

WATER-QUALITY ASSESSMENT OF FRANCIS E. WALTER RESERVOIR,  
LUZERNE AND CARBON COUNTIES, PENNSYLVANIA

By James L. Barker

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## FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

<u>Multitply inch-pound units</u>	<u>By</u>	<u>To obtain SI units</u>
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
acres	$4.047 \times 10^{-3}$	square kilometers (km <sup>2</sup> )
square miles (mi <sup>2</sup> )	2.590	square kilometers (km <sup>2</sup> )
acre-feet (acre-ft)	$1.233 \times 10^{-6}$	cubic kilometers (km <sup>3</sup> )
cubic feet per second (ft <sup>3</sup> /s)	0.02832	cubic meters per second (m <sup>3</sup> /s)
pounds per acre (lbs/acre)	1.1208	kilograms per square hetometer (kg/hm <sup>2</sup> )
tons (short)	0.9072	megagram (Mg)

## DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

WATER-QUALITY ASSESSMENT OF FRANCIS E. WALTER RESERVOIR  
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ABSTRACT

Water-quality data, both past and present, show that the waters of the upper Lehigh River basin are somewhat acidic, but otherwise are generally of good quality. This report contains a summary of all known water-quality data, collected by the U. S. Geological Survey and other agencies, as well as a synopsis of current water-quality conditions in the reservoir and its tributaries.

Water-quality data collected from June 1981 to May 1982 indicate that raising the pool level from 1,300 to approximately 1,392 feet above sea level (NGVD of 1929) has had some significant, if only temporary, detrimental impacts on the reservoir system and its discharge. Depth profile measurements show that, while the impoundment was thermally stratified for only about 2 weeks, the dissolved oxygen concentrations were depressed to levels critical to fishlife throughout much of the reservoir. Another effect of the raised pool was the lowering of pH in the impounded water. Median pH values were less than 6.0 throughout the reservoir, whereas they commonly exceeded 6.5 at the normal pool elevation. Tests for fecal coliform and fecal streptococcus indicate the impounded water is nearly free of enteric bacteria. Algal analyses and nutrient concentrations support the premise that the impoundment is nutrient poor and phosphorus limited.

Raising the water level an additional 125 feet should have no permanent detrimental effect upon water quality and will greatly increase available habitat for fish and waterfowl. Increased retention time should not alter the current trophic status and may decrease the concentration of available nutrients.

INTRODUCTION

Study Area

Francis E. Walter Reservoir, originally known as Bear Creek Reservoir, is on the boundary of Luzerne and Carbon Counties (Fig. 1). It is a manmade impoundment created in 1961 by damming the Lehigh River at the confluence with Bear Creek. The 289 mi<sup>2</sup> drainage basin above the dam is predominantly forested with little development; however, recent commercial enterprises such as a ski area and a growing shopping plaza, and increasing numbers of permanent and seasonal homes have increased the potential for environmental degradation.

The reservoir is currently operated as a flood control project with incidental recreation benefits that include fishing and white-water boating.

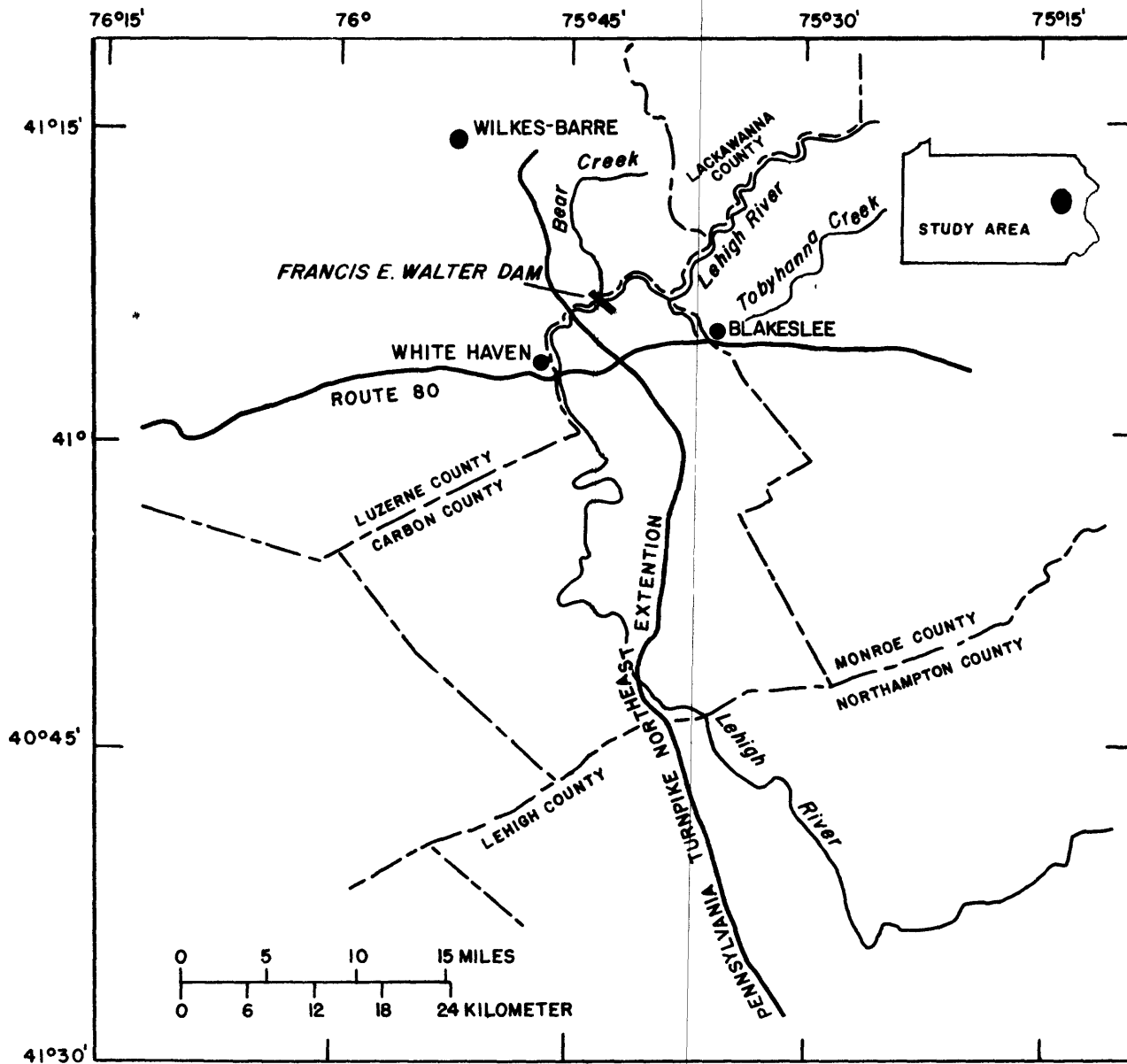


Figure 1.--Location of Francis E. Walter reservoir.

## Objectives and Scope

The principal objectives of this study were to assess the past and current water quality of the impoundment, its major tributaries, and its discharge, and to address the environmental impact of raised pool levels. Data collection was directed toward documenting the temporal and spatial variations in physical, chemical, and biological characteristics of the water, to estimate annual nutrient and suspended sediment loading, and to determine the algal biomass, dominant genera, algal growth potential, and limiting nutrient.

## Previous Studies

Water chemistry and biological data for streams in the upper Lehigh River basin dating back to 1944 provide a historical record and basis for comparing present data. The earlier published data that were intermittantly collected from 1944 to 1966 are found in U.S. Geological Survey Water-Supply Paper 1879-H by McCarren and Keighton (1969). These analyses consisted of what were then known as a "standard complete analysis," and consisted of the major cations and anions, dissolved solids, hardness, total acidity, specific conductance, pH, and color. The results of these analyses, presented in table 1, indicate the water entering the reservoir from Bear and Tobyhanna Creeks and the Lehigh River was of excellent quality - pH 5.3 to 7.1 and specific conductance ranged from 22 to 57 micromhos.

In 1965 and 1966 field studies of the Lehigh River drainage basin were conducted in a cooperative study by the Delaware River Basin Commission, the Pennsylvania Fish Commission, and the Pennsylvania Department of Health. "The primary objective of this investigation was to determine the relation between water quality of the Lehigh River and its biological productivity." (Pollison and Craighead, 1968). The investigation included the quantitative and qualitative measurement of macroinvertebrates, fishes, and vascular plants. Physical and chemical properties were also determined. The report concludes that from the headwaters to White Haven "the chemical and biological results indicate a high level of water quality and low productivity of the biota."

The Pennsylvania Department of Environmental Resources (PaDER) conducted a water-quality sampling program from January 1976 to November 1978 at station 01447500 (Lehigh River gage at Stoddartsville) and Station 014477.20 (Tobyhanna Creek gage near Blakeslee, fig. 2). These analyses were done three to five times a year. The PaDER analyses indicate there has been little, if any, change in water quality over the past 40 years. The maintenance of high quality water has been largely due to the slow development of the basin. The results are summarized in table 2.

Beginning in 1975 and continuing through 1980, various monitoring programs by private laboratories under contract to the U.S. Army Corps of Engineers, Philadelphia District, have collected and analyzed water samples from the upper Lehigh River drainage basin. These samples were collected monthly during the nongrowing season and biweekly during the growing season. The results of this long-term data-collection program are presented in the form of a statistical summary in table 3. The raw data are on file at the Corps of Engineers, Philadelphia District.



Table 1.--Summary of historical water-quality data, collected by U.S. Geological Survey, 1944-66  
(Concentrations in milligrams per liter, except as noted)

(Concentrations in milligrams per liter, except as noted)																				
Date of collection	Mean discharge (ft <sup>3</sup> /s)	Silica SiO <sub>2</sub>	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium and Potassium (K)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids (residue at 180°C)	Calcium and magnesium as CaCO <sub>3</sub>	Specific conductance (μmho)	pH (units)	Color (Pt.-Co.)	
Station 014475.00, Lehigh River at Stoddartsville																				
July 29, 1944	49	2.4	0.02	---	4.3	1.1	---	1.7	---	9	8.0	2.0	0.1	0.2	29	15	39	6.2	25	
April 2, 1945	237	2.1	.03	---	3.5	.9	---	1.0	---	5	8.0	1.0	.2	.3	27	12	34	5.8	30	
Oct. 31, 1945	138	2.9	.01	3.5	1.0	1.0	1.2	---	0.3	6	6.8	1.8	.1	.1	27	13	32	6.0	25	
Oct. 10, 1957	58	---	---	---	---	---	---	9.4	---	6	12	7.5	---	.9	---	8	3	57	5.6	25
Oct. 26, 1960	165	1.9	---	---	3.3	1.2	1.8	---	.9	7	9.2	1.4	.2	.2	40	13	34	6.4	10	
July 12, 1960	85	---	---	---	---	---	---	1.2	---	6	8.6	.5	---	.2	---	12	7	30	6.8	---
Oct. 23, 1963	12	---	---	---	---	---	---	1.8	---	15	5.6	3.0	---	.4	---	19	7	51	6.8	6
Sept. 18, 1964	10	---	---	---	---	---	---	2.1	---	15	7.4	2.0	---	.6	36	19	7	47	6.5	12
June 16, 1966	---	---	---	---	---	---	---	3.0	---	10	8.8	2.0	---	.4	---	14	---	41	6.7	30
Station 014477.20, Tobyhanna Creek near Blakeslee																				
Oct. 31, 1945	159	1.8	0.01	---	2.5	0.8	1.1	0.3	---	6	4.3	1.6	0.2	0.1	22	10	5	22	6.0	37
Oct. 10, 1957	93	---	---	---	---	---	---	3.2	---	10	4.0	1.7	---	.4	---	8	0	37	5.7	30
July 12, 1960	---	---	---	---	---	---	---	1.6	---	5	7.1	1.0	---	.6	---	10	6	29	6.5	---
Oct. 23, 1963	28	---	---	---	---	---	---	2.1	---	10	3.6	2.5	---	.7	---	11	3	33	7.1	8
Sept. 18, 1964	24	---	---	---	---	---	---	1.6	---	10	3.8	1.0	---	1.0	20	11	3	33	6.3	10
Sept. 17, 1966	---	---	---	---	---	---	---	5.5	---	5	7.4	7.0	---	.5	---	10	---	38	6.3	20
Station 014477.50, Bear Creek near White Haven																				
Oct. 31, 1945	53	2.6	0.01	---	2.0	0.8	0.9	0.4	---	2	5.6	1.2	0.1	0.1	19	9	7	22	5.8	12
April 20, 1960	41	---	---	---	---	---	---	3.0	---	7	8.8	1.5	---	.3	35	10	5	35	6.6	4
July 12, 1960	---	---	---	---	---	---	---	3.2	---	4	6.9	3.0	---	.4	---	8	5	25	5.5	---
Oct. 4, 1960	58	---	---	---	---	---	---	.5	---	2	4.8	1.5	---	.4	---	10	9	27	5.3	9
July 11, 1962	3.5	---	---	---	---	---	---	4.6	---	8	6.3	5.0	---	1.0	---	11	5	45	6.7	5
May 13, 1963	84	---	---	---	---	---	---	1.2	---	4	6.8	1.0	---	.4	---	10	7	39	5.7	4
Sept. 16, 1963	2.6	---	---	---	---	---	---	3.2	---	8	4.8	3.5	---	.8	---	10	4	43	6.8	22
Sept. 23, 1964	---	---	---	---	---	---	---	4.4	---	12	4.8	5.5	---	.7	47	14	4	52	6.4	25
Station 014478.00, Lehigh River below Francis R. Walter Reservoir near White Haven																				
Oct. 23, 1963	61	---	---	---	---	---	---	1.4	---	8	4.8	2.0	---	0.6	---	12	6	35	6.8	6
Sept. 18, 1964	41	---	---	---	---	---	---	1.6	---	8	5.6	2.0	---	1.0	31	13	7	35	6.2	15

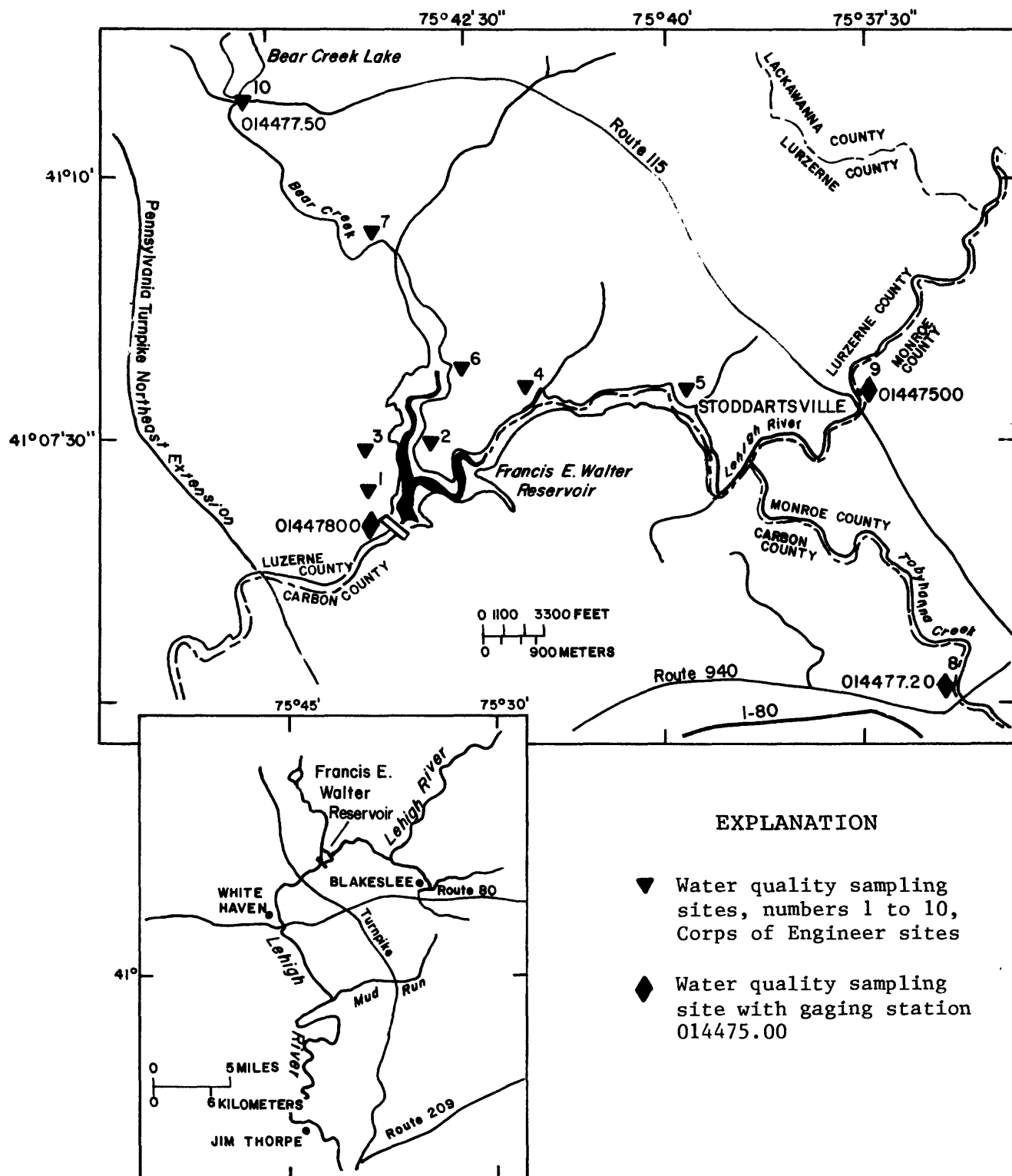


Figure 2.--Francis E. Walter Reservoir showing existing and proposed water levels, major tributaries, and water quality sampling sites.

Table 2.--Summary of historical water-quality data collected by Pennsylvania Department of Environmental Resources, 1976-78  
(Concentrations in milligrams per liter, except as noted)

DATE	LABORATORY ANALYSIS										Mean daily stream flow (cfs/s)	FIELD ANALYSIS		Temperature (°C)	Dissolved Oxygen	pH (units)	Total Phosphorus	Turbidity (NTU units)	Alkalinity	Hardness as CaCO <sub>3</sub>	Chlorides as Cl	Sulfate as SO <sub>4</sub>	Calcium Ca	Magnesium Mg	Total Iron as Fe	Specific Conductance (micromhos/cm @25°C)	Nitrite NO <sub>2</sub>	Nitrate NO <sub>3</sub>	Ammonia NH <sub>3</sub>	Total Coliforms No./100mL	Fecal Coliforms No./100mL

Station 014475.00, Lehigh River at Stoddartsville																																	
01-22-76	127	0	12.0	7.8	0.05	1.0	12	17	10	14	4.8	1.0	0.150	50	0.088	0.64	0.020	-	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-
02-26-76	335	5.0	11.4	7.0	0.07	1.5	10	41	4	12	5.6	6.5	0.180	50	0.082	.72	.040	-	12	8	-	-	-	-	-	-	-	-	-	-	-	-	-
03-12-76	139	11.5	10.1	6.9	0.07	1.5	16	20	4	16	4.0	2.0	0.110	40	0.082	.42	.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08-10-76	478	18.0	11.0	7.3	0.04	5.0	8	21	9	8	4.8	2.3	0.59	39	0.028	.42	.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-09-76	189	4.0	11.0	7.5	0.03	2.5	20	20	9	8	8.0	1.0	0.46	70	0.016	.54	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-24-77	121	1.0	-	-	-	<1.0	14	20	6	5	5.6	1.5	0.15	50	0.018	.64	.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03-22-77	49	13.0	11.2	6.0	0.04	1.0	22	10	6	8	4.8	0	0.13	35	0.032	.58	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-15-77	339	3.0	12.4	9.45	0.04	5.0	2	14	4	10	4.0	6.1	0.22	41	0.028	.60	.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-23-78	108	-10	-	-	0.11	1.0	18	27	4	40	2.4	4.95	0.011	40	0.03	.68	.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03-18-78	1130	10	8.0	9.5	0.06	2.0	10	10	7	10	2.4	1.1	0.22	45	0.02	.76	.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-27-78	26	22	7.8	-	0.07	1.5	16	25	6	15	5.6	3.9	0.14	50	0.01	.44	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-16-78	43	8.0	11.4	-	0.17	<1.0	16	28	6	5	2.4	5.5	0.11	50	0.016	.46	.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Station 014477.20, Tobyhanna Creek near Blakeslee																																	
01-22-76	139	0	12.0	7.8	0.05	1.0	10	18	9	16	4.8	1.5	0.280	60	0.108	0.76	0.030	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-26-76	407	5.0	10.8	6.8	0.05	2.0	6	36	7	4	4.0	6.5	0.140	40	0.058	.68	.020	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
05-12-76	216	12.0	9.7	6.8	0.07	3.0	8	<10	6	14	3.2	-	0.24	40	0.04	.46	.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08-10-76	876	18.0	11.0	7.8	0.04	4.0	10	17	10	8	2.2	2.3	0.56	37	0.034	.58	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-09-76	277	9.0	11.0	7.8	0.03	4.5	26	30	9	8	4.5	3.0	0.88	80	0.022	.52	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-23-77	124	2.0	-	5.9	0.05	1.0	12	20	11	5	5.6	1.5	0.15	92	0.038	.66	.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03-22-77	106	14.0	11.0	6.7	0.04	5.5	18	10	8	8	3.2	2.5	0.44	40	0.024	.62	.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-15-77	531	4.0	11.8	5.6	0.04	5.0	6	14	7	10	3.2	1.65	0.33	40	0.04	.62	.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-23-78	170	-4.0	-	-	0.31	1.0	10	14	8	4	2.4	2.2	0.15	41	0.02	.54	.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03-18-78	1850	10	8.8	8.2	0.07	4.0	8	10	8	10	2.4	1.1	0.3	45	0.01	.68	.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-27-78	53	22	5.5	-	0.97	2.0	10	28	8	15	2.4	6.05	0.3	47	0.01	.90	.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-16-78	34	5.0	10.9	-	0.26	1.0	12	20	9	5	3.2	3.0	0.19	49	0.02	.60	.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.--Summary of historical water-quality data collected by consultants, 1975-80<sup>1</sup>

(Concentrations in milligrams per liter, except as noted)

	Minimum	Maximum	Mean	Standard Deviation
<u>Station 014477.50, Bear Creek, 32 samples</u>				
pH (units)	4.9	7.3	-	-
Dissolved oxygen	6.2	13.6	10.5	1.95
Solids, dissolved	6	134	38.8	25.6
Specific conductance (micromhos/cm @ 25°C)	15	72	46	12.9
Ammonia-N	<.01	.22	<.10	.04
Nitrite and Nitrate-N	<.01	.18	.05	.05
Phosphorus, total	<.003	.039	.01	.01
<u>Station 014475.00, Lehigh River, 90 samples</u>				
pH (units)	5.3	7.5	-	-
Dissolved oxygen	6.6	13.6	9.9	2.2
Solids, dissolved	9.2	240	48.6	35.7
Specific conductance (micromhos/cm @ 25°C)	18	95	43.0	11.2
Ammonia-N	<.01	.88	.29	.48
Nitrite and Nitrate-N	<.01	1.0	.27	.32
Phosphorus, total	0	1.27	.08	.22
<u>Station 014477.20, Tobyhanna Creek, 94 samples</u>				
pH (units)	4.8	8.8	-	-
Dissolved oxygen	5.7	14.5	9.9	2.0
Solids, dissolved	10	234	54.4	43.2
Specific conductance (micromhos/cm @ 25°C)	14	89	41.9	11.6
Ammonia-N	<.01	1.25	.27	.30
Nitrite and nitrate-N	<.01	1.71	.29	.35
Phosphorus, total	<.003	.39	.06	.09
<u>Station 014478.00, Lehigh River below Francis E. Walter Reservoir near White Haven, 78 samples</u>				
pH (units)	4.6	6.8	-	-
Dissolved oxygen	6.2	13.5	11.0	9.9
Solids, dissolved	<.1	200	50.8	35.2
Specific conductance (micromhos/cm @ 25°C)	20	54	39	7
Ammonia-N	<.01	1.07	.29	.26
Nitrite and Nitrate-N	<.01	1.5	.32	.32
Phosphorus, total	0	1.27	.16	.37

<sup>1</sup> Buchart-Horn, York, PA;  
Betz-Converse-Murdoch, Inc, Plymouth Meeting, PA.

In July 1975, the Pennsylvania Fish Commission conducted a survey at Francis E. Walter Reservoir that consisted of profiling the deepest part of the reservoir for temperature, dissolved oxygen, pH, and alkalinity. These data, which are also on file at the Corps of Engineers office, indicate two significant facts: the reservoir did not thermally stratify and the dissolved oxygen content remained high throughout the water column.

In June 1978, the Geological Survey completed a 1-year investigation to determine the loading and average annual transport of phosphorus to the Francis E. Walter Reservoir from gaged and ungaged tributaries. The results indicated an areal loading rate of 15.3g P/m<sup>2</sup>/yr, and an average annual transport of approximately 6 tons. These estimates may be low because of insufficient high-flow data. Studies by Vollenweider (1975), indicate reservoirs similar to Francis E. Walter Reservoir remain relatively low in nutrients because of the short retention time.

### Materials and Methods

Water quality of the tributaries was measured during scheduled monthly field trips and unscheduled storm sampling beginning June 23, 1981. Table 4 lists the Geological Survey and Corps of Engineers sampling stations. The sampling stations on the Lehigh River and Tobyhanna Creek tributaries coincide with stream-gaging stations maintained and operated by the U.S. Geological Survey.

Stream measurement of temperature, dissolved oxygen, pH, and specific conductance were made at all stream sampling stations with a Hydrolab Series 4041<sup>1</sup> multiparameter monitor.

Water samples for chemical analyses were collected with a Kemmerer type water sampler and placed in clean plastic bottles. Water samples for dissolved constituents were filtered through 0.45 micron filters. Nitrogen and phosphorus samples were preserved with mercuric chloride and chilled to 4°C until analyzed at the U.S. Geological Survey Atlanta Central Laboratory. Inorganic chemical constituents were determined by methods described by Skougstad and others, (1979), biological constituents by methods described by Greeson and others, (1977), and suspended sediment by methods described by Guy (1969).

Suspended sediment, total phosphorus, and total nitrogen loading from the three major tributaries were calculated by the flow-duration-curve method described by Miller, (1951). This method of computation provides long-term average transport and is the method the U.S. Geological Survey has been using for years to determine the suspended-sediment transport in streams based on a few observations. The method is widely accepted as the most accurate, short of daily sampling.

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<sup>1</sup> The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 4.--Water-quality sampling sites in Francis E. Walter Reservoir  
drainage basin

U.S. Geological Survey station number	U.S. Army Corps of Engineers reference number	Location
014477.50	7	Bear Creek near White Haven, Pa.
014477.20	8	Tobyhanna Creek near Blakeslee, Pa.
014475.00	9	Lehigh River at Stoddartsville, Pa.
014478.00	outflow	Lehigh River below Francis E. Walter Reservoir near White Haven, Pa.
410656075431300	1	Spillway pool near surface.
410656075431301		Spillway pool near bottom.
410847075430600	6	Bear Creek arm near surface.
410847075430601		Bear Creek arm near bottom.
410745075394700	5	Lehigh River arm near surface.
410754075394701		Lehigh River arm near bottom.

Samples for bacterial analyses were collected several inches below the surface at midstream from the three major inflow tributaries. They were collected in 250-mL sterile polypropylene bottles and immediately chilled to 4°C. The analyses were done by field personnel within 2 hours using membrane filtration techniques in accordance with methods described by Greeson and others, (1977).

Water quality at the three reservoir stations was characterized by biweekly depth profiles from April 9, 1981 to November 4, 1981. Stream measurements of temperature, dissolved oxygen, pH, and specific conductance, were determined at the lake sites with a multiparameter Hydrolab Corporation Series 7000 water-quality monitor by the U.S. Army Corps of Engineers. Measurements were obtained at 5-foot intervals. The reservoir stations are shown in figure 2. In addition to collecting near surface samples at all three reservoir stations for nutrient, bacteriological, and algal analyses, additional water samples were collected near the bottom for nutrient analyses. Transparencies were obtained with a standard 20-cm-diameter Secchi disk attached to a calibrated metal line.

## WATER QUALITY OF STREAMS

### Hydrology

Stream-sampling stations were selected on the basis of their proximity to existing stream-gaging stations and the reservoir. Stream-gaging stations are maintained by the U.S. Geological Survey on Tobyhanna Creek near Blakeslee (station 014477.20), the Lehigh River at Stoddartsville (station 014475.00), and on the Lehigh River near White Haven (station 014478.00), downstream of the dam. The fourth stream-sampling site (station 01477.50) is on Bear Creek near White Haven. Flow-duration curves developed by the U.S. Geological Survey for the Lehigh River, Tobyhanna Creek, and Bear Creek are shown in figure 3.

The drainage area at the outlet of Frances E. Walter Reservoir is 289 mi<sup>2</sup>. The size of the drainage of each major tributary and its contribution to the annual flow is summarized in table 5. Note that 87 percent of the annual inflow is gaged.

As shown in figure 4, the beginning of the 10-month sampling period was relatively dry. Streamflow on the dates sampled in July through October was less than the 4-year monthly average. The sample in late October represented a storm sample.

Additional evidence of lower-than-normal streamflows prior to and during the sampling period is presented in figure 5 from precipitation data gathered at the National Weather Service station at Francis E. Walter Reservoir. The departure below normal precipitation during 1980 was about 16 inches and during 1981, about 7 inches.

The remainder of this section is concerned with selected measurements related to the current water quality of tributary and outflow water. A listing of the chemical, physical and biological data collected at these sites is given in table 6. A statistical summary of these data is presented in table 7.

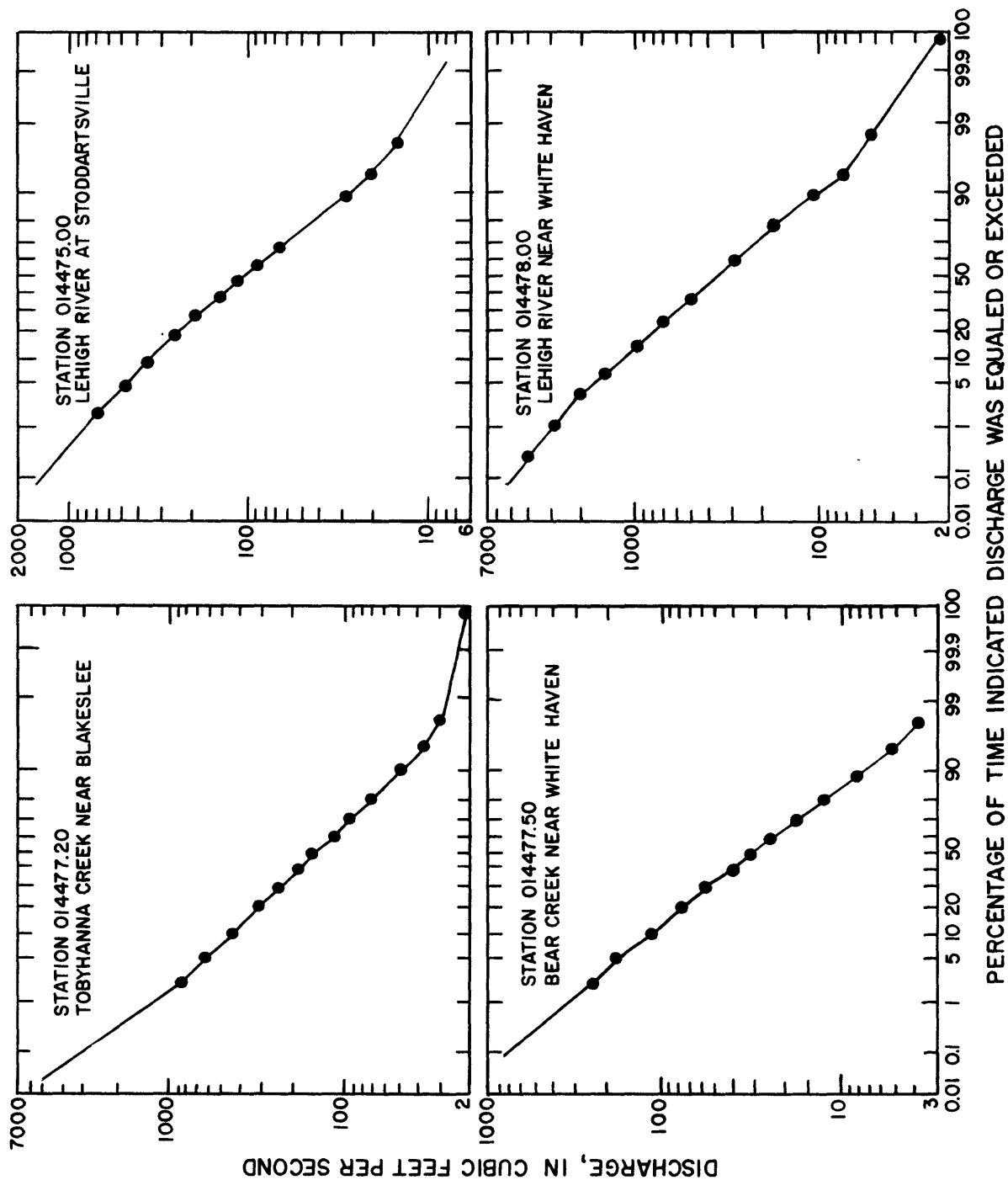


Figure 3.--Flow-duration curves of daily discharges.



Table 5.--Water balance for Francis E. Walter Reservoir  
(Based on 1980 Water Year Data)

Item	<u>Average annual flow</u>		<u>Drainage Area</u>	
	Cubic feet per second	Percent	square mile	Percent
Tobyhanna Creek near Blakeslee, Pa. Station 014477.20.	264	42	118	41
Lehigh River at Stoddartsville, Pa. Station 014475.00.	188	31	91.7	32
Bear Creek near White Haven, Pa. Station 014477.50.	87	14	40	14
Ungaged inflow	82	13	40.67	14
Lehigh River near White Haven, Pa. Station 014478.00 (regulated flow).	620	100	290	100

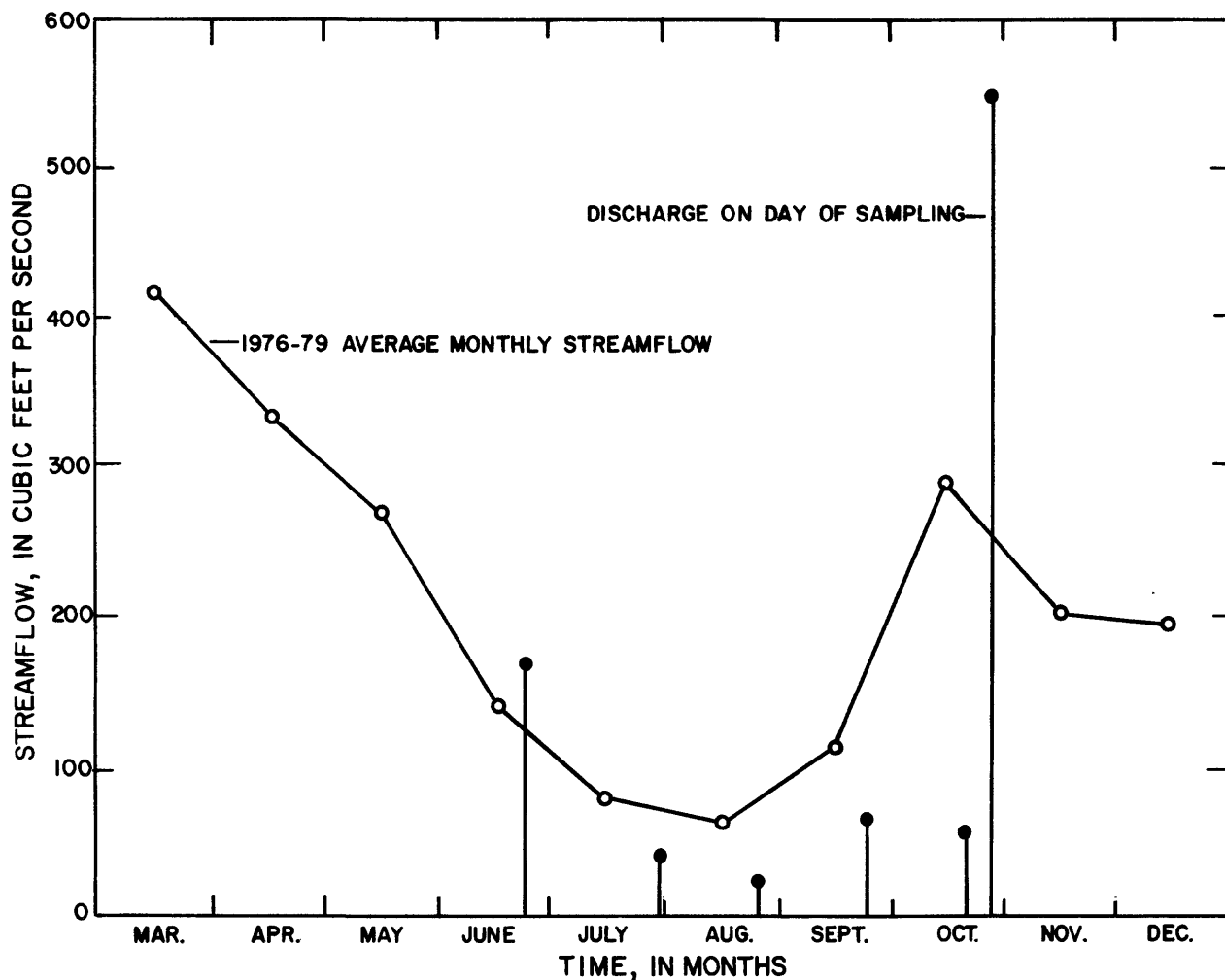


Figure 4.--Comparison of average monthly streamflow with streamflow on days of sampling, Lehigh River at Stoddartsville.

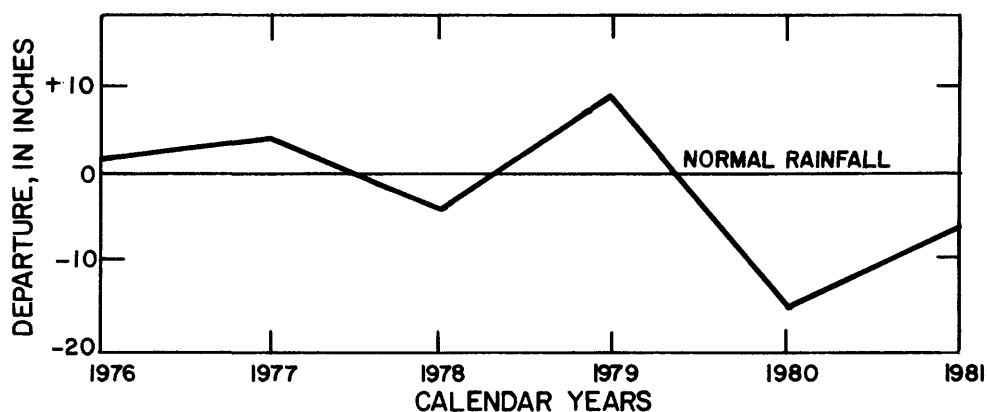


Figure 5.--Precipitation departure from normal. Data from National Weather Service Station at Francis E. Walter Reservoir.

Table 6.--Stream water-quality data collected from June 1981 to May 1982

(Concentrations in milligrams per liter, except as noted)

Date	Temperature (°C)	Specific conductance (umhos)	Stream flow, instantaneous (ft <sup>3</sup> /s)	Oxygen, dissolved (mg/L)	pH	Nitro- gen, total (mg/L as N)	Nitro- gen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitro- gen, total (mg/L as NO <sub>3</sub> )	Coli- form, fecal, 0.7 UM-MF (cols./ 100 mL)	Strep- tococci, fecal, KF agar (cols. per 100 mL)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, dissolved (mg/L as P)	Nitro- gen, ammonia total (mg/L as N)
Station 014475.00, Lehigh River at Stoddartsville, Pa.														
1981:														
June 23...	18.5	39	172	9.4	6.4	0.71	0.11	3.1	75	1500	0.017	0.039	0.005	<0.010
July 28...	19.0	41	49	9.2	6.0	.28	.01	1.2	29	250	.008	—	.000	.010
Aug. 25...	20.9	46	25	10.0	7.9	.71	.05	3.1	10	80	.022	.023	.006	.240
Sept. 23...	12.1	46	73	10.3	5.9	.51	.10	2.3	55	50	.012	.017	.005	.030
Oct. 20...	6.1	36	63	11.0	5.8	.41	.05	1.8	9	1	.005	.003	.005	<0.010
Oct. 28...	—	45	550	—	5.7	.36	.11	1.6	—	—	.010	.033	<.001	.030
1982:														
Jan. 28...	0.1	32	203	13.8	5.8	.64	.25	2.8	—	—	.005	.013	.005	.050
April 05...	2.8	29	604	14.1	5.6	.54	.11	2.4	—	—	.008	.009	.004	.060
May 04...	12.8	35	180	10.4	5.7	.51	.07	2.2	<1	118	<.010	.016	<.010	.020

	Nitro- gen, am- monia + organic total (mg/L as N)	Magne- sium, dis- solved (mg/L as Mg)	Calcium dis- solved (mg/L as Ca)	Chlo- ride, dis- solved (mg/L as Cl)	Hard- ness (mg/L as CaCO <sub>3</sub> )	Manga- nese, dis- solved (µg/L as Mn)	Sodium dis- solved (mg/L as Na)	Sulfate dis- solved (mg/L as SO <sub>4</sub> )	Iron, dis- solved (µg/L as Fe)	Sedi- ment, dis- charge, sus- pended (Ton/d)	Sedi- ment, sus- pended (mg/L)	Alka- linity lab (mg/L as CaCO <sub>3</sub> )
1981:												
June 23...	0.60	—	—	—	—	—	—	—	—	3.3	7	—
July 28...	.27	—	—	—	—	—	—	—	—	—	—	—
Aug. 25...	.66	—	—	—	—	—	—	—	—	.21	3	—
Sept. 23...	.41	1.1	4.7	4.4	16	20	0.3	2.4	7.6	.20	1	—
Oct. 20...	.36	—	—	—	—	—	—	—	—	.17	1	—
Oct. 28...	.25	—	—	—	—	—	—	—	—	18	12	—
1982:												
Jan. 28...	.39	—	—	—	—	—	—	—	—	—	—	—
April 05...	.43	—	—	3.7	—	—	—	8.4	—	—	—	3.0
May 04...	.44	—	—	—	—	—	—	—	—	—	—	—

Date	Temperature (°C)	Specific conductance (umhos)	Stream flow, instantaneous (ft <sup>3</sup> /s)	Oxygen, dissolved (mg/L)	pH	Nitro- gen, total (mg/L as N)	Nitro- gen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitro- gen, total (mg/L as NO <sub>3</sub> )	Coli- form, fecal, 0.7 UM-MF (cols./ 100 mL)	Strep- tococci, fecal, KF agar (cols. per 100 mL)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, dissolved (mg/L as P)	Nitro- gen, ammonia total (mg/L as N)
Station 014477.20, Tobyhanna Creek near Blakeslee, Pa.														
1981:														
June 23...	18.5	39	306	8.6	5.8	0.54	0.06	2.4	70	110	<0.017	0.024	<0.001	<0.010
July 28...	18.8	33	191	8.6	5.7	.53	.07	2.3	20	420	.002	.006	<.001	<.010
Aug. 25...	17.4	36	269	8.9	5.9	.41	.08	1.8	18	154	.004	<.001	.004	.020
Sept. 23...	12.9	37	120	10.1	5.6	.67	.09	2.9	9	242	.011	.022	.005	.040
Oct. 20...	5.5	33	78	11.0	5.8	.82	.05	3.6	4	0	.005	.007	.007	.050
Oct. 28...	—	49	459	—	5.9	.31	.08	1.4	—	—	.008	.026	<.001	.040
1982:														
Jan. 28...	.1	34	224	14.8	5.7	.70	.34	3.1	—	—	.005	.008	.005	.060
April 05...	3.1	31	1170	13.8	4.4	—	—	—	—	—	.007	.018	.005	.040
May 04...	12.0	29	229	10.8	5.5	.65	.10	2.9	<1	80	<.010	.017	<.010	.020

	Nitro- gen, am- monia + organic total (mg/L as N)	Magne- sium, dis- solved (mg/L as Mg)	Calcium dis- solved (mg/L as Ca)	Chlo- ride, dis- solved (mg/L as Cl)	Hard- ness (mg/L as CaCO <sub>3</sub> )	Manga- nese, dis- solved (µg/L as Mn)	Sodium dis- solved (mg/L as Na)	Sulfate dis- solved (mg/L as SO <sub>4</sub> )	Iron, dis- solved (µg/L as Fe)	Sedi- ment, dis- charge, sus- pended (Ton/d)	Sedi- ment, sus- pended (mg/L)	Acidity (mg/L as H)	Acidity (mg/L as CaCO <sub>3</sub> )	Alka- linity lab (mg/L as CaCO <sub>3</sub> )
1981:														
June 23...	0.48	—	—	—	—	—	—	—	—	3.3	4	—	—	—
July 28...	.46	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug. 25...	.33	—	—	—	—	—	—	—	—	1.5	2	—	—	—
Sept. 23...	.58	0.9	3.3	5.5	12	30	0.4	2.9	6.4	.32	1	—	—	—
Oct. 20...	.77	—	—	—	—	—	—	—	—	.21	1	—	—	—
Oct. 28...	.23	—	—	—	—	—	—	—	—	12	10	—	—	—
1982:														
Jan. 28...	.36	—	—	—	—	—	—	—	—	—	—	—	—	—
April 05...	<.10	—	—	6.0	—	—	—	6.5	—	—	—	—	0.1	5.0
May 04...	12.55	—	—	—	—	—	—	—	—	—	—	—	—	—

See footnote at end of table.

Table 6.—Stream water-quality data collected from June 1981 to May 1982—(continued)

(Concentrations in milligrams per liter, except as noted)

Date	Temperature (°C)	Specific conductance (µmhos)	Stream flow, instantaneous (ft <sup>3</sup> /s)	Oxygen, dissolved (mg/L)	pH	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen, total (mg/L as NO <sub>3</sub> )	Coli- form, fecal, 0.7 UM-MF (cols./ 100 mL)	Strep- tococci fecal, KF agar (cols. per 100 mL)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, total (mg/L as P)	Phos- phorus, ortho, dis- solved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	
Station 014477.50, Baar Creek near White Haven, Pa.															
1981:															
June 23...	21.0	52	70	9.0	5.0	0.37	0.02	1.6	56	80	0.004	0.028	<0.001	<0.010	
July 28...	21.2	66	22	7.8	4.5	.16	.01	.70	15	240	.004	.004	<.001	.020	
Aug. 25...	20.7	66	9.0	7.8	4.8	.29	.05	1.3	10	68	.005	<.001	.001	.020	
Sept. 23...	13.9	65	22	9.5	4.5	.42	.04	1.8	3	36	.005	.015	.005	.020	
Oct. 20...	6.9	39	19	10.7	4.3	.37	.05	1.6	41	13	.011	.003	.004	<.010	
Oct. 28...	—	51	—	—	4.9	.34	.11	1.5	—	—	.011	.012	<.001	.220	
1982:															
Jan. 28...	.2	93	67	13.2	4.8	.45	.14	2.0	—	—	.010	.009	.005	.050	
April 05...	1.6	50	230	14.6	4.1	.45	.03	2.0	—	—	.008	.011	.005	.050	
May 04...	13.2	45	56	10.0	4.4	.72	.02	3.2	1	46	<.010	.010	<.010	.020	
	Nitrogen, ammonia + organic total (mg/L as N)	Magnesium, dissolved (mg/L as Mg)	Calcium Dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Hardness (mg/L as CaCO <sub>3</sub> )	Manganese, dissolved (µg/L as Mn)	Sodium adsorption ratio	Sodium, dissolved (mg/L as Na)	Sulfate dissolved (mg/L as SO <sub>4</sub> )	Iron, dissolved (µg/L as Fe)	Sediment, discharge, suspended (Ton/d)	Sediment, suspended (mg/L)	Acidity (mg/L as H)	Acidity (mg/L as CaCO <sub>3</sub> )	Alkalinity lab (mg/L as CaCO <sub>3</sub> )
1981:															
June 23...	0.35	—	—	—	—	—	—	—	—	—	0.76	4	—	—	—
July 28...	.15	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug. 25...	.24	—	—	—	—	—	—	—	—	—	.02	1	—	—	—
Sept. 23...	.38	1.2	2.3	15	11	60	0.9	6.8	7.1	180	.06	1	—	—	—
Oct. 20...	.32	—	—	—	—	—	—	—	—	—	.05	1	—	—	—
Oct. 28...	.23	—	—	—	—	—	—	—	—	—	.50	1	—	—	—
1982:															
Jan. 28...	.31	—	—	—	—	—	—	—	—	—	—	—	—	—	—
April 05...	.42	—	—	8.7	—	—	—	—	9.1	—	—	—	0.1	5.0	<1.0
May 04...	.70	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Nitrogen, ammonia + organic total (mg/L as N)	Magnesium, dissolved (mg/L as Mg)	Calcium Dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Hardness (mg/L as CaCO <sub>3</sub> )	Manganese, dissolved (µg/L as Mn)	Sodium adsorption ratio	Sodium, dissolved (mg/L as Na)	Sulfate dissolved (mg/L as SO <sub>4</sub> )	Iron, dissolved (µg/L as Fe)	Sediment, discharge, suspended (Ton/d)	Sediment, suspended (mg/L)	Acidity (mg/L as H)	Acidity (mg/L as CaCO <sub>3</sub> )	Alkalinity lab (mg/L as CaCO <sub>3</sub> )
1981:															
June 23...	17.0	—	786	10.0	5.7	0.52	0.02	2.3	—	—	<0.001	0.021	<0.001	0.240	
July 28...	19.0	42	172	8.7	5.4	.49	.01	2.1	—	—	.017	.028	.007	.200	
Aug. 25...	19.8	44	41	8.6	5.6	.58	.07	2.6	—	—	.002	.017	.021	.020	
Sept. 23...	15.6	41	44	9.1	5.8	.56	.08	2.5	—	—	.005	.023	.005	.060	
Oct. 20...	12.1	34	182	10.3	5.5	.93	.05	4.1	—	—	.005	.009	.005	.070	
1982:															
April 05...	3.9	35	2710	13.6	5.3	.64	.15	2.8	—	—	.009	.011	.006	.060	
May 04...	11.4	24	502	4.6	5.6	—	<.09	—	1	23	<.010	.011	<.010	.030	
	Nitrogen, ammonia + organic total (mg/L as N)	Magnesium, dissolved (mg/L as Mg)	Calcium Dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Hardness (mg/L as CaCO <sub>3</sub> )	Manganese, dissolved (µg/L as Mn)	Sodium adsorption ratio	Sodium, dissolved (mg/L as Na)	Sulfate dissolved (mg/L as SO <sub>4</sub> )	Iron, dissolved (µg/L as Fe)	Sediment, discharge, suspended (Ton/d)	Sediment, suspended (mg/L)	Acidity (mg/L as H)	Acidity (mg/L as CaCO <sub>3</sub> )	Alkalinity lab (mg/L as CaCO <sub>3</sub> )
1981:															
June 23...	0.50	—	—	—	—	—	—	—	—	—	—	—	—	—	—
July 28...	.48	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug. 25...	.51	—	—	—	—	—	—	—	—	—	0.56	5	—	—	—
Sept. 23...	.48	0.9	3.2	5.3	12	80	0.3	2.7	6.3	120	.12	1	—	—	—
Oct. 20...	.88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1982:															
April 05...	.49	—	—	6.8	—	—	—	—	7.4	—	—	—	—	3.0	—
May 04...	.72	—	—	—	—	—	—	—	—	—	—	—	—	—	—

<sup>1</sup> Best estimated based upon nonideal counting conditions.

Table 7.—Statistical summary of stream water-quality data collected from June 1981 to May 1982  
(Concentrations in milligrams per liter, except as noted)

Parameter code	Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean	Sum
Station 014475.00, Lehigh River at Stoddardsville, Pa.								
00010	Temperature (°C)	8	11.54	7.84	0.10	20.90	2.77	92.30
00095	Specific conductance (µmhos)	9	38.72	6.24	29.00	46.00	2.08	348.50
00061	Streamflow, instantaneous (ft <sup>3</sup> /s)	9	213.32	216.03	23.40	604.00	72.01	1,919.90
00300	Oxygen, dissolved (mg/L)	8	11.03	1.89	9.20	14.10	.67	88.20
00400	pH	9	6.09	.72	5.60	7.90	.24	54.80
70507	Phosphorus, ortho, total (mg/L as P)	9	.01	.01	.01	.02	.00	.10
00665	Phosphorus, total (mg/L as P)	8	.02	.01	.00	.04	.00	.15
00671	Phosphorus, ortho, dissolved (mg/L as P)	9	.00	.00	.00	.01	.00	.04
00610	Nitrogen, ammonia total (mg/L as N)	9	.05	.07	.01	.24	.02	.46
00600	Nitrogen, total (mg/L as N)	9	.52	.15	.28	.71	.05	4.67
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	9	.09	.07	.01	.25	.02	.85
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	9	2.28	.86	1.20	3.10	.22	20.50
00930	Sodium, dissolved (mg/L as Na)	1	2.40	—	2.40	2.40	—	2.40
31625	Coliform, fecal, (cols./100mL)	6	29.83	29.44	1.00	75.00	12.02	179.00
31673	Streptococcus, fecal, (cols./100mL)	6	149.83	193.40	1.00	500.00	78.96	899.00
00925	Magnesium, dissolved (mg/L as Mg)	1	1.10	—	1.10	1.10	—	1.10
00915	Calcium dissolved (mg/L as Ca)	1	4.70	—	4.70	4.70	—	4.70
00940	Chloride, dissolved (mg/L as Cl)	2	4.05	0.49	3.70	4.40	.35	8.10
00900	Hardness (Mg/L as CaCO <sub>3</sub> )	1	16.00	—	16.00	16.00	—	16.00
00931	Sodium adsorption ratio	1	.30	—	.30	.30	—	.30
01056	Manganese, dissolved (µg/L as Mn)	1	20.00	—	20.00	20.00	—	20.00
00930	Sodium, dissolved (mg/L as Na)	1	2.40	—	2.40	2.40	—	2.40
00945	Sulfate dissolved (mg/L as SO <sub>4</sub> )	2	8.00	0.57	7.60	8.40	.40	16.00
01046	Iron, dissolved (µg/L as Fe)	1	90.00	—	90.00	90.00	—	90.00
80155	Sediment, discharge, suspended (ton/d)	5	4.38	7.73	.17	18.00	3.46	21.88
80154	Sediment, suspended (mg/L)	5	4.80	4.71	1.00	12.00	2.11	24.00
90410	Alkalinity lab (mg/L as CaCO <sub>3</sub> )	1	3.00	—	3.00	3.00	—	3.00
Station 014477.20, Tobyhanna Creek near Bleckeslee, Pa.								
00010	Temperature (°C)	8	11.04	7.31	0.10	18.80	2.58	88.30
00095	Specific conductance (µmhos)	9	35.71	5.88	29.00	29.00	1.96	321.40
00061	Streamflow, instantaneous (ft <sup>3</sup> /s)	9	338.34	330.58	78.00	1,170.00	110.19	3,045.10
00300	Oxygen, dissolved (mg/L)	8	10.83	2.35	8.60	14.80	.83	86.60
00400	pH	9	5.59	.46	4.40	5.90	.15	50.30
70507	Phosphorus, ortho, total (mg/L as P)	9	.01	.00	.00	.01	.00	.05
00665	Phosphorus, total (mg/L as P)	9	.01	.01	.00	.03	.00	.13
00671	Phosphorus, ortho, dissolved (mg/L as P)	9	.00	.00	.00	.01	.00	.04
00610	Nitrogen, ammonia total (mg/L as N)	9	.03	.02	.01	.06	.01	.29
00600	Nitrogen, total (mg/L as N)	8	.58	.17	.31	.82	.06	4.63
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	8	.11	.09	.05	.34	.03	.86
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	8	2.55	.72	1.40	3.60	.25	20.40
00930	Sodium, dissolved (mg/L as Na)	1	2.90	—	2.90	2.90	—	2.90
31625	Coliform, fecal, (cols./100mL)	6	20.33	25.46	1.00	70.00	10.39	122.00
31673	Streptococcus, fecal, (cols./100mL)	6	167.67	147.31	.00	420.00	60.14	1,006.00
00925	Magnesium, dissolved (mg/L as Mg)	1	.90	—	.90	.90	—	.90
00915	Calcium dissolved (mg/L as Ca)	1	3.30	—	3.30	3.30	—	3.30
00940	Chloride, dissolved (mg/L as Cl)	2	5.75	0.35	5.30	6.00	0.25	11.50
00900	Hardness (mg/L as CaCO <sub>3</sub> )	1	12.00	—	12.00	12.00	—	12.00
00931	Sodium adsorption ratio	1	.40	—	.40	.40	—	.40
01056	Manganese, dissolved (µg/L as Mn)	1	30.00	—	30.00	30.00	—	30.00
00930	Sodium, dissolved (mg/L as Na)	1	2.90	—	2.90	2.90	—	2.90
00945	Sulfate dissolved (mg/L as SO <sub>4</sub> )	2	6.45	0.07	6.40	6.50	0.05	12.90
01046	Iron, dissolved (µg/L as Fe)	2	110.00	—	110.00	110.00	—	110.00
80155	Sediment, discharge, suspended (ton/d)	5	3.47	4.93	.21	12.00	2.20	17.33
80154	Sediment, suspended (mg/L)	5	3.60	3.78	1.00	10.00	1.69	18.00
71825	Acidity (mg/L as H)	1	.10	—	.10	.10	—	.10
00435	Acidity (mg/L as CaCO <sub>3</sub> )	1	5.00	—	5.00	5.00	—	5.00
90410	Alkalinity lab (mg/L as CaCO <sub>3</sub> )	1	2.00	—	2.00	2.00	—	2.00

Table 7.—Statistical summary of stream water-quality data collected from June 1981 to May 1982—(continued)  
(Concentrations in milligrams per liter, except as noted)

Parameter code	Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean	Sum
Station 014475.50, Bear Creek near White Haven, Pa.								
00010	Temperature (°C)	8	12.34	8.61	0.20	21.20	3.40	98.70
00095	Specific conductance (µmhos)	9	58.60	16.10	39.00	93.00	5.37	527.40
00061	Streamflow, instantaneous (ft <sup>3</sup> /s)	8	61.87	71.92	9.00	230.00	25.43	495.00
00300	Oxygen, dissolved (mg/L)	8	10.33	2.45	7.80	14.60	.87	82.60
00400	pH	9	4.58	.30	4.10	5.00	.10	41.25
70307	Phosphorus, ortho, total (mg/L as P)	9	.01	.00	.00	.01	.00	.07
00665	Phosphorus, total (mg/L as P)	9	.01	.01	.00	.03	.00	.09
00671	Phosphorus, ortho, dissolved (mg/L as P)	9	.00	.00	.00	.01	.00	.03
00610	Nitrogen, ammonia total (mg/L as N)	9	.05	.07	.01	.22	.02	.42
00600	Nitrogen, total (mg/L as N)	9	.40	.15	.16	.72	.05	3.57
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	9	.05	.05	.01	.14	.02	.45
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	9	1.74	.67	.70	3.20	.22	15.70
00930	Sodium, dissolved (mg/L as Na)	1	6.80	---	6.80	6.80	---	6.80
31625	Coliform, fecal, (cols./100mL)	6	21.00	22.39	1.00	56.00	9.14	126.00
00925	Streptococcus, fecal, (cols./100mL)	6	80.50	81.64	13.00	240.00	33.33	483.00
00915	Magnesium, dissolved (mg/L as Mg)	1	1.20	---	1.20	1.20	---	1.20
00940	Calcium, dissolved (mg/L as Ca)	1	2.30	---	2.30	2.30	---	2.30
00900	Chloride, dissolved (mg/L as Cl)	2	11.85	4.45	8.70	15.00	3.15	23.70
00931	Hardness (mg/L as CaCO <sub>3</sub> )	1	11.00	---	11.00	11.00	---	11.00
01056	Sodium adsorption ratio	1	.90	---	.90	.90	---	.90
00930	Manganese, dissolved (µg/L as Mn)	1	60.00	---	60.00	60.00	---	60.00
00945	Sulfate, dissolved (mg/L as Na)	1	6.80	---	6.80	6.80	---	6.80
01046	Sulfate dissolved (mg/L as SO <sub>4</sub> )	2	8.10	1.41	7.10	9.10	1.00	16.20
80155	Iron, dissolved (µg/L as Fe)	1	180.00	---	180.00	180.00	---	180.00
80154	Sediment, discharged, suspended (ton/d)	5	.28	.33	.02	.76	.15	1.39
71825	Sediment, suspended (mg/L)	5	1.60	1.34	1.00	4.00	.60	8.00
00435	Acidity (mg/L as H)	1	.10	---	.10	.10	---	.10
90410	Acidity (mg/L as CaCO <sub>3</sub> )	1	5.00	---	5.00	5.00	---	5.00
	Alkalinity lab (mg/L as CaCO <sub>3</sub> )	1	1.00	---	1.00	1.00	---	1.00
Station 014478.00, Lehigh River below Francis E. Walter Reservoir near White Haven, Pa.								
00010	Temperature (°C)	7	14.11	5.51	3.90	19.80	2.08	98.80
00095	Specific conductance (µmhos)	6	36.67	7.37	24.00	44.00	3.01	220.00
00061	Streamflow, instantaneous (ft <sup>3</sup> /s)	7	634.17	955.32	41.20	2,712.00	361.08	4,439.20
00300	Oxygen, dissolved (mg/L)	7	9.27	2.68	4.60	13.60	1.01	64.90
00400	pH	7	5.56	.17	5.30	5.80	.06	38.90
70307	Phosphorus, ortho, total (mg/L as P)	7	.01	.01	.00	.02	.00	.05
00665	Phosphorus, total (mg/L as P)	7	.02	.01	.01	.03	.00	.12
00671	Phosphorus, ortho, dissolved (mg/L as P)	7	.01	.01	.00	.02	.00	.06
00610	Nitrogen, ammonia total (mg/L as N)	7	.10	.09	.02	.24	.03	.68
00600	Nitrogen, total (mg/L as N)	6	.62	.16	.49	.93	.07	3.72
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	7	.07	.05	.01	.15	.02	.46
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	6	2.73	.71	2.10	4.10	.29	16.40
00930	Sodium, dissolved (mg/L as Na)	1	2.70	---	2.70	2.70	---	2.70
31625	Coliform, fecal, (cols./100mL)	1	1.00	---	1.00	1.00	---	1.00
31673	Streptococcus, fecal, (cols./100mL)	1	23.00	---	23.00	23.00	---	23.00
00925	Magnesium, dissolved (mg/L as Mg)	1	.90	---	.90	.90	---	.90
00940	Calcium dissolved (mg/L as Ca)	1	3.20	---	3.20	3.20	---	3.20
00900	Chloride, dissolved (mg/L as Cl)	2	6.05	1.06	5.30	6.80	0.75	12.10
00931	Hardness (mg/L as CaCO <sub>3</sub> )	1	12.00	---	12.00	12.00	---	12.00
01056	Sodium adsorption ratio	1	.30	---	.30	.30	---	.30
00930	Manganese, dissolved (µg/L as Mn)	1	80.00	---	80.00	80.00	---	80.00
00945	Sulfate, dissolved (mg/L as Na)	1	2.70	---	2.70	2.70	---	2.70
00945	Sulfate dissolved (mg/L as SO <sub>4</sub> )	2	6.85	0.78	6.30	7.40	0.55	13.70
01046	Iron, dissolved (µg/L as Fe)	1	120.00	---	120.00	120.00	---	120.00
80155	Sediment, discharged, suspended (ton/d)	2	.34	.31	.12	.56	.22	.68
80154	Sediment, suspended (mg/L)	2	3.00	2.83	1.00	5.00	2.00	6.00
90410	Alkalinity lab (mg/L as CaCO <sub>3</sub> )	1	3.00	---	3.00	3.00	---	3.00

### Temperature

Water temperature is a controlling factor in the biological characteristics of a stream and influences its physical and chemical regime. Pennsylvania Water Quality Standards (1979) stipulate that for the Lehigh River from its source to Route 903 bridge at Jim Thorpe (fig. 2) there shall be no rise when ambient temperature is 58°F or above; not more than 5°F rise above ambient temperature until the stream reaches 58°F and shall not be changed by more than 2°F during any 1-hour period. Temperatures of all waters within the watershed are currently meeting this water-quality criteria. Maximum stream temperatures recorded were 70°F (21°C). There are no heated effluents discharging into the streams.

### Dissolved Oxygen

Dissolved-oxygen concentrations are perhaps the single most important criterion in determining the health of a stream. It is essential that dissolved-oxygen concentrations be maintained above 5.0 mg/L for a viable cold-water fishery. Pennsylvania Water Quality Standards (1979) for streams in the Upper Lehigh River basin stipulate that dissolved oxygen shall not be less than 7.0 mg/L at any time.

Dissolved-oxygen values determined in conjunction with this study indicate that this criterion is being met most of the time. A check of the biweekly and monthly historical data, collected since 1975, indicates that waters of the Lehigh River and Tobyhanna Creek had dissolved-oxygen concentrations of less than 7.0 mg/L, 4 and 5 percent of the time, respectively; but were never less than 5.0 mg/L. Bear Creek had no values less than 7.0 mg/L.

### Value of pH

The term pH is a universal way of expressing the acidity or alkalinity of a solution. More precisely, it is a way of expressing the hydrogen-ion activity. A pH of 7.0 is neutral; greater than 7.0 is considered alkaline and less than 7.0 is considered acidic.

The streams draining into the Francis E. Walter Reservoir are typical of those draining the Appalachian Plateau, with pH values generally ranging from 5.5 to 7.0. The waters of Bear Creek are somewhat more acidic than those of either the Lehigh River or Tobyhanna Creek with pH values normally in the range of 4.3 to 5.0. The acidic waters are believed the result of acidic precipitation (pH 4.3), high concentrations of carbonic and other organic acids that are products of decaying plant matter, and poor buffering capacity of basin soils.

Pennsylvania Water Quality Standards (1979) for the Lehigh River and tributaries from its source to the Francis E. Walter Reservoir, stipulate that the pH shall be not less than 6.0 and not more than 9.0. Based upon the 1975 to 1981 data, the minimum pH of 6.0 is not being met about 12 percent of the time in the Lehigh River and more frequently in the other tributaries. There is some evidence, as reported in the 1980 Corps of Engineers report number RCS-DAEN-CWE-15, that precipitation results in a decrease in stream pH. A decrease is to be expected because any flushing of the forest and bogs would tend to release waters high in organic acids.

### Specific Conductance and Dissolved Solids

Specific conductance is a measure of the ionic strength and ability of a solution to carry an electrical current. Dissolved solids are the anhydrous residues of the dissolved substances in water.

Freestone streams draining the Appalachian Plateau are termed soft waters because they have specific conductances ranging from 22 to 57 micromhos and dissolved solids ranging from 14 to 40 mg/L. (McCarren and Keighton, 1969). The waters of Bear Creek appear to be slightly higher in dissolved solids than either the Lehigh River at Stoddartsville or Tobyhanna Creek near Blakeslee. Reasons for this are not clear but may be related to differences in soils and geology.

Specific conductance and dissolved solids normally tend to follow the increases and decreases in discharge because of the availability of dissolved matter. As noted in previous Corps of Engineers water-quality-data reports 1978 to 1980, the normal relation ( $DS = 0.66 \pm 0.09 K$ ) between dissolved solids and specific conductance is not found. In fact, a regression analysis of 32 data pairs collected at station 014477.50 from 1978 to 1980 failed to show a good correlation. The reason for the poor correlation is not clear but appears to be related to the retention and delayed flushing of highly organic bog material.

### Anions and Cations

Dissolved sodium, calcium, and magnesium were analyzed from each of the major tributaries. Although cations were not routinely quantified as part of this water-quality study, they may be useful for determining future land use and water-quality relationships. Dissolved chloride and sulfate are likewise useful in categorizing water types and land-use changes. Historical water analyses published by McCarren and Keighton (1969) and samples collected on September 23, 1981 and April 5, 1982 show that the dissolved solids in waters tributary to the impoundment are comprised predominantly of calcium and sulfate ions during higher flows and calcium and bicarbonate ions during base flow. Judging by some concentrations dating back to 1944 (McCarren and Keighton, 1969), there have been no significant changes in water chemistry to date (1982) that have affected the total dissolved-solids content.

### Nitrogen

Principal sources of nitrogen to the reservoir ecosystem are forest runoff, swamp and marsh runoff, precipitation on water surface, septic tank runoff, leaves, dust, pollen, waterfowl waste, and fixation by bacteria and blue-green algae.

Forms of nitrogen examined were total nitrite plus nitrate, total ammonia, total ammonia plus organic nitrogen, and total nitrogen. Standards for the upper Lehigh River basin require that nitrite plus nitrate nitrogen not exceed 10 mg/L (Pennsylvania Water Quality Standards, 1979). U. S. Environmental Protection Agency (1976) criterion for ammonia ( $NH_3 + NH_4$ ) is 0.02 mg/L as unionized ammonia. Due to the equilibrium of dissolved ammonia in water the concentrations of total ammonia in the streams tributary to the Francis E. Walter



Reservoir would have to exceed 3.5 mg/L before the criterion would be exceeded. As evidenced by the maximum total ammonia values of 0.24 mg/L, it is unlikely that any un-ionized ammonia exists in the upper Lehigh River drainage. Nitrite plus nitrate concentrations were also well below the state criteria.

The long-term annual averages of total nitrogen loads transported by tributaries to Francis E. Walter Reservoir and outlet stream are estimated in table 8. The total nitrogen inflow from tributary sources is estimated to be 238 tons per year or 0.82 tons per mi<sup>2</sup>. Total nitrogen transport curves for the three tributaries and the outflow are shown in figure 6.

### Phosphorus

Potential sources of phosphorus to the reservoir include agricultural runoff, swamps and forest runoff, domestic waste, and septic-tank discharge. Other sources are direct precipitation on the water surface, dry fallout such as leaves, dust, seeds, and pollen; groundwater influxes, sediment recycling, and aquatic bird and animal wastes.

Species of phosphorus examined were dissolved orthophosphate, total orthophosphate, and total phosphorus. Due to the anticipated low levels of phosphorus present, all analyses were done at a sensitivity level of 0.001 mg/L. While the 1979 Pennsylvania Water-Quality Standards do not have a criterion for phosphorus, the 1976 Environmental Protection Agency Quality Criteria for Water suggests that "to prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates or phosphorus (P) should not exceed 50 µg/L in any stream at the point where it enters any lake or reservoir."

The tributary samples collected from June 1981 to May 1982 indicate the Environmental Protection Agency criterion is not exceeded, even during runoff events. Somewhat higher concentrations were found in the Lehigh River at Stoddartsville than at other sites. The range and mean values found at each stream station are given in the statistical summary in table 7.

The most biologically active form of phosphorus is dissolved orthophosphate. The soluble orthophosphate is readily taken up by green plants, and therefore, is most important for the growth of algal cells. The concentrations of dissolved orthophosphate phosphorus ranged from 0.000 to 0.007 mg/L.

Phosphorus loading from the major tributaries was calculated by the flow-duration method in the same manner as total nitrogen. The long-term annual averages of total phosphorus transported by tributaries to Francis E. Walter Reservoir and outlet stream are estimated in table 9. The total phosphorus inflow from gaged and ungaged tributaries is estimated to be 10 tons per year, or 0.03 tons per mi<sup>2</sup>. Slightly higher loads at the outflows are attributed to higher concentration in the hypolimnetic water. Total phosphorus transport curves for the three tributaries and the outflow are shown in figure 6.

Table 8.--Long-term annual averages of total nitrogen transported by tributaries to Francis E. Walter Reservoir and from reservoir to Lehigh River

(Data in short tons per year)

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Tributary inflow				
Tobyhanna Creek (Sta 014477.20)	Lehigh River (Sta 014475.00)	Bear Creek (Sta 014477.50)	Ungaged	Lehigh River below reservoir (Sta 014478.00)
109.5	75.6	18	35	284.7

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Total inflow = 238 tons per year.

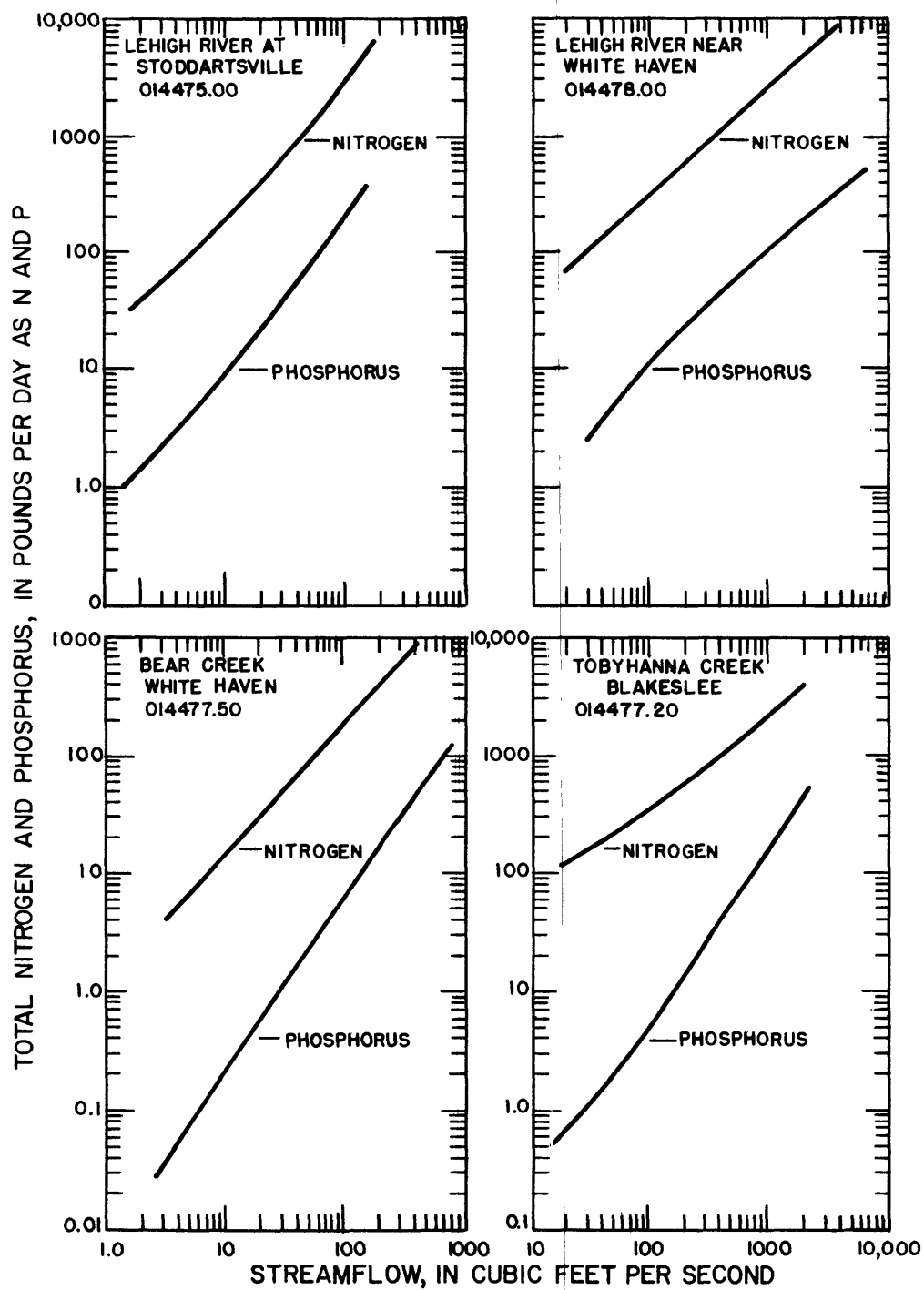


Figure 6.--Nitrogen and phosphorus transport curves for tributary streams.

Table 9.--Long-term annual averages of total phosphorus transported by tributaries to Francis E. Walter Reservoir and from reservoir to Lehigh River

(Data in short tons per year)

Tributary inflow				
Tobyhanna Creek (Sta 014477.20)	Lehigh River (Sta 014475.00)	Bear Creek (Sta 014477.50)	Ungaged	Lehigh River below reservoir (Sta 014478.00)
3.6	4.2	0.8	1.6	11.7

Total inflow = 10.0 tons per year.

### Trace Metals

Trace metals in the outflow water were analyzed because they are representative of the hypolimnetic discharge water and would be of interest to downstream water users. An anaerobic hypolimnion tends to contain the highest concentrations of metals due to chemical reduction. Analyses were done for the dissolved metals - barium, copper, lead, manganese, zinc, cadmium, selenium, arsenic, silver, magnesium, iron, and mercury so that comparisons with stream standards could be made. These data are summarized in table 10. There is no indication, based upon this sample, that any of the metals presently exceed or even approach stream standards (Pennsylvania Water Quality Standards, 1979).

### Bacteria

The use of fecal coliform and fecal streptococcus bacteria as indicators of the possible presence of disease-causing organisms has been standard practice in water microbiology for many years and is the basis of the Pennsylvania Sanitary Water Board (1979) water-quality criterion which states that "during the swimming season (May 1 through September 30) the fecal coliform level shall not exceed a geometric mean of 200 per 100 mL based upon five consecutive samples, each sample collected on different days; for the remainder of the year, the fecal coliform level shall not exceed a geometric mean of 2,000 per 100 mL, based upon five consecutive samples collected on different days."

Fecal coliforms are a group of bacteria specific to the gut of warm-blooded animals. Therefore, their presence in water is a direct indication of fecal contamination. Unfortunately, the fecal coliform test does not distinguish between organisms that originate from humans from those of other warm-blooded animals. Studies by Geldreich and Kenner (1969) demonstrated that fecal coliform are at least four times more numerous than fecal streptococci in the feces of man.

Due to the scope of the sampling program, an insufficient number of samples was examined to calculate geometric means as prescribed in the water-quality criteria. However, enough samples were examined over the 12-month period at various hydrologic and climactic conditions to indicate the range in indicator bacterial densities. Results of the bacterial examination are summarized in table 11. Fecal coliform densities remained well below the levels considered hazardous to water contact forms of recreation and at no time did fecal coliform/fecal streptococcus ratios suggest human wastes were present in the streams.

### Suspended Sediment

Fluvial sedimentation is the process of erosion, transport and deposition of soil by streams. The concentration of suspended sediment in a stream at a given time depends on the season of the year, land use, antecedent moisture conditions, and the nature of the precipitation intensity and pattern on the basin.

Concentrations of suspended sediment in the tributaries to Francis E. Walter Reservoir ranged from less than 1 mg/L at base flow to about 20 mg/L during storm runoff. Concentrations were low, due to the heavily forested soils and because the sandstones and glacial surface material have little fine material to be washed into the stream.

Table 10.--Summary of dissolved trace-metal analyses at station 014478.00 -  
Lehigh River near White Haven, September 23, 1981

(Concentrations in micrograms per liter)

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<u>Element</u>	<u>Concentration</u>
Barium	100
Copper	1
Lead	1
Manganese	80
Zinc	10
Cadmium	<1
Selenium	<1
Arsenic	2
Silver	<1
Iron	120
Mercury	.2
Magnesium	.9

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Table 11.--Summary of fecal coliform and fecal streptococcus analyses

(Concentrations in colonies/100 mL. FC, fecal coliform, FS, fecal streptococcus)

Date	Tobyhanna Creek (Sta 014477.20)		Lehigh River (Sta 014475.00)		Bear Creek (Sta 014477.50)		Spillway Pool (Sta 410656075431300)		Lehigh River Pool (Sta 410745075394700)		Bear Creek Pool (Sta 410847075430600)	
	FC	FS	FC	FS	FC	FS	FC	FS	FC	FS	FC	FS
June 23, 1981	70	110	75	1K500	56	80	2	<1	3	<1	<1	<1
July 28, 1981	20	420	29	250	15	240	<1	<1	1	5	<1	<1
Aug. 25, 1981	1K18	220	1K10	78	1K10	67	<1	<1	<1	<1	1K1	1K1
Sept. 23, 1981	1K9	210	1K55	50	1K3	36	1K2	1K8	1K1	1K12	1K1	1K5
Oct. 20, 1981	1K4	<1	1K9	1K1	41	1K13	1K1	1K1	1K1	1K1	<1	1K3
April 5, 1982	--	88	--	100	--	33	--	--	--	--	--	--
May 4, 1982	<1	80	<1	1K18	1	46	<1	1K2	1K4	1K18	<1	<1

1 Best estimate based upon nonideal counting conditions.

Sediment-transport loads are correspondingly low, ranging from less than 1-ton per day in all tributaries to estimated maximum loads of 100, 150, and 400 tons per day at Lehigh River, Bear Creek, and Tobyhanna Creek, respectively (fig. 7). Annual yields are 5.7, 12, and 12 tons per square mile for the Lehigh River, Bear Creek, and Tobyhanna Creek, respectively. At these annual yields, the reservoir has a sedimentation rate of 5.7 acre-feet per year. This rate may be somewhat below the long-term average due to the below-normal precipitation during the study period.

#### LAND USE

Land use in the Francis E. Walter Dam watershed has been classified into five Geological Survey level I categories (Anderson and others, 1976). These include urban or built-up land, agricultural land, forest land, water, and wetland. The most recent (1973 and 1969) photo-revised 7 1/2 feet Geological Survey topographic series maps were used to estimate land use on each of the three major tributaries.

For classification purposes, urban or built-up land comprises areas of intensive use with much of the land covered by structures. Included are villages, housing developments, strip development along highways, shopping centers, commercial complexes, a winter sports area, and a military reservation. Agricultural land includes cropland, pasture, and orchards. Forest land and water are self-explanatory. Wetlands are those areas where the water table is at, near, or above the land surface for a significant part of most years.

Land uses for each of the stream watersheds are shown in table 12. Forest land is easily the predominant type in each of the subbasins as it comprises from 63 to 90 percent of the land use and 75 percent of the entire reservoir watershed. Another interesting feature, and one which has a strong influence on the hydrology of the watershed, is the large percentage of land (13 percent) that is either under water or wetlands. The Tobyhanna Creek subbasin contains the most urban or built-up land, approximately 18.8 mi<sup>2</sup> or 15 percent while the Bear Creek sub-basin contains the least with 2.3 mi<sup>2</sup> or 4 percent.

### LIMNOLOGY OF FRANCIS E. WALTER RESERVOIR

#### Hydrology

Normal pool elevation for the reservoir is maintained at about 1,300 feet above sea level. Because of below normal precipitation in 1980 and 1981, and the impending drought condition throughout the Delaware River basin, the pool elevation was raised to about 1,392 feet and maintained there until April 1982 when the drought condition was relieved by above normal rainfall.

The additional impounded water had the effect of drowning approximately 600 acres of forest and storing an additional 34,000 acre-feet of water. Some of the effects of this inundation will be discussed in a following section.

The limnology of Francis E. Walter Reservoir includes a discussion of selected chemical, physical, and biological characteristics of the reservoir system that describe the trophic state, the physical setting, and the general quality of the water. The results of the current chemical analysis are reported in table 13. A statistical summary of the data is presented in table 14.



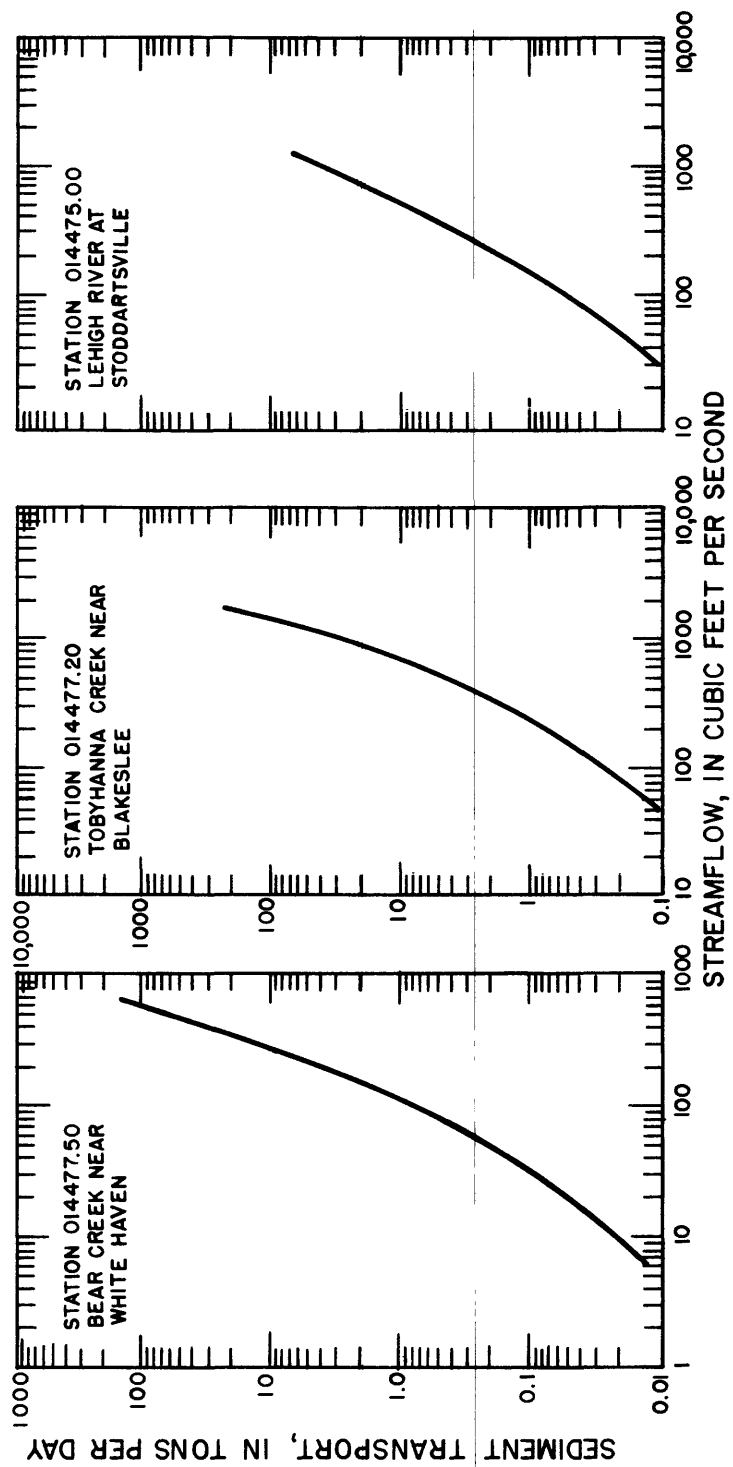


Figure 7.--Sediment-transport curves for tributary streams.

Table 12.--Land use in the Francis E. Walter Reservoir watershed

	<u>Bear Creek</u>		<u>Lehigh River</u>		<u>Tobyhanna Creek</u>		<u>Category Total</u>	
	(mi <sup>2</sup> )	(Percent)	(mi <sup>2</sup> )	(Percent)	(mi <sup>2</sup> )	(Percent)	(mi <sup>2</sup> )	(Percent)
Urban or built-up	2.3	4	7.1	6	18.8	15	28.2	10
Agricultural land	.3	1	2.2	2	3.6	3	6.1	2
Forest land	45.3	90	90.7	82	81.2	63	218.2	75
Water	.9	2	3.4	3	5.1	4	9.4	3
Wetlands	1.5	3	7.3	7	19.3	15	28.1	10
Watershed total	51.3	100	110.7	100	128	100	290.0	100

Table 13.—Reservoir water-quality data collected from June 1981 to May 1982

Station 410656075431300, Francis E. Walter Reservoir, near surface of spillway pool

Date	Transparency (Secchi disk) (in.)	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen, total (mg/L as NO <sub>3</sub> )	Chlor-A Phytoplankton chromo fluorom (µg/L)	Chlor-B Phytoplankton chromo fluorom (µg/L)	Algal-growth potential bottle test (mg/L)
June 24, 1981	72.0	---	---	---	8.50	0.000	0.4
July 29, 1981	77.0	---	<0.00	---	6.52	.000	.4
Aug. 26, 1981	84.0	0.40	.02	1.8	1.32	1.17	.3
Sept. 22, 1981	72.0	2.9	.02	13	1.85	.340	.6
Oct. 21, 1981	---	.77	.08	3.4	.740	<.100	---
May 05, 1982	---	.74	.06	3.3	---	---	---

Date	Phytoplankton total (cells per mL)	Coliform, fecal (cols./100 mL)	Streptococci fecal, (Cols. per 100 mL)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)
June 24, 1981	---	2	0	---	---	---	---	---
July 29, 1981	9100	0	0	<0.001	0.023	<0.001	<0.010	0.59
Aug. 26, 1981	2100	1	0	.015	.002	<.001	.030	.38
Sept. 22, 1981	220	2	8	.005	.024	.005	.130	2.90
Oct. 21, 1981	420	1	1	.012	.006	.004	.120	.69
May 05, 1982	---	<1	1K2	<.010	.014	<.010	.202	.68

Station 410656075431301, Francis E. Walter Reservoir, near bottom of spillway pool

Date	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen total (mg/L as NO <sub>3</sub> )	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)
June 24, 1981	---	<0.00	---	<0.001	0.017	<0.001	0.040	0.42
July 29, 1981	0.28	.01	1.2	.001	.005	<.001	<.010	.27
Aug. 26, 1981	.90	.04	4.0	.020	.043	.030	.230	.86
Sept. 22, 1981	3.7	.04	17	.011	.028	.005	.080	3.70
Oct. 21, 1981	.50	.07	2.2	.017	.008	<.001	.130	.43
May 05, 1982	.64	.06	2.8	<.010	.014	<.010	.020	.58

Table 13.—Reservoir water-quality data collected from June 1981 to May 1982--(continued)

Station 410745075394700, Francis E. Walter Reservoir, near surface of Lehigh pool									
Date	Transparency (Secchi disk) (in.)	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen total (mg/L as NO <sub>3</sub> )	Chlor-A Phytoplankton chromo fluorom (µg/L)	Chlor-B Phytoplankton chromo fluorom (µg/L)	Algal-growth potential bottle test (mg/L)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)
June 24, 1981	50.0	---	---	---	13.7	0.000	0.5	---	---
July 29, 1981	41.0	0.61	0.36	2.7	15.3	.950	.6	0.010	0.25
Aug. 26, 1981	42.0	.50	.02	2.2	6.75	3.80	.3	<.010	.48
Sept. 22, 1981	60.0	5.0	.04	22	14.6	.570	.2	.050	5.00
Oct. 21, 1981	---	.52	.06	2.3	2.53	<.100	.7	.100	.46
May 05, 1982	---	.61	.05	2.7	---	---	---	.020	.56

Station 410745075394701, Francis E. Walter Reservoir, near bottom of Lehigh pool									
Date	Phytoplankton total cells per mL	Coliform, fecal (cols./100 mL)	Streptococci fecal, (cols. per 100 mL)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	
June 24, 1981	---	3	1	---	---	---	---	---	
July 29, 1981	15000	1K1	1K5	0.002	0.022	0.006	<0.010	0.25	
Aug. 26, 1981	9800	1	0	.011	.019	<.001	<.010	.48	
Sept. 22, 1981	1300	1	12	.005	.020	.005	.050	5.00	
Oct. 21, 1981	520	1	1	.005	.010	.003	.100	.46	
May 05, 1982	---	1K4	1K18	<.010	.016	<.010	.020	.56	

Station 410745075394701, Francis E. Walter Reservoir, near bottom of Lehigh pool									
Date	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen total (mg/L as NO <sub>3</sub> )	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	
June 24, 1981	---	0.03	---	<0.001	0.024	<0.001	<0.010	<0.00	
July 29, 1981	0.37	.09	1.6	<.001	.010	<.001	<.010	.28	
Aug. 26, 1981	.39	.06	1.7	.002	.005	.006	<.010	.33	
Sept. 22, 1981	.55	.09	2.4	.017	.018	.005	.030	.46	
Oct. 21, 1981	.63	.04	2.8	.005	<.001	<.001	.020	.59	
May 05, 1982	.55	.06	2.4	<.010	.012	<.010	.020	.49	

Table 13.—Reservoir water-quality data collected from June 1981 to May 1982—(continued)

Station 410847075430600, Francis E. Walter Reservoir, near surface of Bear Creek pool

Date	Transparency (Secchi disk) (in.)	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen total (mg/L as NO <sub>3</sub> )	Chlor-A Phytoplankton chloro fluorom (µg/L)	Chlor-B Phytoplankton chloro fluorom (µg/L)	Algal-growth potential bottle test (mg/L)
June 24, 1981	90.0	---	---	---	11.6	0.000	0.4
July 29, 1981	60.0	0.32	0.02	1.4	8.38	.240	.3
Aug. 26, 1981	72.0	.49	.02	2.2	.840	.590	.3
Sept. 22, 1981	84.0	1.5	.01	6.7	5.41	.860	.3
Oct. 21, 1981	---	.47	.06	3.3	1.00	<.100	---
May 05, 1982	---	.75	.06	---	---	---	---

Date	Phytoplankton total (cells per mL)	Coliform, fecal, (cols./100 mL)	Streptococci fecal, (cols. per 100 mL)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)
June 24, 1981	---	0	0	---	---	---	---	---
July 29, 1981	2900	0	0	<.001	0.025	0.005	0.040	0.30
Aug. 26, 1981	6000	2	1	.005	.004	<.001	.020	.47
Sept. 22, 1981	200	1	5	.005	.018	.005	.100	1.50
Oct. 21, 1981	530	0	3	.005	.005	.002	.100	.41
May 05, 1982	---	<1	<1	<.010	.012	<.010	.020	.69

Station 410847075430601, Francis E. Walter Reservoir, near bottom of Bear Creek pool

Date	Nitrogen, total (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	Nitrogen total (mg/L as NO <sub>3</sub> )	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)
June 24, 1981	---	<0.00	---	<.001	0.021	<.001	<.010	0.50
July 29, 1981	0.35	.02	1.5	.001	.030	<.001	.030	.33
Aug. 26, 1981	.41	.02	1.8	.007	.005	.001	.040	.39
Sept. 22, 1981	4.4	.02	20	.017	.024	.005	.100	4.40
Oct. 21, 1981	.58	.01	2.6	.005	.008	.003	.100	.57
May 05, 1982	.48	.05	2.1	<.010	.026	<.010	.020	.43

<sup>1</sup> K, indicates estimated count based upon non-ideal counting conditions.

Table 14.—Statistical summary of reservoir water-quality data, June 1981 to May 1982  
(Concentrations in milligrams per liter, except as noted)

Parameter code	Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean	Sum
<u>Station 410656075431300, Francis E. Walter Reservoir, near surface of spillway pool</u>								
00077	Transparency (Secchi disk) (in.)	5	77.80	6.02	72.00	84.00	2.69	389.00
70507	Phosphorus, ortho, total (mg/L as P)	5	.01	.01	.00	.02	.00	.04
00665	Phosphorus, total (mg/L as P)	5	.01	.01	.00	.02	.00	.07
00671	Phosphorus, ortho, dissolved (mg/L as P)	5	.00	.00	.00	.01	.00	.02
00610	Nitrogen, ammonia, total (mg/L as N)	5	.06	.06	.01	.13	.03	.31
00600	Nitrogen, total (mg/L as N)	4	1.20	1.14	.40	2.90	.57	4.81
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	5	.03	.03	.00	.08	.01	.17
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	4	5.37	5.14	1.80	13.00	2.57	21.50
70953	Chlor-A phytoplankton chromo fluorom (µg/L)	5	3.79	3.49	.74	8.50	1.56	18.93
70954	Chlor-B phytoplankton chromo fluorom (µg/L)	5	.32	.49	.00	1.17	.22	1.61
85209	Algal-growth potential, bottle test (mg/L)	4	.43	.13	.30	.60	.06	1.70
60050	Phytoplankton, total (cells per mL)	4	2,960.00	4,179.25	220.00	9,100.00	2,089.63	11,840.00
31625	Coliform, fecal, (cols./100mL)	6	1.17	.75	.00	2.00	.31	7.00
31673	Streptococci, fecal, (cols. per 100mL)	6	1.83	3.13	.00	8.00	1.28	11.00
<u>Station 410656075431301, Francis E. Walter Reservoir, near bottom of spillway pool</u>								
70507	Phosphorus, ortho, total (mg/L as P)	6	0.01	0.01	0.00	0.02	0.00	0.06
00665	Phosphorus, total (mg/L as P)	6	.02	.01	.01	.04	.01	.12
00671	Phosphorus, ortho, dissolved (mg/L as P)	6	.01	.01	.00	.03	.00	.05
00610	Nitrogen, ammonia total (mg/L as N)	6	.09	.08	.01	.23	.03	.51
00600	Nitrogen, total (mg/L as N)	5	1.20	1.41	.28	3.70	.63	6.02
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	6	.04	.03	.00	.07	.01	.22
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	5	5.44	6.54	1.20	17.00	2.93	27.20

Table 14.--Statistical summary of reservoir water-quality data, June 1981 to May 1982--(continued)  
(Concentrations in milligrams per liter, except as noted)

Parameter code	Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean	Sum
Station 410745075394700, Francis E. Walter Reservoir, near surface of Lehigh pool								
00077	Transparency (Secchi disk) (in.)	5	47.00	8.12	41.00	60.00	3.63	235.00
70507	Phosphorus, ortho, total (mg/L as P)	5	.01	.00	.00	.01	.00	.03
00665	Phosphorus, total (mg/L as P)	5	.02	.00	.01	.02	.00	.09
00671	Phosphorus, ortho, dissolved (mg/L as P)	5	.01	.00	.00	.01	.00	.03
00610	Nitrogen, ammonia, total (mg/L as N)	5	.04	.04	.01	.10	.02	.19
00600	Nitrogen, total (mg/L as N)	5	1.45	1.99	.50	5.00	.89	7.24
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	5	.10	.14	.02	.36	.06	.52
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	5	6.38	8.73	2.20	22.00	3.91	31.90
70953	Chlor-A phytoplankton chromo fluorom (µg/L)	5	10.58	5.55	2.53	15.30	2.53	52.88
70954	Chlor-B phytoplankton chromo fluorom (µg/L)	5	.94	1.26	.00	3.08	.56	4.70
85209	Algal-growth potential, bottle test (mg/L)	5	.46	.21	.30	.70	.09	2.30
60050	Phytoplankton, total (cells per mL)	4	6,655.00	6,972.43	520.00	15,000.00	3,486.21	26,620.00
31625	Coliform, fecal, (cols./100mL)	6	1.83	1.33	1.00	4.00	.54	11.00
31673	Streptococci fecal, (cols. per 100mL)	6	6.17	7.31	.00	18.00	2.98	37.00
Station 410745075394701, Francis E. Walter Reservoir, near bottom of Lehigh pool								
70507	Phosphorus, ortho, total (mg/L as P)	6	0.01	0.01	0.00	0.02	0.00	0.04
00665	Phosphorus, total (mg/L as P)	6	.01	.01	.00	.02	.00	.07
00671	Phosphorus, ortho, dissolved (mg/L as P)	6	.00	.00	.00	.01	.00	.02
00610	Nitrogen, ammonia total (mg/L as N)	6	.02	.01	.01	.03	.00	.10
00600	Nitrogen, total (mg/L as N)	5	.50	.11	.37	.63	.05	2.49
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	6	.06	.02	.03	.09	.01	.36
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	5	2.18	.51	1.60	2.80	.23	10.90

Table 14.--Statistical summary of reservoir water-quality data, June 1981 to May 1982--(continued)  
(Concentrations in milligrams per liter, except as noted)

Parameter code	Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean	Sum
Station 410847075430600, Francis E. Walter Reservoir, near surface of Bear Creek pool								
00077	Transparency (Secchi disk) (in.)	5	75.60	11.70	60.00	90.00	5.23	378.00
70507	Phosphorus, ortho, total (mg/L as P)	5	.01	.00	.00	.01	.00	.03
00665	Phosphorus, total (mg/L as P)	5	.01	.01	.00	.03	.00	.06
00671	Phosphorus, ortho, dissolved (mg/L as P)	5	.00	.00	.00	.01	.00	.02
00610	Nitrogen, ammonia, total (mg/L as N)	5	.06	.04	.02	.10	.02	.28
00600	Nitrogen, total (mg/L as N)	5	.71	.47	.32	1.50	.21	3.53
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	5	.03	.02	.01	.06	.01	.17
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	5	3.14	2.10	1.40	6.70	.94	15.70
70953	Chlor-A phytoplankton chromo fluorom (ug/L)	5	5.45	4.68	.84	11.60	2.09	27.23
70954	Chlor-B phytoplankton chromo fluorom (ug/L)	5	.36	.36	.00	.86	.16	1.79
85209	Algal-growth potential, bottle test (mg/L)	5	.34	.05	.30	.40	.02	1.70
60050	Phytoplankton, total (cells per mL)	4	2,407.50	2,679.97	200.00	6,000.00	1,339.98	9,630.00
31625	Coliform, fecal, (cols./100mL)	6	.67	.82	.00	2.00	.33	4.00
31673	Streptococci fecal, (cols. per 100mL)	6	1.67	1.97	.00	5.00	.80	10.00
Station 410847075430601, Francis E. Walter Reservoir, near bottom of Bear Creek pool								
70507	Phosphorus, ortho, total (mg/L as P)	6	0.01	0.01	0.00	0.02	0.00	0.04
00665	Phosphorus, total (mg/L as P)	6	.02	.01	.01	.03	.00	.11
00671	Phosphorus, ortho, dissolved (mg/L as P)	6	.00	.00	.00	.01	.00	.02
00610	Nitrogen, ammonia total (mg/L as N)	6	.05	.04	.01	.10	.02	.30
00600	Nitrogen, total (mg/L as N)	5	1.24	1.77	.35	4.40	.79	6.22
00630	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> total (mg/L as N)	6	.02	.02	.00	.05	.01	.12
71887	Nitrogen, total (mg/L as NO <sub>3</sub> )	5	5.60	8.06	1.50	20.00	3.60	28.00



Complete profile data, collected at 5-foot intervals, for temperature, dissolved oxygen, pH, and specific conductance at six locations, is on file at the U.S. Geological Survey, Harrisburg, and the U.S. Army Corps of Engineers, Philadelphia.

### Physical Characteristics

#### Temperature and Dissolved Oxygen

Lakes and reservoirs within the temperate zone generally have temperatures of about 4°C throughout the water column at the time of ice breakup each spring, and are subject to complete mixing by the wind. As air temperatures rise, the upper layers of water are warmed. This process continues until the temperature-density gradient is sufficiently developed to produce a thermocline, and the so-called "summer stagnation period" begins. During this period the upper layer (the epilimnion) is separated from the lower layer (the hypolimnion) by a sharp temperature gradient (the thermocline).

When air temperatures cool in the autumn, the temperature of the epilimnion decreases until it is the same temperature as the hypolimnion. The impoundment then enters the "autumn overturn" and is once more subjected to complete mixing by the wind. This process of heating and cooling is repeated each spring and autumn.

Plots of equal temperature for the deep water sampling station are shown in figure 8. Temperatures in the water column are nearly uniform except for a 2-week period in early July when the impoundment became weakly stratified. During this time, a stable thermocline persisted for only about 2 weeks early in July at a depth of 6.4 meters. The lack of persistent thermal stability is probably due to: (1) the large volume of cool water in comparison to the size of the surface area available for heating and; (2) the constant withdrawal of hypolimnetic water.

Plots equal dissolved-oxygen concentrations for the deep-water station in Francis E. Walter Reservoir are shown in figure 9. Dissolved-oxygen concentrations were found to be within state standards until late in June, when concentrations in the deeper sections dropped below 5.0 mg/L. Oxygen concentration continued to drop throughout the summer and by September the entire profile was less than 2 mg/L. Anaerobic and near-anaerobic conditions prevailed until the autumn overturn early in October.

The temporary low, dissolved-oxygen conditions during the summer of 1981 were undoubtedly due to the high biochemical oxygen demand imposed upon the system by the large mass of decomposing vegetation made available by the inundation of forest lands due to the raising of the pool level. Dissolved-oxygen profiles for shallow parts of the reservoir, Bear Creek and Lehigh River arms are shown in figure 10 and 11. Much of the volume of the more shallow parts of the reservoir remained anoxic or nearly so throughout the season of high biological activity.

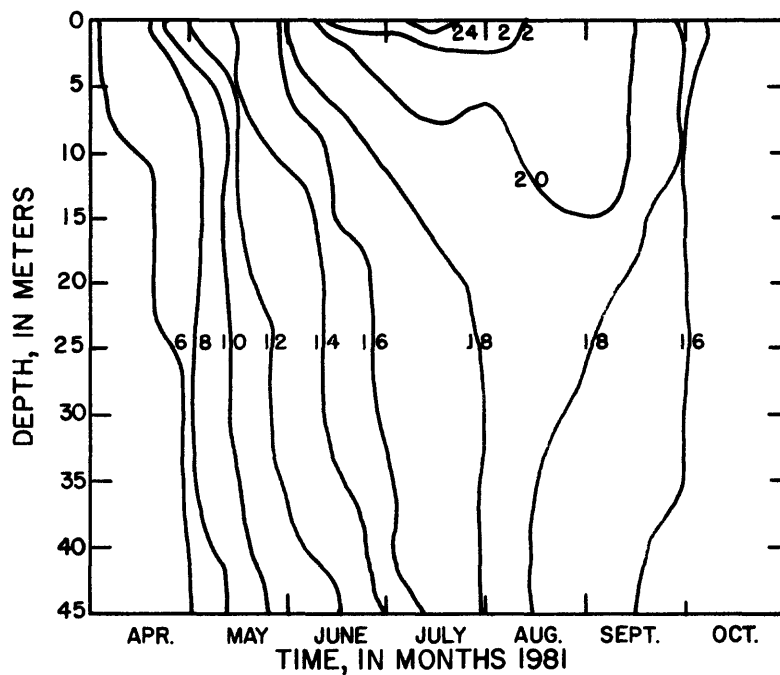


Figure 8.--Plots of equal temperature,  
spillway pool  
(station 4106560754313).

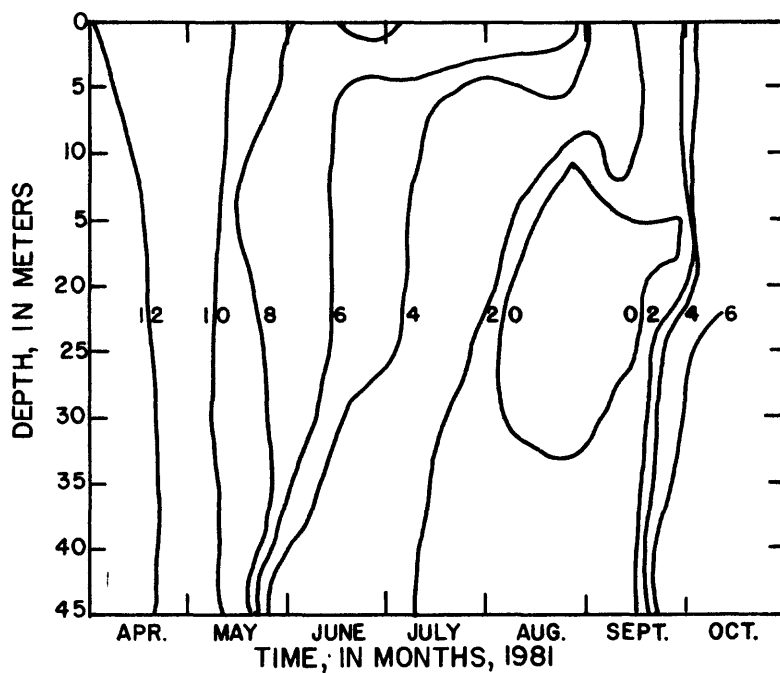


Figure 9.--Plots of equal dissolved oxygen,  
spillway pool  
(station 4106560754313).

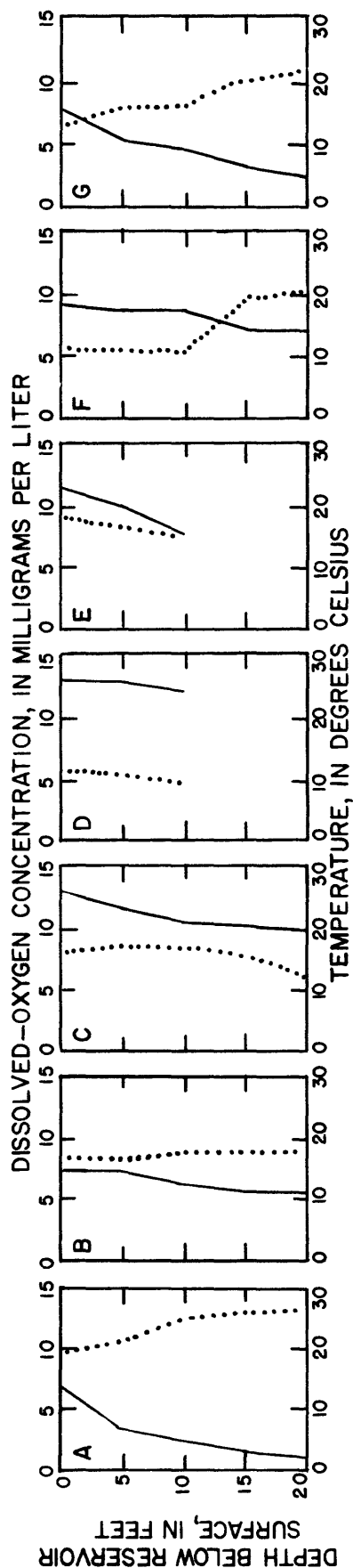


Figure 10.--Dissolved-oxygen and temperature profiles in the Bear Creek tributary arm of reservoir, station 5.

... Dissolved oxygen  
 --- Temperature  
 A April 22, 1981  
 B May 19, 1981  
 C June 16, 1981  
 D July 14, 1981  
 E August 25, 1981  
 F September 22, 1981  
 G October 22, 1981

#### EXPLANATION

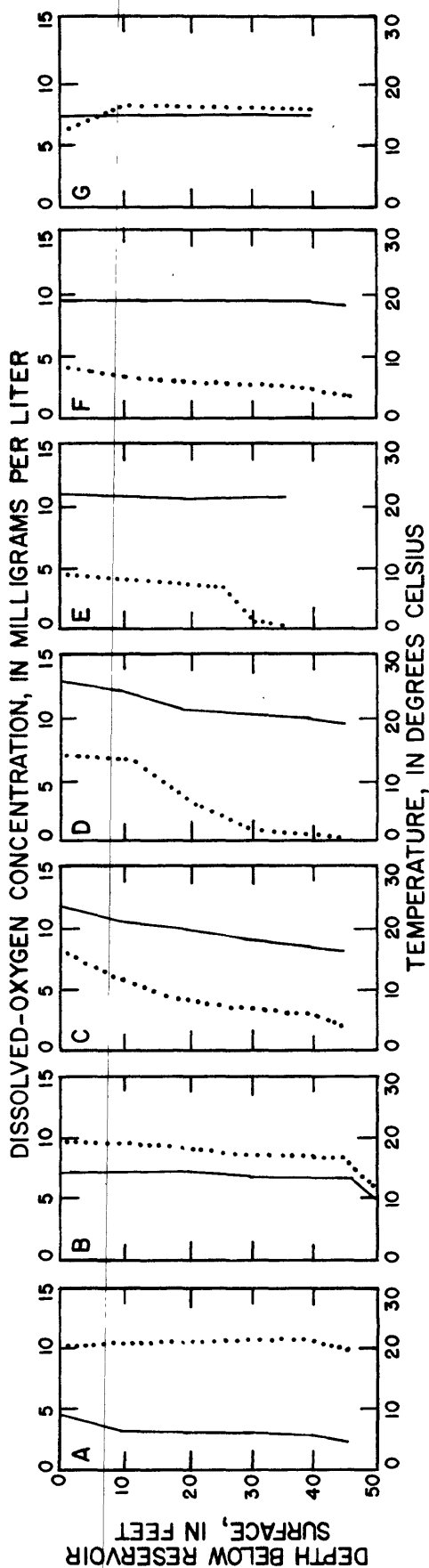


Figure 11.--Dissolved-oxygen and temperature profiles in the Lehigh River tributary arm of reservoir, station 6.

... Dissolved oxygen  
 --- Temperature  
 A April 22, 1981  
 B May 19, 1981  
 C June 16, 1981  
 D July 14, 1981  
 E August 25, 1981  
 F September 22, 1981  
 G October 22, 1981

#### EXPLANATION

## Transparency

Water transparency or visibility was measured with a Secchi disk. The Secchi disk provides a means of comparing the light transmission in similar bodies of water or the same body of water at different times. The depth of light penetration is critical to the depth of the euphotic zone and the productivity of the water body.

The maximum, minimum, and mean values of Secchi disk visibility are shown in table 14. Highest mean visibilities were observed in Bear Creek arm and the lowest in the Lehigh River arm. Higher turbidities in the Lehigh River arm appear to be due to the higher density of phytoplankton (fig. 12). The higher phytoplankton densities are probably a product of higher concentrations of available phosphorus.

## Chemical Characteristics

### Value of pH

The desired pH range of 6.0 to 8.5 is not being met. The pH values were generally in the range of 5.0 to 6.0, with extremes of 4.8 and 6.2 in the main body of the reservoir. The pH values in the two embayments reflect the water quality of the tributaries. The most acidic water is in the Bear Creek pool while the water in the Lehigh River pool is somewhat less acidic. During August and September when the reservoir was nearly anoxic, there is evidence of pH depression throughout the reservoir (fig. 13). The lower pH was probably due to the raised pool and subsequent decomposition of the inundated vegetation, resulting in an increase in carbon dioxide ( $\text{CO}_2$ ), which combines with water ( $\text{H}_2\text{O}$ ) to form carbonic acid ( $\text{H}_2\text{CO}_3$ ). Measurements of pH during the spring of 1982 indicate a continued and increasingly more acidic condition.

The vertical distribution of pH displays a phenomenon referred to as a negative heterograde distribution; that is, pH decreases with depth and then actually rises before reaching the bottom. This dichotomous curve, first described by Yoshimura (1932) in a number of soft-water lakes in Japan, is believed the result of a hypolimnetic oxygen deficit and the diffusion of alkaline earth and ferrous and bicarbonate alkalinity from the sediments.

The acidic condition is a constraint on productivity and diversity of the biota. While the specific effects of low pH on life in the Francis E. Walter Reservoir are beyond the scope of this study, the generalized effects may be summarized as follows:

The inhibition of bacteria at low pH can have profound effects throughout the aquatic ecosystem. Detritus removal, conservation of energy, nutrient recycling, primary production, detritivore production and thus production at higher trophic levels can all be affected by changes in microbial activity. In the pH range of 6.0 to 5.5, there is a reduction in the number of species able to survive and a loss in ability to withstand stress in the surviving species. At a pH of 5.5 to 5.0, even fewer organisms can survive, but a few pH-tolerant organisms may become abundant. Less than pH 5.0 the decomposition of organic detritus will be severely impaired and most fish species will be eliminated. (Hendry and others, 1979).

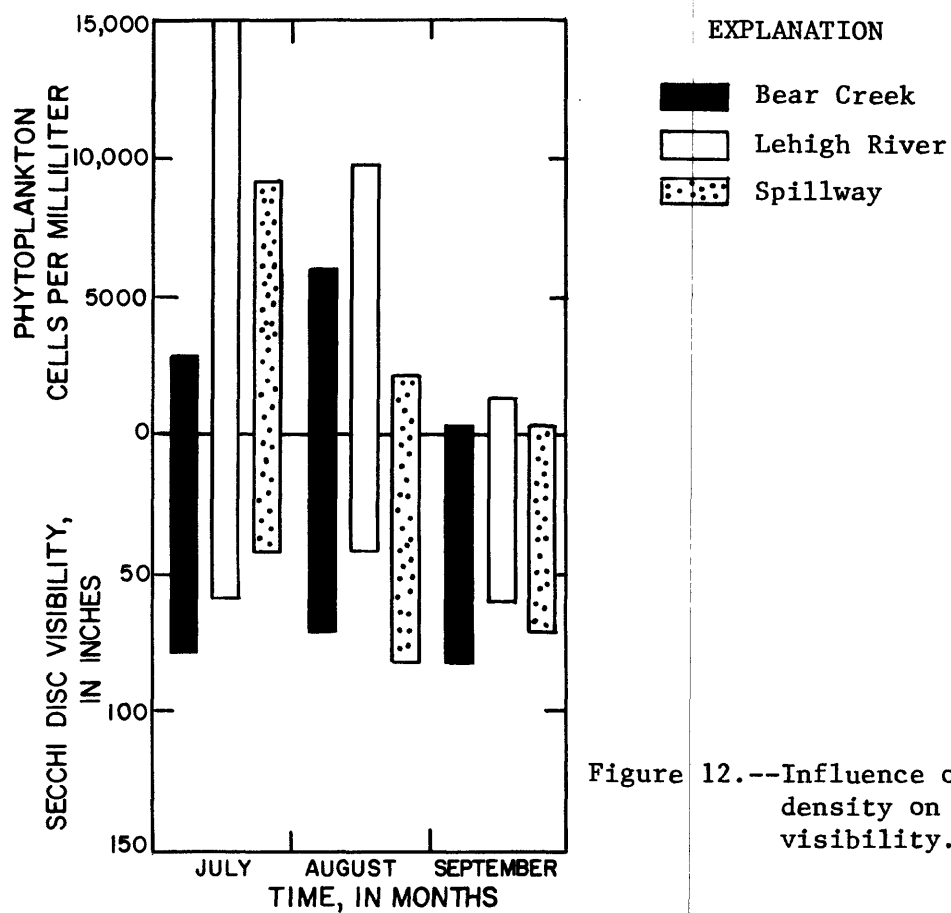


Figure 12.--Influence of phytoplankton density on Secchi disc visibility.

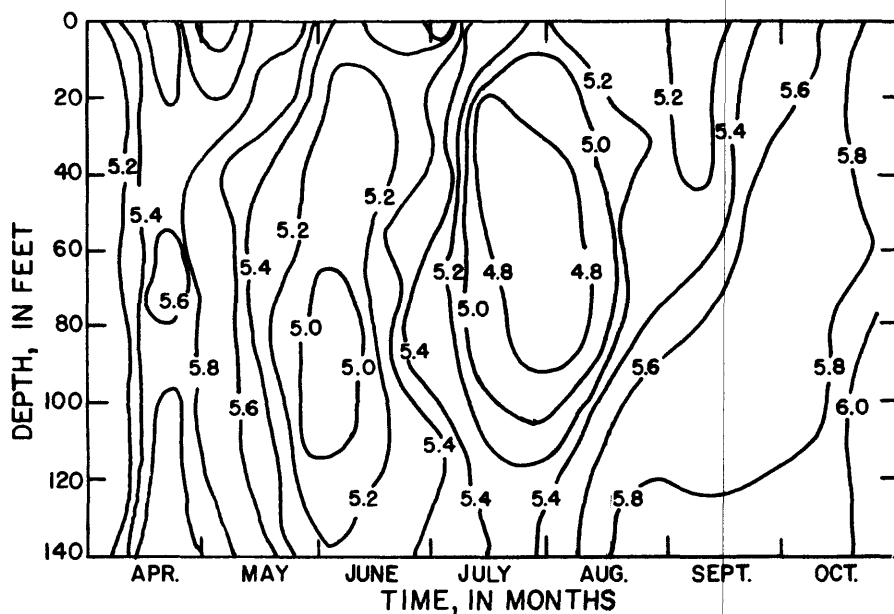


Figure 13.--Depth-time diagram of plots of equal pH at spillway pool site in 1981.

## Specific Conductance and Dissolved Solids

Specific conductance or the ionic strength of the water in the reservoir is typical of the waters draining the sandstone soils of the Pocono Plateau. The specific conductance ranged from 45 to 62 micromhos. The higher value was measured in the bottom waters during the late summer.

## Nitrogen

Nitrogen occurs in natural water as dissolved organic nitrogen and as inorganic nitrogen in the form of ammonia, nitrite, nitrate, and elemental nitrogen. Nitrogen is one of the major essential elements for plant growth and is also one of the principal elemental constituents in amino acids, peptides, proteins, urea, and other organic compounds.

Laboratory tests by Vollenweider (1968), indicate that ammonia and nitrate are the two forms of nitrogen most readily used by planktonic algae. Wang and others (1973) reported that during periods of maximum algal growth, ammonia nitrogen was the preferred source of nitrogen.

The concentration of the various forms of nitrogen in the reservoir is not high and presents no water quality problems. Total nitrogen concentrations in the surface water of the reservoir ranged from 1.5 mg/L to 5.0 mg/L. It is significant that an average of 80 percent of the total nitrogen is in the organic form. As summarized in table 13, nitrogen available for plant uptake or the ammonia and nitrite plus nitrate fraction is very small, averaging 0.06 mg/L for both components. Concentrations of nitrogen were highest in the Lehigh river arm.

## Phosphorus and Algal Growth Potential

### Phosphorus

Phosphorus does not occur free in nature but is found in the form of phosphates in several common minerals and is a constituent of all living matter. Like nitrogen and carbon, phosphorus is one of the essential elements for cellular growth. Because phosphorus is an essential element and is generally available in small quantities, it is often the limiting factor in the development of summer algae blooms.

The mean total phosphorus content of the surface waters of most Pennsylvania lakes ranges from 0.01 to 0.03 mg/L (Barker, 1978; Ulanoski and others, 1981). Total phosphorus concentrations of the surface waters of Francis E. Walter Reservoir ranged from 0.002 mg/L to 0.025 mg/L, with a mean of 0.015 mg/L. Mean concentrations were slightly higher at the Lehigh River pool sampling site. Bottom concentrations were slightly higher than surface waters at all sites, except the Lehigh River pool.

Dissolved orthophosphate ( $\text{PO}_4^{3-}$ ) is the specie of phosphorus most readily used by aquatic plants in photosynthetic processes. Concentrations of dissolved orthophosphorus averaged 0.002 mg/L at the Spillway pool and Bear Creek pool, and 0.003 mg/L at the Lehigh River pool. The means and ranges of total, total ortho, and dissolved ortho phosphorus found in this investigation are given in table 14.

## Algal Growth Potential

Algal growth potential (AGP) is a laboratory test that determines the maximum algal mass (dry weight) of a test algal species (*Selenastrum capricornatum*) that can be grown in native water in a controlled environment. While the test does not necessarily reflect natural conditions, it does provide a means of comparing different waters or the growth potential of the same water on different dates.

Algal growth potential was determined for the surface water at the three reservoir sites from June through October 1981. The results, summarized in table 13, indicate that AGP ranged from 0.2 to 0.7 mg/L, and was similar for all sites, and had no discernable seasonal trends. According to a classification study by the Environmental Protection Agency (Miller and others, 1974) on 49 lakes throughout the United States, Francis E. Walter Reservoir has the potential to be a moderately productive lake solely on the basis of a mean AGP of 0.3 mg/L for the July sampling.

The ratio of total nitrogen to total phosphorus (N:P) provides evidence of the limiting major nutrient. N:P ratios greater than 10 are generally considered to be phosphorus limited. Based upon the N:P ratios of 18 to 400 measured at Francis E. Walter Reservoir, the system is decidedly phosphorus limited.

## Biological Characteristics

### Phytoplankton

The composition and density of phytoplankton communities are a reflection of the trophic state. Oligotrophic or nutrient-poor waters are characterized by a relatively low phytoplankton density with infrequent pulses or blooms. Eutrophic or nutrient-rich waters are at the opposite end of the spectrum with overall high densities of cells with frequent blooms. Most impoundments, including Francis E. Walter Reservoir, fall somewhere in between and are referred to as mesotrophic.

The phytoplankton communities of Francis E. Walter Reservoir are characterized by overall moderate densities and diversities. All densities were highest in the early summer and then leveled off for the remainder of the growing season.

During the growing season, 36 genera were recovered from 12 samples. The genera included 14 green algae, 11 diatoms, 4 yellow-brown algae, 3 blue-green algae, 2 euglenoids, 1 cryptomonad, and 1 dinoflagellate or fire algae. As expected, the highest densities of phytoplankton were found in the Lehigh River arm. This is attributed to the higher concentrations of available nutrients.

Cyanophyta or blue-green algae clearly dominated the population during the warm water growing season. *Anacystis* sp and *Anabeana* sp were the codominant genera. Chlorophyta (green algae) and chrysophyta (yellow-brown and diatoms) were also common surface-water types (tables 15-17). The most common green alga was *Ankistrodesmus*, while the yellow-brown algae were dominated by *Mallomonas* sp and *Dinobryon* sp.

Table 15.--Summary of phytoplankton composition at spillway pool,  
Station 410650754313

	(Percent of population) 1981			
	July	Aug.	Sept.	Oct.
<b>Chlorophyta</b>				
<i>Ankistrodesmus</i>	2	10	6	20
<i>Scenedesmus</i>	--	10	--	27
<i>Sphairocystis</i>	--	--	--	--
<i>Chlamydomonas</i>	2	--	--	10
<i>Schroederia</i>	1	2	--	--
<i>Microactinium</i>	13	--	--	--
<i>Gloeactinium</i>	--	--	--	--
<i>Oocystis</i>	--	--	--	--
<i>Dictyosphaerium</i>	--	--	--	--
<i>Kirchneriella</i>	--	1	--	--
<i>Sphaerocystis</i>	--	--	--	13
<i>Quadrigula</i>	--	--	--	--
<i>Crucigenia</i>	--	3	--	--
<i>Closteriopsis</i>	--	--	--	--
<i>Coelastrum</i>	--	5	--	--
<b>Total</b>	<b>18</b>	<b>34</b>	<b>31</b>	<b>70</b>
<b>Chrysophyta</b>				
<i>Bacillariophyceae</i>	--	--	--	--
<i>Melosira</i>	--	2	--	20
<i>Asterionella</i>	--	1	--	10
<i>Epithemia</i>	--	--	--	--
<i>Fragilaria</i>	--	--	6	--
<i>Tabellaria</i>	4	--	--	--
<i>Cyclotella</i>	1	1	--	--
<i>Synedra</i>	--	--	--	--
<i>Navicula</i>	--	--	--	--
<i>Gomphonema</i>	--	--	--	--
<i>Nitzschia</i>	--	1	--	--
<b>Total</b>	<b>5</b>	<b>5</b>	<b>6</b>	<b>30</b>
<b>Chrysophyceae</b>				
<i>Mallomonas</i>	10	--	--	--
<i>Dinobryon</i>	--	1	--	--
<i>Ochromonas</i>	10	--	--	--
<i>Stenocalyx</i>	--	--	--	--
<b>Total</b>	<b>20</b>	<b>1</b>	<b>0</b>	<b>0</b>
<b>Cryptophyta</b>				
<i>Chroomonas</i>	6	--	--	--
<b>Total</b>	<b>6</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Euglenophyta</b>				
<i>Trachelomonas</i>	--	--	--	--
<i>Euglena</i>	--	--	--	--
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Cyanophyta</b>				
<i>Anacystis</i>	51	46	--	--
<i>Gomphosphaeria</i>	--	--	--	--
<i>Anabaena</i>	--	13	63	--
<b>Total</b>	<b>51</b>	<b>59</b>	<b>63</b>	<b>0</b>
<b>Pyrrhophyta</b>				
<i>Peridinium</i>	--	3	--	--
<b>Total</b>	<b>0</b>	<b>3</b>	<b>0</b>	<b>0</b>
<b>Total number of cells, in milligrams per liter.</b>	<b>9,100</b>	<b>2,100</b>	<b>220</b>	<b>420</b>



Table 16.--Summary of phytoplankton composition at Bear Creek pool,  
Station 41108470754306

	(Percent of Population)			
	1981			
	July	Aug.	Sept.	Oct.
<b>Chlorophyta</b>				
<i>Ankistrodesmus</i>	1	4	36	13
<i>Scenedesmus</i>	--	--	--	16
<i>Sphairocystis</i>	--	--	--	--
<i>Chlamydomonas</i>	1	--	--	--
<i>Schroederia</i>	<1	2	--	--
<i>Microactinium</i>	12	--	--	--
<i>Gloeactinium</i>	2	--	--	--
<i>Oocystis</i>	1	<1	--	--
<i>Dictyosphaerium</i>	--	<1	--	--
<i>Kirchneriella</i>	--	<1	--	3
<i>Sphaerocystis</i>	--	--	64	5
<i>Quadrigula</i>	--	--	--	--
<i>Crucigenia</i>	--	--	--	--
<i>Closteriopsis</i>	--	--	--	--
<b>Total</b>	<b>17</b>	<b>6</b>	<b>100</b>	<b>37</b>
<b>Chrysophyta</b>				
<i>Bacillariophyceae</i>	--	--	--	--
<i>Melosira</i>	--	--	--	5
<i>Asterionella</i>	--	1	--	5
<i>Epithemia</i>	<1	--	--	--
<i>Fragilaria</i>	56	--	--	--
<i>Tabellaria</i>	--	<1	--	--
<i>Cyclotella</i>	--	--	--	11
<i>Synedra</i>	--	--	--	3
<i>Navicula</i>	--	--	--	--
<i>Gomphonema</i>	--	--	--	--
<i>Nitzschia</i>	--	--	--	--
<b>Total</b>	<b>56</b>	<b>1</b>	<b>0</b>	<b>24</b>
<b>Chrysophyceae</b>				
<i>Mallomonas</i>	17	--	--	--
<i>Dinobryon</i>	<1	--	--	--
<i>Ochromonas</i>	1	--	--	--
<i>Stenocalyx</i>	--	<1	--	--
<b>Total</b>	<b>18</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Cryptophyta</b>				
<i>Chroomonas</i>	6	--	--	--
<b>Total</b>	<b>6</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Euglenophyta</b>				
<i>Trachelomonas</i>	--	--	--	--
<i>Euglena</i>	1	--	--	--
<b>Total</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Cyanophyta</b>				
<i>Anacystis</i>	--	66	--	39
<i>Gomphosphaeria</i>	--	26	--	--
<i>Anabaena</i>	--	--	--	--
<b>Total</b>	<b>0</b>	<b>92</b>	<b>0</b>	<b>39</b>
<b>Pyrrhophyta</b>				
<i>Peridinium</i>	--	--	--	--
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Total number of cells, in milligrams per liter.</b>	<b>2,900</b>	<b>6,000</b>	<b>200</b>	<b>530</b>

Table 17.--Summary of phytoplankton composition at Lehigh River pool,  
Station 410750753947

	(Percent of Population) 1981			
	July	Aug.	Sept.	Oct.
<b>Chlorophyta</b>				
<i>Ankistrodesmus</i>	3	<1	2	3
<i>Scenedesmus</i>	2	1	--	37
<i>Sphairocystis</i>	--	--	--	--
<i>Chlamydomonas</i>	1	<1	--	--
<i>Schroederia</i>	1	<1	1	--
<i>Microactinium</i>	--	--	--	--
<i>Gloeactinium</i>	--	--	--	--
<i>Oocystis</i>	--	1	--	--
<i>Dictyosphaerium</i>	5	1	--	--
<i>Kirchneriella</i>	--	--	91	--
<i>Sphaerocystis</i>	--	3	--	--
<i>Quadrigula</i>	--	--	--	--
<i>Crucigenia</i>	--	--	--	--
<i>Closteriopsis</i>	--	--	--	32
<b>Total</b>	<b>12</b>	<b>6</b>	<b>94</b>	<b>72</b>
<b>Chrysophyta</b>				
<i>Bacillariophyceae</i>	--	--	--	--
<i>Melosira</i>	--	<1	--	5
<i>Asterionella</i>	2	<1	--	--
<i>Epithemia</i>	--	--	--	--
<i>Fragilaria</i>	--	--	1	--
<i>Tabellaria</i>	--	<1	--	--
<i>Cyclotella</i>	--	--	1	5
<i>Synedra</i>	1	--	--	5
<i>Navicula</i>	--	<1	--	--
<i>Gomphonema</i>	--	--	--	--
<i>Nitzschia</i>	--	--	--	3
<b>Total</b>	<b>3</b>	<b>&lt;1</b>	<b>2</b>	<b>18</b>
<b>Chrysophyceae</b>				
<i>Mallomonas</i>	84	--	--	--
<i>Dinobryon</i>	--	55	--	--
<i>Ochromonas</i>	1	--	--	--
<i>Stenocalyx</i>	--	--	--	--
<b>Total</b>	<b>85</b>	<b>55</b>	<b>0</b>	<b>0</b>
<b>Cryptophyta</b>				
<i>Chroomonas</i>	--	--	--	--
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Euglenophyta</b>				
<i>Trachelomonas</i>	1	--	1	--
<i>Euglena</i>	--	--	--	3
<b>Total</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>3</b>
<b>Cyanophyta</b>				
<i>Anacystis</i>	--	29	2	8
<i>Gomphosphaeria</i>	--	--	--	--
<i>Anabaena</i>	--	7	--	--
<b>Total</b>	<b>0</b>	<b>36</b>	<b>2</b>	<b>8</b>
<b>Pyrrhophyta</b>				
<i>Peridinium</i>	--	--	--	--
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Total number of cells, in milligrams per liter.</b>	<b>15,000</b>	<b>9,800</b>	<b>1,300</b>	<b>520</b>

### Chlorophyll a and b

Chlorophylls are complex organic chemicals that utilize light energy from the sun and transform it into chemical energy during the photosynthetic process. Because all living green plants contain chlorophyll, and chlorophyll production depends on light, temperature, nutrients, and other factors, the concentration of chlorophyll is a measure of the production rate.

Concentrations of chlorophyll a ranged from 0.74 to 15.3 mg/L. Data in table 13 indicate a higher rate of algae production in the Lehigh River pool. This is to be expected because all other indicators show the same trend. As would be anticipated, the lowest concentrations of chlorophyll were found in the Spillway pool because of the depletion of phosphorus, an essential nutrient.

### Sanitary Bacteria

The contamination of recreational waters with fecal material from the gut of warm-blooded animals is of concern because of the associated bacteria and viruses with pathogenic properties. Because of the difficulty in isolating pathogenic organisms, indicator bacteria are used to suggest the possible presence of disease-causing organisms. The indicator bacteria most commonly used are the fecal coliform and fecal streptococci, both common inhabitants of the intestinal tract of warm-blooded animals. The rationale is that if densities of indicator bacteria are high, then the probability that pathogens are also present increases.

The waters of Francis E. Walter Reservoir were found suitable for all forms of water-contact recreation. Concentrations of fecal coliform and fecal streptococci bacteria were minimal and well within state water-quality criteria (Pennsylvania Water Quality Standards, 1979) 100 percent of the time. Table 14 includes a summary of the bacteria concentrations at the reservoir sites.

## GROUND-WATER HYDROLOGY

By Charles R. Wood

### Geology

The Francis E. Walter Dam and Reservoir are underlain by the sandstones and shales of the lower part of the Pocono Formation and the upper members of the underlying Catskill Formation. These rocks dip northward 5° to 10°. The bedrock is partly covered by ground moraine of Woodfordian Age, a thin (10 to 50 ft) layer of till consisting of an unsorted mixture of clay, silt, sand, pebbles, cobbles, and boulders. It has a low permeability. Ice-contact stratified drift of Woodfordian Age consisting of sand, gravel, cobbles, and boulders, is present locally. This material has a high permeability.

### Ground Water

The Catskill is a fair aquifer. Carswell and Lloyd (1979, p.11) noted that, "On the average, one of every four wells located, drilled, and developed for high yield will probably produce about 75 gal/min or more, with 50 ft of drawdown after 24 hours of pumping." They also note that the dissolved-solids

concentration in water from the Catskill Formation averages about 100 mg/L and that, "The water is soft and acidic, and locally contains excessive concentrations of iron and manganese."

Raising the conservation pool level from the present 1,300-ft elevation to the designed 1,425-ft level will change hydraulic gradients in the aquifers near the reservoir. This change will be large (125 ft) at the reservoir. However, both the land surface and the water table slope steeply (several hundred feet per mile) towards the reservoir; therefore, the change in head caused by raising the pool will be, at most, a few feet at distances of greater than one mile from the reservoir. There are very few wells (probably less than five) near enough to the reservoir to show any rise in water level. These wells will probably increase in yield slightly.

Some degradation of water quality in the aquifer may occur as reservoir water enters the aquifers when the stage in the reservoir is being increased. Higher than normal concentrations of iron and manganese may occur within a few hundred feet of the reservoir. This should be a transient effect, because, after a new equilibrium is reached, water will again flow from the aquifer to the reservoir. This will flush the reservoir water that invaded the aquifer back into the pool. None of the existing wells are close enough to the reservoir to be affected.

#### ENVIRONMENTAL IMPACT AND MANAGEMENT OF A RAISED POOL

The inundation of approximately 1,000 acres of mixed hardwood forest will have negligible impact upon resident terrestrial wildlife such as whitetail deer, bear, turkey, and small mammals. The forest lands bordering the project area are large enough to accommodate the displaced resident wildlife populations.

A positive effect of the raised and more stable pool is the increased habitat for waterfowl in the drowned forest. Species such as the wood duck should benefit most. Species of puddle and diving ducks should also utilize the reservoir as feeding and resting areas.

Additional positive effects will be realized to the lake fishery in the form of increased habitat for spawning and nursery areas. Species such as yellow perch and yellow walleye should benefit most.

Raising the pool level from 1,300 feet to 1,425 ft above sea level will increase the surface area by about 1,200 acres and increase the capacity from 2,000 acre-ft to 72,000 acre-ft. The increased water area will greatly increase both recreational boating and aesthetic appeal. It is significant that the large increase in volume will greatly increase retention time. At the current pool elevation of 1,300 ft and a mean flow of 1,227 acre-ft per day, the retention time is 1.6 days. At a low flow of 119 acre-ft per day, the retention time is 17 days. With the pool capacity increased to 72,000 acre-ft the mean retention time will be 58 days and at low flow the time will increase to 605 days. As illustrated in figure 14, the trophic status of Francis E. Walter Reservoir should improve as the phosphorus loading rate decreases from 15.1 grams/m<sup>2</sup>/yr to 1.6 grams/m<sup>2</sup>/yr.

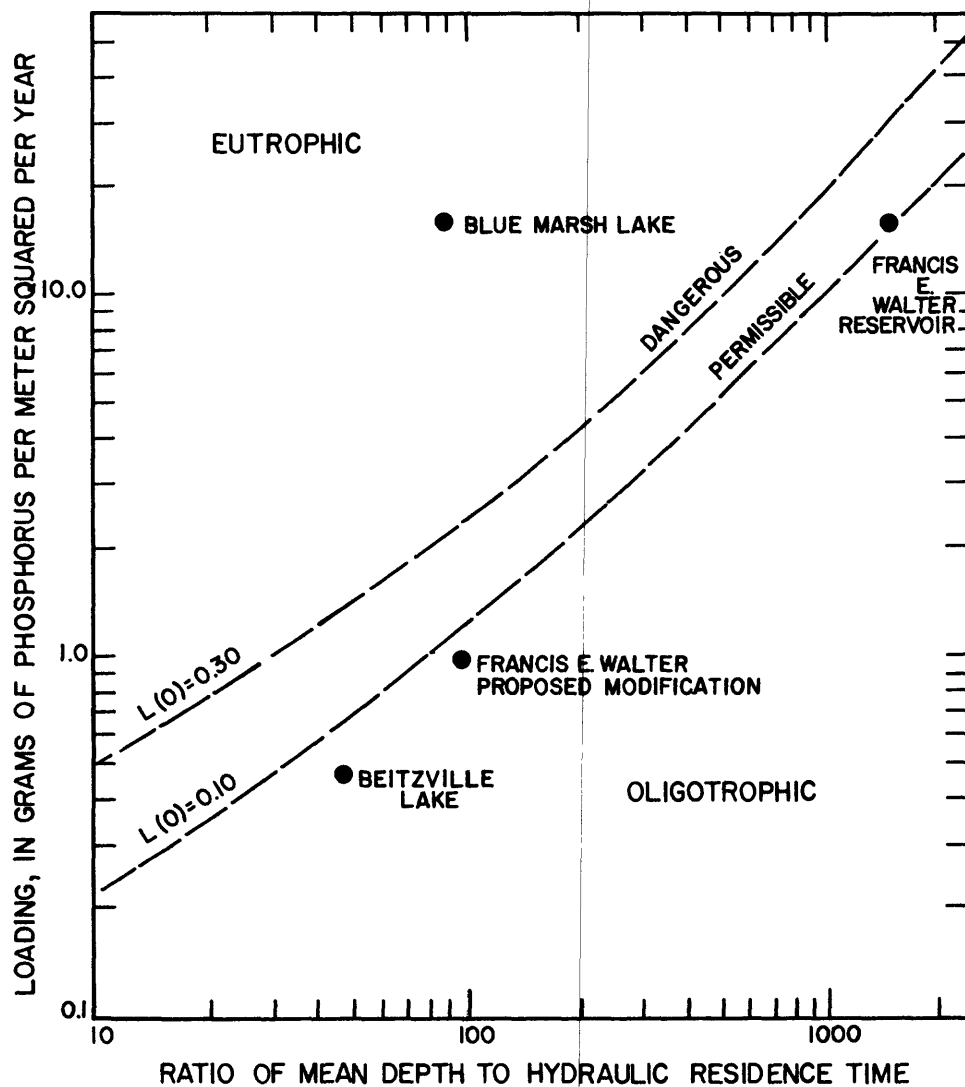


Figure 14.--Total phosphorus loading versus the ratio of mean depth ( $\bar{z}$ ) to hydraulic residence time (TW) and its relation to the eutrophication potential of a lake (from Vollenweider, 1975).

It is possible that increasing the depth from 45 to 170 ft may, given proper climatic conditions, result in sufficient thermal stability to initiate stratification. An anoxic stratum is also possible until the oxygen demand resulting from the inundated vegetation is satisfied. Coordinated monitoring and use of the selective withdrawal gates would minimize stratification and the volume of anoxic water.

A more stable pool elevation and discharge should also benefit fishery interests downstream of the dam as temperature and flows stabilize. However, withdrawal of anoxic water from the reservoir could have a negative impact on the quality of water in the tailrace.

Low pH will continue to be a problem and may tend to restrict the diversity of plants and fish. Increasing the volume and depth will not improve the acidity of the impoundment. Management practices need to be oriented towards maintaining stable pool elevations during the critical spawning and nursery seasons for the important fishes. Nursery areas will be enhanced if rooted vegetation is allowed to proliferate in the limited shallow areas (less than 10 ft deep) of the shoreline. One effective way of doing this is to raise the pool level a few feet during the spawning and nursery season (April-June) and then return the water level to the normal operating elevation for the summer recreation season.

#### SUMMARY

Past and current water quality data indicate the waters of the Upper Lehigh River basin are of good quality. The waters are naturally acidic due to a combination of conditions that include acidic precipitation, bogs, and soils low in buffering capacity to neutralize the acidity. The waters are also low in dissolved minerals; and, therefore, are low in overall productivity. Even under these conditions certain species of phytoplankton can and do attain rather high populations.

Reservoir profiles indicate the impoundment stratifies thermally for only a brief period during the summer while dissolved oxygen concentrations were depressed to levels critical to fish throughout much of the reservoir during the warm-water period. The low dissolved oxygen levels are the result of a temporary high biochemical demand brought about by the inundation of forest vegetation.

Tests for enteric bacteria indicate the waters of the impoundment are nearly free of fecal coliform and fecal streptococcus and are therefore suitable for all forms of contact recreation and potable water supplies.

Raising the pool elevation from 1,300 ft to 1,425 ft above sea level is not expected to have any lasting deleterious effects on the water quality. Low pH will continue to be a problem and restrict the diversity of plants and fishes. Low dissolved oxygen levels found during the summer of 1981 are expected to increase towards saturation as the biochemical demands are satisfied. Increased retention time is not expected to increase future trophic levels because the available phosphorus is presently utilized by the standing crop of primary producers (algae).

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