FLAMING GORGE WATERSHED PROJECT: ANALYSES WITH EXISTING DATA

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ABSTRACT. The Green River drains 12,000 mi^2 of western Wyoming and northeastern Utah. Its basin incorporates a diverse spectrum of geology, soils, topography, climate, and land cover. Land use predominately is associated with forest and range, although an increasing number of industries are locating in the southern half of the drainage. Dissolved and particulate matter in the river derives primarily from non-point sources in the watershed. Output of materials from the basin contributes to processes in Flaming Gorge Reservoir, immediately downstream of the study area. We report on the derivation and application of multiple linear regression models which associate various basin attributes (e.g., stream channel slope, underlying geologic formations, annual precipitation) with existing measurements of nitrate, phosphorus, total dissolved solids, turbidity, and alkalinity in the Green River system. We also estimate point source loads of nitrate and phosphorus, and illustrate how their exclusion affects the models developed by considering all sources. Finally, we show how our models can be used by managers to rank portions of the basin by amount of material contributed to the total dissolved and particulate load.

TABLE OF CONTENTS

INTRODUCTION

Background on Water Quality Problems in Flaming Gorge Reservoir

Flaming Gorge Reservoir impounds water which drains from a western Wyoming watershed of approximately 12,000 mi^2. miles. During recent years upper sections of the reservoir have exhibited severe water quality problems, including dense blue-green algal blooms and hypolimnetic anoxia (U.S. Environmental Protection Agency 1977, Southwestern Wyoming Water Quality Planning Association 1978, Fannin 1983, Verdin et al. 1983). In turn, these problems have lessened the quality of body-contact recreation and adversely affected the salmonid fishery.

In general, water quality problems in lakes and reservoirs result from processes occurring both in the water body and in its drainage basin. The important processes occurring in the basin are those which lead to the output of nutrients, especially phosphorus. Such processes must be considered because they provide the source of nutrient input for the reservoir. When these nutrients reach the reservoir, processes there control how the nutrients are used by algae, the extent of oxygen depletion, etc.

Thus when planning mitigation measures the importance of considering processes both in the reservoir and in the drainage basin is clear. If a mitigation scheme is to cure the causes of problems in the reservoir rather than just minimize their impact (treat symptoms), then a major part of the scheme usually must deal with reducing nutrients which originate in the basin but which ultimately cause algal blooms, etc. in the reservoir.

While water quality in the upper end of Flaming Gorge may at times be poor, the deep, downstream portion of the reservoir is oligotrophic. Thus there exists in Flaming Gorge a longitudinal gradient of water quality which is typical of many reservoirs, but which normally is not found in lakes. This gradient occurs in part as a result of three intergrading regions found in reservoirs but not lakes; a shallow, narrow, upstream riverine zone; an intermediate transition zone; and a deep downstream lacustrine zone.

In lakes anoxia normally occurs first in the deepest waters. In reservoirs oxygen depletion commonly begins in the transition zone. Hannan and Cole (1983) suggest why this difference between lakes and reservoirs may occur. The more turbulent water of rivers is able to carry more suspended matter than the quieter waters typical of lakes. Thus when water moves from the riverine to the transition zone of reservoirs its ability to maintain particles in suspension is reduced. As this occurs particles settle to the bottom of the transition zone. If this area is deep enough to stratify thermally, and if the settling particles are partially organic, then bacterial respiration from decomposition of these organics depletes oxygen in the bottom of the transition zone.

The propensity for oxygen depletion and anoxia in the transition zone has implications for schemes to mitigate problems in Flaming Gorge reservoir. First, this zone is the area where problems presently occur. Hence morphology typical of reservoirs may tend to exacerbate problems of oxygen depletion. Second, anoxia in the transition zone may provide additional nutrients from internal loading (i.e., from "inside" the lake rather than from the drainage basin). Anoxia promotes release of phosphorus from sediments, which are the source of this internal loading. Because the hypolimnion is not deep in the transition zone, transport of phosphorus from the hypolimnion to the epilimnion occurs more rapidly than in deep water. And, the phosphorus transported to the epilimnion is available to support additional algal growth.

In addition to reservoir morphology, the phenomena described above are dependent upon both climate and hydrology. For example, climate affects the onset of thermal stratification. In years with a cool spring the duration of stratification may be insufficient for much internal loading to occur. Climate also interacts with hydrology to affect the movement of river water into, and the mixing of river water with, the lake water of the transition and lacustrine zones. This is important for the development of blooms and oxygen depletion because it affects where in the reservoir the river-borne nutrients and organic matter are found.

If nutrients are to promote algal blooms they must be temporally available. That is, they must be present in the reservoir at a time when the potential for algal growth is great. In Flaming Gorge this means nutrients which lead to the development of nuisance blooms (late summer to October) must be available at this time. However, because in Flaming Gorge nutrient input is strongly related to inflow, most nutrients enter the reservoir during spring and early summer when runoff is greatest. In early fall, runoff-related input must be less.

Another source of nutrient input during late summer or early fall may be algae which are dislodged from the bottom of the Green River. Water released into the Green River from Fontenelle Reservoir is rich in nutrients. These nutrients support the growth of benthic algae during summer, but in early fall the algae begin to slough off. Hence if other conditions in Flaming Gorge are conducive to the development of blooms, then the addition of nutrients from decomposing benthic algae may help trigger or exacerbate the blooms.

Biological availability is another aspect important to how nutrients affect algal blooms. If a nutrient is present in large amounts but occurs in a form which is unavailable for algal use, then that nutrient is unlikely to contribute to the development of blooms. In Flaming Gorge this may be significant because when fall blooms occur, the available nutrients from some point sources (e.g., sewage) should be greater, on a relative basis, than during spring. This is because input from point sources is relatively constant, while runoff-related input is highly seasonal.

Role of This Project in an Overall Scheme for Mitigating Water Quality Problems in Flaming Gorge Reservoir

With the previous discussion providing a brief background of processes and problems in Flaming Gorge, let us now generally review events which could lead to mitigation and the role of this project in such an overall effort. Moving from top to bottom in Figure 1 roughly corresponds to performing chronologically a series of tasks leading to a plan for alleviating water quality problems in Flaming Gorge. Of course the plan would have to be implemented before mitigation actually would occur.

First, geologic and climatic conditions and processes, etc., lead to export of nutrients from the drainage basin (1; Figure 1). This export from the drainage basin provides input, or loading, to the reservoir (2). Next, we must (3): A) evaluate the amount of nutrient provided by i) internal loading from sediments within the reservoir (3a), and ii) external loading from the drainage basin (3d); and B) obtain information on processes within the reservoir (3b) to understand how nutrients lead to the production of water quality problems; reservoir modeling (3c) is an important tool at this step.

There is no disagreement that nutrients are responsible for the problems occurring in Flaming Gorge. However, currently it is not clear whether the most important source of these nutrients is external (drainage basin), internal (sediments within the reservoir), or whether both sources are of approximately equal importance. Because the measures used to mitigate the problems depend on the source of nutrients, it is critical to determine the relative importance of internal versus external loading (4).

At this point it finally will be possible to list the options available for mitigating nutrient input from external and/or internal sources (5). And, after cost-benefit analyses and discussion of mitigation options (6), a plan can be devised to implement the option(s) judged most appropriate (7).

While the water quality problems in Flaming Gorge are located physically in the State of Wyoming, Wyoming is not the only party having an interest in these problems. For example the reservoir extends into the State of Utah, the Bureau of Reclamation operates the reservoir and controls the land immediately around it, the Bureau of Land Management and the Forest Service both administer large blocks of land in the drainage basin, and the Environmental Protection Agency has a general responsibility for protecting the quality of waters.

These agencies are charged with a variety of responsibilities, and the policies and practices of all the agencies affect, to a greater or lesser extent, what occurs in the reservoir. But none has the total and absolute responsibility for all aspects affecting processes in the reservoir. Therefore, mitigating these water quality problems must involve coordinated, cooperative efforts by all interested parties. The State of Wyoming Department of Environmental Quality (DEQ) has taken the lead in coordinating efforts directed at alleviating the water quality problems in Flaming Gorge. At present, DEQ is preparing a Cooperative Agreement for signature by a number of the interested parties.

A long-term goal underlying this work is to alleviate the water quality problems occurring in Flaming Gorge. Obviously, this goal cannot be achieved based on work performed in this project. Rather, our efforts are directed at evaluating conditions and processes in the drainage basin which affect export of nutrients from the basin (1, 2, 3d on Figure 1). Also, we wished to make some estimates of the extent by which external loading could be reduced if certain measures were initiated within the drainage basin. Further, we wanted to accomplish the above using existing data, a process which, if it could be done, would be much less expensive than field work.

Basic premises of our approach

The basic premises which oriented our work were:

There is information in computerized data bases and in the literature which is pertinent to mitigating water quality problems in Flaming Gorge.

To be useful this information must be analyzed in terms of specific questions relevant to the water quality problems of Flaming Gorge.

Such analyses alone will not lead to the attainment of the overall, long-term goal of mitigating water quality problems in Flaming Gorge.

Such analyses will not obviate the need the for field studies, but will complement and help guide field work.

Such analyses will provide useful information quickly and cheaply when compared to field work.

Project Tasks

The five tasks we proposed are listed below.

Task 1: Determine the output of nutrients from point and nonpoint sources within subbasins of the drainage.

This information would be the basis for evaluating nutrient input from the basin, and for developing statistical models.

Task 2: Use existing data to develop statistical models of water quality as a function of basin attributes.

After developing such regression models, we then wanted to use them to infer how water quality might be improved if several types of mitigation measures were implemented in the drainage basin. A next step would be to infer how such within-basin measures affected the water quality problems in Flaming Gorge. Finally, we would provide our data to any of the modeling groups which desired them.

Task 3: Determine the probable temporal and biological availability of nutrients from point and nonpoint sources.

Our objective here was to adjust, using existing data, the results of Task 1 for the biological availability of nutrients. This was thought to be important in relation to the potential import of sewage at a time when other general inputs would be lower owing to lower flows.

Task 4: Determine the probable temporal and biological availability of nutrients from benthic algae dislodged in the Green River (below Fontenelle Reservoir)

Input of nutrients to the reservoir from benthic algae in the river might occur at a critical time in relation to blooms (late summer when flow is lower and hence when input from other general sources might be low). Therefore we wished to try to estimate, using existing data, what the contribution of nutrients might be from sloughed algae.

Task 5: Attempt to determine the extent to which riparian restoration would reduce the output of nutrients from the drainage basin and into Flaming Gorge.

Our objective was to use data from other tasks, and from another ongoing project, to evaluate the feasibility of riparian restoration as a mitigation technique which could decrease nutrient input to the reservoir.

General procedures involved in performing the five tasks

Because all analyses were to be performed with existing information, our first effort was to identify any potentially useful data on water chemistry and flow which existed in electronic data bases. Next we developed criteria which could be used to choose, for our analyses, an ideal subset of data. The data actually used then were chosen as a compromise between what ideally was desired and what was available. Once chosen, these data then had to be obtained from the electronic data base and converted to an electronic form appropriate for our use. Other required information also had to be converted to an appropriate electronic form. For example, information on soils may have been available in tabular or cartographic form by county. We, however, needed such information compiled not by county but by drainage basin. An electronic digitizing board was used to create and record electronically many such additional data.

A major use of the compiled data was to create multiple regression models relating water quality to various attributes of the basin. Because we had 157 independent variables with which to work, the potential set of different models that could be generated was huge. This large potential set was reduced in size to several small groups of models in two ways. i) If particular statistical assumptions were not met, then a model was eliminated. ii) Objective and subjective criteria were established by us for specific questions we wished to ask (e.g., what is the best model to predict total phosphorus, or what is the the best model to predict total phosphorus when using only land use attributes as independent variables).

General Background

The Green River basin of western Wyoming and northeastern Utah is a climatologically, topographically, and geologically diverse watershed. Mean temperatures range from -6° F (-21° C) to 86° F (30° C); mean precipitation varies from 11" (28cm) to 41" (104cm), with the latter figure more typical for the surrounding mountains. The major vegetative cover in the drainage is range and forest (Table 1 and Appendix A). Not

Table 1. Land cover by percentage of total basin area in the Green River and Blacks Fork sections (see Figure 2) of the Green River Basin.

Land cover type	Green River section	Blacks Fork section
Alpine	2	0
Irrigated crops	6	7
Rock or dunes	1	3
Wetlands	1	1
Urban	<1	<1
Range	73	67
Forest	16	20
Total	100	100
Area (mi2)	9500	2920

surprisingly, the area is used by man predominately for grazing and forestry. Other land uses are mining of trona (sodium carbonate) and farming two major areas of irrigated cropland. The basin is sparsely inhabited with 52,300 people (U.S. Bureau of the Census 1981).

Topographically the watershed is a mixture of extensive flats and rolling hills surrounded on three sides by mountains (Figure 2) which have a maximum elevation of 13,804 feet (4207m). Mean elevation of the basin is 7416 feet (2260m). Sixty percent of the drainage is underlain with Tertiary formations and extensive areas of Green River shale.

Although poor water quality has not been a problem in the upper reaches of the basin, the lower reach of the Green River shows a large increase in salinity load as dissolved solids (DeLong 1977). Over half of the increase in salinity load (202,000 tons/year) between Fontenelle Reservoir and Green River city is contributed by the Big Sandy River. The source of this increase tentatively has been identified as saline (5000 mg/l TDS) seeps along and within the Big Sandy River. One of the basin's two major areas of irrigated cropland, the Eden Valley Irrigation Project, lies adjacent to this tributary.

The Green and Blacks Fork Rivers are the two principal tributaries to Flaming Gorge Reservoir, which lies immediately downstream from our study area. Several studies (e.g., U.S. Environmental Protection Agency 1977, Southwestern Wyoming Water Quality Planning Association 1978, Fannin 1983, Parker et al. 1984) have described the sporadic, though increasingly severe, episodes of summer eutrophication which have affected adversely both fishing and body-contact recreation in the reservoir. The basin's low human population density, few industries or facilities requiring surface water discharge permits (Appendix B), and relatively high proportion of agricultural or dispersed land use, support the observation that non-point sources are responsible for 88% of the phosphorus input to Flaming Gorge (Southwestern Wyoming Water Quality Planning Association 1978). Messer et al. (1983) have suggested that recycling of nutrients from the reservoir's sediments (an in-lake process) may exacerbate summer eutrophication, although they do not evaluate recycling's importance relative to external, or riverine, loading.

For mitigation of water quality problems in the drainage, it is useful to know which portions of the basin contribute most to the problems. Similarily, we need to know which characteristics (e.g., geology, land use, rainfall, etc.) of the basin are more important in causing the problems. Description of current relations between the basin and corresponding water quality would provide a point for comparison with future studies of water quality, perhaps when some of the basin attributes have changed. Practical applications of such knowledge, then, would be apportioning chemical loadings to a specific source area of the drainage, predicting changes in water quality from changes in basin characteristics, and investigating whether associations of water quality with basin characteristics change over time. This would help managers choose best where to focus mitigation efforts in the basin.

No systematic basin-wide investigation of the origin of dissolved and suspended substances in the Green River has yet been performed. However, much data concerning its basin is available, albeit from diverse sources (see, for instance, Greb 1983). We report here the results of a basin-wide investigation of associations of watershed characteristics with attributes of the Green River basin of Wyoming and Utah; the associations were derived entirely from previously published or previously available data.

Scope

The objectives of this analysis of existing data from the Green River basin were:

1) to retrieve and compile available information about surface water quality and discharge.

2) to retrieve and compile available information about characteristics of the basin.

3) to derive models associating basin characteristics with basin water quality, using appropriate data from 1) and 2).

4) to compile a list of point sources in the basin, and estimate their contributed loads.

5) to illustrate the effect of excluding point source loads from appropriate models found in 3), and derive unique models from such non-point loadings.

6) to calculate from the models which specific areas of the basin are major contributors of the dissolved and particulate material in the river.

In conducting this analysis we assumed that water quality is indeed a function of physical, chemical, and biological characteristics of the drainage, and that a multiple regression technique is suited for associating such characteristics with water quality. This latter assumption is justified by the work of Lystrom et al. (1978) on the Susquehanna River of New York and Pennsylvania.

The five tasks we proposed originally were:

Task 1: Determine annual and monthly output of point and non-point source nutrients from subbasins in the Green River drainage.

Task 2: Develop statistical models of basin water quality as a function of basin attributes.

Task 3: Determine temporal and biological availability of nutrients from point and non-point sources.

Task 4: Determine availability of nutrients from dislodged benthic algae.

Task 5: Determine the extent to which riparian restoration, with or without beaver, improves water quality and decreases nutrient output.

This report addresses primarily Tasks 1 and 2. Existing data simply were not adequate to allow us to accomplish Tasks 3 and 4. We make some general statements about Task 5 in the Discussion.

The physical scope of the project includes the Blacks Fork drainage above the gauging station near Little America, Wyoming, and the Green River drainage above the gauging station downstream of Green River (city), Wyoming (Figure 2). The Blacks Fork is tributary to the Green River downstream from our study area. Within this report, the terms "Green River basin", "Green River drainage", and "Green River watershed", include both the Blacks Fork and Green River sections, unless specifically stated otherwise. The Green River section encloses about 9000mi^2, the Blacks Fork section about 3000mi^2. We considered three subbasins in the Blacks Fork section, and fifteen subbasins in the Green River section.

Water quality variables investigated were dissolved solids (TDS) load, nitrate (NO_3) load, total phosphorus (P) load, total alkalinity (as $CaCO_3$) load, and turbidity in Jackson turbidity units. Though we searched data for all water years from approximately 1900 to 1980, we chose water years 1965 to 1979 as our study period. Most available water quality data fell within those years, and 1964 was the year Flaming Gorge dam was closed.

We initially compiled and considered over 150 basin attributes in five major categories (Appendix A), although we reduced this number before our statistical analyses. We attempted to compile data on basin attributes from sources which collected information between 1964 and 1979, as we did for data on water quality and discharge.

METHODS AND MATERIALS

Regression Models

Multiple linear regression describes variation in a single dependent variable as a function of variations in several independent variables. In this case, a single water quality parameter is the dependent variable, and its variation is accounted for by the variation in two or more independent variables of physical, chemical, or biological basin characteristics. The general equation (from Edwards 1979) is:

$$Y' = a_1 + b_1 X_1 + b_2 X_2 + \cdots + b_k X_k$$

where Y' is the dependent variable, X's are the independent variables, k is the number of independent variables in the equation, and a is the regression constant. By choosing appropriate independent variables (basin parameters), we seek to maximize the correlation between the predicted value of our water quality variable and the actual value of the variable. The basis for our choice of independent variables is an interpretation of results from an SPSS (Hull and Nie 1981) multiple regression program, as detailed in "Regression", below.

Independent Variables

We define an independent variable as the unique numerical measure of some feature of the drainage basin. The five major types of independent variables (also referred to as "basin attributes") are Geology, Hydrology, Soils, Land Cover/Land Use, and Climate (see Appendix A). These attributes roughly correspond to those of Lystrom et al. (1978). However, the individual attributes within each of our categories were dictated by the data available for the Green River basin.

Much of the data from which we derived basin attributes had to be transformed from maps,charts,or lists. We used a COMPAQ microcomputer with a Houston Instruments 11"x11" digitizing pad to measure areas from maps or charts and LOTUS 123 software (Lotus Development Corporation 1983) to store and manipulate collected information. Sources of information and a description of its transformation into independent variables follow.

The basin attributes may be roughly divided into two classes. The first, which we call "permanent" attributes are those characteristics such as geological formation, maximum and minimum temperature, subbasin area, and basin slope, which cannot easily be altered by man. The second class, of "temporal" attributes, includes such characteristics as land cover and land use, precipitation, erosional tendancy of soils, and many hydrological variables, which have the potential to be affected by human activity. This distinction is important when building models of basin attribute associations with water quality. If we *assume* a cause-effect relationship, we may use models incorporating temporal variables to quantify how management of those variables could improve or worsen water quality.

Geology

We calculated areas of all geological formations shown on three hydrologic investigations maps (Welder and McGreevy 1966, Whitcomb and Lowry 1968, and Welder 1968). The area of each formation in each of 18 subbasins (see "Dependent Variables",Table 2) were recorded and areas of geologically similar formations summed as independent variables. Percentage transformations also were recorded. All geological attributes are permanent variables.

Hydrology

Hydrological variables, except for flood estimates, were calculated using data taken from current U.S. Geological Survey 1:250,000 scale topographic maps of the basin. Areas were obtained with the digitizer, and linear measures with a map measuring wheel. Total streamlength (SLENG) is the length of all streams in a subbasin, including intermittent streams marked on the map, but not including their extension to the drainage divide. Drainage density (DDEN) is the ratio of (SLENG) divided by subbasin area (AREAI). We determined Strahler order number (ORDR; Branson et al. 1981). Main channel length (CHANL) is the length of the longest channel, again including any intermittent portions, but not including the extension to the drainage divide. We calculated main channel slope (CHANS) as the $S_{10/85}$ (Lystrom et al. 1978). Elongation ratio (ELONG; Branson et al. 1981) is the ratio of the diameter of a circle having the same area as the subbasin to the maximum subbasin length. Mean basin elevation (MELEV) and mean basin slope (BASINS) we determined according to Lystrom et al. (1978). The average bifurcation ratio (BIFUR) is the mean of all bifurcation ratios within a subbasin.

We estimated 2-, 10- and 25-year floods (FLOD2, FLOD10, and FLOD25) in two ways. First, where possible, we determined them from a log-Pearson Type III plot generated by the Water Resources Data System, or WRDS, (Wyoming Water Research Center 1983). There were five stations where lack of data required an alternate method. We chose Lowham's (1976) method , with stream width estimates supplied by members of the Wyoming Game & Fish Department knowledgeable about those waters. All peak flows (PK6579, PKPOR) were obtained from WRDS output. Flood ratio (FLDRAT) is calculated by dividing the peak 10-year flood discharge (FLOD10) by the peak discharge in the period of study (PK6579).

All Hydrological variables were considered temporal, except for area, elevation, elongation ratio, and basin slope.

Soils

From Young and Singleton (1977) we found those soil series represented in soil associations in the watershed, and by digitizing determined the area of each association in each subbasin. From corresponding Soil Conservation Service soil series data sheets supplied by Munn (1984), we calculated and weighted the characteristics of all soil series within each association by area to obtain the subbasin value. Missing data or series were not included in weighted averages. Frost-free days, mean annual soil temperature, basin slope and basin elevation were considered permanent attributes.

Land Cover/Land Use

From a map compiled by Anderson et al. (1984), we obtained values of cover, weighted by area, for each subbasin. Since some of the cover classes are subgroups of other categories, we also determined the area of all higher-order classes, as well as percentage transformations. All land cover/land use classes are temporal variables.

Climate

Maps from Lowers (1960) were enlarged xerographically. From the area between adjacent isotherms, we determined minimum and maximum temperatures for each subbasin. Precipitation in the Wyoming portion of the drainage similarly was estimated from a map not yet cleared for public release. Precipitation falling on the Utahn part of the drainage was estimated from an undated precipitation map from the Utah State Engineer's Office. Precipitation was not considered a permanent attribute because of proposals to increase water yield in the basin by seeding clouds.

Reduction of Number of Independent Variables

We reduced the number of independent variables from the original 157 listed in Appendix A by first eliminating variables which were duplicates, percentages, or sums of other variables (except for Geological variables, where we kept the sums and eliminated their components). This reduced set of variables common to all following analyses is listed in Appendix C. We further reduced the number of independent variables by dropping those which were not significantly ($p=0.05$) related to a water quality variable in a simple bivariate regression. Thus, for every dependent water quality variable, we had a unique set of independent basin attributes for the multiple regression analysis. The number of independent variables in these unique sets were further reduced after initial regression analyses, as detailed in "Regression" below.

Dependent Variables

Combined Source Variables

The Wyoming Water Research Center maintains a copy of the the U.S. Geological Survey's surface water quality and discharge data for Wyoming. Samples from which surface water quality is determined are taken from natural water bodies, and therefore measure the effects of all inputs into the waterway. We term the measurements of these effects "combined source variables". Note that reference to this term includes *both* non-point, or diffuse, sources as well as point sources, such as sewage or industrial effluents.

From the Water Research Center's data, we extracted all water quality data on all dates for all sampling stations in the watershed. Stations having daily surface water discharge information also were chosen. We next selected a subset of those stations with the greatest number of "acceptable" water quality parameters. A water quality parameter was acceptable if it had at least four years of data between water years 1965 and 1979, with at least one year of data comprised of ten or more samples. Using these criteria, we found only nine water quality variables for most of eighteen surface water discharge stations. The nine water quality variables and their WRDS (Water Resources Data System) parameter numbers are found in Table 2.

Table 2. Initial water quality variables chosen from WRDS database, including units of measure and WRDS parameter number.

WRDS PARAMETER	VARIABLE	UNITS
665	Phosphorus	mg/l as P
71851	Nitrate	mg/l as NO_3
70301	Dissolved solids	mg/l
70302	" "	tons/day
410	Total alkalinity	mg/l as $CaCO_3$
70	Turbidity	JTU
930	Dissolved sodium	mg/l as Na
95	Conductivity	umhos at 25°C
900	Total hardness	mg/l as $CaCO_3$

The areas above these eighteen stations defined the subbasins for which we compiled independent variable, or basin attribute values. Table 3 shows the correspondence between our stations and those found on the WRDS database.

From concentrations of eight water quality parameters chosen from the WRDS database (PHOSPHORUS, NITRATE, DISSOLVED SOLIDS, ALKALINITY, TURBIDITY, DISSOLVED SODIUM, CONDUCTIVITY, HARDNESS) we constructed via SPSS (Nie et al. 1975) a simple Pearson correlation matrix. We found TOTAL DISSOLVED SOLIDS highly ($R^2 > 0.97$) and significantly ($p=0.001$) correlated with DISSOLVED SODIUM, CONDUCTIVITY, and HARDNESS. We therefore maintain that DISSOLVED SOLIDS (TDS) is a good surrogate variable for these other three, and that results found for TDS will be valid for DISSOLVED SODIUM, CONDUCTIVITY, and HARDNESS. No further analyses were performed with the latter water quality variables.

The concentration of many water quality parameters depends upon discharge (Lystrom et al. 1978). For these parameters, mean loads ideally should be calculated from instantaneous loads derived from instantaneous concentration/instantaneous discharge relationships. For those parameters where concentration is *independent* of discharge, loads may be calculated from average discharges and average concentrations over the study period. Such loads are calculated from the formula (Lystrom et al.)

$$L_n = 0.986\ C_n Q$$

where L_n is the load in tons/year, C_n the average nutrient concentration in mg/l, Q the mean daily discharge in ft^3/sec, and 0.986 a conversion constant for units.

We must first find whether concentration is dependent upon discharge. One way to do this is a within-parameter analysis of variance test using the variance about the mean of concentrations as one group, and the variance about the log-concentration/log-discharge regression line as the other group. This latter value is the standard error of the estimate, or SEE. All but six of our stations (GRBP, BSBD, BSAC, GRBI, BCGR, HFAG) have both surface water discharge and water quality records,

Table 3. Correspondence between sampling stations in this study and those of the WRDS database.

Our station code	WRDS and USGS code	Site location
GREEN RIVER SECTION		
GRWB	9188500	Green R. at Warren Bridge
GRBP	9192600	Green R. at Big Piney
NFAB	9201000	New Fork at Boulder
NFBP	9205000	New Fork at Big Piney
GRLB	9209400	Green R. at Boulder
GRBF	9211200	Green R. below Fontenelle Reservoir
BSLS	9214500	Little Sandy R.
BSPC	9215000	Pacific Creek
BSAF	9216000	Big Sandy R. at Farson
BSBD	7135*	Big Sandy R. at Bone Draw
BSGB	9216050	Big Sandy R. at Gasson Bridge
BSAC	8011*	Big Sandy R. at Confluence
GRBI	9216300	Green R. at Big Island
BCGR	9216950	Bitter Ck. at Green R.
GRGR	9217000	Green R. at Green R.
BLACKS FORK SECTION		
BFAL	9222000	Blacks Fk. at Lyman
HFAG	9224450	Hams Fk. at Granger
BFLA	9224700	Blacks Fk. at Little America

*U.S. Environmental Protection Agency water quality station

so we were able to obtain the appropriate SEE from a WRDS LOAD program. For stations BSBD, BSAC, and HFAG, which have water quality data, but not surface water discharge figures, discharge data from stations immediately upstream (BSAF,BSGB, and Hams Fork at Kemmerer--WRDS #9223500, respectively) were obtained. An SPSS SCATTERGRAM log-log regression was used to find the SEE for these stations. We used a similar approach for stations GRBI and BCGR, adding same-day discharges from upstream stations on two tributaries (GRBF and BSAC, and Bitter Creek at Salt Wells--WRDS #9216562 and Salt Wells Creek at Confluence--WRDS #9216750, respectively) to obtain discharge estimates. Unfortunately, for station BSAC water quality samples were taken after the discharge period of record, and a regression was not done for this station.

Table 4 shows that of the five water quality parameters tested by analysis of variance, only DISSOLVED SOLIDS concentration had a significant difference between SEE's and variance about the mean concentration. Therefore, annual loads for the other three variables (TURBIDITY was analyzed as Jackson turbidity units) were calculated, by the previously given equation, from average concentration and mean annual discharge for our 15-year period of study. Since one of our original nine water quality parameters was DISSOLVED SOLIDS load (tons/day), we used these data for our corresponding regression analyses, rather than converting DISSOLVED SOLIDS concentrations to daily loads via the regression equation and averaging.

Table 4. Significant differences between standard error of the estimate (SEE) of concentration gathered from a log-concentration/log-discharge regression, and variance (s^2) about the concentration mean. Data are presented for five water quality parameters.

PARAMETER	SEE	S^2	F RATIO	F PROBABILITY
Phosphorus	.7182	.6870	.127	.7255
Nitrate	.5975	.3847	3.19	.0879
Dissolved solids	.1037	.1967	20.5	.0002**
Alkalinity	.0768	.0910	1.15	.3083
Turbidity	.5321	.5750	.280	.6027

Our dependent variables in multiple regression analyses were, then, mean annual loads of phosphorus, nitrate, dissolved solids, and alkalinity. Turbidity is measured in Jackson turbidity units of opacity; a "load" of turbidity would not be very informative unless one could convert that opacity into another variable such as suspended solids mg/l.

Point Source Variables

From information supplied by the Wyoming Department of Environmental Quality (Wagner 1984) we calculated annual phosphorus and nitrate loads contributed by permitted discharges in each subbasin (Appendix B). These figures were subtracted from combined source loads to yield values for non-point source loads. We then generated models specifically from these non-point loads as well.

Regressions

All five of the water quality parameters initially had a *common* set of independent variables (Appendix C). Pearson correlation analyses (Nie et al. 1975) of each dependent variable with this common set, both normally and log-transformed, were used to cull those independent variables which were not significantly ($p=0.05$) correlated with the dependent variable in a simple bivariate relation. Thus, each of the water quality parameters had a *unique* set of associated basin attributes eligible for further analyses.

These Pearson analyses also showed many high ($r^2>0.6$) correlations, termed multicollinearity, among basin attributes in each unique set. Multicollinearity can seriously violate assumptions of the multiple regression technique, and "...in some situations render the regression model almost useless" (Montgomery and Peck 1982). We therefore structured our regression analyses to exclude variables with high intercorrelation from the regression models. For the regression method we chose Hull and Nie's (1981) stepwise NEW REGRESSION, with *probabilities* of F-to-enter and F-to-remove at default values of 0.05 and 0.10 respectively. Tolerance at 0.4 ensured that once a variable was entered, another variable intercorrelated with it at $r^2>0.6$ would not be considered; conversely, if a variable was removed on a step, those highly intercorrelated would then be eligible for inclusion in the succeeding step.

Our first regressions were of a water quality parameter against its unique set of associated permanent and temporal basin attributes. To not overfit the regression equation, a rule of thumb is that the number of independent variables considered should not exceed the number of cases (number of stations). So, our next series of regressions were made using subsets of the unique sets of basin attributes.

Our interpretation of regression results to find the "best" association of water quality with basin attributes hinged on objective criteria and one somewhat philosophical principle. Our first criterion was that a good regression equation explains most of the variance about the dependent variable (i.e., has a higher adjusted R^2), and has a lower measure of error (in this case, a lower residual mean square) than would an equation with a poorer fit. The residual mean square is especially helpful for comparing the accuracy of different models of the same water quality variable. Our second criterion was that the equation minimize combinations of strongly interacting independent variables, as defined by a correlation of $r^2>0.60$. Also, a better equation should more closely fit a 1:1 normal probability plot of observed versus expected standardized residuals (standardized residuals are the portions of variance not explained by the model, adjusted to mean=0 and standard deviation=1). Inspection of such a plot, especially its shape, provides information on how variances are distributed.

Given these criteria, we tempered their strict application by the philosophy that "...a relationship may be statistically significant without being substantively important" (Milliken and Johnson 1984). Lystrom et al. 1978 also chose their best models based on other-than-statistical criteria; that is, "conceptual knowledge of the water-quality processes". In other words, if a regression was best statistically, but we could find no conceptual reason for the association of its basin attributes with water quality, we chose a statistically less good but conceptually more sensible model.

All SPSS analyses were conducted on a Control Data Corporation Cyber 760 computer.

RESULTS

Combined Source Regressions

Initial Regressions

The results of our initial stepwise regressions of permanent and temporal basin attributes on the water quality effects of point and non-point sources (combined sources) are shown in Table 5. Dependent variables are expressed as water quality parameter loads, except for TURBIDITY, which was modeled as JTU. Independent variables were chosen from the unique sets of basin attributes, both normal and log-transformed, significantly ($p=0.05$) correlated with the dependent variable in a bivariate regression. Colinearity ratio is the number of off-diagonal high correlations ($r^2>0.6$) of independent variables divided by the total number of off-diagonal correlations; it is a measure of multi-collinearity in the independent variable data set. "Fit" of the probability plot of standardized residuals is a rating of excellent, good, fair, or poor, based on inspection.

All of the models in Table 5 explain over eighty percent of the variance in the water quality parameters, four of which do so with only a

Table 5. Initial regression models associating Green River basin water quality with basin attributes*. The models are derived from combined source (point and non-point) water quality data and both permanent and temporal basin attributes.

REGRESSION EQUATION	(ADJUSTED R2)/ (RESIDUAL MEAN SQUARE)/ (FIT OF RESIDUAL PLOT)	(# ATTRIBUTES CONSIDERED)/ (COLINEARITY RATIO)
TURBIDITY (JTU) = 21.2 + 2.29 (EXPOS)	0.844/565/GOOD	6/0.07
PHOSPHORUS (TONS/YEAR) = 1.76 + 5.59 (URBAN)	0.890/6.00/EXCELLENT	50/0.23
ALKALINITY (TONS/YEAR) = 1.56×10^3 + 64.0 (QUART)	0.973/1.87 X 101/FAIR	41/0.31
NITRATE (TONS/YEAR) = 2.77 + 7.52×10^{-3} (FLOOD25)	0.844/421.7/FAIR	36/0.37
DISSOLVED SOLIDS (TONS/YEAR) = 2.56×10^4 + 88.4 (STREAMLENGTH) + 211 (PINE)	0.963/1.23×10^9/GOOD	30/0.48

*For a full explanation of attribute names, see Appendix C.

single basin attribute. Four of the models violate the rule of thumb that the number of independent variables initially considered shouldn't exceed the number of cases (i.e., since each of our stations is a case, the number of variables should be eighteen or fewer), and at least two of the models could fit the standardized residuals probability plot better. While there is no generally accepted value of colinearity ratio above which multicollinearity is a problem, three of the models have colinearity ratios above 0.30.

Although several specialized regression methods (e.g., ridge regression, principal components regression, and latent roots regression; see Montgomery and Peck 1982) can deal with multicollinearity in independent data sets, two other tactics may be used to minimize associated problems. First, one can create a new variable which is a composite of a set of highly intercorrelated variables (via factor analysis, cluster analysis, or other multivariate techniques). Second, one may choose only one variable from the set of intercorrelated variables to act as a representative of that set. This may be done by principal components analysis or the "conceptual knowledge" noted by Lystrom et al. 1978. To reduce the number of intercorrelated basin attributes in our data sets, we chose representative variables from sets of intercorrelated variables by using our knowledge of the basin and the data set.

Final Regressions

Aside from reducing intercorrelation within a data set, another reason to remove variables from consideration is to investigate the effects of specific basin attributes upon water quality. We wished to find a model which could be used to estimate change in combined phosphorus from human-induced or natural changes in basin attributes. This required eliminating permanent basin characteristics from consideration as a first step, then selecting an appropriate model from a set of models derived from temporal basin attributes and combined phosphorus loadings.

The final models listed in Table 6 should not be considered as the "best" or "only" associations of basin attributes with water quality. Between the initial regressions and the final regressions, many others were evaluated. These intermediate models were indeed valid statistical models; succeeding trials, however, yielded models which had a higher adjusted R^2, lower residual mean square, better fit of the probability plot of residuals, and/or seemed conceptually more sound. The final regressions, then, are the optimum models found in the set of models which we derived, but by no means are the only, or only good, models of water quality in the Green River basin.

The final model for TURBIDITY (Table 6) was also the initial model tried. ALKALINITY load is better estimated by the final model, with slightly more variance explained and slightly less error in the residuals, but with considerably better fit of the standardized residuals to a normal probability plot. The initial model for NITRATE is the same as the final model, but the final model was derived from fewer independent variables. It was difficult to develop adequate models for NO_3, perhaps because its concentration was very nearly dependent upon discharge (Table 4) at our criterion of $p=0.05$. Although the final model for DISSOLVED SOLIDS load shows a reduction in variance explained and an increase in residual mean square, the dramatic increase in fit of the standardized residuals to the 1:1 probability plot justified the choice of the final, rather than the initial, model.

Table 6. Final regression models associating water quality with attributes* of the Green River basin. The models are derived from combined source water quality data (point plus non-point). The PHOSPHORUS model B is inferred from temporal basin attributes only; all others from both temporal and permanent attributes.

REGRESSION EQUATION	(ADJUSTED R2)/ (RESIDUAL MEAN SQUARE)/ (FIT OF RESIDUAL PLOT)	(# ATTRIBUTES CONSIDERED)/ (COLINEARITY RATIO)
TURBIDITY (JTU) = 21.2 + 2.29 (EXPOS)	0.844/565/GOOD	6/0.07
ALKALINITY (TONS/YEAR) = 4.00 (FLOOD25) + 4.73 X 10^4 LOG(MINSLOPE) - 3.06 X 10^4	0.976/1.62 X 10^7/EXCELLENT	12/0.20
NITRATE (TONS/YEAR) = 2.77 + 7.52 X 10^{-3} (FLOOD25)	0.844/421.7/FAIR	12/0.32
DISSOLVED SOLIDS (TONS/YEAR) = 3.22 X 10^4 + 120 (STREAMLENGTH)	0.921/2.61 X 10^9/EXCELLENT	6/1.00
MODEL A PHOSPHORUS (TONS/YEAR) = 0.691 + 2.81 X 10^{-3} (AREA)	0.849/8.25/EXCELLENT	14/0.19
MODEL B PHOSPHORUS (TONS/YEAR) = 0.848 + 4.71 X 10^{-3} (STREAMLENGTH)	0.833/9.16/GOOD	15/0.36

*For a full explanation of attribute names, see Appendix C.

The PHOSPHORUS load modeled by considering both permanent and temporal basin attributes may be better modeled, in terms of a more accurately and easily measured attribute and lower number of attributes, by PHOSPHORUS model A in Table 6. PHOSPHORUS model A incorporates a permanent attribute, subbasin area (AREA),as the independent variable.

To derive a PHOSPHORUS model suitable for calculating effects of mitigation of load by altering management practices in the basin, PHOSPHORUS model A would not be suitable. The initial PHOSPHORUS model (Table 5) does incorporate a temporal variable, urban area in the subbasin (SURBAN), but we felt that measurement of this attribute was not as accurately measured as other variables (see "Discussion"). Also, the number of independent variables considered in the initial model was 50. This far exceeds the number of cases in the analysis. We selectively removed all permanent attributes, then removed temporal attributes from consideration until we determined that PHOSPHORUS model B was the best overall from the set of models tested.

A measure of model accuracy is the standard error of the estimate. Unlike the residual mean square, which was used to compare accuracy of models generated for the same water quality parameter, the standard error of the estimate (SEE) is used to compare the accuracy of models of different water quality parameters. To compare models of different parameters, however, the SEE must be standardized by calculating it as a percent of the mean of the observed parameter values. Table 7 gives the standard error of the estimate for our final models as such a percentage.

Table 7. Accuracy of the final combined source regression models as illustrated by their percent standard error of the estimate (PERCENT SEE).

PARAMETER	PERCENT SEE
TURBIDITY	51
ALKALINITY	16
NITRATE	34
DISSOLVED SOLIDS	27
A MODEL PHOSPHORUS	41
B MODEL PHOSPHORUS	43

Accuracy of the Predicted Water Quality Values

From the models in Table 6 we generated predicted loads (Table 10). The measures of accuracy of a model (e.g., percent standard error of the estimate, residual mean square) tell how well the model fits the data used to generate it. Only by comparing the predicted values to independent estimates of the same parameters can we tell how well the model fits the actual processes. We were able to do this for phosphorus load and for dissolved solids, since other's estimates of loads in the Green River basin are available.

Estimates for phosphorus loading into Flaming Gorge Reservoir, about 20 miles downstream of Green River city, have been made by Southwestern Wyoming Water Quality Planning Association (1978), and by personnel in the predecessor agency of the Wyoming Water Research Center--the Wyoming Water Resources Research Institute (WRRI; 1977). The former reference calculated a combined load of 295 tons per year (t/yr), but neglected to mention in which form phosphorus was reported. If phosphate, $PO_4^{=}$, their results would be equivalent to a P load of 96 t/yr. The latter reference above calculated a phosphate load, which they refer to as a phosphorus load, of 84 t/yr. This converts to a P load of 27 t/yr, which is exactly our phosphorus (P) prediction at Green River city (GRGR; see Table 10).

Note that the difference in predicted DISSOLVED SOLIDS loads between the Green River stations below Fontenelle Reservoir (GRBF) and at Green River city (GRGR) is 375840 t/yr (701320 t/yr-325480 t/yr = 375840 t/yr). We included the contribution of Bitter Creek at its confluence with the Green River (BCGR), 178720 t/yr, in the difference estimate. DeLong, in his 1977 study of dissolved solids in the lower Green River, did not. If we subtract BCGR's predicted contribution to the difference, our predicted difference in DISSOLVED SOLIDS load between GRBF and GRGR is 375840 t/yr - 178720 t/yr, or 197120 t/yr. This compares favorably with DeLong's estimate of 202000 t/yr difference between the two stations.

Another estimate of DISSOLVED SOLIDS at Green River city (GRGR) is 826926 t/yr (Wyoming Water Resources Research Institute 1977). This figure is less than 20% greater than our prediction of 701320 t/yr.

Point Source Inputs

Permitted discharges in the Green River basin are routinely monitored for only two of our water quality parameters--nitrate (NO_3) and phosphorus (total P) concentrations. The estimated loads from contributing subbasins in the Green River basin are listed as Appendix B. Since by definition the difference between the combined load and the point source load is the non-point source load, we were able to specifically model non-point sources in the watershed as we modeled combined sources.

Non-point Source Regressions

We used two approaches to modeling non-point source regressions. First, we used non-point source data in our combined source PHOSPHORUS model B (Table 6) and compared the results to those obtained from combined source data. Secondly, we derived non-point source models for PHOSPHORUS from non-point source data just as we obtained PHOSPHORUS models from combined source data.

Non-point Source Phosphorus Loads Applied to Combined Source Model B

A comparison of the combined source PHOSPHORUS model B (from Table 6) using both combined source loads and non-point source loads is shown in Table 8. Though the combined source model explains 91% of the variance, the plot of the standardized residuals was so poor that we felt the assumptions of multiple regression analysis may not have been met.

Table 8. Comparison of regression metrics for the combined source (point and non-point) PHOSPHORUS model B, i) using combined source and ii) non-point source loads as input data.

METRIC	COMBINED SOURCE	NON-POINT SOURCE
VARIABLE(S) IN MODEL:	STREAMLENGTH	FLOOD25, JUNIPER
VALUE OF ADJUSTED R^2:	0.833	0.912
RESIDUAL MEAN SQUARE:	9.16	1.30
PERCENT STANDARD ERROR OF THE ESTIMATE:	43	22
FIT OF RESIDUAL PLOT:	GOOD	POOR

Non-point Source Model

Parameters for the final PHOSPHORUS non-point source model calculated from temporal basin attributes and non-point source loads are shown in Table 9. Only 71% of the variance in non-point source loads is explained by the model, and there is only a fair fit of the plot of standardized residuals. This model reflects, however, nearly the best fit found and the highest variance explained in the set of models we formulated and tested. In addition, it incorporates a basin attribute, the discharge of the 25-year flood (FLOOD25), which we felt was more accurately measured than land cover/land use attributes included in intermediate non-point source PHOSPHORUS models.

Table 11 lists the predicted non-point source PHOSPHORUS loads from each subbasin in the Green River drainage. A one way analysis of variance of these predicted non-point source results against predictions of the combined source PHOSPHORUS Model B (Table 10) predictions showed a significant difference between the two sets of preloads.

Table 9. Final regression models associating non-point source PHOSPHORUS loads with temporal attributes* of the Green River basin.

REGRESSION EQUATION	(ADJUSTED R2)/ (RESIDUAL MEAN SQUARE)/ (FIT OF RESIDUAL PLOT)	(# ATTRIBUTES CONSIDERED)/ (COLINEARITY RATIO)
NON-POINT SOURCE PHOSPHORUS (TONS/YEAR [T/YR]) =		
$1.159 + 5.15 \times 10^{-2}$ (FLOOD25)		
	0.707/4.34/FAIR	5/0.10

*For a full explanation of attribute names, see Appendix C.

Application of Combined Source Models to Locate Subbasins which are Major Sources (see Table 10)

We applied the six final combined source models (Table 6) to basin attributes in our original data set to estimate loads exiting each of our 18 subbasins (Table 10). We assumed that all water falling upon,

Table 10. The values in this table were predicted from combined source models in Table 6. Presented are i) predicted combined source (point plus non-point) loads, ii) low and high values of the 95% confidence interval, and iii) increase in load contributed between each station in the Green River watershed.

CODE	TURBIDITY (JTU)				ALKALINITY (T/YR)		NITRATE (T/YR)			
	Pred.	Low	Hi	Increase	Pred.	Increase	Pred.	Low	Hi	Increase
GRWB	21±13.5	8	35	21	2083	2083	37±11.4	26	48	37
GRBP	21±13.5	8	35	0	20020	17937	55±10.3	45	65	18
NFAB	21±13.5	8	35	21	-5767	-5767	49±10.5	39	60	49
NFBP	21±13.5	8	35	0	3434	9201	67±10.4	57	77	18
GRLB	21±13.5	8	35	-21	53689	30235	134±19.2	115	153	12
GRBF	21±13.5	8	35	0	55690	2001	138±19.9	118	158	4
BSLS	21±13.5	8	35	21	-13519	-13519	8±15.3	-7	23	8
BSPC	21±13.5	8	35	21	2131	2131	11±14.9	-4	26	11
BSAF	21±13.5	8	35	-21	4018	15406	25±12.8	12	38	6
BSBD	21±13.5	8	35	0	4018	0	25±12.8	12	38	0
BSGB	21±13.5	8	35	0	20020	16002	55±10.3	45	65	30
BSAC	21±13.5	8	35	0	20020	0	55±10.3	45	65	0
GRBI	21±13.5	8	35	-21	77627	1917	164±24.9	139	189	-29
BCGR	21±13.5	8	35	21	17	17	18±13.8	4	32	18
GRGR	21±13.5	8	35	-21	60025	-17619	131±18.6	112	150	-51
BFAL	170±81.4	89	251	170	-12568	-12568	37±11.5	26	49	37
HFAG	21±13.5	8	35	21	2018	2018	22±13.3	9	35	22
BFLA	214± 104	110	318	22	16019	26569	48±10.6	37	59	-11

Table 10 continues

Table 10 (continued). The values in this table were predicted from combined source models in Table 6. Presented are i) predicted combined source (point plus non-point) loads, ii) low and high values of the 95% confidence interval, and iii) increase in load contributed between each station in the Green River watershed.

CODE	PHOSPHORUS MODEL A (T/YR)				PHOSPHORUS MODEL B (T/YR)				DISSOLVED SOLIDS (T/YR)			
	Pred.	Low	Hi	Increase	Pred.	Low	Hi	Increase	Predicted	Low	Hi	Increase
GRWB	2±1.9	0.1	3.9	2	2±1.9	0.3	4.1	2	66880±31600	35280	98480	66880
GRBP	4±1.7	2.3	5.7	2	4±1.7	2.4	5.7	2	113440±28052	85388	141492	46560
NFAB	2±1.9	0.1	3.9	2	2±1.9	-0.1	3.7	2	56800±32509	24291	89309	56800
NFBP	4±1.7	2.3	5.7	2	3±1.7	1.5	5.0	1	93760±29398	64362	123158	36960
GRLB	11±1.6	9.4	12.6	3	11±1.8	9.4	12.9	4	295120±30043	265077	325163	87920
GRBF	12±1.7	10.3	13.7	1	12±1.9	10.4	14.3	1	325480±32678	292802	358158	30360
BSLS	1±2.1	-1.1	3.1	1	1±2.0	-0.6	3.4	1	45280±33609	11671	78889	45280
BSPC	2±2.0	.0	4.0	2	2±1.9	0.1	3.9	2	61240±32101	29139	93341	61240
BSAF	5±1.6	3.4	6.6	2	5±1.6	3.5	6.7	2	140200±26645	113555	166845	33680
BSBD	5±1.6	3.4	6.6	0	5±1.6	3.5	6.7	0	140200±26645	113555	166845	0
BSGB	5±1.6	3.4	6.6	0	5±1.6	3.8	6.9	0	147160±26368	120792	173528	6960
BSAC	5±1.6	3.4	6.6	0	5±1.6	3.9	7.0	0	150280±26257	124023	176537	3120
GRBI	20±2.8	17.2	22.8	3	20±3.3	16.7	23.3	2	520600±55922	464678	576522	44840
BCGR	7±1.5	5.5	8.5	7	7±1.5	5.1	8.1	7	178720±25617	153103	204337	178720
GRGR	27±4.3	22.7	31.3	0	27±4.8	22.3	31.9	0	701320±81083	620237	782403	2000
BFAL	3±1.8	1.2	4.8	3	3±1.8	1.0	4.6	3	82600±30263	52337	112863	82600
HFAG	2±1.9	0.1	3.9	2	3±1.8	1.1	4.6	3	83320±30205	53115	113525	83320
BFLA	9±1.4	7.6	10.4	4	8±1.5	6.8	9.9	3	223480±26043	197437	249523	57560

Table 11. Presented are i) Predicted annual loads of non-point PHOSPHORUS, ii) low and high values of the 95% confidence interval, and ii) increase in the predicted annual load contributed by each subbasin of the Green River watershed. Values in this table were predicted using the PHOSPHORUS model in Table 9.

CODE	PHOSPHORUS (T/YR)			
	Predicted	Low	Hi	Increase
GRWB	4±1.2	2.8	5.2	4
GRBP	5±1.1	3.9	6.1	1
NFAB	4±1.1	2.9	5.1	4
NFBP	6±1.1	4.9	7.1	2
GRLB	10±2.0	8.0	12.0	-1
GRBF	10±2.0	8.0	12.0	0
BSLS	2±1.6	0.4	3.6	2
BSPC	2±1.5	0.5	3.5	2
BSAF	3±1.3	1.7	4.3	-1
BSBD	3±1.3	1.7	4.3	0
BSGB	5±1.1	3.9	6.1	2
BSAC	5±1.1	3.9	6.1	0
GRBI	12±2.5	9.5	14.5	-3
BCGR	2±1.4	0.6	3.4	2
GRGR	10±1.9	8.1	11.9	-4
BFAL	3±1.2	1.8	4.2	3
HFAG	2±1.4	0.6	3.4	2
BFLA	4±1.1	2.9	5.1	-1

and all groundwater entering a headwater subbasin (i.e., a basin with no riverine inflows) holds no dissolved or particulate material. Therefore, the increase of a water quality parameter from source to mouth in a headwater subbasin, as shown in Table 10, is the same as the value predicted as exiting from the subbasin.

Bitter Creek is the major source of DISSOLVED SOLIDS in the Green River basin, contributing nearly 180000 t/yr. The second greatest contributor is the Big Sandy drainage, which yields about 150000 t/yr at its confluence with the Green (BSAC).

Headwater streams such as the upper New Fork (NFAB), upper Green River (GRWB), Hams Fork (HFAG), and upper Blacks Fork (BFAL) contribute a large part of NITRATE load in the basin. PHOSPHORUS is contributed fairly evenly throughout the basin; Bitter Creek (BCGR) delivers the most at 7 t/yr.

The Green River, rather than the Blacks Fork contributes to Flaming Gorge Reservoir the greater loads of ALKALINITY, NITRATE, DISSOLVED SOLIDS, and PHOSPHORUS. The contribution of these compounds from the Blacks Fork (BFLA) is about one-third of the Green. TURBIDITY in the Blacks Fork, on the other hand, is ten times that in the Green River (GRGR).

The Green River at Green River city, 20 miles upstream from Flaming Gorge Reservoir, contributes a combined source ALKALINITY load of 60025 t/yr, according to the combined source model in Table 6. The NITRATE load, similarly calculated, is 131 t/yr. DISSOLVED SOLIDS from combined sources is 701320 t/yr. From PHOSPHORUS Model B in Table 6, we calculated that 27 t/yr of PHOSPHORUS enters the reservoir via the Green River. Turbidity remains the same throughout the river system.

Loads from the Blacks Fork, calculated identically, are 16019 t/yr of ALKALINITY, 48 t/yr of NITRATE, 223480 t/yr DISSOLVED SOLIDS, and 8 t/yr of PHOSPHORUS. TURBIDITY in the Blacks Fork section is much higher than in the Green. It is 214 JTU at Little America (BFLA) versus 21 JTU at Green River city (GRGR).

Some parameters exhibit a negative increase (i.e., a decrease) in load in some subbasins (Table 10). This may be attributable to error in the models, but it may also signify some physical or even biological transformation or sequestering of the parameter in the subbasin.

DISCUSSION

We discuss the results of our analyses of existing data on the Green River basin as it relates to each of our five originally proposed tasks.

> Task 1: Determine annual and monthly output of point and non-point source nutrients from subbasins in the Green River drainage.

We obtained the data on point source discharges from the Wyoming Department of Environmental Quality (Wagner 1984). They document outfalls from domestic waste treatment facilities and industrial plants. None of the plants was noted as seasonal in its discharge. We assume that discharge from domestic sources is constant. Therefore, output of phosphorus and nitrates from point sources in the basin may be considered uniform from month to month. Monthly loads can be found by dividing the annual loads in Appendix B by 12.

On a percentage basis, a constant outfall of point source nitrate and phosphorus may make seasonally variable contributions to the total load measured of a receiving water. This is because during late summer, fall, and winter when snowmelt flows are low, the contribution of point sources will be proportionally greater than during snowmelt and summer storms. Consequently, loading from point sources will have a proportionally greater contribution to processes in Flaming Gorge during base flow. Algal blooms in the reservoir may be caused by loading from external, internal, or both sources. Since we do not know yet whether eutrophication in the reservoir is driven by in-lake processes or external loading, or both, we cannot estimate the effects of the seasonally higher point source contribution.

We computed annual loadings of non-point source phosphorus simply by subtracting the average annual load of point source phosphorus from the combined annual phosphorus load in each appropriate subbasin. These average annual non-point source loads, computed as the mean from 15 years of data, are required for developing the statistical models required in Task 2, but do eliminate the information about year to year variance. However, winter measurements were not consistently acquired in the Green River drainage (see below), and annual means of loads and discharge would have probably been estimated too high.

Monthly loadings of non-point source nutrients may be found by subtracting daily point source loads from combined source loads, then averaging by month over the period of record. For some stations during all years, and at other stations during some years, flow and chemical data were obtained in the field for only three quarters of the year. Winter (December, January and February, or January, February and March) information is spotty in the WRDS database, so estimates of winter loading may be less accurate than for the other three seasons.

The data required to calculate annual, and therefore monthly loads, was too great by far for manipulation using our COMPAQ microcomputer. We depended upon the University of Wyoming's Cyber mainframes for such manipulation, after writing and debugging our own Fortran programs to do so. And, a modification of the Fortran program which calculated annual loadings could have been used to estimate monthly loads. But since we had originally proposed to use packaged database management software on the COMPAQ, this dependence on the Cyber consumed much more time than anticipated. We felt that other tasks, especially Task 2, should have a greater share of our effort, so average monthly and yearly average non-point source phosphorus loads were not calculated.

Task 2: Develop statistical models of basin water quality as a function of basin attributes.

Constraints Imposed by the Available Data

Investigating and monitoring water quality is performed by institutions only in areas of interest to them or their constituents. Southwestern Wyoming has few inhabitants, and little cropped land. Therefore, water quality sampling stations with a wide range of parameters sampled and a long history of sampling are rare in the basin, confined generally to large streams and rivers, or to areas with water quality problems. We were able to find eighteen stations that generally met our criteria, but even these stations did not have data for all water quality parameters considered in this study.

The fact that water quality stations in the basin are confined to larger watercourses means that water quality models derived from such data are applied best to streams of a similar size, or to basins of a similar size. Therefore, one should be very careful when using our models on, for example, a small alpine stream.

From water quality data in the basin, we were not able to find values for all of our parameters at all of our stations. A basin-wide study of water quality/discharge relationships could disclose which parameters may be reliably estimated by other water quality parameters and/or discharge. For example, the fact that we found a strong relationship between DISSOLVED SOLIDS, DISSOLVED SODIUM, CONDUCTIVITY, and HARDNESS indicates that there may be similar relations between other parameters as well. Such relations would be valuable in estimating values for unmeasured water quality parameters.

The Models--Sensitivity and Application

We have retrieved and compiled information about physical and biological attributes of the basin (Appendix A). Such information is necessarily broad-scale considering the area of the basin, but it is suitable for modeling relationships with water quality in the watershed. The models are appropriate to use in identifying differences from subbasin to subbasin, and for exploring the predicted values for trends or anomalies. For example, predicted nitrate load in the Big Sandy River is significantly higher at the lower two stations (BSGB and BSAC) than the upper four stations (BSPC, BSLS, BSAF, and BSBD; see Table 10 and Figure

6). Only after noting this could we ask questions about the reason for this difference. Is the explanation somehow associated with runoff and return water from the irrigation project along the Big Sandy?

Robust models are those which maintained water quality/attribute associations with small changes in values of the data. Using data on water quality and basin attributes, we developed a series of models calculating water quality as a function of basin characteristics. Although variables of land cover/land use modeled some water quality parameters in our initial efforts (Table 5), more robust models were based on topographical or hydrological features such as area of the subbasin or flood discharge.

Further study is needed to determine the reason for this difference in sensitivity of the two categories of models (i.e., robust and non-robust). We think, however, that it may be due to more accurate measures of hydrological or topographical features as opposed to, for example, land use or cover, or climatological variables. There are fewer than 18 recording weather stations in the basin, from which temperatures and precipitation were extracted. In addition, the stations are not uniformly distributed, and are especially sparse in alpine areas. A measure of channel slope, on the other hand, is based upon altitudinal contour intervals of 200 feet, distributed throughout the basin. Thus measurements of channel slope are probably more accurate than estimates of climatic variables.

There are two implications of the difference in sensitivity of our initial non-robust and final more robust models (note that the robust incorporated easily measured topographical or hydrological variables). First, the initial, sensitive models would respond to small changes in the data. This would give a manager more lead time to formulate responses to predicted changes in water quality. However, the independent variables must be measured very accurately, since the model will respond to slightly erroneous values with altered predictions.

The second implication of the models' differences in sensitivity is that if the more robust models are applied, small but true changes in the data that would cause a response in less robust models would not appreciably change the predictions of the robust models.

Finally, if we assume a cause-effect relation between the basin attribute and water quality variable, it should be possible to see how water quality changes as basin attributes are manipulated. For example, by reducing the magnitude of the 25-year flood from the New Fork (NFBP) subbasin by 25% (from 8500 ft^3/sec to 6375 ft^3/sec; Appendix A), the mean nitrate export should be reduced from 67 t/yr (Table 10) to 51 t/yr.

The Models--Accuracy

As noted in "Results", a model has two types of accuracy. The first type of accuracy reflects how well the model mimics or explains the data used to build it. Measures of such accuracy are the adjusted R^2 and standard error of the estimate of the regression equation. How well the equation mimics the data be translated to a particular predicted value by inspecting the size of the 95% confidence interval of the predicted value. The interval is the range in which we would expect to find our predicted value 95% of the time given the constraints of the data. If it is small, the equation fits the data well at that predicted value.

In Figures 3 and 5 through 9, the confidence intervals are relatively small, with the exception of those loads predicted for non-point source PHOSPHORUS (Figure 9). The latter model does not fit the data quite as well as the two combined source PHOSPHORUS models, which have relatively narrow confidence intervals. Note also that if 95% confidence intervals overlap, the respective predicted values cannot be considered different from each other (p=0.05).

The second type of accuracy reflects how well the predictions of one model fit predictions from an independent test of the data. Such accuracy seems quite good for the final DISSOLVED SOLIDS model. An indication of this accuracy is the close agreement of its prediction for increased load between Fontenelle Reservoir and Green River city with that of DeLong (1977). Though DeLong used a multiple regression technique on a subset of the variables we used, both his approach and independent variables were different from ours. An independently calculated estimate of DISSOLVED SOLIDS load at Green River city (Wyoming Water Research Institute 1977) was within the 95% confidence limits of our value.

Predictions from our PHOSPHORUS models for combined sources (Models A and B, Table 6) closely match those of the Wyoming Water Research Institute (1977) for PHOSPHORUS (as P) near Green River city. Indeed, their estimate of 27 t/yr lies within our prediction's 95% confidence interval. Their calculations used a subset of our data. The Southwestern Wyoming Water Quality Planning Association's 1978 prediction of 96t/yr as phosphorus is three times larger than our upper 95% confidence limit. Their calculations were based primarily upon estimated phosphorus exports per square mile from various land types.

The close agreement of our estimates with those of others, some using a subset of our data, some independent, argues for the value of the multiple regression approach to predicting water quality in this study.

The Models--Use of Subjective Criteria for Choosing Independent Variables

One of our subjective criteria for choosing a basin attribute to include in the data set for a model was ease and accuracy of measuring the attribute. Since, for example, channel slope (CHANS) is more accurately measured than mean precipitation (PPT2), as discussed above, we would choose channel slope over precipitation as an independent variable from the set of those significantly correlated with water quality. This not only improves accuracy of the resulting model, but also makes subsequent application of the model easier. In a highly correlated matrix of independent variables, all of which are significantly correlated with the dependent variable, subjective criteria were frequently applied to choose basin attributes for inclusion in model building.

It would be interesting to apply multivariate statistical techniques to the attribute data sets to determine if any underlying structure or "supervariables" exist. For example, if the attributes of minimum temperature, maximum slope, alpine vegetation and annual precipitation were all highly intercorrelated, the underlying supervariable could be classified as some type of altitudinal relation. Using principal components or factor analysis, we could quantify these supervariables and use them as basin attribute values in models of water quality. This would not help subsequent application of the model, since factors and principal components are not directly measurable in the field. But it might help in deciding which of a set of intercorrelated basin attributes to choose in building an improved model.

The Results--Annual Export and Allocation of Mitigation Efforts

Table 12 lists the annual absolute and areal export of our water quality parameters from the Green River and Blacks Fork sections of the basin. These may be considered annual loads received by Flaming Gorge Reservoir.

Table 12. Annual export of selected water quality parameters from the Green River basin to Flaming Gorge Reservoir.

PARAMETER	GREEN RIVER SECTION		BLACKS FORK SECTION	
	Absolute (t/yr)	Areal (t/yr/mi^2)	Absolute (t/yr)	Areal (t/yr/mi^2)
PHOSPHORUS as P (MODEL B)	27	0.003	8	0.003
NITRATE as NO_3	131	0.014	48	0.016
DISS. SOLIDS	701320	74	223480	77
ALKALINITY	60025	6	16019	5
TURBIDITY	21 JTU	N/A	214 JTU	N/A

Since both sections of the drainage have the same areal contribution of constituents to the reservoir, there would be no advantage in concentrating mitigation efforts in one basin over the other. This simple conclusion does not consider in-reservoir processes, however, which could exacerbate eutrophic symptoms in one arm of the reservoir even if each arm receives equal loading. Nor does it account for the fact that the Green River section has about three times more area than the Blacks Fork section.

Comparison of areal loading as a way to allocate mitigation practices can be applied to other water quality parameters and other areas in the Green River watershed. In the example above, we calculated annual loading from two entire subbasins. We also can calculate areal loadings from each of the stream sections *between* stations. This is done as:

Difference = increase in loading from section between stations = (areas of subbasins located upstream of the station of interest) - (total area above and including the station of interest)

The area subtracted is considered noncontributing. By dividing the increase in loading (i.e., the columns labeled "Increase" in Table 10) by the contributing drainage area, we calculate the areal loading arising from land *between* stations. The results of such calculations are shown graphically in Figures 10 through 15.

Mitigation efforts generally must be applied where one can reap the most benefit from a limited investment. Those areas between stations which have higher areal loadings are probably better candidates than areas with lower areal loadings. Thus practices to mitigate loading of DISSOLVED SOLIDS (Figure 11) would best be applied to the Little Sandy and Pacific Creek above BSLS and BSPC, with secondary attention to the Green River above GRWB and the Hams Fork above HFAG.

Steps to mitigate nutrient export would be most effective for combined source PHOSPHORUS in, again, the Little Sandy and Pacific Creek, the Green River above GRWB (Figures 13 and 14), and either the Hams Fork (Figure 14) or Blacks Fork (Figure 13) above BFAL. Combined source NITRATE could be most effectively controlled on the Big Sandy between BSBD and BSGB, shortly before the confluence with the Green River (Figure 12). Other good candidate areas for NITRATE control are the Little Sandy, Green River above station GRWB, and the New Fork above NFAB.

PHOSPHORUS from non-point sources has a greater loading per square mile in the Big Sandy between BSBD and BSGB, the Little Sandy above station BSLS, the Green above GRWB, and the New Fork above NFAB. Mitigation strategies to reduce non-point source PHOSPHORUS perhaps could be best applied in these areas.

The most obvious area for controlling loading of ALKALINITY is on the Big Sandy between stations BSBD and BSGB (Figure 10).

We must apply two caveats to the above discussion. First, notice that many of the areas with high loadings are headwater portions of watercourses. The high loadings may be an artifact of the assumption we made in computing increases in absolute loading between stations. The assumption was that the loading calculated at headwater stations was in fact entirely derived from the area above that station.

If the above assumption holds, the second caveat is that we based our rating of "suitability for mitigation" soley upon the magnitude of areal loading. This may not be the best or only criteria to use when making such decisions. Entirely aside from transportation costs to headwaters versus areas more conveniently located, land ownership, etc., proximity to the mainstem Green River or Flaming Gorge Reservoir may be as important as areal loading. The effect of loading contributed by an area may be magnified, as far as processes in Flaming Gorge Reservoir are concerned, by the proximity of its source to the reservoir. This is because many processes in rivers that tend to alter water quality constituents have relatively little time act on the inflow of proximal streams.

The Results--PHOSPHORUS loading from Combined and Non-point Sources

We found a significant difference between annual PHOSPHORUS loads predicted by PHOSPHORUS Model B for i) combined sources (Table 10) and ii) non-point sources (Table 11). By definition the mathematical difference between these two predicted loads is the predicted point source load [(combined load) - (non-point source load) = (point source load)]. Performing these calculations for point source loading at Green River city (GRGR) yields a value of 17±7 t/yr (mean ± 95% confidence limit; 10 to 24 t/yr). We make two important points using these values:

1) The predicted value for point sources of PHOSPHORUS is within 60% of the value calculated using data on discharge permits (Appendix B): [100-(39 t/yr*100)/(24 t/yr)].

2) The predicted annual PHOSPHORUS load from point sources ranges from 31% to 92% of the predicted combined load. These values seem considerably larger (1.8 to 5.4 times larger) than the estimate of 17% made by the Southwestern Wyoming Water Quality Planning Association (1978).

As yet we cannot say from our calculations if reduction of point sources of phosphorus in the Green River basin would allieviate eutrophication in Flaming Gorge Reservoir. To do this requires interpreting how a reduced load affects algal blooms, etc. in the reservoir.

The Results--Focusing Mitigation Efforts

Paramount in discussing the results of these models and their practicality for determining where mitigation of loading should be addressed is the fact that these *are not* models of cause and effect. They model an association between the way in which a water quality parameter varies in the drainage and the way one or more basin attributes vary. This association in no way implies that a change in the basin attribute will cause a corresponding change in water quality. We therefore must *assume* such a cause-effect relationship to discuss predicted changes in water quality as a function of changing a basin attribute.

One way these models are useful does not require our making that assumption. To do so we apply our model equation to a subbasin where only the independent variable, or basin attribute, is known, and predict the corresponding water quality value. This value will be bounded by a 95% confidence interval for extrapolations, which is somewhat larger than the 95% confidence interval for interpolated estimates of water quality. In this way the model can be used to rank portions of a larger basin by their loadings, even if water quality samples have not been acquired.

Assuming a cause-effect relationship for our associations, most of the final regression models (Table 6) show changes in water quality as a function of hydrological or topographical basin attributes (e.g., floods, slope, area). For example mitigation to reduce the magnitude of the 25-year flood (FLOOD25) and/or total length of stream courses in the subbasin (STREAMLENGTH) is predicted to reduce export of PHOSPHORUS, DISSOLVED SOLIDS, NITRATE, and ALKALINITY. While it would be imprudent to start a large mitigation effort based only on our models, they do suggest generally what variables should be considered.

In reality, almost always we would focus mitigation efforts not on reducing the value of the independent variable itself (e.g., 25-year flood). Rather, we would need to mitigate via a secondary factor which would have an effect on the independent variable of the regression model. For example, increased vegetative cover will alter runoff patterns and should decrease the peak discharge of a 25-year flood. Similarly, extensive complexes of beaver dams should markedly decrease the peak discharge during storm events, including a 25-year storm.

If the models do not involve variables which are those we directly alter during mitigation, then how are the models useful? In at least two ways. First, they can suggest the magnitude of change which must occur to reduce export by a given amount. We will see below, for example, that a mean reduction of the 25-year flood in the Bitter Creek by 100 ft3/sec produces about a 60% reduction in the export of phosphorus predicted by PHOSPHORUS Model A. This reduction is equivalent to that which might be produced by extensive complexes of beaver dams.

Second, the models are useful because of what they suggest in a more general way. As mentioned above, topographic and hydrologic attributes are those which the models use to predict water quality. That is, the models can be interpreted to suggest that topography and hydrology control water quality. In most of the Green River drainage this seems reasonable. Lowham et al. (1982) suggests that banks or bank erosion are important sources of sediment and dissolved substances. Our work with beaver dam complexes (Maret 1985) strongly supports such a conclusion. Roseboom (1985) found that "...bank erosion from just seven bank erosion sites represents a significant proportion of the sediment, phosphorus, and ammonia leaving the entire watershed..." Although Roseboom's work was performed in Illinois, it quantifies the major role which may be played by bank erosion as a process producing sediments and nutrients.

Thus the independent variables of the regression models are those experimental work has found to be important in affecting water quality. And, we can see why mitigation measures secondary to variables in the regression models would be appropriate to use. In general these measures relate to reducing bank erosion, by stabilizing banks and/or by reducing the power of water to erode by reducing water velocity. One possibly important alternate mitigation measure might be reducing point source loading during periods critical for the development of blooms in the reservoir.

Task 3. Determine temporal and biological availability of nutrients from point and non-point sources.

Because of the few data collection sites, episodic sampling dates, and especially because of the inconsistent sampling of bioavailable forms of nutrients (e.g., orthophosphorus, ammonia nitrogen), we were not able to use existing data to determine temporal or biological availability of nutrients from either non-point or combined sources. One may assume that a high proportion of point source domestic discharges are bioavailable. Though we cannot estimate the proportion, we can assume that they are temporally constant flowing into the receiving water. Their contribution to the load in the stream should be proportionally greater during base flow periods.

Task 4. Determine availability of nutrients from dislodged benthic algae.

We did not accomplish Task 4, which was to determine availability of nutrients from dislodged benthic algae in the Green River. Lack of data on such principal variables as algal biomass and production, rates and timing of sloughing, and chemical composition of the algae were critical in our decision not to pursue Task 4 with data that does exist. The 7 t/yr decrease in NITRATE load (138 t/yr - 131 t/yr; Table 10) in the Green River between Fontenelle Dam (GRBF) and Green River city (GRGR) may warrant further study, but the stations are not significantly different in NITRATE load (Figure 6).

Task 5. Determine the extent to which riparian restoration, with or without beaver, improves water quality and decreases nutrient output.

Recent work by Maret (1985) suggests that beaver ponds may play an important role in reducing phosphorus export in a stream. This research was performed on Currant Creek, a second order stream which flows into the northeast section of Flaming Gorge Reservoir. Beaver ponds serve as traps for particulates, since water flowing into a pond slows and deposits part of its sediment load. Phosphorus sorbs strongly to sediments, so concentrations of phosphorus in the water decrease as sediments are removed. Three factors appear to be important in determining if beaver ponds will reduce the phosphorus load in a stream. These factors are all associated with the transport of sediments. The factors are:

1) FLOW. The greater the water velocity, the greater the capacity for stream bank and channel erosion. Evidence also indicates that ponds are more effective at reducing phosphorus export at high flows than at base flow.

2) SUBSTRATE. More sediment (and accompanying phosphorus) will enter the stream from erosion if the stream bottom and banks consist of easily erodable materials.

3) LOCATION OF THE PONDS. The importance of location (e.g., headwaters, downstream, etc.) is related to the erodability of substrate. If erodable substrate exists downstream from the ponds, then bank and channel erosion downstream may contribute sediments and nutrients to clean water exiting from the dam complex.

Other factors which may affect the the ability of beaver ponds to retain phosphorus include the area occupied by the ponds and the age of the ponds. Both of these factors are related to the capacity of the ponds to trap and hold additional sediment.

Beaver ponds should have the greatest potential for trapping phosphorus in areas with easily erodable substrates, since concentrations of suspended solids should be high in such waters. However, if easily erodable areas exist between the ponds and the receiving water, bank and channel erosion downstream from the ponds may cause the phosphorus load reaching the receiving water to be as great as that which entered the ponds.

Beside serving as sediment and nutrient traps, beaver ponds also may play an important role in stream channel stabilization. By reducing stream gradient, both erosion and sediment transport rates are reduced (Heede, 1982). With less bank and channel erosion, nutrient export should be reduced.

The capacity of beaver ponds to reduce phosphorus loads depends partly on the functions they perform. Ponds located along an entire stream section which aid both in trapping sediments and in controlling erosion would markedly reduce phosphorus export. Occasional ponds acting primarily to trap sediment but not to reduce erosion would affect phosphorus export less. Maret (1985) found in Currant Creek that beaver ponds reduced annual phosphorus export from a stream section by approximately 20 percent (year to year differences have not been studied, so variability between years in not known). He estimates that stabilizing a highly erosive section of stream with beaver ponds potentially could reduce phosphorus export by as much as 60 percent.

Our model cannot incorporate directly the effects of beaver ponds on phosphorus loads. However, consider export of non-point source phosphorus from Bitter Creek. We can estimate the extent by which FLOOD25 (the independent variable) must decrease in the model of non-point source PHOSPHORUS (Table 6) to produce any given reduction in phosphorus export. And, to reduce phosphorus export by an amount equal to that caused by beaver (above), the 25-year flood by would have to decrease by 100 ft^3/sec.

Task 5 could not be accomplished with the existing data for two reasons. First, though basin attributes which are significantly related to water quality variables (our unique sets of independent variables) included area of wetlands and area of aspen, neither of these variables was included in our final models. We therefore could not use changes in these variables to model associated changes in water quality.

Secondly, the models we did develop usually included hydrological and/or topographical basin attributes. Though activity of beaver may alter these attributes, by reducing peak flows, channel slope, etc., they do so only indirectly. With the existing data, we could not adequately or reliably model the effects of beaver or riparian restoration upon nutrient export from the subbasins.

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Figures 1 through 15

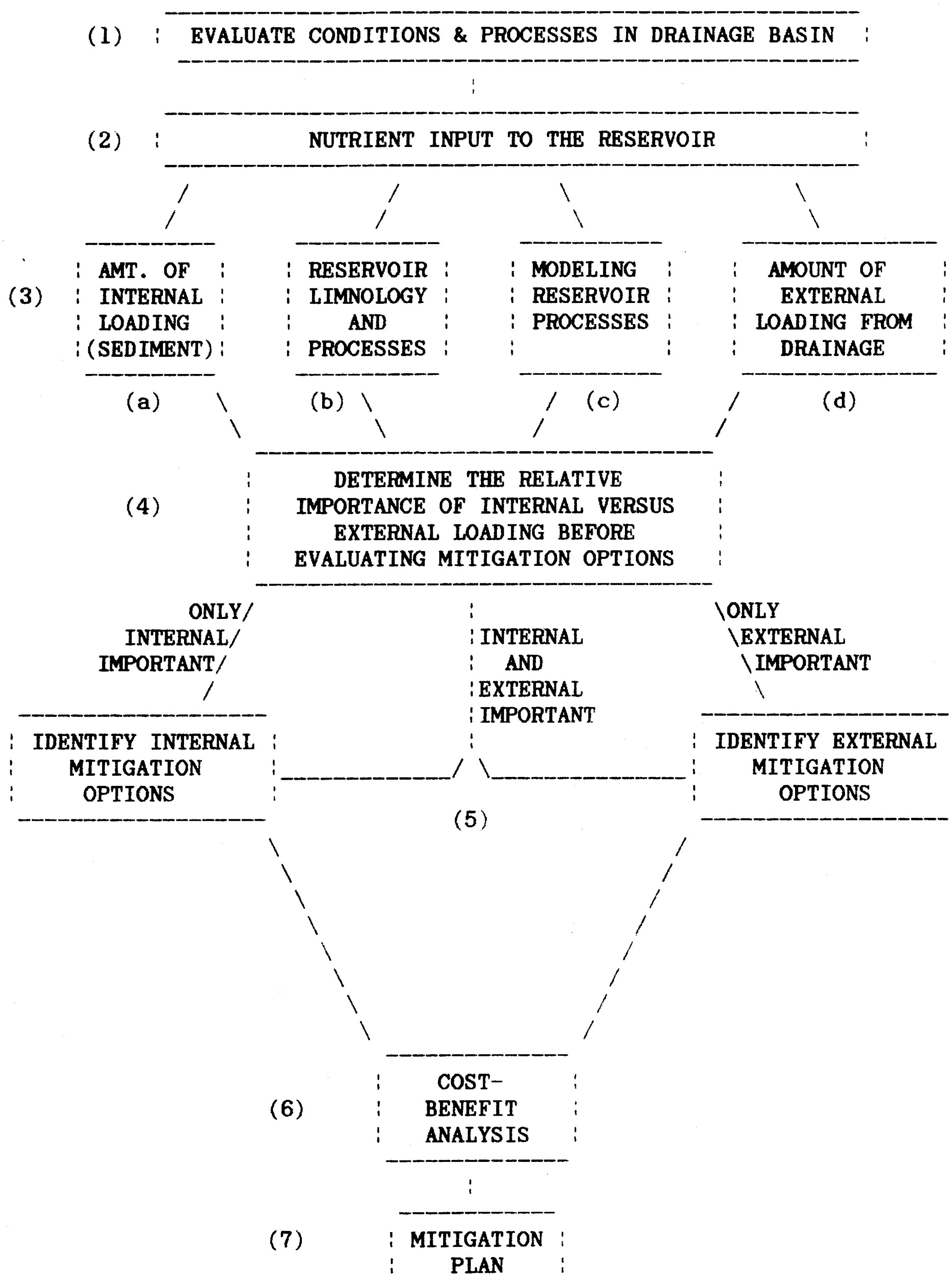

FIGURE 1. A simplified diagram of information, processes and decisions needed to develop a plan for mitigating water quality problems in Flaming Gorge Reservoir.

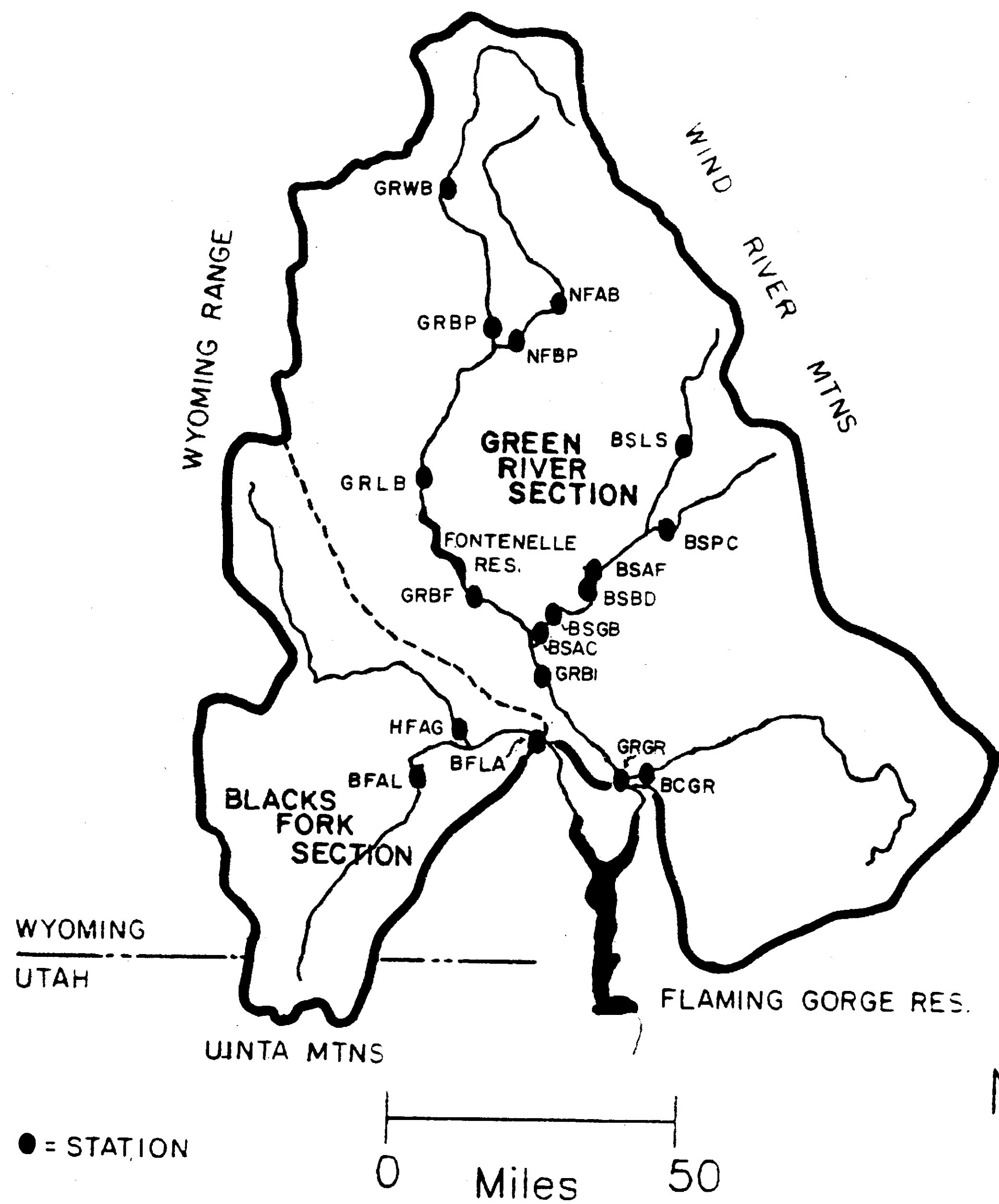

Figure 2. Map of the Green River basin showing i) the Green River section, ii) the Blacks Fork section, and iii) sampling stations in each section. The sections are separated by the dashed line.

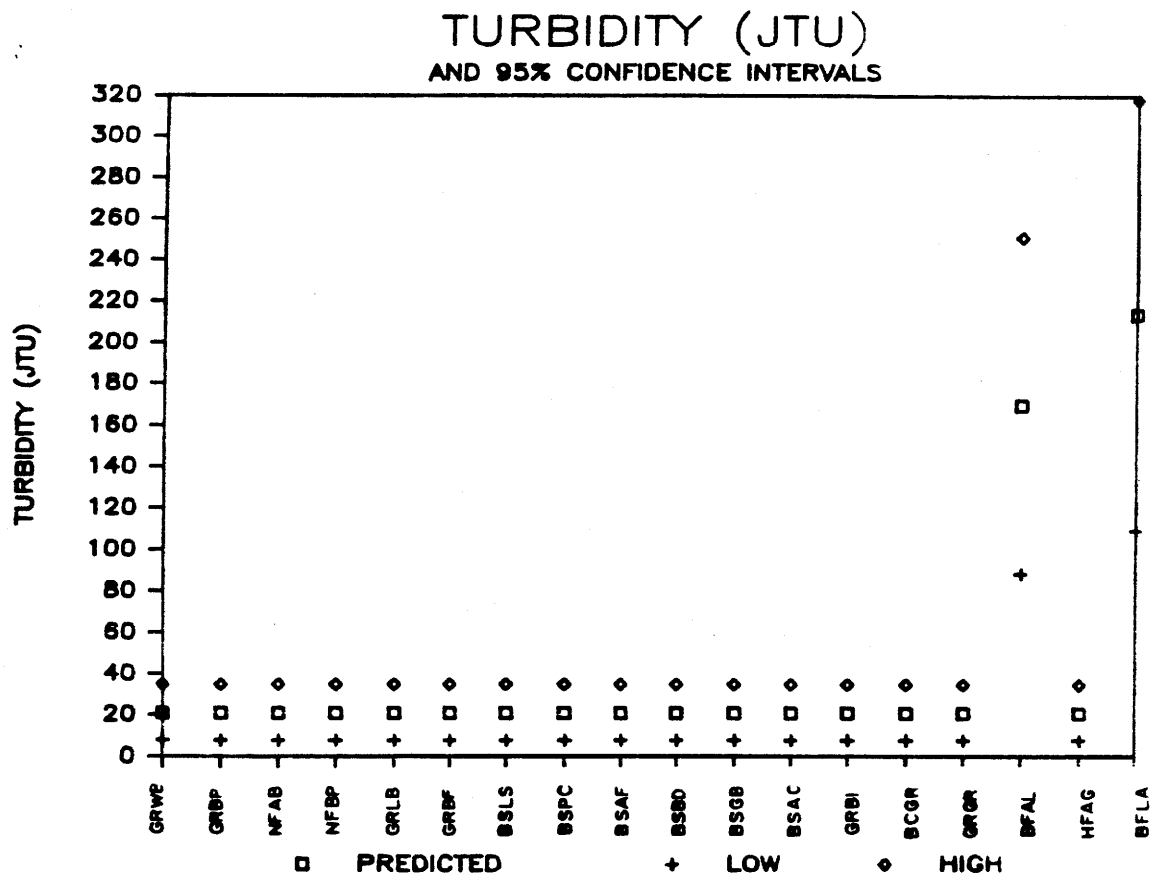

Figure 3. Predicted turbidity in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from models in Table 6.

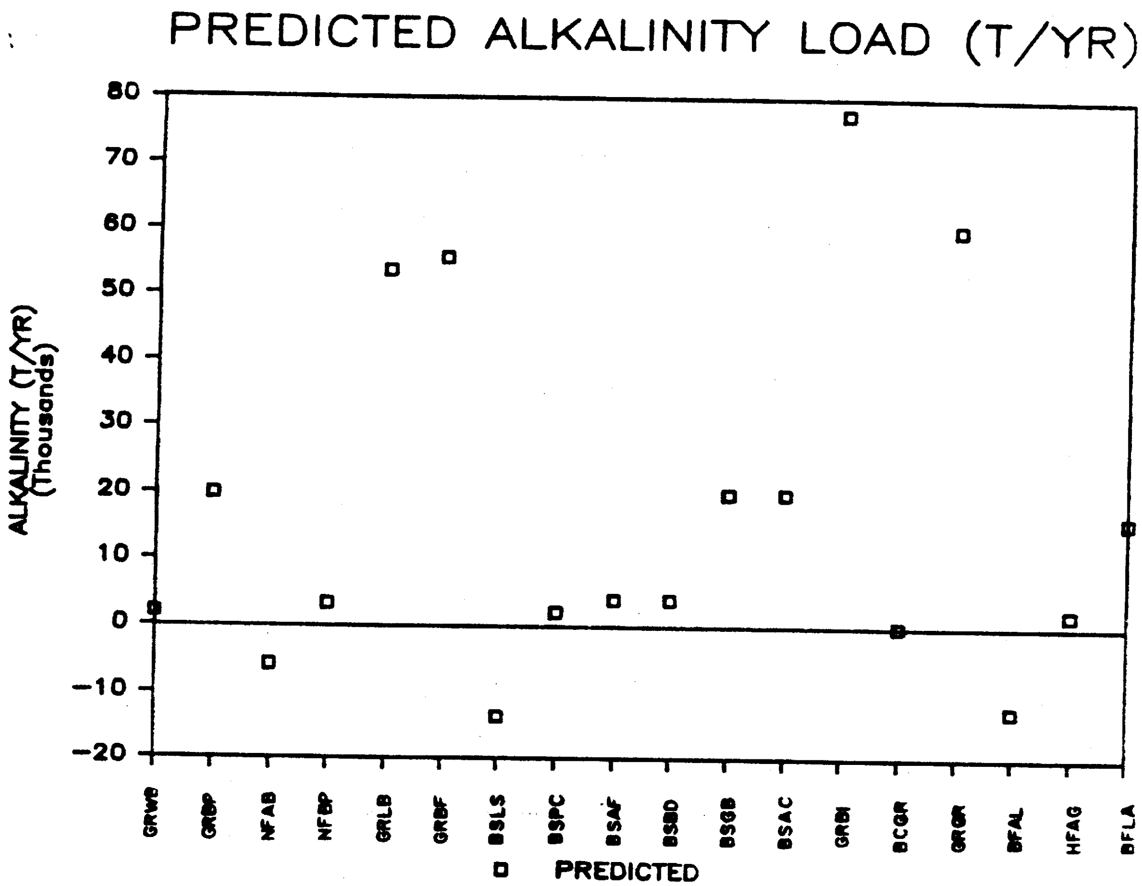

Figure 4. Predicted total alkalinity load (as $CaCO_3$) in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from models in Table 6.

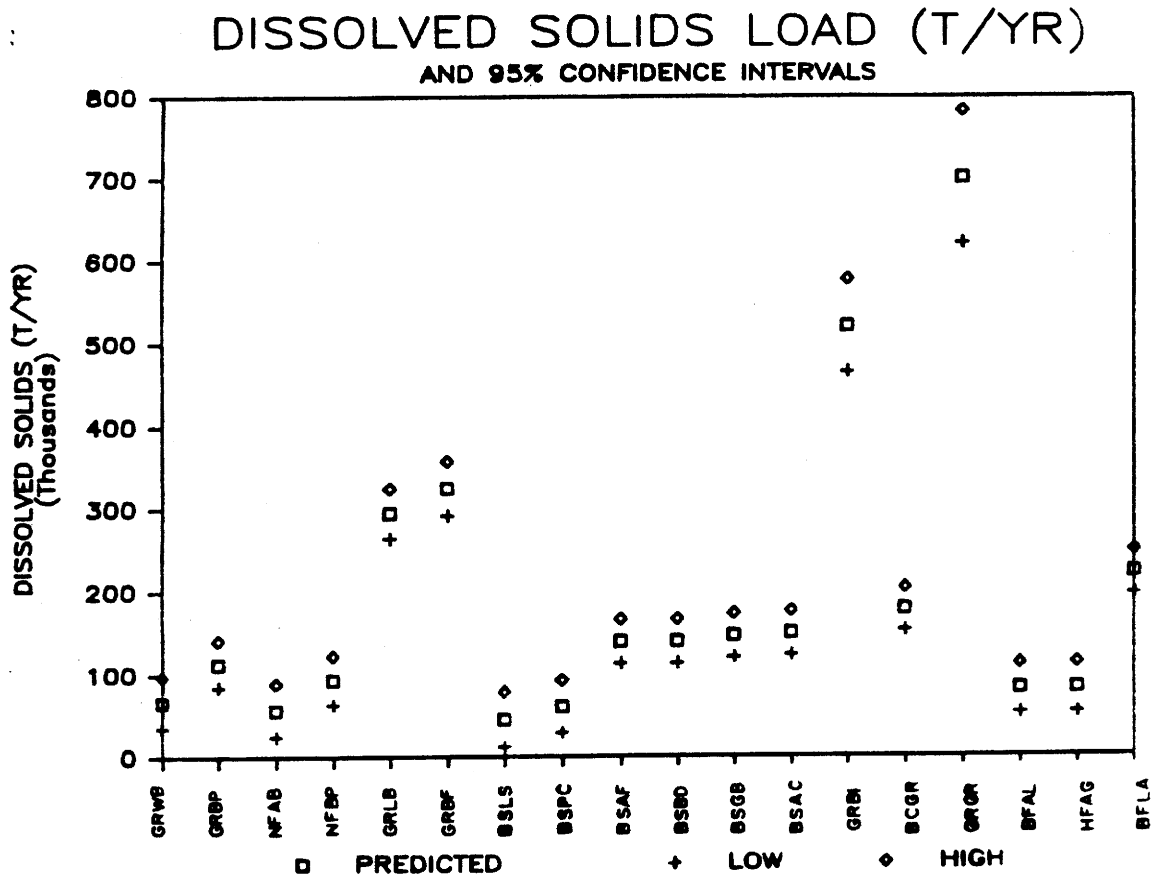

Figure 5. Predicted dissolved solids load in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from models in Table 6.

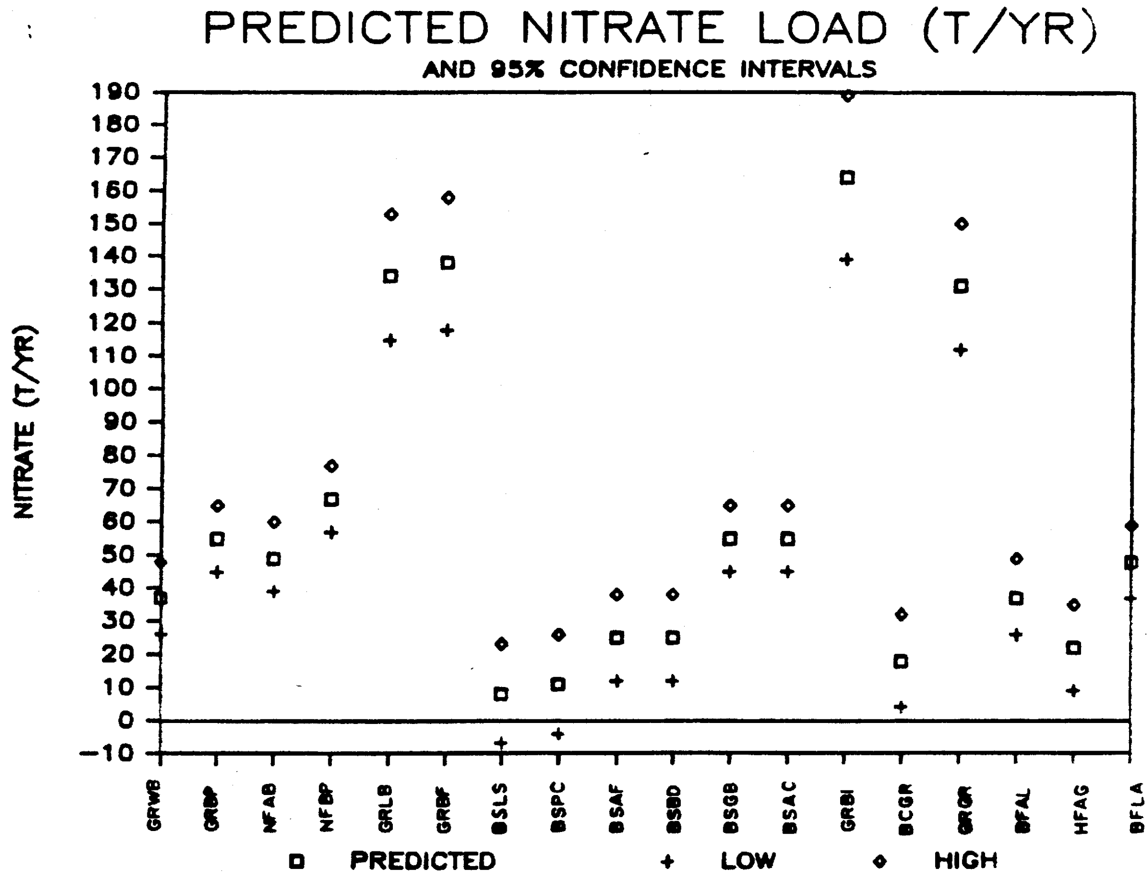

Figure 6. Predicted nitrate load (as NO_3) in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from models in Table 6.

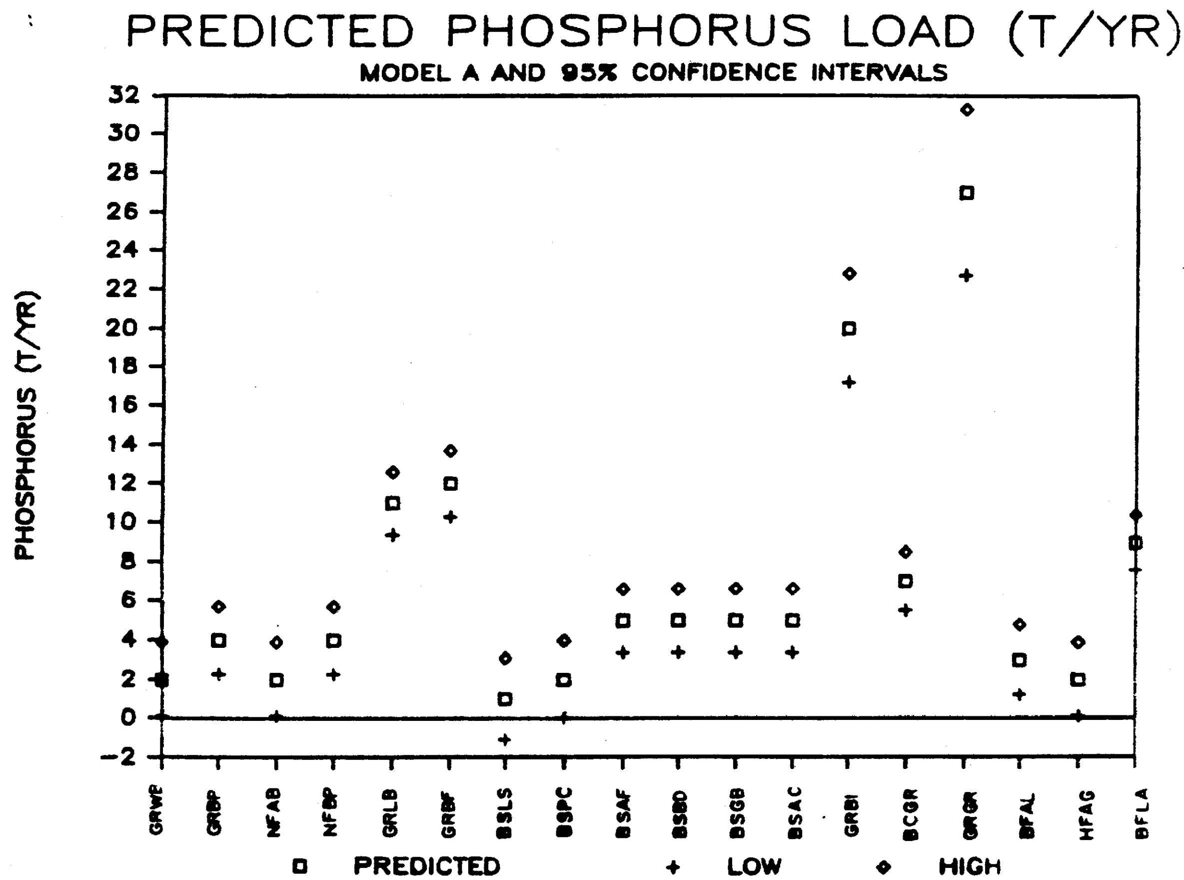

Figure 7. Predicted phosphorus load (as P) in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from Model A in Table 6.

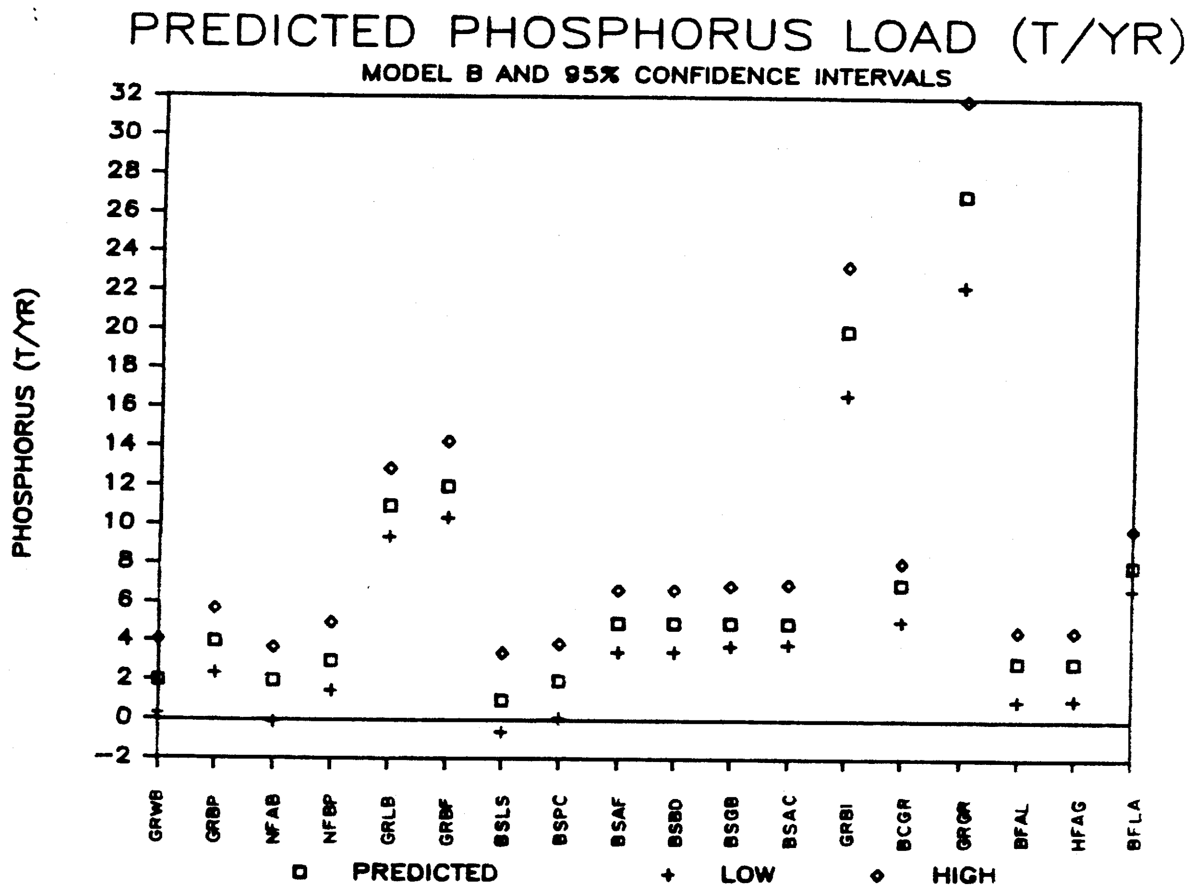

Figure 8. Predicted phosphorus load (as P) in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from Model B in Table 6.

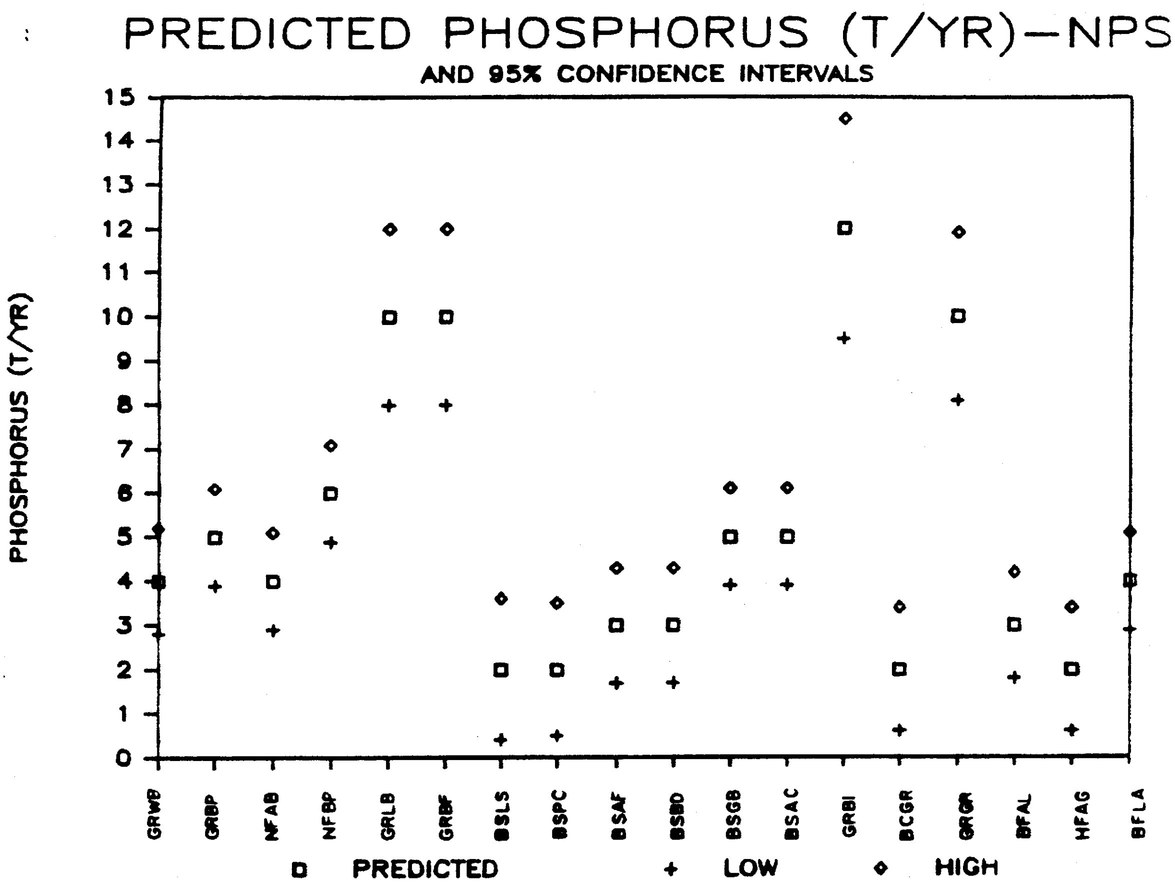

Figure 9. Predicted phosphorus load (as P) from non-point sources in the Green River drainage at each of 18 stations. 95% confidence intervals are included. Predictions were calculated from the model in Table 9.

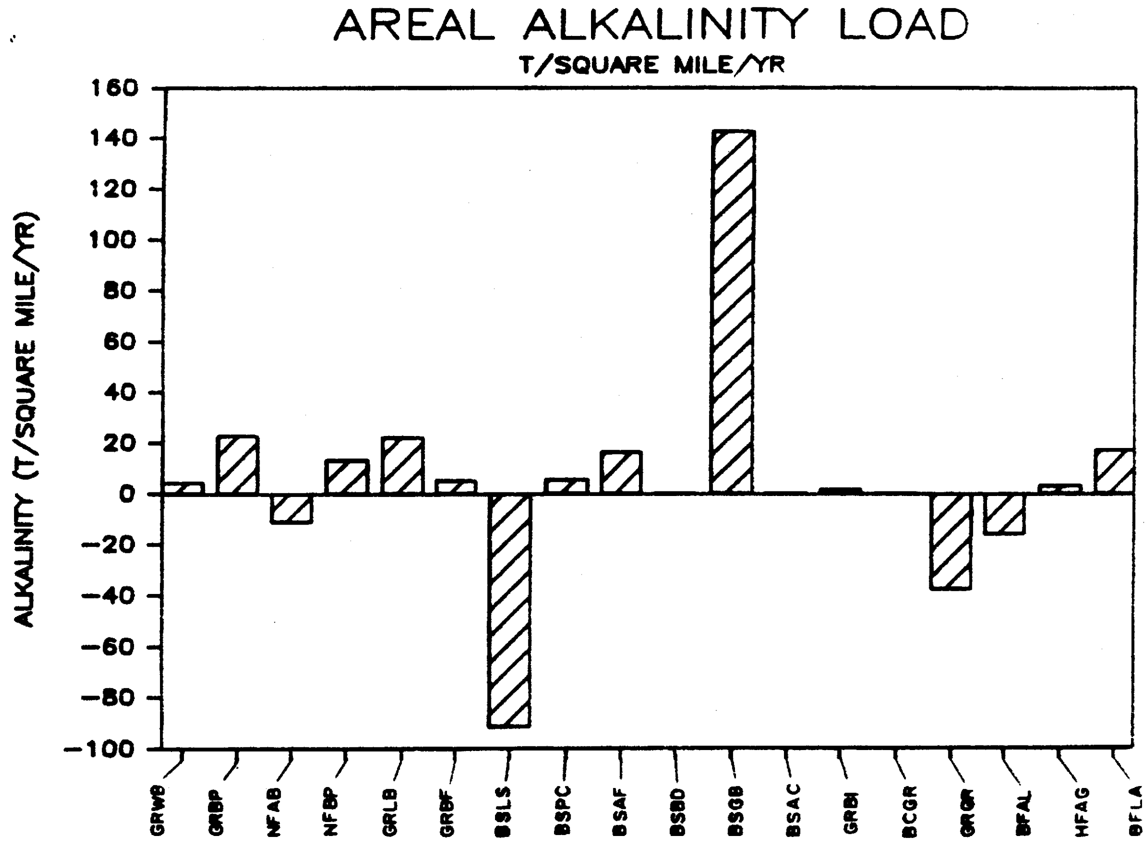

Figure 10. Loading of total alkalinity (as $CaCO_3$) to watercourses in the Green River drainage. Areal calculations were made from the increase in load between stations and the drainage area *between* stations.

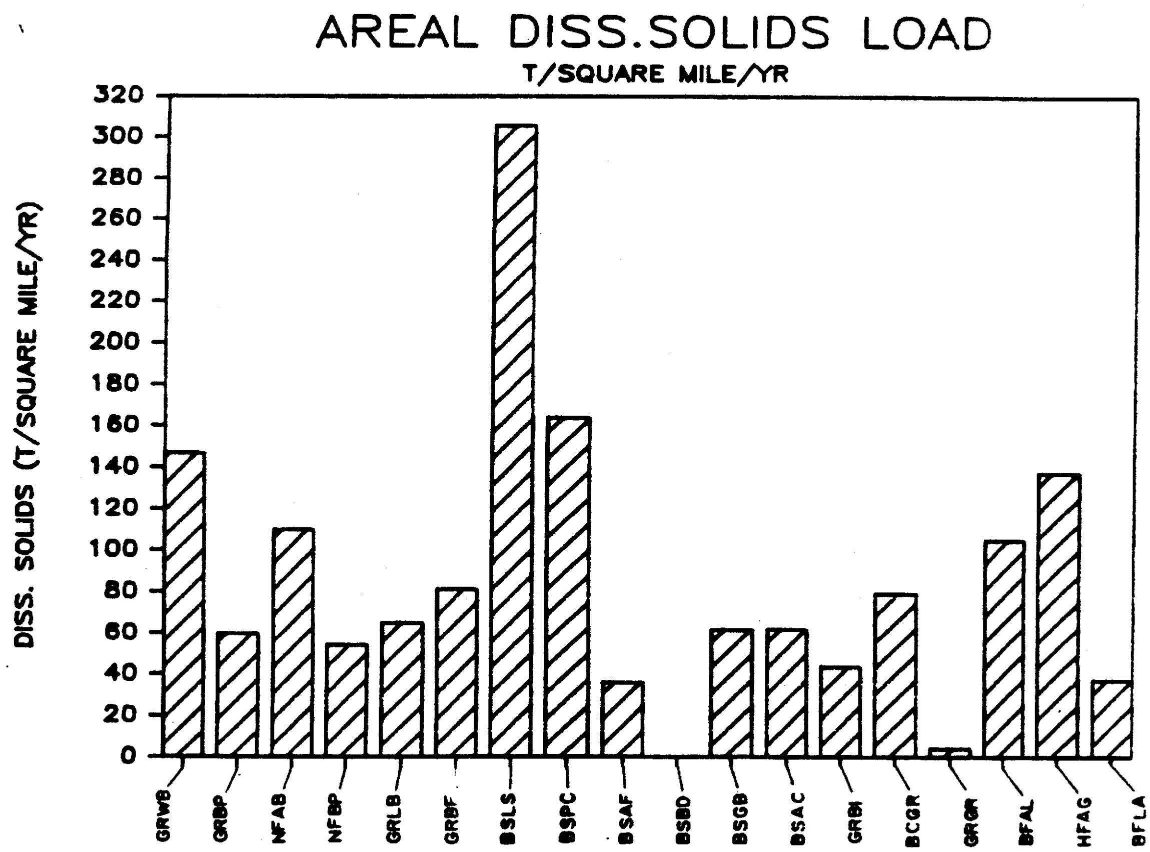

Figure 11. Loading of dissolved solids to watercourses in the Green River drainage. Areal calculations were made from the increase in load between stations and the drainage area *between* stations.

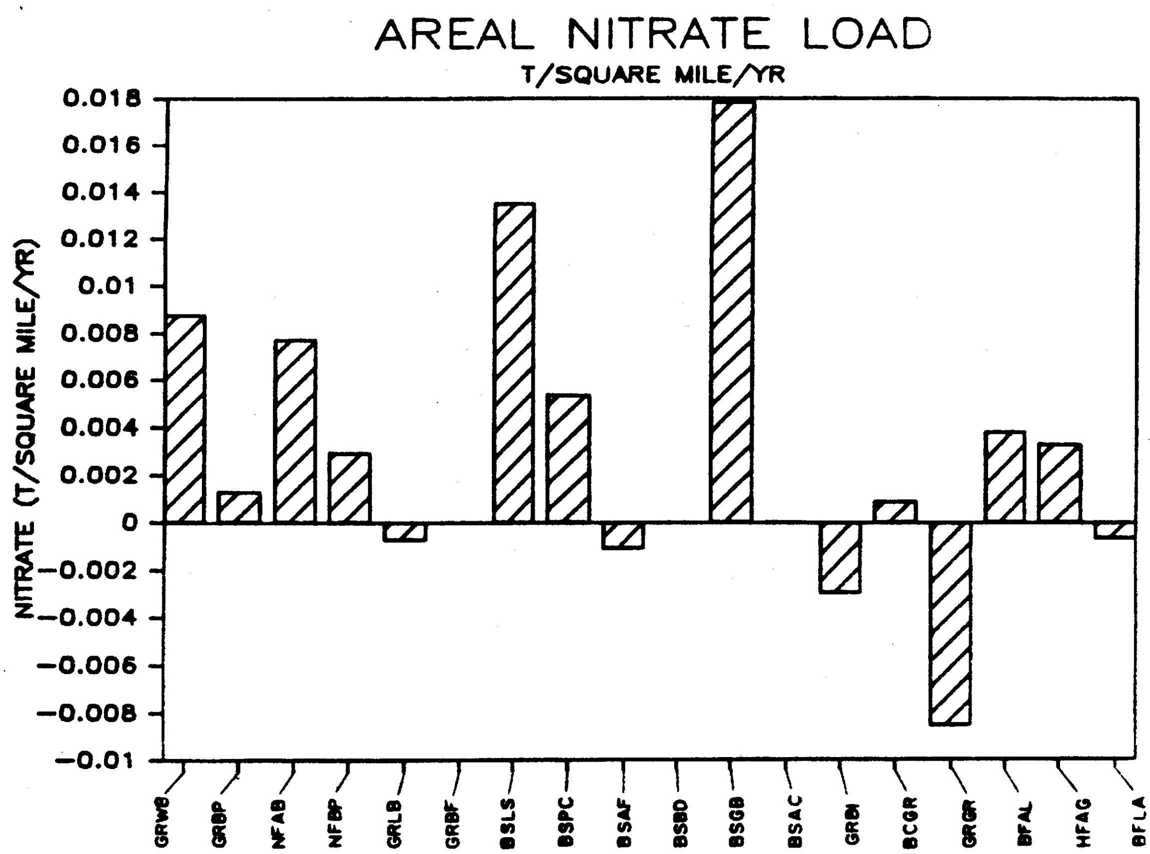

Figure 12. Loading of nitrate (as NO_3) to watercourses in the Green River drainage. Areal calculations were made from the increase in load between stations and the drainage area *between* stations.

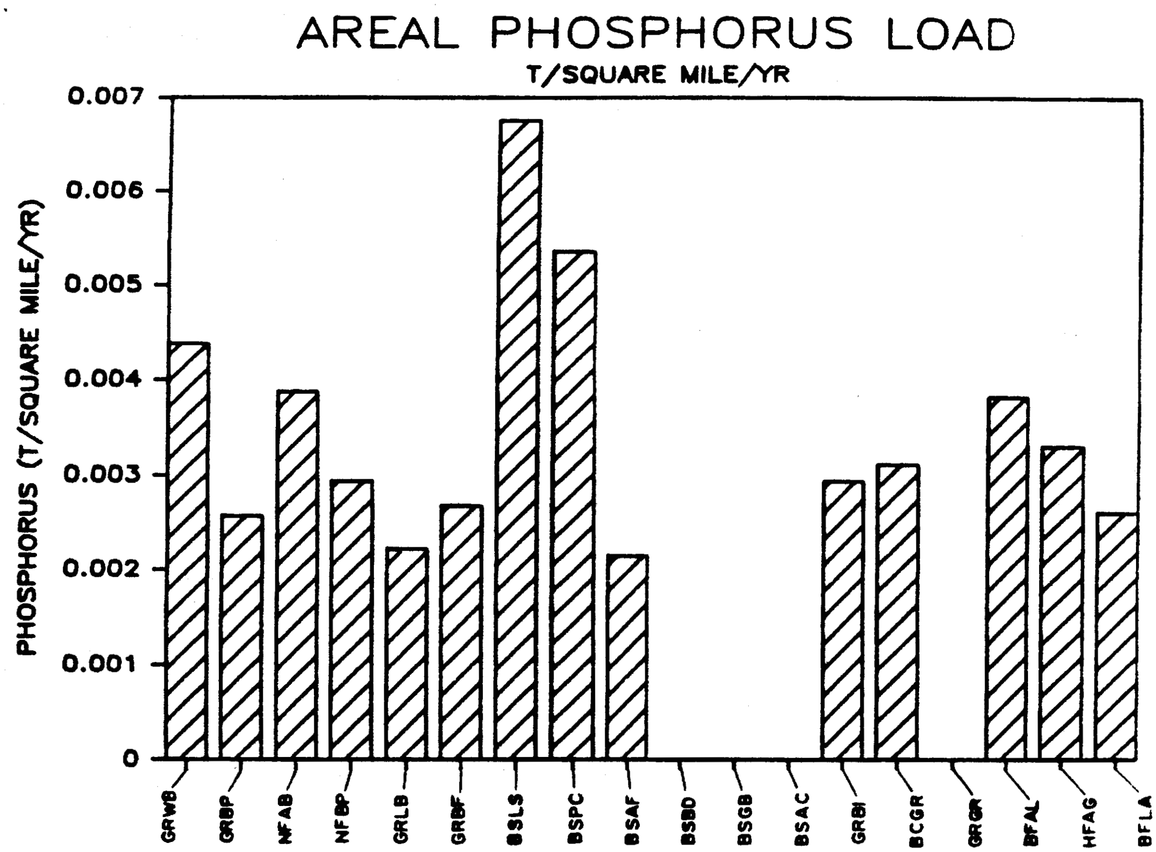

Figure 13. Loading of phosphorus (as P) to watercourses in the Green River drainage. Original loads were calculate from Model A in Table 6; areal calculations were made from the increase in load between stations and the drainage area *between* stations.

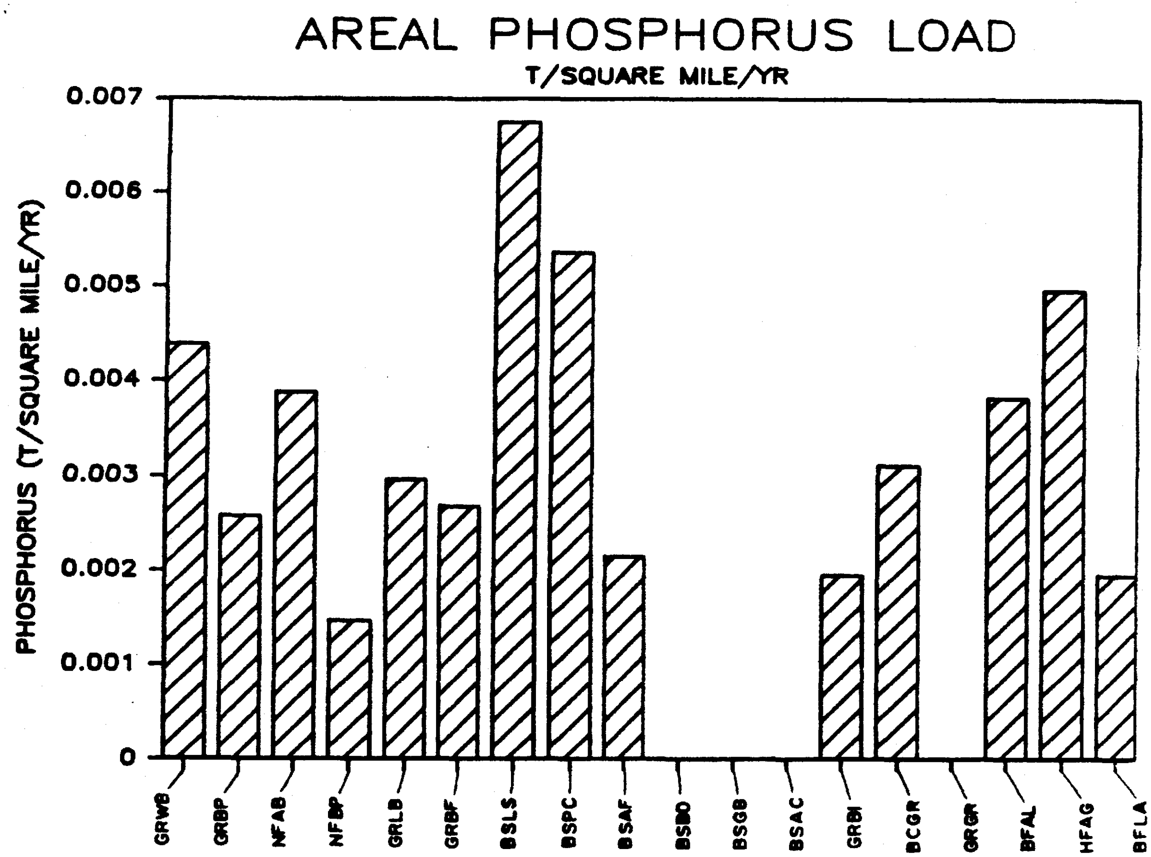

Figure 14. Loading of phosphorus (as P) to watercourses in the Green River drainage. Original loads were calculate from Model B in Table 6; areal calculations were made from the increase in load between stations and the drainage area *between* stations.

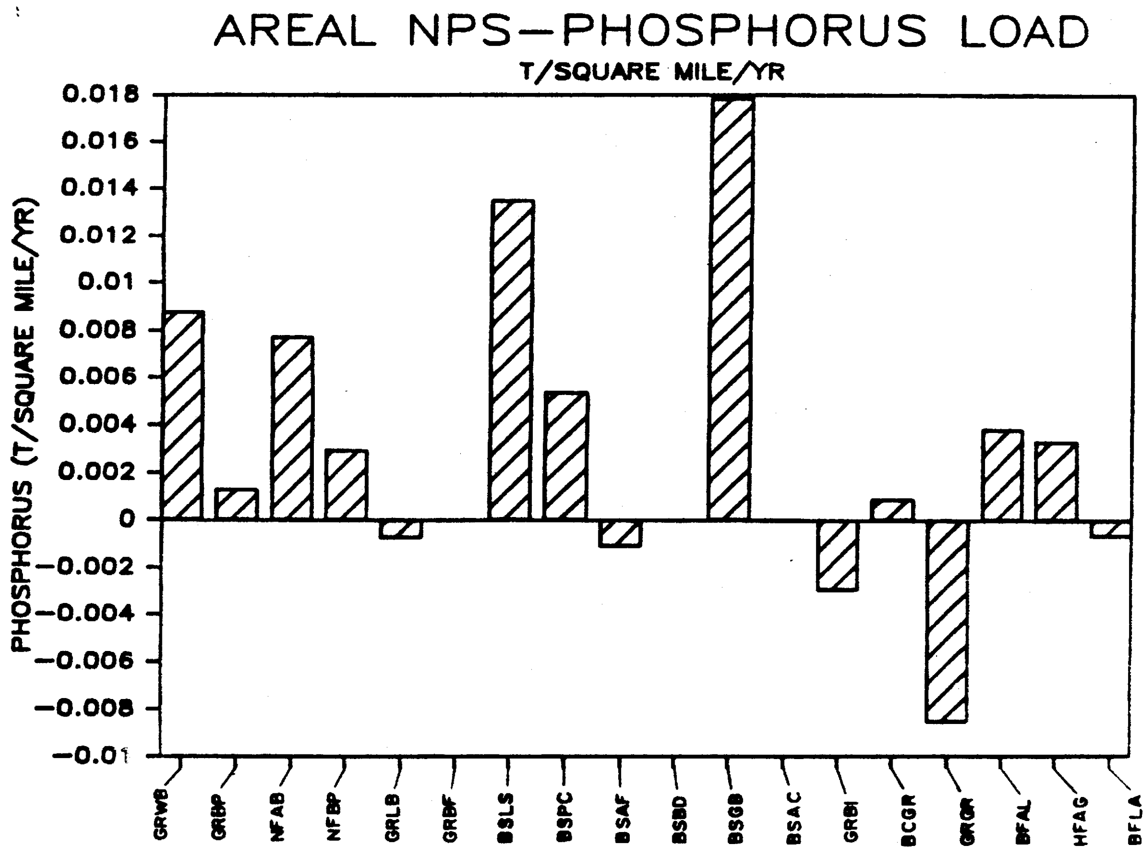

Figure 15. Loading of phosphorus (as P) from non-point sources to watercourses in the Green River drainage. Original loads were calculate from the model in Table 7; areal calculations were made from the increase in load between stations and the drainage area *between* stations.

APPENDIX A. Parameter values for water quality variables and basin attributes.

APPENDIX A. Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

STATN STATION#	STATION CODE	DIS15 MEAN 15-YR DISCHARGE	DIS15M DISCHG X .986	PHOSC MEAN PHOS(P) MG/L
9188500	GRWB	52581	51845	0.018
9192600	GRBP	60477	59630	0.024
9201000	NFAB	44069	43452	-999.000
9205000	NFBP	78396	77298	0.023
9209400	GRLB	171593	169191	0.027
9211200	GRBF	171398	168998	0.017
9214500	BSLS	2197	2166	0.097
9215000	BSPC	479	472	-999.000
9216000	BSAF	5762	5681	0.102
7135	BSBD	5762	5681	-999.000
9216050	BSGB	7532	7427	0.122
8011	BSAC	7532	7427	-999.000
9216300	GRBI	178930	176425	0.023
9216950	BCGR	762	751	-999.000
9217000	GRGR	182520	179965	0.053
9222000	BFAL	16516	16285	-999.000
9224450	HFAG	17872	17622	0.082
9224700	BFLA	35317	34823	-999.000

STATN STATION#	STATION CODE	PHOSL PHOS(P) (TONS/YR)	NITC NITRATE(NO3) MG/L	NITL NITRATE(NO3) T/YEAR
9188500	GRWB	933	0.151	7829
9192600	GRBP	1431	0.271	16160
9201000	NFAB	-999	0.229	9951
9205000	NFBP	1778	0.266	20561
9209400	GRLB	4568	0.270	45681
9211200	GRBF	2873	0.384	64895
9214500	BSLS	210	-999.000	-999
9215000	BSPC	-999	-999.000	-999
9216000	BSAF	579	2.303	13084
7135	BSBD	-999	-999.000	-999
9216050	BSGB	906	1.941	14415
8011	BSAC	-999	-999.000	-999
9216300	GRBI	4058	0.296	52222
9216950	BCGR	-999	7.765	5834
9217000	GRGR	9538	0.165	29694
9222000	BFAL	-999	0.486	7914
9224450	HFAG	1445	0.354	6238
9224700	BFLA	-999	0.356	12397

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TDSTD	TDSTDY	TDSC	TDSL
STATION CODE	MEAN TDS IN TPD	MEAN TDS (TONS/YEAR)	MEAN TDS(SOC) MG/L	TDS(SOC)(T/YEAR)
GRWB	223.781	81736	252.312	13081082
GRBP	456.193	166624	274.140	16347056
NFAB	115.168	42065	113.675	4939410
NFBP	184.199	67279	114.157	8824160
GRLB	904.697	330441	215.865	36522350
GRBF	985.600	359990	249.285	42128773
BSLS	9.197	3359	223.080	483245
BSPC	-999.000	-999	-999.000	-999
BSAF	236.831	86503	1934.775	10992099
BSBD	-999.000	-999	2815.429	15995387
BSGB	403.106	147234	2633.134	19555107
BSAC	-999.000	-999	2635.478	19572514
GRBI	1376.198	502656	386.468	68182609
BCGR	150.588	55002	-999.000	-999
GRGR	1669.137	609652	398.188	71659792
BFAL	382.033	139538	1359.876	22145276
HFAG	130.246	47572	430.904	7593301
BFLA	588.522	214958	1095.622	38152365

	ALKC	ALKL	TURJTU	RELDIS
STATION CODE	MEAN TOTL ALK(MG/L CaCO3)	MEAN ALK (TONS/YR)	TURBIDITY(JTU)	RELATIVE DISCH RATIO
GRWB	98.389	5100965	2.260	0.288
GRBP	141.640	8446039	5.559	0.331
NFAB	90.000	3910683	-999.000	0.241
NFBP	81.306	6284828	2.714	0.430
GRLB	131.534	22254329	11.133	0.940
GRBF	133.368	22538982	2.298	0.939
BSLS	75.125	162739	25.982	0.012
BSPC	-999.000	-999	-999.000	0.003
BSAF	201.687	1145851	-999.000	0.032
BSBD	-999.000	-999	-999.000	0.032
BSGB	248.915	1848580	56.723	0.041
BSAC	-999.000	-999	-999.000	0.041
GRBI	140.690	24821230	12.176	0.980
BCGR	278.541	209277	-999.000	0.004
GRGR	144.218	25954152	18.924	1.000
BFAL	189.675	3088815	184.788	0.090
HFAG	184.946	3259080	17.974	0.098
BFLA	217.651	7579165	141.988	0.193

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TURREL	SODC	SODL	COND
STATION CODE	RELATIVE TURBIDITY	DISSOLVED Na(MG/L)	SODIUM (TONS/YR)	MEAN COND(UMHO/CM)
GRWB	0.651	3.225	167200	384.605
GRBP	1.842	10.043	598867	428.902
NFAB	-999.000	6.469	281091	195.190
NFBP	1.166	8.808	680845	189.902
GRLB	10.466	14.849	2512313	363.892
GRBF	2.158	19.470	3290399	414.929
BSLS	0.313	32.893	71254	362.170
BSPC	-999.000	-999.000	-999	-999.000
BSAF	-999.000	304.602	1730545	2427.339
BSBD	-999.000	360.093	2045808	3082.500
BSGB	2.341	446.351	3314849	3303.006
BSAC	-999.000	431.552	3204943	2906.567
GRBI	11.937	45.987	8113256	608.599
BCGR	-999.000	632.757	475411	3680.000
GRGR	18.924	52.168	9388400	645.059
BFAL	16.721	201.612	3283206	1808.317
HFAG	1.760	42.364	746530	690.403
BFLA	27.474	184.377	6420480	1455.606

	RELCON	HARDC	HARDL	AREAI
STATION CODE	RELATIVE COND.LOAD	MEAN TOTL HARD(MG/L)	TOT HRDNESS LOAD(T/YR)	TOTAL AREA mi2
GRWB	110.798	204.275	10590610	455
GRBP	142.114	215.043	12823083	1230
NFAB	47.128	83.619	3633416	515
NFBP	81.567	78.818	6092510	1194
GRLB	342.107	161.159	27266604	3771
GRBF	389.645	173.892	29387475	4144
BSLS	4.359	110.850	240128	148
BSPC	-999.000	-999.000	-999	373
BSAF	76.629	796.929	4527618	1449
BSBD	97.312	-999.000	-999	1449
BSGB	136.304	1088.021	8080245	1561
BSAC	119.944	-999.000	-999	1611
GRBI	596.628	223.484	39428160	6774
BCGR	15.364	642.973	483086	2244
GRGR	645.059	233.666	42051636	9487
BFAL	163.632	527.879	8596391	783
HFAG	67.603	277.750	4894453	605
BFLA	281.655	395.902	13786322	2919

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	QGL	QAL	QG	QS
STATION CODE	QGL:GLACIAL	QAL:ALLUVIUM	QG:GRAVEL	QS:AEOLIANsand
GRWB	131	22	0	0
GRBP	167	170	12	0
NFAB	142	49	43	0
NFBP	216	76	140	0
GRLB	383	403	152	0
GRBF	383	412	152	0
BSLS	6	0	0	0
BSPC	0	7	0	0
BSAF	23	16	11	28
BSBD	23	16	11	28
BSGB	23	17	12	28
BSAC	23	20	24	28
GRBI	406	450	231	28
BCGR	0	48	0	40
GRGR	406	508	244	68
BFAL	86	65	81	0
HFAG	0	69	27	0
BFLA	90	191	129	0

	QAO	KCR	PCR	LAKEA
STATION CODE	QAO:(QAL?)	KCR:CAMBR TO CREAT	PCR:PRECAMB	LAKE AREA
GRWB	0	173	125	0
GRBP	0	284	125	0
NFAB	0	1	201	18
NFBP	0	2	477	18
GRLB	0	600	602	18
GRBF	0	769	602	39
BSLS	0	0	26	0
BSPC	0	0	0	0
BSAF	0	0	114	3
BSBD	0	0	114	3
BSGB	0	0	114	3
BSAC	0	0	114	3
GRBI	0	806	716	42
BCGR	0	0	0	0
GRGR	0	806	716	42
BFAL	4	11	86	3
HFAG	0	206	0	0
BFLA	4	430	86	3

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TU	TW	TGM	TWN
STATION CODE	TU:UNDIVIDED	TW:WASATCH	TGM:MID GR FMN	TWN:NFKofWASATCH
GRWB	4	0	0	0
GRBP	152	320	0	0
NFAB	10	51	0	0
NFBP	10	255	0	0
GRLB	162	1230	3	11
GRBF	162	1255	28	16
BSLS	83	11	0	0
BSPC	17	164	0	0
BSAF	200	358	0	0
BSBD	200	358	0	0
BSGB	200	358	0	0
BSAC	200	358	0	0
GRBI	362	1629	46	21
BCGR	0	592	0	0
GRGR	362	2221	46	21
BFAL	0	0	0	0
HFAG	158	7	1	0
BFLA	456	90	31	0

	TGL	TGWE	TGF	TB
STATION CODE	TGL:LANEYSHALE	TGWE:MXD NFK&GRF	TGF:FONTofGRF	TB:BRIDGERfmn
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	38	127	42	0
GRBF	38	206	44	9
BSLS	21	0	0	1
BSPC	91	0	0	12
BSAF	477	0	0	120
BSBD	477	0	0	120
BSGB	520	0	0	187
BSAC	538	0	0	204
GRBI	633	596	48	618
BCGR	186	0	0	1
GRGR	1093	596	48	777
BFAL	0	32	0	282
HFAG	0	45	9	81
BFLA	0	207	29	904

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TBP	TWU	TGU	TI
STATION CODE	TBP:BROWNSPKfmn	TWU:UPR WASATCH	TGU:UPR GRF	TI:IGNEOUS plug
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	25	4	0
BSLS	0	0	0	0
BSPC	0	0	0	1
BSAF	0	0	0	1
BSBD	0	0	0	1
BSGB	0	0	0	1
BSAC	0	0	0	1
GRBI	0	32	11	1
BCGR	0	0	0	6
GRGR	0	32	11	8
BFAL	56	0	0	0
HFAG	0	1	1	0
BFLA	75	84	33	0

	TWC	TGT	TGW	TTWA
STATION CODE	TWC:CATHBLUFFSofWSCH	TGT:TIPTONSHALEgrf	TGW:WILKINSofGRF	TTWA:TPtrailFMN
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	33	43	5	0
BSAF	35	51	8	4
BSBD	35	51	8	4
BSGB	35	51	8	4
BSAC	35	51	8	4
GRBI	35	51	8	4
BCGR	34	60	27	0
GRGR	69	111	48	4
BFAL	0	0	0	0
HFAG	0	0	0	0
BFLA	0	0	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TUB	TBI	TF	KBA
STATION CODE	TUB:UNTA&BRDGRfmn	TBI:BISHOPconglom	TF:FTUNIONfmn	KBA:BAXTERshale
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	0	0	0	0
BSAF	0	0	0	0
BSBD	0	0	0	0
BSGB	0	0	0	0
BSAC	0	0	0	0
GRBI	0	0	0	0
BCGR	48	79	141	180
GRGR	48	79	141	180
BFAL	0	77	0	0
HFAG	0	0	0	0
BFLA	0	77	0	0

	KLA	KAL	KE	KR
STATION CODE	KLA:LANCEfmn	KAL:ALMONDfmn	KE:ERICKSNfmn	KR:RSPGSfmn
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	0	0	0	0
BSAF	0	0	0	0
BSBD	0	0	0	0
BSGB	0	0	0	0
BSAC	0	0	0	0
GRBI	0	0	0	0
BCGR	48	140	129	238
GRGR	48	140	129	238
BFAL	0	0	0	0
HFAG	0	0	0	0
BFLA	0	0	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	KBL	KLE	C2C	CREAT
STATION CODE	KBL:BLAIRfmn	KLE:LEWISshale	SUM PRECAMBRIAN	SUM CAMBR TO CREAT
GRWB	0	0	125	173
GRBP	0	0	125	284
NFAB	0	0	201	1
NFBP	0	0	477	2
GRLB	0	0	602	600
GRBF	0	0	602	769
BSLS	0	0	26	0
BSPC	0	0	0	0
BSAF	0	0	114	0
BSBD	0	0	114	0
BSGB	0	0	114	0
BSAC	0	0	114	0
GRBI	0	0	716	806
BCGR	193	54	0	0
GRGR	193	54	716	806
BFAL	0	0	86	11
HFAG	0	0	0	206
BFLA	0	0	86	430

	CREAT	TERT	QUART	PPCAM
STATION CODE	SUM CREATACEOUS	SUM TERTIARY	SUM QUARTERNARY	%PRECAMBRIAN/100
GRWB	0	4	153	0.27
GRBP	0	472	349	0.10
NFAB	0	61	234	0.39
NFBP	0	265	432	0.40
GRLB	0	1613	938	0.16
GRBF	0	1787	947	0.15
BSLS	0	116	6	0.18
BSPC	0	366	7	0.00
BSAF	0	1254	78	0.08
BSBD	0	1254	78	0.08
BSGB	0	1364	80	0.07
BSAC	0	1399	95	0.07
GRBI	0	4095	1115	0.11
BCGR	982	1174	88	0.00
GRGR	982	5715	1226	0.08
BFAL	0	447	236	0.11
HFAG	0	303	96	0.00
BFLA	0	1986	414	0.03

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	PC2C	PCREAT	PTERT	PQUAT
STATION CODE	%CAMB TO CREAT	% CREATACEOUS	% TERTIARY	% QUARTERNARY
GRWB	0.38	0.00	0.01	0.34
GRBP	0.23	0.00	0.38	0.28
NFAB	.00	0.00	0.12	0.45
NFBP	.00	0.00	0.22	0.36
GRLB	0.16	0.00	0.43	0.25
GRBF	0.19	0.00	0.43	0.23
BSLS	0.00	0.00	0.78	0.04
BSPC	0.00	0.00	0.98	0.02
BSAF	0.00	0.00	0.87	0.05
BSBD	0.00	0.00	0.87	0.05
BSGB	0.00	0.00	0.87	0.05
BSAC	0.00	0.00	0.87	0.06
GRBI	0.12	0.00	0.60	0.16
BCGR	0.00	0.44	0.52	0.04
GRGR	0.08	0.10	0.60	0.13
BFAL	0.01	0.00	0.57	0.30
HFAG	0.34	0.00	0.50	0.16
BFLA	0.15	0.00	0.68	0.14

	SGRF	SWAS	SHALE	PGRF
STATION CODE	SUM GREEN R FMN	SUM WASATCH FMN	sum DESIGNATED shales	%GRFMN/100
GRWB	0	0	0	0.00
GRBP	0	320	0	0.00
NFAB	0	51	0	0.00
NFBP	0	255	0	0.00
GRLB	210	1368	38	0.06
GRBF	320	1502	38	0.08
BSLS	21	11	21	0.14
BSPC	139	197	134	0.37
BSAF	536	393	528	0.37
BSBD	536	393	528	0.37
BSGB	579	393	571	0.37
BSAC	597	393	589	0.37
GRBI	1393	2313	684	0.21
BCGR	273	626	480	0.12
GRGR	1953	2939	1438	0.21
BFAL	32	32	0	0.04
HFAG	56	53	0	0.09
BFLA	300	381	0	0.10

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

STATION CODE	PWAS %WASATCH FMN/100	PSHALE % DESIGNATED shales	FLOD2 2YR FLOOD CFS	FLOD10 10YR FLOOD CFS
GRWB	0.00	0.00	2900	4000
GRBP	0.26	0.00	3900	6000
NFAB	0.10	0.00	2800	4700
NFBP	0.21	0.00	5300	7700
GRLB	0.36	0.01	9600	15000
GRBF	0.36	0.01	7500	15000
BSLS	0.07	0.14	185	400
BSPC	0.53	0.36	280	790
BSAF	0.27	0.36	450	1700
BSBD	0.27	0.36	450	1700
BSGB	0.25	0.37	500	2600
BSAC	0.24	0.37	500	2600
GRBI	0.34	0.10	5400	15000
BCGR	0.28	0.21	360	1300
GRGR	0.31	0.15	8500	15000
BFAL	0.04	0.00	1700	3500
HFAG	0.09	0.00	460	1600
BFLA	0.13	0.00	2900	5000

STATION CODE	FLOD25 25YR FLOOD CFS	PKPOR PEAK CFS P.O.R.	PK6579 PEAK CFS 1965-79	FLDRAT 10YR FLOOD/STUDY PK
GRWB	4600	4840	4840	0.83
GRBP	7000	-999	-999	-999
NFAB	6200	12300	4420	1.06
NFBP	8500	9170	9170	0.84
GRLB	17500	18000	18000	0.83
GRBF	18000	19400	19400	0.77
BSLS	700	1450	350	1.14
BSPC	1050	972	972	0.81
BSAF	3000	7430	1440	1.18
BSBD	3000	7430	1440	1.18
BSGB	7000	7430	1130	2.30
BSAC	7000	7430	1130	2.30
GRBI	21400	-999	-999	-999
BCGR	2000	-999	-999	-999
GRGR	17000	16800	16800	0.89
BFAL	4500	7960	7960	0.44
HFAG	2500	-999	-999	-999
BFLA	6000	9980	9980	0.50

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	SLENG	AREA2	DDEN	ORDR
STATION CODE	TOT STREAMLENGTH(mi)	SUBBASIN AREA(mi2)	DRAINAGE DENSITY	STREAM ORDER @ STATN
GRWB	289	455	0.635	4
GRBP	677	1229	0.551	5
NFAB	205	520	0.394	4
NFBP	513	1210	0.424	5
GRLB	2191	3770	0.581	6
GRBF	2444	4144	0.590	6
BSLS	109	148	0.736	4
BSPC	242	369	0.656	4
BSAF	900	1441	0.625	5
BSBD	900	1441	0.625	5
BSGB	958	1553	0.617	5
BSAC	984	1604	0.613	5
GRBI	4070	6767	0.601	6
BCGR	1221	2248	0.543	5
GRGR	5576	9479	0.588	6
BFAL	420	800	0.525	4
HFAG	426	605	0.704	4
BFLA	1594	2943	0.542	5

	CHANL	CHANS	AC	ELONG
STATION CODE	MAIN CHANL L (mi)	MAIN CHANL m (ft/mi)	Ac	ELONGATN RATIO
GRWB	51.0	10.4	24	0.471
GRBP	90.7	14.7	40	0.441
NFAB	41.5	25.7	26	0.627
NFBP	59.5	20.6	39	0.655
GRLB	124.3	12.9	69	0.555
GRBF	140.8	13.2	73	0.518
BSLS	38.0	86.0	14	0.368
BSPC	30.1	15.5	22	0.731
BSAF	70.7	47.2	43	0.608
BSBD	70.7	47.2	43	0.608
BSGB	80.1	40.8	44	0.549
BSAC	89.3	32.1	45	0.504
GRBI	168.9	11.4	93	0.551
BCGR	81.7	9.8	53	0.649
GRGR	191.4	11.1	110	0.575
BFAL	60.1	71.0	32	0.532
HFAG	85.2	18.8	28	0.329
BFLA	100.6	32.5	61	0.606

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	MELEV	BASINS	BIFUR	AREA3
STATION CODE	MEAN BASIN ELEV (ft)	MEAN BASIN m (ft/mi)	AVG BIFURCATION RATIO	AREA (mi)
GRWB	9262	163.6	4.1	471
GRBP	8300	78.9	2.8	1237
NFAB	8630	125.1	2.9	522
NFBP	8696	102.0	3.0	1173
GRLB	8282	74.3	3.0	3724
GRBF	7958	56.1	3.0	4074
BSLS	8032	248.2	2.4	188
BSPC	7302	78.8	3.1	362
BSAF	7444	88.1	3.1	1486
BSBD	7444	88.1	3.1	1486
BSGB	7438	89.5	3.1	1649
BSAC	7288	63.1	3.1	1672
GRBI	7716	66.8	3.1	6732
BCGR	7094	39.0	3.5	2220
GRGR	7416	45.7	3.2	9390
BFAL	9198	93.3	3.0	718
HFAG	7638	92.2	3.5	720
BFLA	8038	72.3	3.5	3015

	MINS	MAXS	MINEL	MAXEL
STATION CODE	MIN SLOPE o	MAX SLOPE o	MIN ELEV(ft)	MAX ELEV(ft)
GRWB	2	35	7067	8359
GRBP	3	29	6109	7358
NFAB	1	25	5761	6885
NFBP	1	24	5700	6812
GRLB	2	27	6005	7150
GRBF	2	29	6084	7224
BSLS	2	24	6124	7377
BSPC	4	34	6246	7306
BSAF	3	25	6197	7183
BSBD	3	23	6197	7183
BSGB	3	25	6226	7188
BSAC	3	25	6232	7188
GRBI	3	28	6190	7226
BCGR	3	39	6575	7277
GRGR	3	30	6289	7237
BFAL	1	26	6786	7785
HFAG	3	44	7084	8207
BFLA	3	36	6930	7856

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TBP	TWU	TGU	TI
STATION CODE	TBP:BROWNSPKfmn	TWU:UPR WASATCH	TGU:UPR GRF	TI:IGNEOUS plug
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	25	4	0
BSLS	0	0	0	0
BSPC	0	0	0	1
BSAF	0	0	0	1
BSBD	0	0	0	1
BSGB	0	0	0	1
BSAC	0	0	0	1
GRBI	0	32	11	1
BCGR	0	0	0	6
GRGR	0	32	11	8
BFAL	56	0	0	0
HFAG	0	1	1	0
BFLA	75	84	33	0

	TWC	TGT	TGW	TTWA
STATION CODE	TWC:CATHBLUFFSofWSCH	TGT:TIPTONSHALEgrf	TGW:WILKINSofGRF	TTWA:TPtrailFMN
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	33	43	5	0
BSAF	35	51	8	4
BSBD	35	51	8	4
BSGB	35	51	8	4
BSAC	35	51	8	4
GRBI	35	51	8	4
BCGR	34	60	27	0
GRGR	69	111	48	4
BFAL	0	0	0	0
HFAG	0	0	0	0
BFLA	0	0	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	TUB	TBI	TF	KBA
STATION CODE	TUB:UNTA&BRDGRfmn	TBI:BISHOPconglom	TF:FTUNIONfmn	KBA:BAXTERshale
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	0	0	0	0
BSAF	0	0	0	0
BSBD	0	0	0	0
BSGB	0	0	0	0
BSAC	0	0	0	0
GRBI	0	0	0	0
BCGR	48	79	141	180
GRGR	48	79	141	180
BFAL	0	77	0	0
HFAG	0	0	0	0
BFLA	0	77	0	0

	KLA	KAL	KE	KR
STATION CODE	KLA:LANCEfmn	KAL:ALMONDfmn	KE:ERICKSNfmn	KR:RSPGSfmn
GRWB	0	0	0	0
GRBP	0	0	0	0
NFAB	0	0	0	0
NFBP	0	0	0	0
GRLB	0	0	0	0
GRBF	0	0	0	0
BSLS	0	0	0	0
BSPC	0	0	0	0
BSAF	0	0	0	0
BSBD	0	0	0	0
BSGB	0	0	0	0
BSAC	0	0	0	0
GRBI	0	0	0	0
BCGR	48	140	129	238
GRGR	48	140	129	238
BFAL	0	0	0	0
HFAG	0	0	0	0
BFLA	0	0	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	PHSOIL	ALPA	ALPV	SALP
STATION CODE	SOIL pH	ALPINE AREA:1	ALPINE VEG:11	ALPINE AREA SUM
GRWB	6.2	71	15	86
GRBP	6.5	81	15	96
NFAB	6.3	38	0	38
NFBP	6.4	50	0	50
GRLB	6.6	135	15	150
GRBF	6.6	135	15	150
BSLS	6.8	7	0	7
BSPC	7.6	0	0	0
BSAF	7.0	11	0	11
BSBD	7.0	11	0	11
BSGB	7.1	11	0	11
BSAC	7.1	11	0	11
GRBI	6.7	146	15	161
BCGR	7.6	0	0	0
GRGR	6.9	146	15	161
BFAL	6.9	0	0	0
HFAG	7.1	0	0	0
BFLA	7.2	0	0	0

	CROPI	CROPD	SCROP	DUNE
STATION CODE	CROP IRR:21	CROP DRY:22	CROPPED AREA SUM	DUNES:31
GRWB	0	0	0	0
GRBP	179	0	179	0
NFAB	84	0	84	0
NFBP	158	0	158	0
GRLB	484	0	484	0
GRBF	494	0	494	0
BSLS	0	2	2	0
BSPC	0	0	0	7
BSAF	52	3	55	20
BSBD	52	3	55	20
BSGB	52	3	55	20
BSAC	52	3	55	20
GRBI	551	3	554	20
BCGR	0	0	0	62
GRGR	551	0	551	82
BFAL	159	1	160	0
HFAG	30	0	30	0
BFLA	194	1	195	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	EXPOS	SDUNE	LACUS	PLAUS
STATION CODE	EXPOSED:32	BARE OR DUNE AREA	LACUSTRINE:42	PALUSTRINE:43
GRWB	0	0	2	0
GRBP	0	0	2	0
NFAB	0	0	32	0
NFBP	0	0	45	0
GRLB	0	0	49	3
GRBF	0	0	71	3
BSLS	0	0	1	0
BSPC	0	7	0	0
BSAF	0	20	6	0
BSBD	0	20	6	0
BSGB	0	20	6	0
BSAC	0	20	6	0
GRBI	0	20	77	3
BCGR	0	62	0	0
GRGR	0	82	79	3
BFAL	65	65	1	0
HFAG	0	0	2	5
BFLA	84	84	4	18
	0	0	2	5
	84	84	4	18

	SWET	SURBAN	BASIN	SHERB
STATION CODE	WETLAND AREA SUM	URBAN:52	W. BASIN & FTHLS:612	HERB RANGE SUM
GRWB	2	0	0	0
GRBP	2	0	12	12
NFAB	32	1	0	0
NFBP	45	1	0	0
GRLB	52	1	13	13
GRBF	74	1	13	13
BSLS	1	0	0	0
BSPC	0	0	0	0
BSAF	6	0	0	0
BSBD	6	0	0	0
BSGB	6	0	0	0
BSAC	6	0	0	0
GRBI	80	2	13	13
BCGR	0	2	0	0
GRGR	82	5	13	13
BFAL	1	1	0	0
HFAG	7	1	0	0
BFLA	22	2	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	SHRUBR	SAGE	HALOS	SHRUBM
STATION CODE	SHRUB RANGE:62	SAGE:621	HALOPHYT SHRUB:622	MIXED SHRUB:624
GRWB	0	58	0	0
GRBP	0	389	0	0
NFAB	1	78	0	0
NFBP	3	188	0	0
GRLB	17	1357	0	0
GRBF	17	1617	0	0
BSLS	0	52	0	0
BSPC	0	50	0	0
BSAF	0	678	0	0
BSBD	0	678	0	0
BSGB	0	797	0	21
BSAC	0	797	0	46
GRBI	17	3264	15	186
BCGR	0	506	177	1058
GRGR	17	4142	200	1310
BFAL	0	200	0	0
HFAG	0	383	0	0
BFLA	0	1843	0	0

	SSHRUB	MIXEDR	SRANGE	JUNIP
STATION CODE	SHRUB RANGE SUM	MIXED RANGE:63	TOTAL RANGE SUM	JUNIPER:71
GRWB	58	0	58	0
GRBP	389	0	401	0
NFAB	79	73	152	0
NFBP	191	323	514	0
GRLB	1374	369	1756	0
GRBF	1634	369	2016	0
BSLS	52	99	151	0
BSPC	50	311	361	0
BSAF	678	612	1290	0
BSBD	678	612	1290	0
BSGB	818	612	1430	0
BSAC	843	612	1455	0
GRBI	3482	981	4476	0
BCGR	1741	143	1884	250
GRGR	5669	1124	6806	250
BFAL	200	0	200	10
HFAG	383	7	390	0
BFLA	1843	119	1962	82

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	SWOOD	ASPEN	SDECID	CONIF
STATION CODE	WOODLAND SUM	ASPEN:811	DECID FOR SUM	CONIFER:82
GRWB	0	0	0	152
GRBP	0	0	0	152
NFAB	0	0	0	217
NFBP	0	0	0	447
GRLB	0	0	0	599
GRBF	0	0	0	599
BSLS	0	0	0	14
BSPC	0	0	0	0
BSAF	0	0	0	88
BSBD	0	0	0	88
BSGB	0	0	0	88
BSAC	0	0	0	88
GRBI	0	0	0	687
BCGR	250	0	0	0
GRGR	250	0	0	687
BFAL	10	2	2	0
HFAG	0	0	0	0
BFLA	82	14	14	0

	PINE	SCONIF	MIXEDF	SMIXF
STATION CODE	PINE:823	CONIF FOR SUM	MIXED FOREST:83	MIXED FOREST SUM
GRWB	86	238	73	73
GRBP	302	454	90	90
NFAB	0	217	0	0
NFBP	0	447	0	0
GRLB	588	1187	90	90
GRBF	675	1274	90	90
BSLS	0	14	0	0
BSPC	0	0	0	0
BSAF	0	88	0	0
BSBD	0	88	0	0
BSGB	0	88	0	0
BSAC	0	88	0	0
GRBI	675	1362	90	90
BCGR	1	1	0	0
GRGR	676	1363	90	90
BFAL	354	354	0	0
HFAG	190	190	0	0
BFLA	578	578	0	0

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	SFORST	AREA4	PALPA	PALPV
STATION CODE	ALL FOREST SUM	*STATION AREA (mi2)*	% ALPINE AREA:1	% ALPINE VEG:11
GRWB	311	457	0.155	0.033
GRBP	544	1222	0.066	0.012
NFAB	217	526	0.072	0.000
NFBP	447	1215	0.041	0.000
GRLB	1277	3720	0.036	0.004
GRBF	1364	4099	0.033	0.004
BSLS	14	177	0.040	0.000
BSPC	0	368	0.000	0.000
BSAF	88	1470	0.007	0.000
BSBD	88	1470	0.007	0.000
BSGB	88	1610	0.007	0.000
BSAC	88	1635	0.007	0.000
GRBI	1452	6745	0.022	0.002
BCGR	1	2199	0.000	0.000
GRGR	1453	9393	0.016	0.002
BFAL	356	793	0.000	0.000
HFAG	190	620	0.000	0.000
BFLA	592	2939	0.000	0.000

	PALP	PCI	PCD	PCROP
STATION CODE	TOTAL ALPINE AREA %	% CROP IRR:21	%CROP DRY:22	TOTAL CROPPED AREA %
GRWB	0.188	0.000	0.000	0.000
GRBP	0.079	0.146	0.000	0.146
NFAB	0.072	0.160	0.000	0.160
NFBP	0.041	0.130	0.000	0.130
GRLB	0.040	0.130	0.000	0.130
GRBF	0.037	0.121	0.000	0.121
BSLS	0.040	0.000	0.011	0.011
BSPC	0.000	0.000	0.000	0.000
BSAF	0.007	0.035	0.002	0.037
BSBD	0.007	0.035	0.002	0.037
BSGB	0.007	0.032	0.002	0.034
BSAC	0.007	0.032	0.002	0.034
GRBI	0.024	0.082	.000	0.082
BCGR	0.000	0.000	0.000	0.000
GRGR	0.017	0.059	0.000	0.059
BFAL	0.000	0.201	0.001	0.202
HFAG	0.000	0.048	0.000	0.048
BFLA	0.000	0.066	.000	0.066

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	PDUNE	PEXP	PBARE	PLAC
STATION CODE	% DUNES:31	% EXPOSED:32	% BARE OR DUNE AREA	% LACUSTRINE:42
GRWB	0.000	0.000	0.000	0.004
GRBP	0.000	0.000	0.000	0.002
NFAB	0.000	0.000	0.000	0.061
NFBP	0.000	0.000	0.000	0.037
GRLB	0.000	0.000	0.000	0.013
GRBF	0.000	0.000	0.000	0.017
BSLS	0.000	0.000	0.000	0.006
BSPC	0.019	0.000	0.019	0.000
BSAF	0.014	0.000	0.014	0.004
BSBD	0.014	0.000	0.014	0.004
BSGB	0.012	0.000	0.012	0.004
BSAC	0.012	0.000	0.012	0.004
GRBI	0.003	0.000	0.003	0.011
BCGR	0.028	0.000	0.028	0.000
GRGR	0.009	0.000	0.009	0.008
BFAL	0.000	0.082	0.082	0.001
HFAG	0.000	0.000	0.000	0.003
BFLA	0.000	0.029	0.029	0.001

	PPAL	PWET	PURBAN	PBASIN
STATION CODE	% PALUSTRINE:43	TOTAL WETLAND AREA %	% URBAN:52	% W BASN&FTHLS:612
GRWB	0.000	0.004	0.000	0.000
GRBP	0.000	0.002	0.000	0.010
NFAB	0.000	0.061	0.002	0.000
NFBP	0.000	0.037	0.001	0.000
GRLB	0.001	0.014	.000	0.003
GRBF	0.001	0.018	.000	0.003
BSLS	0.000	0.006	0.000	0.000
BSPC	0.000	0.000	0.000	0.000
BSAF	0.000	0.004	0.000	0.000
BSBD	0.000	0.004	0.000	0.000
BSGB	0.000	0.004	0.000	0.000
BSAC	0.000	0.004	0.000	0.000
GRBI	.000	0.012	.000	0.002
BCGR	0.000	0.000	0.001	0.000
GRGR	.000	0.009	0.001	0.001
BFAL	0.000	0.001	0.001	0.000
HFAG	0.008	0.011	0.002	0.000
BFLA	0.006	0.007	0.001	0.000

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

STATION CODE	PHERB TOTAL HERB RANGE %	PSHRUB % SHRUB RANGE:62	PSAGE % SAGE:621	PHALO % HALOPHYT SHRUB:622
GRWB	0.000	0.000	0.127	0.000
GRBP	0.010	0.000	0.318	0.000
NFAB	0.000	0.002	0.148	0.000
NFBP	0.000	0.002	0.155	0.000
GRLB	0.003	0.005	0.365	0.000
GRBF	0.003	0.004	0.394	0.000
BSLS	0.000	0.000	0.294	0.000
BSPC	0.000	0.000	0.136	0.000
BSAF	0.000	0.000	0.461	0.000
BSBD	0.000	0.000	0.461	0.000
BSGB	0.000	0.000	0.495	0.000
BSAC	0.000	0.000	0.487	0.000
GRBI	0.002	0.003	0.484	0.002
BCGR	0.000	0.000	0.230	0.080
GRGR	0.001	0.002	0.441	0.021
BFAL	0.000	0.000	0.252	0.000
HFAG	0.000	0.000	0.618	0.000
BFLA	0.000	0.000	0.627	0.000

STATION CODE	PSHRBM % MIXED SHRUB:624	PSHRBR TOTAL SHRUB RANGE %	PMIXR % MIXED RANGE:63	PRANGE TOTAL RANGE %
GRWB	0.000	0.127	0.000	0.127
GRBP	0.000	0.318	0.000	0.328
NFAB	0.000	0.150	0.139	0.289
NFBP	0.000	0.157	0.266	0.423
GRLB	0.000	0.369	0.099	0.472
GRBF	0.000	0.399	0.090	0.492
BSLS	0.000	0.294	0.559	0.853
BSPC	0.000	0.136	0.845	0.981
BSAF	0.000	0.461	0.416	0.878
BSBD	0.000	0.461	0.416	0.878
BSGB	0.013	0.508	0.380	0.888
BSAC	0.028	0.516	0.374	0.890
GRBI	0.028	0.516	0.145	0.664
BCGR	0.481	0.792	0.065	0.857
GRGR	0.139	0.604	0.120	0.725
BFAL	0.000	0.252	0.000	0.252
HFAG	0.000	0.618	0.011	0.629
BFLA	0.000	0.627	0.040	0.668

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	PJUN	PWOOD	PASPN	PDECID
STATION CODE	% JUNIPER:71	TOTAL WOODLAND %	% ASPEN:811	TOTAL DECID FOR %
GRWB	0.000	0.000	0.000	0.000
GRBP	0.000	0.000	0.000	0.000
NFAB	0.000	0.000	0.000	0.000
NFBP	0.000	0.000	0.000	0.000
GRLB	0.000	0.000	0.000	0.000
GRBF	0.000	0.000	0.000	0.000
BSLS	0.000	0.000	0.000	0.000
BSPC	0.000	0.000	0.000	0.000
BSAF	0.000	0.000	0.000	0.000
BSBD	0.000	0.000	0.000	0.000
BSGB	0.000	0.000	0.000	0.000
BSAC	0.000	0.000	0.000	0.000
GRBI	0.000	0.000	0.000	0.000
BCGR	0.114	0.114	0.000	0.000
GRGR	0.027	0.027	0.000	0.000
BFAL	0.013	0.013	0.003	0.003
HFAG	0.000	0.000	0.000	0.000
BFLA	0.028	0.028	0.005	0.005

	PCON	PPINE	PCONF	PMIX
STATION CODE	% CONIFER:82	% PINE:823	TOTAL CONIF FOR %	% MIXED FOREST:83
GRWB	0.333	0.188	0.521	0.160
GRBP	0.124	0.247	0.372	0.074
NFAB	0.413	0.000	0.413	0.000
NFBP	0.368	0.000	0.368	0.000
GRLB	0.161	0.158	0.319	0.024
GRBF	0.146	0.165	0.311	0.022
BSLS	0.079	0.000	0.079	0.000
BSPC	0.000	0.000	0.000	0.000
BSAF	0.060	0.000	0.060	0.000
BSBD	0.060	0.000	0.060	0.000
BSGB	0.055	0.000	0.055	0.000
BSAC	0.054	0.000	0.054	0.000
GRBI	0.102	0.100	0.202	0.013
BCGR	0.000	.000	.000	0.000
GRGR	0.073	0.072	0.145	0.010
BFAL	0.000	0.446	0.446	0.000
HFAG	0.000	0.306	0.306	0.000
BFLA	0.000	0.197	0.197	0.000

APPENDIX A (Continued). Parameter values for water quality variables and basin attributes. The regression models were developed from these values. The first heading for a column is the abbreviation used to identify the parameter, and the second heading briefly describes the parameter. A value of -999 indicates missing data.

	PMXFOR	PFORST	PPT2	MAXT
STATION CODE	TOTAL MIXED FOREST %	TOTAL FOREST %	*TOTAL PRECIP ("/YR)*	*MEAN JULY MAXT (F)*
GRWB	0.160	0.681	41	72
GRBP	0.074	0.445	29	75
NFAB	0.000	0.413	25	76
NFBP	0.000	0.368	22	76
GRLB	0.024	0.343	23	76
GRBF	0.022	0.333	22	77
BSLS	0.000	0.079	15	75
BSPC	0.000	0.000	13	81
BSAF	0.000	0.060	12	80
BSBD	0.000	0.060	11	80
BSGB	0.000	0.055	11	80
BSAC	0.000	0.054	11	81
GRBI	0.013	0.215	17	79
BCGR	0.000	.000	12	86
GRGR	0.010	0.155	15	81
BFAL	0.000	0.449	19	76
HFAG	0.000	0.306	17	82
BFLA	0.000	0.201	14	80

	MINT
STATION CODE	*MEAN JAN MINT (F)*
GRWB	-5
GRBP	-6
NFAB	-4
NFBP	-5
GRLB	-6
GRBF	-6
BSLS	-3
BSPC	0
BSAF	-4
BSBD	-4
BSGB	-4
BSAC	-4
GRBI	-5
BCGR	9
GRGR	-1
BFAL	8
HFAG	0
BFLA	5

APPENDIX B. Point source discharges in the Green River basin.

APPENDIX B. Point source discharges in the Green River Basin permitted by the Wyoming Department of Environmental Quality. Note that the discharges are listed by subbasin.

WRDS STATION	CODE	SOURCE#	FLOW(MGD)	N CONC (mg/l)	P CONC (mg/l)	N LOAD(T/DAY)	P LOAD(T/DAY)	N(T/YR)	P(T/YR)
9201000	NFAB	1	0.5	1.5	3.85	3.13E-03	8.04E-03	1.144	2.937
9209400	GRLB	1	0.25	1.5	3.85	1.57E-03	4.02E-03	0.572	1.468
		2	0.03	2.9	7.7	3.63E-04	9.65E-04	0.133	0.352
		3	0.05	2.9	7.7	6.06E-04	1.61E-03	0.221	0.587
	SUM							0.926	2.408
9216950	BCGR	1	2	2.9	7.7	2.42E-02	6.43E-02	8.848	23.493
		2	0.2	2.9	7.7	2.42E-03	6.43E-03	0.885	2.349
		3	0.05	2.9	7.7	6.06E-04	1.61E-03	0.221	0.587
		4	0.01	2.9	7.7	1.21E-04	3.22E-04	0.044	0.117
		5	0.005	2.9	7.7	6.06E-05	1.61E-04	0.022	0.059
		6	0.04	2.9	7.7	4.84E-04	1.29E-03	0.177	0.470
		7	0.01	2.9	7.7	1.21E-04	3.22E-04	0.044	0.117
		8	2.7	0	1.5	0.00E+00	1.69E-02	0.000	6.178
	SUM							10.241	33.371
9217000	GRGR	1	2	2.9	7.7	2.42E-02	6.43E-02	8.848	23.493
		2	0.02	0	0.2	0.00E+00	1.67E-05	0.000	0.006
	SUM							8.848	23.499
9224450	HFAG	1	0.6	2.9	7.7	7.27E-03	1.93E-02	2.654	7.048
		2	0.001	2.9	7.7	1.21E-05	3.22E-05	0.004	0.012
		3	0.01	2.9	7.7	1.21E-04	3.22E-04	0.044	0.117
		4	5	0	0.3	0.00E+00	6.26E-03	0.000	2.288
	SUM							2.703	9.465
9222000	BFAL	1	0.1	2.9	7.7	1.21E-03	3.22E-03	0.442	1.175

APPENDIX C. Basin attributes (independent variables) common to all regression analyses.

Appendix C. Basin attributes (independent variables) common to all regression analyses. This set was further reduced to unique sets for each dependent variable as detailed in "Reduction of Number of Independent Variables". Explanation of abbreviations is found in Appendix A.

Geology:	Hydrology:	Soils:	Land cover/land use:	Climate:
QGL	AREAI	MINS	ALPA	PPT2
QAL	FLOD2	MAXS	ALPV	MAXT
QG	FLOD10	MINEL	CROPI	MINT
QS	FLOD25	MAXEL	CROPD	
QAO	PKPOR	MAST	DUNE	
TU	PK6579	MINFFD	EXPOS	
TW	FLDRAT	MAXFFD	LACUS	
TGM	SLENG	D2RK	PALUS	
TWN	DDEN	FRAC3	SURBAN	
TGL	ORDR	M200	BASIN	
TGWE	CHANL	PCLAY	SHRUBR	
TGF	CHANS	PERM	SAGE	
TB	ELONG	H2OCAP	HALOS	
TBP	MELEV	SAL	SHRUBM	
TWU	BASINS	SSC	MIXEDR	
TGU	BIFUR	KFAC	JUNIP	
TI		TFAC	ASPEN	
TWC		WIND	CONIF	
TGT		PORG	PINE	
TGW		PHSOIL	MIXEDF	
TTWA				
TUB				
TBI				
TF				
KBA				
KLA				
KAL				
KE				
KR				
KBL				
KLE				