Prepared in cooperation with the Idaho Department of Environmental Quality

Phosphorus and Suspended Sediment Load Estimates for the Lower Boise River, Idaho, 1994 – 2002

Scientific Investigations Report 2004–5235
Version 2.00, December 2005

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

Multiply	By	To obtain
mile (mi)	1.609	kilometer (km)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
pound, avoirdupois, per day (lb/d)	0.4536	kilogram per day (kg/d)
ton per day (ton/d)	0.9072	metric ton per day
ton, short (2,000 lb)	0.9072	megagram (Mg)

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Phosphorus and Suspended Sediment Load Estimates for the Lower Boise River, Idaho, 1994 – 2002

By Mary M. Donato and Dorene E. MacCoy

Abstract

The U.S. Geological Survey used LOADEST, newly developed load estimation software, to develop regression equations and estimate loads of total phosphorus (TP), dissolved orthophosphorus (OP), and suspended sediment (SS) from January 1994 through September 2002 at four sites on the lower Boise River: Boise River below Diversion Dam near Boise, Boise River at Glenwood Bridge at Boise, Boise River near Middleton, and Boise River near Parma. The objective was to help the Idaho Department of Environmental Quality develop and implement total maximum daily loads (TMDLs) by providing spatial and temporal resolution for phosphorus and sediment loads and enabling load estimates made by mass balance calculations to be refined and validated.

Regression models for TP and OP generally were well fit on the basis of regression coefficients of determination (R^2), but results varied in quality from site to site. The TP and OP results for Glenwood probably were affected by the upstream wastewater-treatment plant outlet, which provides a variable phosphorus input that is unrelated to river discharge. Regression models for SS generally were statistically well fit. Regression models for Middleton for all constituents, although statistically acceptable, were of limited usefulness because sparse and intermittent discharge data at that site caused many gaps in the resulting estimates.

Although the models successfully simulated measured loads under predominant flow conditions, errors in TP and SS estimates at Middleton and in TP estimates at Parma were larger during high- and low-flow conditions. This shortcoming might be improved if additional concentration data for a wider range of flow conditions were available for calibrating the model.

The average estimated daily TP load ranged from less than 250 pounds per day (lb/d) at Diversion to nearly 2,200 lb/d at Parma. Estimated TP loads at all four sites displayed cyclical variations coinciding with seasonal fluctuations in discharge. Estimated annual loads of TP ranged from less than 8 tons at Diversion to 570 tons at Parma. Annual loads of dissolved OP peaked in 1997 at all sites and were consistently higher at Parma than at the other sites.

The ratio of OP to TP varied considerably throughout the year at all sites. Peaks in the OP:TP ratio occurred primarily when flows were at their lowest annual stages; estimated seasonal OP:TP ratios were highest in autumn at all sites. Conversely, when flows were high, the ratio was low, reflecting increased TP associated with particulate matter during high flows. Parma exhibited the highest OP:TP ratio during all seasons, at least 0.60 in spring and nearly 0.90 in autumn. Similar OP:TP ratios were estimated at Glenwood. Whereas the OP:TP ratio for Parma and Glenwood peaked in November or December, decreased from January through May, and increased again after June, estimates for Diversion showed nearly the opposite pattern — ratios were highest in July and lowest in January and February. This difference might reflect complex biological and geochemical processes involving nutrient cycling in Lucky Peak Lake, but further data are needed to substantiate this hypothesis.

Estimated monthly average SS loads were highest at Parma, about 250 tons per day (ton/d). Average annual loads from 1994 through 2002 were 13,000 tons at Diversion, 33,000 tons at Glenwood, and 88,000 tons at Parma. Estimated SS loads peaked in the spring at all sites, coinciding with high flows.

Increases in TP in the reach from Diversion to Glenwood ranged from 200 to 350 lb/d. Decreases in TP were small in this reach only during high flows in January and February 1997. Decreases in SS, were large during high-flow conditions indicating sediment deposition in the reach. Intermittent data at Middleton indicated that increases and decreases in TP in the reach from Glenwood to Middleton were during low- and high-flow conditions, respectively. All constituents increased in the reach from Middleton to Parma, particularly in May 1995. Periods of large increases in SS were interpreted as times of active erosion of sediment in the channel and (or) addition of sediment to the river from tributaries.

Statistically significant downward temporal trends in load were determined for SS at Glenwood, for OP at Middleton, and for TP, OP, and SS at Parma. A significant upward trend in TP was determined at Diversion.

Calculated annual flow-weighted concentrations highlighted the strong interaction between flow and particle-associated constituents such as TP and SS and enabled concentrations to be assessed despite the large range in flows. At Parma and Glenwood, where the OP:TP ratio was high, the flow-weighted concentration of TP was inversely related to load because of dilution and the strong effect of flow on the load calculation. At Diversion, where the OP:TP ratio was low, load and concentration were directly related because particulate matter was increased, not diluted, during high flows. Relations were similar for SS.

LOADEST average daily TP load estimates indicated that reductions in load of 24 to 75 percent would have been necessary to meet the proposed goal of 565 lb/d set forth in the Snake River-Hells Canyon TMDL. Estimated average daily loads of SS at Parma from 1994 through 2002 exceeded the current lower Boise River TMDL load allocation of 101 ton/d at Parma except in 2001.

The LOADEST model provided spatial and temporal resolution to help refine mass-balance spreadsheet calculations used for TP TMDL allocations between Diversion and Parma. LOADEST results compared favorably with previous mass-balance spreadsheet load estimates for TP and have an advantage over spreadsheet estimates in that they allow more detailed examination of loads at different timescales, whereas spreadsheet estimates are static.

Introduction

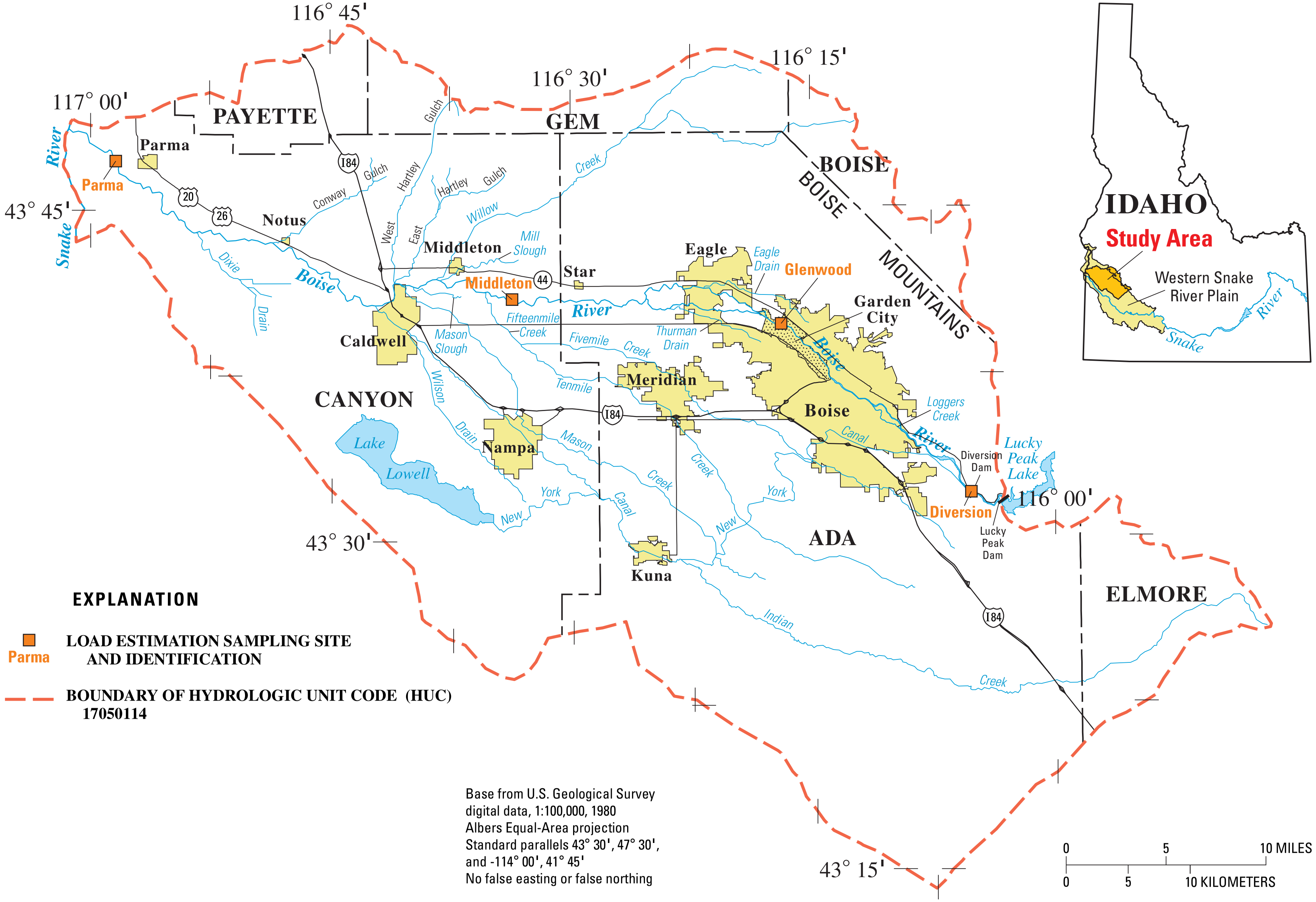
Water-quality and biological conditions of the lower Boise River have been affected by human activities such as agricultural land and water use, urbanization, and river channel alteration, as described by MacCoy (2004). The Lower Boise River Water Quality Plan, Inc., established in 1992 and composed of public and private agencies, groups, and individuals, identified a need to assess water-quality conditions of the lower Boise River. To address this need and to provide a baseline from which to assess future trends, the U.S. Geological Survey (USGS), in cooperation with the Idaho Department of Environmental Quality (IDEQ), began an 8-year comprehensive assessment of the river in 1994. Data collection was completed in 2002. Water-quality and biological data from 1994 through 1997 were summarized in interim reports by Mullins (1998 and 1999). Water-quality and biological conditions for the entire study period, through 2002, were summarized by MacCoy (2004).

In October 1994, the lower Boise River was listed as water-quality limited in accordance with Section 303(d) of the Clean Water Act (U.S. Environmental Protection Agency, 1994, p. 6). This listing required the State of Idaho to develop total maximum daily loads (TMDLs) for the lower Boise River. Constituents of concern that must be addressed in the TMDL are nutrients, suspended sediment, bacteria, elevated water temperature, low dissolved-oxygen concentrations, oil and grease, and flow modification.

The TMDL for suspended sediment in the lower Boise River was completed in 1999 (Idaho Department of Environmental Quality, 1999). The TMDL for phosphorus is currently undergoing final review and revision. In support of these efforts, the USGS used the LOADEST software (Runkel and others, 2004) to estimate and interpret total phosphorus, orthophosphorus, and suspended sediment loads at four sites on the lower Boise River: Boise River below Diversion Dam near Boise (USGS gaging station 13203510; hereafter called Diversion), Boise River at Glenwood Bridge at Boise (USGS gaging station 13206000; hereafter called Glenwood), Boise River near Middleton (USGS gaging station 13210050; hereafter called Middleton), and Boise River near Parma (USGS gaging station 13213000; hereafter called Parma) (fig. 1) from 1994 through 2002. Instantaneous loads for various constituents calculated from synoptic sampling data collected during that period were presented in earlier reports (Mullins, 1998; MacCoy, 2004). LOADEST augments this information by providing continuous time-series load estimates, thus offering better temporal and spatial resolution for constituent inputs.

Modeling results can be used to refine mass-balance calculations that form the basis for allocating loads in the reaches between Diversion and Glenwood, Glenwood and Middleton, and Middleton and Parma. The results also will be useful for planning and implementing additional synoptic sampling to further improve the mass-balance calculations. This report briefly describes the LOADEST software and summarizes the results of the modeling work on the lower Boise River.

Greg Clark and Paul Woods of the U.S. Geological Survey provided valuable technical advice about using the LOADEST model and contributed to the interpretation of the results.



Base from U.S. Geological Survey
digital data, 1:100,000, 1980
Albers Equal-Area projection
Standard parallels 43° 30', 47° 30',
and -114° 00', 41° 45'
No false easting or false northing

Figure 1. Location of the lower Boise River Basin and load estimation sampling sites, Idaho.

Method for Estimating Phosphorus and Suspended Sediment Loads

Total phosphorus (TP), dissolved orthophosphorus (OP), and suspended sediment (SS) loads in the lower Boise River were estimated with the USGS software called LOADEST, which uses time-series streamflow data and constituent concentrations to calibrate a regression model that describes constituent loads in terms of various functions of streamflow and time (Runkel and others, 2004). The software then uses the regression model to estimate loads over a user-specified interval. The model output includes statistical data to enable the user to evaluate the quality of the model. Model output also includes upper and lower 95-percent confidence interval (CI) values with the monthly average load estimates to provide an understanding of the precision of the monthly estimates. In this study, separate regression models were calibrated for TP, OP, and SS for each of the four sampling sites.

The software performs calibration procedures and makes load estimates using four statistical estimation methods: Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE), Linear Attribution Method (LAM), and Least Absolute Deviation (LAD). The user chooses the most appropriate method for the data being analyzed. AMLE and MLE are suitable when the model calibration errors (residuals) are normally distributed; AMLE is the more appropriate method of the two when the calibration data set contains censored data (data that are reported as less than or greater than some threshold). LAM and LAD are useful when the residuals are not normally distributed.

The software output includes the probability plot correlation coefficient (Vogel, 1986), Turnbull-Weiss likelihood ratio (Turnbull and Weiss, 1978), data for constructing a normal-probability plot, and standardized residuals. Because the input data in this study included censored data, and because the model calibration residuals were normally distributed within acceptable limits, the AMLE estimation method was selected in all cases.

The software allows the user to choose between selecting the general form of the regression from among several predefined models and letting the software automatically choose the best model, on the basis of the Akaike Information Criterion (Akaike, 1981). The selection criterion is designed to achieve a good balance between using as many predictor variables as possible to explain the variance in load while minimizing the standard error of the resulting estimates. For this study, the software was allowed to choose the best model.

The output regression equations take the following general form:

$$\begin{aligned}\ln(L) &= a + b(\ln Q) + c)\ln Q^2) \\ &\quad + d[\sin(2\pi \mathrm{T})] + e[\cos(2\pi \mathrm{T})] \\ &\quad + f\mathrm{T} + g\mathrm{T}^2\end{aligned} \tag{1}$$

where

L is the constituent load, in pounds per day;
Q is stream discharge, in cubic feet per second;
T is time, in decimal years from the beginning of the calibration period; and
a, b, c, d, e, f, and g are regression coefficients.

Some of the regression equations in this study did not include all of the above terms, depending on the particular model chosen by the software. A complete discussion of the theory and principles behind the calibration and estimation methods used by the LOADEST software is given by Runkel and others (2004).

Input Data

Calibration Files

The model calibration procedure performed by LOADEST uses instantaneous discharge data and concurrent instantaneous concentration data, provided by the user in a calibration file for each site. Data used in the calibration files for this study were collected at specific intervals between 1994 and 2003 as part of the ongoing assessment of water-quality and biological conditions of the Boise River. Surface-water samples were collected monthly or bimonthly during the nonirrigation season (October through March) and as often as twice a month during the irrigation season (April through September). Further details of the water-quality analyses are given in a report by MacCoy (2004).

The number and frequency of available calibration data varied from site to site. The total number of concentration measurements suitable for use in the calibration files also varied, depending on the constituent, but ranged from 55 at

Diversion (SS) to 79 at Glenwood (TP and OP). Overall, more measurements were collected at Glenwood and Parma than at Diversion and Middleton. In addition, measurements were not evenly distributed in time throughout the estimation period. For example, in 1997 only two TP and OP concentration measurements were available for Diversion (both collected during high-flow periods), but nine measurements were available for 2002 and covered a wide range of flow conditions.

After this report was completed, the SS data in the USGS database were updated to include new analyses of samples, which had been collected between 1994 and 2003, but which were not entered in the database until mid-2005. Although the new data were not used in our load estimates, new LOADEST SS load estimates based on the complete data were not significantly different from our results (Greg Clark, U.S. Geological Survey, oral commun., 2005).

Concentrations of TP and OP generally were highest in winter, when river flows are low. Conversely, concentrations were lowest in spring and early summer, when flows are highest. Suspended sediment showed the opposite pattern and was highest during high flows. The relations between SS, TP, and OP concentrations and discharge for the four sites are shown in figure 2.

The Glenwood site is about 1 mi downstream from an outlet of a wastewater-treatment plant that contributed an average of 330 lb/d of TP to the Boise River during the estimation period (City of Boise, written commun., 2002) Although discharge and concentration data for the effluent exist and attempts were made to adjust the Glenwood data to compensate for this known input, meaningful results were not obtained. Therefore, phosphorus concentrations for the Glenwood site include contributions from this source.

Discharge Data

Instantaneous discharge was measured using standard USGS methods (Rantz and others, 1982) at the same time water-quality samples were collected. Instantaneous discharge measurements used in the calibration files usually were within a few percent of the daily average discharge recorded at the gage for that day, but a few measurements differed by more than 10 percent. One possible explanation for these discrepancies is a sudden change in discharge during a single day as a result of irrigation water-management practices (turning on or off a diversion), causing the daily average flow to be much different than the instantaneous measurement. Instantaneous loads were calculated using the onsite discharge measurements; the software used daily average discharge data to estimate daily, monthly, and seasonal loads (see section, “Estimation Files”).

Water-Quality Data

Depth- and width-integrated water samples for constituent concentration analysis were collected, processed, and preserved according to the methods described by Wilde and others (1999). Phosphorus and dissolved orthophosphorus were analyzed by the USGS National Water-Quality Laboratory according to the methods described by Fishman (1993); quality-assurance/quality-control protocols described by Pritt and Raese (1995) were followed. Suspended sediment was analyzed by the USGS Cascades Volcano Observatory Sediment Laboratory using methods described by Guy (1969). Concentrations of OP, TP, and SS were reported in milligrams per liter. Load estimates produced by LOADEST were in pounds per day for OP and TP and in tons per day for SS.

LOADEST is capable of handling censored data with the AMLE method. Censored data were a substantial part of the input data only at Diversion, where nearly one-half the data for TP and OP were reported to be less than the detection limits. Minimum detection limits for TP and OP varied throughout the data-collection period because analytical methods changed during that time. Detection limits for TP ranged from 0.01 to 0.06 mg/L; detection limits for OP ranged from 0.01 to 0.02 mg/L.

In 9 of 88 sampling events at Glenwood, OP concentrations slightly exceeded the concurrent TP concentrations. This suggested a problem with these analyses, because OP should always be less than or equal to TP. However, it was not certain whether TP or OP was in error, so both OP and TP measurements for those dates were omitted from the calibration files. The remaining 79 data points were sufficient to perform the regressions.

Estimation Files

Estimation files containing daily average discharge data, in cubic feet per second, were used by the software to estimate daily, monthly, and seasonal loads from January 19, 1994, through September 30, 2002. The software estimates loads only for days for which discharge data are provided by the user. The number of days for which discharge data were available for each site are shown in table 1. The maximum possible number of days in the estimation period was 3,177.

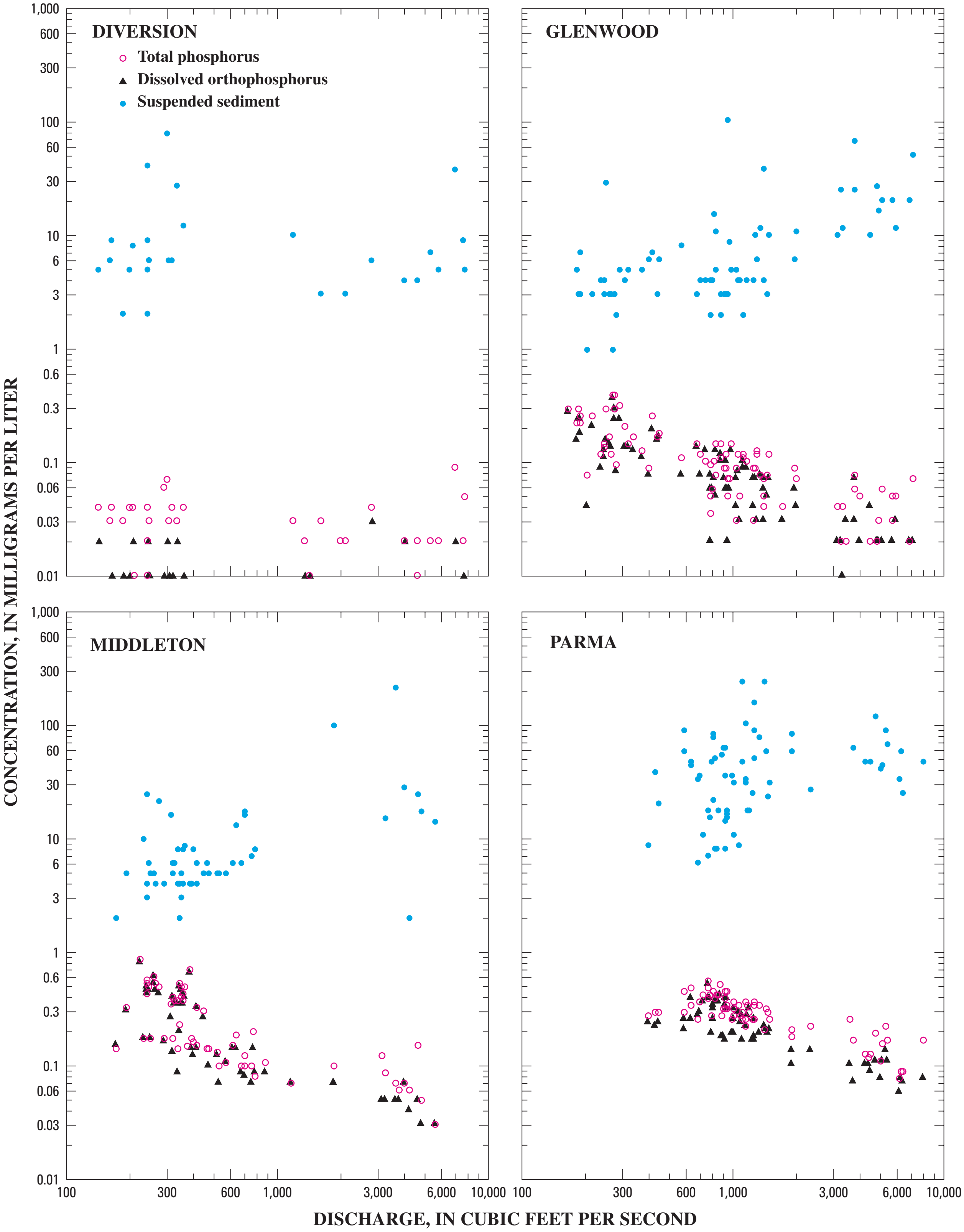


Figure 2. Relation between constituent concentration and discharge at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Table 1. Number of days per year and percentage of year for which daily loads were estimated at four sites on the lower Boise River, Idaho, January 19, 1994, through September 30, 2002.

[Site locations are shown in figure 1]

Year	Diversion		Glenwood		Middleton		Parma	
	Number of days	Percentage of year	Number of days	Percentage of year	Number of days	Percentage of year	Number of days	Percentage of year
1994	347	95	347	95	347	95	347	95
1995	361	99	365	100	352	96	365	100
1996	366	100	366	100	205	56	366	100
1997	364	100	365	100	110	30	365	100
1998	365	100	365	100	0	0	365	100
1999	360	99	365	100	202	55	365	100
2000	346	95	366	100	310	85	366	100
2001	365	100	365	100	365	100	365	100
2002	266	73	273	75	261	72	268	73
Entire estimation period	3,140	99	3,177	100	2,152	68	3,172	100

Daily average discharge data for the estimation input files were obtained from various sources. Complete daily average discharge data for the estimation period were available from USGS gaging station records for Glenwood; Parma lacked only 5 days. Discharge data for Middleton were available from USGS and Idaho Power Company data archives, but data were lacking for nine time periods totaling 1,025 of the 3,177 days in the estimation period (including the entire year 1998). Complete data were available only for 2001; as a result, there are many omissions and discontinuities in the load estimates for Middleton.

The USGS gaging station at Diversion was discontinued on September 30, 1994. Provisional discharge data for Diversion from October 1, 1994, through September 30, 2001, were obtained from the Bureau of Reclamation online data server, Hydromet (http://www.usbr.gov/pn/hydromet/). These values are not direct measurements and were obtained by subtracting the measured discharge in the New York Canal from the discharge at the USGS gaging station 13202000 (Boise River near Boise). Discharge data from October 1, 2001, through September 30, 2002, are not available from Hydromet but were calculated by subtraction in the same manner, using discharge data from the New York Canal provided by Idaho Power Company and published data from USGS gaging station 13202000.

Discharge from 1995 through 1999 was relatively high and peaked in February 1997 at approximately 8,000 ft^3/s at Parma. In 1994 and from 2000 through 2002, discharge, even during spring runoff, was relatively low. A graph of monthly average discharge data for the four sites is given in figure 3.

Other Input Data

Other routine input data necessary for LOADEST to perform the regression and load estimations, such as number of constituents and the reporting units of constituents, were provided in input files. In addition, four seasons, based on the following dates, were defined to allow the software to perform optional seasonal estimations: spring, March 1 through May 31; summer, June 1 through August 31; autumn, September 1 through November 30, and winter, December 1 through February 29.

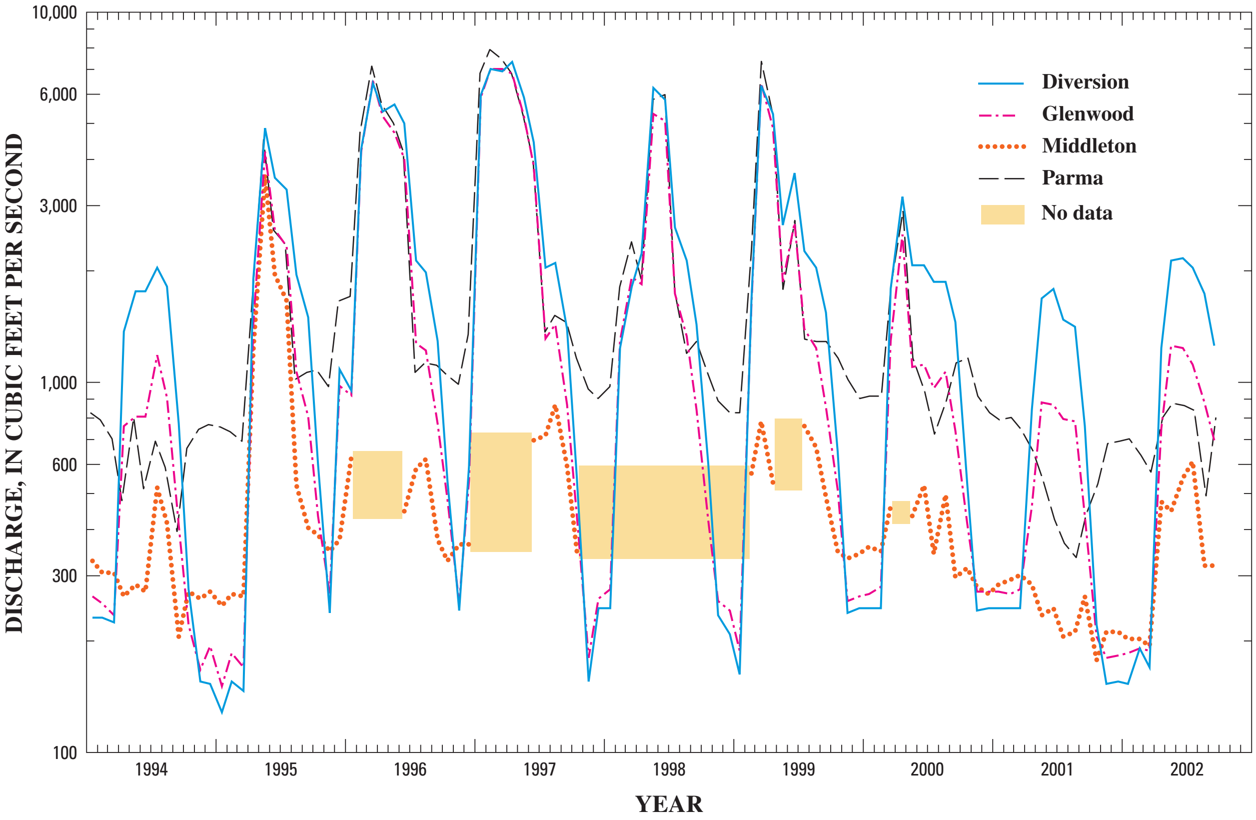


Figure 3. Monthly average discharge at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

LOADEST Modeling Results

Regression Evaluation

Coefficients of determination (R^2) for the best-fit regression models for loads of TP, OP, and SS for the four studied sites (table 2) tended to be somewhat inflated because of the form of the regression equation. Because load is a function of flow (see equation 1), a strong relation (high R^2) is expected, unless there are very large variations in concentration.

The relatively high R^2 values indicate that, with few exceptions, the models for all three constituents successfully simulated the variability in constituent loads at most sites. An exception was Glenwood, where R^2 values for OP and TP were 26 and 58 percent, respectively. Overall, results for SS exhibited the highest R^2 values.

Although the R^2 values for most constituents at Middleton were not notably smaller than at the other sites, the resulting load estimates were of limited usefulness because they were intermittent and contained large gaps owing to missing discharge data. The load estimates for Middleton are discussed in this report, with the caveat that they are based on limited and intermittent data.

Measured instantaneous TP loads for all sites were plotted against estimated loads for the same day to visually assess the fitness of the model (fig. 4). Points falling above the 1:1 line are cases in which the estimated value was smaller than the measured value; points below the line are cases in which the estimated value was larger than the measured value. If the model were perfect, all points would fall on the line. In most cases, the points are close to and evenly distributed across the 1:1 line, indicating that the model neither systematically overestimated nor underestimated loads. At Diversion, more points lie above the line, possibly suggesting a slight negative bias (that is, the model systematically underestimated TP loads at this site). At Middleton and at Parma, points are more scattered at very large loads, suggesting that the model was not as successful in estimating TP loads in this range of values as it was at smaller values. The large amount of scatter in the graph for Glenwood reflects the low R^2 and the poor fit of the model for the TP regression at this site (table 2).

Table 2. Regression coefficients and coefficients of determination (R^2) for load models used to estimate total phosphorus, dissolved orthophosphorus, and suspended sediment at four sites on the lower Boise River, Idaho, January 14, 1994, through September 30, 2002.

[Site locations are shown in figure 1. The regression equation is $\ln(L) = a + b(\ln Q) + c(\ln Q^2) + d\,[sin(2\pi T)] + e[cos(2\pi T)] + fT + gT^2$: where L is the constituent load, in pounds per day or tons per day; Q is stream discharge, in cubic feet per second; T is time in decimal years from the beginning of the calibration period; *a,b,c,d,e,f*, and *g* are regression coefficients; R^2 represents the amount of variance explained by the model. –. coefficient for term not used in the model]

Site name	Regression coefficient							R^2 (percent)
	a	*b*	*c*	*d*	*e*	*f*	*g*	
				Total phosphorus				
Diversion	3.433	1.150	0.208	-0.491	0.306	0.108	–	75
Glenwood	5.458	.463	–	–	–	–	–	58
Middleton	5.993	.495	–	-.463	.321	–	–	68
Parma	7.111	.490	-.170	-.087	.203	-.017	–	86
				Dissolved orthophosphorus				
Diversion	3.337	1.123	0.022	-0.370	0.124	0.019	-0.022	89
Glenwood	5.056	.308	–	–	–	–	–	26
Middleton	5.704	.374	–	-.581	.325	-.044	–	71
Parma	6.803	.439	-.151	-.229	.172	-.027	–	85
				Suspended sediment				
Diversion	8.793	1.198	0.161	-0.323	0.409	-0.0003	0.045	71
Glenwood	9.810	1.577	–	.003	.344	-.094	–	86
Middleton	10.093	1.345	–	.290	.350	–	–	82
Parma	12.048	.941	-.246	.491	-.671	-.074	–	81

The relation between estimated and measured OP loads at Diversion (fig. 5) suggests that the model underestimated large loads at this site but performed reasonably well at moderate loads. At Glenwood, scatter is very large; the R^2 for this regression is lower than for all others. Note that the model selected by the software has only two terms (table 2), indicating that the load at Glenwood is best described simply as a function of discharge. Including terms that described load as a function of time did not improve the fitness of the model.

The points for OP at Middleton are moderately scattered; the sparseness of the data contributed to time gaps in the results. Points for Parma are tightly clustered near the line, reflecting the relatively high R^2 (85 percent) and overall fitness of the model.

Similar relations between estimated and measured SS loads at Parma, Glenwood, and Diversion (fig. 6) indicate reasonably tight distributions near the 1:1 line over a wide range of loads. At Middleton, however, large loads were not as well modeled.

LOADEST provides information on the errors associated with the load estimates, including upper and lower limits of the 95-percent CI for each monthly estimate. Confidence intervals varied with flow conditions in many cases. For example, at Parma, the largest CIs for all constituents (as a percentage of the estimated load) were associated with flows lower than about 800 ft^3/s and higher than about 6,000 ft^3/s. This is because the model is best suited to the overall flow conditions and is less successful at predicting loads under extreme flow conditions.

Monthly average load estimates for SS generally were the least precise; the average width of the 95-percent CI, as a percentage of the mean estimated load of SS, ranged from 88 percent at Parma to 129 percent at Diversion. In contrast, TP and OP average CIs at Parma were about 24 and 23 percent, respectively, of the estimated monthly average loads.

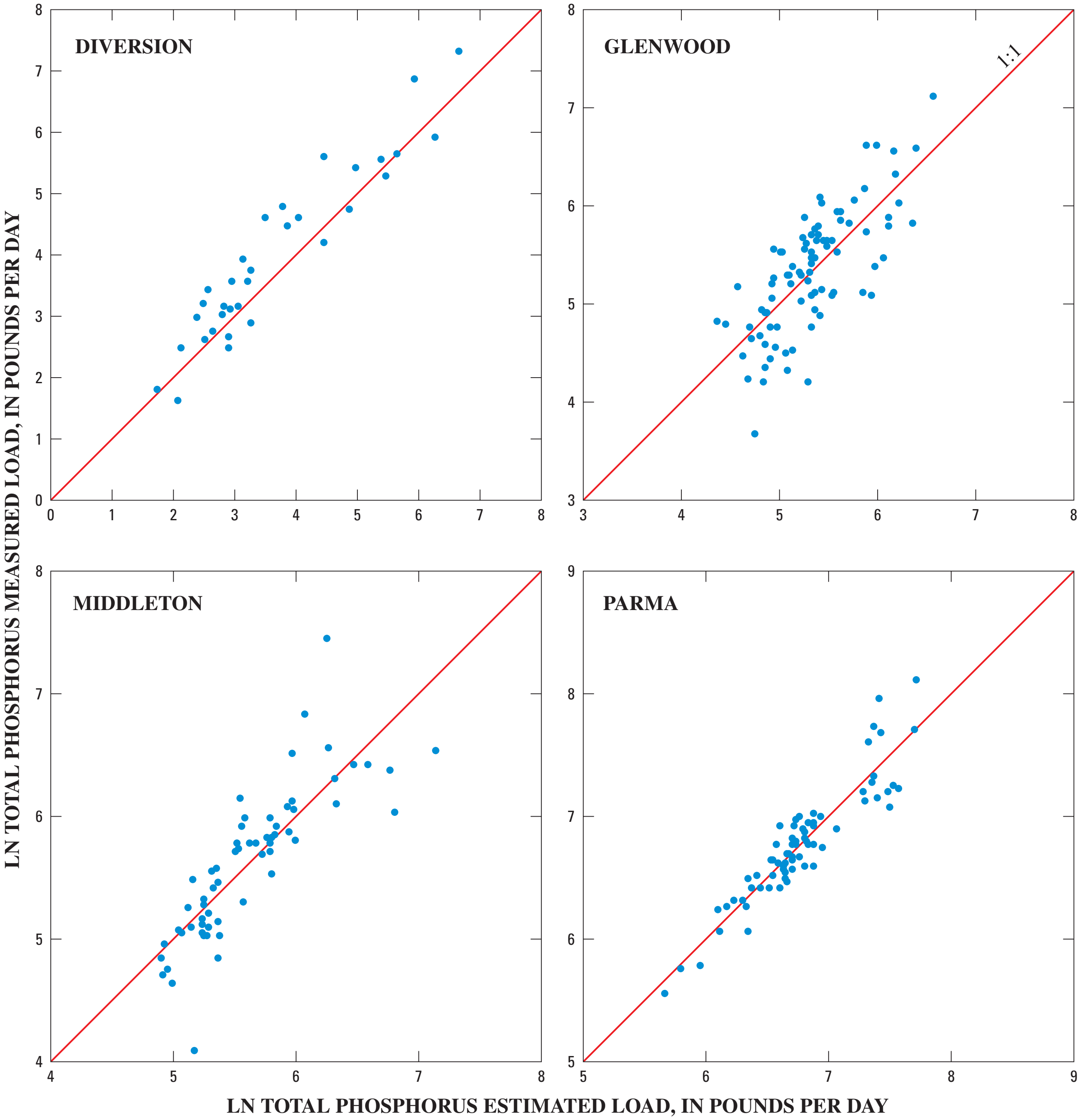


Figure 4. Relation between estimated and measured loads of total phosphorus at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

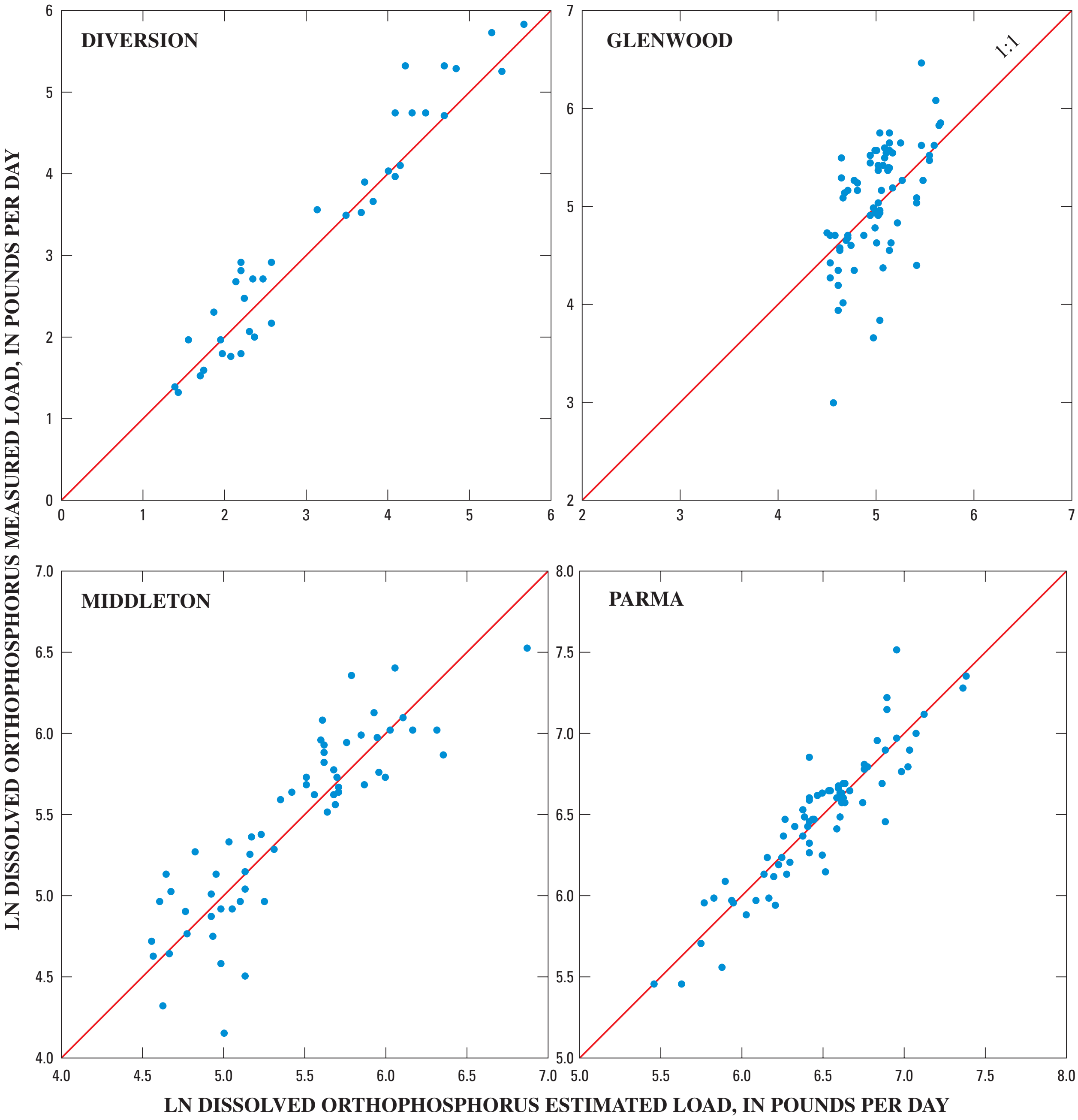


Figure 5. Relation between estimated and measured loads of dissolved orthophosphorus at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

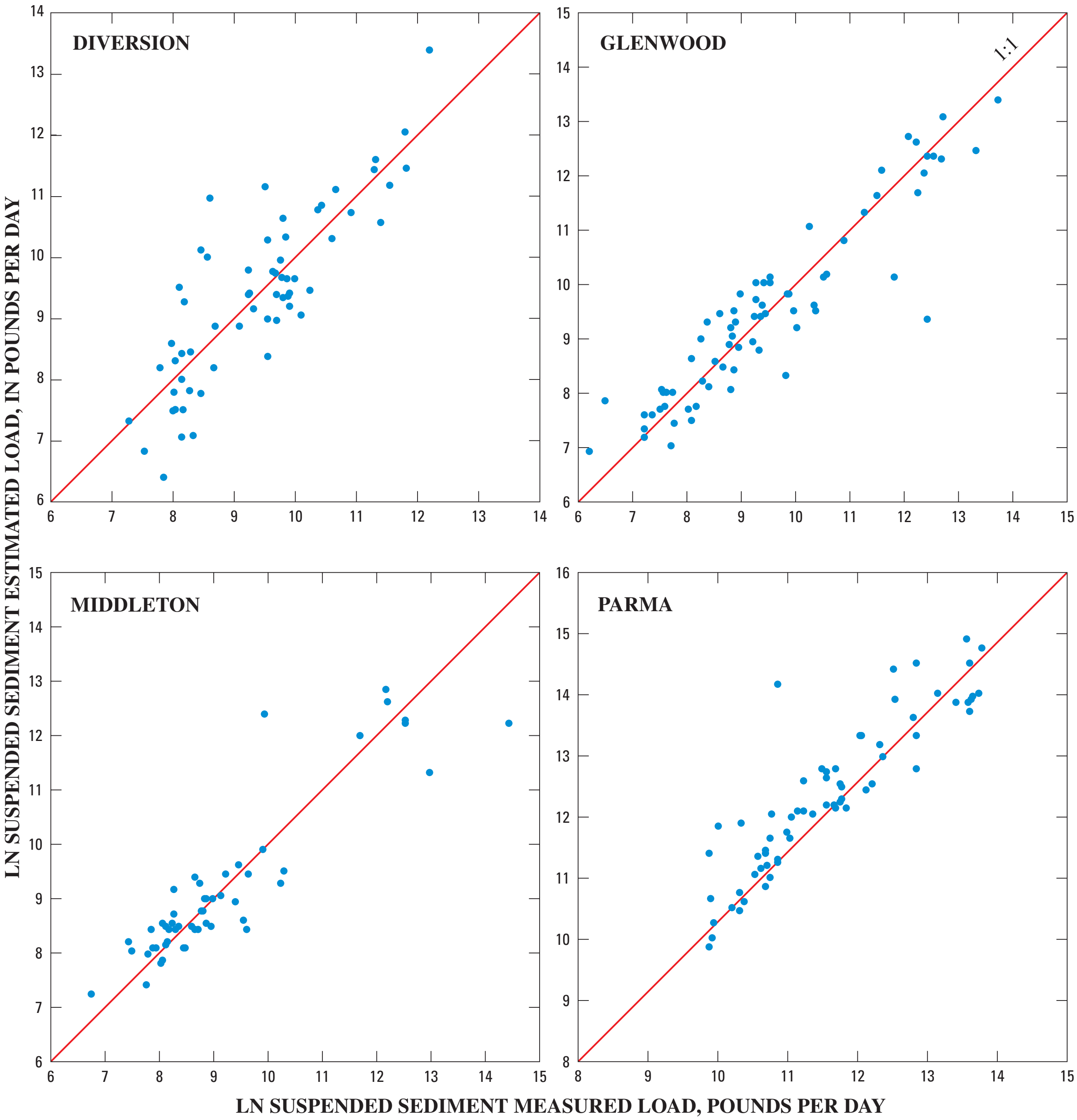


Figure 6. Relation between estimated and measured loads of suspended sediment at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Estimated Loads

Although the model provided daily load estimates, they are not discussed in detail in this report because of their limited usefulness (see the section “Limitations and Advantages of the LOADEST Model”). Monthly and seasonal (as defined in the section “Other Input Data”) average loads were a more suitable way to synthesize the data because day-to-day variation (which can be misleading and cause invalid interpretation) tended to be minimized. Therefore, most of the discussion in the following sections refers to monthly, seasonal, and annual load estimates. In the case of the Middleton site, monthly averages were calculated only for months with complete data. This eliminated 38 of the 105 months; therefore, Middleton data might not be entirely representative of conditions during the estimation period.

Although the model generally closely estimated loads under the predominant flow conditions, estimated loads for extreme flow conditions had larger errors, as discussed previously in the section “Regression Evaluation.” At Parma, for example, considerable errors in estimated versus measured loads were observed at high and low flows (fig. 7). The relation for SS at Middleton was similar.

Annual loads for all sites for all constituents from 1994 through 2002 were calculated to give an overview of loads throughout the estimation period. Note that data for 2002 represent only 9 months, not a complete year, and that Middleton data for several years were incomplete. Annual loads were calculated as the sum of the daily loads in each year (table 3). Estimated annual loads of TP were largest in 1997, the year of highest discharge.

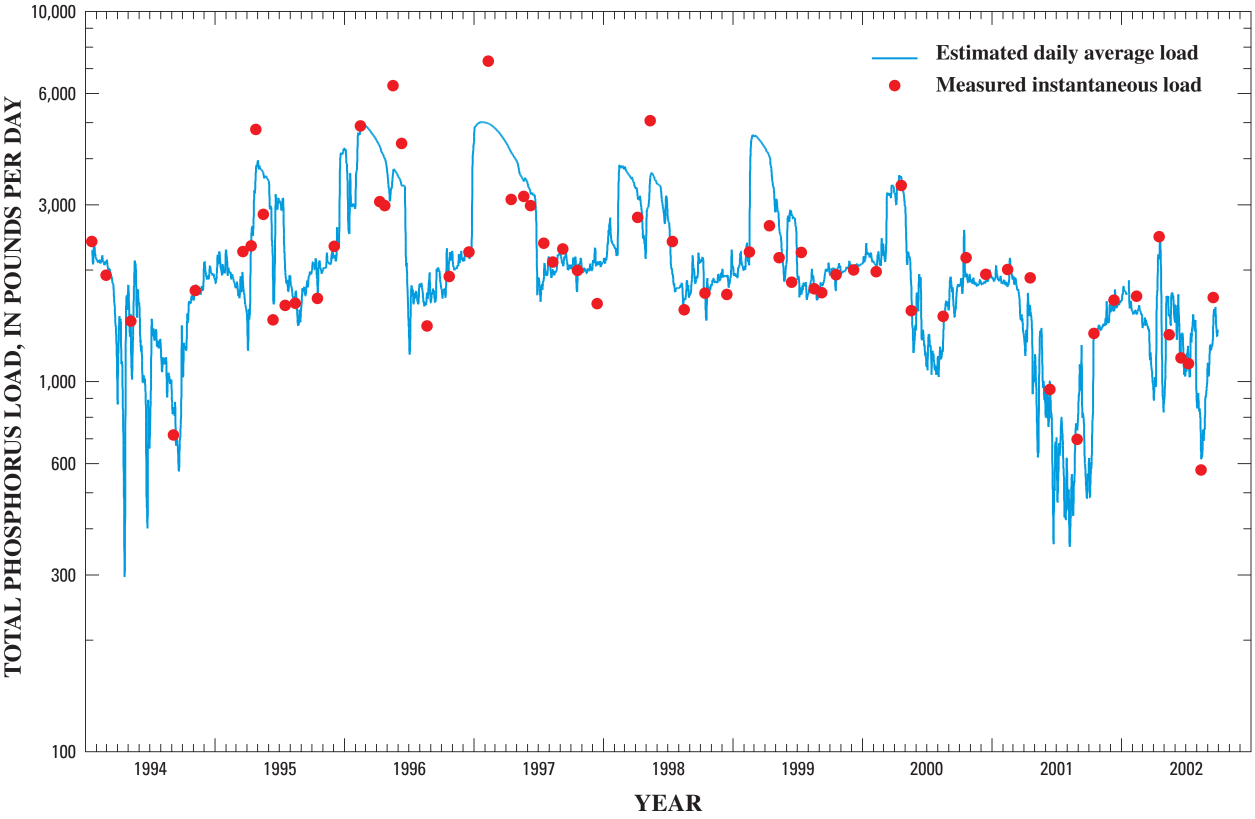


Figure 7. Estimated daily average loads and measured instantaneous loads of total phosphorus in the lower Boise River at Parma, Idaho, January 1994 through September 2002.

Table 3. Annual loads of total phosphorus, dissolved orthophosphorus, and suspended sediment at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

[Site locations are shown in figure 1. Annual loads, in tons, were calculated as the sum of the daily loads for each day of the year. Number of days per year for each site is shown in table 1. Numbers were rounded to three significant figures. –, no data.]

Site name	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total phosphorus									
Diversion	8	22	63	118	43	59	23	14	[1]19
Glenwood	68	96	138	157	115	117	89	69	[1]62
Middleton	92	130	66	29	–	65	92	92	[1]65
Parma	255	419	533	570	455	456	364	222	[1]181
Dissolved orthophosphorus									
Diversion	6	15	33	51	26	29	15	8	[1]9
Glenwood	54	67	86	93	76	77	65	55	[1]46
Middleton	100	121	[1]64	[1]24	–	[1]55	77	76	[1]49
Parma	212	325	395	416	334	331	271	174	[1]131
Suspended sediment									
Diversion	7,400	13,000	25,300	34,100	10,600	12,500	5,200	3,400	[1]5,400
Glenwood	4,930	23,100	75,400	109,000	30,300	38,200	7,800	2,230	[1]2,960
Middleton	2,400	16,600	[1]2,000	[1]1,670	–	[1]2,280	2,710	1,940	[1]2,540
Parma	35,700	116,000	160,000	167,000	116,000	104,000	56,100	17,600	[1]23,100

[1] Totals represent fewer than 300 days of data.

Total Phosphorus

Time-series graphs comparing monthly average TP loads at all four sites displayed the cyclical nature of the variation in loads with seasonal fluctuations in discharge, even though the dates of peak discharge were not the same every year (fig. 8). Overall, TP estimates were comparable at Middleton and Glenwood; loads at these sites rarely exceeded 1,000 lb/d. Loads at Diversion were smallest of all, averaging less than 250 lb/d for the entire estimation period. Estimated loads at Parma were notably larger than at the other sites, averaging nearly 2,200 lb/d and exceeding that value nearly 30 percent of the time. This result was expected, because both flows and constituent concentrations are higher at Parma. Peak TP loads for the estimation period occurred during January and February 1997 at all sites, coinciding with maximum flows. Estimated loads at Parma during that time approached 5,000 lb/d, whereas estimated loads at Glenwood and Diversion exceeded 1,500 lb/d. Loads at all sites were smallest in the late summer months throughout the estimation period.

Average TP loads, by month, were calculated by averaging the monthly averages for each month of the year (for example, the average of all January monthly averages, all February monthly averages, and so on). In terms of average loads, by month, estimated TP loads at Parma exceeded 1,800 lb/d from November through June and peaked in March at about 3,000 lb/d (fig. 9). The total load at Parma during the main irrigation season, May through September, exceeded 140 tons.

Seasonal loads of TP generally peaked in spring, decreased during summer and autumn, and increased again in winter (fig. 10), reflecting fluctuations in discharge as a result of the combined effects of seasonal runoff patterns and irrigation water management, the exact timing of which vary from year to year.

Annual loads of TP at Parma ranged from 222 tons in 2001 to 570 tons in 1997. In contrast, estimated annual loads at Diversion ranged from less than 8 tons (1994) to 118 tons (1997). Estimated loads at Glenwood ranged from 68 tons (1994) to 157 tons (1997). Data for Middleton were complete only for 2001; the estimated total load for that year was 92 tons (table 3).

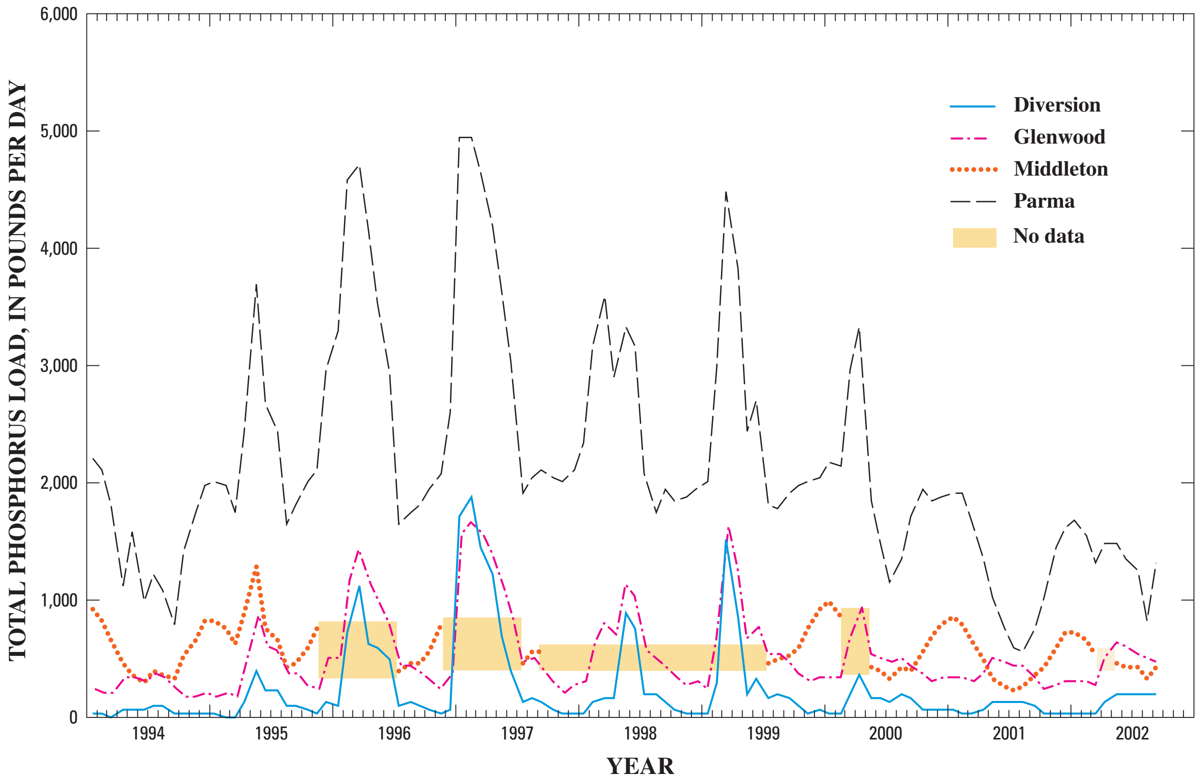


Figure 8. Estimated monthly average loads of total phosphorus at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

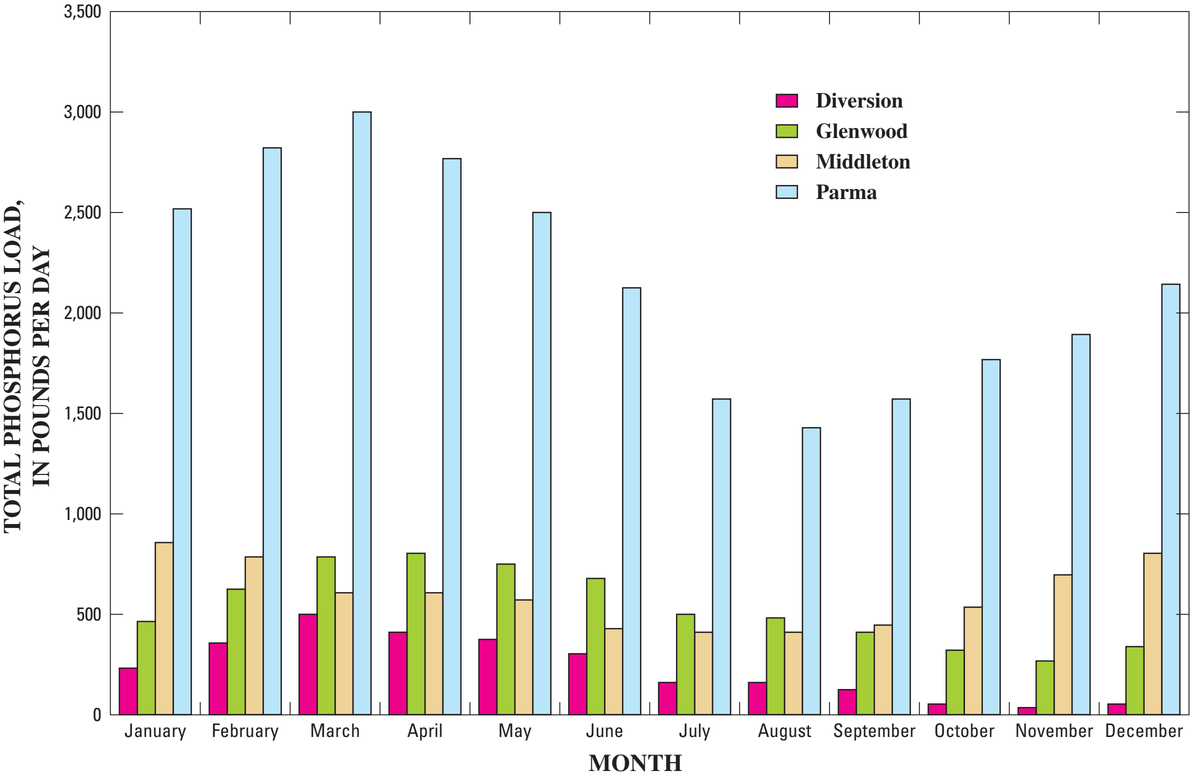


Figure 9. Estimated average loads of total phosphorus, by month, at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

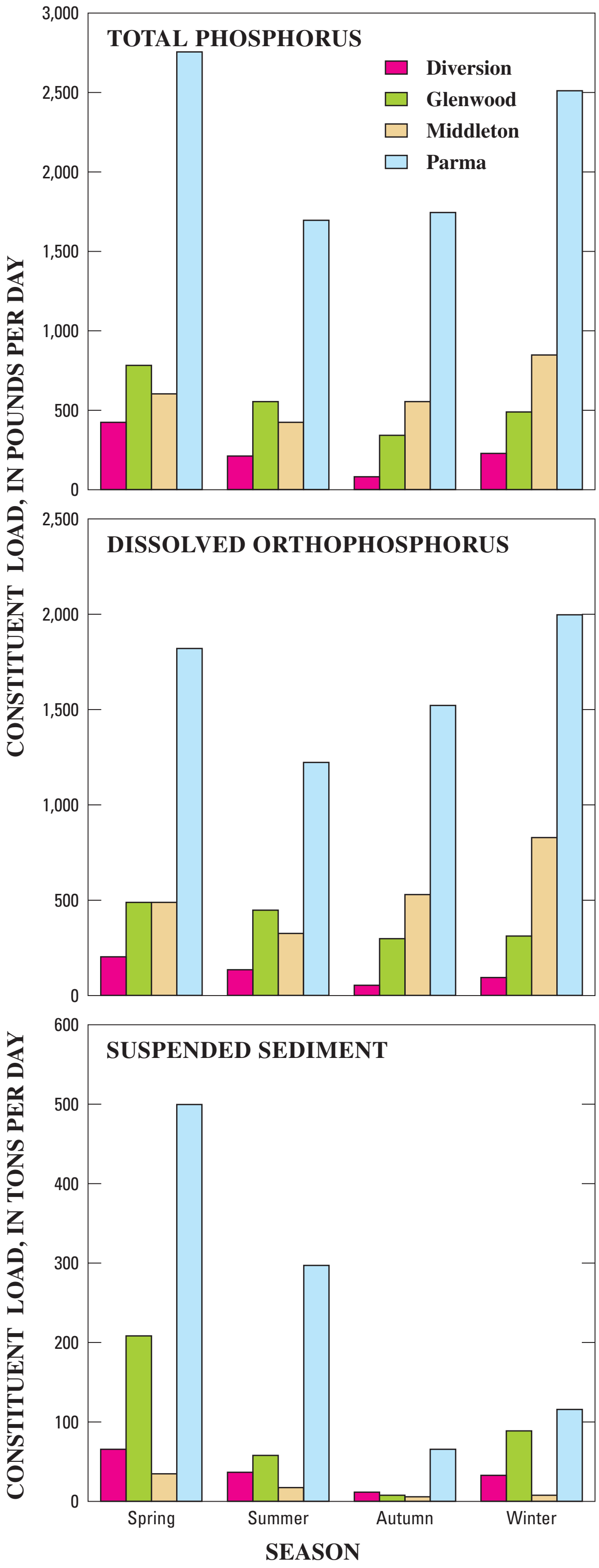


Figure 10. Estimated seasonal loads of total phosphorus, dissolved orthophosphorus, and suspended sediment at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Dissolved Orthophosphorus

Monthly loads of OP generally peaked in early months of the year (January through May) throughout the estimation period, coinciding with times of high discharge. The largest monthly load, about 3,800 lb/d, was estimated at Parma in January 1997. Monthly OP loads at Diversion (654 lb/d) and at Glenwood (739 lb/d) were largest in February 1997.

Annual loads of OP peaked in 1997 at all sites (table 3). Loads were largest at Parma and ranged from 174 tons in 2001 to more than 400 tons in 1997, the year of highest discharge. Annual loads of OP at Glenwood averaged about 70 tons during the estimation period. Annual loads at Diversion ranged between 6 and 51 tons. Annual OP loads at Parma fluctuated by the largest amount throughout the estimation period, both in terms of range in absolute load and relative percentage of load. Although the magnitude of the OP load at Diversion was usually only about 5 percent of the OP load at Parma, large relative annual fluctuations in OP also were estimated at Diversion.

The magnitudes of OP loads mimicked those of TP loads because OP is a component of TP, but the fraction of OP (the ratio of OP to TP) varied considerably throughout the year. Therefore, it was useful to view OP estimates as a ratio of OP to TP. Clear cyclical variations in the ratio are visible in figure 11. Peaks in the OP:TP ratio (that is, times when the OP:TP ratio is high) occurred primarily when flows were at their lowest annual stages; conversely, when flows were high, the ratio was low. This probably reflects increased TP associated with particulate matter during high flows. Although this pattern generally is true at most sites, the remarkably consistent variation of the ratio at Parma from year to year despite differences in annual flow suggests that seasonal (perhaps biological) processes affect the OP:TP ratio.

At Parma, OP:TP ratio minima mimicked those at Glenwood but did not exactly coincide with peak flows for 1996, 1997, and 1999 (several of the highest flow years). Instead, these minima occurred on the descending limb of the hydrographs. At Diversion, flow and the OP:TP ratio were inversely related during high flow years but, in 1994 and from 2000 through 2002 (all low-flow years), high flows coincided with high OP:TP ratios, not with low ones. At Middleton, the OP:TP ratio was higher than 1 during the low-flow periods from 1994 through 1996. Although the calibration data did not include any cases where the OP value exceeded the TP value, the regressions resulted in estimates in which OP was higher than TP at Glenwood. As previously discussed, this situation cannot actually exist and must be interpreted as error in the TP estimate, the OP estimate, or both estimates.

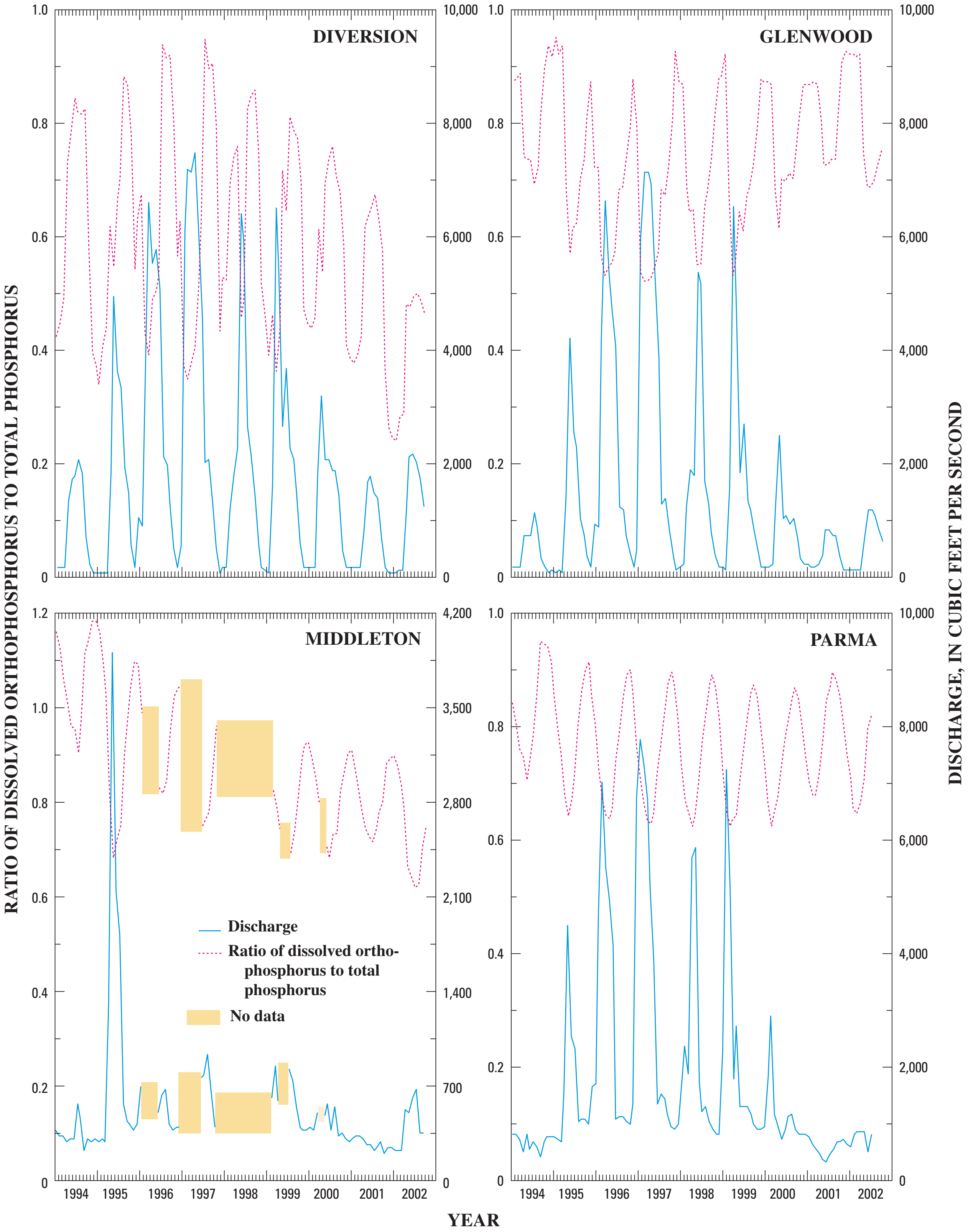


Figure 11. Estimated monthly average ratio of dissolved orthophosphorus to total phosphorus and monthly average discharge at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Estimated seasonal values of the OP:TP ratio were highest in autumn at all sites (fig. 12; Middleton is excluded from this discussion because of insufficient data). The ratio was highest at Parma during all seasons. In autumn, nearly 90 percent of the TP was in the OP:TP ratio, but even in spring, that portion was not less than 60 percent. Similar, but slightly lower, values were estimated for the OP:TP ratio at Glenwood. The estimated values for Diversion were notably lower during winter and spring, when less than one-half the TP was in the dissolved state.

Viewing average OP:TP ratio by month (fig. 13) further highlights the pronounced difference in ratio between Diversion and the other sites. Whereas the OP:TP ratio for the other sites was highest in November or December, decreased from January through May and increased again after June, estimates for Diversion showed nearly the opposite pattern: the estimated ratio was highest in July and lowest in January and February (also see fig. 11). Although the reason for this difference presently is not well understood, it might be a result of complex biological and geochemical processes involving nutrient cycling in Lucky Peak Lake, about 2 mi upstream of the site at Diversion. Additional information about thermal, biological, and chemical conditions in the lake throughout the year might shed light on the mechanisms contributing to this phenomenon.

On an annual basis, the OP:TP ratio remained fairly constant during the estimation period at most sites. The average annual ratio at Parma was particularly consistent from year to year: the ratio varied only about 10 percent between 1994 and 2002 (0.73 to 0.83). At Diversion, the average annual ratio remained close to about 0.60 until it decreased to about 0.40 in 2001.

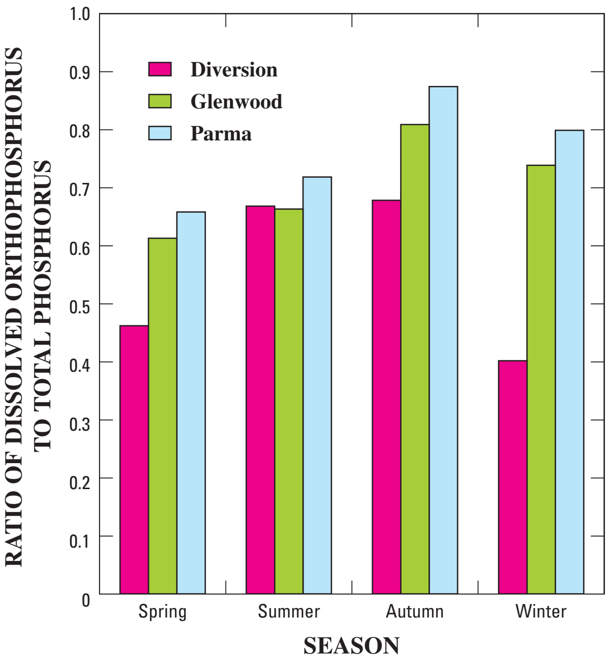


Figure 12. Estimated seasonal ratio of dissolved orthophosphorus to total phosphorus at three sites on the lower Boise River, Idaho, January 1994 through September 2002.

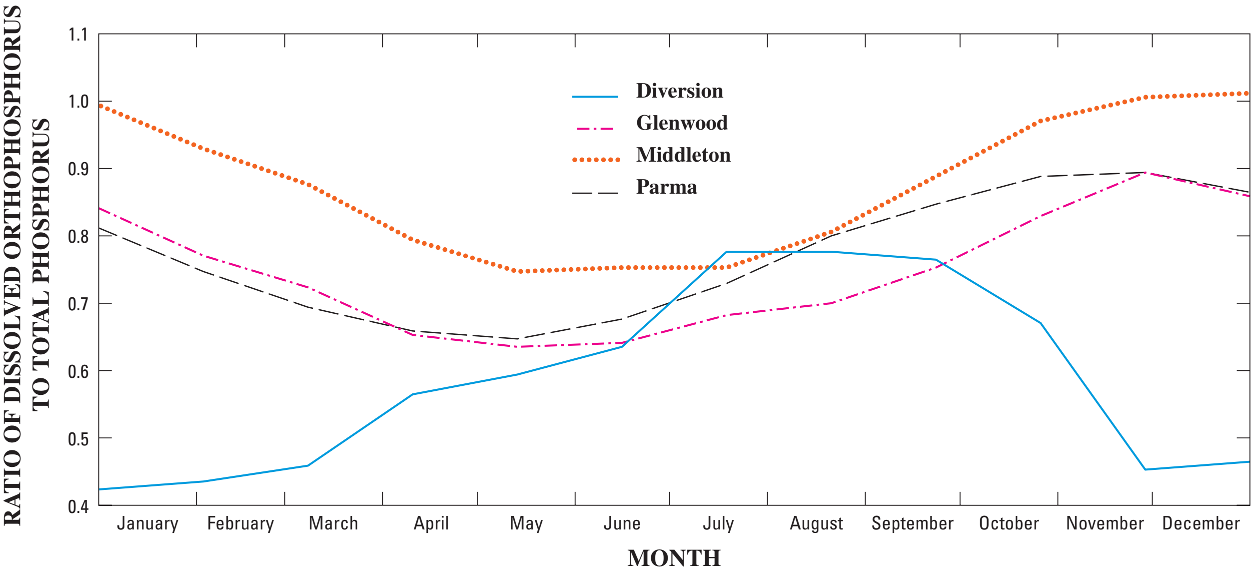


Figure 13. Estimated average ratio of dissolved orthophosphorus to total phosphorus, by month, at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Suspended Sediment

Overall, estimated SS loads were largest at Parma (fig. 14), where the average daily load for the estimation period was about 260 ton/d. The maximum monthly loads at Parma occurred in May 1995, 1996, and 1997, when peak monthly loads ranged from 1,120 to 1,220 ton/d. In contrast, the smallest average daily SS loads, about 37 ton/d, were estimated at Diversion. Maximum monthly loads at Diversion occurred in March 1996 (about 220 ton/d) and in February 1997 (about 260 ton/d).

Seasonal loads of SS were largest in spring and smallest in autumn at all sites (fig. 14), corresponding with variations in discharge. The relative range in SS loads was greatest at Glenwood, where maximum loads exceeded minimum loads by a factor of about 30. In contrast, maximum loads at Parma exceeded minimum loads by only a factor of 8.

Total loads of suspended sediment from 1994 through 2002 at Parma ranged from 17,600 tons in 2001 to 167,000 tons in 1997, whereas annual loads at Diversion ranged from 3,400 to 34,100 tons for the same years (table 3). At Glenwood, annual SS loads ranged from 2,230 to 109,000 tons. Average annual loads for the estimation period were 13,000 tons at Diversion, 33,000 tons at Glenwood, and 88,000 tons at Parma.

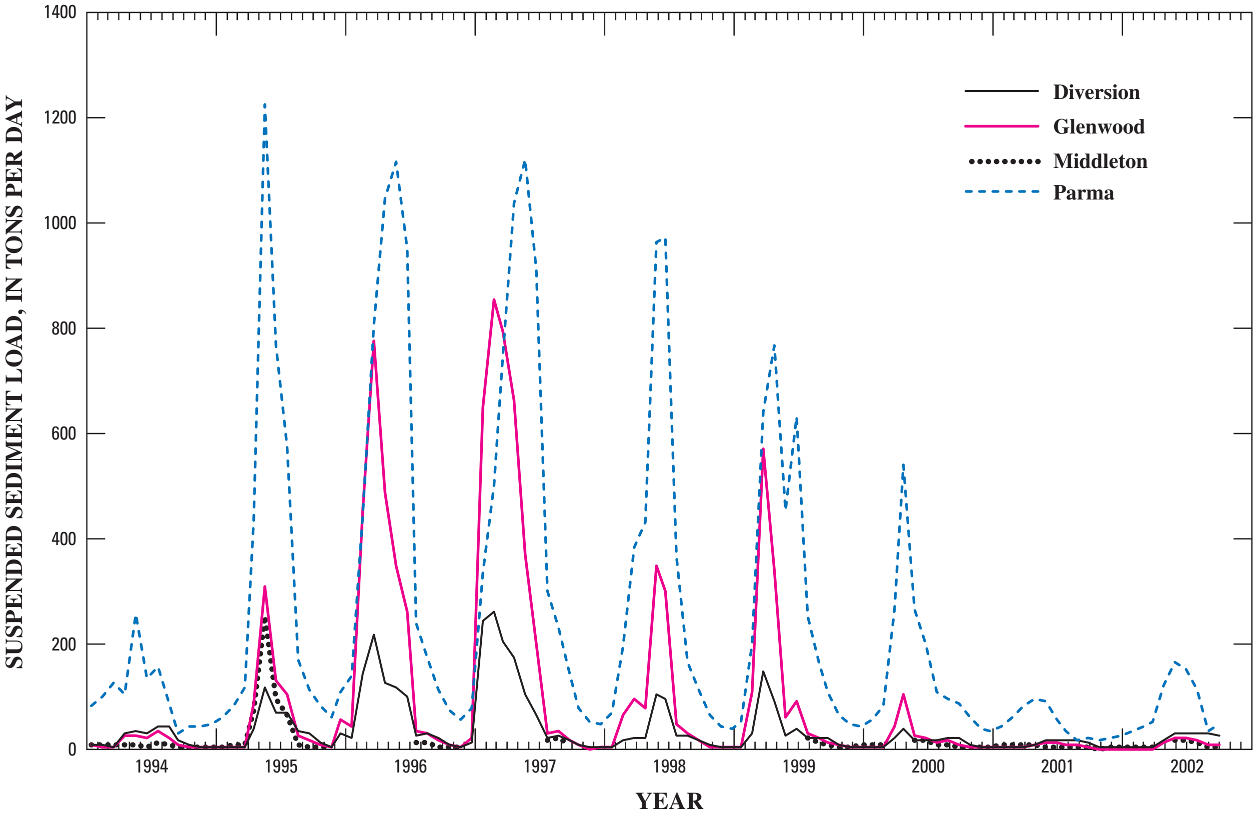


Figure 14. Estimated monthly average suspended sediment load at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

Monthly Average Increases and Decreases of Constituent Loads Within Reaches

Monthly average increases and decreases of the constituent loads in the three reaches between the four modeled sites were calculated by subtracting the monthly average load at the upstream site from the monthly average load at the downstream site. Positive differences indicated an increase; negative differences indicated a decrease. Because the data for Middleton were incomplete, increases and decreases for the Glenwood-to-Middleton and Middleton-to-Parma reaches were based on fewer months of data than were increases and decreases for the Diversion-to-Glenwood reach. Therefore, data for these reaches might not adequately reflect the actual monthly average increases and decreases for the entire estimation period. Estimated monthly average increases and decreases of TP, OP, and SS for the reaches Diversion to Glenwood, Glenwood to Middleton, and Middleton to Parma from January 1994 through September 2002 are shown in figure 15.

Diversion to Glenwood

TP and OP were increasing in the reach from Diversion to Glenwood during most of the estimation period. In that reach, daily decreases in TP that occurred during high flows in January and February 1997 were not reflected in the monthly averages. Increases in TP were largest in March 1998, but large monthly increases also were typical in April and May. The cyclical pattern of fluctuating increases followed the seasonal discharge patterns— increases were largest in spring and decreased throughout the summer. Minima usually occurred in winter and early spring. Monthly average TP increases ranged from about 200 to about 350 lb/d for the estimation period; monthly average OP increases ranged from 250 to 300 lb/d. Annual TP increases in this reach averaged 60 tons per year for the estimation period.

Annual increases in SS from Diversion to Glenwood were predominant from 1994 to 2002. Increases ranged from 327 tons in 1995 to 2,500 tons in 1997, the highest-flow year in the estimation interval. Small annual decreases ranging from 40 to 83 tons were estimated for 1994, 2001, and 2002.

Glenwood to Middleton

Incomplete estimates for the Middleton site hindered adequate interpretation of increases and decreases except for a few time intervals. Small to moderate monthly decreases in TP were estimated during May through August in the reach from Glenwood to Middleton; large increases, sometimes more than 600 lb/d, were estimated for December and January (fig. 15). Orthophosphorus followed the same cyclical pattern. Suspended sediment exhibited only small increases or decreases during these periods. Increases, representing periods of sediment erosion or addition of sediment to the system, occurred from September through April; decreases, representing deposition, occurred from May through August.

Middleton to Parma

Again, increases and decreases for the reach from Middleton to Parma were difficult to assess because of incomplete results for Middleton. This probably is the reason that a cyclical fluctuating pattern of relative increases was not as well defined as it was in the other reaches. Data indicated increases, but no decreases, during the entire estimation period. Large increases were estimated in TP, OP, and SS in May 1995. Incomplete data indicated large increases of SS in June 1996 and of TP in December 1996. Large increases occurred during high-flow conditions, indicating active erosion or influx of sediment from tributaries.

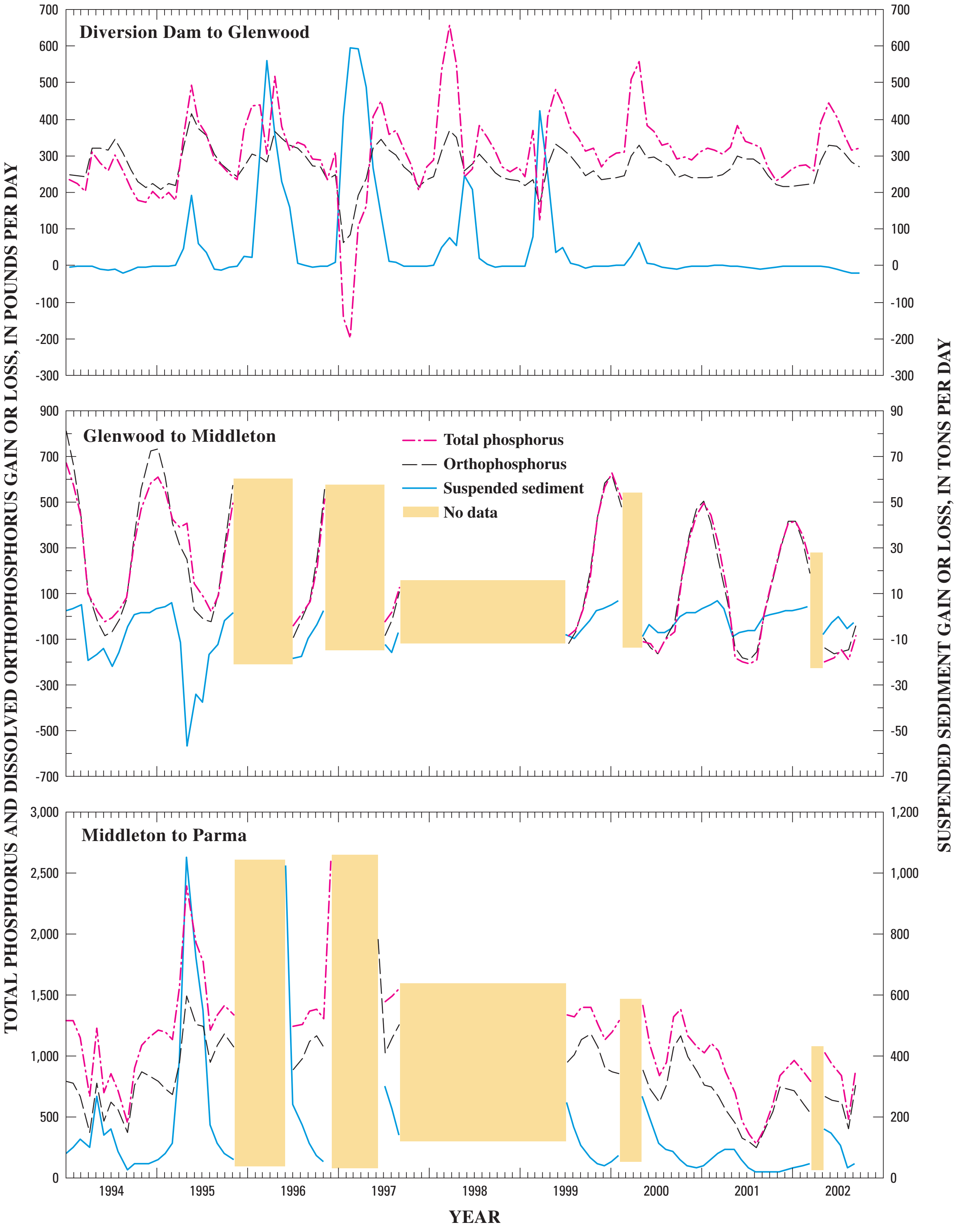


Figure 15. Estimated monthly average increases and decreases of total phosphorus, dissolved orthophosphorus, and suspended sediment in three reaches of the lower Boise River, Idaho, January 1994 through September 2002.

Temporal Trends

If loads change consistently as a function of time throughout the estimation period, LOADEST would determine that a trend is present. A trend is indicated in the modeled equation by the presence of a term with time as the variable (term fT in equation 1). If the coefficient of this term (f in table 2) is positive, an upward trend is indicated; if the coefficient is negative, a downward trend in indicated. The size of the coefficient suggests the relative strength of the trend. Statistically significant (95-percent confidence level) downward trends were determined in SS at Glenwood, in OP at Middleton, and in TP, OP, and SS at Parma (table 4). A significant upward trend in TP was determined at Diversion. Other regression equations suggested trends, but the trends were not statistically significant at the 95-percent confidence level.

The percentage of change per year produced by the trend can be calculated with the following equation:

$$\text{Percentage of change per year} = 100\text{x}(e^{f} - 1) \tag{2}$$

where

f Is the coefficient of the time term.

Annual percentage of changes are shown in table 4.

Table 4. Annual trends and significance level of trends in total phosphorus, dissolved orthophosphorus, and suspended sediment loads at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

[Site locations are shown in figure 1. Annual trends: +. upward trend; -, downward trend, --, no trend found; *p*-value indicates statistical significance of trends; *p*-values greater than 0.05 are not statistically significant at the 95-percent confidence level. n.s., not statistically signficant; <, less than]

Constituent load	Diversion		Glenwood		Middleton		Parma	
	Annual trend (percent)	*p*-value	Annual trend (percent)	*p*-value	Annual trend (percent)	*p*-value	Annual trend (percent)	*p*-value
Total phosphorus	+11	0.002	--	--	--	--	-2	0.031
Dissolved orthophosphorus	n.s.	.387	--	--	-4	0.015	-3	<.001
Suspended sediment	n.s.	.995	-9	0.008	--	--	-7	.014

Comparison with Mass Balance Spreadsheet Load Estimates

A mass balance spreadsheet method for estimating loads currently is being developed by the IDEQ to track phosphorus loads in the lower Boise River. This method is an accounting system of inputs and outputs of TP from Lucky Peak Dam to Parma for a particular time interval. Loads are calculated as the product of flow and TP concentration. Cumulative TP loads at about 90 points (including the four mainstem sites at Diversion, Glenwood, Middleton, and Parma) along the lower Boise River from Lucky Peak Dam to Parma are calculated from measured and estimated data, including inflow and outflow from irrigation diversions and returns, ground water, and tributaries. Because one goal of the LOADEST modeling was to refine the spreadsheet method, TP load estimates from a preliminary spreadsheet from April 15 through October 15, 1996, were compared with LOADEST estimates for the same period (table 5). For the sites at Diversion and Parma, the LOADEST estimates of daily average TP load were about 5 percent lower than the spreadsheet estimates; LOADEST estimates for Glenwood were about 17 percent higher than the spreadsheet estimates. LOADEST estimates for Middleton were incomplete because of lack of discharge data for this time interval.

Although the similarity of the results for the daily average loads is not surprising (both methods use the same concentration and flow data for these sites), the LOADEST results provide detail that the spreadsheet does not. For example, a graph comparing the spreadsheet estimates with the monthly TP load estimates and 95-percent CIs at Parma from April through October shows that the average load (2,560 lb/d by the spreadsheet method) probably was exceeded during approximately the first 2 months of the period but decreased to less than about 2,000 lb/d during the remaining months (fig. 16). Note that the LOADEST monthly estimates include the entire months of April and October. The ability to examine loads readily at various timescales, rather than as a single static average, is a key advantage of the LOADEST estimation method over the spreadsheet method.

Table 5. Comparison between daily average loads of total phosphorus estimated by mass balance spreadsheet method and daily average loads and monthly average 95-percent confidence intervals estimated by LOADEST at three sites on the lower Boise River, Idaho, April 15, 1996 through October 15, 1996.

[Site locations are shown in figure 1. **Estimated load values**: Spreadsheet—Values taken from preliminary spreadsheet provided by Idaho Department of Environmental Quality (written commun., 2004). LOADEST—Values represent upper and lower limits of 95-percent confidence interval for monthly load estimates, April through October 1996. CI, confidence interval]

Site name	Estimated load (pounds per day)			
		LOADEST		
	Spreadsheet	Mean	Upper 95-percent CI	Lower 95-percent CI
Diversion	303	288	493	172
Glenwood	665	779	960	630
Parma	2,560	2,431	2,837	2,266

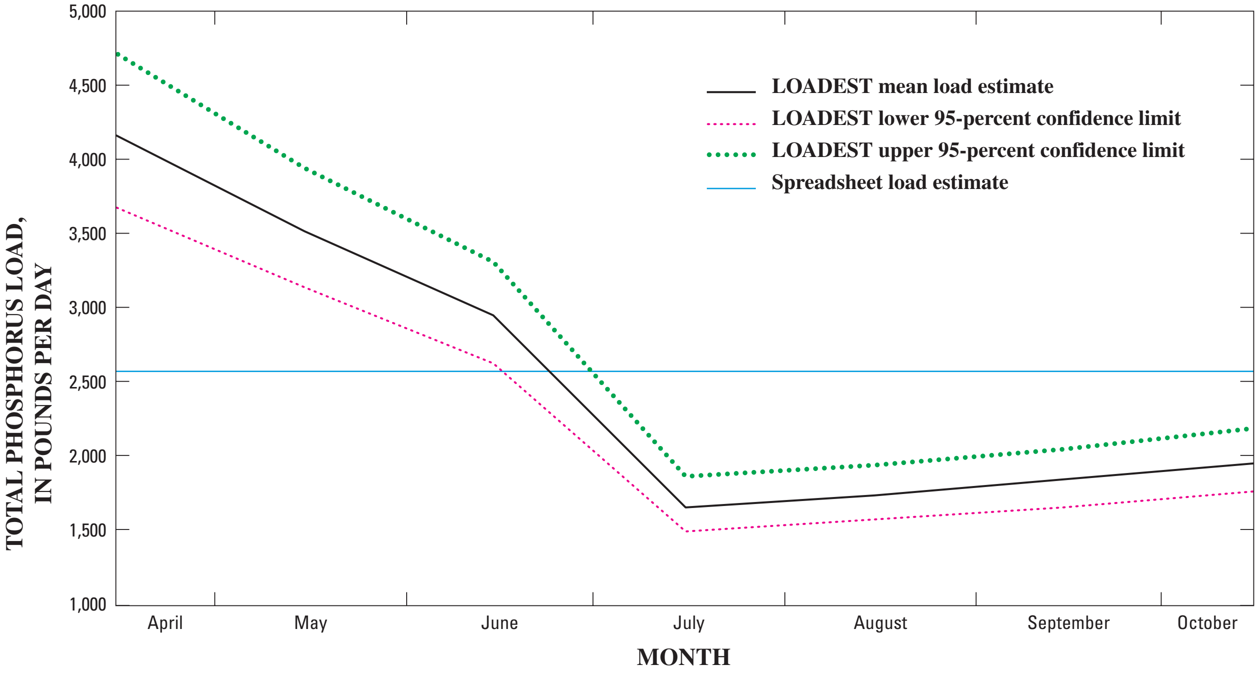


Figure 16. Monthly average loads of total phosphorus at Parma, Idaho, estimated using LOADEST model and using mass balance spreadsheet method, April 15, 1996, through October 15, 1996.

Annual Flow-Weighted Concentrations

Because flow is a strong determinant of load, and because flow varied greatly from year to year, annual flow-weighted concentrations (FWCs) were calculated to better assess changes in concentration over the estimation period. Annual FWCs of TP, OP, and SS were calculated for Diversion, Glenwood, and Parma by dividing the annual constituent load for each year (in pounds) by the total annual flow (in cubic feet) and applying appropriate conversion factors to yield concentration (in milligrams per liter). Annual FWCs of TP, OP, and SS from 1994 through 2002 are given in table 6.

At Parma and Glenwood, where the OP:TP ratio was high (average 0.70 to 0.75), annual FWCs of TP were inversely related to load; that is, FWCs were smallest during high-flow years, even though the estimated loads were large (fig. 17). This is because the OP is diluted (low concentrations) by high flows, but the estimated loads were large because of the dominance of flow. In contrast, at Diversion, where the OP:TP ratio was low (average 0.56), load and concentration were directly related, because phosphorus associated with entrained particulate matter is increased during high flows, not diluted. Similar relations between annual FWC and load were apparent for SS. Thus, annual FWCs highlight the strong interaction between flow and particle-associated constituents such as TP and SS.

Table 6. Annual flow-weighted concentrations of total phosphorus, dissolved orthophosphorus, and suspended sediment at four sites on the lower Boise River, Idaho, January 1994 through September 2002.

[Site locations are shown in figure 1. mg/L, milligram per liter; –, no data]

Site name	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total phosphorus (mg/L)									
Diversion	0.009	0.014	0.022	0.033	0.021	0.028	0.019	0.019	[1]0.020
Glenwood	.137	.080	.056	.048	.068	.064	.105	.148	[1].115
Middleton	.319	.142	[1].258	[1].143	–	[1].238	.299	.383	[1].254
Parma	.412	.266	.185	.153	.214	.204	.307	.384	[1].342
Dissolved orthophosphorus (mg/L)									
Diversion	0.007	0.009	0.011	0.014	0.013	0.014	0.012	0.010	0.010
Glenwood	.108	.056	.035	.028	.045	.042	.077	.119	.087
Middleton	.346	.132	.251	.118		.200	.249	.316	.189
Parma	.343	.206	.137	.112	.157	.148	.228	.301	0.248
Suspended sediment (mg/L)									
Diversion	8.4	8.1	9.0	9.5	5.2	5.9	4.4	4.5	[1]5.9
Glenwood	10	19	30	33	18	21	9.2	4.8	[1]5.5
Middleton	8.4	18	[1]7.8	[1]8.3	–	[1]8.4	8.8	8.1	[1]10
Parma	58	74	55	45	55	47	47	30	[1]43

[1] Average represents fewer than 300 days of data.

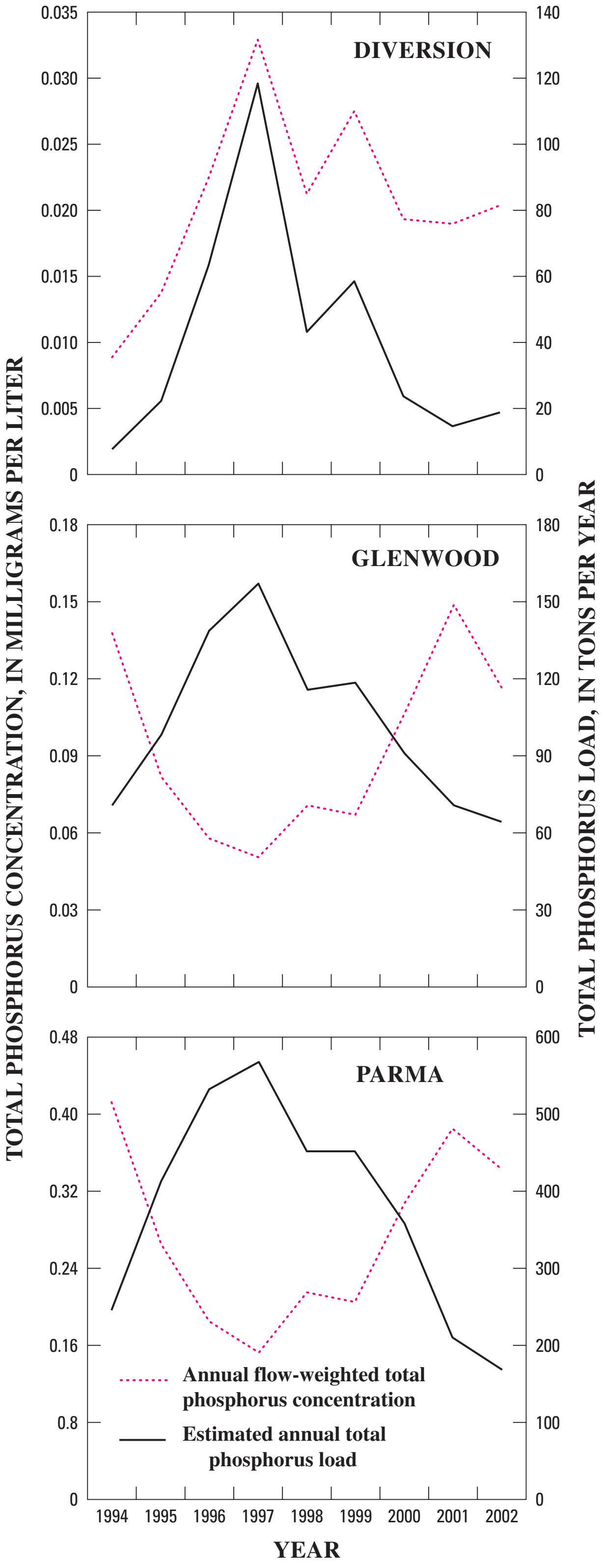


Figure 17. Average annual flow-weighted concentrations and estimated loads of total phosphorus at three sites on the lower Boise River, Idaho, January 1994 through September 2002.

Implications for Total Maximum Daily Load Implementation

Total Phosphorus

The current Snake River-Hells Canyon TMDL (Idaho Department of Environmental Quality, 2004) suggested TP allocations for upstream tributaries to meet TP loads. On the basis of average flow and TP concentrations from May through September, the lower Boise River contributed the largest load (estimate of about 2,450 lb/d) of all the tributaries evaluated. To reach a target TP concentration of 0.07 mg/L in the Snake River, TP loads in the lower Boise River must be decreased to 532 lb/d. A TMDL for TP for the lower Boise River currently is being developed; an implementation plan subsequently will be developed.

LOADEST average TP load estimates from May through September, 1994 through 2002, ranged from 740 lb/d in 2001 to 2,550 lb/d in 1997; the target of 532 lb/d was exceeded every year. These estimates indicate that reductions in load of about 28 to 76 percent would have been necessary to meet the proposed goal during this period.

Because load and flow are strongly related, large estimated loads would be expected in high-flow years. However, annual FWCs of TP were inversely related to load estimates and flow measurements at Parma; that is, TP concentrations at Parma were lower in high-flow years than in low-flow years, as discussed in the section "Annual Flow-Weighted Concentrations." Annual flow-weighted concentrations of TP for this time interval ranged from 0.41 to 0.35 mg/L. LOADEST TP load estimates, 95-percent upper and lower CIs, and annual FWCs are given in table 7.

Suspended Sediment

The lower Boise River TMDL for suspended sediment was completed and load allocations determined at Parma, Middleton, and several tributaries to the lower Boise River in 1999. Lower Boise River suspended sediment allocations were based on the 30-day low-flow period February 15 through June 14, the period during which the most significant loads of sediment are generated. According to the lower Boise River TMDL, the SS load allocation is 4.4 ton/d at Middleton and about 101 ton/d at Parma, on the basis of an upper-limit concentration of 50 mg/L (Idaho Department of Environmental Quality, 1999). The allocation at Parma incorporates a 37-percent decrease from 1995 calculated loads.

LOADEST daily average SS loads at Parma from February 15 to June 14, 1994 through 2002, ranged from 86 ton/d in 2001 to 968 ton/d in 1996. Estimated annual loads exceeded the allocation at Parma except in 2001. In all years except 1999 and 2001, low-flow years, the annual FWCs of SS exceeded 50 mg/L. Daily average SS loads, 95-percent upper and lower CIs, and FWCs at Parma, estimated by LOADEST, are given in table 8.

Table 7. Estimated average annual loads, monthly average upper and lower 95-percent confidence intervals, total flow volumes, and annual flow-weighted concentrations of total phosphorus at Parma, Idaho, May through September, 1994 through 2002.

[Site locations are shown in figure 1. **95-percent confidence intervals**: Values represent upper and lower limits of 95-percent confidence interval for monthly load estimates for May through September, 1994 through 2002; **Abbreviations**: CI, confidence interval; lb/d, pound per day; m/ft^3, millions of cubic feet; mg/L, milligram per liter]

Year	Estimated average load (lb /d))	Lower 95-percent CI	Upper 95-percent CI	Total flow volume (m/ft^3)	Annual flow-weighted concen-tration (mg/L)
1994	1,140	970	1,330	59,970	0.35
1995	2,450	2,190	2,740	230,200	.20
1996	2,330	2,090	2,600	247,800	.17
1997	2,550	2,280	2,840	268,000	.17
1998	2,450	2,180	2,760	316,800	.14
1999	2,130	1,920	2,360	166,700	.23
2000	1,520	1,370	1,680	96,570	.29
2001	740	624	874	42,180	.32
2002	1,240	1,110	1,380	76,800	.30

Table 8. Estimated average daily loads, monthly average upper and lower 95-percent confidence intervals, total flow volumes, and annual flow-weighted concentrations of suspended sediment at Parma, Idaho, February 15 through June 14, 1994 through 2002.

[Site locations are shown in figure 1. **95-percent confidence intervals**: Values represent upper and lower limits of 95-percent confidence interval for monthly load estimates for May through September, 1994 through 2002. **Abbreviations**: CI, confidence interval; ton/d, tons per day; m/ft^3, millions of cubic feet; mg/L, milligram per liter]

Year	Estimated average load (ton/d))	Lower 95-percent CI	Upper 95-percent CI	Total flow volume (m/ft^3)	Annual flow-weighted concen-tration (mg/L)
1994	161	245	79	52,900	87.7
1995	562	783	338	167,000	97.1
1996	968	1,340	543	466,000	60.3
1997	931	1,360	522	499,000	53.7
1998	624	918	358	300,000	59.8
1999	585	819	338	343,000	49.2
2000	313	392	181	137,000	66.3
2001	86	119	49	50,800	49.0
2002	114	157	70	59,300	55.1

Limitations and Advantages of the LOADEST Model

Modeling results for Diversion, Glenwood, and Parma demonstrate that LOADEST can be used to gain insight to the timing and distribution of constituent loads in the lower Boise River over a range of timescales. Although the model output includes estimated daily loads, daily values have limitations. The primary reason for this is that the software is unable to accommodate sudden changes in streamflow and constituent transport that occur within a day as a result of water-management practices, which results in large errors, primarily during extremely high flows. Thus, an estimate for a particular day could be unrepresentative of actual loads. However, because the model performs well for the prevalent conditions, the overall effect of these inaccuracies is diminished as longer time periods are examined. Therefore, monthly, seasonal, and annual timescales are useful intervals in which to examine load estimates.

As with any model, the quality of the results (or lack thereof) is determined by the quality of the input data. LOADEST estimates loads only for days for which discharge data are available. Because there were many gaps in the Middleton discharge data, load estimates for long, continuous periods are absent. In addition, input data should represent samples collected over a wide range of flow conditions in order for the model to be calibrated over the complete range of flow conditions. In this study, the best available data were used but, in many cases, sampling events did not represent a sufficiently wide range of flow conditions. For example, data for only two samples were available for Diversion in 1997, both during high springtime flows. The lack of low-flow samples during 1997 could affect the reliability of the results for that year at Diversion and also could bias the overall model results. Ideally, deliberate and regular sampling before, during, and after high flows would have improved the model's ability to estimate loads accurately over a wider range of flow conditions.

The TP regression equation for Glenwood indicates that loads were related only to flow and that terms involving harmonic functions or time were not important (table 2). This site was the only case where the regression equations took this form. Also, this simple regression model, although it was statistically the best, was able to explain only 58 percent of the variation in the data. This probably is related to the known source of phosphorus at the outlet of the wastewater-treatment plant 1 mi upstream. This source of phosphorus is independent of river discharge and could have introduced a large amount of variability that the model was unable to account for.

Another problem, described by Clark (2003) and Woods (2001), involves errors resulting from hysteresis effects, that is, different measured constituent concentration values for the same discharge value. Hysteresis is an important factor for TP and SS. As Clark (2003) pointed out, certain samples from the Coeur d'Alene River Basin that were collected during the ascending limb and near the peak of the hydrograph typically contained higher concentrations of sediment than did samples collected during the descending limb at the same discharge. This is because material that had accumulated in the stream channel prior to spring runoff becomes mobile as stream velocities rise; later, concentrations measured at the same discharge were low because the channel had been flushed of accumulated sediment. However, the model does not account for hysteresis; as a result, changes in load resulting from rapid changes in streamflow may not be modeled accurately. An example of this phenomenon is shown for Parma in figure 18. During July 1996 through December 1997, measured and estimated TP loads during low or moderate flows were in reasonable agreement, but the load measured during high flow was underestimated by the model by about 40 percent. On the descending limb of the hydrograph, measured loads were slightly overestimated by the model. This is one important reason that daily load estimates can be highly inaccurate; monthly, seasonal, and annual averages are more representative.

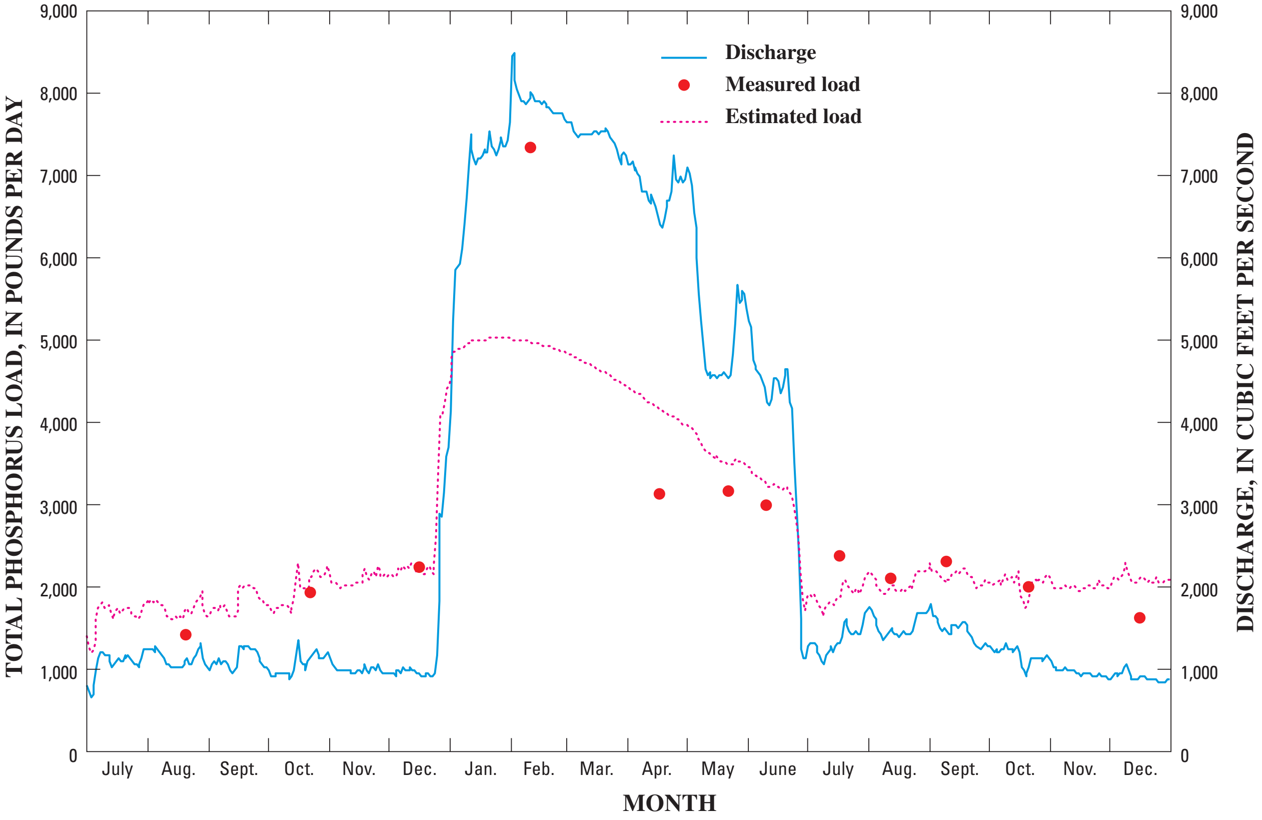


Figure 18. Daily average discharge and measured and estimated daily average loads of total phosphorus at Parma, Idaho, July 1, 1996, through December 31, 1997.

Summary

The U.S. Geological Survey software program LOADEST was used to develop regression equations and to estimate loads of total phosphorus (TP), dissolved orthophosphorus (OP), and suspended sediment (SS) at four sites on the lower Boise River from January 1994 through September 2002. The equations and loads were based on water-quality and discharge data from the following sites: Boise River below Diversion Dam near Boise, Boise River at Glenwood Bridge at Boise, Boise River near Middleton, and Boise River near Parma.

The regression models generally were well fit on the basis of R^2 values, but the fitness varied from site to site. Results for all constituents for the site at Middleton were of limited usefulness because discharge data for the estimation period were incomplete and intermittent; data were unavailable for about one-third of the estimation period.

Comparisons between instantaneous loads used in the calibration procedure and estimated daily loads for the same days indicate that the models successfully simulated TP and SS loads under the predominant flow conditions but, in some cases, larger errors were associated with flows that were higher or lower than the predominant flow conditions for the estimation period. Load estimates probably would have been improved for all sites if constituent sampling had taken place over a more complete range of flow conditions, including rising limbs, peaks, and falling limbs of high-flow hydrographs.

The model estimated daily, monthly, seasonal, and annual loads for all constituents. Although the daily load estimates provided some valuable information, monthly, seasonal, and annual load estimates were the most representative because the longer timescales tended to minimize day-to-day variability in daily estimates that otherwise might have been misleading.

Regression models for TP and OP for Glenwood were the least successful in explaining variation in the data, as shown by the low R^2 values compared with those for other studied sites. This most likely is due to the proximity of the Glenwood site to a municipal wastewater treatment plant outlet, which provides a variable phosphorus input that is unrelated to discharge. Results for SS were statistically well fit at all sites, probably because of the strong correspondence between SS and discharge.

The estimated average daily TP load at Diversion was less than 250 pounds per day (lb/d). Overall, TP estimates at Glenwood were similar to those at Middleton and rarely exceeded 1,000 lb/d. Estimated TP loads at Parma were notably larger than at the other sites, averaging nearly 2,200 lb/d and exceeding that value nearly 30 percent of the time. TP loads for the estimation period were largest during January and February 1997, coinciding with maximum flows. TP loads at all four sites displayed cyclical variation coinciding with seasonal fluctuations in discharge, even though the dates of peak discharge were not the same every year. Estimated TP loads generally peaked in spring, decreased in summer and autumn, and increased again in winter at all sites, reflecting the combined effects of seasonal runoff patterns and irrigation water management. Estimated annual loads of TP for the estimation period ranged from less than 8 to 118 tons at Diversion, from 68 to 157 tons at Glenwood, and from 222 to 570 tons at Parma.

Annual loads of OP peaked in 1997 at all sites. Dissolved orthophosphorus loads were largest at Parma. The fraction of OP (the ratio of OP to TP) varied considerably throughout the year at all sites and was a useful way to gain insight to phosphorus cycling and processes in the lower Boise River. Peaks in the OP:TP ratio occurred primarily when flows were at their lowest annual stages, typically in autumn at all sites. Conversely, when flows were high, the ratio was low, reflecting increased TP associated with particulate matter during high flows. The estimated OP:TP ratios for Diversion were notably lower during winter and spring, when less than one-half the TP was in the OP:TP ratio. Parma exhibited the highest OP:TP ratio during all seasons, at least 0.60 in spring and nearly 0.90 in autumn. Similar, but slightly lower, values were estimated for the OP:TP ratio at Glenwood. On an annual basis, the OP:TP ratio remained fairly constant during the estimation period at most sites. The average annual ratio at Parma was consistent from year to year and varied about 10 percent between 1994 and 2002.

Whereas the OP:TP ratios for Glenwood and Parma peaked in November or December, diminished from January through May, and increased again after June, estimates for Diversion showed nearly the opposite pattern—the ratio was highest in July and lowest in January and February. The difference might reflect complex biological and geochemical processes involving nutrient cycling in Lucky Peak Lake, but further data are needed to substantiate this hypothesis.

Estimated SS loads peaked in the spring at all sites, coinciding with high flows. Estimated average monthly SS loads were largest at Parma, about 250 tons per day (ton/d). In contrast, the monthly average load at Diversion was about 37 ton/d. At Parma, the peak monthly average loads occurred in May and June from 1995 through 1998, and averaged about 970 to 1,200 ton/d. Average annual loads from 1994 through 2002 were 88,400 tons at Parma, 33,000 tons at Glenwood, and 13,000 tons at Diversion.

Monthly average TP increases in the reach from Diversion to Glenwood ranged from about 200 lb/d to about 350 lb/d from 1994 through 2002; monthly average OP increases ranged from 250 to 300 lb/d. Total annual TP increases in this reach averaged 60 tons per year for the estimation period. Total phosphorus decreases occurred only during high flows in January and February 1997. Large SS decreases (360,000 tons in 1997) were estimated because abundant sediment stored in the channel upstream of Diversion is mobilized during high-flow periods but is mostly redeposited before reaching Glenwood. During moderate- and high-flow conditions, smaller decreases, and even slight increases, were estimated.

Incomplete data for the Middleton site hindered investigation of the increases and decreases in the reaches between Glenwood and Middleton and between Middleton and Parma. The intermittent available load estimates for the reach from Glenwood to Middleton suggested cyclical increases and decreases in monthly average TP, corresponding to changes in discharge. Increases were estimated in December and January; small to moderate decreases were estimated from May through August. The reach from Middleton to Parma exhibited increases but no decreases for all constituents. May 1995 marked a time of particularly large increases in TP, OP, and SS in this reach. The results also indicated large increases of SS in June 1996 and of TP in December 1996. These periods of large increases suggested erosion of sediment in the channel and (or) addition of sediment to the river from tributaries.

Statistically significant downward temporal trends in all constituent loads were determined at Parma. A significant upward trend in TP was determined at Diversion. Other regression equations suggested trends, but the trends were not statistically significant at the 95-percent confidence level.

Because flow strongly affects the calculation of load, annual flow-weighted concentrations (FWCs) were calculated to facilitate assessment of changes in concentration over the estimation period despite a large range in flows. At Parma and Glenwood, where the OP:TP ratio was high, annual FWCs of TP were inversely related to load. This is most likely because the OP was diluted by high flows, but calculated loads are large as a result of the dominance of flow. In contrast, at Diversion, where OP was a smaller fraction of TP, load and FWCs were directly related, because entrained particulate matter is increased during high flows, not diluted. Relations between FWCs and loads of SS were similar. Thus, FWCs bring to light the strong interaction between flow and particle-associated constituents such as TP and SS.

The Snake River-Hells Canyon TMDL for TP calls for loads in the lower Boise River at Parma to be capped at 532 lb/d from May through September. LOADEST TP load estimates from 1994 through 2002 ranged from 740 to 2,550 lb/d and indicated that decreases in load of 28 to 76 percent would have been necessary to meet the proposed goal during this period. The present SS load allocation to Parma for lower Boise River TMDL purposes is about 101 ton/d (Idaho Department of Environmental Quality, 1999). Estimated loads from 1994 through 2002 ranged from 86 to 968 ton/d and exceeded the allocation at Parma except in 2001.

The LOADEST model is a useful tool for providing spatial and temporal resolution to help refine mass balance spreadsheet calculations used to allocate loads of phosphorus and SS in the lower Boise River. The LOADEST daily average TP load estimate from April 15, 1996, through October 15, 1996, compared favorably with the load estimate made by mass balance spreadsheet calculations for the same period, but monthly average load estimates showed that the loads changed considerably within that time interval. Therefore, a key advantage of the LOADEST method is the ability to examine loads at a variety of timescales, whereas spreadsheet estimates are static.

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