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# EFFECTS OF PASTURE RUNOFF ON WATER CHEMISTRY, BUFFALO NATIONAL RIVER, USA

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ABSTRACT The effects of pasture runoff on the water chemistry of the Buffalo River were investigated by sampling from an upstream site (pristine), and a downstream site (below a pasture area) during four rainstorms. Changes in fecal coliform and nutrient concentrations were attributed to the cattle grazing between the two sites. Pasture runoff waters were calculated to have average fecal coliform concentrations 50 times greater than upstream samples. A single rain event can flush as many bacteria into the Buffalo River as are transported during 150 low flow days. Nutrient concentrations were generally higher at the downstream station and seasonal variations in nutrient behavior were significant.

## INTRODUCTION

The predominant land use in Boxley Valley, Arkansas, is cattle grazing. Previous studies (Malcolm *et al.*, 1976; Weeks, 1987) presented evidence that cattle grazing in Boxley Valley is degrading the natural water quality of the Buffalo River. The most notable degradation has been observed in association with rainstorms.

Because the Buffalo National River, administered by the National Park Service (NPS), receives significant recreational usage as well as being classified as Extraordinary Resource Waters by the state of Arkansas, the parameters of most concern are fecal coliform bacteria (FC) and nutrients. To quantify the effect of cattle pasture runoff on the water chemistry of the Buffalo River, samples were collected upstream and downstream from Boxley Valley from the rising and falling portions of the storm hydrograph during four rainstorms. Samples collected upstream from Boxley Valley represented natural background conditions. Changes in the concentrations of FC and nutrients below Boxley Valley resulted from the cattle grazing between the two stations.

The Buffalo River generally flows eastward through the Ozarks region for 240 km from its headwaters in the Boston Mountains to its confluence with the White River. This study was conducted in the headwaters region located 40 km southwest of Harrison in northwestern Arkansas.

## SITE CHARACTERIZATION

The Buffalo River cuts through Ordovician and Mississippian aged limestone, dolomite, sandstone and shale at Boxley Valley (Aley, 1982). The area of the watershed associated with the upstream station (US) is 147 km$^2$. The area of the watershed associated with the downstream station (DS), exclusive of the watershed associated with US, is 132.3 km$^2$. The area of Boxley Valley used for agricultural purposes is 6.1 km$^2$ which represents approximately 2.2% of the total watershed (US Department of Interior, National Park Service, 1985). The remaining 97.8% of the watershed is covered by a deciduous hardwood forest and represents natural background conditions.

*TABLE 1 Linear regression data for rain event 1.*

| Parameter | Station | Slope | PCC | SCC |
|---|---|---|---|---|
| Fecal Coliform | US | 0.302 | 0.787 | 0.854 |
| | DS | 0.283 | 0.490 | 0.539 |
| | US* | 0.372 | 0.942 | 0.600 |
| | DS* | 0.456 | 0.831 | 0.900 |
| Total Kjeldahl Nitrogen | US | 0.000 46 | 0.564 | 0.618 |
| | DS | 0.000 45 | 0.786 | 0.800 |
| | US* | 0.000 50 | 0.789 | 0.900 |
| | DS* | 0.000 54 | 0.939 | 0.900 |
| Total Phosphate | US | 0.000 05 | 0.846 | 0.884 |
| | DS | 0.000 03 | 0.922 | 0.890 |
| | US* | 0.000 06 | 0.975 | 0.700 |
| | DS* | 0.000 03 | 0.937 | 0.950 |
| Nitrate plus Nitrite Nitrogen | US | 0.000 01 | 0.544 | 0.491 |
| | DS | 0.000 00 | 0.162 | 0.078 |
| | US* | -0.000 02 | 0.978 | 0.700 |
| | DS* | 0.000 00 | 0.021 | 0.400 |
| Ammonium | US | 0.000 03 | 0.318 | 0.433 |
| | DS | 0.000 06 | 0.732 | 0.654 |
| | US* | 0.000 05 | 0.533 | 0.650 |
| | DS* | 0.015 90 | 0.970 | 1.000 |

PCC = Pearson product moment correlation coefficient.
SCC = Spearman rank correlation coefficient.
* First five samples from rising portion of storm hydrograph.

Valley bottom soils are dominated by floodplain deposits (productive sandy and silty loams) characterized by high hydraulic conductivity. Vadose recharge, especially in the limestone terrain, adds significantly to the discharge of the river during rain events.

Approximately 60 people live within Boxley Valley and land use is largely devoted to hay and pasture. The largest number of cattle, about 800, are present during the winter. In spring and summer months, cattle are moved so that hay, predominantly fescue and bermuda grass, can be harvested. Cattle are estimated to average 400 head during spring and summer months (Liles, personal communication). Boxley Valley is 11 km long and averages 900 m width. The pastures are immediately adjacent to the Buffalo River and primarily within the floodplain (US Department of Interior, National Park Service, 1985).

## COMPUTATION METHODOLOGY

### Linear regression analysis

In this study, discharge acted as the causal variable upon which the concentration of the parameter is dependent. Discharge is accurate to within 10%. Linear regression analysis was performed using the method of least squares and the test of correlation defined by Pearson's product moment correlation coefficient. To test for the occurrence of large values of x in association with large values of y where this relation was curvilinear, Spearman's rank correlation coefficient was employed.

The rain event data were examined two ways through the use of linear regression. For the first approach, listed in Table 1, the slope and correlation of the best fit line through all the data points from Rain Event 1 (RE1) were evaluated. For the second approach, which also is listed in Table 1, the samples associated with the rising portion of the storm hydrograph were separated and linear regression analysis was performed on these first five samples from RE1. The second method proved valuable because surface sources of fecal coliform bacteria and nutrients were depleted during or soon after the rising portion of the storm hydrograph while discharge remained high. Data from the rising portion of the hydrograph typically produced a better correlation.

### Discharge normalization

The main focus of this study was to evaluate the relation between discharge and parameter concentrations at each station and compare results between the two stations. To compensate for different discharges at the two stations, discharge was normalized at US and DS before performing linear regression analysis for the data listed in Table 2. The normalization procedure is as follows:

$$x_{ni} = (x_i - x_{min})(x_{max} - x_{min})^{-1} \qquad (1)$$

where $x_{ni}$ = normalized $x_i$ value
$x_i$ = discharge at time t
$x_{min}$ = minimum $x_i$ value
$x_{max}$ = maximum $x_i$ value

Normalization constrains all discharge values between the range of 0 and 1 and allows the relative magnitude of the slopes to be compared between stations. For example, a normalized slope for the regression of fecal coliform on discharge was 335.4 for US and 558 for DS. Thus, the change in y (FC) per unit change in x (discharge) is 66% greater at DS than at US.

*TABLE 2 Results of a linear regression analysis of water quality parameters on normalized discharge at the upstream (US) and downstream (DS) stations on the Buffalo National River.*

| Parameter | Slope US | Slope DS | *PCC US | *PCC DS | Change at DS(%) |
|---|---|---|---|---|---|
| Rain event 1 (all samples) | | | | | |
| Fecal Coliform | 335.4 | 558 | 0.79 | 0.49 | 66.37 |
| TKN | 0.511 | 0.894 | 0.56 | 0.79 | 74.95 |
| Ammonium | 0.034 | 0.125 | 0.32 | 0.74 | 267.65 |
| Total Phosphate | 0.052 | 0.064 | 0.85 | 0.92 | 23.08 |
| Rain event 1 (first five samples) | | | | | |
| Fecal Coliform | 412.5 | 902.4 | 0.94 | 0.83 | 118.76 |
| TKN | 0.55 | 1.08 | 0.79 | 0.94 | 96.36 |
| Ammonium | 0.054 | 0.169 | 0.53 | 0.99 | 212.96 |
| Total Phosphate | 0.0642 | 0.062 | 0.98 | 0.94 | -3.43 |
| Rain event 4 (all samples) | | | | | |
| Fecal Coliform | 304.9 | 462.1 | 0.71 | 0.64 | 51.56 |
| TKN | 0.209 | -0.07 | 0.49 | -0.19 | -66.51 |
| Ammonium | — | — | — | — | — |
| Total Phosphate | 7.167 | 37.44 | 0.24 | 0.62 | 422.00 |

*PCC = Pearson product moment correlation coefficient

## Mass balance

During rainstorms, water samples collected at DS represent a mixture of water from natural background sources and from the pastures in Boxley Valley. For a uniformly distributed rainstorm, 97.8% of the water in a sample originates from background areas, while 2.2% of the sample originates from Boxley Valley.

To quantify the average concentration of a parameter in the runoff from Boxley Valley the following two component mixing model was used:

$$V_{DS}\,C_{DS} = V_{BG}\,C_{BG} + V_{BV}\,C_{BV} \qquad (2)$$

where $V_{DS}$ = total discharge at DS
$V_{BG}$ = 0.978 $V_{DS}$
$V_{BV}$ = 0.022 $V_{DS}$
$C_{DS}$ = average concentration at DS
$C_{BG}$ = average concentration at US
$C_{BV}$ = average concentration of Boxley Valley runoff

To calculate the total discharge at DS, the area under the hydrograph for the rainstorm was computed. The total discharge was then multiplied by 0.978 to determine the volume originating from the background area and by 0.022 to determine the volume originating from Boxley Valley. The average concentration for a parameter at stations US and DS was determined by digitizing the parameter concentrations from time versus concentration plots at one hour intervals, summing these values over the course of a rainstorm, and dividing the total by the number of collection hours (see Fig. 1). The average parameter concentration in the waters originating from Boxley Valley can be determined by:

$$C_{BV} = (V_{DS}\,C_{DS} - V_{BG}\,C_{BG})\,V_{BV}^{-1} \tag{3}$$

The average concentrations for Boxley Valley are not intended to be used as absolute quantitative measurements. Rather, these concentrations provide a measure of the relative change in the average concentration of Boxley Valley's waters from background concentrations (Table 3).

*TABLE 3 Mass balance of fecal material for rainstorms 1 and 4.*

| Rainstorm 1 | Rainstorm 4 |
|---|---|
| $V_{DS}$ = 3129009 $m^3$ | $V_{DS}$ = 2164441 $m^3$ |
| $V_{BG}$ = 3060171 $m^3$ | $V_{BG}$ = 2116823 $m^3$ |
| $V_{BV}$ = 68838 $m^3$ | $V_{BV}$ = 47618 $m^3$ |
| $V_{US}$ = 1732455 $m^3$ | $V_{US}$ = 1352215 $m^3$ |

| | $C_{DS}$ | $C_{BG}$ | $C_{BV}$ | Number or mass | Total feces | * Days for accumulation |
|---|---|---|---|---|---|---|
| Rain Event 1 | | | | | | |
| FC (col $100^{-1}$ $ml^{-1}$) | 371.5 | 155.2 | 9987 | 6.874 x $10^{12}$ col | 52877 kg | 2.8-5.6 |
| TKN (mg $l^{-1}$) | 1.07 | 1.04 | 2.4 | 165212 g | 24754 kg | 1.3-2.6 |
| Rain event 4 | | | | | | |
| FC (col $100^{-1}$ $ml^{-1}$) | 419.6 | 185 | 10849 | 5.165 x $10^{12}$ col | 39733 kg | 2.1-4.2 |
| TKN (mg $l^{-1}$) | 0.208 | 0.153 | 2.653 | 126330 g | 18865 kg | 1-2 |

*Lower value based on 800 head of cattle and higher value based on 400 head of cattle.

The average concentration of the waters draining from Boxley Valley were used to calculate the mass balance given in Table 3. Fecal coliform colonies per gram of cattle feces (Reddy, 1980) were used to convert the parameter mass to total cattle feces required to deliver the calculated volume of the parameter. Average daily weight of feces produced by cattle (Reddy, 1980) were used to convert the weight of fecal material to days required for the fecal accumulation. A similar approach was used in calculating the mass for total Kjeldahl nitrogen (TKN) (Reddy, 1980; Bowen, 1978).

The days required for accumulation is an estimate of days needed for the cattle in Boxley Valley to produce the total feces given in the mass balance. This estimate does not imply that all feces produced immediately before a rainstorm were transported to the Buffalo River. The total feces actually contributing bacteria and TKN consists of both older feces and a portion of the feces produced during the given required accumulation time.

## RESULTS

### Fecal coliform bacteria (FC)

Figure 1 shows higher FC concentrations at DS than at US throughout RE1. Of the four rain events sampled, RE1 demonstrated the highest maximum FC concentration of 1500 col $100^{-1}$ $ml^{-1}$ at DS. Maximum FC concentrations were associated with RE1 because this rain event:

(a) produced the most rainfall and largest volume of runoff;
(b) occurred during the winter season when vegetative ground cover was sparse and the maximum number of cattle were present;
(c) occurred when there had been a relatively long dry period.

Maximum concentrations observed at US were 500 col $100^{-1}$ $ml^{-1}$ during RE1. Total discharge was less in the other three rainstorms, yet the pattern of higher fecal coliform levels at DS was the same in all four rainstorms.

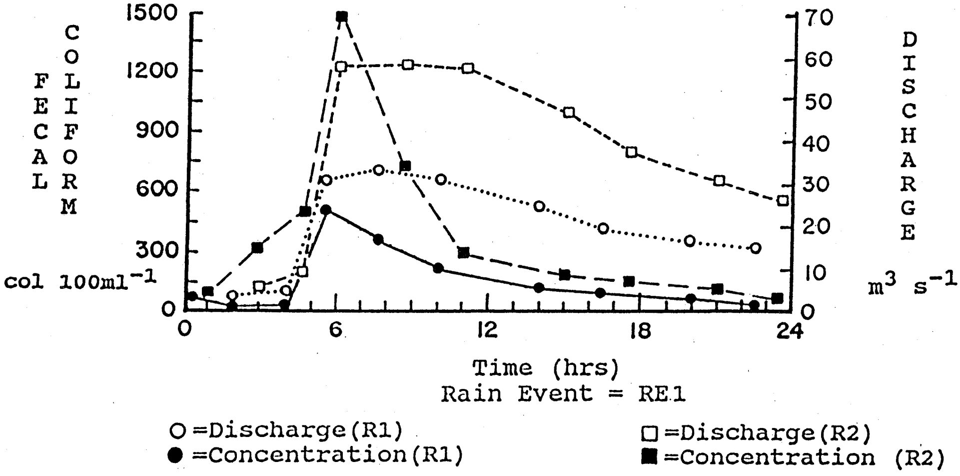

*FIG. 1 Behavior of fecal coliform bacteria and discharge during a winter rain event (RE1).*

Both Spearman's and Pearson's correlation coefficients (PCC) indicate a positive relation between discharge and FC concentrations (Table 1). Poorer correlation at DS (PCC = 0.490) compared to US (PCC = 0.787), resulted from a few very high concentrations on the rising limb of the storm hydrograph. The FC concentrations peaked rapidly in RE1 and declined while the discharge remained high for several hours. As observed in Table 1, correlation is highest for the rising limb of the storm hydrograph in RE1 at each station, but the improvement is greater at DS. In general, FC concentrations demonstrated better correlation with turbidity, TKN, and total phosphate (TP) than with the dissolved constituents suggesting that FC were more likely associated with suspended solids than to exist as water extractable (free floating) organisms.

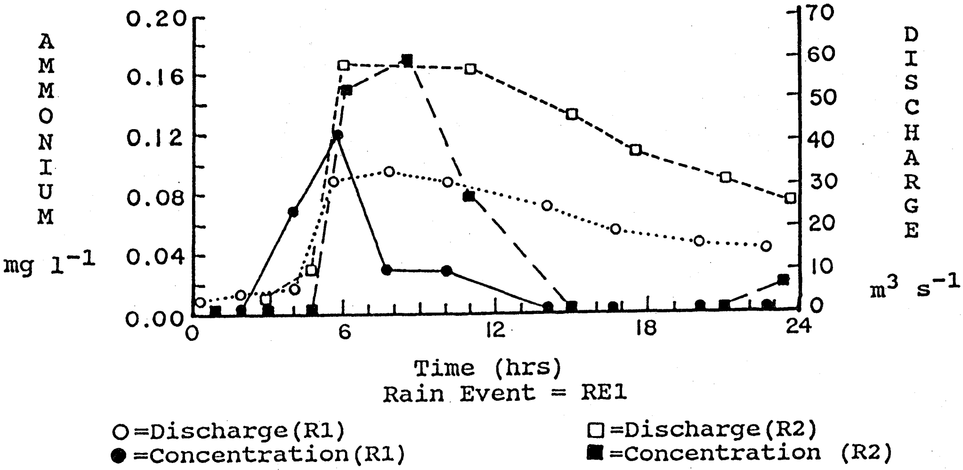

*FIG. 2 Behavior of ammonium and discharge during a winter rain event (RE1).*

The change in the FC concentration per unit change in normalized discharge at DS was 66% greater than at US (Table 2). Because both discharge and the rate of change in FC per unit of discharge were increasing at a greater rate at DS, FC concentrations downstream from the pasture area were as much as three times higher than background concentrations. The normalized slope for the regression of FC on discharge at DS was 118% greater than at US when samples from the rising limb of the storm hydrograph were used for RE1.

Average FC concentrations increased at DS during both RE1 and RE4 and were greater than two times those at US (Table 3). In addition, the FC concentration of the waters draining the fields in Boxley Valley was more than 50 times the background concentrations at US. Fecal coliform concentrations greater than 10 000 col 100$^{-1}$ ml$^{-1}$ were observed previously in tributaries to the Buffalo River at Boxley Valley during routine National Park Service water quality monitoring. The accumulation period of feces is similar for RE1 and RE4, although RE4 received less rain, and had less cows, more vegetation, and a shorter time since the previous rainstorm than RE1. This comparison suggests that the most recent manure is the dominant source of the FC which is consistent with an evaluation of the decay rate of FC. The half-life of FC indicates that the majority die after 8 days (Reddy, 1980).

The positive relation between FC and discharge suggests that extremely large total transport occurs during a storm, e.g. 6.894 x $10^{12}$ colonies for RE1. The low flow daily FC loading at DS is 4.04 x $10^{10}$ colonies, derived from an average of 33 col 100$^{-1}$ ml$^{-1}$ and a discharge of 1.42 m$^3$ s$^{-1}$. Thus, more than 150 days of low flow transport would be required to produce the same amount of FC that was produced during RE1.

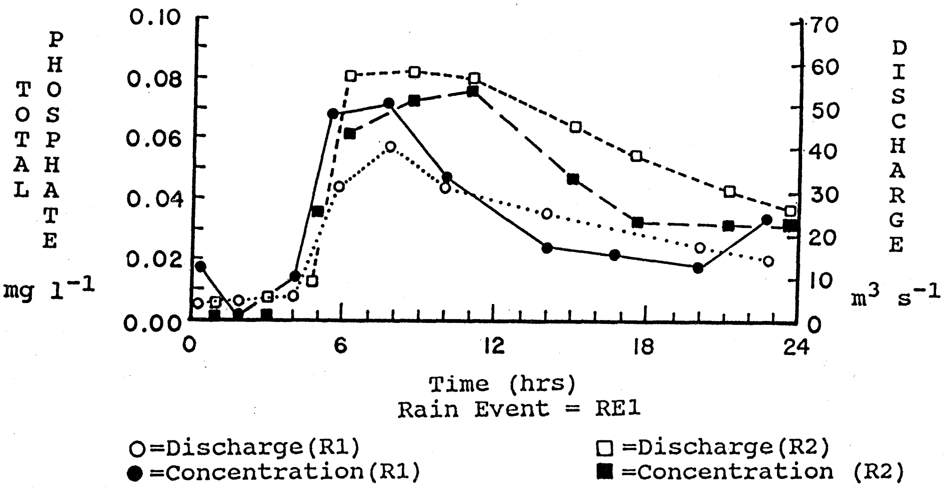

*FIG. 3 Behavior of total phosphate and discharge during a winter rain event (RE1).*

Nutrients

Figures 2 through 5 show the behavior of ammonium and TP at US and DS during a winter and a spring rainstorm (RE1 and RE4, respectively). During the winter rainstorms, Figs 2 and 3 show both dissolved and total nutrient concentrations generally correlated with discharge (Table 1). As demonstrated in Fig. 4, concentration of soluble nutrients such as ammonium did not correlate well with increased discharge during spring rainstorms; whereas, concentrations of total nutrients correlated well with discharge as shown in Fig. 5. The spring rainstorms had lower concentrations of nutrients at both US and DS compared to the winter rainstorms. In spring, the relatively lower nutrient concentrations and poorer correlation with discharge is attributed to increased plant activity in both the aquatic and riparian environments.

The slopes for the relations with normalized discharge at DS were larger than at US, especially during the winter rainstorm (Table 2). Correlation coefficients for nutrients also were consistently larger at DS during the winter rainstorm than at US; the coefficients at each station were lower for the spring rainstorm than the winter rainstorm. The average TKN concentrations at DS were similar to those at US during each storm (Table 3). Average TKN concentration estimated for the waters draining from Boxley Valley are approximately two times greater than the background concentrations. The total feces required to deliver the TKN from Boxley Valley and the required accumulation times are half that estimated from the FC data. These differences suggest:

(a) a good survival and transport rate for fecal coliform bacteria from field to stream;
(b) higher attenuation of the original organic nitrogen by soil adsorption;
(c) significant conversion from organic to inorganic forms of nitrogen with subsequent absorption by plant roots or volatilization of ammonia.

In winter, soil adsorption and volatilization are probably the dominant processes; whereas, in spring, plant absorption, soil adsorption, and ammonia volatilization would combine to attenuate nitrogen to a greater degree.

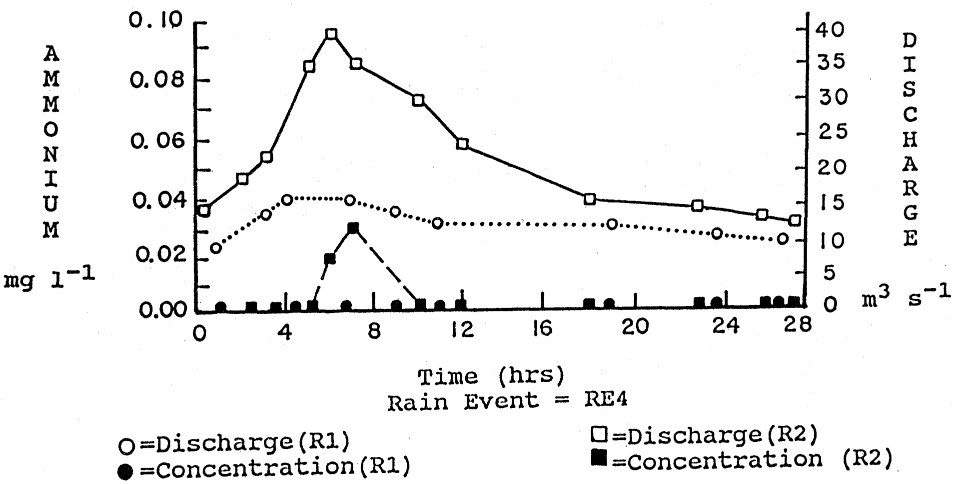

*FIG. 4 Behavior of ammonium and discharge during a spring rain event (RE4).*

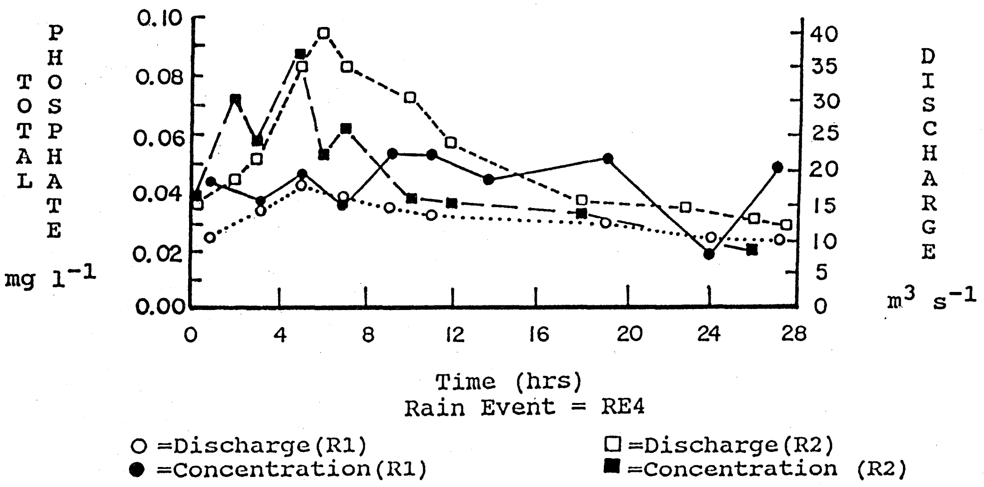

*FIG. 5 Behavior of total phosphate and discharge during a spring rain event (RE4).*

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