/30/90	ABVMILL		24.0	16.0	7.6	0.005	0.04
09/06/90	ABVMILL			18.5	8.40	0.006	0.03
09/10/90	ABVMILL	WQB				0.005	0.02
09/21/90	ABVMILL		19.0	14.0	8.2	0.006	0.04
09/28/90	ABVMILL			13.5	7.9	0.010	0.03
07/13/90	BELMILL			22	7.9	0.005	< 0.01
07/17/90	BELMILL	WQB				0.006	< 0.005
07/26/90	BELMILL		16.0	16.0	6.4	0.010	0.07
07/31/90	BELMILL		25.0	20.5	7.6	0.015	0.04
08/06/90	BELMILL	WQB				0.005	0.01
08/16/90	BELMILL		35.0	22.0	7.6	0.028	0.03
08/23/90	BELMILL		25.0	17.0	8.5	0.014	0.05
08/30/90	BELMILL		18.0	12.0	12.0	0.010	0.03
09/06/90	BELMILL			19.5	8.60	0.007	< 0.01
09/10/90	BELMILL	WQB				0.007	< 0.005
09/21/90	BELMILL		22.0	15.5	8.7	0.007	0.02
09/28/90	BELMILL			15.0	?	0.008	0.02

TABLE 2. CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990 (cont)

DATE	Site		Air T	H2O T	pH	SRP	NO3
07/13/90	ALB		37.5	21	7.9	0.008	< 0.01
07/17/90	ALB	WQB				0.005	< 0.01
07/31/90	ALB		29.0	21.5	7.4	0.012	0.03
08/06/90	ALB	WQB				0.006	0.01
08/23/90	ALB		25.0	18.0	7.5	0.011	0.05
09/06/90	ALB			20.5	8.40	0.007	< 0.01
09/10/90	ALB	WQB				0.007	< 0.01
09/21/90	ALB		26.5	16.0	8.7	0.006	< 0.01
09/28/90	ALB			15.0	8	0.008	< 0.01
07/13/90	SU		35	23	7.9	0.006	< 0.01
07/18/90	SU	WQB				0.003	< 0.01
07/31/90	SU		19.5	20.5	7.7	0.014	< 0.01
08/06/90	SU	WQB				0.005	< 0.01
08/23/90	SU		26.0	17.0	7.5	0.024	0.05
09/10/90	SU	WQB				0.005	< 0.01
09/21/90	SU		26.0	16.5	8.8	0.006	< 0.01
07/13/90	AFH		35	22	7.6	0.005	< 0.01
07/18/90	AFH	WQB				0.003	< 0.01
07/31/90	AFH		22.5	20.5	7.4	0.005	0.01
08/07/90	AFH	WQB				0.006	< 0.01
08/23/90	AFH		22.0	20.0	7.1	0.005	< 0.01
09/11/90	AFH	WQB				0.003	< 0.01
09/21/90	AFH		26.0	15.5	8.7	0.004	0.02
07/13/90	FH		35	25	7.8	0.005	< 0.01
07/18/90	FH	WQB				< 0.001	< 0.01
07/31/90	FH		20.0	21.0	7.4	0.032	< 0.01
08/08/90	FH	WQB				0.002	< 0.01
08/23/90	FH		22.0	19.5	7.5	0.004	< 0.01
09/11/90	FH	WQB				0.001	< 0.01
09/21/90	FH		26.0	19.0	8.9	0.002	0.02
07/13/90	BFH		32	25	7.6	0.002	0.01
07/18/90	BFH	WQB				0.007	< 0.01
07/31/90	BFH		19.5	21.5	7.3	0.002	< 0.01
08/08/90	BFH	WQB				0.007	< 0.01
08/23/90	BFH		21.5	20.0	7.2	0.006	0.01
09/11/90	BFH	WQB				0.009	< 0.01
09/21/90	BFH		26	18	8.7	0.002	0.02

SITES IDENTIFIED IN TABLE 1

AIR T = AIR TEMPERATURE, H2O T = WATER TEMPERATURE, BOTH IN DE
SRP = SOLUBLE REACTIVE PHOSPHORUS IN ppb
NO3 = NITRATES AND NITRITES IN ppb

WQB = MONTANA WATER QUALITY BUREAU

CLARK FORK RIVER NUTRIENT DATA, SUMMER 1990

LIST OF FIGURES IN APPENDIX N

NUTRIENT LEVELS IN THE CLARK FORK RIVER, JULY-OCTOBER, 1990
SOLUBLE REACTIVE PHOSPHORUS (SRP)
NITRATES & NITRITES (NO3)

FIG 1N. MAXIMUM, MINIMUM, MEDIAN SRP, ALL SITES

FIG 2N. WEEKLY SRP VALUES AT WARM SPRINGS AND DEER LODGE

FIG 3N. WEEKLY SRP VALUES AT 5 UPPER RIVER SITES

FIG 4N. WEEKLY SRP VALUES AT 4 UPPER RIVER SITES, INCLUDING 2 NOT SAMPLED BY THE WATER QUALITY BUREAU

FIG 5N. WEEKLY FLOW AND SRP AT GOLD CREEK

FIG 6N. WEEKLY SRP IN MIDDLE RIVER

FIG 7N. MAXIMUM, MINIMUM, MEDIAN NO3 ALL SITES

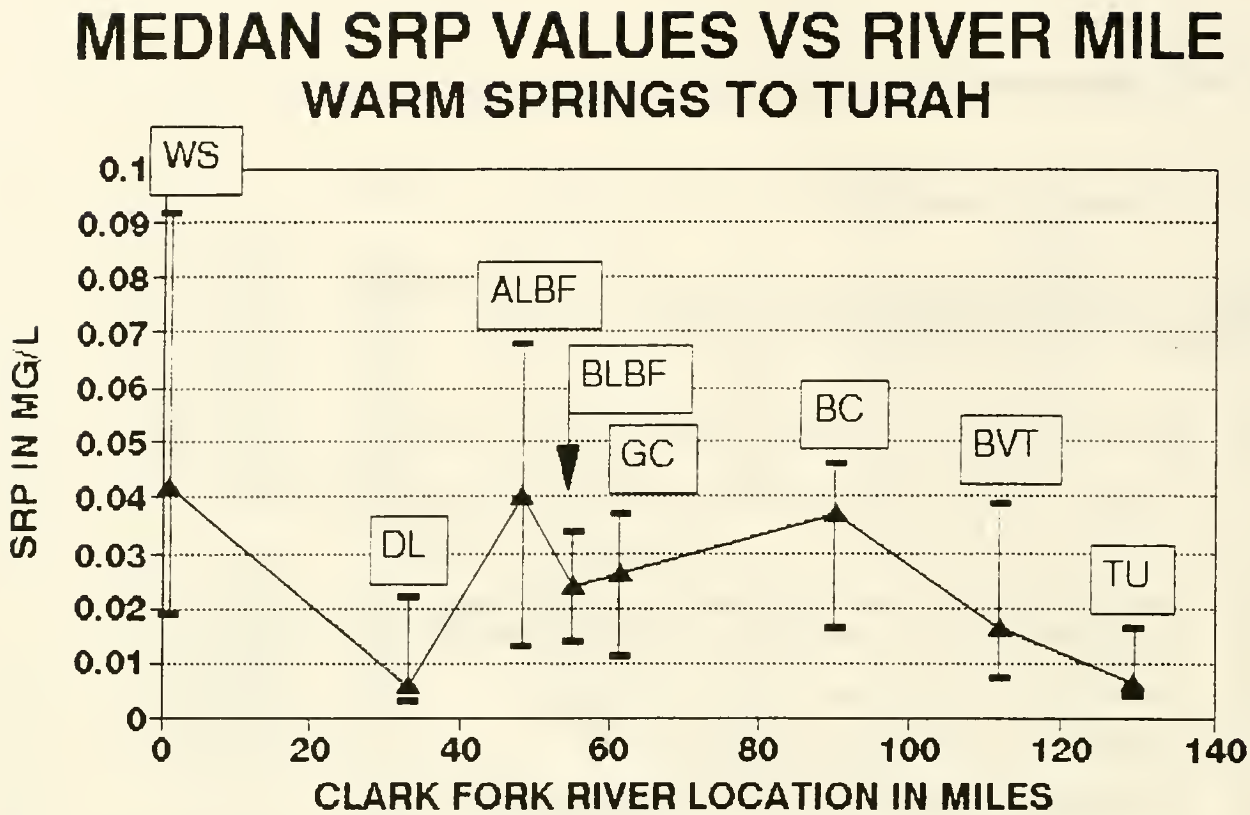
FIG 8N. WEEKLY NO3 LEVELS, WARM SPRINGS TO ABOVE LITTLE BLACKFOOT

FIG 9N. WEEKLY FLOWS AND NO3 AT DEER LODGE

FIG 10N. WEEKLY NO3 IN MIDDLE RIVER

FIG 11N. WEEKLY SOLUBLE INORGANIC NITROGEN (SIN), MIDDLE RIVER (SIN = NITRATES, NITRITES AND AMMONIA)

SITES IDENTIFIED ON TABLE 1.


MEDIAN SRP VALUES VS RIVER MILE
WARM SPRINGS TO TURAH
WS
ALBF
BLBF
GC
BC
BVT
DL
TU
SRP IN MG/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
140
CLARK FORK RIVER LOCATION IN MILES

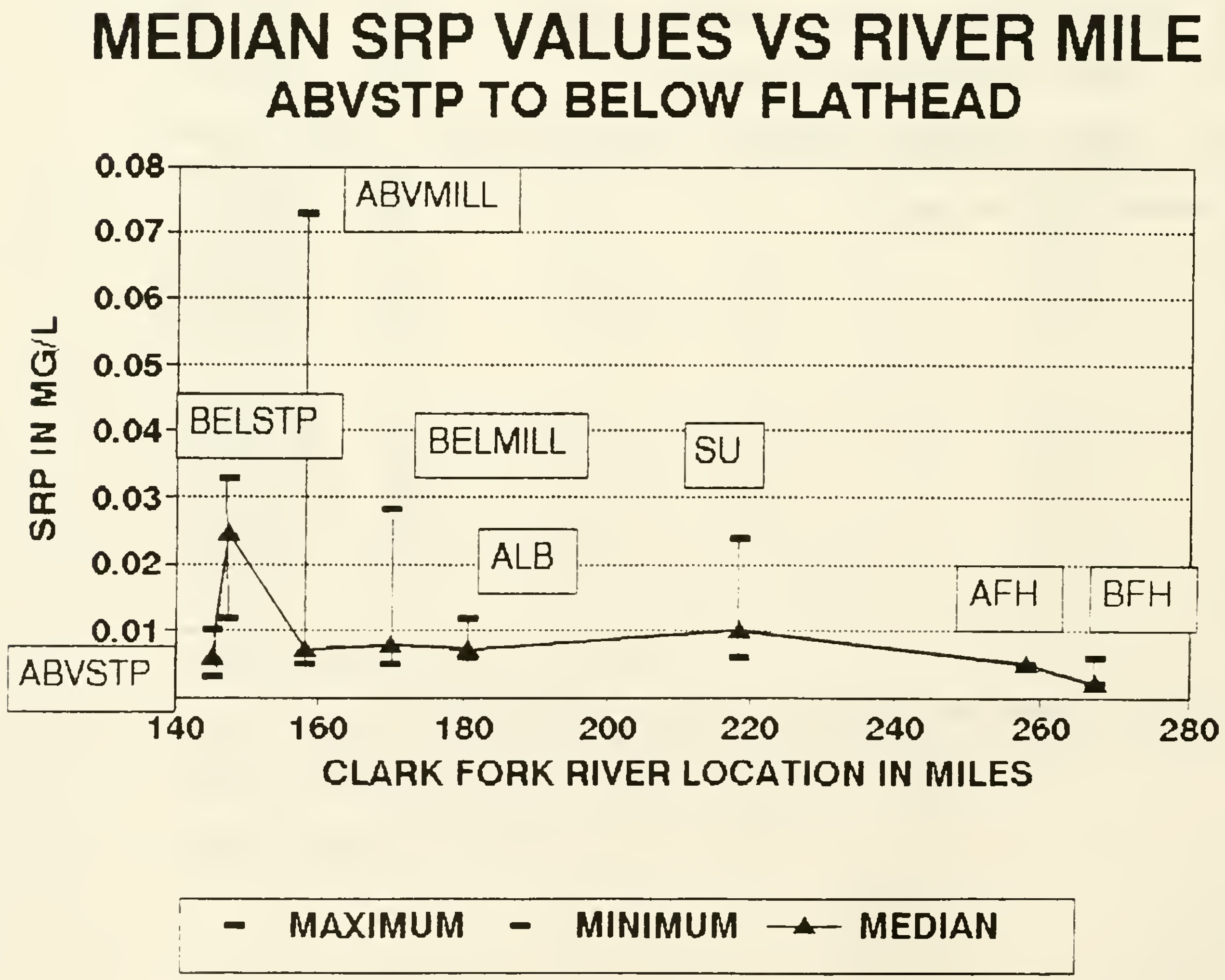

MEDIAN SRP VALUES VS RIVER MILE
ABVSTP TO BELOW FLATHEAD
ABVMILL
BELSTP
BELMILL
SU
ALB
AFH
BFH
ABVSTP
SRP IN MG/L
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
140
160
180
200
220
240
260
280
CLARK FORK RIVER LOCATION IN MILES
MAXIMUM
MINIMUM
MEDIAN

Figure 1N

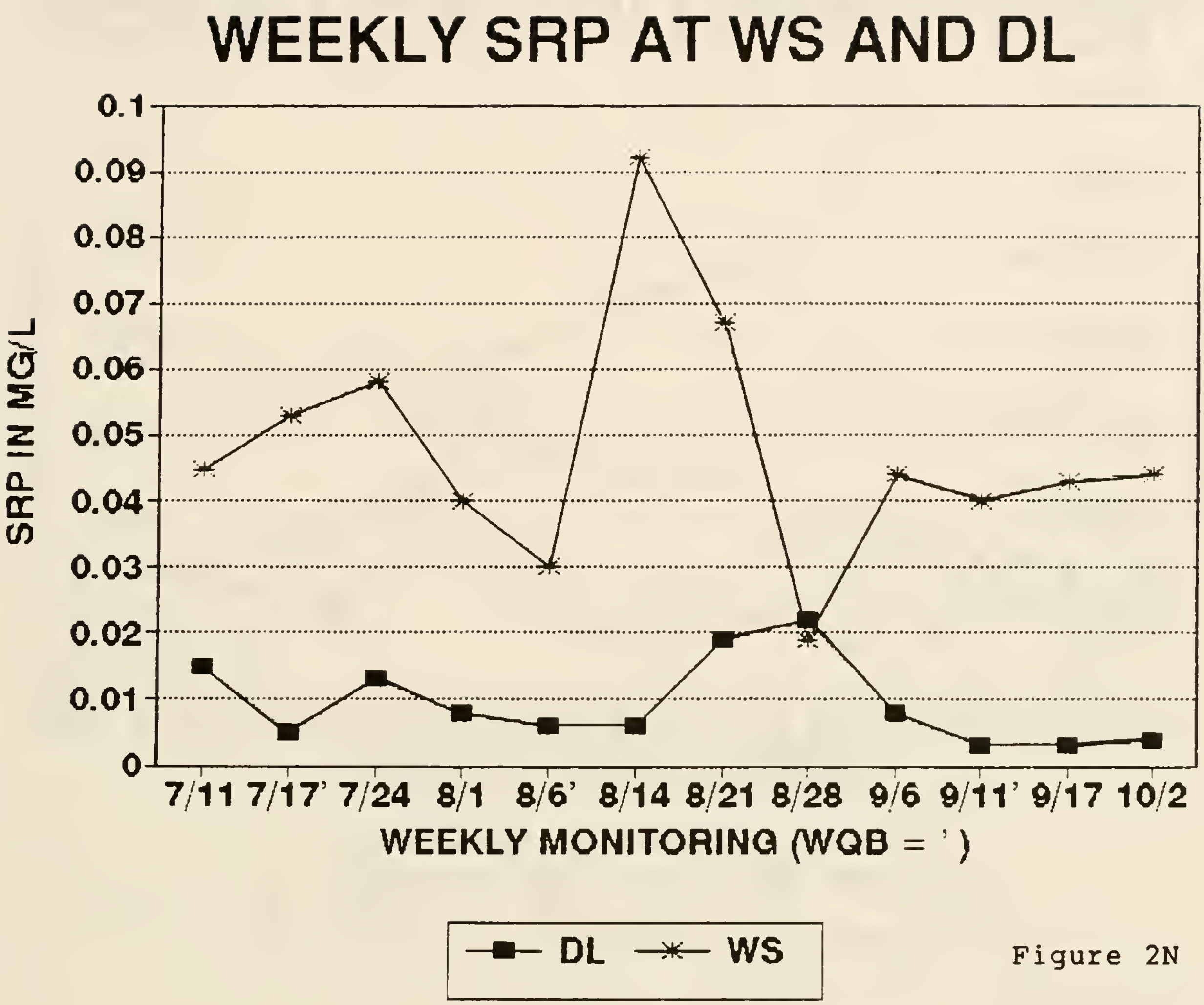

WEEKLY SRP AT WS AND DL
SRP IN MG/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
7/11 7/17' 7/24 8/1 8/6' 8/14 8/21 8/28 9/6 9/11' 9/17 10/2
WEEKLY MONITORING (WQB = ')
DL
WS

Figure 2N

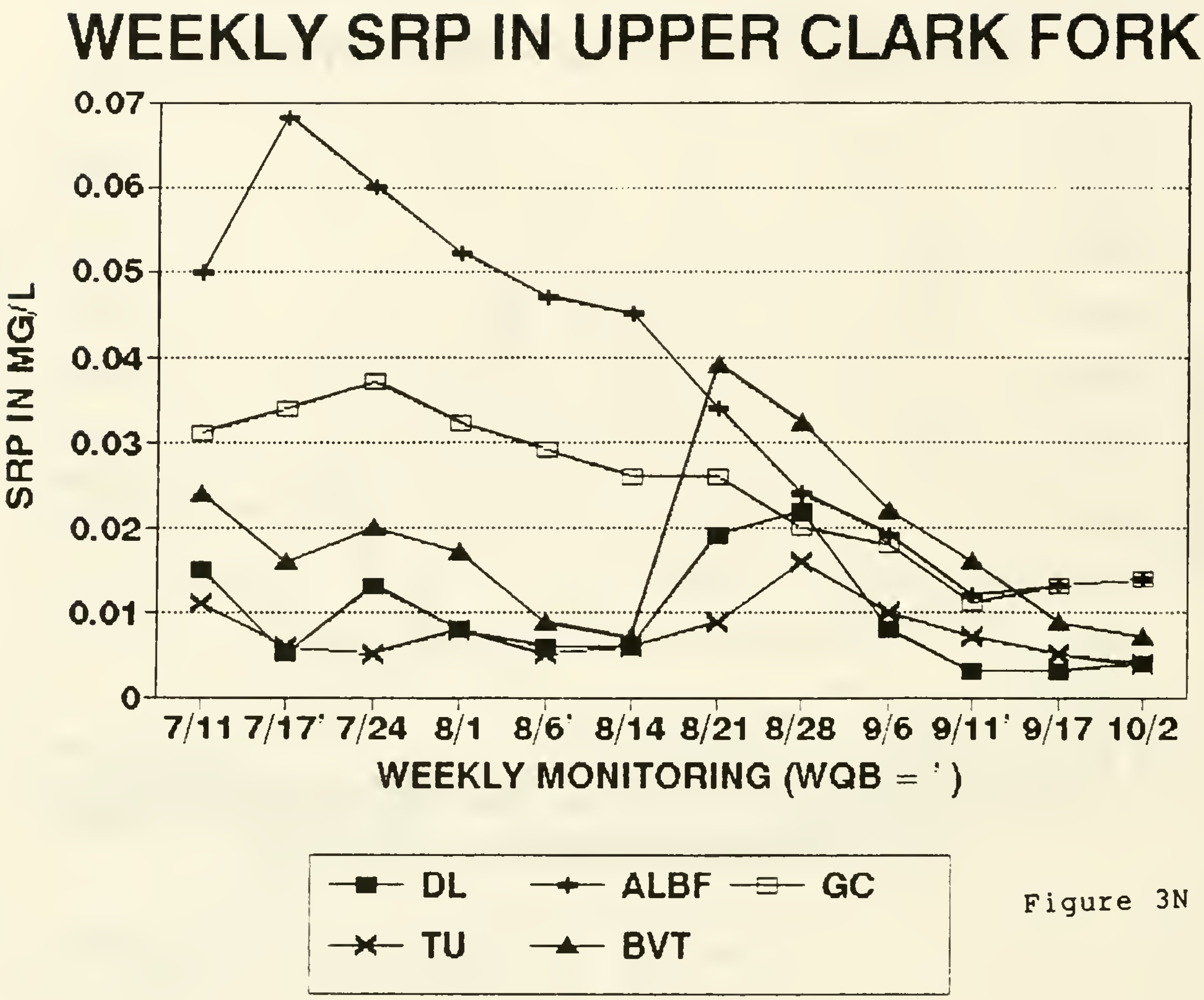

WEEKLY SRP IN UPPER CLARK FORK
SRP IN MG/L
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
7/11 7/17' 7/24 8/1 8/6' 8/14 8/21 8/28 9/6 9/11' 9/17 10/2
WEEKLY MONITORING (WQB = ')
DL
ALBF
GC
TU
BVT

Figure 3N

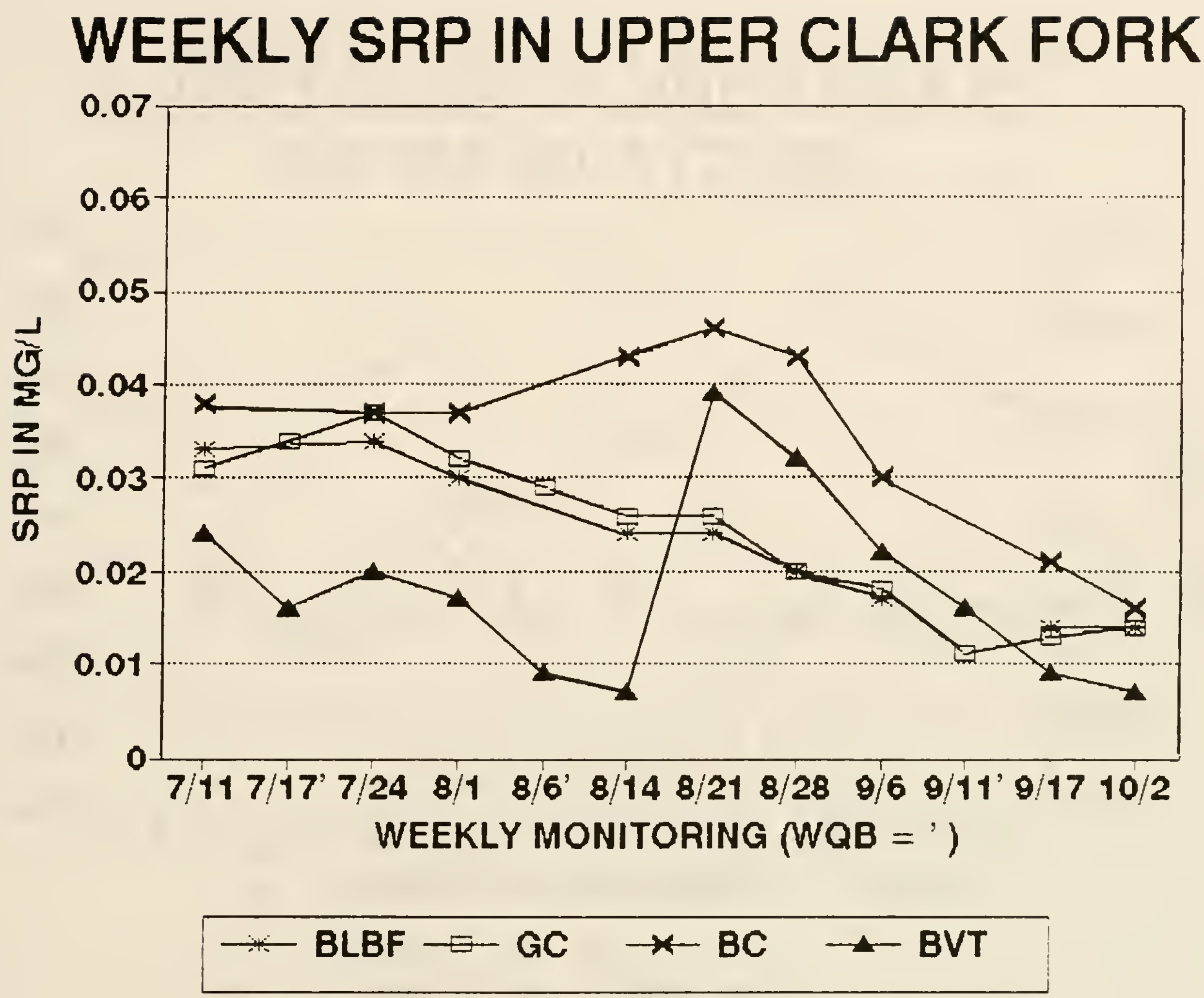

WEEKLY SRP IN UPPER CLARK FORK
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SRP IN MG/L
7/11 7/17' 7/24 8/1 8/6' 8/14 8/21 8/28 9/6 9/11' 9/17 10/2
WEEKLY MONITORING (WQB = ')
BLBF
GC
BC
BVT

Figure 4N

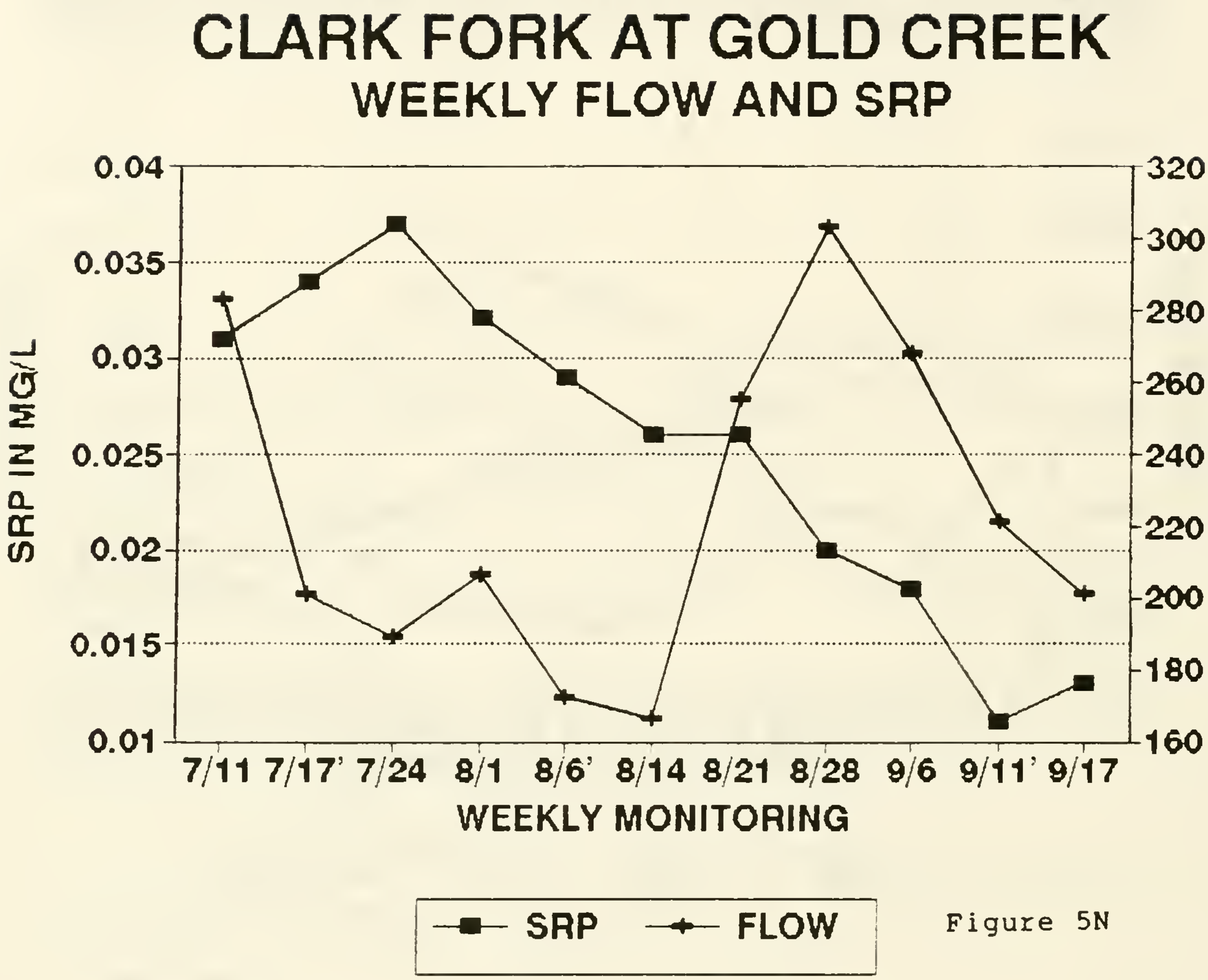

CLARK FORK AT GOLD CREEK
WEEKLY FLOW AND SRP
SRP IN MG/L
FLOW IN CFS
0.04
0.035
0.03
0.025
0.02
0.015
0.01
320
300
280
260
240
220
200
180
160
7/11 7/17 7/24 8/1 8/6 8/14 8/21 8/28 9/6 9/11 9/17
WEEKLY MONITORING
SRP
FLOW

Figure 5N

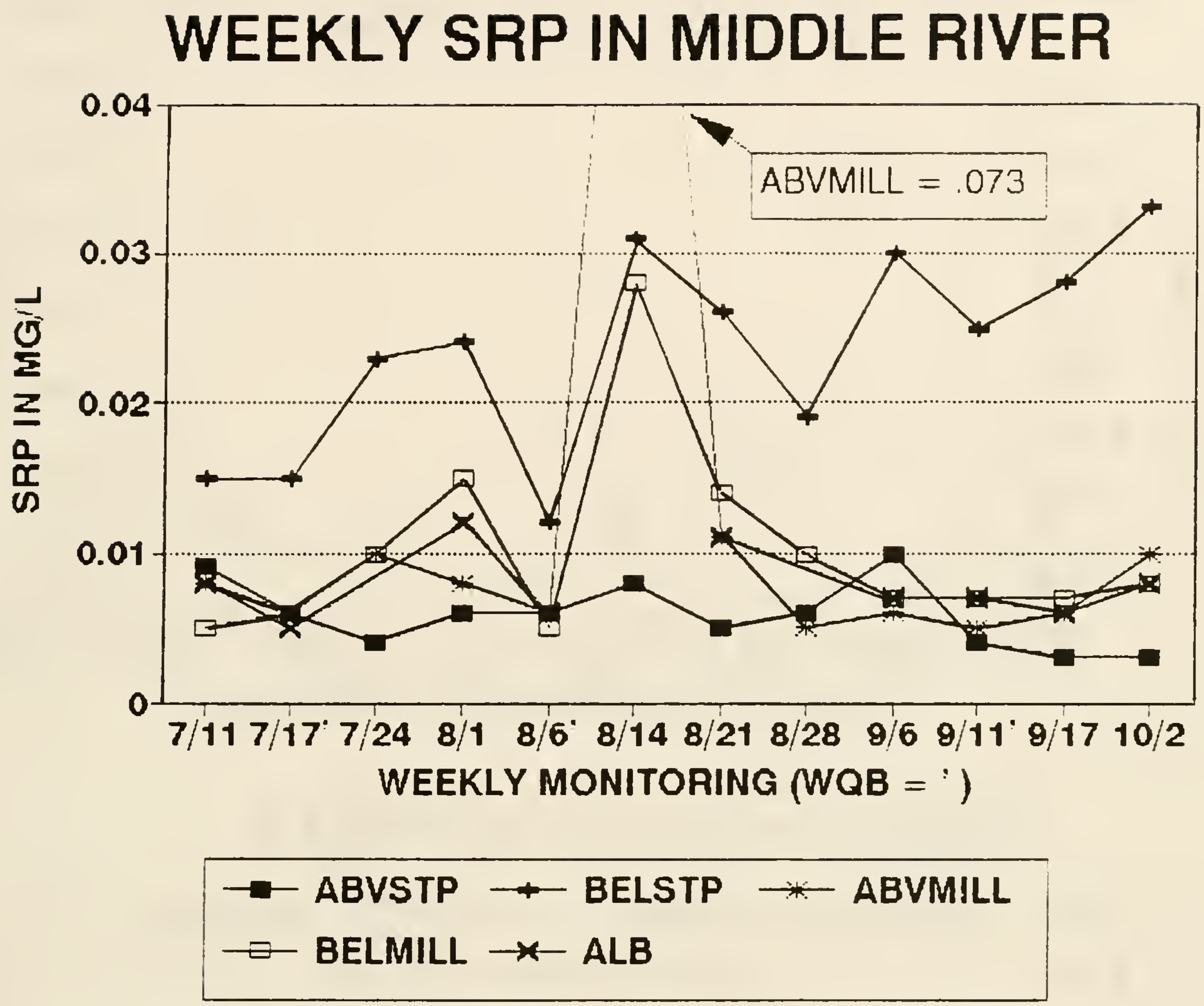

WEEKLY SRP IN MIDDLE RIVER
0.04
0.03
0.02
0.01
0
SRP IN MG/L
ABVMILL = .073
7/11 7/17' 7/24 8/1 8/6' 8/14 8/21 8/28 9/6 9/11' 9/17 10/2
WEEKLY MONITORING (WQB = ')
ABVSTP
BELSTP
ABVMILL
BELMILL
ALB

Figure 6N

MEDIAN NITRATE VS RIVER MILE

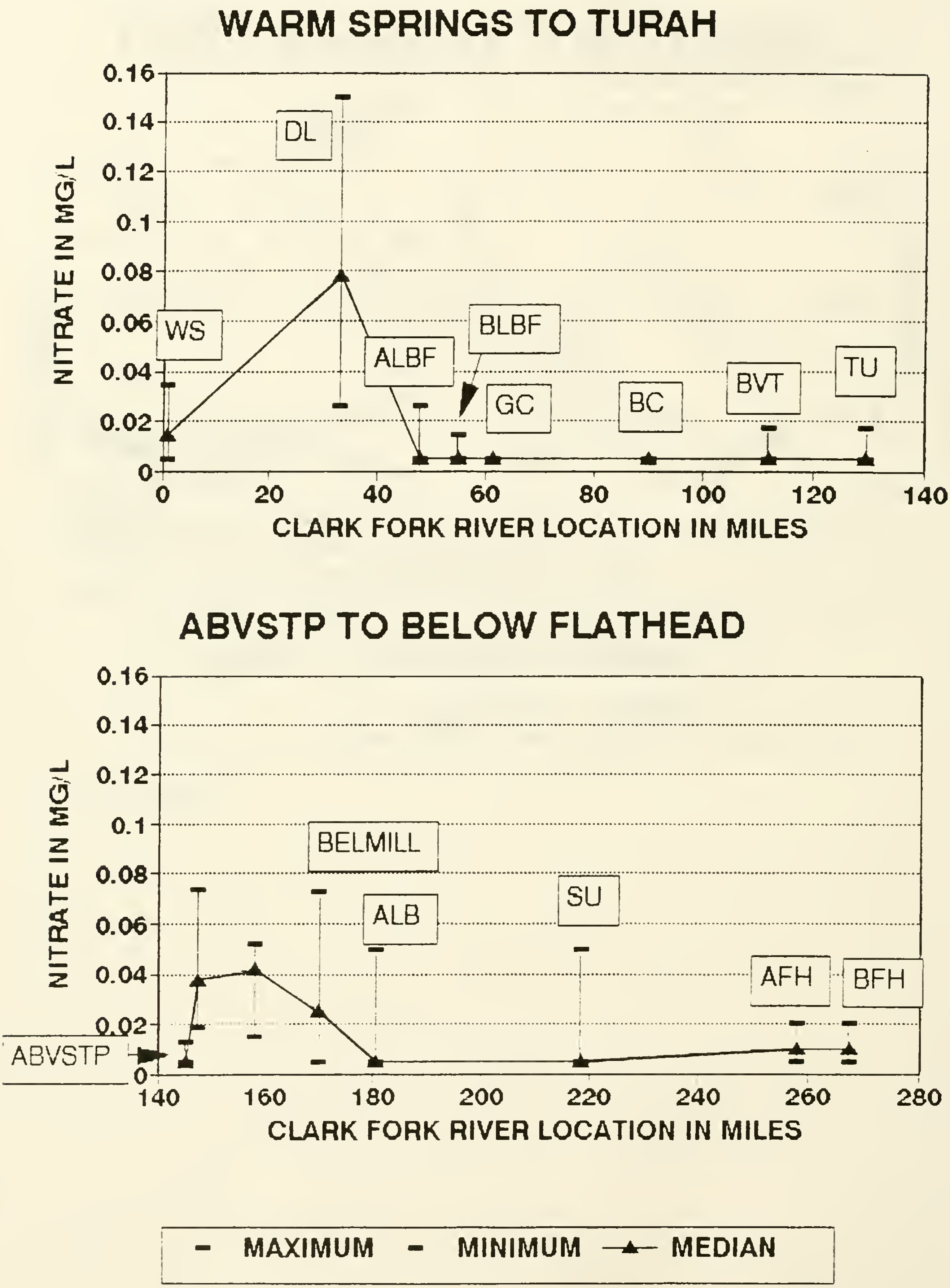


Figure 7N

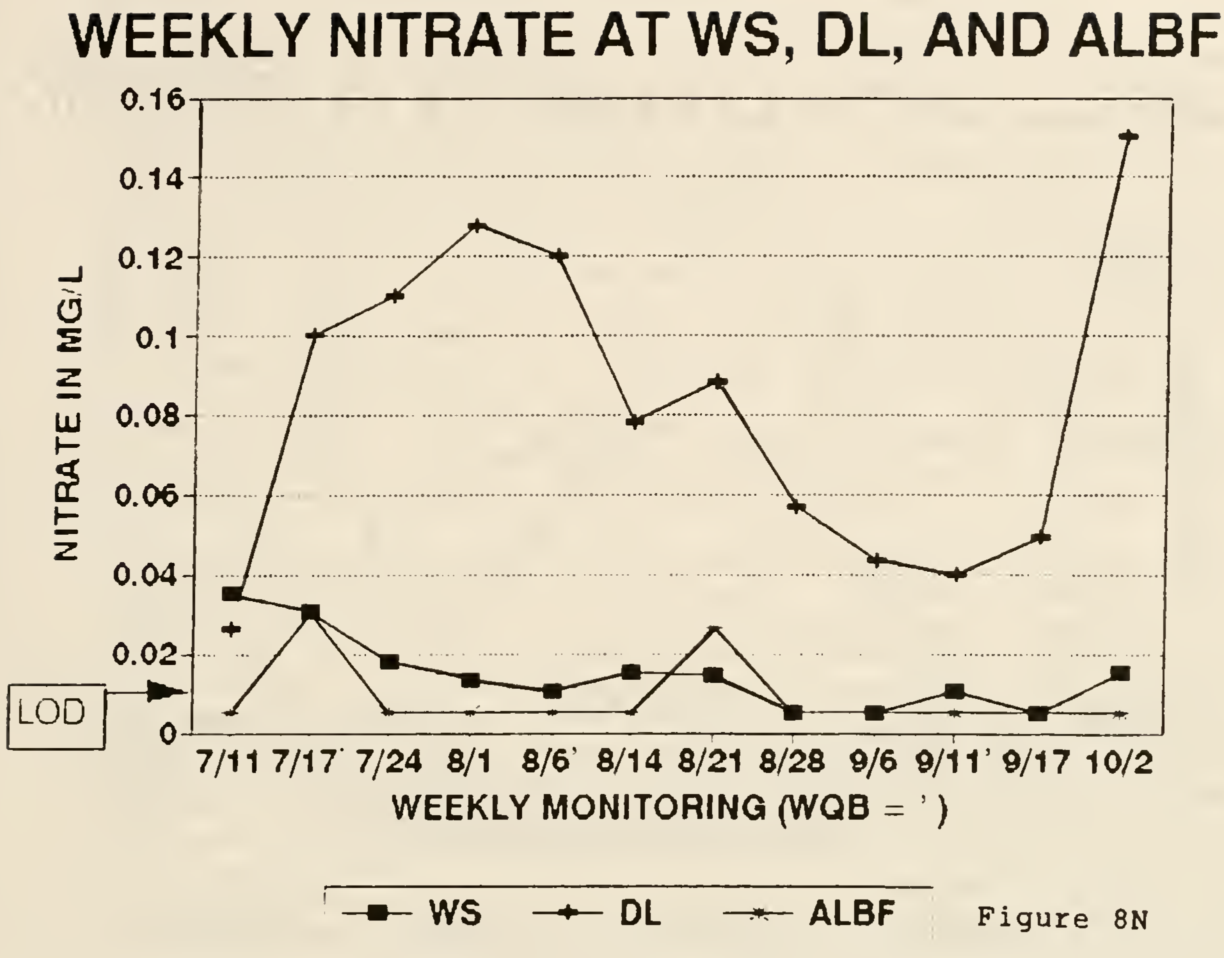


Figure 8N

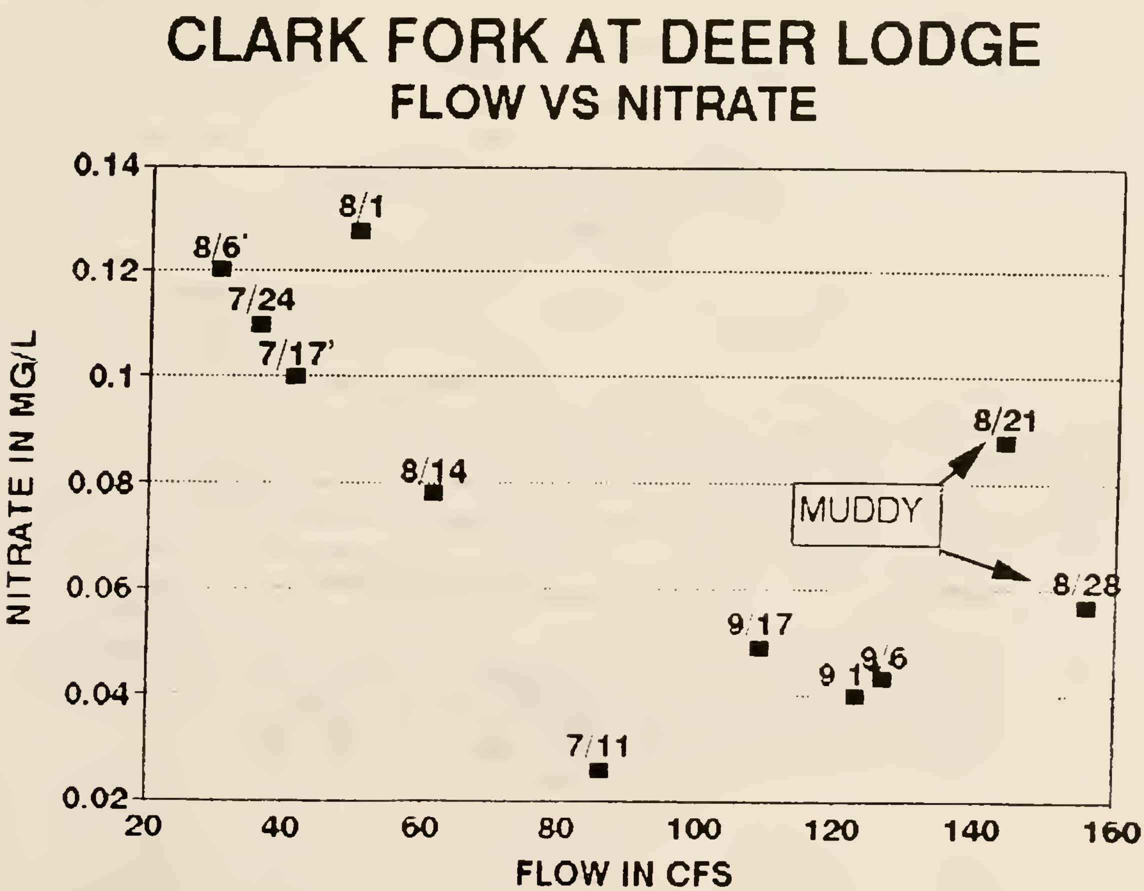


Figure 9N

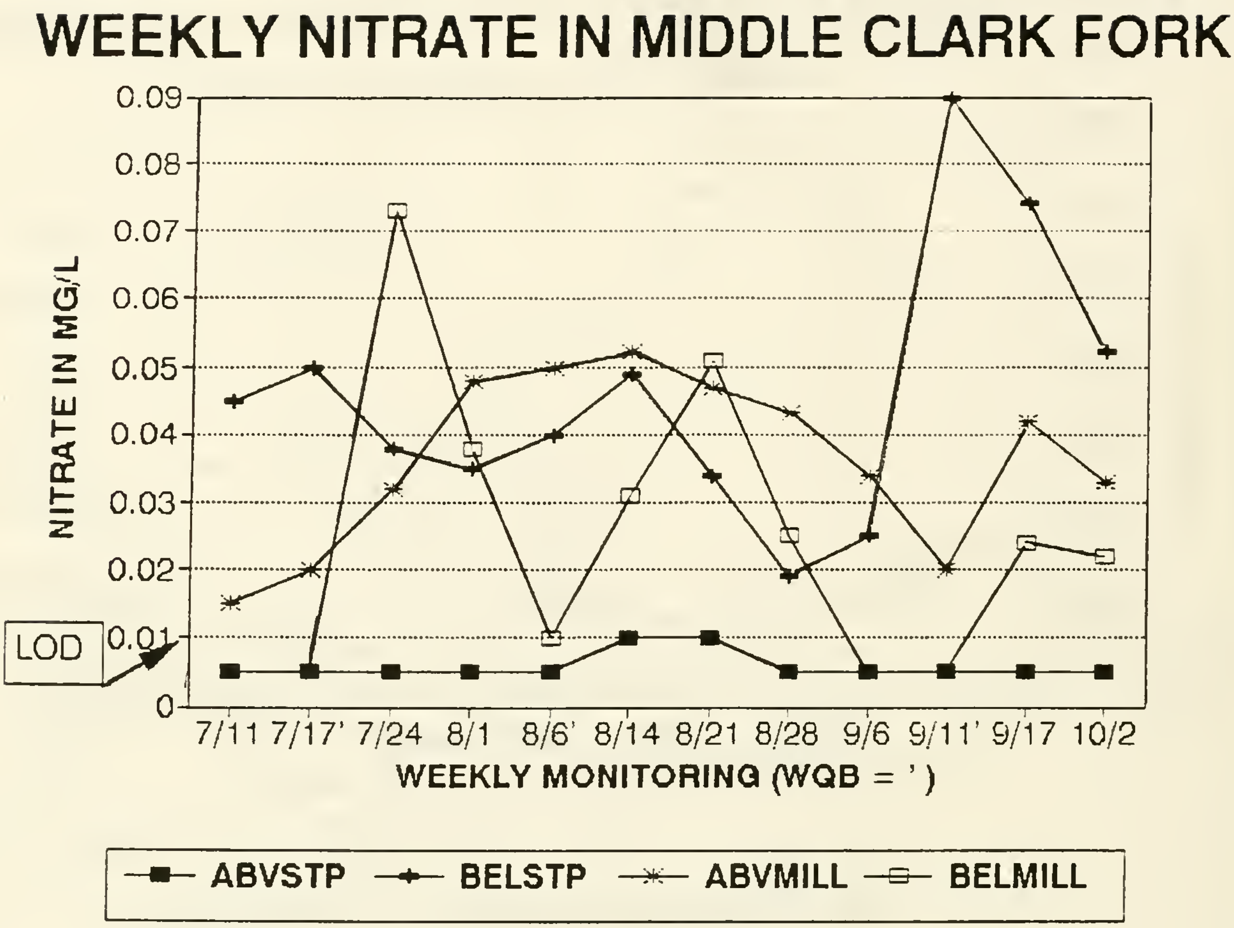


Figure 10N

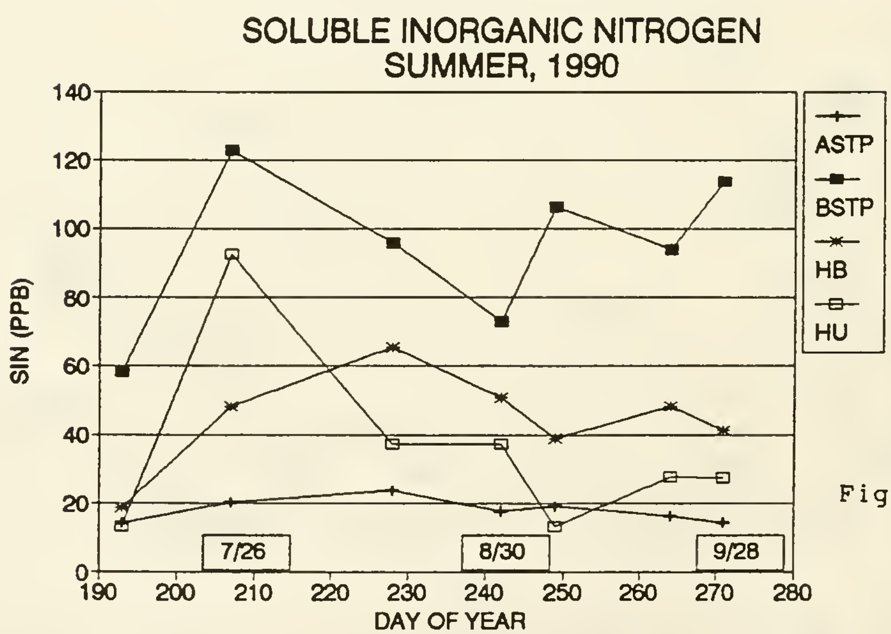


Figure 11N

APPENDIX T--UPPER RIVER RECIPROCAL TRANSPLANT STUDY

In summer, the upper Clark Fork is generally much higher in phosphorus and lower in nitrogen than is the middle river (exceptions include the high P levels below the Missoula WWTP and the high N levels in Deer Lodge). In addition, the algal community is dominated by Cladophora, a filamentous green alga, while the middle river is dominated by a mixed community of diatoms. It has proven difficult to study Cladophora in artificial streams and determine what nutrient levels limit standing crop of this alga. Instream studies on artificial substrates are hampered by the long time required for this alga to become established on substrates. Hence we attempted to study the response of this alga to different nutrient levels by transplanting rocks already colonized with Cladophora to different parts of the river. Sites were chosen that differed in nitrogen and phosphorus levels.

In summer the Deer Lodge(DL) site is relatively high in nitrate (40-120ppb) and low in phosphorus (5-20ppb), while the Warm Springs (WS) site is high in P (30-90ppb) and lower in nitrate (10-30ppb). Nitrate is usually below detection (<10ppb) at the sites below Gold Creek (GC) and Bear Creek (BC). Both these sites have moderately high P levels (10-35 ppb), but in 1990 GC had the higher P levels early in the summer while the BC area had higher P levels later in summer. If nutrients are the most important factors limiting accumulation and if P is more limiting than N, the Deer Lodge site should show the least accumulation, followed by GC and BC with WS showing the most accumulation. If N is more limiting at these levels, DL should show the most accumulation, followed by WS, then GC and BC.

METHODS--In mid July, rocks colonized with Cladophora (and other periphyton) were collected from the river bed just below the confluence with Warm Springs creek (WS) and at Beavertail Hill campground (BVT). Rocks from both these source sites were transported in river water in coolers to the four test sites (WS,DL,GC,BC). Here rocks were placed in shallow aluminum pans which were dug into the substrate so the rocks were almost flush with the surrounding substrate. A ring of vaseline was applied to the lip of the pans to reduce movement of insects into the pans. Pans were checked weekly and kept at 20-30cm deep in rapidly flowing water (0.3m/s +/- 0.1m/s).

Known areas of mixed attached algae community were sampled from ten rocks from each source site at the beginning of the study (7-17-90). Ten rocks from each source site were collected from the transplant pans at each test site after one and two months (mid August and mid September). In some cases only 5 rocks were available because of loss of pans. The algal material was analyzed for chlorophyll a and for ash free dry weight by Standard Methods (1985).

RESULTS--Initial algal biomass levels (on 7/17) and those present after 1-2 months at test sites appear in figures T1 and T2.

Initially, the Cladophora from WS was 3-6 inches long and bright green. The Cladophora from BVT was only one to two inches long and was covered with a thick mass of brown diatoms. Within a month, the algae on the rocks from both sites took on the appearance of the Cladophora at the test site (similar color and growth form). Over the first month, the WS rocks incubated at WS increased in both chl a and AFDW (filaments had increased to 6 to 8 inches in length); however, biomass dropped dramatically in the second month. By mid September, the rocks were stripped bare and were covered with caddisflies and other aquatic insects. The BVT rocks decreased in biomass at the WS site in both months. The first month the algae simply appeared to be less healthy, the second month these rocks also appeared to be stripped bare.

At the Deer Lodge site, the algae on the rocks from both WS and BVT took on the rich dark green color and the very long growth form (filaments up to 2 feet long) that characterized the rocks at the Deer Lodge site. By mid August, the biomass on the WS rocks increased at this site but the biomass on the BVT rocks did not increase significantly. The Deer Lodge site was vandalized before the September sampling.

At the Gold Creek site, the transplanted algae assumed the bright green color and long filaments that characterized this site. Initially, chlorophyll levels actually decreased at this site, while AFDW increased on the WS rocks but not on the BVT rocks. But by mid September, the WS rocks showed a significant increase in biomass, while biomass levels on the BVT rocks were too variable to make valid comparisons.

At the Bear Creek site, the transplanted algae took on the pale yellowish green color and long filaments that characterized this site. With the exception of an initial increase in AFDW on the WS rocks, there was little change in biomass on the rocks incubated at this site.

How could the filaments increase in length without increasing significantly in biomass? The data presented here is based on samples collected from 10 sq. cm. on the top center surface of each rock. The remaining algal material on the rock was also collected and the rock's upper surface area was estimated. This latter approach yielded higher average values; however, these measurements were much more variable and so generally did not show significant increases either. More replicates would no doubt have narrowed the confidence interval and shown more significant differences. Forty rocks were placed at each of the 4 test sites to allow two samplings of 10 from each source site. However, losses of some pans caused only 5 replicates to be available for later sampling at some sites. Finding and transporting more than 160 rocks with similar amounts of Cladophora would be difficult.

What can be made of all this? If one looks at AFDW, there was little change in the BVT algae at all the sites (except for the decrease at WS which may have been due to metals toxicity or heavy macroinvertebrate grazing). The AFDW of the WS algae showed similar increases at all the sites in August, but in September lost AFDW at WS & BC while gaining at GC. If one looks at chlorophyll and the first month of incubation, higher nitrogen sites (DL & WS) exhibited a significant increase in chlorophyll on the WS rocks while the lower nutrient sites farther downstream did not. However, the September sampling suggests that factors other than nutrients were more important in determining chlorophyll levels at this time. As for the BVT rocks, the very great variability in two of the samplings make it difficult to discern a pattern in these data. BVT data will be more closely inspected for outliers to determine if the confidence intervals can be narrowed.

It should be noted that with the exception of the final sampling at WS, all the rocks visually appeared to have much more algal biomass after incubation--*Cladophora* filaments were much longer and more noticeable. This increase is observed in the WS data. However, the heavy layer of diatoms on the BVT *Cladophora* seemed to be lost, and the increase in *Cladophora* biomass did not appear to offset the loss of the diatoms.

Because the loss of the diatoms obscures the increase in *Cladophora* on the BVT rocks, I will concentrate on the WS rocks. Perhaps the most interesting result is the similarity of the response at WS and DL despite the very different N:P ratios of these sites. The P levels at these sites are both high enough that little difference in P limitation would be expected but N levels are low enough at WS that N limitation of standing crop might be expected. N levels did drop over the summer and perhaps this partly explains the low September algal levels at WS. Aquatic insects were much more noticeable at WS in September and differential grazing may explain the different algae levels; however, in late summer, 1989, there were more aquatic insects at DL than at WS (Rokosch and Watson, unpublished data).

The two downstream sites (GC & BC) had lower nitrate levels than WS or DL but had P levels intermediate between these sites. Their P levels were high enough to expect P saturation, however, so their main response should be to the lower N levels. These sites initially produced less chlorophyll than the two upper river sites but not less AFDW. The loss of the DL site for the second sampling is a problem--if this site had shown the highest biomass levels at the second sampling, algal levels would have been approximately proportional to nitrate levels. Certainly the surrounding rocks at the DL site seemed to have the darkest green and most massive *Cladophora* growths at this time, however, visual evaluations are not always in agreement with quantitative sampling.

As for the effects of differential grazing at the sites--in late summer 1989, the GC and BC sites had similar aquatic insect abundances and biomass to the WS sites but less than at DL (Rokosch and Watson, unpub. data). Perhaps the WQB's 1990 insect data would shed light on whether differential grazing may help explain these patterns.

So perhaps the clearest conclusion from all this is that by mid August the WS rocks had accumulated more chlorophyll at the high nitrate sites than at the low nitrate sites. P seemed to be sufficient at all sites since the low P DL site accumulated more than did higher P sites. It would seem necessary to reduce P levels below the 10 ppb levels observed at DL to achieve much reduction in algae levels through P limitation. A careful evaluation of point sources is necessary to determine if this is possible by point source control alone. As for limitiation by nitrates, the relationship between algal levels and nitrate levels was not that strong suggesting that other factors are important in regulating algal accumulation. Reduction of nitrate below detection levels might result in some reduction in chlorophyll levels but did not appear to reduce AFDW levels.

The difficulty of drawing conclusions from instream studies given the many confounding variables is obvious. But it is clear that nutrient differences between these sites were not an overriding factor in determining algal levels as might be expected where nutrient levels are fairly high.

Acknowledgements

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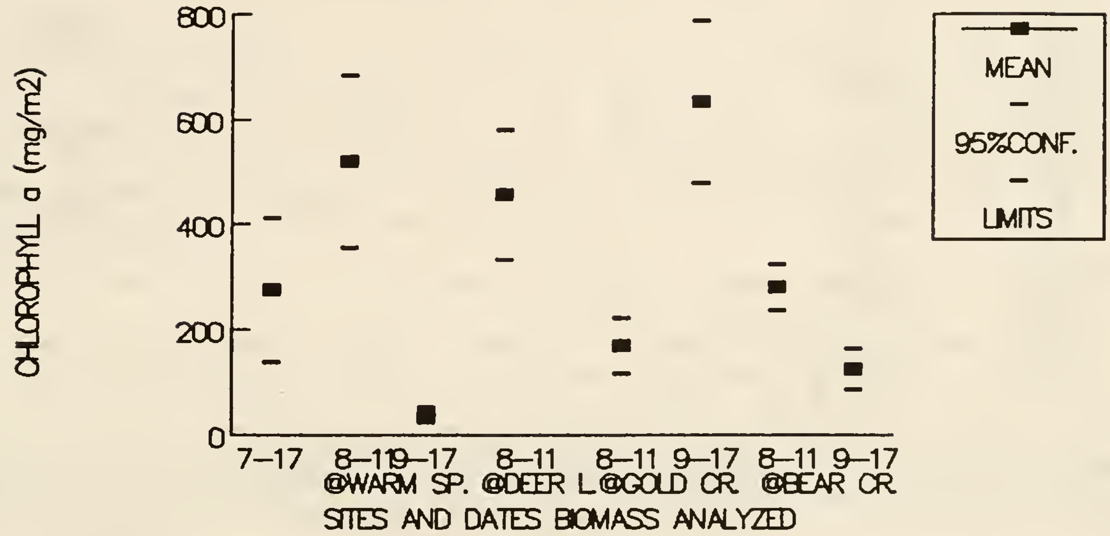
ALGAL BIOMASS ON WARM SPRINGS ROCKS TRANSPLANTED TO SITES IN CLARK FORK



ALGAL BIOMASS ON BEAVERTAIL ROCKS TRANSPLANTED TO SITES IN CLARK FORK

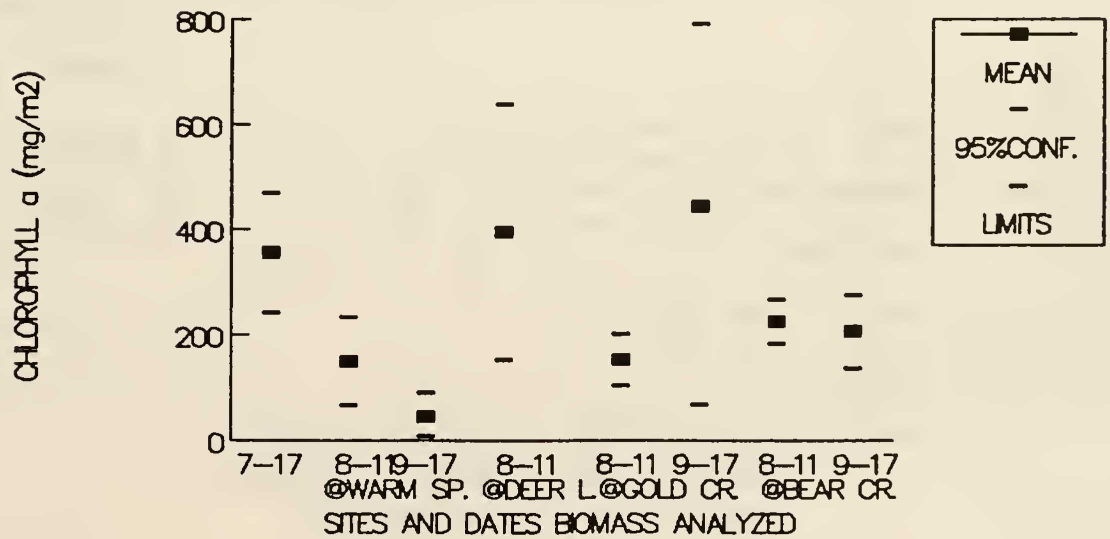
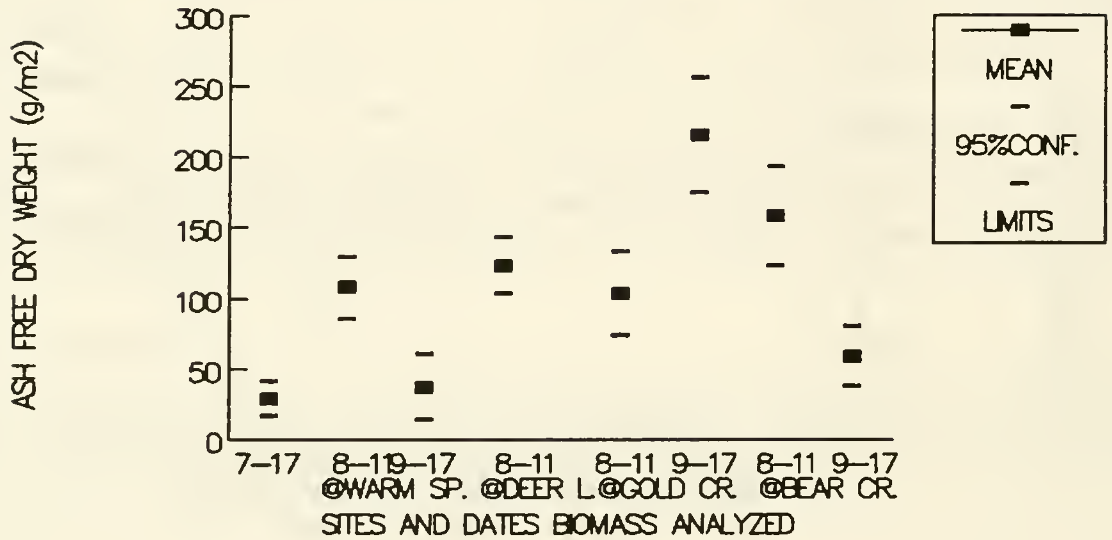


Figure T1

ALGAL BIOMASS ON WARM SPRINGS ROCKS

TRANSPLANTED TO SITES IN CLARK FORK



ALGAL BIOMASS ON BEAVERTAIL ROCKS

TRANSPLANTED TO SITES IN CLARK FORK

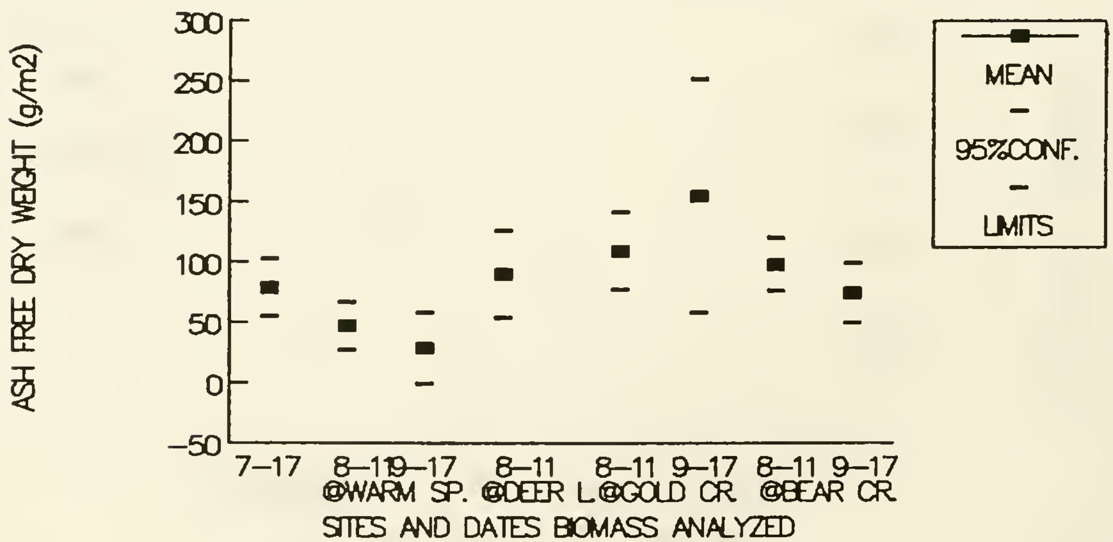


Figure T2

APPENDIX M--DESCRIPTION OF RIVER ALGAE ACCUMULATION MODEL (PERISIM)

PERISIM is a computer 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 losses are 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:

$$Bt = Bt\text{-}1 + Bt\text{-}1 * (\text{rates of growth} - \text{respiration} - \text{sloughing})$$

where Bt = biomass at time t, Bt-1 = biomass at previous point in time. The time step used in this model 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--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 or light dependence of growth = (IZ/IOPT)*exp(1-IZ/IOPT)

where 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. But temperatures in the Clark Fork rarely exceed the optimum (around 25 C 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). Hence nutrient dependence is calculated as:

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

where P is the concentration of soluble reactive P (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 1/2 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:

Respiration rate R = 0.04 * T * Kr

Where Kr is maximum daily respiration rate (0.1/day) and T is as before. 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 and turbulence and the vigor of the algal community. Artificial stream studies show that, following colonization, algal biomass increases at a rapid exponential rate than 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 level. That is, under higher nutrient levels, algal biomass accumulates to a higher level before leveling 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 increases. This is accomplished by the formula:

$$\text{Sloughing rate} = SLMAX * B/Bmax$$

where SLMAX is the maximum 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 approached Bmax, the growth rate slowed due to shading, nutrient limitation and waste buildup and the sloughing rate increased. The formulations used were:

growth dependance = 1-(B/Bmax)
sloughing rate = max rate (B/Bmax) for a given wind speed

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 (ppb of SRP). 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 data 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 table 1.

Model Outputs

PERISIM estimates ash free dry weight of attached algae per sq. 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 (like Below Missoula STP and Harper Bridge--which tend to be richer in chlorophyll), 300 for low nutrient sites (above Missoula, Plains) and 200 for moderate nutrient sites (all others).

Limitations of the model

The intent of this modeling exercise was to find the simplest model that would estimate the seasonal changes in algal biomass levels in the middle and lower Clark Fork with acceptable accuracy. The model was made more complex only as seemed necessary to obtain accurate reproductions of the river's observed algal levels. As was stated, the current version of the model is capable of reasonably accurate reproductions of the observed algal levels of 1988 and 1990 (as seen in figures 5 through 12 of the main body of this final report).

Many refinements could be added to make the model more realistic, and these refinements may or may not increase the accuracy of the model's predictions. These include growth limitation by multiple nutrients (particularly adding limitation by nitrogen) and the effects of grazing, scouring flows, turbidity, and cloudy weather. Adding these and other refinements to the model does not greatly complicate the model, but it does greatly complicate the problem of obtaining input data for a given year and a given site. The less data hungry the model, the more useful it is, as long as it provides reasonably accurate predictions.

The refinement that would most improve the model's usefulness in predicting algal accumulation in the Clark Fork would be adding nitrogen limitation to the model, and this is planned for the future. However, there is much less information available on growth parameters for N than for P.

In addition, it would be useful to modify the model so that it could simulate the accumulation of the perennial alga <u>Cladophora</u>. This is a more complex task since one river rock may be starting the growing season with no <u>Cladophora</u> while another may be starting with a growth that is several years old. Validating a <u>Cladophora</u> model is also more difficult because it is harder to obtain validation data. One must measure accumulation on natural substrates or on artificial substrates that have been in the river for a year or more. These efforts are more labor intensive and the data is much more variable than is true of measurements of diatom community accumulation. Obviously, this is a long term project.

References

Auer, M. T. and R. P. Canale. 1980. Phosphorus uptake dynamics as related to mathematical modeling of Cladophora at a site on Lake Huron. J. Great Lakes Res. 6(1):1-7.

Bothwell, M. L. 1989. Phosphorus limited growth dynamics of lotic periphytic diatom communities: areal biomass & cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46(6):1293-1301.

Canale, R. P. and M. T. Auer. 1982. Ecological studies and mathematical odeling of Cladophora in Lake Huron: 5. Model development & calibration. J. Great Lakes Res. 8(1):112-125.

DiToro, D. M. 1980. Applicability of cellular equilibrium and Monod theory to phytoplankton growth kinetics. Ecol. Modelling 8:201-18.

Graham, J. M., Auer, M. T., Canale, R. P. Hoffman, J. P. 1982. Ecological studies and mathematical modeling of Cladophora in Lake Huron: 4. Photosynthesis & respiration as functions of light and temperature. J. Great Lakes Res. 8(1): 100-11.

Hutchinson, G. E. 1975. A treatise on limnology. John Wiley & Sons.

Lehman, J. T., D. B. Botkin, and G. E. Likens. 1975. The assumptions and rationales of a computer model of phytoplankton population dynamics. Limnol. Oceanogr. 20:343-64.

Spain, J. D. 1982. BASIC microcomputer models in biology. Addison-Wesley. Publ. Co. London.

Watson, V. J. 1981. Seasonal phosphorus dynamics in a stratified lake ecosystem: an evaluation of external and internal loading and control. PhD dissertation, Botany, Univ. Wisconsin-Madison.

________. 1983. Application of a seasonal phosphorus dynamics model to a lake ecosystem: assessing lake loading tolerance. pp. 575-592. In Lauenroth, W. K., G. V. Skogerboe and M. Flug(eds.) Analysis of ecological systems: state of the art of ecological modeling. Elsevier Scientific Publ. Amsterdam.

________1990. Improving the biotic resources of the upper Clark Fork River. Streamside artificial stream studies. Report to Montana Dept. Natural Resources and Conservation.

Whitton, B. A. 1967. Studies on growth of riverain Cladophora in culture. Archiv. fur Mikrobiologie. 58:21-29.

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