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The Effect on Water Quality Operations of a Reallocation of Flood Control Storage to Water Storage in Bloomington Reservoir

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The Effect on Water Quality Operations of a Reallocation of Flood Control Storage to Water Storage in Bloomington Reservoir

Introduction

This report summarizes one task of the Interstate Commission on the Potomac River Basin's study of the feasibility of maximizing Potomac inflow to the Chesapeake Bay during periods of drought. While the focus of the feasibility study is the innovative operation of Bloomington Reservoir (the largest impoundment in the Potomac Basin) the focus of this task is to determine whether current objectives for water quality operations would be attainable with these alternative operational strategies.

The Water Qaulity Problem

This analysis further examined the impacts of a change in the allocation of flood control storage in Bloomington reservoir, on the water quality goals of the project. Bloomington reservoir is a multiple purpose project authorized for water quality, flood control, and water supply. The water quality storage is used to maintain downstream flowby requirements with water quality characteristics conducive to the growth of fish and other aquatic life. Maintaining water quality objectives has taken the form of meeting downstream temperature and acidity targets.

While considering any operating changes that would significantly change the level of the lake at various times over the course of the summer, one must also consider the impacts on water quality within the lake and in the downstream reaches. There is substantial ability to control the water quality of releases from Bloomington. Bloomington reservoir was constructed with a selective withdrawal system which allows the withdrawal of water from different elevations within the lake; as a result of hydrologic and climitological factors, the water at different levels exhibits different quality characteristics. A schematic of a selective withdrawal tower is shown in Figure 1. The water quality ports are represented by the smaller circles in the upper portion of the tower. These ports span the upper 100 feet of the reservoir. The flood gate which may release a flow of twice the order of magnitude as a water quality port is located at the base of the tower.

In examining the potential for reallocating storage in Bloomington reservoir, the U.S. Army Corps of Engineers (COE) concluded that construction of additional withdrawal ports at a higher elevation would be required in order to meet the project's water quality functions (1). However, these additional ports may not be necessary if operational decisions include the predictability of water quality within the lake.

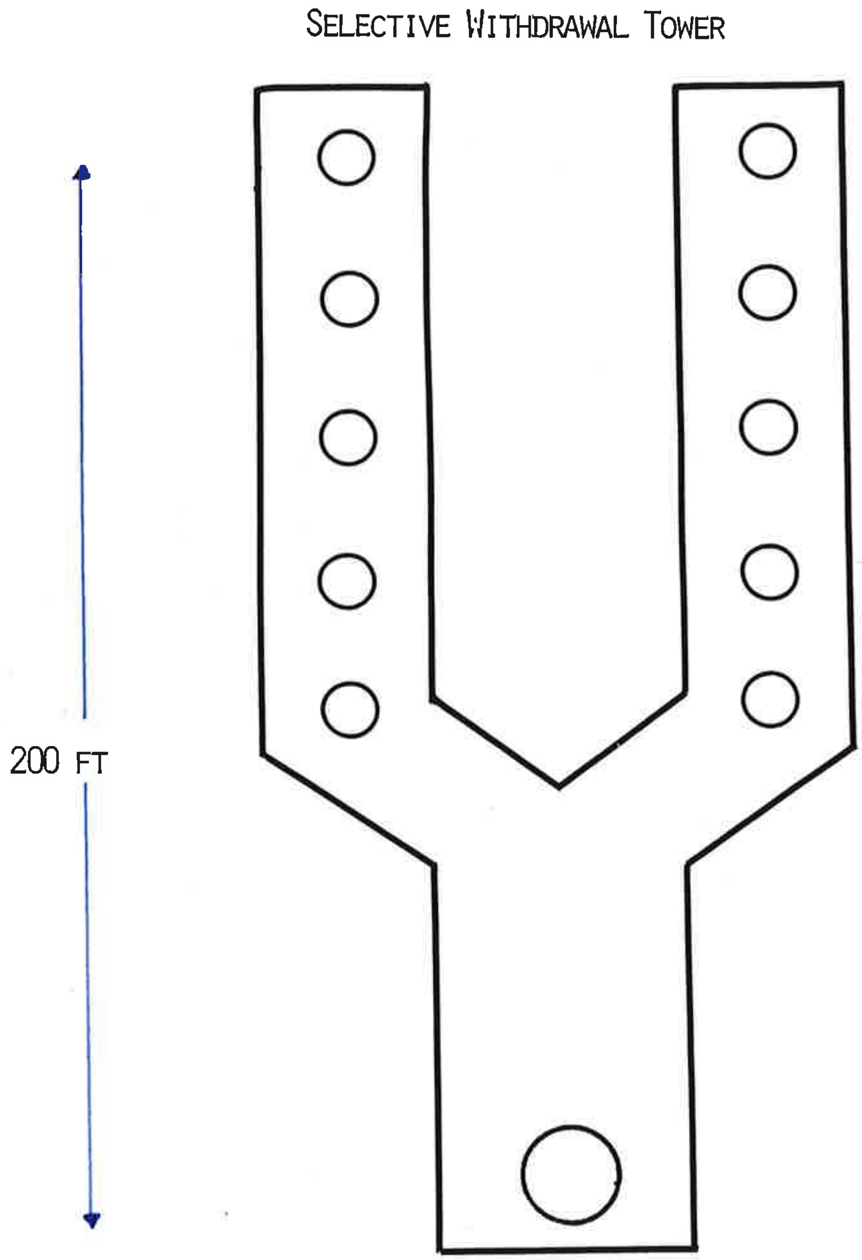

Figure 1. Schematic of Selective Withdrawal System

The effect on water quality operations of filling the reservoir to a higher level has been examined in a previous study (2); the results of further analysis are the subject of this report. The results of the previous study showed the following:

1. Downstream acidity was uniformly improved with the higher maximum pool elevation.

2. Downstream temperature was slightly degraded with the higher maximum pool elevation, but with the largest violation being less than 0.5 degrees C.

3. Additional water quality ports are not required for a nine foot reallocation of storage.

The previous study employed several limiting operational assumptions including constant daily releases and constant downstream water quality targets.

In this study, one of the operational assumptions is relaxed and an additional reallocation alternative is examined. Specifically, the water quality targets are linked to the time of year to better reflect what is feasible on a seasonal basis. This results in wider ranges of acceptable temperatures in the late spring and the early fall. In addition, two alternative reallocations of storage are examined. This includes the nine foot reallocation which provides 8,800 acre-feet of additional water storage and an eighteen foot reallocation which provides 18,200 acre-feet of additional storage (both reallocation alternatives were identified by the U.S. Army Corps of Engineers).

This study demonstrates that neither reallocation alternative requires the construction of additional water quality ports so as to meet the downstream targets. The substantiating results follow a reiteration of the methodology used in the analysis and how this methodology reflects the physical processes which are measured at Bloomington Lake. A discussion of the data used in the previous study and this study is also provided.

Methodology and Applicability to Bloomington Reservoir

The methodology used in this study consists of the joint operation of simulation and optimization models. These models describe the physical processes which exist in the reservoir system and thereby provide water quality information which is required for the daily operational decisions made for Bloomington. The physical processes of interest are those which influence the temperature distribution within the lake. This distribution changes over time; a lake situated in a temperate region exhibits nearly isothermal conditions in early spring, experiences warming of the upper layers over the course of the summer and returns to isothermal conditions by late fall. This overall process of thermal stratification results from a number of contributing processes which distribute heat. For example, in the late spring and summer, the dominant heat sources are heat exchange at the air-water interface, solar heating, and the advective inflow of heat. These sources heat the upper regions of the lake, the epilimnion, which then becomes lighter in weight, and a density or thermal gradient results. The gradient becomes more pronounced with the progression of the warm months. Thermal profiles (variation of temperature with lake depth) constructed for Bloomington Lake data which were collected by the COE are shown in Figure 2. The two curves represent profiles in the summer and winter months. The summer profile shows the degree to which stratification can develop by the end of the summer. The winter profile shows that reverse stratification can occur in deep reservoirs. The invariable lower temperatures are characteristic of deep reservoirs.

From an operational standpoint, it is important to notice that the warm season profile is monotonically increasing with elevation above sea level. Thermal instabilities that may result from the inflow or release of water are resolved through density driven mixing. Therefore, a wide range of temperatures exists in the reservoir by late summer, and the range develops in a systematic fashion responding to natural phenomena. It is also important to note that the range of desirable temperatures may span a relatively limited range of elevations. The development of this distribution of temperatures is one function of the simulation model.

A confounding feature of water quality operations at Bloomington Reservoir results from the occurrence of highly acidic inflows to the lake in the late summer. Currently, both the acidity and the temperature of the releases from Bloomington are controlled through the operation of the selective withdrawal ports. In effect, the reservoir is being used to attenuate the effects of acid mine drainage from abandoned upstream coal mines.

The distribution of acid within the lake is governed by the density gradient that exists when the acidic waters enter the lake (3,4). That is, the inflow enters the water column of the lake at a neutrally buoyant elevation, as determined by comparative densities, and the acidity of that elevation is determined by the acidity of the inflow modified slightly through mixing with adjacent waters. By late summer, the water exhibiting the desirable temperatures is also the water with the greatest acidity values.

Both the temperature and the acidity values within the lake are predicted by the simulation model, WESTEX, a thermal stratification model developed by the COE at the Waterway Experimental Station in Vicksburg, Mississippi. WESTEX is a one-dimensional finite-difference model. One dimensionality implies that the vertical variations in water quality dominate the horizontal variations. This is usually a reasonable assumption in deep reservoirs in general and has been shown to be appropriate for Bloomington Reservoir, in particular. Figures 3 and 4 display data from Bloomington which are consistent with this assumption. Figure 3 exhibits thermal profiles for the monitoring stations located along the longitudinal axis of the lake. Station 9 is at the headwaters and station 2 is near the withdrawal tower, five

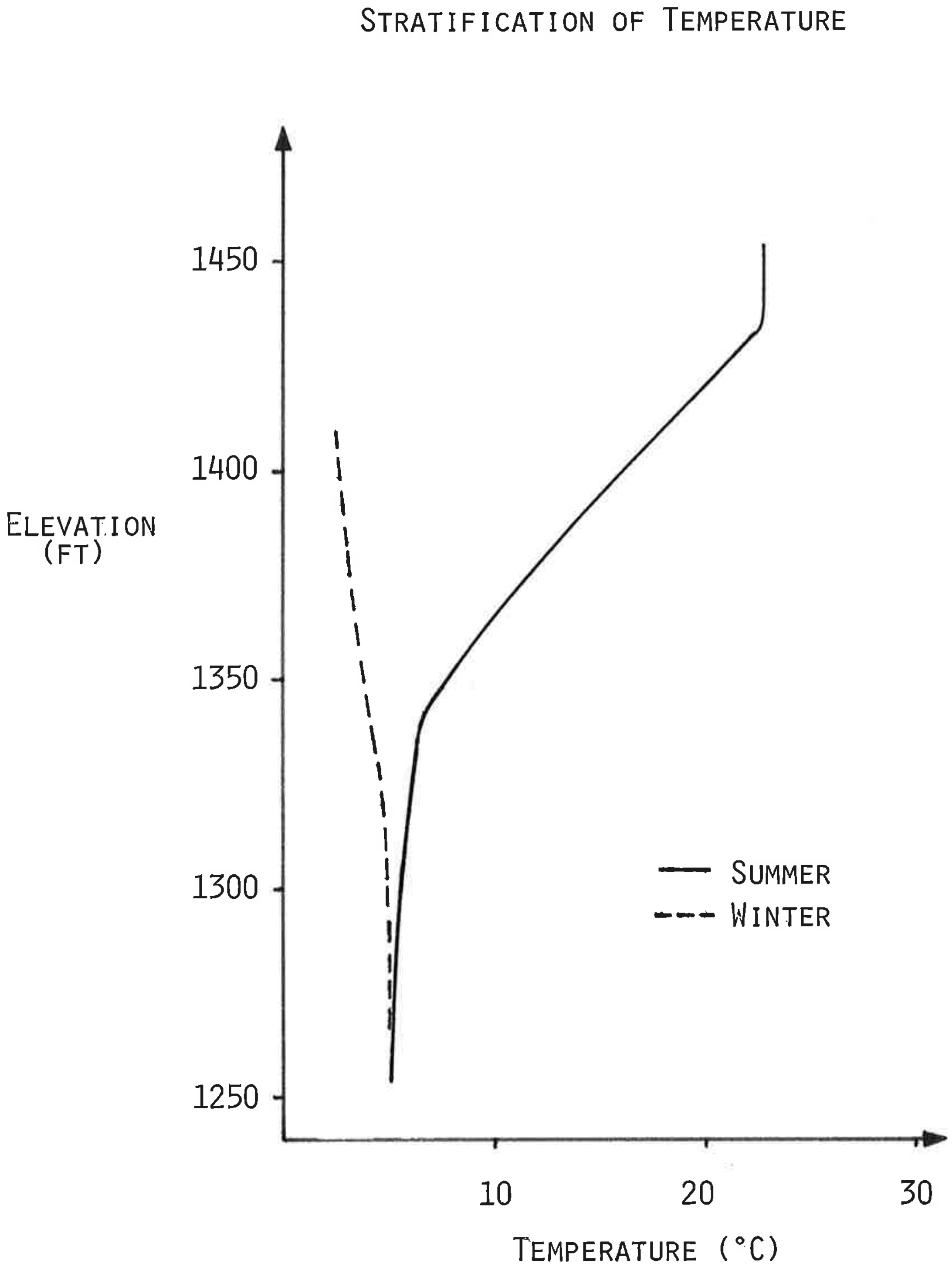

Figure 2. Stratification of Temperature

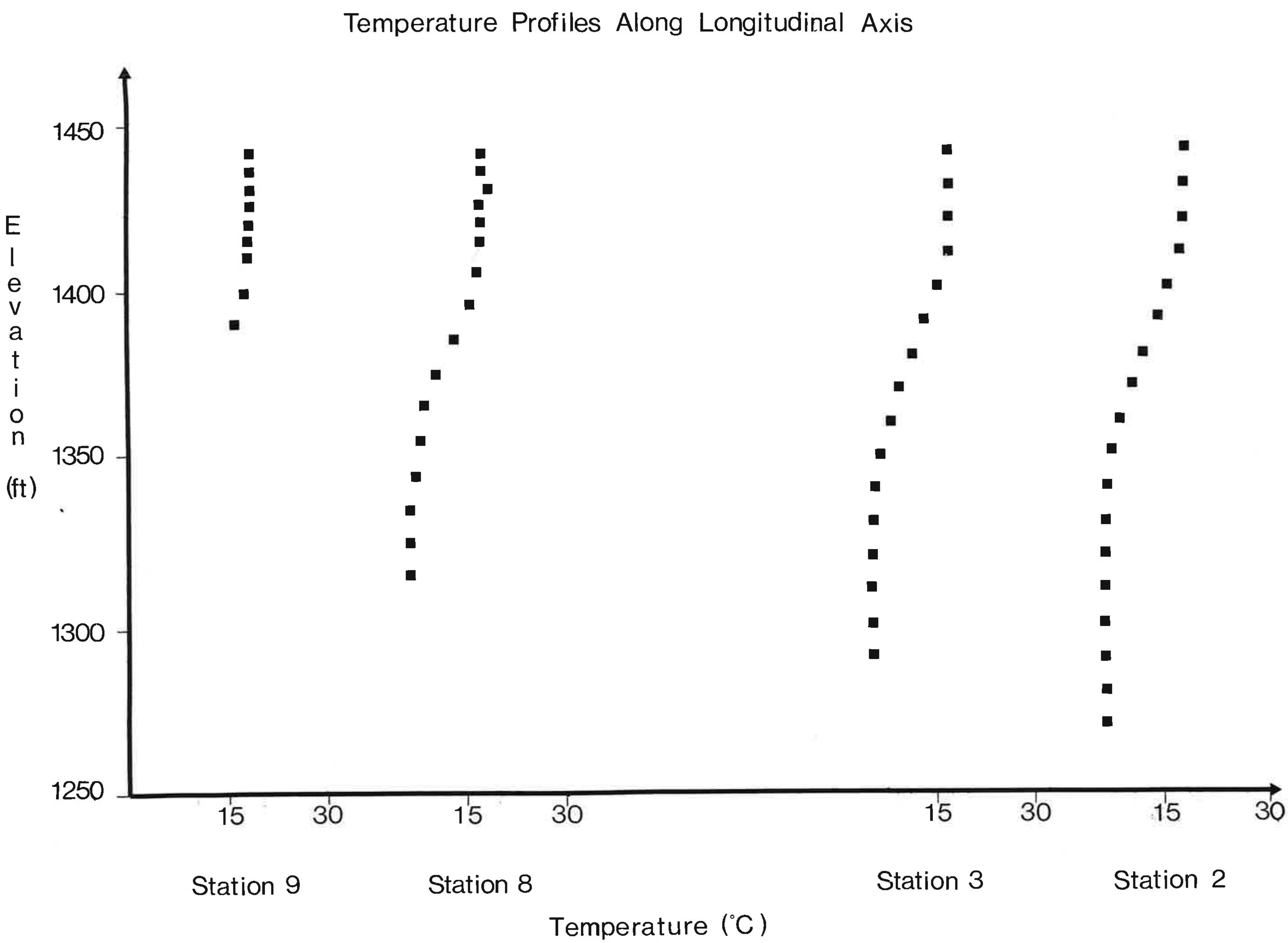

Figure 3. Horizontal homogeneity in temperature profiles for Bloomington Lake

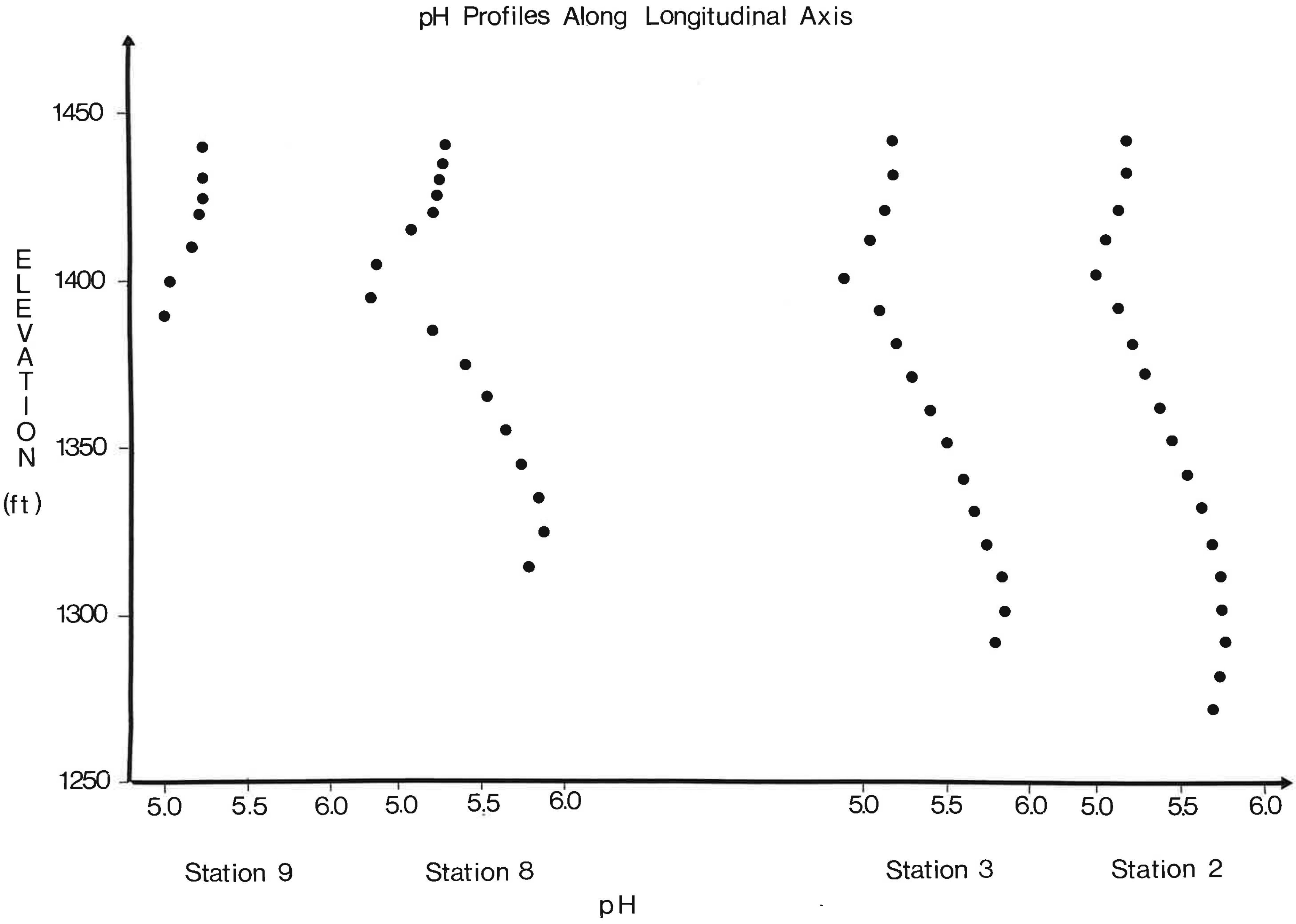

Figure 4. Horizontal homogeneity in pH profiles for Bloomington Lake

miles down the lake. A marked degree of horizontal homogeneity is present. Figure 4 is the analogous picture for pH (- log [H+]) values in the lake which may be used to reflect concentrations of acid. Again a marked degree of horizontal homogeneity exists.

With the predictions of temperature and acidity at each of the ports, daily decisions are made with regard to what quantity of water to release from each port so as to provide the ~~to~~ prescribed total downstream release. The release decisions are made through the use of an optimization model which employs a number of objectives and ensures that decisions which are made do not violate the physical limitations of the system. The objectives of the model fall into two categories. The first set of objectives minimizes the deviations from the downstream water quality targets. With the second type of objective, the effect of releases made one day on the water quality of the lake the following day is acknowledged. This objective seeks to maximize the release of the water form the port corresponding to the worst water quality in the lake; here, the worst water quality is defined by the greatest acidity. This objective is only maximized once the deviations are minimized, that is, in only a hierarchical manner. The use of this objective increases the ability of the lake to dilute future inflows of acidic water.

Outline of Scenarios

The simulation/optimization models were run with various hydrologic conditions and operational parameters for each of the maximum pool levels. The input data is representative of the range of conditions expected to occur in the North Branch basin. Two characteristics of the reservoir system were varied to produce a total of twenty scenarios. These are discussed below:

1. Hydrologic Input -- Two historical water years were selected, one typical of an average rainfall year, 1962, and one typical of an above average rainfall year, 1973. A dry year was not chosen because the upper ports would be exposed early under such conditions and concern about not being able to access the uppermost waters would be unnecessary. The streamflow was obtained from USGS water data publications for the Kitzmiller, Maryland gaging station and is shown in Figures 5 and 6.

2. Magnitude of Release -- A constant daily release was made over the operational horizon. The magnitude of the release assumed the values of 100 cfs, 200 cfs, and 300 cfs for each maximum pool level and an additional value of 400 cfs for the 1484 pool level. The volume of water released over the operational period with these settings corresponds to the volume released under current operations.

The time horizon for each run was May 1 through October 31. This horizon includes the period within which water quality operations

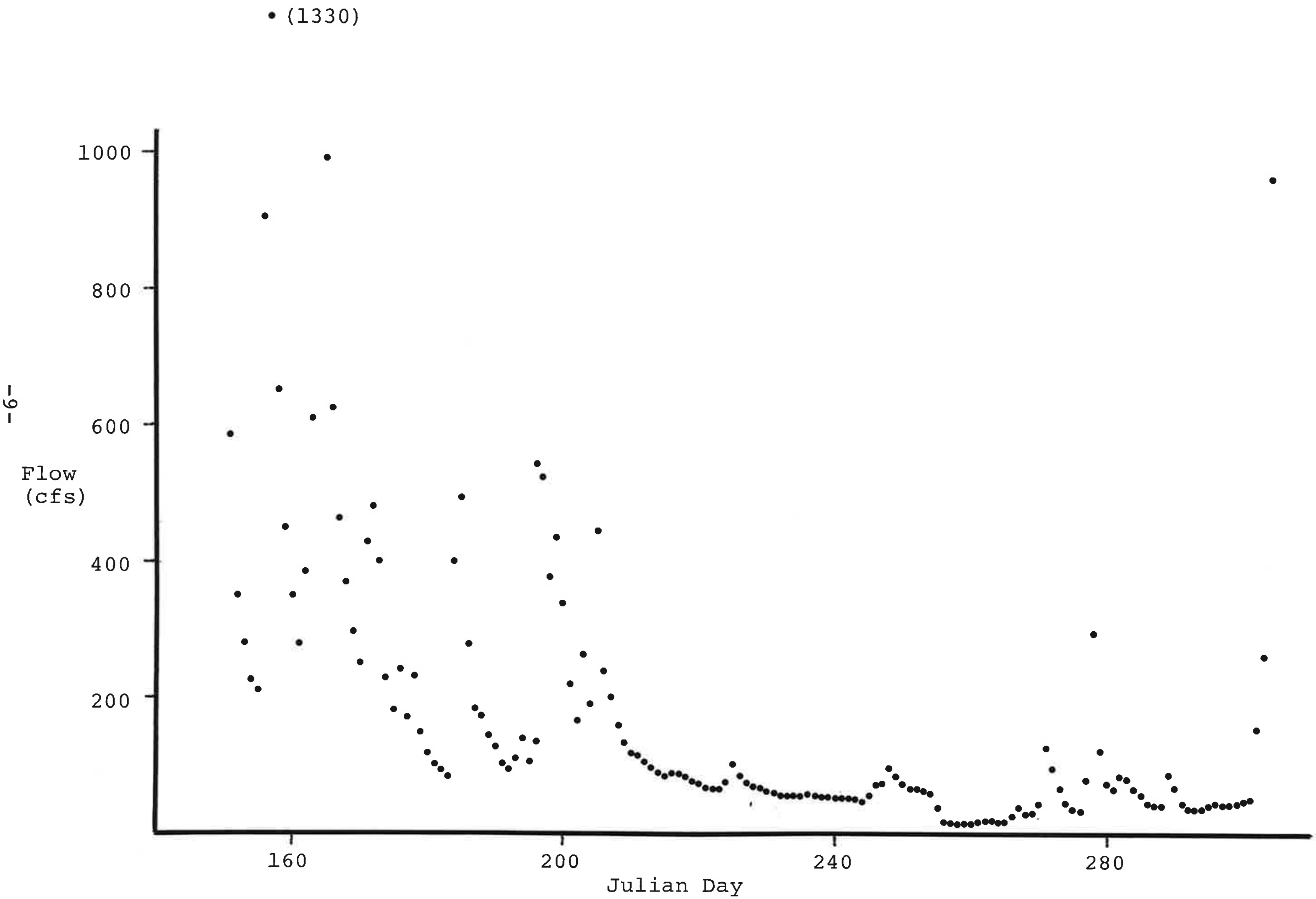

Figure 5. Streamflow at Kitzmiller, Md. during 1962

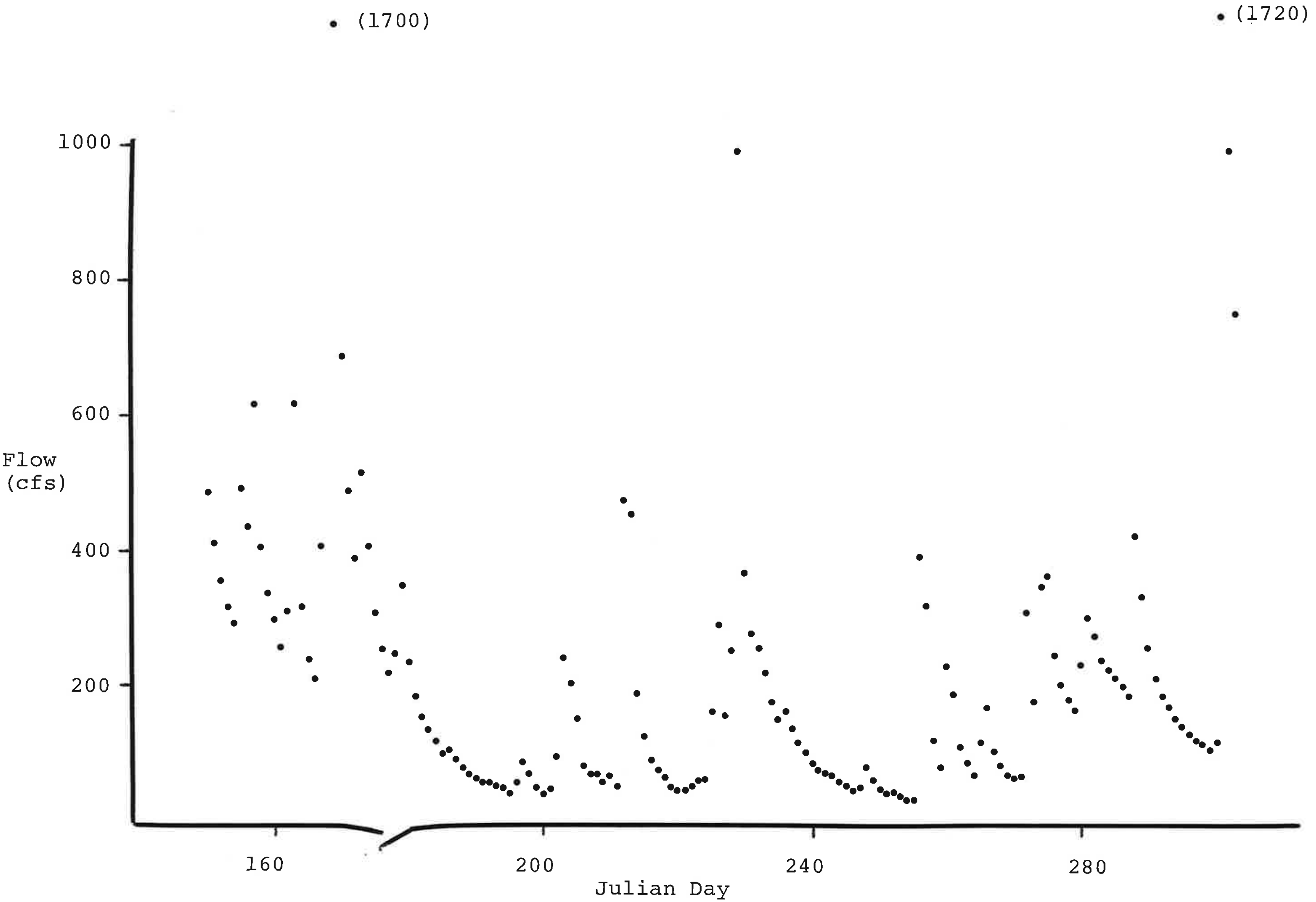

Figure 6. Streamflow at Kitzmiller, Md. during 1973

become most difficult: the months of August and September which experience the inflows with the greatest acidities. This horizon also allows the development of the thermal and water quality profiles in response to climatological inputs over the course of the summer. Each simulation began from the same initial thermal and water quality profile on May 1st (see Table 1).

The models require daily input of the inflow temperature and the inflow acidity. The acidity of the inflow was obtained by constructing sequences which maintain the inverse relationship between acidity and magnitude of flow observed in the monthly acidity data collected by the COE. The sequences generated here are representative of post-1980 conditions which are not as severe as pre-1980 conditions. The temperature sequences were obtained from USGS water quality publications for the Kitzmiller, Maryland monitoring station. The data for both water years are provided in Tables 2 - 5.

Downstream water quality targets were specified with an emphasis on the ability of the downstream area to support fish life. The temperature and acidity targets were defined as follows:

Release Temperature
    15 - 18 °C for June 1 through September 30
    13 - 18 °C for May and October

Release Acidity
    Less than 8 mg/l CaCO

Summary of Water Quality Operation Simulations

The running of the simulation/optimization models yields daily sequences of the temperature and the acidity of the release for the operational period. An example of these sequences is shown in Figure 7. Deviations from the water quality targets are those which lie to the wrong side of the broken lines.

Two basic statistics were compiled for these sequences for each of the twenty simulations. These were the maximum deviation from the water quality targets and the sum of deviations experienced over the entire horizon. Each statistic represents deviations in one direction only. That is, releasing water with an acidity less than 8 mg/l is desirable; only values above this target were counted as violations. Similarly, for the temperature of the release, there is a range of equally desirable temperatures above and below which deviations are counted. The statistics are presented in Tables 6 and 7 for the water years 1962 and 1973, respectively.

The results for water year 1962, an average rainfall year in the North Branch basin, are examined first. Table 6 provides the deviations from the water quality targets for each elevation considered and each constant daily release. Comparisons are made between these statistics in two ways, both using the statistics resulting from an initial reservoir storage of 1466 feet as representative of current

Table 1

Water Quality Profiles for May 1st of each Simulation

Reservoir Elevation	Temperature (°C)	Acidity (mg/l)
1465	8.7	6.0
1460	8.7	6.0
1455	8.5	6.0
1450	8.3	6.0
1445	8.1	6.0
1440	8.0	6.0
1435	7.9	6.0
1430	7.8	6.0
1425	7.7	6.0
1420	7.2	6.0
1415	6.7	6.0
1410	6.2	6.0
1405	6.0	6.0
1400	5.9	7.0
1395	5.8	7.0
1390	5.7	7.0
1385	5.6	7.0
1380	5.5	7.0
1375	5.4	7.0
1370	5.3	7.0
1365	5.3	7.0
1360	5.2	8.0
1355	5.1	8.0
1350	5.0	8.0
1345	4.9	8.0
1340	4.8	8.0
1335	4.6	8.0
1330	4.5	8.0
1325	4.5	8.0
1320	4.5	8.0
1315	4.5	8.0
1310	4.5	8.0
1305	4.5	8.0
1300	4.5	8.0
1295	4.5	8.0
1290	4.5	8.0
1285	4.5	8.0
1280	4.5	8.0
1275	4.5	8.0
1270	4.5	8.0
1265	4.5	10.0
1260	4.5	10.0
1255	4.5	10.0
1250	4.5	10.0
1245	4.5	10.0

Table 2

Streamflow Temperatures (°C) at Kitzmiller, Maryland for 1962

			Month			
Day	May	June	July	August	September	October
1	16.69	18.34	18.34	22.19	21.09	12.19
2	15.79	18.64	17.79	21.64	20.54	15.54
3	13.29	17.74	16.94	20.54	19.69	15.54
4	13.89	16.94	14.99	21.39	19.99	15.24
5	14.44	16.94	16.64	22.49	20.54	14.69
6	14.99	16.39	18.09	23.59	18.34	14.44
7	16.09	15.79	19.44	23.89	17.24	13.84
8	14.14	15.54	20.79	22.74	17.79	15.54
9	14.14	16.64	20.24	22.19	18.34	15.84
10	12.49	17.79	19.44	20.79	19.99	14.44
11	12.49	17.49	19.44	20.54	19.69	14.44
12	12.74	16.64	19.69	21.09	19.44	15.84
13	13.04	16.09	20.54	21.39	19.44	15.79
14	15.24	14.44	19.14	21.09	19.99	14.44
15	17.79	14.99	18.29	20.54	19.39	16.34
16	17.79	15.24	16.94	21.64	18.64	17.19
17	17.49	16.64	17.19	20.79	18.34	15.54
18	18.34	18.09	16.94	19.99	15.79	12.79
19	18.34	18.29	18.04	20.54	15.24	12.79
20	17.49	17.19	18.34	22.49	14.44	11.64
21	18.89	16.09	18.29	23.89	13.59	12.24
22	18.34	16.64	18.89	22.19	12.24	11.64
23	18.34	18.34	19.69	21.09	14.44	9.99
24	17.79	18.59	17.74	20.54	14.44	7.79
25	16.94	18.89	22.07	19.99	14.74	5.84
26	18.34	17.79	19.10	19.69	15.54	4.44
27	17.49	18.34	18.49	20.24	14.99	4.44
28	15.24	18.34	20.41	19.19	13.84	8.34
29	16.24	17.79	18.39	19.19	13.27	8.34
30	17.24	17.24	23.17	20.54	13.29	6.69
31	17.07	-	21.09	21.08	-	6.69

Table 3

Constructed Acid Concentrations (mg/l) for Kitzmiller, Maryland for 1962

	Month					
Day	May	June	July	August	September	October
1	6.	6.	8.	12.	24.	20.
2	6.	8.	10.	12.	23.	24.
3	8.	8.	6.	15.	22.	26.
4	8.	8.	6.	17.	22.	18.
5	8.	6.	8.	18.	20.	12.
6	8.	6.	8.	20.	20.	14.
7	8.	6.	8.	24.	22.	18.
8	8.	6.	8.	20.	22.	19.
9	6.	6.	8.	20.	22.	17.
10	6.	8.	8.	18.	22.	17.
11	8.	8.	10.	20.	22.	18.
12	8.	6.	8.	18.	29.	18.
13	8.	4.	8.	18.	32.	20.
14	8.	6.	10.	15.	32.	20.
15	8.	6.	6.	18.	32.	20.
16	6.	6.	6.	18.	32.	16.
17	6.	6.	6.	20.	32.	17.
18	6.	8.	6.	20.	30.	22.
19	6.	8.	6.	20.	25.	24.
20	6.	6.	8.	20.	25.	24.
21	6.	6.	8.	24.	25.	24.
22	6.	8.	8.	26.	25.	23.
23	8.	8.	10.	24.	24.	22.
24	6.	8.	6.	30.	24.	22.
25	6.	8.	8.	25.	24.	22.
26	6.	8.	8.	22.	24.	21.
27	6.	8.	8.	24.	24.	21.
28	6.	10.	8.	26.	15.	19.
29	6.	10.	10.	22.	16.	17.
30	6.	8.	12.	20.	18.	11.
31	6.	-	10.	24.	-	6.

Table 4

Streamflow Temperatures (°C) at Kitzmiller, Maryland for 1973

			Month			
Day	May	June	July	August	September	October
1	11.25	19.75	21.75	21.00	17.00	15.50
2	13.50	20.50	22.00	20.75	18.50	14.25
3	13.75	19.25	22.50	20.00	20.00	16.00
4	13.00	17.50	20.25	20.25	20.00	16.75
5	10.75	16.50	20.00	20.00	21.25	16.50
6	13.00	16.75	20.75	21.75	18.75	13.50
7	15.25	17.50	22.00	24.50	17.00	13.00
8	17.00	16.00	21.00	24.25	16.50	14.75
9	17.75	16.00	20.50	23.50	18.00	16.00
10	16.00	15.50	22.00	23.00	16.75	16.75
11	14.50	16.25	21.50	23.00	16.75	16.00
12	15.25	18.25	21.50	22.50	17.75	16.50
13	16.00	19.00	20.25	22.25	16.75	16.00
14	17.25	17.00	20.50	21.75	15.00	16.00
15	17.75	15.75	19.25	21.25	13.25	14.50
16	16.50	14.00	19.25	23.75	11.50	13.75
17	14.00	14.25	19.25	23.75	11.75	10.50
18	12.00	15.75	20.25	23.75	14.00	9.50
19	12.75	15.75	21.25	23.25	14.00	10.00
20	12.75	15.75	22.25	22.75	16.75	11.00
21	14.00	15.00	22.00	21.75	15.50	10.75
22	13.00	17.00	21.00	21.25	13.75	10.25
23	13.50	18.00	20.25	20.00	11.00	10.75
24	13.75	17.75	20.75	20.00	12.50	10.50
25	13.00	20.25	21.00	20.75	12.50	9.75
26	13.75	20.25	21.00	18.75	11.00	10.25
27	15.00	19.75	21.25	16.75	10.50	10.50
28	16.75	19.75	20.00	15.00	10.75	9.75
29	16.75	21.00	19.25	14.25	12.75	9.75
30	17.75	21.00	20.75	14.25	13.00	9.00
31	18.00	-	23.00	16.25	-	8.75

Table 5

Constructed Acid Concentrations (mg/l) at Kitzmiller, Maryland for 1973

			Month			
Day	May	June	July	August	September	October
1	4.	6.	8.	10.	14.	15.
2	4.	8.	8.	8.	18.	10.
3	5.	8.	10.	12.	22.	10.
4	5.	8.	8.	14.	22.	11.
5	5.	6.	10.	16.	22.	12.
6	6.	6.	12.	20.	20.	14.
7	6.	6.	26.	22.	22.	14.
8	5.	6.	26.	24.	24.	11.
9	7.	6.	24.	24.	28.	10.
10	5.	6.	18.	26.	28.	11.
11	5.	7.	20.	26.	28.	11.
12	5.	6.	20.	26.	28.	11.
13	6.	8.	22.	28.	32.	10.
14	6.	6.	22.	14.	12.	11.
15	8.	6.	20.	10.	10.	12.
16	8.	8.	18.	12.	12.	9.
17	6.	6.	20.	10.	28.	10.
18	6.	5.	24.	8.	12.	11.
19	8.	6.	24.	9.	13.	12.
20	8.	7.	26.	9.	15.	14.
21	8.	7.	12.	9.	18.	14.
22	8.	6.	10.	10.	18.	15.
23	8.	7.	10.	11.	15.	15.
24	7.	7.	12.	12.	12.	16.
25	6.	8.	18.	11.	14.	16.
26	8.	8.	20.	12.	15.	17.
27	8.	8.	20.	10.	18.	17.
28	5.	8.	24.	12.	18.	17.
29	7.	9.	24.	14.	20.	4.
30	6.	8.	24.	14.	10.	4.
31	6.	-	26.	14.	-	5.

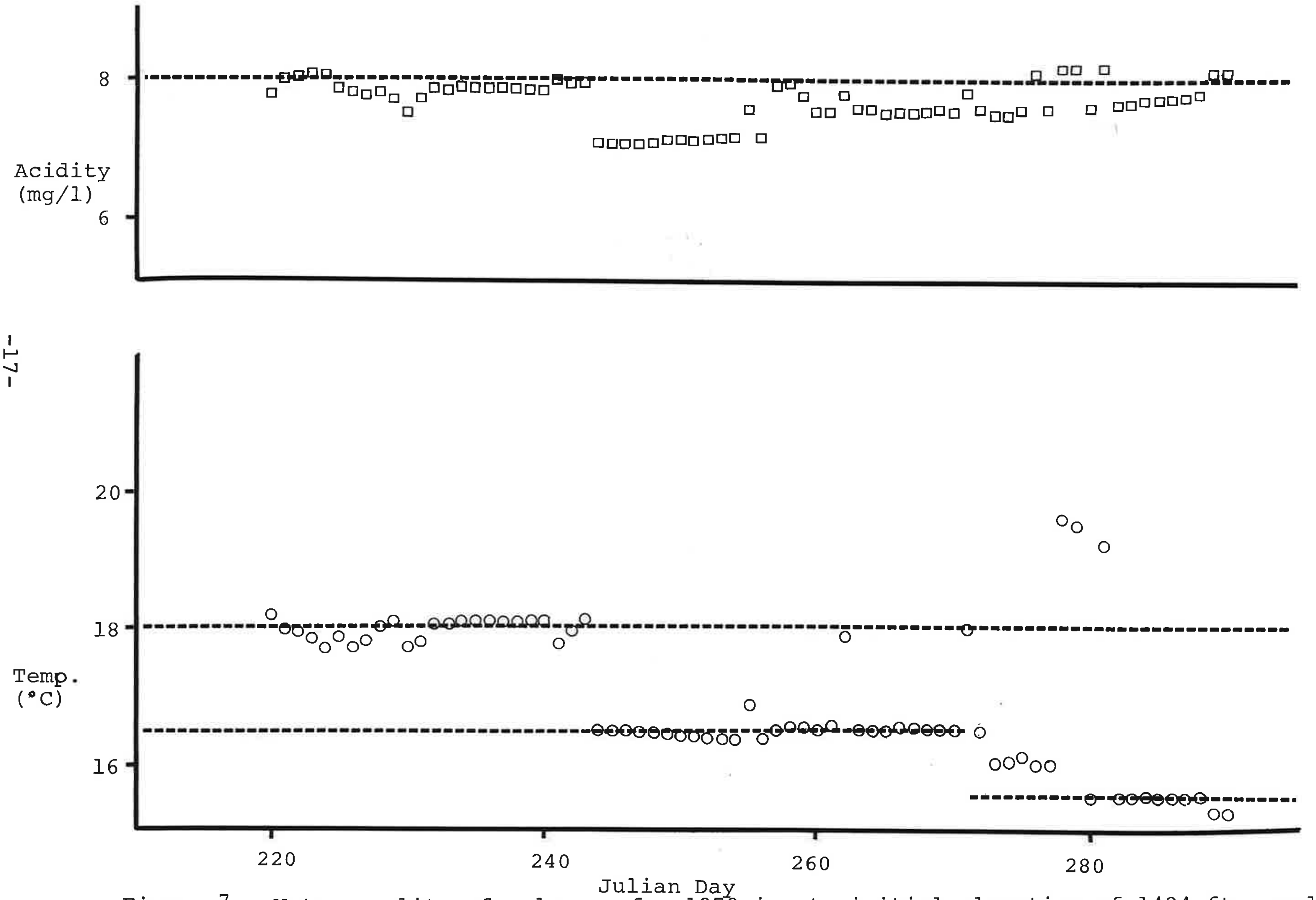

Figure 7. Water quality of releases for 1973 input, initial elevation of 1484 ft., and constant release of 100 cfs.

Table 6. Deviations from water quality targets for scenarios with 1962 hydrologic input

Parameters		Deviations						
		T Upper		T Lower		Acid		Total
Initial Elev. (ft)	Sustained Release (cfs)	Sum (°C)	Max (°C)	Sum (°C)	Max (°C)	Sum (mg/l)	Max (mg/l)	Dev'n
1466	100	206.5	5.7	17.9	1.1	0.5	0.1	224.9
	200	214.8	5.6	1.0	0.2	6.7	0.5	222.5
	300	118.3	6.0	1.6	0.2	5.2	0.7	125.1
1475	100	120.2	5.0	66.0	2.1	0.2	+(1)	186.4
	200	191.3	5.4	0.9	0.5	2.9	0.2	195.1
	300	93.7	5.2	1.4	0.5	3.1	0.3	98.2
1484	100	114.7	5.8	36.1	2.2	0.3	+	150.8
	200	124.4	4.9	11.0	1.4	+	+	135.4
	300	47.7	4.9	11.0	1.4	3.6	0.4	62.3
	400	18.8	5.1	11.2	1.4	2.0	0.3	32.0

(1) a concentration less than 0.05 mg/l

Table 7. Deviations from water quality targets for scenarios with 1973 hydrologic input

Parameters		Deviations						
Initial Elev. (ft)	Sustained Release (cfs)	T Upper		T Lower		Acid		Total Dev'n
		Sum (°C)	Max (°C)	Sum (°C)	Max (°C)	Sum (mg/l)	Max (mg/l)	
1466	100	30.8	6.3	32.6	8.7	0.3	0.2	63.7
	200	87.7	7.4	20.5	6.8	0.7	0.2	108.7
	300	20.4	7.0	62.6	7.3	3.0	0.3	86.0
1475	100	4.1	0.4	48.9	2.3	0.1	+(1)	53.1
	200	110.9	6.9	5.7	1.3	2.6	0.3	119.2
	300	47.1	7.0	34.2	5.0	1.1	0.2	82.4
1484	100	13.5	3.1	57.6	3.0	0.4	0.1	71.5
	200	42.0	5.4	12.4	1.5	0.7	0.1	55.1
	300	50.6	6.3	4.9	0.9	2.2	0.5	57.7
	400	16.2	5.6	64.6	6.9	3.5	0.7	84.3

(1) a concentration less than 0.05 mg/l

operations. First, the same quantity of water may be released over an operational period, beginning and ending at different storage levels, without any degradation of the water quality of the downstream reaches (the lower temperature target is violated more frequently, however, with a maximum deviation of 2.1 °C which is compensated by a reduction in the deviations from the upper temperature target totalling 86.3 °C). This scenario may be viewed as holding additional storage for Chesapeake Bay releases while meeting the water quality objectives of the project.

A second type of comparison involves examining simulations which draw the reservoir down to similar levels by the end of the operational period. That is, if the additional storage is used over the course of the summer, the effects on water quality operations can be examined. The final reservoir levels or lake depths are provided in Table 8. Table 8 shows that releasing 200 cfs/day from the reservoir when filled to 1466 feet yields nearly the same final storage (196.6 ft) as releasing 300 cfs/day from the reservoir when filled to 1484 ft (191.4 ft). The maintenance of the downstream targets is significantly better in the second instance for both the upper temperature target and the acidity target (47.7 °C in contrast to 214.8 °C and 3.6 mg/l in contrast to 6.7 mg/l). The lower temperature target is missed more frequently with a total deviation of 10 °C and a maximum deviation of 1.4 °C.

The set of operational parameters which correspond to the best performances is an initial reservoir elevation of 1481 feet and the release of 300 - 400 cfs/day. That is, use of the water allocated to water quality storage does not negatively impact the ability to meet project goals.

Similar values are presented for 1973, a year of above average rainfall, in Table 7. Examination of these values reveals that although some degradation in meeting the downstream targets occurs when releasing the same quantity of water while starting with higher initial storages, the degradation is not severe. For example, when releasing 200 cfs/day from the reservoir with an initial elevation of 1466 feet, the upper temperature target deviations total 87.7 °C with a maximum deviation of 7.4 °C. Releasing the same quantity yet starting with an initial level of 1475 feet produces a greater total of deviations from the upper temperature target yet the maximum deviation is reduced to 6.9 °C. Furthermore, releasing the same quantity from the reservoir with an initial level of 1484 feet has the lowest total of upper temperature target deviations of the three. The total of the deviations from the acidity target is the largest for the 1475 initial level case. The maximum deviation increases to 0.3 from 0.1 mg/l. The release of 300 cfs/day produces similar deviation totals regardless of the initial elevation.

The second type of comparison is difficult to make with the simulations for 1973 since the final elevations are all fairly different. The best candidates include runs for which the constant release was 100 cfs. This is a slightly misleading parameter for the

Table 8. Reservoir depth at the end of the operational period

Parameters		Reservoir Depth (ft)	
Initial Elev. (ft)	Sustained Release (cfs)	1962	1973
1466	100	224.2	225.4
	200	196.6	219.8
	300	163.3	189.1
1475	100	233.5	232.3
	200	207.4	228.2
	300	177.0	199.5
1484	100	239.9	243.4
	200	219.6	238.3
	300	191.4	211.1
	400	144.5	177.7

A lake depth of 141 ft corresponds to complete usage of the water quality storage

1973 simulations since maintaining the reservoir level below the maximum level often required a release greater than 100 cfs. Releasing greater quantities of water seems to allow greater flexibility in determining a desirable blend of water from the reservoir.

The quality of the water released downstream may be examined in another manner. That is, the average acidity of the release over the operational period may be calculated. These values are provided in Table 9 for each simulation. Acidity is shown since it has been identified as the most important quality characteristic. This table shows that the average acidity of the released water is generally better when the reservoir has been filled to a higher level. The average acidity of the release is greater with larger constant releases, however it is consistently lower when the maximum pool level is higher.

Conclusions

The water quality of the downstream reaches does not appear to be severely degraded with higher reservoir pool elevations. The extent that the acidity of the released water violated downstream targets over the operational period, which includes the period of highest acid inflows (August and September), decreased when the reservoir was filled to higher elevations. Filling the reservoir with good quality water early in the season seems to dilute the acidity of the flows of late summer. Not being able to access this good quality water in early summer does not appear to limit the ability to meet project goals.

On the average, the temperature targets were met as well with releases from the deeper reservoirs. There is some interaction between meeting the upper temperature target and meeting the lower temperture target. Simulations which produced lower upper temperature target deviations produced high lower target deviations and vise versa. If one end of the temperature range plays a more dominant role with regard to the maintenance of aquatic life, the relative importance can be built into the models.

Degradation of the downstream water quality is not a limitation in the reallocation of flood control storage. Furthermore, structural modifications do not seem to be necessary to maintain operations at their current level of performance yet with greater lake depths. Further analysis into water quality operations could be useful to determine how to best minimize the deviations from downstream targets during daily operations.

Table 9. Average acidity of the release over the operational period

Parameters		Average Acidity (mg/l)	
Initial Elev. (ft)	Sustained Release (cfs)	1962	1973
1466	100	7.5	7.2
	200	7.6	7.3
	300	7.6	7.4
1475	100	7.1	7.2
	200	7.3	7.3
	300	7.3	7.3
1484	100	7.2	7.0
	200	7.3	7.1
	300	7.4	7.3
	400	7.3	7.4

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