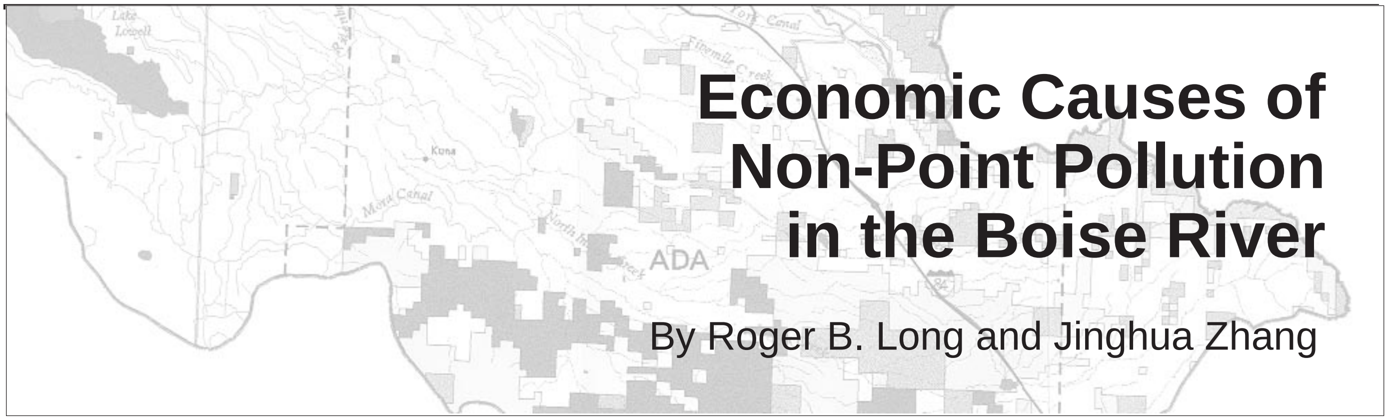


Economic Causes of Non-Point Pollution in the Boise River

By Roger B. Long and Jinghua Zhang

Both point pollutants and non-point pollutants are responsible for water pollution. While the former can easily be traced to a source, such as a manufacturing plant, the latter cannot. Non-point pollution creates a perplexing problem, since it is difficult to relate it to specific causes. Although agriculture is believed to be the major cause of surface-water pollution in the nation today (Crutchfiled 1995), urban activity also contributes to the problem. Exactly who is responsible for non-point pollution and to what degree are largely unanswered questions that need to be addressed by research.

The Boise River of southern Idaho offers a unique opportunity to study non-point pollution. The river has a relatively pure source of water from snow melt and is only 60 miles long downstream from the city of Boise. It has two major potential sources of water pollution: urban activity and irrigated agriculture. Boise is located along the river and has been steadily growing over the past 20 years. Downstream from Boise is a long-established irrigated area (primarily flood irrigated) producing up to 60 commercial crops on about 150,000 acres. Along with irrigation are well-established livestock and food-processing activities that are supported by irrigated crops. Consequently, upstream pollution primarily comes from urban activities, while downstream pollution is primarily related to agricultural activities. State and federal environmental agencies have done much to control point sources of pollution over the past 20 years. Additional sewage treatment plants have been constructed in major urban areas as population has grown. Non-point pollution, however, is still a problem.

Water is taken from the Boise River above Boise and distributed to irrigators downriver. A series of drains returns unused and excess water to the river near Parma, which is a short distance from where the Boise River empties into the Snake River. By comparing measurements of nitrogen and phosphorus at Lucky Peak Dam (above Boise) with similar measurements at Parma, an estimate of pollution from both urban and rural sources along the river can be made. Contamination concentrations vary greatly with the level of stream flow because of the dilution effect. Stream flow varies greatly from year to year and within the year, depending upon the amount of runoff available from snowfall in the mountains. This complicates the analysis of the causes of non-point pollution, because high flows carry more pollutants (loads) but also have the effect of diluting pollution concentrations.

Previous Studies

Long (1976) and Fitzsimmons (1978) studied the impacts of irrigation on water quality and quantified the economic losses that resulted from irrigating land in the Boise Valley nearly 20 years ago. The impacts on water quality were determined by studying and comparing water quality parameters associated with irrigation above Boise before the water was used for irrigation and at Notus, where the Boise River enters the Snake River. The parameters measured were specific conductivity (an indicator of salts and suspended solids), three forms of nitrogen, and phosphorus. Results showed that the average yearly specific conductivity (the ability to conduct electricity) reading at Notus was much higher than at Boise, indicating increased concentrations of salts in the

Refer to the map and chart of **Boise River Diversions and Drains, 1995** on pages 6 and 7 (centerfold) to locate mileage references contained in the text.

Boise River at Notus. Nitrogen, phosphorus, and sediment levels were also compared. Results showed that they were much higher near Caldwell than below Lucky Peak Dam, implying that irrigation did impact water quality at that time.

Clark and Bauer (1983) established a water quality monitoring program on the irrigation drainage system in the lower Boise River Valley as part of a "208 project" to develop a pollution abatement plan for agricultural lands. The 208-project area encompassed irrigated lands along the Boise River from Caldwell to the Snake River. The area was divided into the following groups based on watersheds: Conway Drain and Sand Hollow Drain on the north side; Dixie Drain; Ross East End Drain; and South Boise Drain on the south side. Suspended sediment loads (materials in the river) were calculated on an annual and irrigation season basis. Annual suspended sediment loads for the major drains were: Sand Hollow Drain, 11,040 tons; Dixie Drain, 11,900 tons; Ross East Drain, 4,100 tons; and South Boise Drain, 3,260 tons. It was also found that concentrations of total phosphorus and inorganic nitrogen exceeded accepted in-stream criteria in most drains throughout the year. Calculated total phosphorus loads showed that the drains contribute large quantities of phosphorus to the Boise and Snake rivers. Annual mean concentrations of inorganic nitrogen ranged from 2.20 to 4.80 milligrams per liter (mg/l). Fish were analyzed for pesticide residues in this study. Results showed that of the 18 pesticides or other trace organic factors analyzed, only two, DDT and toxaphene, were consistently above minimum detection limits. A comparison of total phosphorus concentrations during the irrigation season and the non-irrigation season showed that there was a slight increase in total phosphorus concentrations during the irrigation season. Therefore, Clark and Bauer concluded that increases in phosphorus loads during the irrigation season were due primarily to increased drain discharges during this period.

Calkins (1980) provided an economic evaluation of best management practices (BMPs) for controlling sedimentation in irrigation return flows. His study area was the LQ drain, a 3,300-acre watershed in the Magic Valley of southcentral Idaho and the site of a project demonstrating sediment control practices. The additional costs of BMPs implementated above baseline management costs were calculated for six crop rotations on six land classes for a representative 320-acre farm. Crop budgets were compiled using the "Oklahoma State Budget Generator." Costs for sediment retention structures were obtained from a construction firm local to the LQ drain. Capital and ownership costs of long-term investments were calculated using engineering economics. Sediment reduction resulting from BMPs implementation on crop rotations and land classes was determined by monitoring studies. Calkins determined the cost-effectiveness of best management practices in reducing sediment for each crop rotation and land class combination by comparing the implementation costs to the reduction efficiency of each practice. Cost-effective practices included vegetative filter strips, mini-basins, buried drain runoff control systems, and sediment basins. Vegetative filter strips on land with 0-2 percent slope showed an increased net income of 75 percent. For total control of sediment, tailwater recovery-pumpback and side-roll sprinklers were cost-effective. Practices not cost-effective on all land classes included semi-automated gated pipe, gravity-improved management and I-slot sediment structures. A linear programming model was used in this study to simulate the least-cost mix of BMPs achieving varied reductions of sediment in the entire LQ watershed. Results showed that simultaneous consideration of crop rotations and land classes was possible. Sediment delivery reductions of up to 54 percent from the watershed resulted in a modest income penalty of less than 1 percent. Greater sediment control became progressively more costly with mini-basins and sediment basins being implemented on 0-2 percent-sloped land. Total sediment control on relatively level land (0-2% slope) and side-roll sprinklers on steeper land (2+% slope) decreased income by nearly 20 percent.

As the above studies indicate, stream pollution problems and the means of their solutions have been studied for almost 20 years. It is also known from Idaho Department of Health and Welfare sources that additional sewage treatment and better farm management practices have been adopted over this period. Data, however, are not available regarding the extent of these efforts. The focus of this study is to better establish the relationships between urban and rural activities associated with pollution in the Boise River.

Glade Walker

Boise Project, Arrowrock Division, Anderson Ranch Dam. Located on the South Fork of the Boise River, 20 miles northeast of Mountain Home, this earthfill structure is 456 feet high and has a storage capacity of 493,200 acre-feet.

Historical Pollution Trends

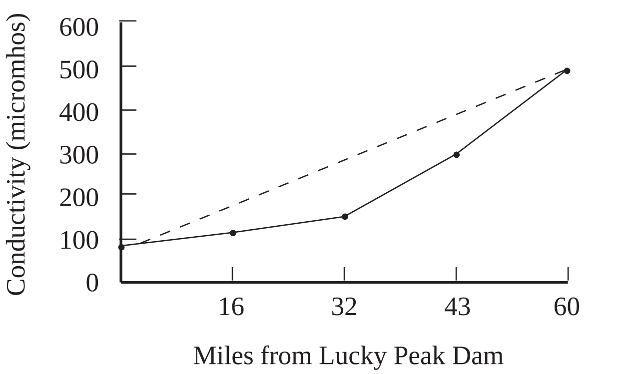
Data on pollution levels have been collected by several government agencies at different points along the Boise River for the past 40 years. These data help one understand how pollution increases as the river flows from Lucky Peak Dam to Parma. Pollution indicators that are high near Boise, but decline toward Parma, are likely to be caused by urban sources. On the other hand, sudden increases in pollution levels near Parma are more likely to be associated with agricultural activities. As is true for much of the United States, even common water-quality data have not been collected in a systematic way or for the same periods of time in the Boise River.

Two methods are commonly used to measure water pollution. These methods are pollutant concentrations (mg/l) and total load of pollutants (lb/day). Each method has advantages and disadvantages. Pollutant concentrations are inversely related to stream flow. When stream flow is high, pollutant concentrations are low, and when stream flows are low concentrations are high. On the other hand, total load (pounds of pollutants) is directly related to stream flows, that is, larger volumes of water at low concentration levels carry more pollutants. Depending on how one defines pollution, the measurement used may influence the results. Because the Boise River had relatively low flows in the late 1980s and early 1990s, it was felt that concentration measurements (mg/l) best represented the pollution situation, since loads would be very low. Whichever method of measurement is used presents a problem. The important point is that any analysis made of these data must include stream flow as a variable since it influences the results significantly.

Specific Conductivity

Conductivity measurements reflect the levels of salts and sediments in the river and would be expected to increase with economic activity that puts material into streams. Data collected from 1973 to 1992 by the Environmental Protection Agency showed that the average conductivity measurements over this time increased by 38 percent as the river passed through the city of Boise (fig. 1). By the time the river reached Parma, conductivity measurements increased by five times the level at Lucky Peak Dam. While the data are not conclusive, they do indicate that conductivity levels in the Boise River increased at an increasing rate between Boise and Parma. Since an index of conductivity measurements, using the average at Lucky Peak Dam as a base of 100, increased by only 38 percent just outside Boise (mile 16) to over 511 percent at Parma, it suggests that salts and sediment from downstream users were more responsible than upstream urban users. Although some conductivity increase is normal as water moves downstream and picks up various materials, high specific conductivity is associated with flood irrigation activities that increase salt and sediment levels in the river.

Figure 1. Average Specific Conductivity Levels, Boise River, 1973-92



Nitrogen

Data are available for nitrogen concentrations in three forms: NO_3-N, NH_3 + NH_4-N dissolved, and NO_2 total. NO_3-N is a form of nitrogen closely associated with human activity, including both urban and agriculture activity. Ada and Canyon county population centers and activities tend to be located along the Boise River, so county population was thought to impact pollution. Using a pollution index of 100, based on an average of available measurements from 1973 to 1981 at Lucky Peak Dam, NO_3-N increased by 300 percent just downstream from Boise and rose to 1,082 by the time the river reached Parma (fig. 2). In other words, there was a nine-fold increase; one-third of that occurred just below Boise. When observations between Boise and Parma were plotted graphically against distance, the results were nearly linear (as indicated by the dashed line), showing a steady increase in nitrogen as the river moved downstream.

Data for NH_3 + NH_4-N dissolved were quite different from NO_3-N. Data were available from 1973 to 1992 from the Environmental Protection Agency. The average reading for this time period at Lucky Peak Dam was the base or 100. The results showed there was a 700 percent increase just outside Boise, and only a 418 percent increase by Parma. These data indicate NH_3 + NH_4-N dissolved increases were due mostly to urban

Figure 2. Average Nitrogen (NO_3-N) Levels, Boise River, 1973-81

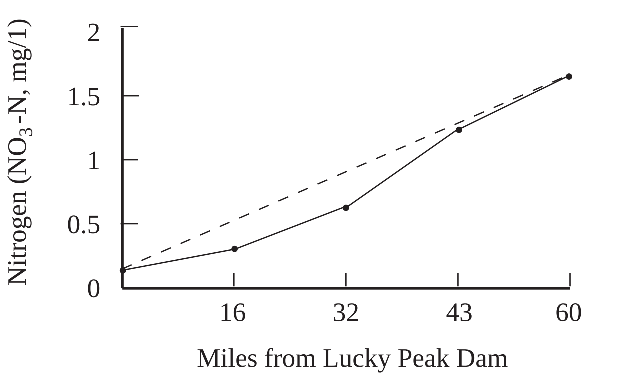
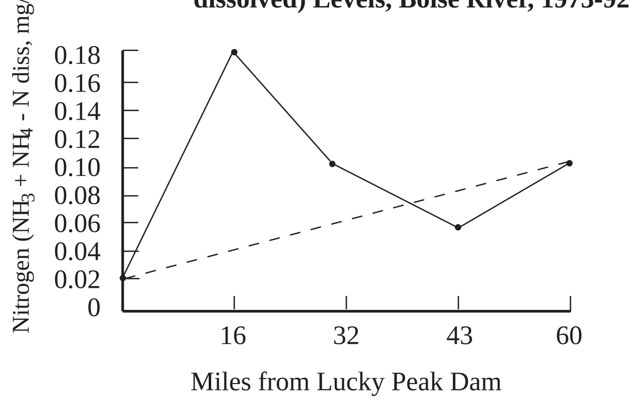


Figure 3. Average Nitrogen (NH_3 + NH_4-N dissolved) Levels, Boise River, 1973-92



activities and that concentrations became diluted as the river flowed downstream to Caldwell (fig. 3). Past Caldwell, $NH_3 + NH_4$-N dissolved increased again. The major cause of nitrogen pollution was probably from urban rather than agricultural activities.

On the other hand, NO_2-total readings were nearly linear between Lucky Peak Dam and Parma and were slightly above the dashed trend-line just outside Boise (fig. 4). An index level of 100, based on observations at Lucky Peak Dam, showed the measure increased by 347 percent just outside Boise and by 808 percent at Parma for the 1973 to 1992 period.

In summary, where nitrogen is concerned, pollution appears to be caused by both urban and rural water users. Increased nitrogen levels downriver caused by urban and rural runoff are not easily separated.

Phosphorus

Like nitrogen, phosphorus is an important contributor to stream pollution that may be caused by using soaps and fertilizer in urban areas or fertilizer in rural areas. Historical data on phosphorus levels in the Boise River generally parallel those for nitrogen, with levels increasing between Lucky Peak Dam and Parma (fig. 5). However, phosphorus levels, unlike nitrogen, tended to be above EPA standards.

Using average phosphorus levels from 1973 to 1992, and using Lucky Peak Dam as an index of 100, phosphorus levels increased by 547 percent just outside Boise and increased by 945 percent downriver at Parma. This indicates that urban contributions were greater than those from rural (downriver) sources. Phosphorus levels grew at a faster rate between Lucky Peak Dam and Glenwood Bridge (mile 16) than between Lucky Peak Dam and Parma. It appears that phosphorus in the river comes from both urban and rural sources.

The data cited above for the five pollution indicators were collected over various periods of time and represent past historical trends. They may misrepresent the current situation in the river since much effort has occurred to improve sewage treatment at major population centers in recent years. Unfortunately, sewage treatment data were not collected over time. Data indicate that nitrogen and phosphorus levels do increase with the flow of the river and are probably caused by both urban and rural activities. These observations may no longer represent the current situation since the number of sewage treatment facilities has increased in recent years and point pollution has also been reduced.

Average Annual Nitrogen Levels

Figure 6 shows average annual levels of nitrogen ($NH_3 + NH_4$-N dissolved) from 1973 to 1990 (EPA data) at Lucky Peak Dam and Parma. The EPA criterion level for pollution is also included (IDHW 1973). In spite of increases in population, the nitrogen level has steadily dropped over the period. This decrease can be attributed to better sewage treatment facilities, reduced contributions from point sources, and better irrigation management practices. Unfortunately, measurements for pollution control efforts are not available. The only years that nitrogen was a potential problem were 1973 and 1975. By 1990, nitrogen concentration levels dropped to about .05 mg/l from .41 mg/l, only a fraction of the EPA criterion level of 0.30 mg/l.

Annual data clearly show the results of pollution control efforts on the Boise River. In spite

Figure 4. Average Nitrogen (NO_2-total), Levels Boise River, 1973-92

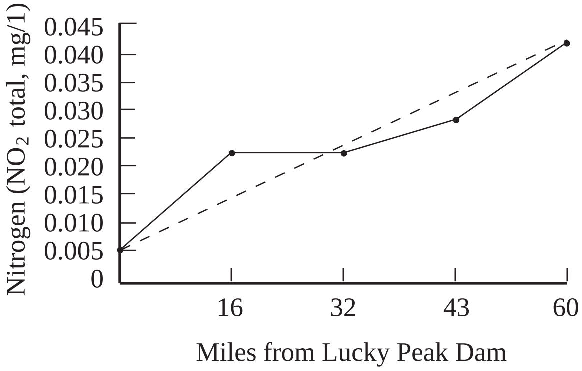
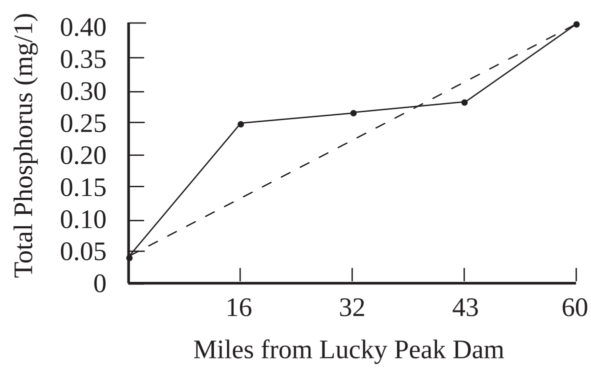
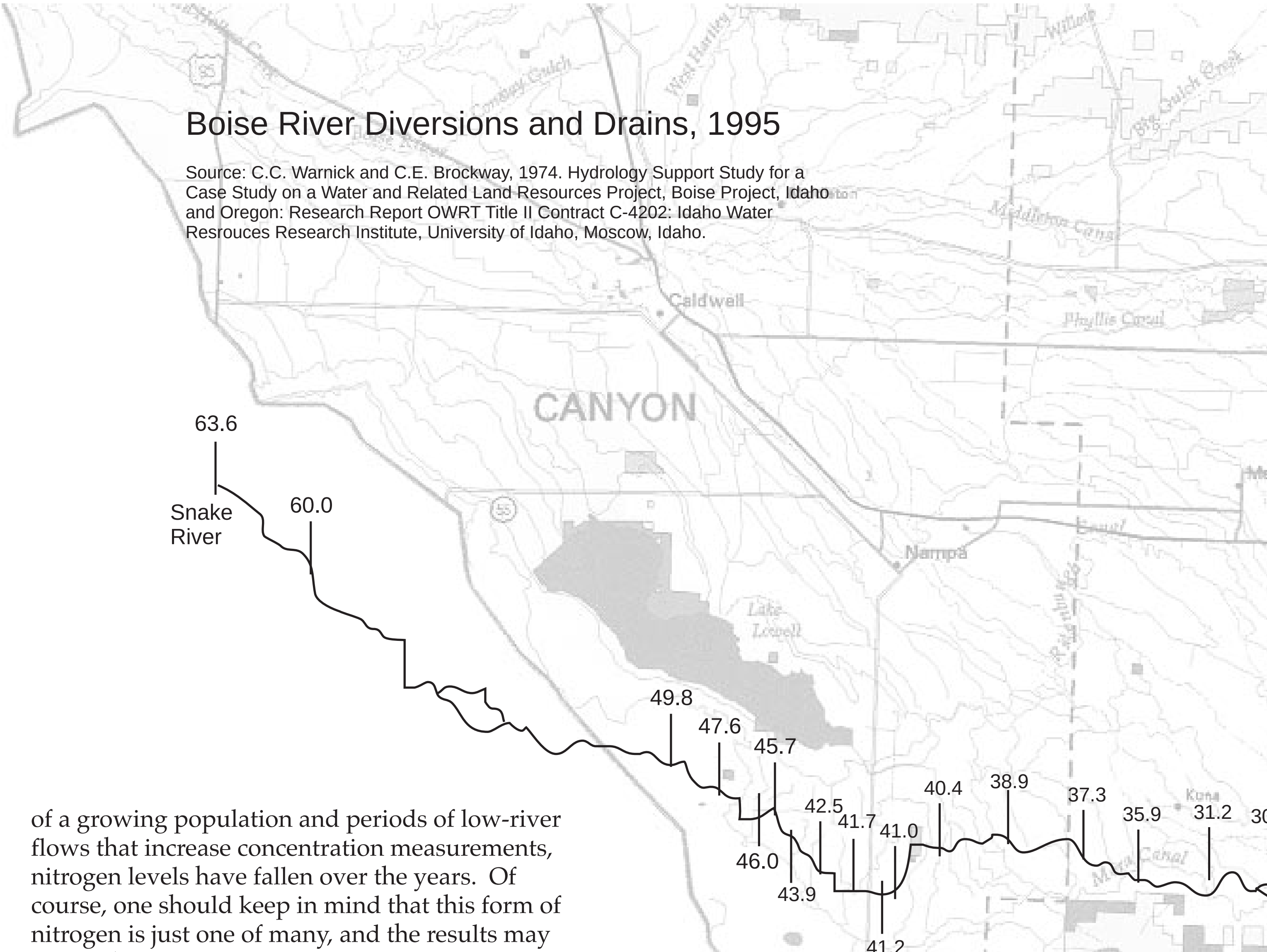


Figure 5. Average Total Phosphorus Levels, Boise River, 1973-92



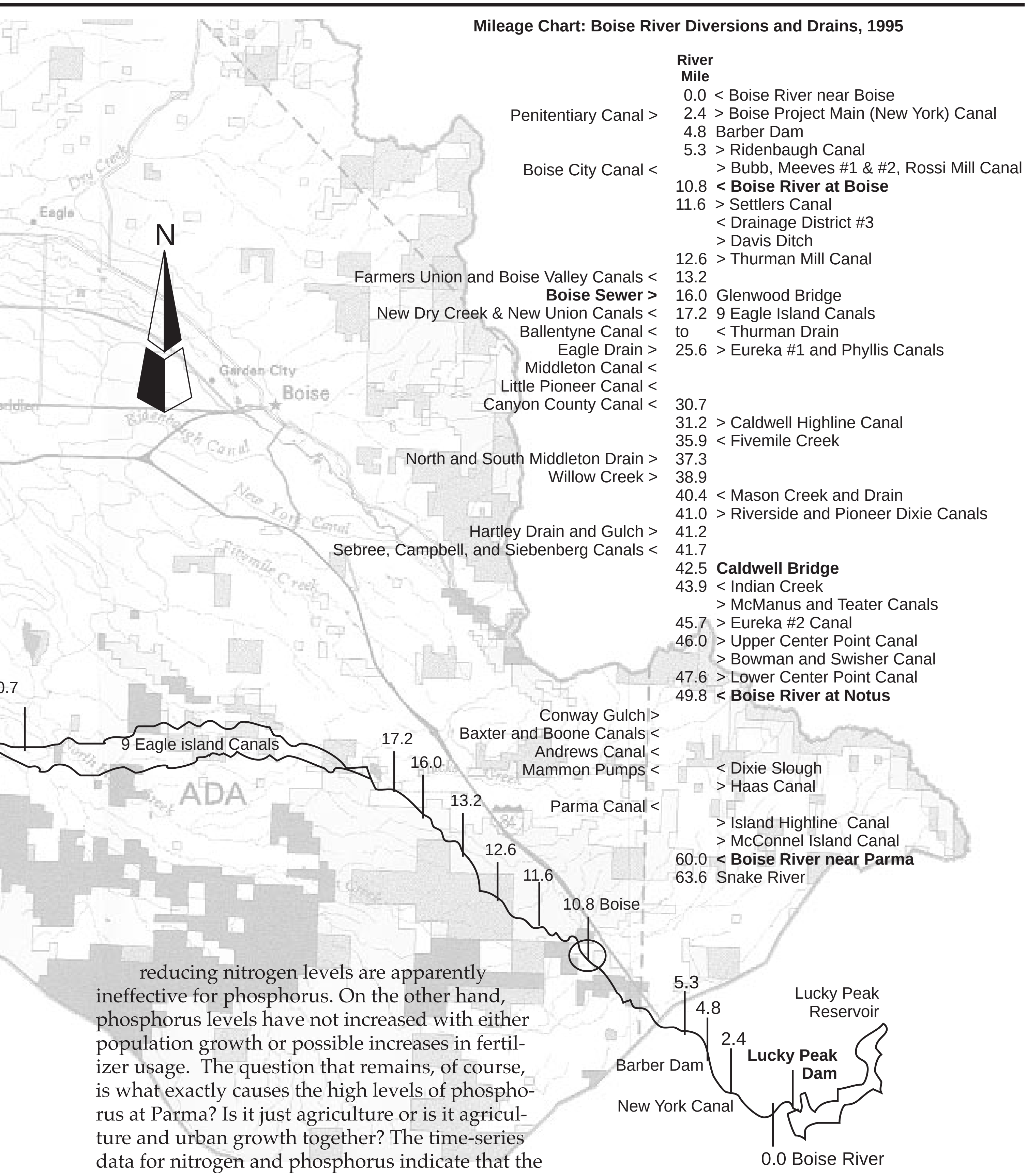


of a growing population and periods of low-river flows that increase concentration measurements, nitrogen levels have fallen over the years. Of course, one should keep in mind that this form of nitrogen is just one of many, and the results may not be the same for all forms of nitrogen. Pollution control efforts appear to be highly effective for this type of nitrogen. Water quality in recent years was nearly as good at Parma as it was at Lucky Peak Dam before the river entered the city or the irrigated area. The downward trend in concentrates indicate that this form of nitrogen is not currently an environmental problem and probably will not be in the future. Nitrogen may be leached into the soil or volatilized before it can run off. If anything, the efforts for controlling nitrogen levels may be carried beyond reasonable levels if other pollution factors are being ignored.

Average Annual Phosphorus Levels

Figure 7 shows average annual phosphorus levels from 1973 to 1990 at Parma and Lucky Peak Dam and the EPA criterion level. Unfortunately, efforts to control phosphorus levels have not been as successful as with nitrogen. Essentially, phosphorus levels have stayed constant from 1973 to 1990 at Parma. Phosphorus levels have fluctuated on a year-to-year basis with an average value staying at 0.36 mg/l, while the EPA criterion level is 0.10 mg/l. The average level at Lucky Peak Dam was less than 0.05 mg/l over this period.

Several conclusions are apparent from the data in figure 7. First, the EPA criterion level for eutrophication (oxygen-deficient water) is only two or three times the phosphorus level at Lucky Peak Dam, so it does not take much additional phosphorus to exceed the critical level. Second, the average phosphorus level has remained relatively constant from 1973 to 1990 at 0.40 mg/l, or four times the EPA criterion level. A statistical test did not reveal any significant trend. Third, the efforts to reduce pollution in this area that worked so well



reducing nitrogen levels are apparently ineffective for phosphorus. On the other hand, phosphorus levels have not increased with either population growth or possible increases in fertilizer usage. The question that remains, of course, is what exactly causes the high levels of phosphorus at Parma? Is it just agriculture or is it agriculture and urban growth together? The time-series data for nitrogen and phosphorus indicate that the two sources of pollution are not related: nitrogen levels decreased, while phosphorus levels showed no significant trend.

Monthly Data for Nitrogen and Phosphorus

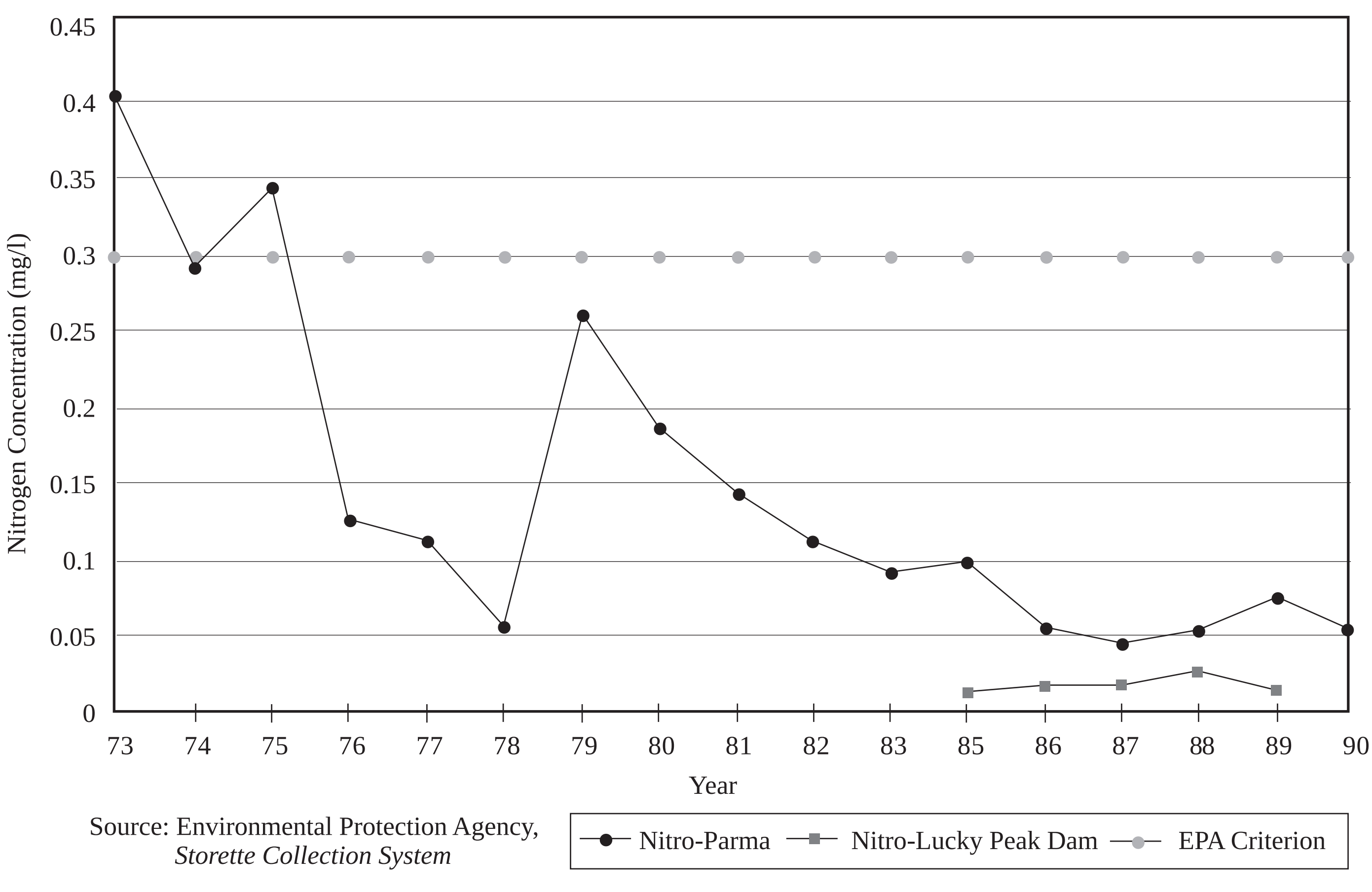
Figures 8 and 9 show monthly observations on a calendar-year basis from 1973 to 1990 for both nitrogen and phosphorus, while the previous figures were for average annual data. Figures 8 and 9 show that pollution concentration levels tend to increase during the winter months when stream flows are low and the dilution effect is reduced. In the case of nitrogen, figure 8 shows that, in spite of continually reduced nitrogen levels between 1973 and 1990, spikes above the EPA criterion level still occurred, usually during the winter months. As the average level of nitrogen has been reduced, so have the annual increases due to low-river flows. Several farm management practices are employed to reduce runoff from irrigation, which can contribute to pollution.

Figure 9 shows increases in phosphorus concentration levels, which also tend to be more prevalent during periods of low flow. Figure 9 also indicates some interesting information about phosphorus levels. First, phosphorus concentration levels are seldom below the EPA standard for pollution (0.1 mg/l). Second, most spikes of phosphorus concentration levels tend to be about double the average levels (about 0.4 mg/l). Finally, the amplitude of the spike observations for phosphorus does not vary as greatly relative to the mean level as do those for nitrogen. It is still very apparent that average annual phosphorus concentration levels exceed EPA standards by a factor of four, while nitrogen levels are only about one-third the EPA standard. From the monthly phosphorus data, it appears that nothing has happened from 1973 to 1990 to change the annual pattern, and the question remains as to who is responsible for non-point pollution in the Boise River: agriculture or urban water users.

Presentation of Study Data

After consideration of the possible causes of phosphorus pollution in the Boise River, three factors were tentatively specified as major contributors to the problem. Since Boise is a city with little industry to cause pollution, population growth was specified as a potential factor for

Figure 6. Annual Average Nitrogen ($NH_3 + NH_4$-N dissolved) Level at Parma and Lucky Peak Dam and the EPA Criterion (1973-90)



Source: Environmental Protection Agency, *Storette Collection System* changes in phosphorus levels. Because of the impact of stream flows in diluting pollutants and reducing concentration levels, stream flows in cubic feet per second (cfs) were also considered to be a relevant variable. Where agriculture is concerned, both crop and animal activities could contribute to pollution. Animal numbers, however, have been relatively constant from 1973 to 1990 according to the U.S. Census of Agriculture, but there are no data available on an annual basis since the Census is only taken every five years. Consequently, animal numbers were excluded from the analysis.

Irrigated cropland was the variable thought to be most likely associated with phosphorus pollution, since some crops are known to receive high application rates (table 1). For analytical purposes, irrigated acreage was separated into three classes: irrigated acres with crop values less than $500 per acre, irrigated acres with crop values between $500 and $999 per acre, and irrigated acres with crop values of $1,000 per acre or more. The model that gave the most significant statistical results was one that included population, stream flow, and high-valued irrigated crop acreage (value over $1,000/acre).

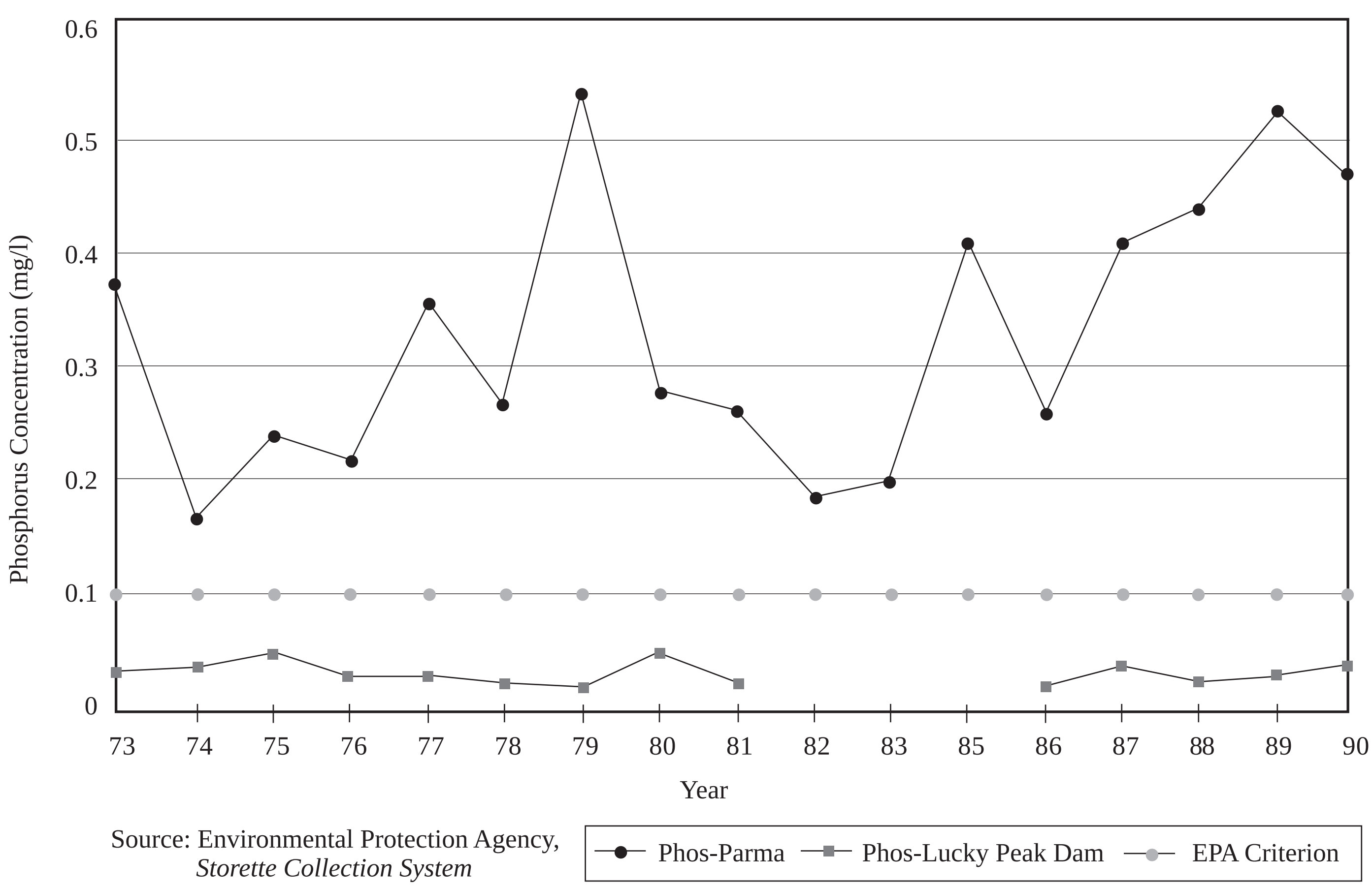
Table 1. Fertilizer Use in Southwestern Idaho

Crops	Phosphate (lb/acre)	Nitrogen (lb/acre)
Corn Silage	80	150
Corn Seed	65	140
Onions*	115	50
Potatoes*	160	100
Feed Barley	30	135
Spring Wheat	50	135
Winter Wheat	50	140
Alfalfa Hay	60	0

Source: University of Idaho, Department of Agricultural Economics. *Southwestern Idaho Crop Enterprise Budget*, 1993.

* high-valued crops

Figure 7. Annual Average Phosphorus Level at Parma and Lucky Peak Dam and the EPA Criterion (1973-90)



Source: Environmental Protection Agency, *Storette Collection System*

Large portions of irrigated land used for hay crops and grain receive little phosphorus fertilizer. Higher economically valued crops such as onions and potatoes, however, were more likely to receive fertilizer, especially high doses of phosphorus. For this reason crop acreage for low-, medium-, and high-valued crops, based on Bureau of Reclamation *Crop Reports*, were determined and used as variables in the analysis of phosphorus concentration levels. Low- and medium-valued crops were not statistically associated with phosphorus pollution based on similar regression analyses. Water quality and flow data were obtained from the Environmental Protection Agency *Storette Collection System*. Population data were obtained from U.S. Census Bureau reports. Irrigated acreage and value data came from Bureau of Reclamation *Annual Reports*. Data were not adjusted prior to the analysis.

Analysis and Results

Phosphorus concentration levels were found to be related to high-valued crop acreage, population, and stream flow as shown by the following regression equation. (t statistics are in parentheses.)

$$Y = -0.0473 + 5.44 \times 10^{-7} X_1 - 2.79 \times 10^{-5} X_2 + 2.18 \times 10^{-5} X_3$$
$$(-0.33) \quad (1.79) \quad (-2.73) \quad (3.23)$$

$R^2 = 0.817$, adjusted for sample size $R^2 = 0.775$, where

Y = phosphorus concentrations (mg/l) at Parma

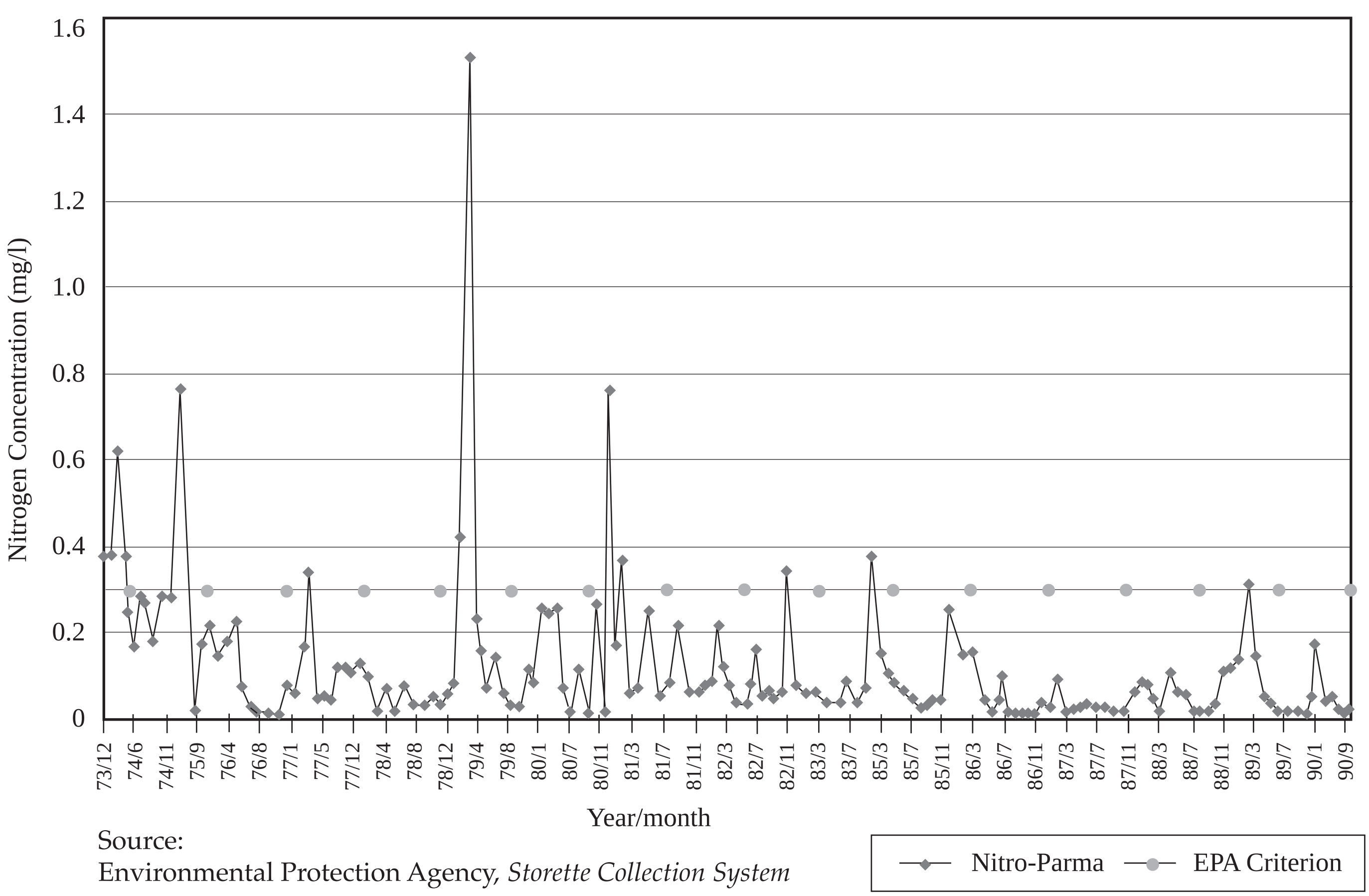
X_1 = population in Ada and Canyon counties

X_2 = stream flow (cfs) at Parma

X_3 = high-valued irrigated crop acreage (value of \$1,000/acre or more) in Ada and Canyon counties

These results indicate that all three independent variables are associated with changes in phosphorus levels at Parma, although population was significant at a lower level than stream flow or high-valued crops. Variation in the three independent variables was associated with 78 percent of the variation in the dependent variable. This evidence indicates that both population and high-valued crop acreage expansion increased phosphorus levels. As expected, stream flow was

Figure 8. The Monthly Nitrogen (NH_3 + NH_4-N dissolved) Concentrations at Parma (1973-90)



Source:
Environmental Protection Agency, *Storette Collection System*

Table 2. Calculation of Ada and Canyon county crop acreage and population impacts on phosphorus concentrations in the Boise River at Parma

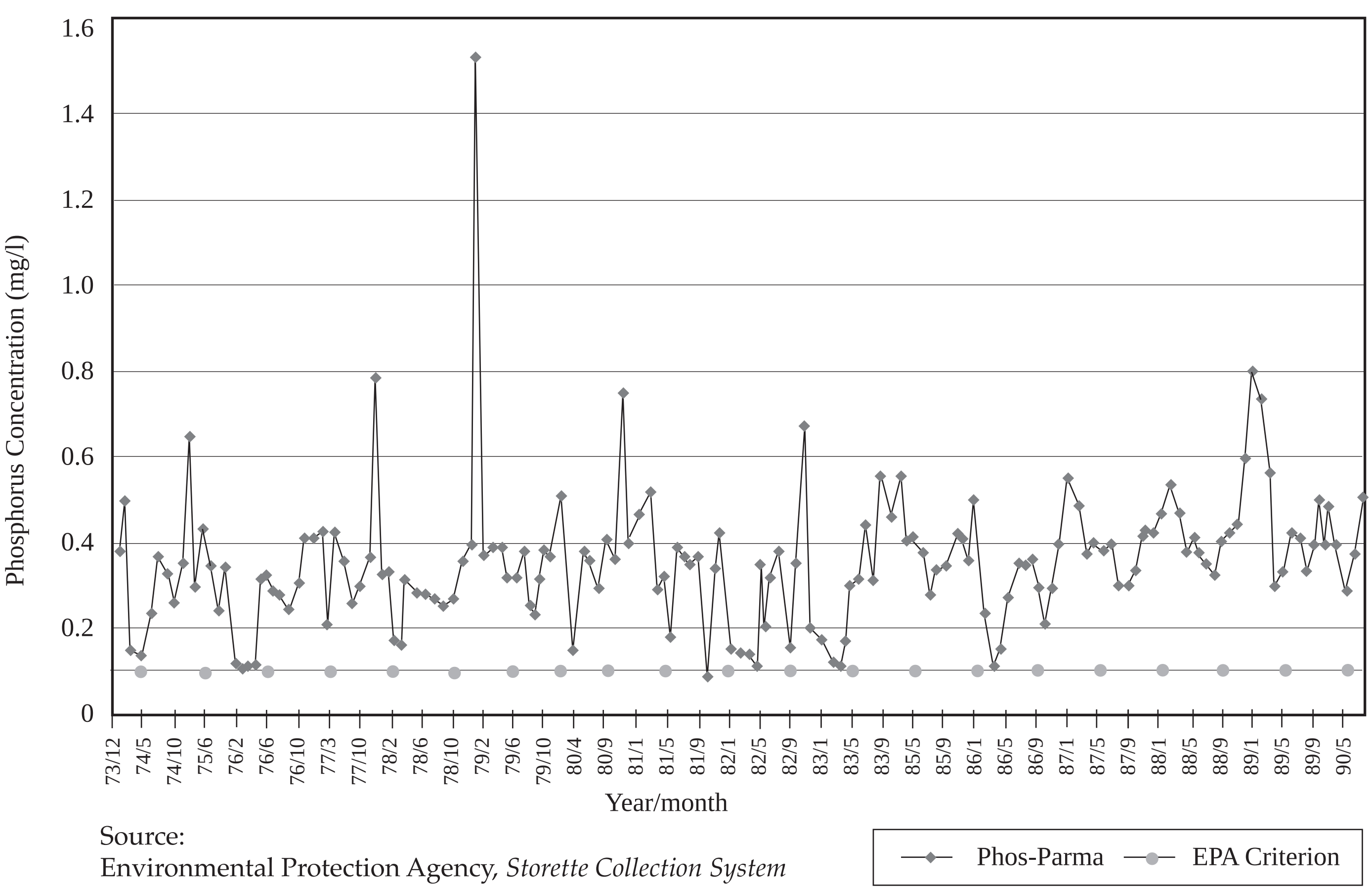
	High-Valued Crop Impact	Population Impact
Year	**Parameter Estimate (acres)**	**Parameter Estimate (population)**
1990	$2.18 \times 10^{-5} \times 17{,}732$	$5.44 \times 10^{-7} \times 295{,}851$
1973	$2.18 \times 10^{-5} \times 16{,}199$	$5.44 \times 10^{-7} \times 198{,}527$
Impact	0.03 mg/l increase phosphorus concentrations	0.05 mg/l increase phosphorus concentrations

inversely related to phosphorus levels. These independent variables are not related to each other nor do they appear to be related to previous observations over time. Population increased steadily over time, and stream flows varied greatly from year to year and within each year. High-valued crop acreage generally increased but also varied widely between years. A similar analysis was conducted for nitrogen. Some forms of nitrogen data were limited, however, and information about nitrogen control measures was unavailable.

Impact of Population and Irrigated Crops on Water Quality

Employing the regression equation, results and observations for 1973 and 1990 gave the estimated impacts as shown in table 2.

Figure 9. The Monthly Phosphorus Concentrations at Parma (1973-90)



Source:
Environmental Protection Agency, *Storette Collection System*

Using the actual changes in crop acreage and population for 1973 and 1990, the relative impact of each variable was estimated using regression parameters. The increased high-valued irrigated crop acreage was estimated to have increased phosphorus measurements by 0.03 mg/l, while increased population was estimated to have increased phosphorus measurements by 0.05 mg/l. In total, they increased phosphorus levels by 0.08 mg/l: irrigation accounted for 38 percent and population 62 percent. While these results are not conclusive, or may not represent the current situation, they do indicate that both urban growth and high-valued crop acreage contributed to additional phosphorus levels in the Boise River.

Conclusions

Based on the results of this study, the following conclusions were drawn. Past farm management efforts to control nitrogen pollution and better sewage treatment facilities have been very effective in terms of reducing nitrogen levels below EPA standards in the Boise River. The same is not true for phosphorus concentration levels, which exceeded EPA standards from 1973 to 1990. Population, stream flow, and high-valued irrigated crop acreage were associated with nearly 80 percent of the variations in phosphorus levels in the Boise River at Parma during these years. Increases in urban population and high-valued crop acreage raised phosphorus levels by an estimated 0.08 mg/l. Population increases accounted for 62 percent of this change, and high-valued crops accounted for 38 percent. Lawn fertilizers and certain detergents contributed to higher urban phosphorus levels. However, even if population and high-valued crop acreage had not increased from 1973 to 1990, phosphorus levels would still be above EPA standards. Even modest amounts of economic activities would bring phosphorus levels from what they are at Lucky Peak Dam to levels beyond EPA standards.

This study demonstrated that non-point pollution in the Boise River can be determined for aggregate causes. Pollution levels from both urban and rural activities were estimated by using time-series data. Further research in this area may be improved, however, by better experimental design and using data collected in a more systematic way. Examining pollutant loads, in addition to concentration levels, may also benefit the analysis of non-point pollution.

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