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THE PHOSPHORUS BUDGET OF T LITTLE BEAR RIVER-- HYRUM RESERVOIR WATERSHED

by

William A. Luce

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

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William A. Luce

TABLE OF CONTENTS

Page

Chapter

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

ABSTRACT

Phosphorus Budget of the Hyrum Reservoir - Little Bear River System

by

William A. Luce, Master of Science

Utah State University, 1974

Major Professor: Dr. Donald B. Porcella
Department: Civil and Environmental Engineering

Phosphorus concentrations in the water of the Hyrum Reservoir - Little Bear River Watershed were determined by collecting 12 samples every two weeks over a seven month period and analyzing them for dissolved orthophosphate, total dissolved phosphorus, and total unfiltered phosphorus.

The concentrations obtained were used in conjunction with a water budget to determine a phosphorus budget. Apparent major inputs of phosphorus to the reservoir included a trout farm and runoff from agricultural land in the watershed.

Statistical analyses of the data were made to determine what effect precipitation, streamflow, and mileage downstream had on the concentrations of phosphorus in the watershed.

(89 pages)

CHAPTER I

INTRODUCTION

Nature of the Problem

Eutrophication of surface waters is of great concern to anyone involved in the utilization of these waters, whether it be for aesthetic appreciation, domestic water supplies, agricultural purposes, or water contact sports. Nutrient enrichment, followed by dense algal blooms, adversely affects bodies of water, both aesthetically and functionally. Nutrient enrichment is presently of concern at Hyrum Reservoir (Murray, 1972), a small multipurpose reservoir in northern Utah.

Phosphorus may be the limiting nutrient in this reservoir. Therefore, a determination of the major source or sources, and an evaluation of the sources of phosphorus entering the reservoir may provide a basis for action to retard the nutrient enrichment process.

Objectives

The purpose of the study was to determine the major sources of phosphorus to Hyrum Reservoir with the following specific objectives:

1. A water budget would be determined over the period of study.
2. The water comprising the water budget would be chemically analyzed for concentrations of dissolved orthophosphate, total dissolved phosphorus, and total phosphorus.
3. A phosphorus budget over the period of study would be determined, and the principal sources and sinks of phosphorus within the Hyrum Reservoir Watershed would be identified.

CHAPTER II

LITERATURE REVIEW OF PHOSPHORUS BUDGETS

The retention of phosphorus in bodies of water caused by assimilation and mineralization of organic matter together with changes in circulation patterns may lead to an imbalance between photosynthetic and respiratory activity which may cause dense algal blooms and eutrophic conditions (Stumm and Leckie, 1970). Studying a phosphorus budget showing the various sources and sinks may allow definition of the events leading to such an imbalance.

Sources of Phosphorus

Rural runoff

Phosphorus can be contributed to a watershed largely by rural runoff, as shown by Sprenger (1965) who estimated that 60 to 65 percent of the phosphorus produced in the area he observed, was a result of this particular source. Among the various categories of rural runoff which may contribute phosphorus to a water system are runoff from feedlots, runoff from cultivated land, and runoff from frozen land onto which manure has been applied.

Although usually not contributing a large volume of water, runoff from feedlots may contribute substantially to localized high phosphorus concentrations. Scalf et al. (1971) reported runoff from feedlots contained concentrations of organic matter and nutrients one order of magnitude higher than raw municipal wastewater (about 100 $mg \cdot l^{-1}$ of total phosphorus). Murray (1972), in an investigation of feedlot runoff at Hyrum Reservoir, has reported total dissolved phosphorus concentrations as high as 350 $\mu g \cdot l^{-1}$, and dissolved orthophosphate concentrations as high as 170 $\mu g \cdot l^{-1}$. The difference in the values for the two authors is probably due to different types of feedlots. The water which Murray sampled was springwater which continually ran through a feedlot with good dilution, while it appears that the area Scalf et al. observed was a more densely populated feedlot with little dilution of the waste. Meyers et al. (1972), on a study of Summit Creek in northern Utah found significant increases in orthophosphate concentrations below two small livestock feedlots.

Timmons and Holt (1970), while studying runoff from cultivated lands, investigated leaching of nutrients from crop residues in runoff to surface waters, and concluded that the leaching of alfalfa and bluegrass by surface water runoff could contribute substantial amounts of nitrogen and phosphorus to lakes and streams. Also, these investigators observed that freezing and thawing followed by drying resulted in destruction of cell walls and the increasing of leaching effectiveness. Runoff from a cultivated 1.45 acre (0.59 ha) field containing winter wheat was found by Weibel et al. (1964) to contain 1.7 $mg \cdot l^{-1}$ total hydrolyzable phosphorus. Other studies showed phosphorus contributed to the ecosystem in the amount of 0.35-0.39 pounds per acre drained per year (0.39-0.44 $kg \cdot yr.^{-1} \cdot ha^{-1}$) (Mackenthun, 1968).

Irrigation return flow may also contribute phosphorus to streams. This usually occurs when an excess of fertilizer is applied or when plant debris is added to the water. Surface irrigation return flows in the Yakima River Basin contributed from 0.09 to 0.39 pounds of phosphorus per acre per year (.10 to .44 $kg\cdot yr\cdot^{-1}\cdot ha$) (Mackenthun, 1968).

Many investigators feel manured fields can be a major contributor of phosphorus in rural areas where manure is spread on frozen lands and relatively large losses of nutrients may occur with spring runoff. Minshall et al. (1970) reported as high as 13 percent of the phosphorus added by the application of manure may be lost to runoff. Another report estimated that each cow in the watershed produced 15 tons (13,608 kg) of manure per year, and of the portion spread on the fields during the winter, approximately 1 pound in 10 was lost to runoff (Lee, 1966).

Precipitation

Although precipitation is usually not considered a major contributor of phosphorus to a water system, the concentrations present in any given volume of rainwater can be important. Sawyer (1947) reported concentrations of inorganic phosphorus in rainfall as high as 0.03 $mg\cdot l^{-1}$. Allen (1968) found inorganic phosphorus in rainfall in the amount of 0.2 to 2.0 $kg\cdot yr^{-1}\cdot ha^{-1}$, which would amount to approximately 0.08 to 0.8 $kg\cdot yr^{-1}\cdot acre^{-1}$. Reimold and Aiber (1967) reported higher concentrations of phosphorus in the rainwater during the summer, which they concluded was most likely due to increased agricultural activity.

Industries

The only industry present in the Hyrum Reservoir Watershed, other than agriculture, is the raising and packing of fish at White's Trout Farm located in Paradise, Utah. Little detailed research has been done on trout farm discharges. Liao (1970) has suggested three major groupings of pollutants from such establishments; 1) Fish fecal wastes and residual foods, 2) chemicals and drugs, and 3) pathogenic bacteria and parasites. Fish fecal wastes and residual foods were noted as being the major problem at the installation observed. Hinshaw (1972) investigated White's Trout Farm and found concentration increases for settleable, suspended, and total dissolved solids, turbidity, nitrites, ammonia, BOD, MPN coliform, and carbon dioxide while dissolved oxygen and pH were reduced as the Little Bear River water flowed through the hatchery. No mention was made of the effect on phosphorus levels.

Wildlife and livestock

Howmiller (1969) studied bird droppings at Arcturus Lake which supported a bird population consisting mainly of boobies and frigates. Bird droppings were reportedly the only source of nutrients to the lake and phosphorus concentrations as high as 1.38 $mg \cdot l^{-1}$ were observed in the water. Mackenthun (1968) listed wild ducks as a source of phosphorus contributing as much as 0.45 pounds phosphorus per duck per year (.20 kg phosphorus per duck per year).

Also to be considered are cattle that are allowed to graze on the shores of streams and lakes. This may be especially critical at reservoirs such as Hyrum, where the waste material becomes submerged as the water level rises in the spring and early summer.

Plant life

Although sometimes neglected, this source of nutrients has been shown to be of considerable importance in some nutrient budgets (Putman, 1966; and Wentz and Lee, 1969). Leaf litter has been studied and was shown to add as much as 200 pounds of phosphorus per acre per year (224 kg phosphorus$\cdot$yr$^{-1}\cdot$ha^{-1}) to the drainage area of the River Thames (Mathews and Kowalczewski, 1969). Another report lists tree leaves as supplying as much as 3.3 pounds phosphorus per acre of trees per year (3.7 kg$\cdot$yr$^{-1}\cdot$ha^{-1}) (Mackenthun, 1968). The difference may have been due to the density or type of trees present or the type of drainage area. Putman (1966) found that decaying spermatophytes using the bottom muds as a source of phosphorus, may supply enough nutrients to cause sudden algal blooms. Eelgrass was found by McRoy and Barsdate (1970) to act as a means of transferring phosphorus from the muds to the water column. This was thought to be partly due to the size of its leaves, which were 2 to 3 feet (0.61 to 0.91m) in length.

Bottom muds

If the bottom muds of lakes or reservoirs can act as a source of nutrients to the water column, it may take many years for a lake or reservoir to reach a state where the nutrient supply is exhausted. Frink (1967) found in a Connecticut lake, that the upper 1 cm. of sediments contained at least 10 times the annual input of phosphorus. Moreover, he submits that the reservoir of nutrients in the sediments should be capable of supporting plant growth for some time, even if all the input of nutrients to the lake could be eliminated. The upper cm. contained several times as much nitrogen and phosphorus as necessary to produce heavy algal blooms.

The amount of phosphorus available from the muds is present in varying amounts and the concentration varies with depth. A study using the radioisotope ^{32}P showed that phosphorus was released from the muds to a depth of 4cm. (Prokhorv, 1970). Skoch (1969) showed that the top 5cm. had a higher concentration than the deeper muds and also the concentration of phosphorus and iron in the deposits was considerably higher than that present in overlying waters. Johnson and Owen (1971) stated in their study that there was about 15 times more phosphorus in the upper 1 inch (2.54 cm.) of mud than the yearly input to the overlying body of water. Porcella et al. (1970), in their study of laboratory microcosms have submitted that all of the available phosphorus would eventually be removed from the depth of 15 cm. of sediment observed.

Schmalz (1971) stated that sediment analysis at Hyrum Reservoir revealed an average total phosphorus content of 755 $\mu g \cdot g^{-1}$, with organic phosphorus making up approximately 97 percent of total phosphorus. Hasler (1963) reported sediments from Lake Mendota, Wisconsin, having total phosphorus concentrations of 200 to 1200 $\mu g \cdot g^{-1}$. Porcella et al. (1970) have shown a range of from 50 to 305 $\mu g \cdot g^{-1}$ available phosphorus was present in the sediments of the five lakes they studied. Wentz and Lee (1969) found total phosphorus concentrations of approximately 1000 $\mu g \cdot g^{-1}$ in dry bottom sediments from Lake Mendota.

Although phosphorus may be available in abundance in the sediments, the availability of it to overlying waters is based on complex physical, biological, and chemical factors (Porcella et al., 1970). The following physical factors have been demonstrated to affect the rate of phosphorus transfer between the sediments and overlying waters; sedimentation, diffusion, depth of water, mixing due to wind currents, seiche currents, benthic algae, and benthic and aquatic organisms. Biological factors include the metabolic activity of bacteria and other benthic organisms in the sediment and on the sediment surfaces, and the activity of plants and algae. Chemical factors include pH, composition and origin of sediments, sorption, oxidation-reduction, and precipitation-solubilization. Discussion of examples of these factors will not be given here as these topics were adequately covered in a previous report by Schmalz concerning the sediments of Hyrum Reservoir (1971).

There are in many cases, then, adequate reserves of phosphorus in the sediments to support algal blooms and also many methods of sediment-water nutrient interchange. However, not much study has been done as to the rate at which this interchange takes place. Porcella et al. (1970) have suggested that the rate of phosphorus removal from the sediments was affected by productivity, the development of a thick mat of Oscillatoria on the sediments, and the presence of organic matter. Also, phosphorus transfer from the sediments could occur on the order of days. Furthermore, anaerobic conditions with resulting lowering of redox potential and pH could lead to the release of phosphorus. Stumm and Leckie (1970) studied the rate of transport from various sediments to overlying water and reported the rate determining step as the diffusional transport through the interstitial water. They estimated a maximum diffusional rate of 0.27 $mg \cdot m^{-2} \cdot day^{-1}$. They also stated that bacterial activity, by affecting the concentration gradient, may accelerate the rate.

Other sources

Another factor, depending on the location, is the amount of phosphorus present in the surrounding geological formations (Mackenthun, 1968), along with the release of dissolved organic phosphorus compounds into solution by zooplankton and lysing organisms. In addition, Watt and Hayes (1963) noted that dissolved organic compounds were absorbed by bacteria, and inorganic phosphorus was released.

Sinks for Phosphorus

Bottom muds

As stated previously, the benthic sediments may contain a great reserve of phosphorus. This is primarily present as inorganic precipitates and minerals attached to the surfaces of other minerals, in solution in the interstitial water, and as organic phosphorus (Porcella et al., 1970). Wentz and Lee (1969) mention six ways phosphorus may be deposited in the muds; 1) Sedimentation in combination with autochthonous organic matter, 2) erosion of phosphorus-containing minerals from the watershed and deposition in unaltered form, 3) co-precipitation with iron and manganese, 4) sedimentation in combination with allochthonous organic matter, 5) sorption, and 6) association with carbonates. Evidence of such deposition was given by Waldichuk (1969) who stated that in the estuary he studied, the algae, after incorporating nutrients into their cells, died and, due to the lack of flushing action in the body of water, settled to the bottom, thereby creating a sink. Golterman (1967) found that anaerobic muds can absorb large quantities of phosphorus, probably as $Fe_3(PO_4)_2$. Ahlgren (1967) found that only 50 percent of the phosphorus passed from Lake Norrviken during his study, and he concluded that precipitation of phosphorus was occurring. Shapiro (1970) maintains that sediments do not act as a source but only as a sink. He states that lake sediments are formed from the remains of phytoplankton and zooplankton, and he proposes that the very fact that sediment phosphorus exists indicates that sediments act as a sink.

The factors that regulate whether and to what extent the muds act as a sink are generally the same, although opposite in sign, as those factors determining the importance of muds as a source of phosphorus.

Biota

Much of the phosphorus in reservoirs is removed by phytoplankton, and the higher aquatic plants, and zooplankton. Some of this is returned to the water or sediments either as dissolved or particulate, organic, or inorganic phosphorus.

Lawrence (1968) measured the amount of phosphorus in *Aphanizomenon flos aquae* and found it to be 1.17 percent phosphorus as dry weight of algae. Kuentzel (1969) stated that roughly 10 $\mu g \cdot l^{-1}$ of phosphorus were needed per gram of algae. Borchardt and Azad (1968) found that algae could store large quantities of phosphorus and use it for growth at later times when the available concentration was low. At phosphorus concentrations above 1.5 $mg \cdot l^{-1}$ certain algae could take up amounts not needed for immediate growth, a process known as luxury uptake. Porcella et al. (1970) stated that algae can be considered a sink which continually forces phosphorus from the sediments maintaining an equilibrium between the water and sediments.

Fish and other consumer organisms also enter into the phosphorus cycle by ingesting phytoplankton and bacteria. Lawrence (1968) studied nutrients in an Alabama lake and reported that the average phosphorus content of bluegills and sunfish was 24,846 ppm and 53,238 ppm respectively, where 1 ppm = 1 $\mu g \cdot g^{-1}$ dry weight of fish.

Minor sinks

There are other lesser sinks that are either difficult to evaluate or are small in magnitude. Brezonik (1969) listed insect emergence as a sink, and evaporation, in the form of aerosol formation from surface foam, also accounted for a loss of phosphorus.

CHAPTER III

METHODS AND MATERIALS

Sampling Methodology

Sample designation and location

The sampling stations (Table 1, Figures 1 and 2) were selected with the purpose of being able to identify various sources of pollution. Among the apparent major sources were rural runoff, White's Trout Farm, and Hyrum City Dump. Rural runoff in the Little Bear River Watershed consists mainly of irrigation return flow, runoff from feedlots, runoff from cultivated land, and spring runoff from fields onto which manure has been spread during winter. White's Trout Farm, the main industry adjacent to the river, diverts a significant portion of the Little Bear River flow. Hyrum City Dump is located on the western end of the reservoir (Figure 2) and any runoff from the dump flows into the reservoir near Station No. 1. The reservoir stations lettered 0-a, b, and c, were located to obtain a representative composite sample of the reservoir.

Sampling timing and period

All stations except for 5 and 11 were sampled at approximately two-week intervals from April 6, 1971 through November 4, 1971. Stations 5 and 11 were chosen later in the study as the need arose for more detail. The total period of study (April-November) accounted for the spring runoff, summer growth period, and the reservoir turnover in the fall.

Table 1. Sampling stations in Little Bear - Hyrum Reservoir Watershed.

Station No.	Figure No.	Location or Description of Station
0	2	Hyrum Reservoir (composite)
1	2	Hyrum Reservoir in cove below Hyrum City Dump
2	2	Little Bear River just above Hyrum Reservoir
3	1	Little Bear River adjacent to bridge on Mt. Pisgah Road west of Paradise (includes partial input from White's Trout Farm)
4	1	Canal adjacent to culvert on Mt. Pisgah Road (measures main effluent from White's Trout Farm not including irrigation return flow)
5	1	Little Bear River at White's Trout Farm Diversion
6	1	Little Bear River (south fork) below Davenport Creek at USGS gaging station 10-1047
7	1	Little Bear River (east fork) adjacent to bridge at intersection south of Avon
8	1	Little Bear River (east fork) at Porcupine Dam discharge
9	1	Groundwater source on La Plata Road adjacent to Little Bear River (east fork)
10	1	Groundwater source running through feedlot on La Plata Road
11	1	Little Bear River adjacent to bridge northwest of Avon

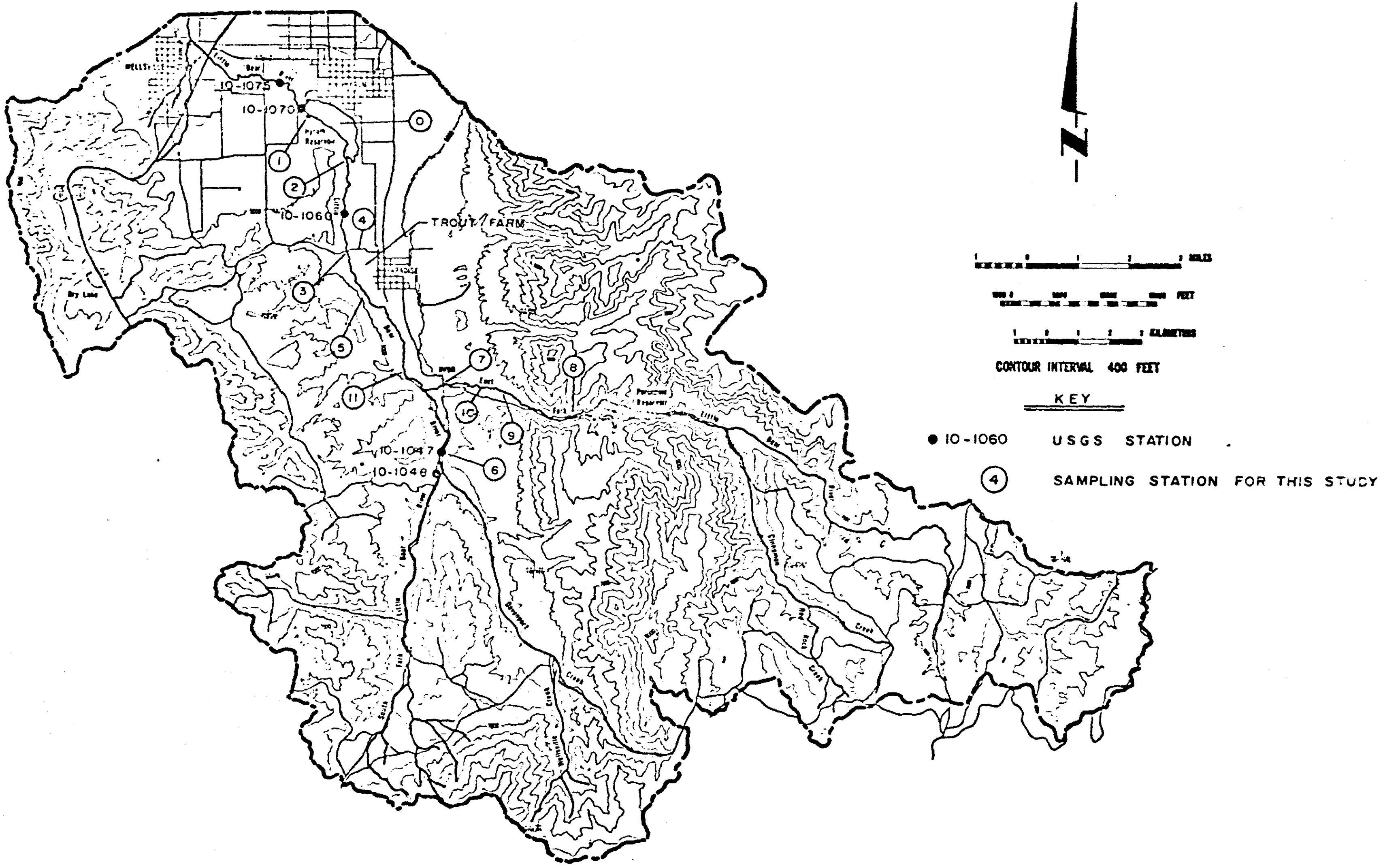
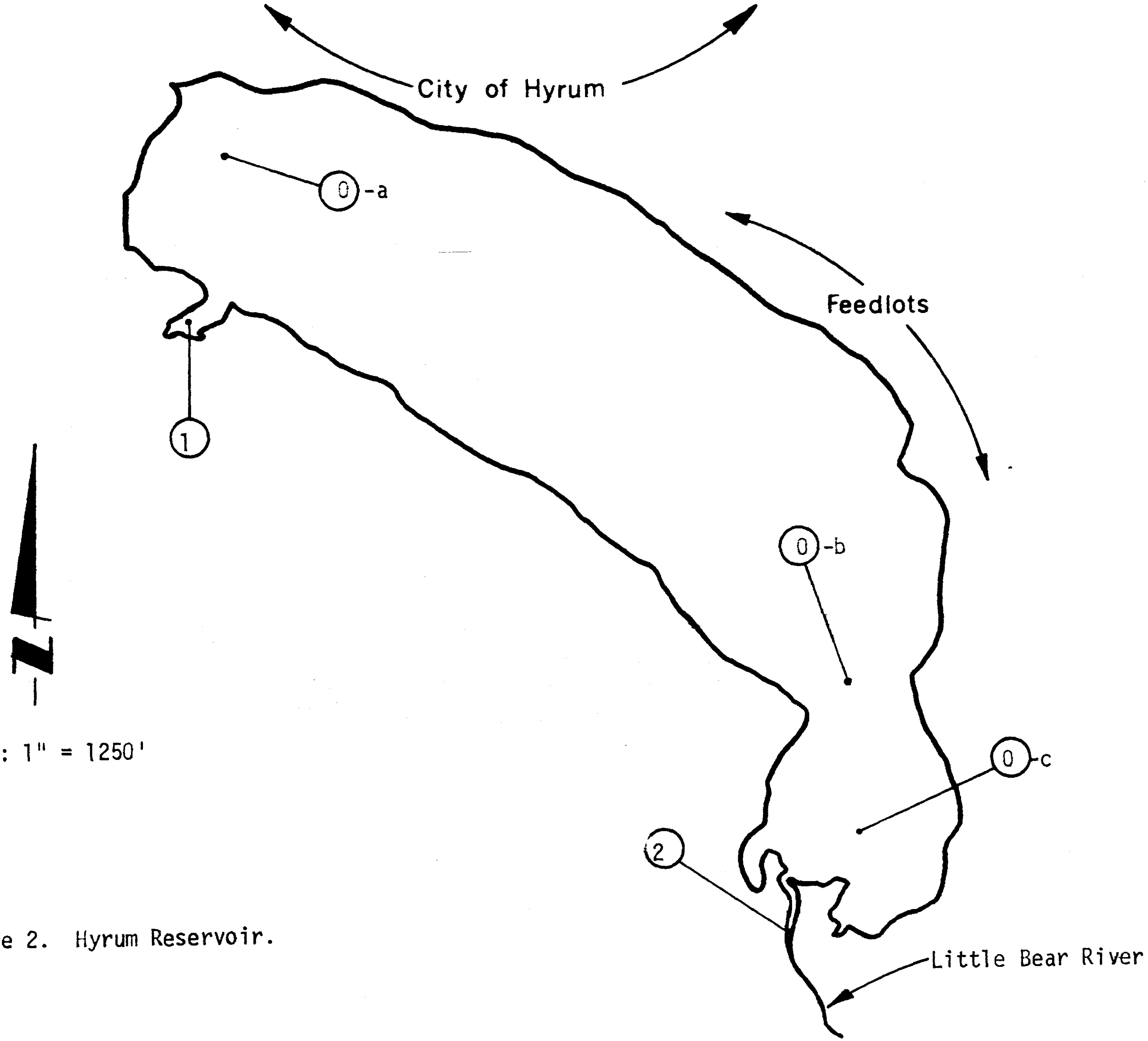


Figure 1. Little Bear River Watershed.



Scale: 1" = 1250'

Figure 2. Hyrum Reservoir.

Sampling procedure

Stream samples were as representative as possible of the major portion of streamflow, and were taken as grab samples and stored in polyethylene containers. The temperature of the samples was measured at the time of sampling with a mercury bulb thermometer. The samples in the reservoir were obtained with a 2-liter Kemmerer Water Bottle at the three different sampling points (0-a, b, and c), from the surface to the bottom at approximately 3-meter intervals, and composited to form a single sample. The temperature of each individual sample was measured with a mercury bulb thermometer upon being brought to the surface. All samples were transported to the lab and stored unfiltered at four degrees centigrade in polyethylene containers until analysis was performed. Typical storage time was not longer than 24 hours except for the first two sets obtained which were frozen and then stored a maximum period of one month prior to analysis.

Water Budget for Hyrum Reservoir

The water budget was determined by using data available from the United States Geological Survey, Utah State Engineer's Office, and the United States Weather Bureau. Further details combined with the results are shown in Chapter IV of this report.

Phosphorus Budget for Hyrum Reservoir

The phosphorus budget was determined by combining the water budget with the results of the chemical analyses performed on samples taken at the various stations during the period of study. Further details combined with the results are shown in Chapter IV of this report.

Chemical Analyses

The chemical analysis to determine phosphorus concentration were performed using both total samples and filtrates passing a membrane filter (Type HA, 0.45 μ MF). The ascorbic acid method (FWPCA, 1969) was used for analysis of orthophosphate. Total and organic fractions were converted to orthophosphate by persulfate-acid digestion (FWPCA, 1969). The so-called dissolved organic fraction is the difference between the total dissolved portion and the dissolved orthophosphate. (The acid hydrolyzable fraction was assumed to be negligible since there were no municipal wastewater discharges to the watershed.) Particulate phosphorus is the difference between total phosphorus and total dissolved phosphorus.

Measurements to determine optical density were performed using a Beckman Model B spectrophotometer. The 5cm. cells used were capable of measuring phosphorus concentrations over a range of 0 $\mu g \cdot l^{-1}$ to approximately 300 $\mu g \cdot l^{-1}$.

Statistical Calculations

The data obtained from the various sources were analyzed using both analysis of variance and analysis of correlation (Dixon and Massey, 1969).

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

Water Budget for Hyrum Reservoir

Water budget components

The equation used to determine the water budget during the period of study is shown below:

$$\Delta S = I_r + I_{pr} + I_{ro} - 0_e - 0_{inf} - 0_c - 0_r \quad . \; . \; . \; . \; . \; . \; . \; . \qquad (1)$$

where

$$\Delta S = \text{change in storage}$$

$$\text{Input} \begin{cases} I_r & = \text{input from Little Bear River} \\ I_{pr} & = \text{input from precipitation} \\ I_{ro} & = \text{input from runoff} \end{cases}$$

$$\text{Output} \begin{cases} 0_e & = \text{output due to evaporation} \\ 0_{inf} & = \text{output due to infiltration} \\ 0_c & = \text{output to irrigation canals} \\ 0_r & = \text{output to Little Bear River} \end{cases}$$

Climatological factors

The evaporation, precipitation, and air temperature data which were incorporated into the budget during the period of study were obtained for the United States Weather Bureau Logan 5SW Station which is located approximately 4 miles north of Hyrum Reservoir. The data obtained are shown in Tables 20, 21, and 22 (Appendix) and Figure 3. To show the validity of the data obtained with respect to the area

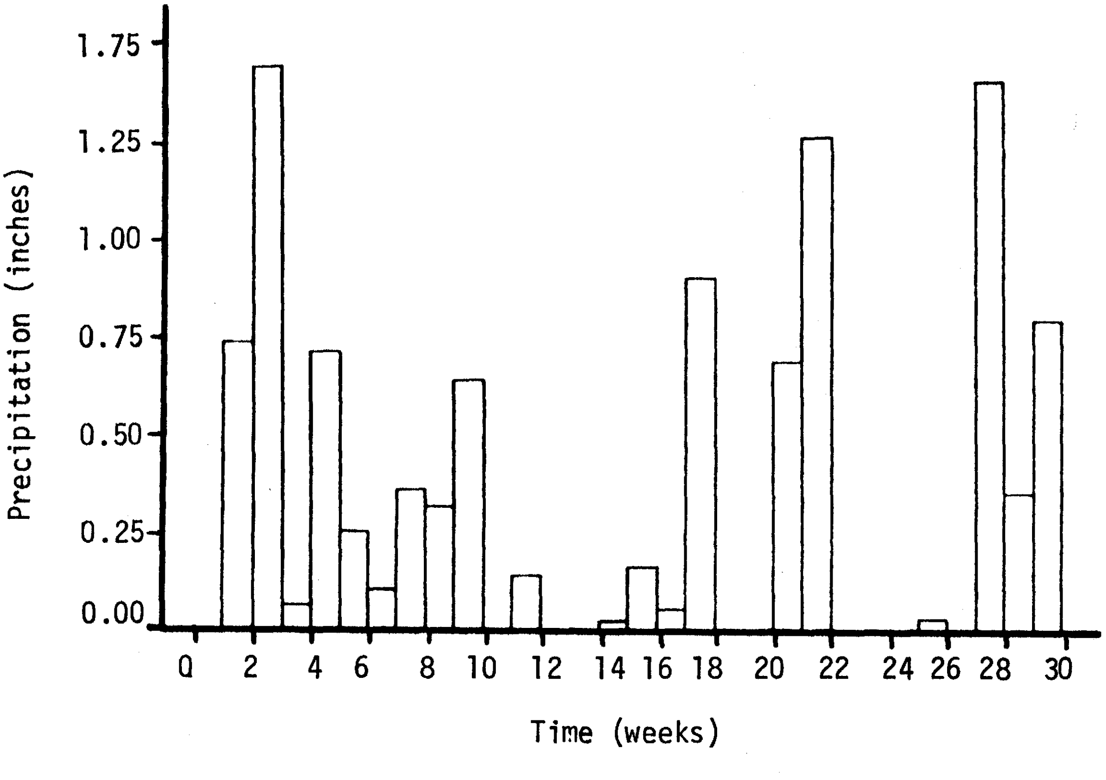


Figure 3. Precipitation at the Logan 5SW station. (April-November, 1971.) Note: Precipitation summations started one week prior to phosphorus sampling.

studied, reference is made to a study by Dixon et al. (1970) which showed little difference between data obtained at the Logan USU weather station located on the campus of Utah State University and that data obtained within the study area. It was therefore felt since the Logan 5SW Station was closer to the reservoir and at a more representative elevation than was the Logan USU station, that even more valid data could be obtained at the Logan 5SW Station.

To calculate evaporation from the surface area of Hyrum Reservoir it was necessary to determine reservoir water surface elevation information. This was obtained for USGS Station 10-1070 (Table 18, Appendix) and were used in conjunction with the graph shown as Figure 4 (USDI, 1926) to obtain the change in storage and surface area. Surface area data, pan evaporation data (Table 20, Appendix), and a pan evaporation coefficient of 0.715 (USDC, 1971) were used to obtain the reservoir evaporation data shown in Table 2.

Streamflow

Daily streamflow data for the Little Bear River at Paradise, USGS Station 10-1060 (Figure 5), and the south fork of the Little Bear River, USGS Station 10-1047 (Figure 6) are shown in Tables 16 and 17 (Appendix). USGS Station 10-1060 is located between sampling stations 2 and 3 as designated for this study. Sampling Station 6 as designated for this study was located at USGS Station 10-1047. No flow data were collected for the east fork of the Little Bear River below Porcupine Reservoir. Therefore, to obtain an approximate value for statistical analysis with phosphorus data, the difference in the flows between USGS Stations 10-1060 and 10-1047 was used.

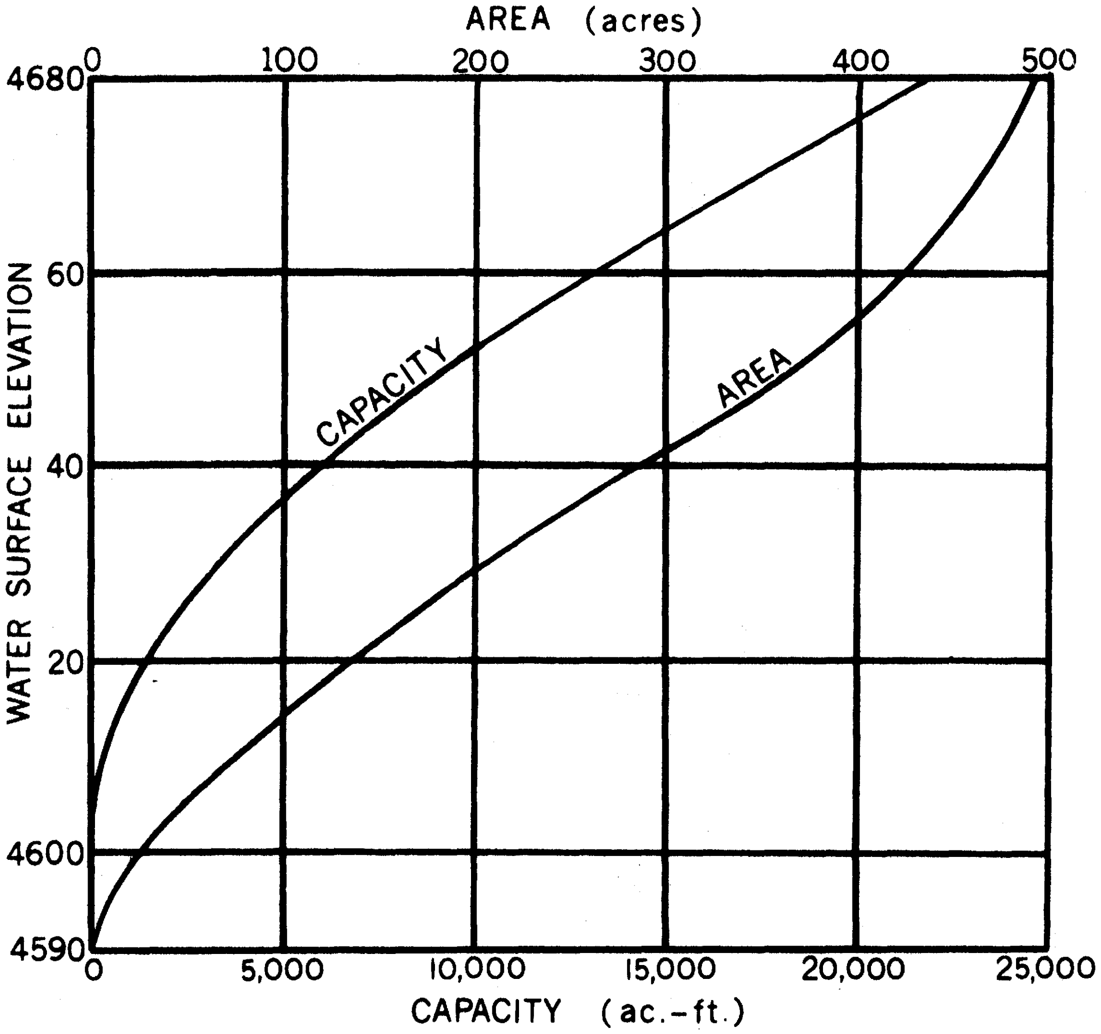


Figure 4. Capacity and area curves for Hyrum Reservoir (USDI, 1926).

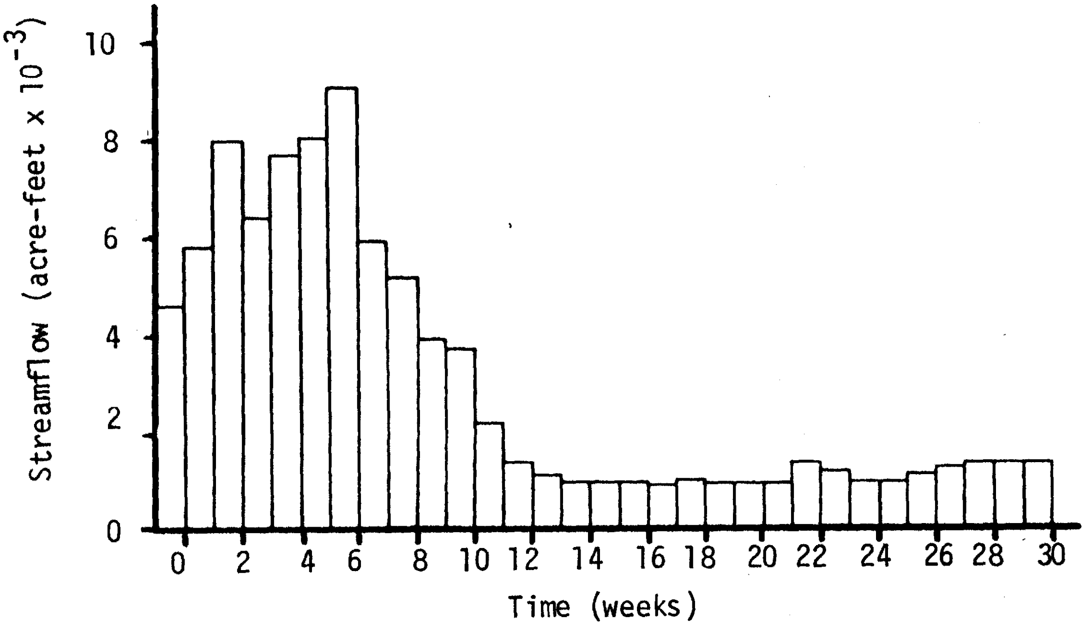


Figure 5. Streamflow for USGS Station 10-1060. (April-November, 1971.) Note: Streamflow summations started one week prior to phosphorus sampling.

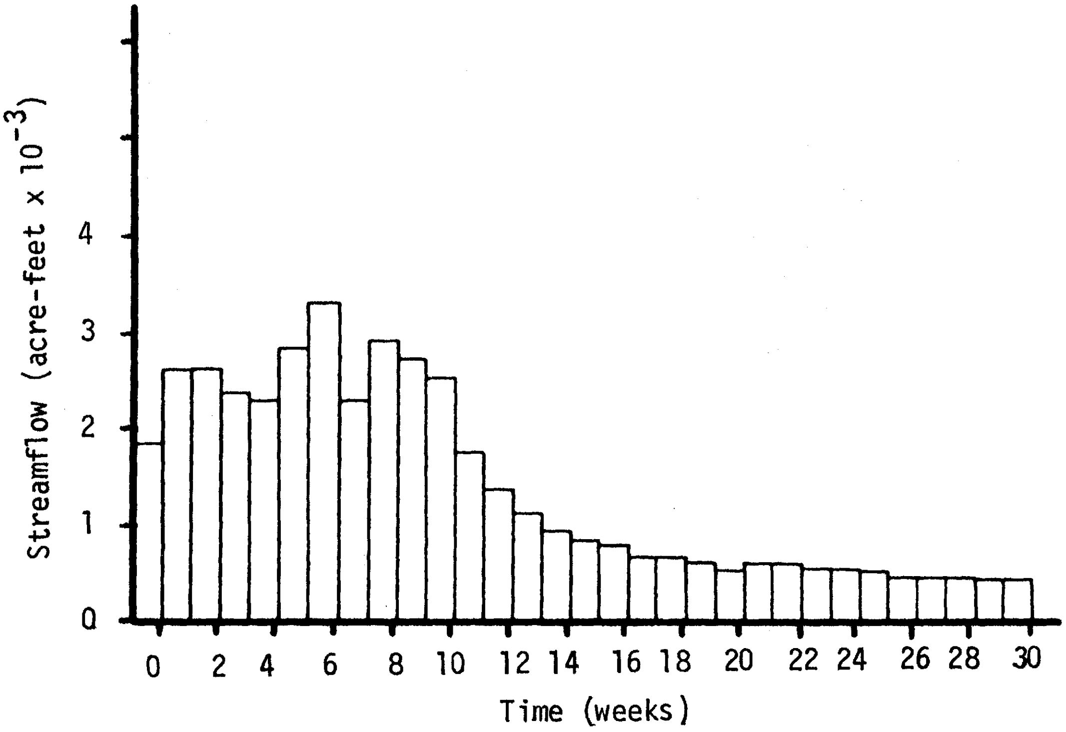


Figure 6. Streamflow for USGS Station 10-1047. (April-November, 1971.) Note: Streamflow summations started one week prior to phosphorus sampling.

Daily flow data were obtained for USGS Station 10-1075 (Table 19, Appendix) which records water leaving Hyrum Reservoir by way of the Little Bear River. Daily flow data for the five irrigation canals originating in Hyrum Reservoir were obtained from the Utah State Engineer's Office.

Runoff flows

Runoff data include only that portion of the flow added to the Little Bear River below USGS Station 10-1060. All other surface runoff from the watershed, which has an area of approximately 200 square miles, entered the Little Bear River upstream from the gaging station (Thomas et al., 1971). The runoff area below station 10-1060 is approximately 8 square miles or approximately 4 percent of the total watershed area. Runoff factors utilized for this small area were as follows; 0.30 for the month of April and 0.10 for the remaining months of the study (Lee, 1966).

The only flows not included in the budget were those originating in springs on the banks of the reservoir. Personal observation has shown these to be about $(10)^{-2}$ cfs, or approximately 2 $(10)^{-2}$ acre-feet per day. This figure amounts to approximately 4.48 acre-feet for the total study period. While insignificant in relation to the water budget, this source was noteworthy in the phosphorus budget.

Water budget results

The results of the water budget (Table 2) indicated a value for all components of the water budget equation with infiltration being the only unknown. Solving Equation (1) for infiltration (O_{inf}) gave a value of 406 acre-feet over the period of study. This figure together with an

Table 2. Water budget for Hyrum Reservoir during the period of study.

				Input				Output			
				Precipitation				Pan Evaporation			
Month	Mean Reservoir Surface Elevation (feet)	Surface Area (acres)	Storage (acre-feet)	(inches)	(acre-feet)	Runoff (acre-feet)	Little Bear River Influent (acre-feet)	(inches)	(acre-feet)	Little Bear River Effluent (acre-feet)	Canal Flow (acre-feet)
April	4664.5	442	11,800	2.25	83	288	25,630	4.55	120	25,100	0
May	4667.4	450		1.20	45	51	32,480	6.56	176	29,150	1021
June	4671.1	465		1.32	52	56	12,130	8.13	225	4,900	5153
July	4665.4	445		0.18	7	8	3,930	8.30	220	252	6954
Aug.	4660.4	425		1.64	58	71	3,800	8.87	225	262	5642
Sept.	4661.0	427		1.29	46	55	4,360	6.17	157	3,730	1080
Oct.	4661.9	430		2.54	91	147	5,550	2.68	69	5,070	0
Nov.	4661.9	430	10,650	0.00	0	0	1,599	0.00	0	1,775	0
Sub Totals				10.42	382	676	89,479	45.26	1,192	70,239	19,850
ΔS			- 1,150								
Totals			- 1,150				+90,537				-91,281

average water surface area of 445 acres and a total time period of 224 days resulted in an infiltration loss rate of 0.0040 feet per day. McGauhey et al. (1970) have shown an infiltration rate of 0.0332 feet per day for Indian Creek Reservoir from May 29, 1969 to July 29, 1969. The difference in the two values was probably a result of the age difference of the two bodies of water. Indian Creek Reservoir was a fairly new reservoir, having been completed in 1968, while Hyrum Reservoir was completed in 1936. Hyrum, being the older, had most likely accumulated much more sediment than had Indian Creek and by accumulating more sediment the bottom of Hyrum Reservoir would have become sealed to a greater degree.

Evaluation of Phosphorus Sources

Variation in phosphorus concentrations

Baseline stations. Stations 6 and 8 (Figures 7 and 8) showed much the same pattern for all three fractions over the period of study. The higher values for the particulate fraction at the beginning of the study were most likely due to spring runoff at Station 6. The high level of the particulate fraction at the beginning of the study for Station 8 may have also simply been due to spring runoff, as the reservoir volume was at a low level at this time and mean residence time would have been relatively short. Also the temperature profile at this time was fairly constant as shown for Hyrum Reservoir in Table 24 (Appendix). Cold, silt laden runoff could have formed a density current along the bottom and short-curcuited the reservoir, which would shorten the flow through time even more. It has also been shown by Drury (1974) that spring overturn in Hyrum Reservoir increased the concentration of total

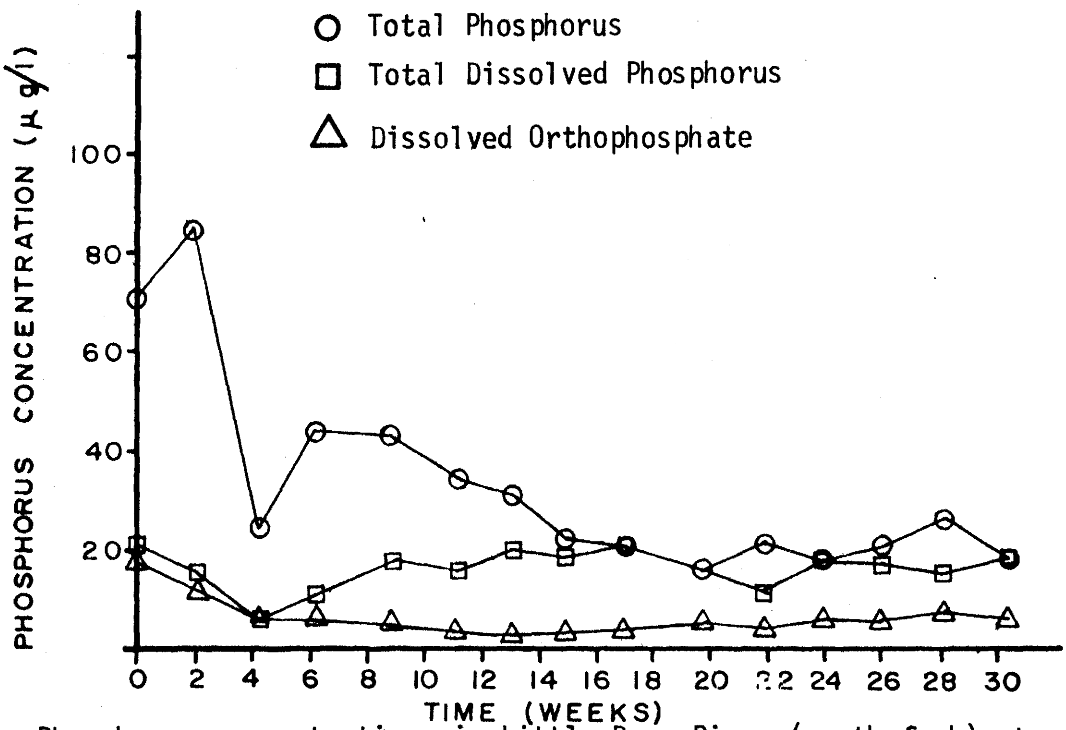


Figure 7. Phosphorus concentrations in Little Bear River (south fork) at USGS Gaging Station 10-1047 (Station 6). April-November, 1971.

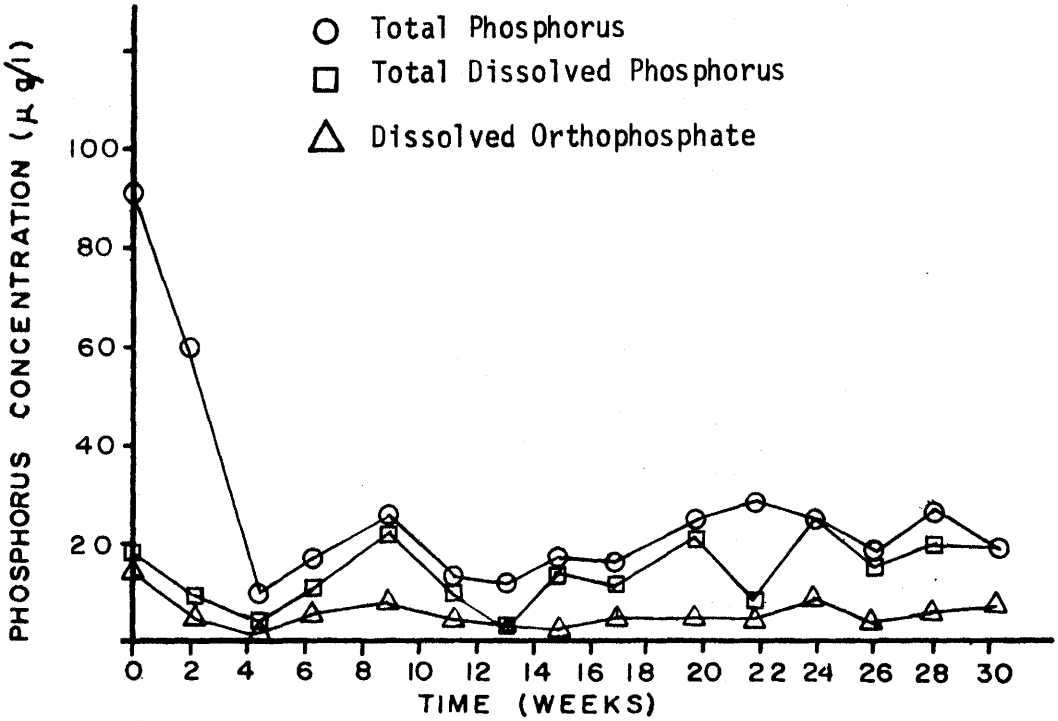


Figure 8. Phosphorus concentrations in Little Bear River (east fork) at discharge from Porcupine Reservoir (Station 8). April-November, 1971.

phosphorus in the water considerably. This may also have been the case at Porcupine Reservoir.

Stations below minor development. Phosphorus concentrations at Station 7 (Figure 9) showed much the same pattern as Station 8 which would be expected as there was little development between Stations 8 and 7.

Phosphorus at Station 9 as shown in Figure 10 was mostly in the dissolved form as would be expected for a groundwater source. Groundwater sources in this area may account for a significant portion of the phosphorus in the surface flow, depending, of course, on the quantity of groundwater involved.

Station 10 (Figure 11) was chosen to demonstrate what type of loads might be expected from typical barnyard and feedlot runoff. The quantities of flow were small but the concentrations of phosphorus were somewhat higher than that of the surrounding streamflows.

Station 11 (Figure 12) indicated a low level of phosphorus during the later months of the sampling period, much the same as Stations 6 and 7 which were above Station 11.

Stations associated with White's Trout Farm. Station 5 (Figure 13) showed a slight increase in total phosphorus over Station 11 which is upstream, but still the same relatively low concentrations were observed as for the upstream stations.

The phosphorus levels at Station 4 as shown in Figure 14 indicated that a large percentage of the phosphorus in the effluent from the trout farm was in the ortho form. It should be noted here also the difference between Station 5, which was the trout farm diversion, and

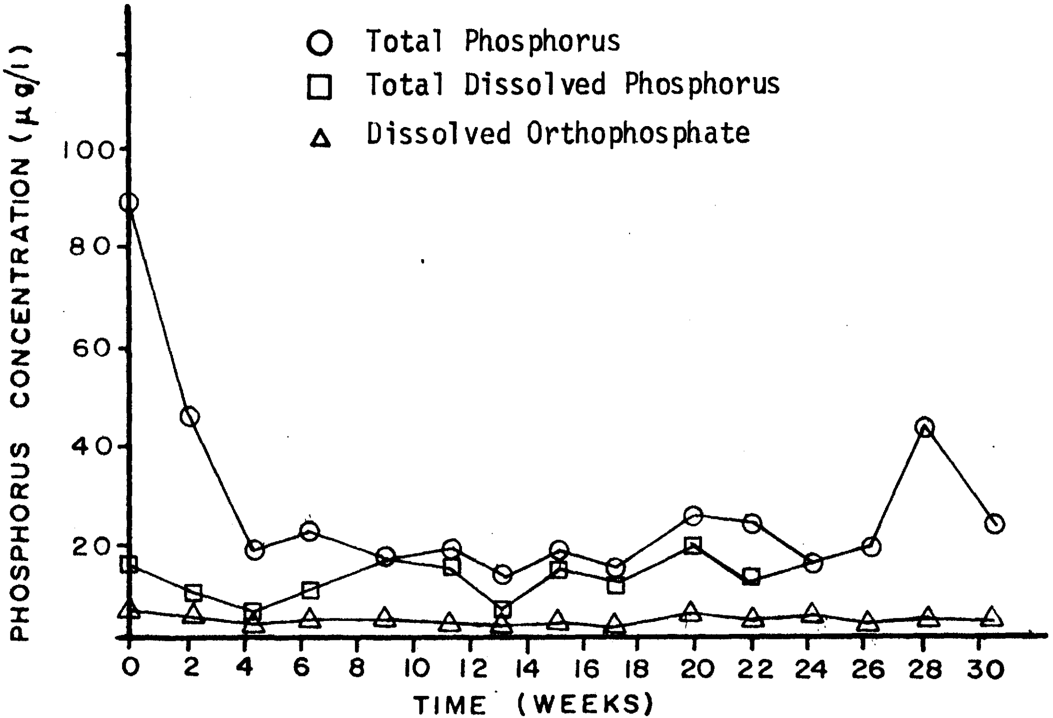


Figure 9. Phosphorus concentrations in Little Bear River (east fork) at Avon (Station 7). April-November, 1971.

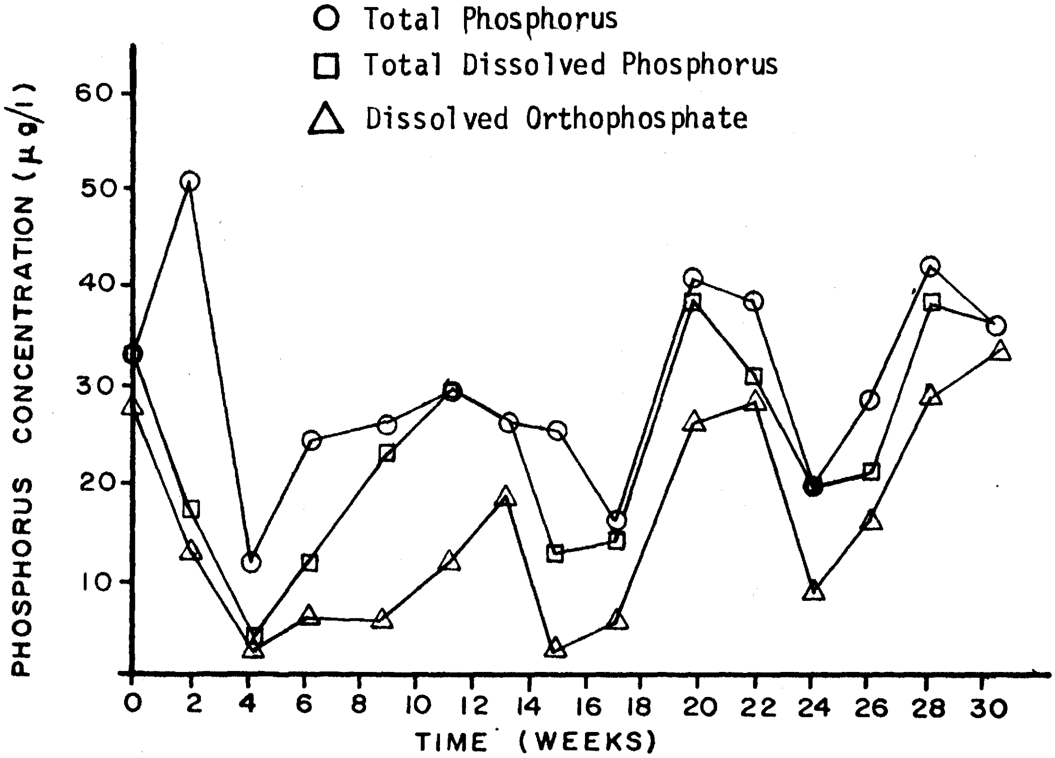


Figure 10. Phosphorus concentrations in groundwater source adjacent to Little Bear River (east fork) (Station 9). April-November, 1971.

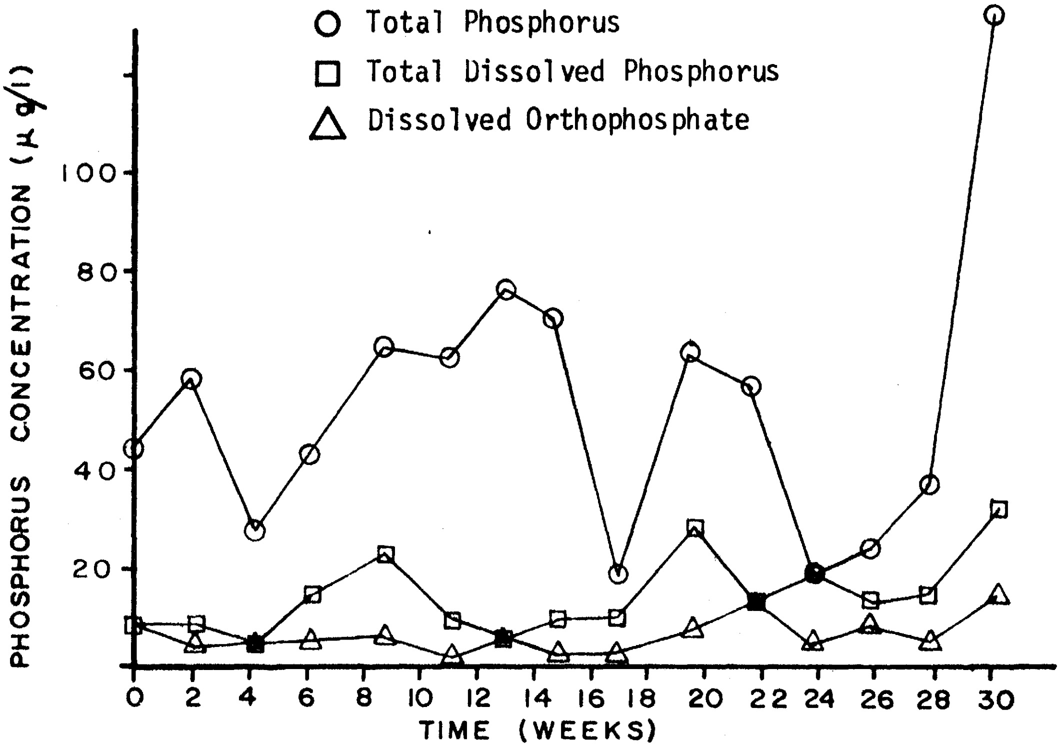


Figure 11. Phosphorus concentrations in feedlot runoff near Avon on Little Bear River (east fork) (Station 10). April-November, 1971.

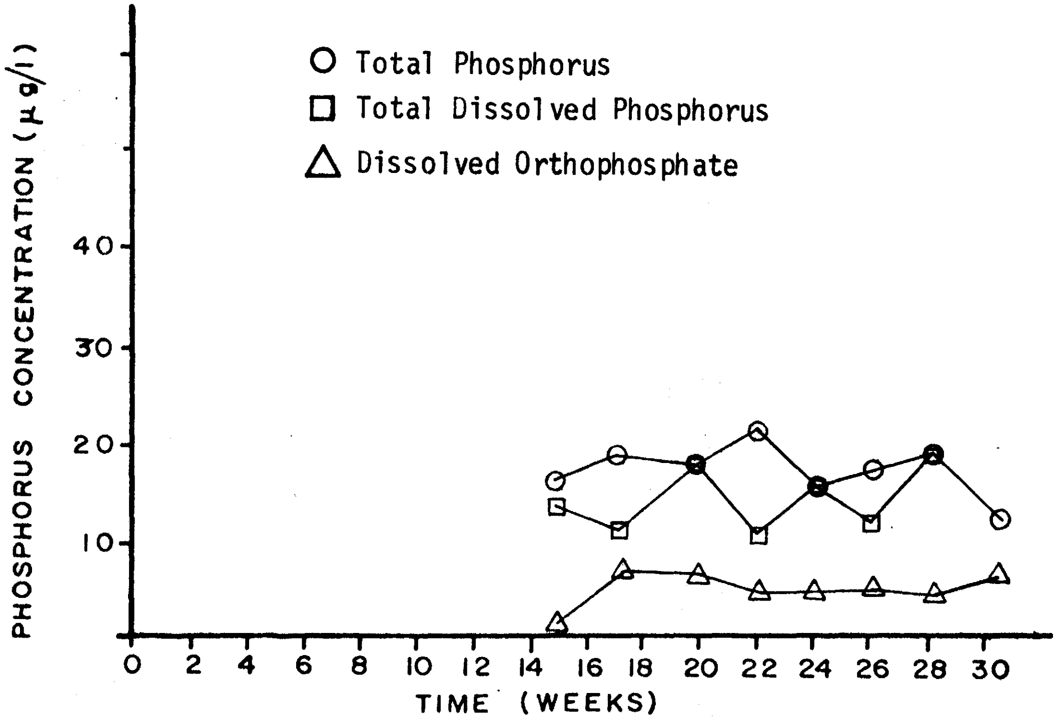


Figure 12. Phosphorus concentrations in Little Bear River northwest of Avon (Station 11). July-November, 1971.

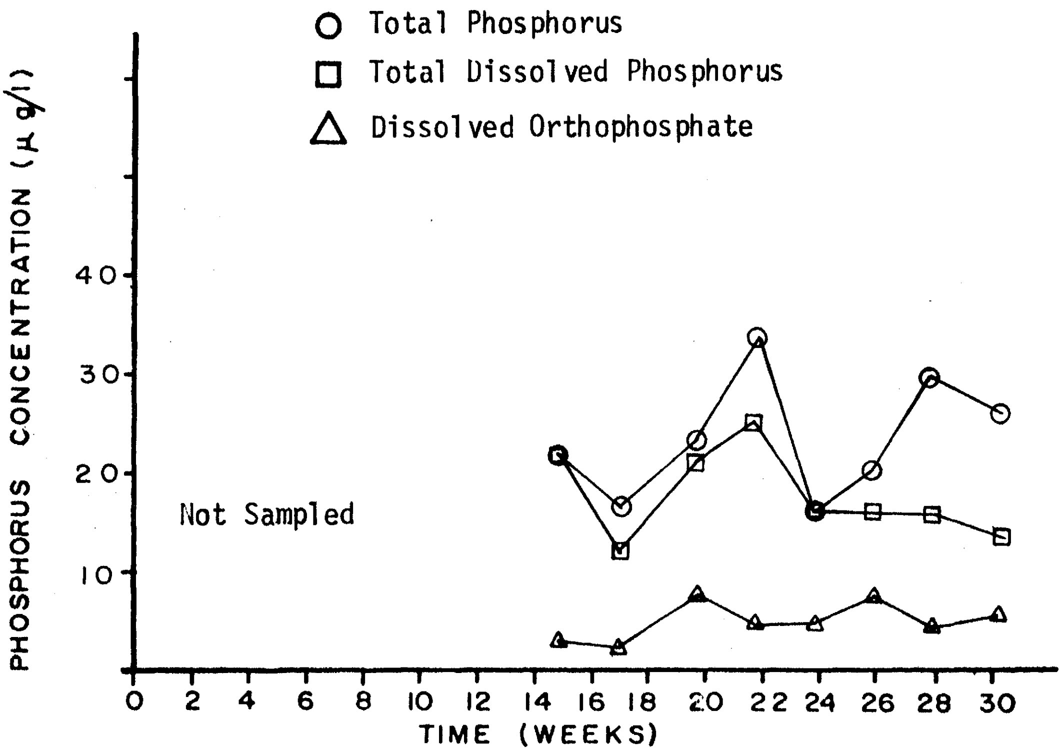


Figure 13. Phosphorus concentrations in Little Bear River at White's Trout Farm diversion (Station 5). July-November, 1971.

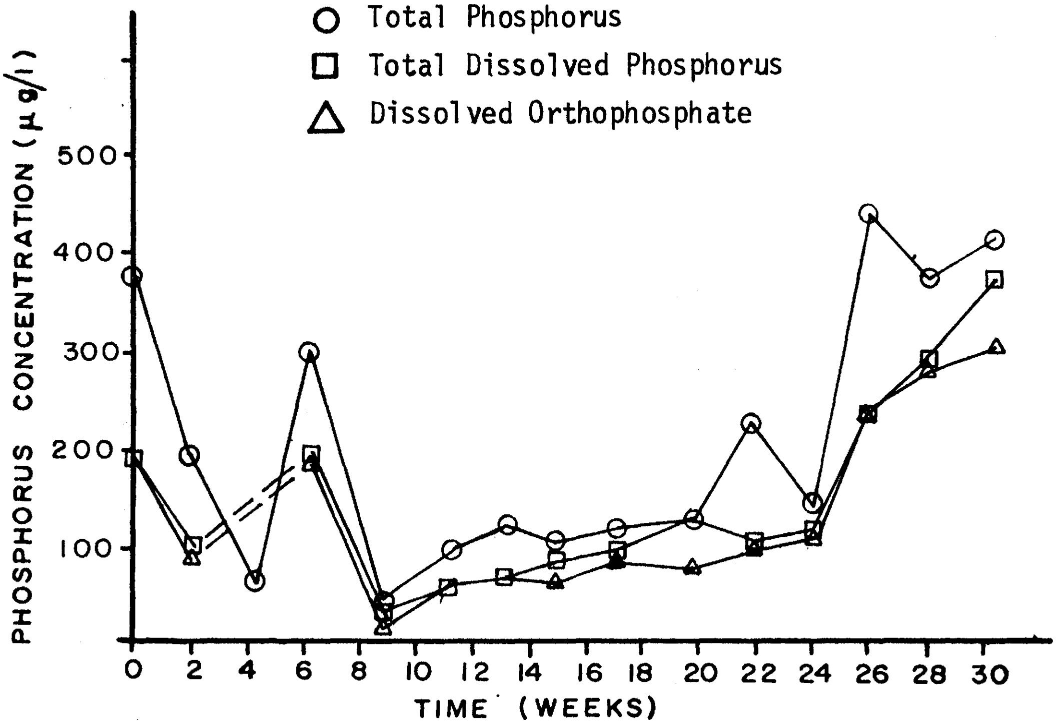


Figure 14. Phosphorus concentrations in White's Trout Farm effluent (Station 4). April-November, 1971.

Station 4, which was the trout farm effluent. The trout farm effluent for the period October 4 to the end of the study showed phosphorus concentrations of approximately 10 times that shown for the influent.

Figure 15 shows the effect of the trout farm discharge on the river and indicates a fairly consistent range of values over the entire sampling period. The closeness of the three fractions at the end of the study indicates again that a large portion of the phosphorus which came from the trout farm was in the ortho form. In the fall when the waters cool and the algae within the trout farm die, the phosphorus is released, which may in part account for the high percentage of the ortho form.

Stations associated with Hyrum Reservoir. Figure 16 indicates that the phosphorus input to Hyrum Reservoir by the Little Bear River (Station 2) during the spring months was mostly in the particulate form which is to be expected with spring runoff. It also shows the dissolved phosphorus input in the later months of the study was mostly in the ortho form as was the discharge from the trout farm. This was not true for the stations above the trout farm.

The phosphorus concentrations for Stations 0 and 1 were similar as might be expected because both stations were located within the reservoir (Figures 17 and 18). However, the higher values for Station 1 in the first portion of the study indicated an apparent input of phosphorus from garbage dump runoff coming from upstream of this station (see Figure 2). The relatively low levels during the middle of the sampling period were probably due to the settling out of the particulate fraction, which entered with the spring runoff. Both stations also showed an increase in all three fractions toward the end

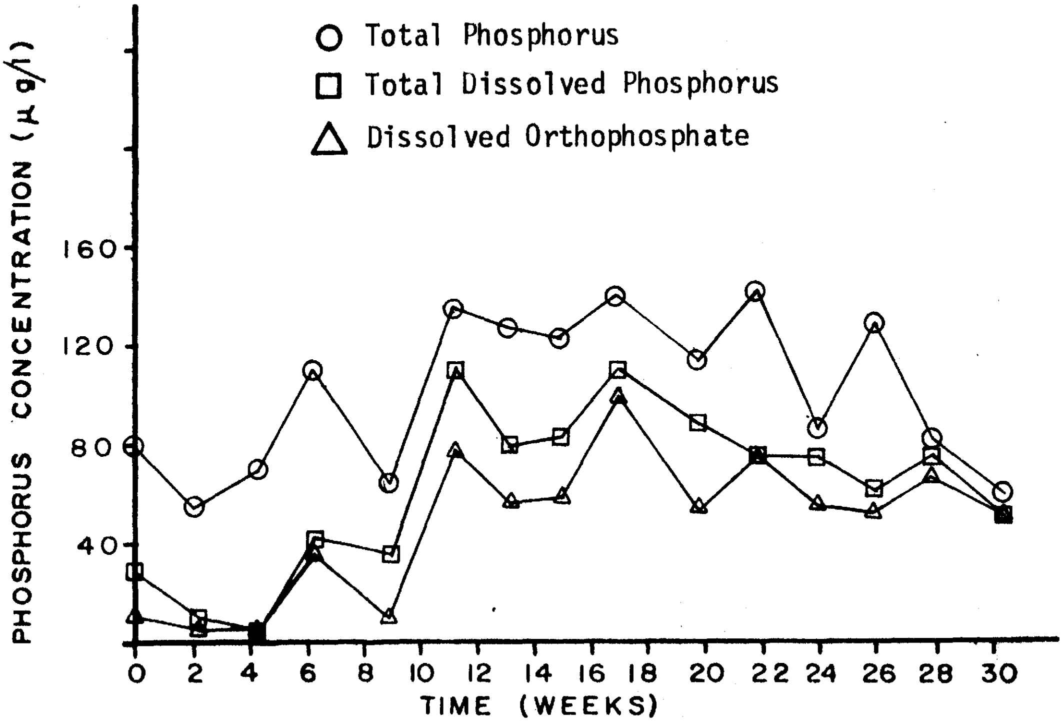


Figure 15. Phosphorus concentrations in Little Bear River below White's Trout Farm effluent (Station 3). April-November, 1971.

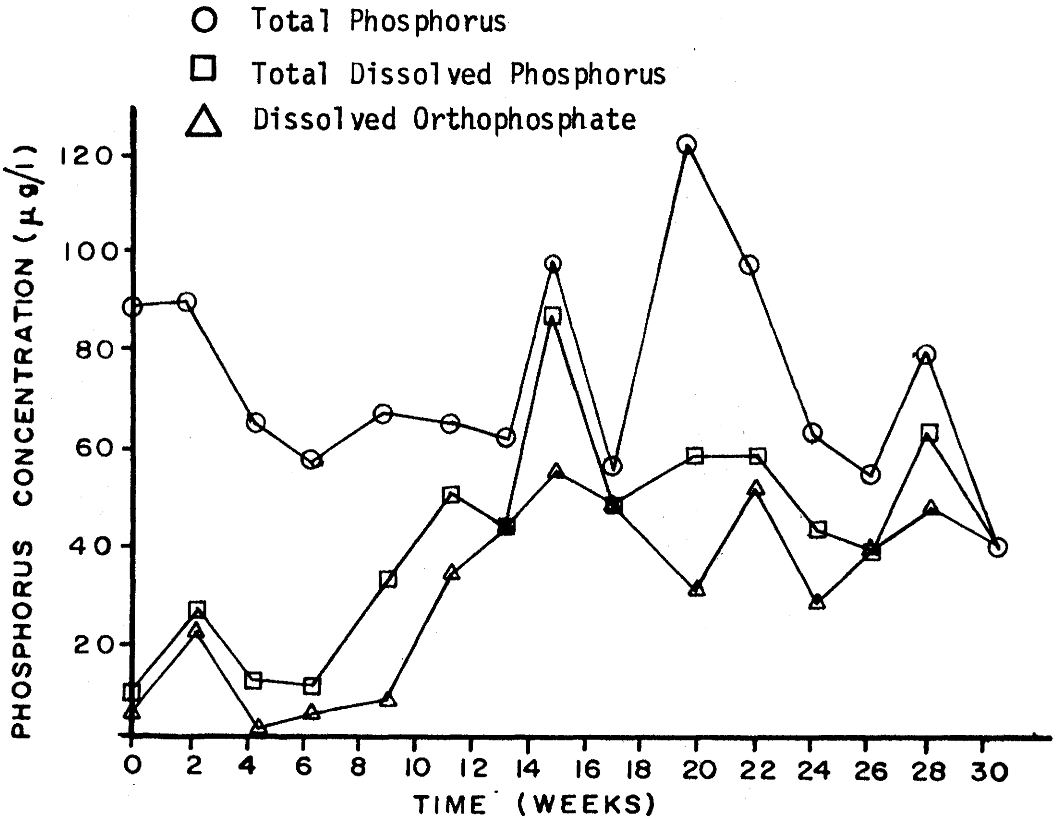


Figure 16. Phosphorus concentrations in Little Bear River above Hyrum Reservoir (Station 2). April-November, 1971.

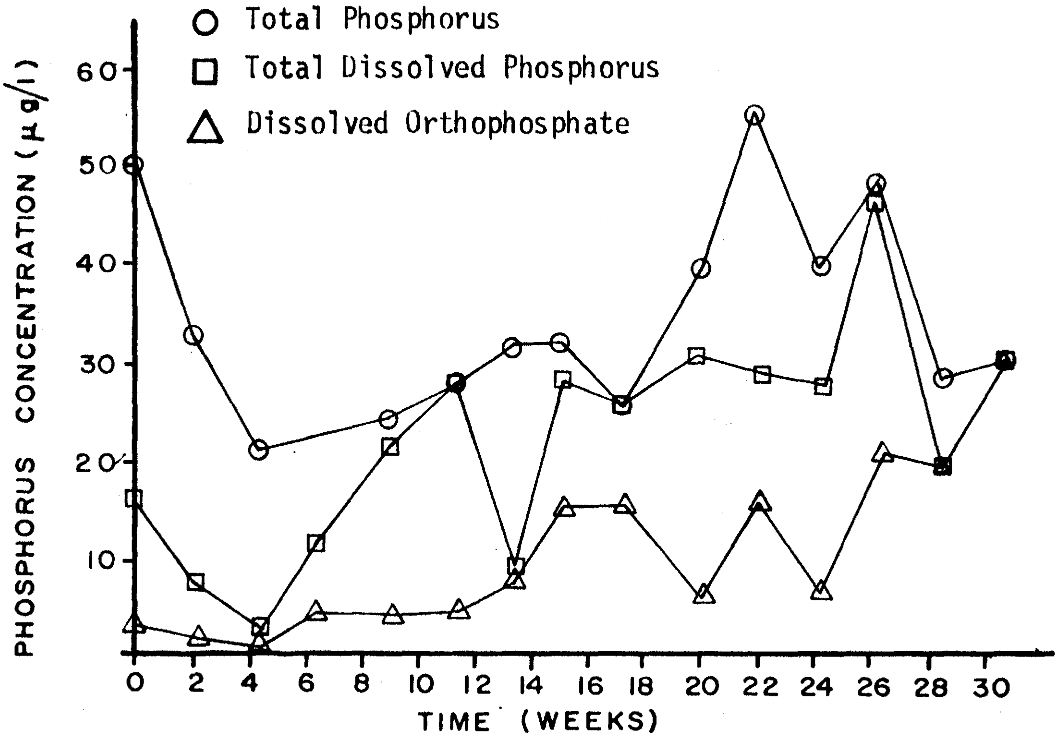


Figure 17. Phosphorus concentrations in composite samples. Hyrum Reservoir. (Station 0). April-November, 1971.

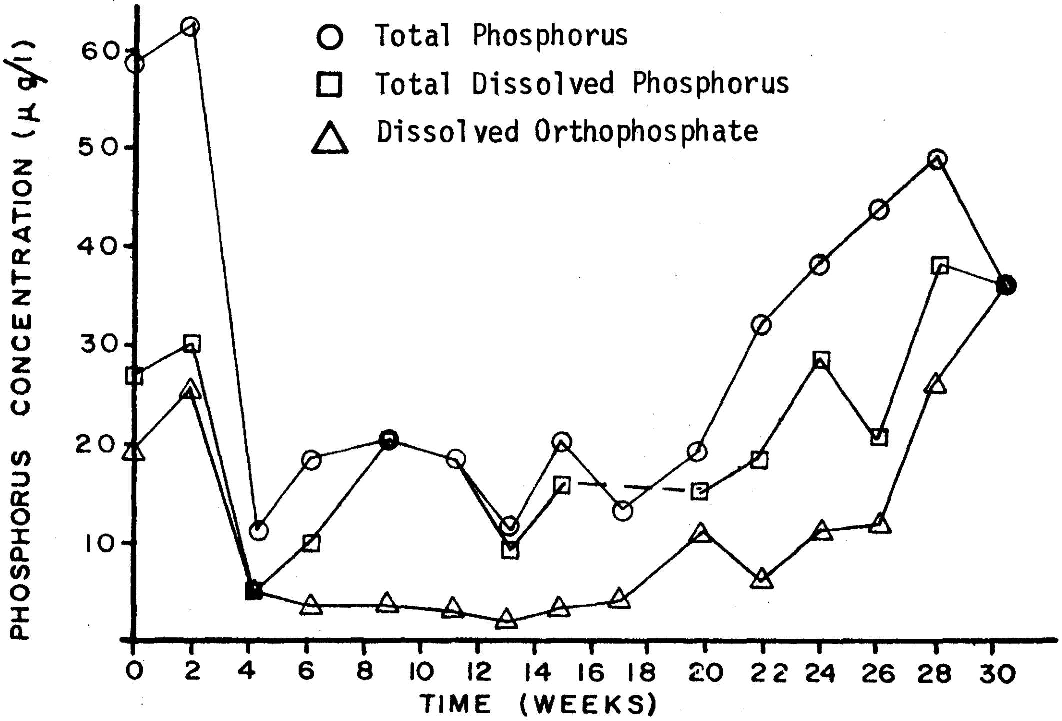


Figure 18. Phosphorus concentrations in Hyrum Reservoir adjacent to Hyrum City Dump (Station 1). April-November, 1971.

of the study period. This may have been due to inputs from irrigation return flow. Also, fall turnover may have dispersed the phosphorus from the bottom sediments throughout the reservoir.

Mean phosphorus concentrations

The mean phosphorus concentrations (Table 3) for all stations gives an idea of the relative importance of some stations. Station 4 which was the effluent from White's Trout Farm showed a major contribution of phosphorus. A comparison of Station 5 which was the trout farm diversion with Station 2 which was just above Hyrum Reservoir and downstream from the trout farm effluent discharge shows the actual increase in phosphorus concentration in the Little Bear River. Station 10 which was a groundwater source picked up a relatively large amount of particulate material as it flowed through a barnyard.

Also the dissolved organic phosphorus levels remained fairly constant ranging from approximately 8 $\mu g \cdot l^{-1}$ to 14 $\mu g \cdot l^{-1}$ over the study period.

Statistical Comparison of Phosphorus Sampling Results

Sampling stations

Among the various statistical analyses performed was the analysis of variance, in which the mean phosphorus concentrations over the sampling period for various combinations of stations were compared to determine the major sources of phosphorus. The results of these analyses are shown in Table 4. Comparisons were made only between parameters considered to have some relationship. Among the apparent observations to be made here is that there was no significant difference

Table 3. Mean concentrations of phosphorus ($\mu g \cdot l^{-1}$) for all stations during the period of study.

Station No. (See Table 1)	Total Phosphorus	Particulate Phosphorus	Total Dissolved Phosphorus	Dissolved Organic Phosphorus	Ortho-phosphate
Baseline stations					
6	31.42	17.05	14.37	9.64	4.73
8	25.52	12.72	12.80	8.87	3.93
Stations below minor development					
9	29.81	6.18	23.63	8.17	15.46
10	53.00	39.08	13.92	8.52	5.40
7	26.02	11.71	14.31	11.66	2.66
11	16.73	3.38	13.35	9.27	4.08
Stations associated with White's Trout Farm					
5	23.34	5.75	17.59	13.13	4.46
4	203.79	61.78	142.01	17.05	124.96
3	101.55	39.84	61.71	13.77	47.94
Stations associated with Hyrum Reservoir					
2	73.69	32.95	40.74	10.85	29.89
1	29.89	9.33	20.56	9.44	11.12
0	33.95	12.16	21.79	11.96	9.83

Table 4. Analysis of variance for mean phosphorus concentrations during the period of study for various combinations of sampling stations.

Station Combination (see Table 1)	Degrees of Freedom	"t" Phosphorus Fraction Total Phosphorus	Total Dissolved Phosphorus	Orthophosphate
0-1	28	0.78169	0.30988	0.36355
0-2	28	-6.05206*	2.93966*	3.72199*
4-5	14	-4.28942*	-4.16092*	-4.08641*
5-11	14	-2.68657*	-2.05011*	-0.41369
6-11	14	-0.45166	0.44875	-1.47600
7-8	28	-0.06322	-1.50289	1.05858
7-11	14	-1.20372	1.18984	1.91579*
7-5	14	0.55485	-0.11698	2.34264*
6-5	14	2.36900*	1.68863	1.92968*
7-6	28	0.70561	0.02246	-1.67387
2-5	14	-4.80450*	5.68570*	10.02289*
8-0	28	1.33510	-2.62910*	-2.36550*

*Significant at $P \geq 95$ percent.

between the mean phosphorus concentrations for Stations 0 and 1. This seems to indicate that despite the higher values for Station 1 at the first part of the study, runoff from the city dump had little effect on phosphorus concentration in the reservoir. However, a significant difference was evident between Stations 0 and 2, establishing the Little Bear River as a major source of phosphorus. Stations 4 and 5 having a significant difference seems to indicate that White's Trout Farm altered the quality of the water diverted from the Little Bear River for its use. There was no significant difference between most of the upper adjacent stream stations, but there was a significant difference between the uppermost and lowermost stations. This indicated a gradual buildup of phosphorus concentration as the river passed through the watershed above Paradise. However, there was a significant difference between the mean total phosphorus concentrations at Stations 5 and 7 and also Stations 5 and 6. This indicates that a significant amount of phosphorus was added, mostly in the particulate form between Stations 7 and 6 and Station 5. This may have been due to the higher amount of agricultural activity in this area. Comparing Stations 0 and 8 resulted in a significant difference for total phosphorus and total dissolved but not for orthophosphate. This seems to indicate a fairly constant amount of orthophosphate was present in both reservoirs and that much biological activity took place in the watershed as the river flowed from Porcupine Reservoir to Hyrum Reservoir.

Streamflow relation to sampling stations

It was felt that perhaps a more meaningful relationship between the data could be shown through correlation analyses. The pairs of data selected for analysis were those which appeared as though they might have a significant correlation. Among the pairs of data analyzed were phosphorus concentrations at a particular station over the sampling period versus a 3-day average of the streamflow at the same station over the sampling period. A graphical comparison at Station 6 for these two categories of data is shown as Figure 19. The statistical comparison of these two sets of data gave the results as shown in Table 5.

Table 5. Correlation analysis for phosphorus concentrations at a particular station versus a 3-day average of the streamflow at the same station for the respective sampling dates during the period of study.

Comparison Mode	Number of Data Points	Correlation Coefficient Phosphorus Fraction	
		Total Dissolved Phosphorus	Orthophosphate
South Fork - Station 6	15	-0.03	0.50*
East Fork - Station 7	15	-0.35	0.12
Total River - Station 5	8	0.40	0.01
Total River - Station 11	8	-0.55	-0.13

*Significant at P $\geq$ 95 percent.

Only one of these values was significant at the 95 percent level. However, the relatively high negative correlation on some combinations seems to indicate a rather constant input of phosphorus to the stream, possibly from the local geological conditions.

Precipitation effects on phosphorus concentration

Another combination of data analyzed was precipitation (summation of all precipitation with 4 days prior to the time of sampling) related to

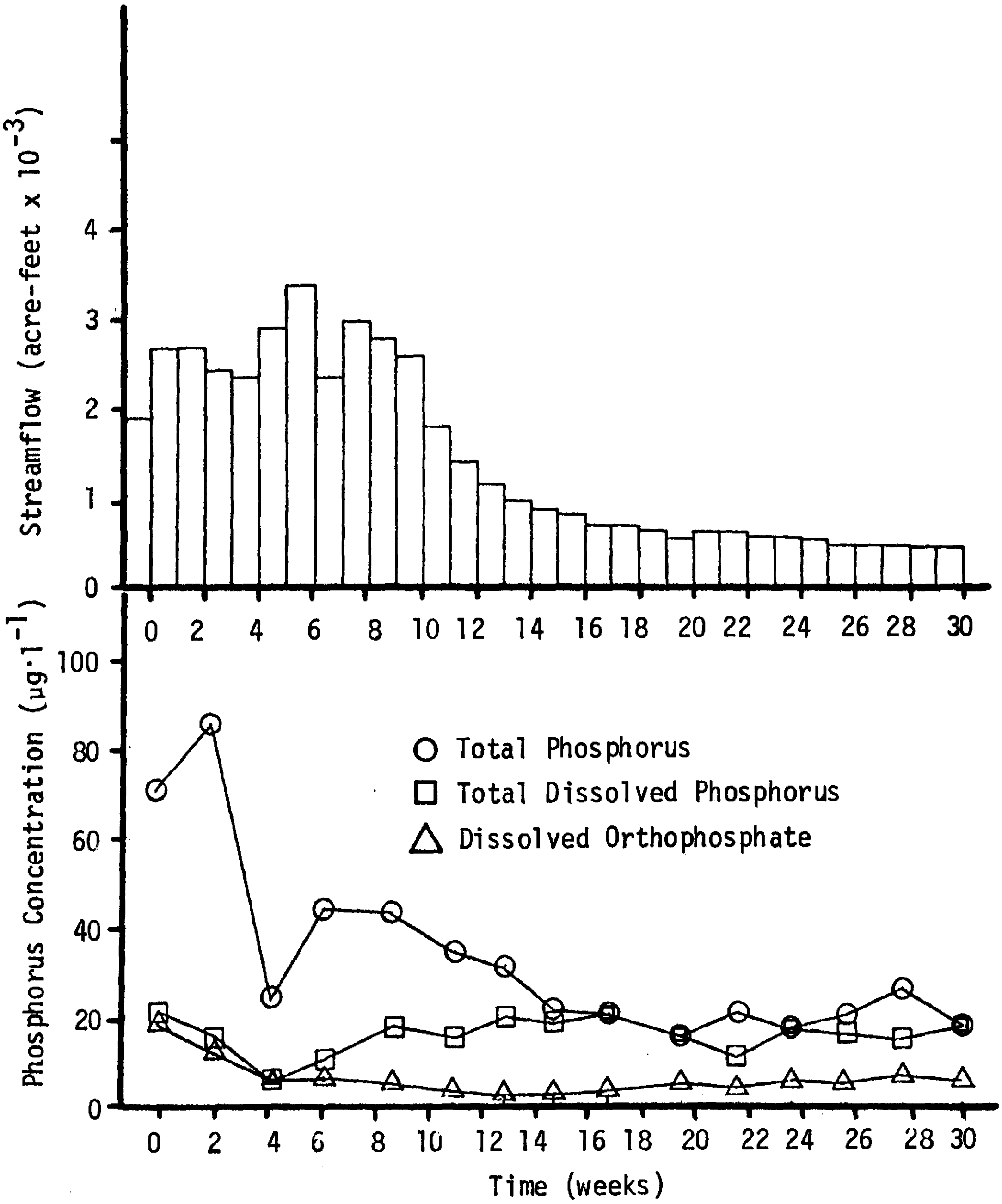


Figure 19. Phosphorus concentration versus streamflow in Little Bear River (Station 6). April-November, 1971.

phosphorus concentration at a particular station over the sampling period. A graphical comparison at Station 1 of these two categories of data is shown as Figure 20. The statistical comparison of these two sets of data gave the results as shown in Table 6.

Table 6. Correlation analysis for phosphorus concentrations at a particular station versus summation of precipitation within four days prior to the time of sampling over the sampling period.

Comparison Mode	Number of Data Points	Correlation Coefficient		
		Phosphorus Fraction		
		Total Phosphorus	Total Dissolved Phosphorus	Ortho-phosphate
Precipitation - Station 1	15	0.38	0.44*	0.32
Precipitation - Station 0	15	0.07	-0.15	0.47*
Precipitation - Station 6	15	0.06	-0.33	0.04
Precipitation - Station 7	15	0.20	0.53*	0.08
Precipitation - Station 11	8	0.65*	0.31	-0.13
Precipitation - Station 5	8	0.42	0.31	-0.14

*Significant at P ≥ 95 percent.

Few of the above results were significant at the 95 percent level. Significance at Station 1 may indicate that Hyrum City Dump was a source of phosphorus to the reservoir. It appears though that average rainstorms and the runoff produced had little effect on the phosphorus concentrations in this watershed.

Interstation comparison of phosphorus concentrations

A third combination of data analyzed was phosphorus concentration at a particular station over the sampling period versus the same for

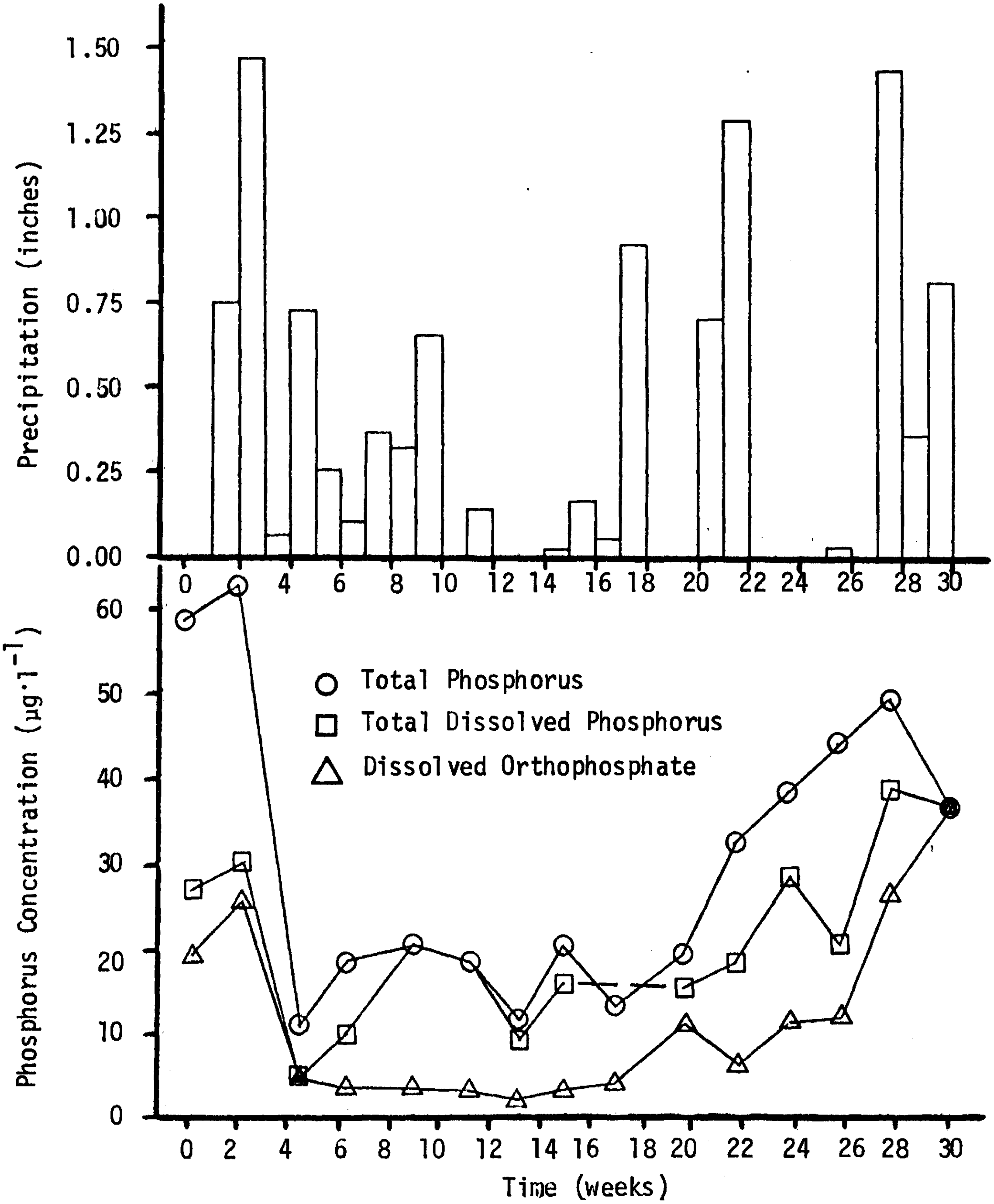


Figure 20. Phosphorus concentration versus precipitation at Hyrum Reservoir (Station 1). April-November, 1971.

another station over the sampling period. The statistical comparison of these pairs of data gave the results shown in Table 7.

Table 7. Correlation analysis for phosphorus concentrations at two stations over the sampling period.

Comparison Mode Station Combination	Number of Data Points	Correlation Coefficient		
		Phosphorus Fraction		
		Total Phosphorus	Total Dissolved Phosphorus	Orthophosphate
0-1	15	0.49*	0.22	0.49*
0-2	15	0.40	0.48*	0.63*
0-4	15	0.40	0.21	0.68*
2-3	15	0.11	0.73*	0.82*
2-5	8	0.32	0.58	-0.69*
5-11	8	0.41	-0.04	0.47
11-6	8	0.52	-0.07	0.38
11-7	8	0.21	0.71*	0.43
7-8	15	0.92*	0.61*	0.73*
7-10	15	-0.02	0.46*	0.29
7-9	15	0.23	0.62*	0.35

*Significant at $P \geq 95$ percent.

The high correlation shown for orthophosphate between Station 0 and Stations 2 and 4 showed the apparent effect White's Trout Farm had on the reservoir phosphorus levels. The correlation between Stations 2 and 3 showed even better the magnifying effect of the trout farm on the phosphorus level in the main source of water to the reservoir.

The high correlation between Stations 7 and 8 was logical as there was little activity between these two stations. The correlation between Stations 7 and 9 may indicate that groundwater had some effect on this particular portion of the river, although it does not seem reasonable because the amounts of groundwater flow observed were minimal.

Accumulation of phosphorus moving downstream

A fourth combination of data analyzed was mileage downstream versus phosphorus concentrations for three particular sampling dates as shown in Table 8. The stations used were numbers 8, 7, 11, 5, 3, and 2, which were 0.0, 3.2, 4.4, 6.1, 7.4, and 9.5 miles downstream from Porcupine Reservoir respectively.

Table 8. Correlation analysis for phosphorus concentrations versus mileage downstream from Porcupine Reservoir.

Date	Number of Data Points	Correlation Coefficient Phosphorus Fraction Total Phosphorus	 Total Dissolved Phosphorus	 Ortho-phosphate
April 24, 1971	6	0.64	0.82*	0.88*
July 22, 1971	6	0.75*	0.82*	0.78*
October 21, 1971	6	0.64	0.66	0.72

*Significant at P $\geq$ 95 percent.

On the first date, two out of three of the correlation coefficients were significant at the 95 percent level. Apparently a large amount of orthophosphate entered the water course at the time of spring runoff. This may have been due to over-fertilizing of the fields by farmers, the practice of spreading manure on the fields, or the inherent characteristics of the soil itself.

All three correlation coefficients were significant on July 22. This may have been a result of irrigation return flow as this was the time when the farmers were irrigating heavily.

The data for October 21 seemed to verify the assumptions made about the results for April 24 and July 22. The agricultural activity in the watershed had all but ceased for the growth year and runoff was at a minimum during this period. However the orthophosphate correlation coefficient for October 21st was nearly significant at the 95 percent level. This may indicate the dying of algae in the stream and the releasing of the available form. This may also indicate some cleaning operation at White's Trout Farm, the effluent from which showed an increase in effluent phosphorus concentration after October 4th.

Phosphorus Budget for Hyrum Reservoir

Phosphorus budget components

The equation used to determine the phosphorus budget during the period of study is shown below:

$$\Delta P = P_i + P_{pr} + P_{ro} - (P_c + P_r) \pm P_m \pm P_w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

ΔP = change in quantity of phosphorus in the reservoir

Sources
P_i = quantity of phosphorus in the influent
P_{pr} = quantity of phosphorus in precipitation
P_{ro} = quantity of phosphorus in the runoff to the reservoir

Sinks
P_c = quantity of phosphorus in the discharge to the irrigation canals
P_r = quantity of phosphorus in the discharge to the Little Bear River

Sources or Sinks

P_m = quantity of phosphorus added by, or removed by the reservoir bottom muds.

P_w = quantity of phosphorus added by or removed by wildlife

Phosphorus input to the Little Bear River above USGS Station 10-1060

The input of phosphorus from the Little Bear River (Table 9) was determined by using the streamflow for USGS Station No. 10-1060 and average monthly phosphorus concentrations from Station No. 2 as designated for this study. A conversion factor of $1.235\ (10)^{-3}$ $\mathrm{kg \cdot (acre\text{-}foot \cdot \mu g \cdot l^{-1})^{-1}}$ was used with all water volume and phosphorus concentration data to obtain the quantity of phosphorus in kg.

Phosphorus input from runoff below USGS Station 10-1060

The area runoff from 8 square miles located below USGS Station No. 10-1060 was determined as shown in the water budget. No data were obtained during this study or were available for phosphorus concentrations from this particular source. However, Weibel et al. (1964) has shown a phosphorus concentration of $1.7\ \mathrm{mg \cdot l^{-1}}$ for runoff from a cultivated field. Using the concentration in conjunction with the previously presented runoff data resulted in an input of 1420 kg during the period of study or approximately 2460 kg per year.

In another study, Mackenthun (1968) listed cultivated agricultural drainage as contributing from 0.39 to 0.44 $\mathrm{kg \cdot yr^{-1} \cdot ha^{-1}}$. Applied to this study the input would have been approximately 860 kg per year or 500 kg during the period of study.

A third estimate was made by extracting the input from the land above USGS Station No. 10-1060 and reducing it to correspond to the

Table 9. Amounts of various phosphorus fractions entering Hyrum Reservoir by way of the Little Bear River during the period of study.

Month	Little Bear River Flow (acre-feet)	Orthophosphate		Total Dissolved Phosphorus		Total Phosphorus	
		Average Concentration ($\mu g \cdot l^{-1}$)	kg In	Average Concentration ($\mu g \cdot l^{-1}$)	kg In	Average Concentration ($\mu g \cdot l^{-1}$)	kg In
April	25,630	12.4	392	16.4	519	89.1	2,820
May	32,480	1.6	64	9.8	393	62.4	2,503
June	12,130	20.5	307	41.4	620	62.0	929
July	3,930	49.6	241	66.8	324	80.3	390
Aug.	3,800	39.9	187	53.4	251	92.0	432
Sept.	4,360	40.5	218	50.7	273	80.0	431
Oct.	5,550	42.1	289	49.3	338	65.6	450
Nov.[1]	1,599	35.5	70	35.5	70	35.9	71
Totals			1,768		2,788		8,026

[1] November 1-10 only.

8 square miles involved. Using the phosphorus concentrations from Stations 5 and 6 (above White's Trout Farm) and the flow data from USGS Station No. 10-1060 the phosphorus contributions from runoff during the period of study for the larger area were estimated as follows:

Orthophosphate	817 kg
Total Dissolved Phosphorus	1530 kg
Total Phosphorus	5029 kg

The quantities came from an area of 200 square miles. An approximation for phosphorus input from the smaller area, which had much the same land usage was obtained by multiplying the above results by 8 square miles/200 square miles, or 0.04 which gave the following results:

Orthophosphate	33 kg
Total Dissolved Phosphorus	61 kg
Total Phosphorus	201 kg

This estimate was used in the budget as it was felt that it was most representative of the area.

Phosphorus inputs from runoff directly to Hyrum Reservoir

The second type of phosphorus input from runoff was that coming from the banks of the reservoir itself. Included in this type were runoff from feedlots and runoff from the garbage dump. Runoff from feedlots will not be covered in detail at this time since a separate report on this subject has been made by Murray (1972). However, an estimate obtained by using the 4.48 acre-feet of continuous flow for feedlot runoff from the water budget in conjunction with average phosphorus concentrations from Murray's data gave the following input from feedlots during the period of study:

Orthophosphate	0.533 kg
Total Dissolved Phosphorus	0.995 kg
Total Phosphorus	3.0 kg (estimated)

The assumption was made that total phosphorus would have been approximately three times the dissolved fraction as was found for the area runoff.

Runoff from the dump was periodic and even though the concentrations of phosphorus may have been as high as the continuous feedlot runoff, the total amount of phosphorus added was assumed to be negligible relative to the amount added by the other sources.

Phosphorus input from precipitation

The phosphorus input from precipitation directly onto the reservoir, relative to the amount added by the Little Bear River and runoff appeared small. Using an estimated phosphorus concentration of 30 $\mu g \cdot l^{-1}$ for orthophosphate and 40 $\mu g \cdot l^{-1}$ for both total dissolved and total phosphorus (Brezonik et al., 1969), combined with precipitation data from the water budget, the total inputs over the period of study were approximately 15, 20, and 20 kg respectively for the various fractions.

Phosphorus sinks for Hyrum Reservoir

The output of phosphorus to the rivers and canals was determined by using the streamflow data presented in the water budget in conjunction with the phosphorus data for Station O, which was a composite sample of the reservoir. The amounts of phosphorus leaving Hyrum Reservoir by way of the Little Bear River and the canals during the period of study were as shown in Table 10.

Table 10. Amounts of various phosphorus fractions leaving Hyrum Reservoir by way of the Little Bear River and irrigation canals during the period of study.

				Orthophosphate		Total Dissolved Phosphorus		Total Phosphorus	
Month	Little Bear Outflow (acre-feet)	Canal Outflow (acre-feet)	Total Outflow (acre-feet)	Average Concentration ($\mu g \cdot l^{-1}$)	kg Out	Average Concentration ($\mu g \cdot l^{-1}$)	kg Out	Average Concentration ($\mu g \cdot l^{-1}$)	kg Out
April	25,100	0	25,100	1.7	53	11.4	354	41.6	1,290
May	29,150	1,021	30,171	1.4	52	7.3	272	22.0	820
June	4,900	5,153	10,053	4.1	51	25.0	310	26.5	329
July	252	6,954	7,206	10.9	97	18.0	160	32.5	289
Aug.	262	5,642	5,904	10.2	74	27.6	201	32.3	236
Sept.	3,730	1,080	4,810	10.7	64	27.7	165	47.3	281
Oct.	5,070	0	5,070	19.6	123	32.0	200	38.0	238
Nov.[1]	1,775	0	1,775	29.3	64	29.3	64	29.3	64
Totals	70,239	19,850	90,089		578		1,726		3,547

[1] November 1-10 only.

Phosphorus budget results for Hyrum Reservoir

The phosphorus budget equations for the measured and estimated sources and sinks are as follows:

$$\Delta P = P_i + P_{pr} + P_{ro} - (P_c + P_r) \pm P_m \pm P_w \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

Orthophosphate

$$+ 349 \text{ kg} = 1768 \text{ kg} + 15 \text{ kg} + 34 \text{ kg} - 578 \text{ kg} \pm P_m \pm P_w$$

$$- 890 \text{ kg} = \pm P_m \pm P_w$$

Total Dissolved Phosphorus

$$+ 168 \text{ kg} = 2788 \text{ kg} + 20 \text{ kg} + 62 \text{ kg} - 1726 \text{ kg} \pm P_m \pm P_w$$

$$- 976 \text{ kg} = \pm P_m \pm P_w$$

Total Phosphorus

$$- 330 \text{ kg} = 8026 \text{ kg} + 20 \text{ kg} + 204 \text{ kg} - 3547 \text{ kg} \pm P_m \pm P_w$$

$$- 5033 \text{ kg} = \pm P_m \pm P_w$$

The ΔP values used in the equations were obtained from Table 11.

In evaluating the three water budget equations, one is tempted to name the muds as the major unknown sink. However, in a previous study, Schmalz (1971) observed a low correlation between sedimentation and phosphorus content of the muds at Hyrum. This would tend to support the fact that possibly fish or other related aquatic species were acting as an important sink. McGauhey et al. (1970) have shown an estimated two tons of trout in Indian Creek Reservoir which had roughly one-third the surface area of Hyrum Reservoir. Using this figure and an estimated 40,000 $\mu gP \cdot g^{-1}$ dry weight of fish from a report by Lawrence (1968), this amounted to approximately 216 kg of phosphorus or about 4 percent of the unknown total phosphorus sink.

Table 11. ΔP for various phosphorus fractions in Hyrum Reservoir during the period of study.

Month	S (acre-feet)	Total Phosphorus (kg)	Particulate Phosphorus (kg)	Total Dissolved Phosphorus (kg)	Dissolved Organic Phosphorus (kg)	Dissolved Orthophosphate (kg)
April	11,630	715	498	217	181	36
November	10,650	385	0	385	0	385
ΔP		-330	-498	+168	-181	+349

Perhaps then the remaining 96 percent of the unknown sink was being incorporated into the bottom sediments. A summary of all known and estimated sources and sinks is shown in Table 12.

Table 12. Summary of all known and estimated phosphorus sources and sinks for Hyrum Reservoir during the period of study.

Source	Mass (kg)	Percent of Total	Sink	Mass (kg)	Percent of Total
Orthophosphate					
Little Bear River	1768	97.3	Outlets	578	39.4
Precipitation	15	0.8	Fish, etc.	890	60.6
Runoff	34	1.9	Muds		
Total	1817	100.0		1468	100.0
Total Dissolved Phosphate					
Little Bear River	2788	97.1	Outlets	1726	63.9
Precipitation	20	0.7	Fish, etc.	976	36.1
Runoff	62	2.2	Muds		
Total	2870	100.0		2702	100.0
Total Phosphorus					
Little Bear River	8026	97.3	Outlets	3547	41.3
Precipitation	20	0.2	Fish, etc.	201	2.4
Runoff	204	2.5	Muds	4832	56.3
Total	8250	100.0		8580	100.0

It should be noted that the amounts of phosphorus added by the Little Bear River were not totally from agricultural runoff. As previously shown in this report the phosphorus input due to agricultural runoff above USGS Station 10-1060 was approximately as follows:

Orthophosphate	817 kg
Total Dissolved Phosphorus	1530 kg
Total Phosphorus	5029 kg

Comparing these amounts to the total amounts added by the Little Bear River (1768 kg Orthophosphate, 2788 kg Total Dissolved Phosphorus, and 8026 kg Total Phosphorus), there was approximately 40 to 50 percent of the total Little Bear River phosphorus load which was not accounted for. White's Trout Farm, which diverted a large portion of the Little Bear River for its use, and whose effluent concentrations were relatively high, did, then, add a significant amount of phosphorus to the river.

CHAPTER V

CONCLUSIONS

Based on the data presented, the water and phosphorus budgets, and the statistical analyses, the following conclusions were drawn:

1. An infiltration loss rate for Hyrum Reservoir was calculated to be 0.0040 feet per day.
2. The baseline sampling stations (6 and 8) showed a relatively high percentage of particulate phosphorus in the early portion of the study. This was attributed to spring runoff.
3. Groundwater, depending on the quantity of flow, was shown to be a potentially significant contributor of phosphorus in a specific area, but insignificant to the system as a whole.
4. Water flowing through barnyards was shown to pick up a high percentage of particulate phosphorus.
5. A large percentage of the phosphorus contributed by White's Trout Farm was in the orthophosphate form.
6. The trout farm effluent for the period from October 4 to the end of the study showed phosphorus concentrations of approximately 10 times that shown for the influent.
7. The mean organic phosphorus concentrations for all stations remained fairly constant throughout the study, ranging from approximately 8 $\mu g \cdot l^{-1}$ to 14 $\mu g \cdot l^{-1}$.
8. Statistically, a significant amount of particulate phosphorus was shown to be added between Stations 7 and 6, and Station 5. This was attributed to agricultural activity in this area.

9. There was indication, both graphically and statistically, that Hyrum City Dump contributed phosphorus to Hyrum Reservoir following periods of rainfall.
10. Input of phosphorus to the reservoir other than the Little Bear River were made by precipitation (less than 1 percent) and runoff from the area immediately around the reservoir (approximately 2 percent).
11. The amount of Total Phosphorus leaving the reservoir by way of the river or canals during the period of study was approximately 43 percent of the input. Apparently much of the incoming phosphorus was transferred to the bottom sediments.
12. Approximately 97 percent of the phosphorus added to Hyrum Reservoir during the period of study came from the Little Bear River. Of this percentage approximately 50 to 60 percent originated in agricultural runoff from cultivated land and the remaining percentage was contributed by White's Trout Farm.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER STUDY

This study pointed out the need for other various types of data needed and studies which could be done in this watershed:

1. A detailed study of White's Trout Farm effluent along with recommendations for treatment. This is ongoing at present (White, 1974).
2. A study involving phosphorus profiles in the reservoir over a year's time.
3. A study involving inputs from irrigation return flow.
4. A study involving nutrient inputs from recreational activities at Hyrum Reservoir.
5. A detailed study involving nutrients in rainfall in this geographical area.

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APPENDIX

Table 13. Total phosphorus concentrations ($\mu g \cdot l^{-1}$) during the period of study.

Station	4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22
0	49.8	33.4	21.4	22.6	24.6	28.3	32.1	32.8
1	59.2	63.0	11.3	18.3	20.5	18.0	12.0	19.5
2	88.8	89.4	64.9	57.9	68.0	64.9	63.0	97.6
3	81.2	56.1	73.1	113.3	63.0	136.7	128.0	122.8
4	367.0	187.0	49.8	295.5	30.8	88.7	116.5	98.8
5	0	0	0	0	0	0	0	21.6
11	0	0	0	0	0	0	0	15.1
6	71.2	83.7	24.6	44.7	44.1	33.4	30.2	20.8
7	90.7	46.6	18.3	22.6	14.7	17.6	11.3	17.6
8	92.0	59.2	6.9	15.7	27.1	12.0	8.8	16.4
10	46.0	59.2	27.1	43.5	66.2	61.7	75.6	68.0
9	33.3	51.0	12.0	24.6	25.8	29.6	25.8	25.2

Table 13. (Continued).

Station	8/5	8/23	9/6	9/20	10/4	10/21	11/4
	Date						
0	24.9	39.6	54.8	39.7	48.5	27.4	29.3
1	12.6	18.9	30.8	37.2	43.5	48.5	35.1
2	55.4	128.5	97.0	63.0	51.7	79.4	35.9
3	141.2	111.4	145.5	86.3	128.5	77.5	58.6
4	112.8	129.9	224.5	140.5	439.0	365.0	411.0
5	16.4	23.3	34.0	15.8	20.2	29.6	25.8
11	18.2	16.7	21,4	15.1	17.0	18.9	11.4
6	19.3	13.9	18.9	14.2	15.8	22.0	14.5
7	10.1	24.6	21.4	13.6	17.0	42.2	22.0
8	14.5	22.6	27.1	22.7	17.0	23.9	17.0
10	18.3	63.6	56.7	17.3	25.2	33.4	133.0
9	16.4	40.9	38.4	18.9	27.7	43.5	35.2

Table 14. Total dissolved phosphorus concentrations ($\mu g \cdot l^{-1}$) during the period of study.

	Date							
Station	4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22
0	15.1	7.6	2.5	12.0	21.6	28.3	8.2	27.7
1	26.4	30.2	4.3	10.1	20.5	18.0	9.5	15.7
2	6.9	25.8	10.1	9.5	33.1	49.7	44.9	88.8
3	30.2	11.3	3.2	42.2	36.3	112.8	80.6	82.4
4	185.0	97.0	0	190.3	26.5	56.1	61.8	79.3
5	0	0	0	0	0	0	0	21.6
11	0	0	0	0	0	0	0	13.2
6	21.4	16.4	4.6	10.1	17.6	14.5	18.3	17.6
7	15.1	8.8	3.8	9.5	14.7	15.7	2.5	13.9
8	19.5	7.6	1.9	10.1	22.4	8.8	1.3	12.6
10	8.2	7.6	3.9	15.1	24.6	9.5	3.8	10.1
9	33.3	17.0	2.5	11.4	23.9	29.6	25.8	13.2

Table 14. (Continued).

	Date						
Station	8/5	8/23	9/6	9/20	10/4	10/21	11/1
0	24.9	30.2	28.3	27.1	46.0	18.1	29.3
1	-	14.5	17.6	27.7	19.5	38.4	35.5
2	49.5	57.3	58.6	42.8	36.2	62.4	35.5
3	108.9	88.1	77.5	71.2	59.2	73.7	48.1
4	90.0	129.9	99.5	107.8	229.0	273.0	363.0
5	11.3	20.8	25.8	15.8	16.4	16.4	12.6
11	11.3	16.7	9.5	15.1	10.7	18.9	11.4
6	19.3	13.8	8.8	14.2	13.2	11.3	14.5
7	8.8	18.3	8.8	13.6	17.0	42.2	22.0
8	10.1	18.9	6.3	22.7	14.5	18.3	17.0
10	10.1	27.7	11.5	17.3	13.2	15.1	30.9
9	13.9	38.4	30.8	18.9	20.8	38.4	35.2

Table 15. Orthophosphate concentration ($\mu g \cdot l^{-1}$) during the period of study.

Station	Date 4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22
0	2.5	0.9	0.0	3.8	3.5	4.7	7.2	14.5
1	19.5	26.1	4.3	3.5	3.5	3.2	1.3	2.2
2	2.2	22.6	0.0	3.2	7.3	33.7	44.9	54.2
3	16.4	5.4	.32	35.9	14.0	79.5	56.8	59.5
4	183.0	93.8	0	184.0	4.7	56.1	61.8	49.2
5	0	0	0	0	0	0	0	2.2
11	0	0	0	0	0	0	0	0.3
6	18.3	12.3	4.6	5.0	3.5	1.9	1.6	1.6
7	4.7	3.5	.63	3.8	3.8	1.3	1.6	0.9
8	18.0	3.1	0.0	3.8	6.0	1.9	0.0	0.0
10	8.5	2.8	3.9	4.7	6.0	1.3	3.2	1.2
9	28.0	13.2	1.6	5.7	5.4	12.3	18.6	1.6

Table 15. (Continued).

	Date						
Station	8/5	8/23	9/6	9/20	10/4	10/21	11/1
0	15.1	5.4	15.7	5.7	21.1	18.1	29.3
1	3.2	11.0	6.0	10.4	11.3	25.8	35.5
2	49.5	30.2	52.6	28.4	36.2	47.9	35.5
3	100.0	53.5	75.5	55.7	51.7	66.8	48.1
4	82.8	64.2	88.8	98.6	229.0	265.0	288.5
5	1.9	6.6	4.1	4.1	7.25	4.1	5.4
11	5.4	5.4	3.5	3.5	4.4	3.8	6.3
6	2.2	3.8	1.9	3.8	2.5	4.7	3.2
7	1.6	3.8	1.9	4.4	1.6	3.2	3.2
8	2.8	2.5	2.5	6.3	1.6	4.4	6.0
10	1.9	7.3	11.5	3.5	9.1	4.4	11.7
9	4.7	26.4	28.0	8.5	16.1	28.4	33.4

Table 16. Streamflow (cfs) for United States Geological Survey Station 10-1047 during the period of study (USGS, 1971-1972).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	99	139	197	86	45	39	37	33
2	97	158	185	54	44	38	36	33
3	112	188	186	80	44	45	36	33
4	124	206	186	77	48	42	36	34
5	137	205	186	75	47	40	35	34
6	167	190	193	72	48	39	35	31
7	193	187	189	70	47	41	34	32
8	187	198	195	71	46	39	33	32
9	195	196	218	68	46	39	32	32
10	215	194	207	66	44	37	32	33
11	190	217	217	66	43	37	32	
12	174	236	189	64	43	37	31	
13	164	252	174	62	42	36	31	
14	172	240	163	60	42	35	30	
15	183	249	160	60	41	35	31	
16	185	258	154	58	41	35	37	
17	190	230	146	57	41	35	36	
18	189	241	141	57	40	35	35	
19	178	183	134	57	35	35	34	
20	184	162	121	56	38	34	34	
21	195	156	115	56	37	35	34	
22	188	154	109	54	36	35	33	
23	159	150	102	52	38	35	33	
24	162	153	102	52	36	35	33	
25	163	173	98	53	36	35	34	
26	177	204	94	52	36	34	33	
27	184	218	98	70	35	34	35	
28	146	230	97	47	37	34	35	
29	139	217	94	48	46	34	34	
30	125	206	91	46	43	36	34	
31		196		45	40		34	
Total cfs	4961	6186	4541	1921	1290	1098	1049	327
Acre-Feet	9840	12,270	9010	3810	2560	2180	2080	648

Table 17. Streamflow (cfs) for United States Geological Survey Station 10-1060 during the period of study (USGS, 1971-1972).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	277	466	337	83	64	60	87	91
2	268	550	308	80	64	60	100	94
3	271	647	291	78	63	74	94	94
4	277	714	288	77	57	100	94	94
5	305	647	281	74	60	102	91	94
6	322	583	271	70	63	99	89	87
7	355	564	255	69	64	106	89	87
8	371	564	258	64	64	99	87	87
9	382	564	281	63	69	93	83	85
10	417	546	271	60	64	90	83	85
11	398	574	305	58	64	87	83	
12	382	612	277	54	61	83	83	
13	382	647	258	58	60	66	83	
14	555	683	243	60	60	63	83	
15	647	683	237	58	60	58	85	
16	683	714	223	60	58	60	98	
17	642	652	206	60	57	63	100	
18	612	597	183	60	58	63	103	
19	518	532	162	72	57	61	94	
20	450	492	149	63	58	61	94	
21	421	450	136	61	60	66	91	
22	454	425	121	63	60	66	89	
23	413	402	110	63	61	64	87	
24	425	382	104	63	63	63	89	
25	458	382	99	61	61	61	89	
26	501	398	97	60	63	64	87	
27	514	409	93	60	66	64	96	
28	429	413	92	60	61	63	98	
29	390	378	90	58	61	63	94	
30	405	367	88	57	61	78	85	
31		340		55	58		89	
Total cfs	12,924	16,377	6,114	1982	1914	2200	2797	898
Acre-Feet	25,630	32,480	12,130	3930	3800	4360	5550	1599

Table 18. Reservoir data for United States Geological Survey Station 10-1070 during the period of study (USGS, 1971-1972).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	11,630		13,500	14,760	12,170	10,010	10,760	10,650
2			13,870	14,670	12,120	10,010		
3		11,850	14,200	14,530		10,050		
4			14,480	14,430	12,030	10,140		
5			14,760			10,220		
6		12,390	15,040	14,250	11,850	10,260		
7		12,350	15,280	14,100	11,760	10,310		
8		12,300		14,010	11,630	10,310		
9								
10		12,300		13,730	11,450	10,310		
11		12,260	15,900	13,590		10,310		
12				13,500	11,220	10,310		
13		12,350		13,310				
14		12,580			11,090			
15		12,620		13,080	11,000	10,260		
16				12,990	10,870	10,260		
17		12,670		12,990	10,740			
18		12,620		12,990	10,650	10,220		
19		12,440		12,900		10,220		
20		12,210		12,850	10,440			
21		12,080		12,760	10,310			
22		11,940		12,670	10,220	10,220		
23				12,620				
24		11,760	15,420	12,580	10,050			
25		11,670		12,580	9,960	10,220		
26		11,630	15,280	12,530	9,920			
27		11,630	15,190	12,480	9,880			
28		12,170	15,090	12,390	9,840			
29		12,580	15,000		9,840			
30	11,900	12,850	14,860	12,260	9,880	10,260		
31		13,130		12,210	10,010		10,650	
(†)	4664.7	4667.4	4671.1	4665.4	4660.4	4661.0	4661.9	4661.9
(‡)	+270	+1,230	+1,730	-2,650	-2,200	+250	+390	0

† Elevation, in feet, at end of month.

‡ Change in contents, in acre-feet.

Table 19. Streamflow (cfs) for United States Geological Survey Station 10-1075 during the period of study (USGS, 1971-1972).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	318	421	51	5.4	3.1	11	73	90
2	296	463	52	5.0	2.7	13	78	91
3	290	527	54	4.0	3.3	26	86	90
4	289	595	52	3.2	3.7	50	64	90
5	297	616	55	4.3	4.0	71	52	91
6	312	606	54	2.8	3.8	83	62	90
7	332	578	33	3.1	3.2	91	70	89
8	345	562	47	3.0	3.3	92	75	89
9	350	558	115	3.2	3.2	88	78	88
10	362	552	160	5.0	2.8	84	80	87
11	377	558	190	4.9	2.9	81	81	
12	366	581	206	4.5	3.3	79	81	
13	354	613	196	3.9	4.3	72	81	
14	394	666	184	3.9	6.2	67	80	
15	475	681	175	4.0	4.9	66	80	
16	558	692	177	3.6	4.4	65	84	
17	600	696	151	3.5	5.7	62	91	
18	608	657	180	4.5	4.3	62	95	
19	579	592	113	4.1	5.3	62	93	
20	539	529	89	4.4	6.9	60	91	
21	507	482	69	5.1	5.9	60	90	
22	482	440	45	5.8	4.7	61	89	
23	466	405	21	6.2	4.2	61	87	
24	446	376	7.7	5.0	4.0	60	87	
25	445	351	7.3	3.8	4.0	58	87	
26	461	340	7.3	3.5	3.6	57	86	
27	478	154	7.7	3.1	3.5	59	89	
28	472	51	7.3	3.1	3.6	60	94	
29	439	124	7.7	3.2	4.1	58	92	
30	416	132	7.7	3.9	4.4	63	90	
31		98	6.4	4.0	8.7		90	
Total cfs	12,653	14,696	2470.4	127.0	132.0	1882	2556	895
Acre-Feet	25,100	29,150	4900.0	252.0	262.0	3730	5070	1775

Table 20. Pan evaporation (inches) for United States Weather Bureau Station Logan 5SW during the period of study (USDC, 1971).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	0	.25	.05	.15	.34	.30	0	0
2	.04	.23	.26	.40	.38	.30	0	0
3	.12	.37	.24	.38	.42	.50	.14	0
4	.22	.33	.20	.13	.38	.03	.10	0
5	.19	.14	.16	.22	.38	.15	.11	0
6	.19	.04	.16	.30	0	.15	.14	0
7	.28	.25	.19	.17	.20	.07	.13	0
8	.30	.14	.30	.28	.25	.12	.15	0
9	.28	.16	.30	.31	.29	.15	.17	0
10	.30	.13	.23	.31	.35	.23	.19	0
11	.38	.20	.23	.29	.39	.28	.22	
12	.15	.33	.15	.30	.32	.22	.13	
13	.21	.35	.28	.27	.41	.27	.14	
14	.34	.15	.26	.23	.34	.27	.17	
15	.20	.22	.30	.27	.37	.19	.10	
16	.25	.36	.33	.28	.34	.15	.16	
17	.21	.19	.27	.38	.36	.26	.07	
18	0	.13	.32	.20	.27	.20	.02	
19	.13	.20	.41	.36	.30	.22	.04	
20	0	.30	.36	.18	.36	.24	.09	
21	.04	0	.31	.18	.28	.16	.10	
22	.15	.18	.37	.32	.38	.14	.04	
23	.04	.05	.37	.06	.34	.19	.05	
24	.06	.22	.39	.24	.29	.20	.18	
25	.08	.26	.39	.30	.28	.25	0	
26	0	.29	.39	.37	.16	.33	.04	
27	.01	.35	.38	.29	.25	.22		
28	.13	.29	.09	.31	.21	0		
29	.04	.26	.19	.29	.00	.15		
30	.21	.19	.25	.30	.00	.23		
31	0	0	0	.23	.23	0		
Total	4.55	6.56	8.13	8.30	8.87	6.17	2.68	

Table 21. Precipitation (inches) for United States Weather Bureau Station Logan 5SW during period of study (USDC, 1971).

Day	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1			.23					
2								
3						.77		
4					.05	.16		
5			.02					
6		.12	.25		.77			
7						.34		
8		.05						
9		.44	.05		.14			
10		.11						
11			.36					
12			.28					
13								
14		.17						
15								
16		.08					.02	
17	.15						.91	
18	.21						.48	
19	.09							
20	.23			.01				
21	.06	.07		.01				
22	.26							
23		.03		.16				
24	.11							
25	.16						.14	
26	.63							
27	.27		.08				.20	
28	.02		.05				.55	
29	.06				.19			
30					.49	.02	.04	
31		.13					.20	
Total	2.25	1.20	1.32	0.18	1.64	1.29	2.54	

Table 22. Air temperature (°F) on sampling dates during period of study (USDC, 1971).

Date	4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22	8/5	8/23	9/6	9/20	10/5
Maximum	62	51	64	69	78	90	81	85	93	90	77	67	63
Minimum	31	38	37	42	50	53	60	60	62	56	45	33	34

Table 22. (Continued)

Date	10/21	11/4
Maximum	60	40
Minimum	37	14

Table 23. Water temperature (^{o}C) for stream stations during period of study.

	Date							
Station	4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22
1	0	0	0	10.3	18.8	0	0	0
2	0	0	0	8.0	12.5	0	0	0
3	9.0	7.5	10.0	9.5	16.0	13.0	13.5	16.0
4	10.5	9.0	12.7	10.0	16.2	12.8	13.0	15.8
5	0	0	0	0	0	0	0	19.2
11	0	0	0	0	0	0	0	18.5
6	10.5	7.0	10.3	9.8	16.0	11.8	12.5	18.3
7	6.5	6.8	7.9	9.2	15.0	13.0	13.0	16.8
8	5.0	6.0	7.8	8.2	10.5	9.5	9.5	11.0
10	13.0	8.8	10.0	13.5	22.0	18.0	18.0	22.5
9	9.5	9.8	9.8	10.5	10.8	11.0	11.0	11.0

Table 23. (Continued).

Station	Date 8/5	8/23	9/6	9/20	10/4	10/21	11/4
1	26.0	23.0	0	16.0	16.5	11.8	7.8
2	18.5	16.0	17.5	10.0	12.0	9.7	6.0
3	16.0	12.8	14.0	10.5	12.0	9.0	6.0
4	14.0	12.5	13.5	12.0	13.5	11.0	10.5
5	17.5	14.0	14.5	12.0	13.5	9.3	7.0
11	17.8	14.0	14.0	11.0	13.3	9.0	7.0
6	17.0	12.8	13.8	11.0	13.8	9.0	7.2
7	17.5	17.2	17.2	13.0	15.3	11.0	8.5
8	13.5	16.2	17.0	14.5	13.0	10.5	7.5
10	21.0	19.0	16.5	12.2	16.5	10.8	9.2
9	11.5	10.9	10.7	10.0	10.3	10.0	9.0

Table 24. Temperature profile of Hyrum Reservoir at Station 0 (a) - (°C)[1] during period of study.

	Date							
Depth[2]	4/6	4/24	5/8	5/22	6/10	6/25	7/8	7/22
1	7.0	9.0	9.8	11.0	17.5	20.5	23.0	22.3
3	7.0	8.5	10.0	11.0	17.0	17.5	22.5	22.2
6	7.0	8.5	10.0	10.5	12.0	14.5	21.5	20.2
9	7.0	8.5	10.0	10.0	12.0	12.0	19.5	19.0
12	7.0	8.5	10.0	9.5	12.0	10.5	17.5	15.7
15	7.0	8.5	10.0	8.5	12.0	9.5	14.0	12.8
18	6.0	8.0	9.0	8.5	11.5	9.5	14.0	11.7
21	6.0	8.0	8.5	10.5	11.0	9.3	13.5	11.2

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[1] Data for 6/22, 7/20, 9/6 from Bruce Murray (1972).

[2] Meters.

Table 24. (Continued).

Depth	Date 8/5	8/23	9/6	9/20	10/5	10/21	11/4
1	24.0	23.0	19.7	15.8	14.5	12.5	7.5
3	24.0	22.5	19.4	15.8	14.0	12.0	7.2
6	22.5	22.5	19.2	15.8	13.5	11.8	7.2
9	21.5	22.5	18.7	15.8	13.5	11.6	7.0
12	20.5	21.5	18.7	15.8	13.5	11.6	7.0
15	20.0	21.5	18.4	15.5	13.5	11.4	7.0
18	18.0	20.5	17.6	15.4	13.0	11.0	7.0
21	16.5	20.0	0	0	0	0	0

Table 25. List of abbreviations.

Abbreviation	Definition
cfs	Cubic feet per second
cm.	Centimeter
^oC	Degree centigrade
^oF	Degree Farenheit
ft.	Foot
FWPCA	Federal Water Pollution Control Administration
in.	Inch
kg	Kilogram
$kg \cdot yr^{-1} \cdot ha^{-1}$	Kilograms per year per hectare
lb	Pound
$mg \cdot l^{-1}$	Milligrams per liter
$mg \cdot m^{-2} \cdot day^{-1}$	Milligrams per square meter per day
ppm	Parts per million
USDC	United States Department of Commerce
USDI	United States Department of Interior
USGS	United States Geologic Survey
μ	Micron
$\mu g \cdot l^{-1}$	Micrograms per liter
$\mu g \cdot g^{-1}$	Micrograms per gram
m	Meter

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