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Hydrologic Engineering Center

Pennypack Creek Water Quality Study

November 1979

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Pennypack Creek Water Quality Study

November 1979

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PR-5

**In Memoriam
of
Jesse Walter Abbott**

Jess Abbott, HEC's "Red Baron" of urban hydrology and stormwater management studies, was killed on September 8, 1978, while driving to work.

Jess was born in Helena, Montana and shortly thereafter his family moved to Boise, Idaho where he grew up and went to Meridian High School. His civil engineering career began at the University of Idaho, Moscow, where he earned his BS and MS degrees. Jess was designated an Outstanding Civil Engineering Student in his graduate studies.

After graduating from the university, Jess undertook his military service as an officer in the U.S. Public Health Service. He began his Hydraulic Engineering career with the U.S. Army Corps of Engineers, Walla Walla District. From there he went to the North Pacific Division Office in Portland, Oregon. He then joined the Hydrologic Engineering Center, Davis, California in 1973.

At the Hydrologic Engineering Center, Jess was a Research Hydraulic Engineer in charge of the Center's urban hydrology program. Jess was instrumental in furthering the development and application of the computer program, STORM, which is one of the primary tools in the U.S. for simulating the quantity and quality of urban storm water runoff. He coordinated the usage of the STORM program within the Corps, the Environmental Protection Agency, and many private engineering firms. He was an active contributor to the American Society of Civil Engineers Urban Water Resources Research Program.

Outside the office, Jess took every opportunity to pursue his love of the outdoors, especially flying his plane through the skies of California and the Northwest. One of Jess' unique contributions to our lives, and to everyone he met, was his unending supply of good humor. He had an appropriate "one-liner" for any occasion and was always the highlight of the training course introductions at the HEC.

PENNYPACK CREEK
WATER QUALITY ANALYSIS

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PENNYPACK CREEK
WATER QUALITY ANALYSIS

I INTRODUCTION

Background

This study of the water quality of the Pennypack Creek Basin was conducted as part of the expanded scope flood plain information (XFPI) study done by the Philadelphia District Corps of Engineers. The XFPI prepared by the Philadelphia District generally follows the techniques utilized by the Savannah and Fort Worth Districts and the Hydrologic Engineering Center (HEC) in the Upper Oconee River Pilot Study¹/ (Trail Creek Test) and the Rowlett Creek Pilot Study,²/ respectively. The basic concept in undertaking the XFPI was to create and maintain a data bank of basin characteristics which will be interfaced with computer programs to analyze the impact of land use changes in the basin. Information developed during the preparation of the XFPI included hydrologic, hydraulic, and environmental data as well as flood damage analyses.

During the development of the XFPI geographic data bank, the Philadelphia District requested the HEC to perform an analysis of the Pennypack Creek water quality consistent with the XFPI objectives and methodology. Thus, the existing and future water quality of the Pennypack Creek, within the study area, would be simulated. A

geographic data bank would be used as the basis for land use inputs to the existing HEC storm runoff model (STORM)^{3/} and a new receiving water quality module (RWQM)^{4/} for STORM being developed for this project. The STORM runoff module would be used for determining the quantity and quality of land surface runoff and the receiving water quality module would be used to simulate water quality in the stream network. That is, the land surface runoff from the runoff module would be input to the receiving water module to simulate the resultant stream water quality. Limited historical data regarding the water quality of the Pennypack Creek were obtained from the city of Philadelphia, U.S. Geological Survey, and the Pennsylvania Department of Environmental Resources. Streamflow data for the Pennypack Creek were obtained from the U.S. Geological Survey for the two recording gages located in the watershed. In some cases where data were not sufficient, general experience gained during other water quality studies was used to ascertain whether the model results were acceptable.

Scope and Objectives

The objective of this study was to make a preliminary analysis of the impact of changing land use on the water quality of Pennypack Creek in the city of Philadelphia. In particular, the existing land use condition and one future land use condition would be simulated. The relative proportions of storm runoff and and dry weather flow were to be estimated. These proportions will aid in decisions regarding additional pollution control measures in the basin.

Study Team

This study was carried out by the HEC with direct involvement by personnel from the Philadelphia District. The District provided general guidance about the objectives of the XFPI study and supplied most of the required data for use in the models. The study was conducted as a team effort. Jess Abbott and John Colt of the HEC conducted the application of the STORM model. John Gahagan of the Philadelphia District assisted in preparation of data, calibration and application of STORM for use in runoff simulation. Robert Schrieber of Resource Analysis, Inc. and R. G. Willey of the HEC conducted the application of the RWQM. Allan Sleeper of the Philadelphia District and R. G. Willey of the HEC prepared data for use in the instream water quality simulations.

II SUMMARY AND CONCLUSIONS

The Pennypack Creek watershed is presently undergoing significant change in land use. This study compared existing land use with a future land use representing maximum development. Under future land use conditions, it is estimated that the average annual runoff will increase by 14%.

The treated effluent loads from the Upper Moreland Hatboro (UMH) sewage treatment plant are one of the most significant impacts on the water quality of Pennypack Creek for both existing and future conditions. Between 70 and 90 percent of the total nutrient loads (i.e., ammonia and orthophosphate) for both existing and future conditions were predicted to be generated by effluent from the sewage treatment plant. These loadings cause stream conditions which are far worse than the standards allow.

Approximately 100 percent of fecal coliform populations were predicted to come from stormwater runoff. The estimated concentrations are far worse than the standards allow.

The carbonaceous biochemical oxygen demand (CBOD) from the UMH discharge is approximately 25% of the CBOD for existing conditions, but increases to approximately 32% and 46% for future conditions A and B. Therefore, further reduction in the loads from the treatment plant would have the greatest effect in improving the nutrient concentrations of

Pennypack Creek, but would have little impact on fecal coliform for existing or future conditions or on CBOD for existing land use conditions.

The impacts of future land use conditions are relatively small compared to the potential impact of existing discharges from the UMH plant and from present stormwater runoff.

Future land use conditions tested have little impact on the Pennypack Creek, but should be considered for their potential impact on the Delaware River eutrophication.

III PENNYPACK CREEK BASIN DATA AVAILABILITY

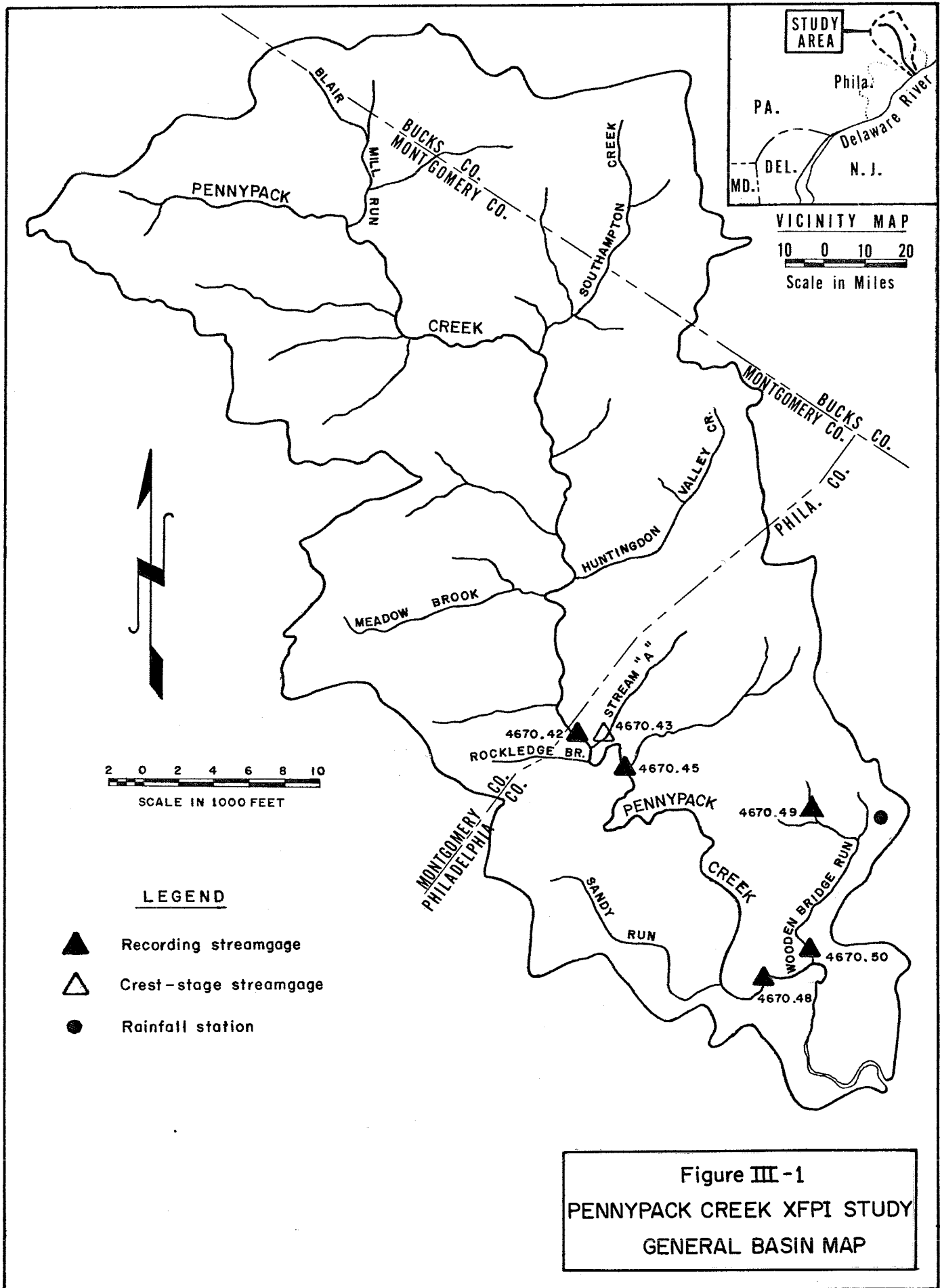
General

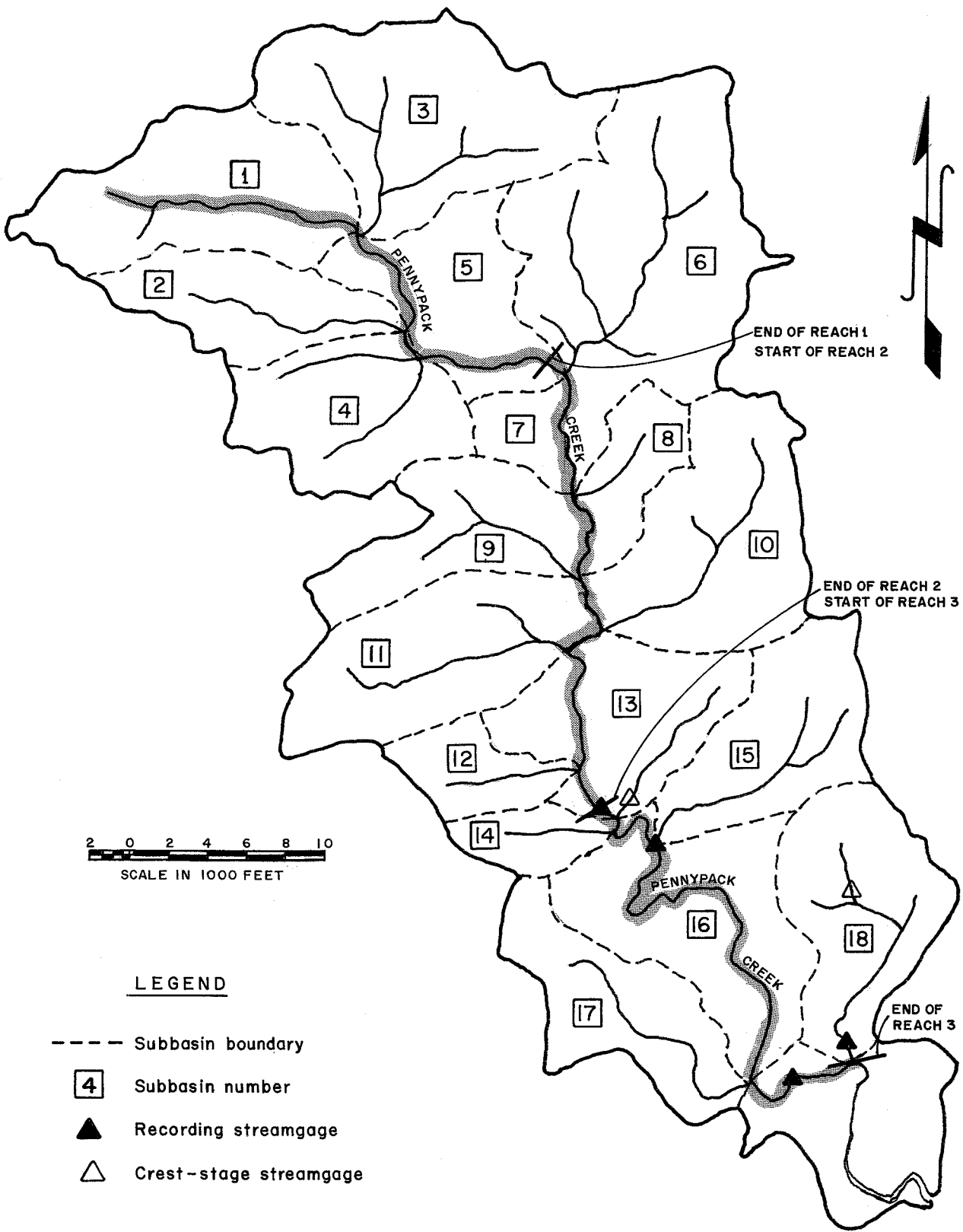
The Pennypack Creek has its origin in Horsham township, Montgomery County and flows in generally a southeastern direction toward its confluence with the Delaware River. A location map is shown on Figure III-1.

The study boundaries for this project extend from the confluence of Blair Mill Run and Pennypack Creek in Hatboro township, Montgomery County, downstream to a small dam located approximately 570 feet upstream of Frankford Avenue, in the city of Philadelphia. The Pennypack Creek study area with subbasins and instream water quality reaches is shown in Figure III-2, and schematics are shown in Figures III-3a through III-3c.

Meteorology

The meteorological data for the runoff analysis were obtained from the Asheville, North Carolina Office of National Weather Service. Magnetic tapes of hourly and daily rainfall data at the North Philadelphia Airport were obtained for use in the STORM model.



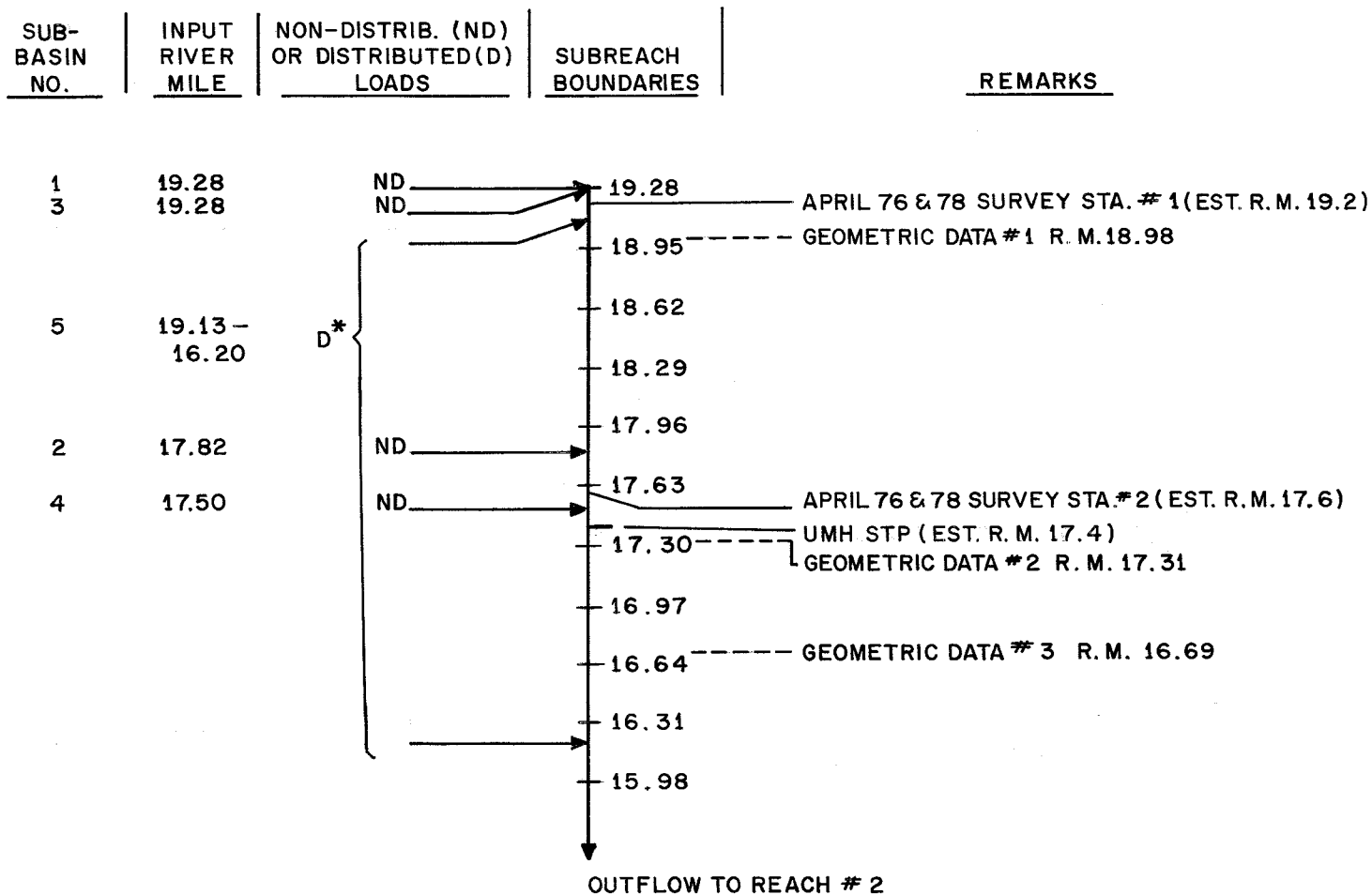


2 0 2 4 6 8 10
SCALE IN 1000 FEET

LEGEND

- Subbasin boundary
- 4 Subbasin number
- ▲ Recording streamgage
- △ Crest-stage streamgage

Figure III-2
PENNYPACK CREEK XFPI STUDY
SUBBASIN LOCATION MAP



* River Mile 19.13 defines the upstream boundary of subbasin 5 distributed load, and river mile 16.20 defines the lower boundary.

Figure III-3a. Schematic of Reach 1 of Pennypack Creek

SUB-BASIN NO.	INPUT RIVER MILE	NON-DISTRIB. (ND) OR DISTRIBUTED (D) LOADS	SUBREACH BOUNDARIES	REMARKS
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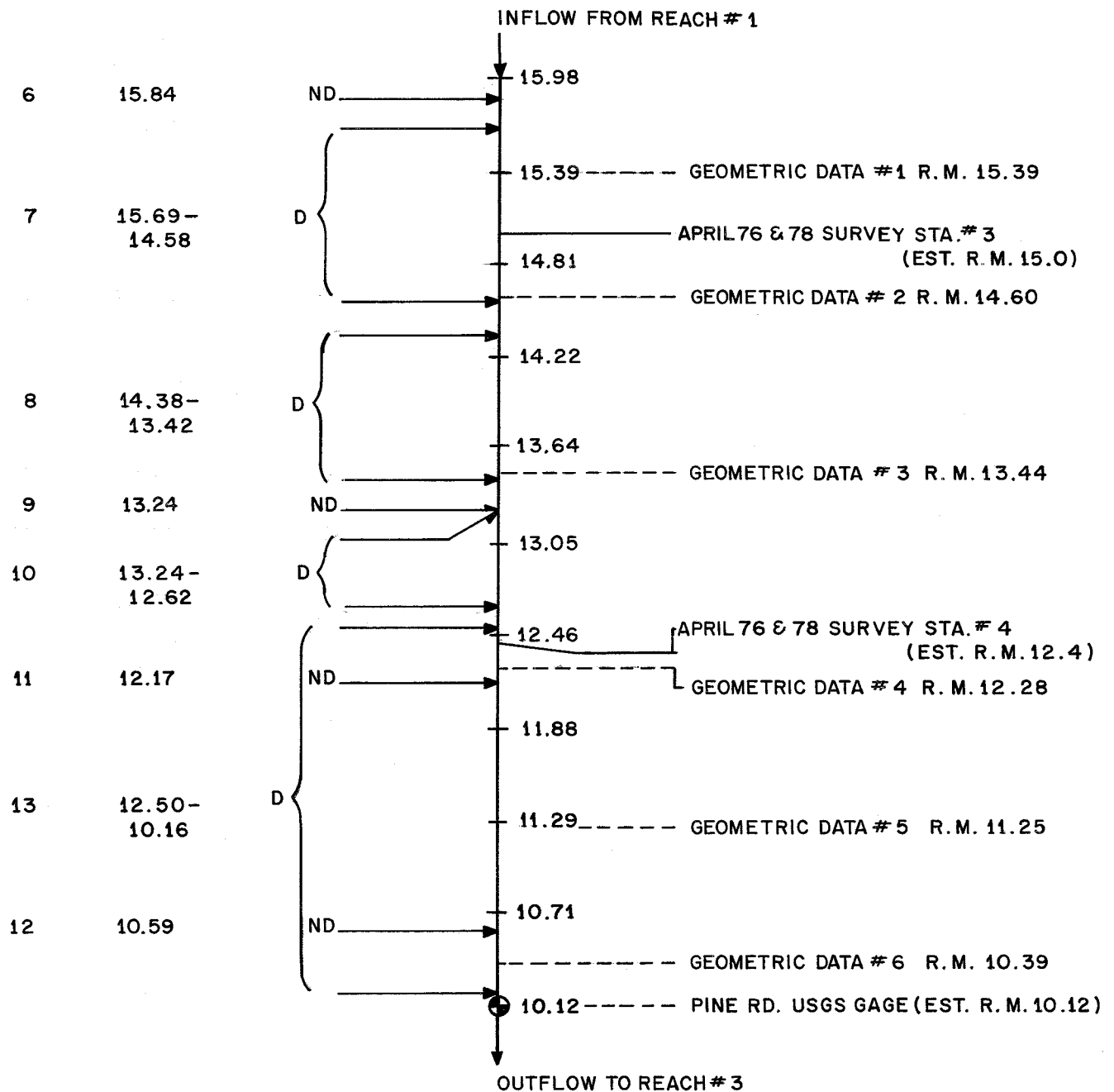


Figure III-3b. Schematic of Reach 2 of Pennypack Creek

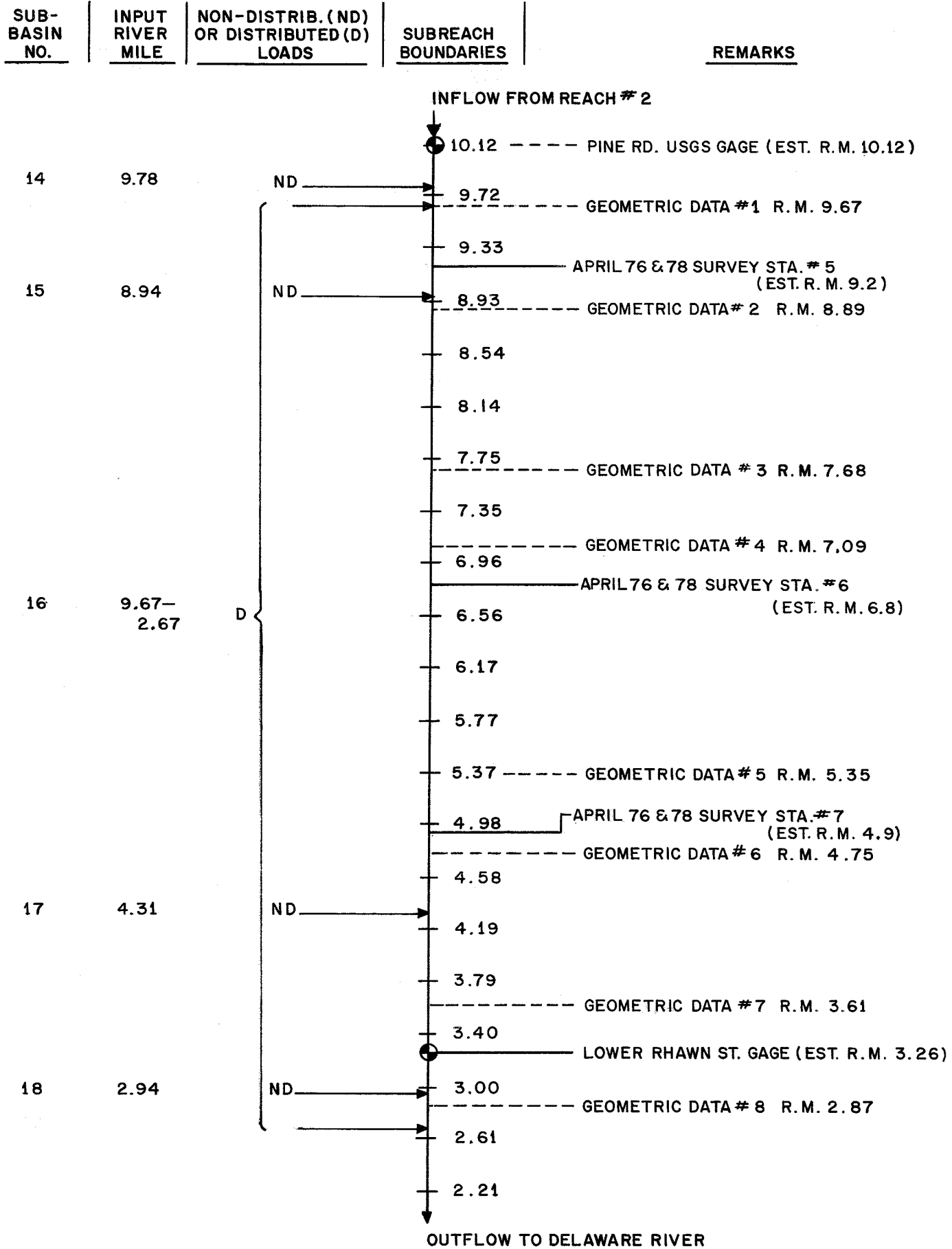


Figure III-3c. Schematic of Reach 3 of Pennypack Creek

The meteorological data for the instream analysis were obtained from the literature.5/

Land Use

Land use is one of the main determinants of the quantity and quality of runoff computed by the STORM model. It is especially important in this study since one of the main objectives is to assess the impact of future development (as characterized by changing land use) on the water quality of the Pennypack Creek. Land use for each subbasin was computed directly from the grid cell data bank by a utility program, as shown in Figure III-4. Figure III-4 also shows the computational system schematic for the analysis from the land use data bank to the land surface runoff to the instream water quality. The specific land use categories that were used in this study are as follows:

Code No.	Designation
1	Residential-Single family, high value
2	Residential-Single family, low value
3	Residential-Twins, high value
4	Residential-Twins, median value
5	Residential-Twins, low value
6	Residential-Apartments, high value
7	Residential-Apartments, low value
8	Light Industry
9	Heavy Industry
10	Transportation
11	Communication and Utility
12	Commercial, high value
13	Commercial, low value
14	Community Services, high value
15	Community Services, low value
16	Military
17	Recreation and Cultural

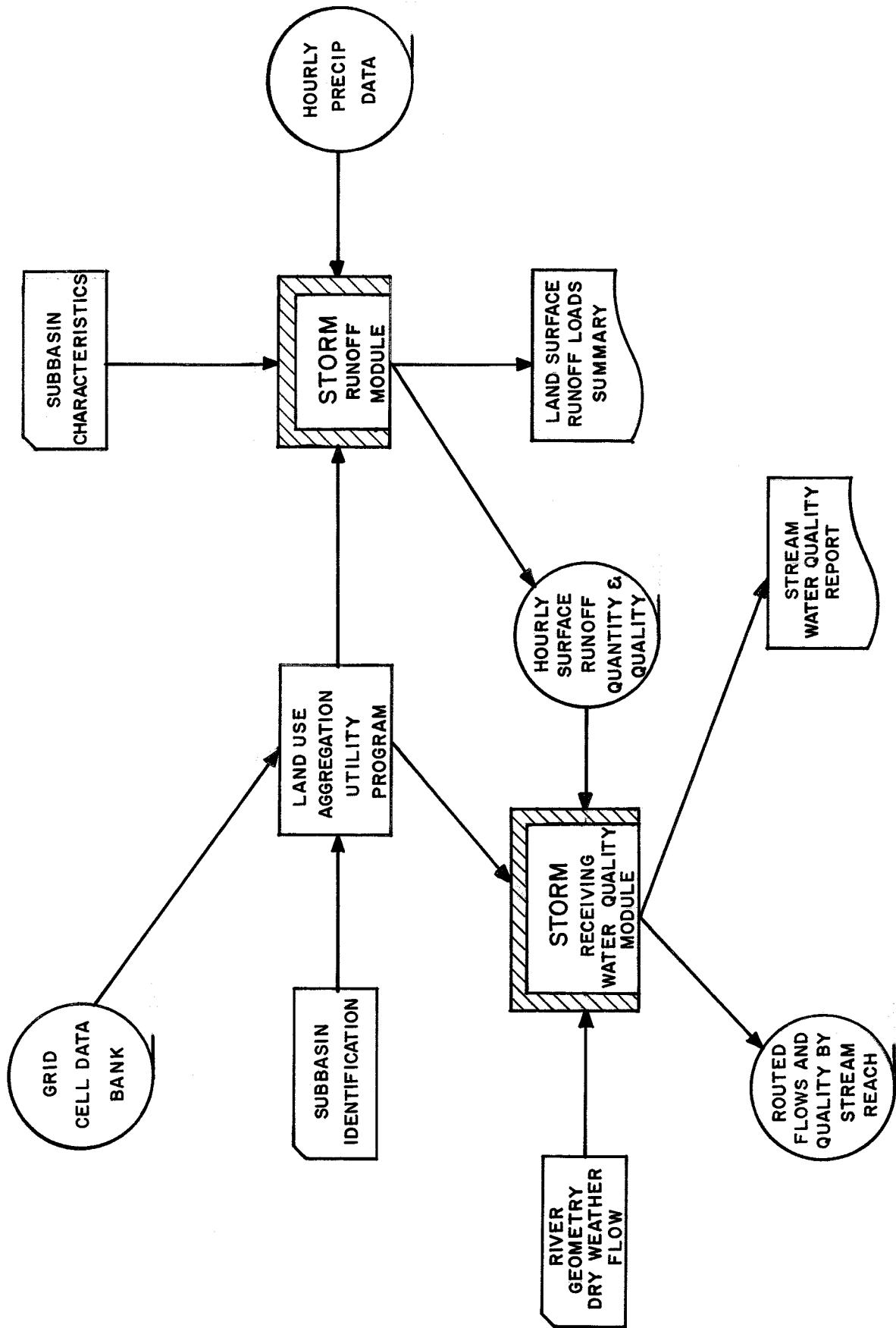


Figure III - 4
 INPUT / OUTPUT AND COMPUTATIONAL SYSTEMS SCHEMATIC

Code No.	Designation
18	Agriculture
19	Mining
20	Forest and Undeveloped

The geographic grid cell data base contains 21 land uses; however, the maximum number which can be utilized in the STORM model is 20. For that reason, the 21st land use, water bodies, was included in the forest and undeveloped category. Table III-1 shows the land use for each STORM basin for both existing and one alternative future (maximum development).

TABLE III-1

LAND USE BY WATERSHED AND REACH

Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
1	1	2445	Residential S/F, High	31.22	56.23
			Residential, Twins, Low		9.76
			Apartments, Low	5.31	6.45
			Light Industry	0.63	2.88
			Heavy Industry	0.45	0.39
			Transportation	0.21	0.21
			Communication & Utility	0.06	0.06
			Commercial, Low	3.39	6.12
			Community Services, Low	2.61	3.33
			Military	0.03	0.03
			Recreation & Cultural	4.95	3.15
			Agricultural	29.00	1.95
			Forest & Undeveloped	22.13	9.43
1	2	1376	Residential, S/F, High	17.99	33.35
			Residential, Twins, Low		0.64
			Apartments, Low	3.69	3.53
			Light Industry	11.62	34.37
			Heavy Industry	5.46	4.28
			Transportation	6.10	5.94
			Communication & Utility	0.21	0.16
			Commercial, Low	6.64	10.12
			Community Services, Low	1.87	1.77
			Recreation & Cultural	0.48	.27
			Agricultural	31.16	1.66
			Forest & Undeveloped	14.78	3.91
			1	3	2950
Residential, Twins, Med.	1.75	2.36			
Residential, Twins, Low	0.06	0.17			
Apartments, Low	7.82	8.16			
Light Industry	4.51	4.97			
Heavy Industry	2.50	2.39			
Transportation	0.32	0.29			
Communication & Utility	1.72	1.72			
Commercial, Low	4.74	5.11			

Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
			Community Services, High	0.06	0.06
			Community Services, Low	4.57	4.86
			Recreation & Cultural	2.18	2.04
			Agricultural	3.74	0.03
			Forest & Undeveloped	9.68	6.29
1	4	1890	Residential, S/F, High	58.07	61.29
			Residential, Twins, Med.	0.62	3.22
			Residential, Twins, Low		0.04
			Apartments, Low	4.62	7.21
			Light Industry	1.09	3.22
			Heavy Industry	1.86	1.63
			Transportation	0.19	0.19
			Communication & Utility	0.66	0.39
			Commercial, Low	9.62	8.57
			Community Services, Low	3.06	2.91
			Recreational & Cultural	6.90	6.79
			Agricultural	0.35	0.16
			Forest & Undeveloped	12.96	4.38
1	5	1613	Residential, S/F, High	37.78	56.21
			Residential, Twins, Med.	0.55	0.46
			Residential, Apart, Low	3.91	3.32
			Light Industry	1.09	5.96
			Heavy Industry	5.10	4.82
			Transportation	1.73	1.64
			Community & Utility	0.46	0.41
			Commercial, Low	4.78	5.83
			Community Services, High	1.00	1.00
			Community Services, Low	1.23	1.91
			Recreational & Cultural	5.64	12.88
			Agricultural	8.69	0.09
			Forest & Undeveloped	28.04	5.46
2	6	3994	Residential, S/F, High	52.58	57.66
			Residential, Twins, Med.	0.68	1.94
			Residential, Twins, Low	0.55	0.52
			Residential, Apart, Low	3.30	5.49
			Light Industry	1.06	1.56
			Heavy Industry	1.15	0.71

Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
			Transportation	1.58	1.42
			Communication & Utility	0.41	0.49
			Commercial, Low	3.88	7.29
			Community Services, Low	8.93	8.33
			Recreational & Cultural	2.62	3.19
			Agricultural	7.45	1.94
			Forest & Undeveloped	15.81	9.47
2	7	781	Residential, S/F, High	18.86	76.08
			Residential Twins, Low		8.26
			Commercial Low		0.28
			Community Services, Low		6.66
			Agricultural	25.98	4.32
			Forest & Undeveloped	15.81	9.47
2	8	813	Residential, S/F, High	27.98	65.88
			Residential, Twins, Low	0.63	5.42
			Residential, Apart, Low		1.35
			Transportation	0.18	0.09
			Commercial, Low	0.81	0.81
			Community Services, Low	0.99	7.94
			Recreation & Cultural	8.21	7.40
			Agricultural	21.03	0.72
			Forest & Undeveloped	40.16	10.38
2	9	1446	Residential, S/F, High	49.85	71.54
			Residential, Apart, Low	0.56	0.56
			Transportation	0.15	0.15
			Commercial, Low	2.39	2.29
			Community Services, Low	2.24	2.18
			Recreation & Cultural	20.78	19.21
			Agricultural	10.32	0.36
			Forest & Undeveloped	13.72	3.71
2	10	2797	Residential, S/F, High	39.39	48.10
			Residential, Twins, Low	0.10	0.52
			Residential, Apart, High	1.26	1.26
			Residential, Apart, Low	0.42	2.91
			Light Industry	0.18	5.93

Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
			Heavy Industry	5.75	5.27
			Transportation	0.26	0.29
			Communication & Utility	0.45	0.76
			Commercial, Low	2.47	3.59
			Community Services, Low	3.59	8.58
			Recreation & Cultural	14.30	12.75
			Agricultural	11.57	2.70
			Mining	0.71	0.68
			Forest & Undeveloped	19.54	6.64
2	11	2330	Residential, S/F, High	54.90	83.38
			Residential, Twins, Low	0.22	0.22
			Residential, Apart, Low	1.45	1.80
			Light Industry	0.60	0.60
			Transportation	0.47	0.38
			Commercial, Low	4.20	4.36
			Community Services, Low	3.98	3.51
			Recreation & Cultural	2.09	1.80
			Agricultural	5.25	0.09
			Forest & Undeveloped	26.83	3.86
2	12	748	Residential, S/F, High	63.91	73.35
			Residential, Apart, Low		2.16
			Transportation	0.59	0.49
			Commercial, Low	2.26	2.26
			Community Services, Low	2.36	1.97
			Recreation & Cultural	6.69	12.19
			Agricultural	4.62	0.10
			Forest & Undeveloped	19.57	7.47
2	13	2003	Residential, S/F, High	43.51	53.63
			Residential, Twins, Low	0.07	0.04
			Residential, Apart, High		0.18
			Residential, Apart, Low	1.39	6.45
			Light Industry		3.04
			Heavy Industry	2.60	2.60
			Transportation	0.95	0.73
			Communication & Utility	0.40	0.62
			Commercial, High	1.50	1.28
			Commercial, Low	0.11	0.11

Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
			Community Services, Low	1.58	1.36
			Recreation & Cultural	0.88	16.50
			Agricultural	12.76	1.21
			Forest & Undeveloped	34.23	12.24
3	14	474	Residential, S/F, High	45.05	59.60
			Residential, Twins, Low	4.33	4.33
			Residential, Apart, High	9.44	7.74
			Residential, Apart, Low	1.24	3.72
			Light Industry	0.77	0.77
			Heavy Industry	0.31	0.15
			Transportation	0.31	0.31
			Commercial, Low	5.26	4.49
			Community Services, Low	3.87	4.43
			Recreation & Cultural	2.48	6.81
			Agricultural	7.28	0.15
			Forest & Undeveloped	19.66	7.59
3	15	1658	Residential, S/F, High	53.54	54.43
			Residential, Apart, High	7.17	9.84
			Light Industry	0.80	7.48
			Heavy Industry	7.17	6.90
			Transportation	0.67	0.71
			Communication & Utility	0.18	0.45
			Commercial, High	5.38	5.70
			Community Services, Low	4.05	4.81
			Recreation & Cultural	4.01	4.01
			Agricultural	2.31	0.71
			Forest & Undeveloped	14.73	4.98
3	16	3162	Residential, S/F, High	37.75	37.98
			Residential, Apart, High	5.55	9.12
			Light Industry	0.26	2.99
			Heavy Industry	0.46	0.37
			Transportation	1.88	1.81
			Communication & Utility	0.19	0.19
			Commercial, High	5.10	4.99
			Community Services, Low	3.85	3.57
			Recreation & Cultural	2.30	2.53
			Agricultural	3.85	1.62
			Forest & Undeveloped	38.81	34.82

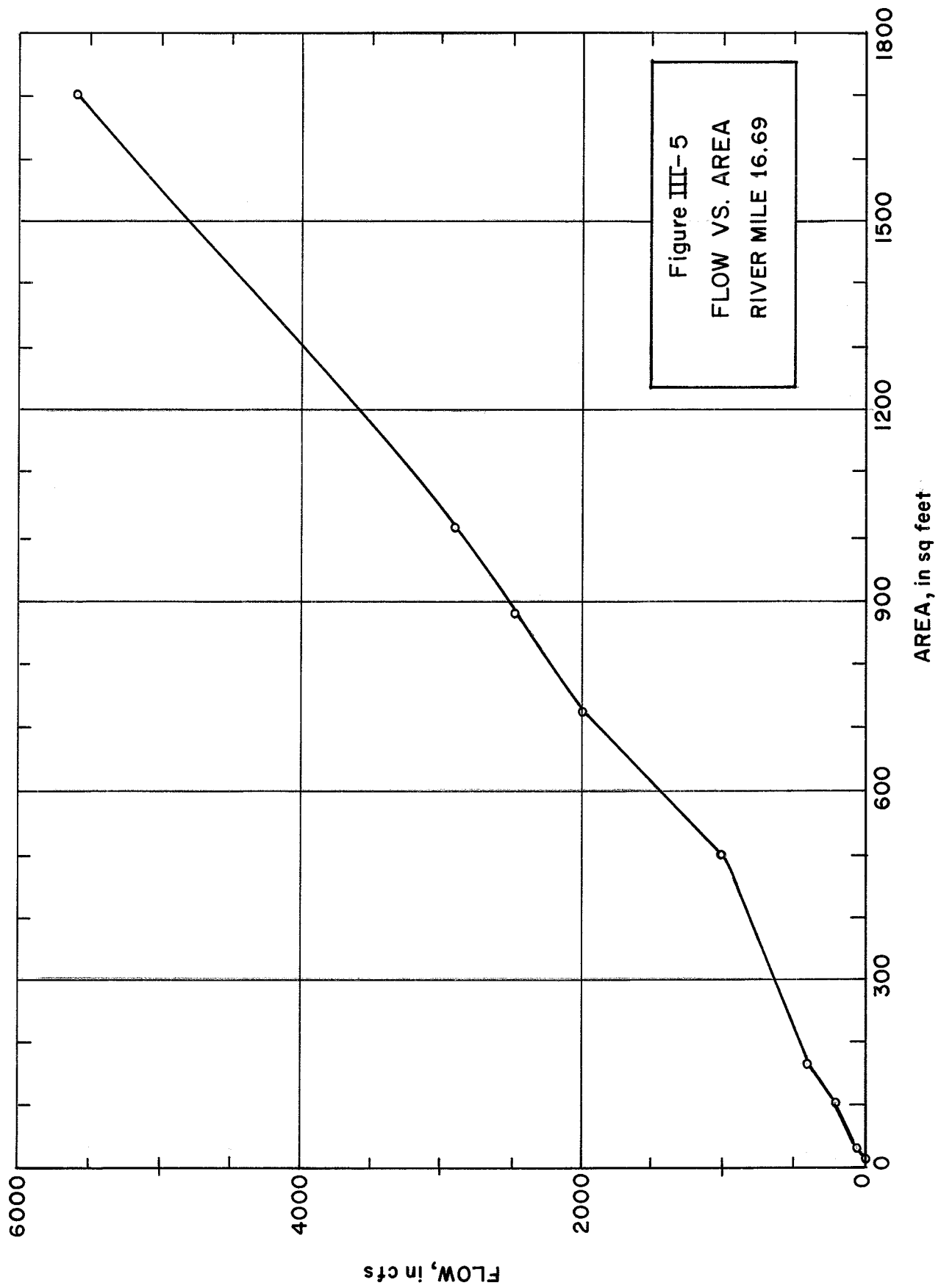
Reach No.	Storm Sub-Basin No.	Area (acres)	Land Use	Existing %	Future %
3	17	1728	Residential, S/F, High	54.15	53.90
			Residential, Twins, Low	0.04	0.04
			Residential, Apart, High	8.64	11.11
			Light Industry	0.94	0.85
			Heavy Industry	1.02	0.89
			Transportation	2.04	2.04
			Communication & Utility	1.49	1.79
			Commercial, High	15.03	15.20
			Commercial, Low	0.04	0.04
			Community Services, Low	3.96	4.60
			Recreation & Cultural	5.41	6.26
			Forest & Undeveloped	7.24	7.28
3	18	2245	Residential, S/F, High	24.68	27.66
			Residential, Apart, High	3.99	3.53
			Light Industry	5.79	15.46
			Heavy Industry	4.90	4.28
			Transportation	22.07	21.38
			Communication & Utility	0.29	0.26
			Commercial, High	7.26	7.75
			Community Services, Low	1.41	1.41
			Recreation & Cultural	3.99	4.77
			Agricultural	4.45	0.03
			Forest & Undeveloped	21.18	13.47

Channel Geometry

Cross section data at irregular intervals along the Pennypack Creek were provided by the Philadelphia District. HEC-2, Water Surface Profile program^{6/} output from the district provided information on stream discharge versus top width and area at each cross section. These data are required input for the STORM Receiving Water Quality Module (RWQM). Plots of area and top width versus discharge for one example station are shown in Figures III-5 and III-6. These are used to define the channel cross-sectional geometric properties from the stream segment in which they are located (or to the downstream boundary if it is the most downstream input for the reach) to the next segment in the upstream direction for which geometric properties are specified. For example, in Figure III-3a geometric data number 3 defines the cross section shape from river mile 15.98 to river mile 17.30. Geometric data number 2 defines the shape from river mile 17.30 to river mile 18.95.

Hydrology

Runoff quantity was computed by STORM using the SCS curve number option. Infiltration parameters required for this option were taken from an SCS publication.^{7/} STORM infiltration parameters were calibrated for the basin area above Pine Road. Table III-2 shows the hydrologic characteristics used for each STORM subbasin.



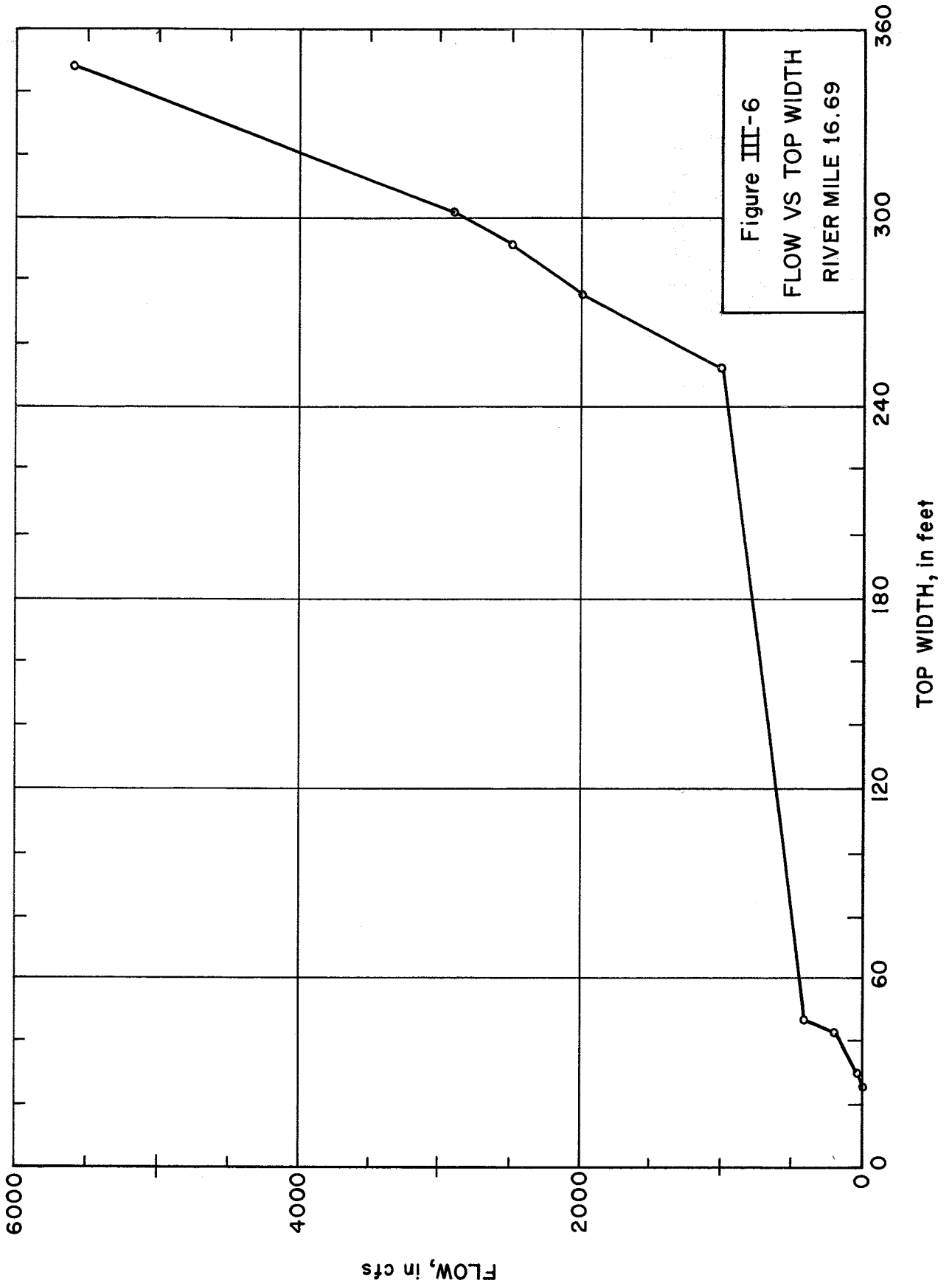


Figure III-6
 FLOW VS TOP WIDTH
 RIVER MILE 16.69

STORM uses a triangular unit hydrograph derived from the time of concentration of the subbasin and the ratio of the descending limb of the unit hydrograph to the rising limb of the unit hydrograph. The standard value of 1.67 for the ratio was used. The time of concentration and the subbasin lags were computed using the equations shown in Reference 3. The STORM program was used to evaluate overland flow runoff only.

By examination of the USGS streamflow records at the Lower Rawn Street gage, the average annual low flow was estimated to be 20.9 cfs. Since the mean annual discharge from the major municipal sewage treatment plant is 8.4 cfs, the base flow from the subbasins was calculated to be 12.5 cfs.

The RWQM was used to combine and route the stormwater runoff, the subbasin's baseflow and the municipal sewage treatment plant's discharge.

Water Quality

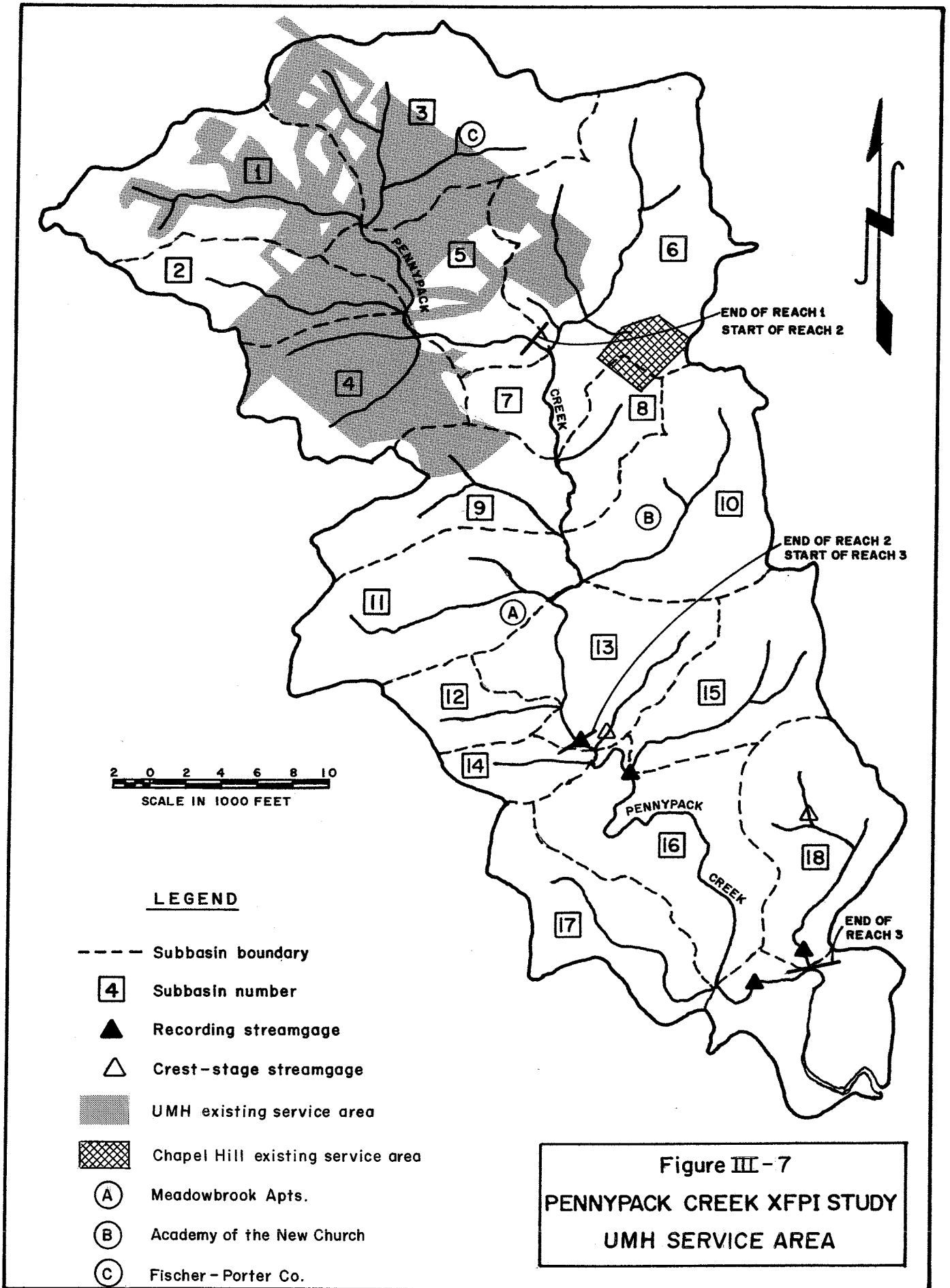
The Pennypack Creek basin was found to have limited water quality data available for use in this study. Available historical data were obtained from the U.S. Geological Survey, the city of Philadelphia, the Pennsylvania Department of Environmental Resources.^{8/} In cases where data were not sufficient, general experience from other water quality studies would be used to ascertain acceptable calibration and performance of the simulation model.

The Upper Moreland Hatboro (UMH) Treatment Plant effluent data was obtained from the following sources:

<u>Source</u>	<u>Parameters</u>
UMH Plant Records	Flow, CBOD, DO
State Dept. of Envir. Resources	Temperature, NBOD, Fecal Coliform, Orthophosphate

The resultant estimate of UMH average annual effluent is shown in Table III-3. The service area for UMH plant is shown in Figure III-7. All other sewage generated within the Pennypack Creek watershed was assumed to be either insignificant in quantity or transported out of the watershed. Support documentation for these assumptions is shown in the Appendix.

The baseflow from the subbasins was estimated to total 8.05 MGD (12.5 cfs), i.e., 0.15 MGD/sq mi. (0.23 cfs/sq. mi.). The quality of



2 0 2 4 6 8 10
SCALE IN 1000 FEET

LEGEND

- Subbasin boundary
- 4 Subbasin number
- ▲ Recording streamgage
- △ Crest-stage streamgage
- UMH existing service area
- ▩ Chapel Hill existing service area
- (A) Meadowbrook Apts.
- (B) Academy of the New Church
- (C) Fischer - Porter Co.

Figure III-7
PENNYPACK CREEK XFPI STUDY
UMH SERVICE AREA

the baseflow was estimated from the average of all available data collected from the channel above the UMH plant effluent by the State Department of Environmental Resources. The resultant baseflow quantity is tabulated by subbasin in Table III-4 and the quality of baseflow for all subbasins in Table III-5.

TABLE III-3
UPPER MORELAND HATBORO SEWAGE TREATMENT
PLANT EFFLUENT*

<u>Parameter</u>	<u>Magnitude and Units</u>
Temperature	58° F
DO	4.8 mg/l
CBOD ₅	12.8 mg/l
CBOD _μ	20.0 mg/l
NH ₃ -N	6.6 mg/l
NBOD	30.0 mg/l
PO ₄ -P	5.3 mg/l
Fecal Coliform	90 MPN/100 ml

* These data are average annual estimates.

TABLE III-4
AVERAGE BASEFLOW QUANTITY*

<u>Subbasin</u>	<u>Average Baseflow (MGD)</u>
1	0.57
2	0.32
3	0.69
4	0.44
5	0.38
6	0.94
7	0.18
8	0.19
9	0.34
10	0.66
11	0.55
12	0.18
13	0.47
14	0.11
15	0.39
16	0.74
17	0.40
18	0.53

* These data are average annual estimates.

TABLE III-5
BASEFLOW QUALITY*

<u>Parameter</u>	<u>Magnitude and Units</u>
CBOD ₅	.4 mg/l
CBOD _μ	.6 mg/l
NH ₃ -N	.4 mg/l
NBOD	1.8 mg/l
PO ₄ -P	.25 mg/l
Fecal Coliform	250 MPN/100 ml

* These data are average annual estimates.

IV MODELING CONCEPTS APPLIED

STORM: Land Surface Runoff

The Storage, Treatment, Overflow Runoff Model (STORM) is a continuous simulation model designed to be used in metropolitan master planning studies for evaluating storage and treatment capacities required to reduce raw sewage overflows. Pollutograph (pollutant mass-emission rates) loadings can also be computed for use in a receiving water assessment model.

Since STORM is intended for use in planning studies or for screening alternatives, some of its analytical techniques are necessarily simplified. For example, the two procedures used to compute the quantity of runoff are the coefficient method and the United States Soil Conservation Service (SCS) method. ^{9/} In the coefficient method, a single land-use weighted runoff coefficient is applied to each hour of rainfall excess above depression storage to compute runoff. The runoff coefficient is a function of the individual runoff coefficients for the pervious and impervious areas of the watershed. Antecedent conditions (except for a depression storage term) and rainfall intensity are not taken into account using this method.

The SCS runoff curve number technique is considered to be conceptually more correct than the coefficient method. The SCS curve

consists of a nonlinear relationship between accumulated rainfall and accumulated runoff. Since STORM requires a continuous analysis, a procedure has been added that computes the curve number for each event based on the number of dry hours since the previous runoff event and accounting for prior evapotranspiration and percolation. Unit hydrographs can be used to transform the surface runoff excesses into basin outflow hydrographs.

Loads and concentrations for six basic water quality parameters are computed. These are suspended and settleable solids, biochemical oxygen demand, total nitrogen, total orthophosphate, and coliform. Urban and nonurban areas may be described by up to 20 land uses. Other features of STORM are the capabilities to compute snowfall/snowmelt, dry-weather flow quantity and quality, and land surface erosion.

STORM: Dry Weather Flow and Instream Water Quality

A recently developed planning level river water quality analysis model (RWQM) was tested on this study. The model simulates long-term water quality conditions using STORM-generated land surface runoff, treatment plant loadings, and other effluents and withdrawals in the system. The instream model simulates temperature, dissolved oxygen, CBOD, nitrogenous biochemical oxygen demand (NBOD), phosphate (PO_4), and coliform bacteria. The model balances the mass of pollutants at combining points. The resultant mass is routed downstream accounting for heat transfer, first order decay of CBOD and NBOD and the associated

change in dissolved oxygen. Decreases in bacteria are accounted for by a normal die-off function. Phosphate is treated as a conservative parameter.

RWQM simulates the receiving water quality condition for long term record and produces summary statistics of the water quality.

V WATER QUANTITY AND QUALITY SIMULATION RESULTS

Quantity Calibration

The runoff quantity portion of STORM was calibrated using the Pine Road U.S. Geological Survey (USGS) stream gage. Several small watersheds were also investigated to ascertain their potential for use in calibration. It was determined that these basin sizes were too small and their gage records too short to be of value in calibrating STORM for this study.

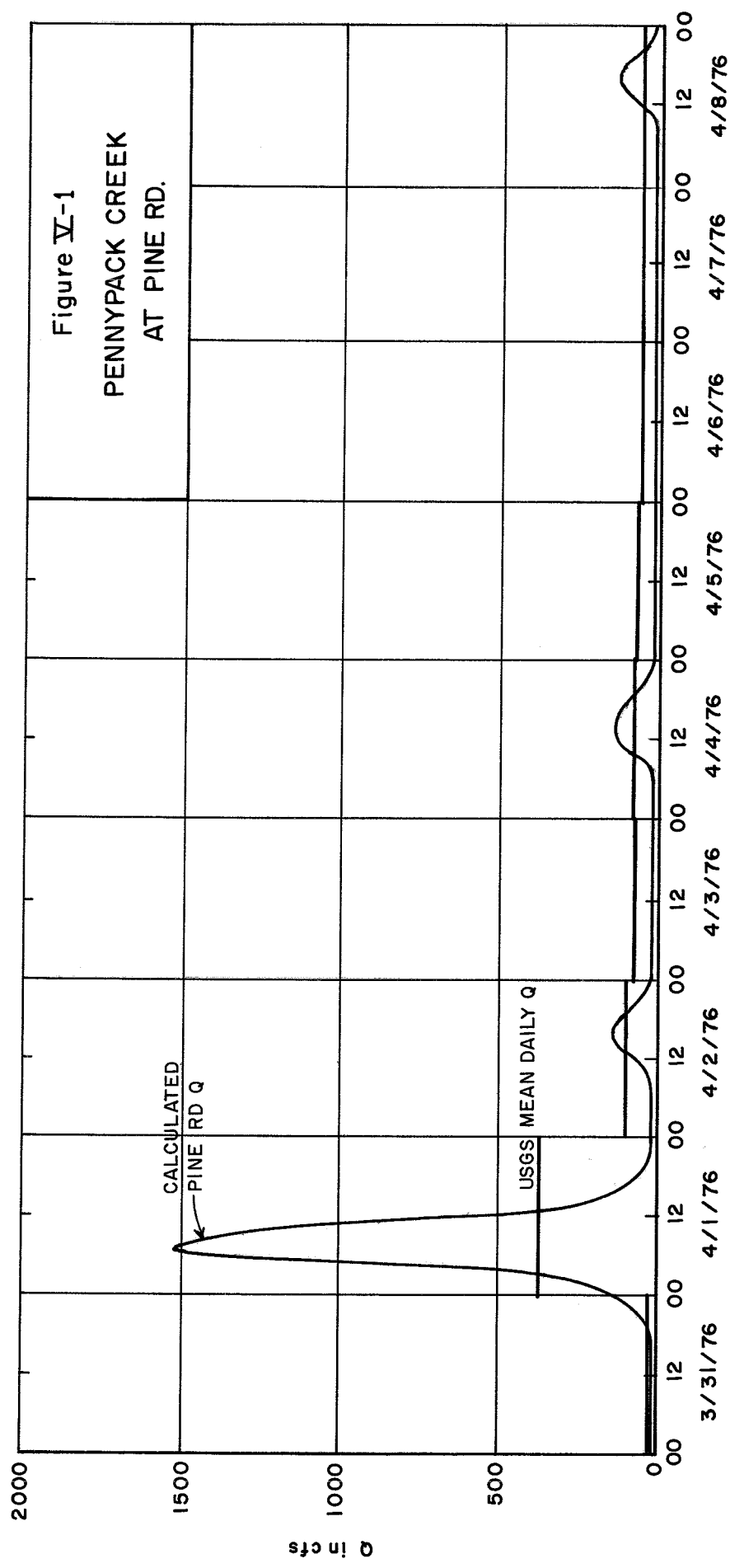
The general procedure used in calibration of STORM for quantity of runoff was to make initial adjustments based primarily on volumes and subsequent adjustments based primarily on hydrograph shapes. The model parameters regulating runoff quantity were adjusted so that annual, monthly, and daily volumes most nearly matched the values from the USGS records. About five years of data were simulated (WY 72-WY 76). The unit hydrograph parameters were then adjusted so that the observed hydrograph shapes most nearly matched ten hourly observed hydrographs. Some guidance was obtained from reconstitution of the hydrographs using HEC-110/ in an optimization mode. The average of the optimized times of concentration was used as a first estimate of the time of concentration for STORM.

The degree of difference between the observed and computed hydrographs is mostly attributable to two causes, spatial variation in

precipitation and not accurately representing the physical situation with the model representation. The precipitation gage is located approximately 20 miles from the centroid of the Pennypack watershed. Considerable differences could exist between precipitation depths and intensities measured at the airport gage and the Pennypack basin average values, particularly for convective type rainfall events that occur during the spring and summer. The level of accuracy was judged to be adequate for this study.

Quantity calibration in the RWQM involved first estimating the baseflow values by subbasin. The method used involved assuming that the mean study period low flow value at the Lower Rhawn Street gage is about 13.5 MGD (20.9 cfs). Since the mean UMH plant discharge is about 5.45 MGD (8.4 cfs), the baseflow directly from the subbasins is about 8.05 MGD (12.5 cfs), i.e., 0.15 MGD/sq. mi. (0.23 cfs/sq. mi.).

Further quantity calibration in the RWQM during storms is not very practical since the inputs from STORM are generally more questionable than the adjustments that can be made in RWQM. Figures V-1 and V-2 show that during early April 1976, the calculated flow values at both Pine Road and Lower Rhawn Street compare reasonably well with the mean daily USGS observed data.



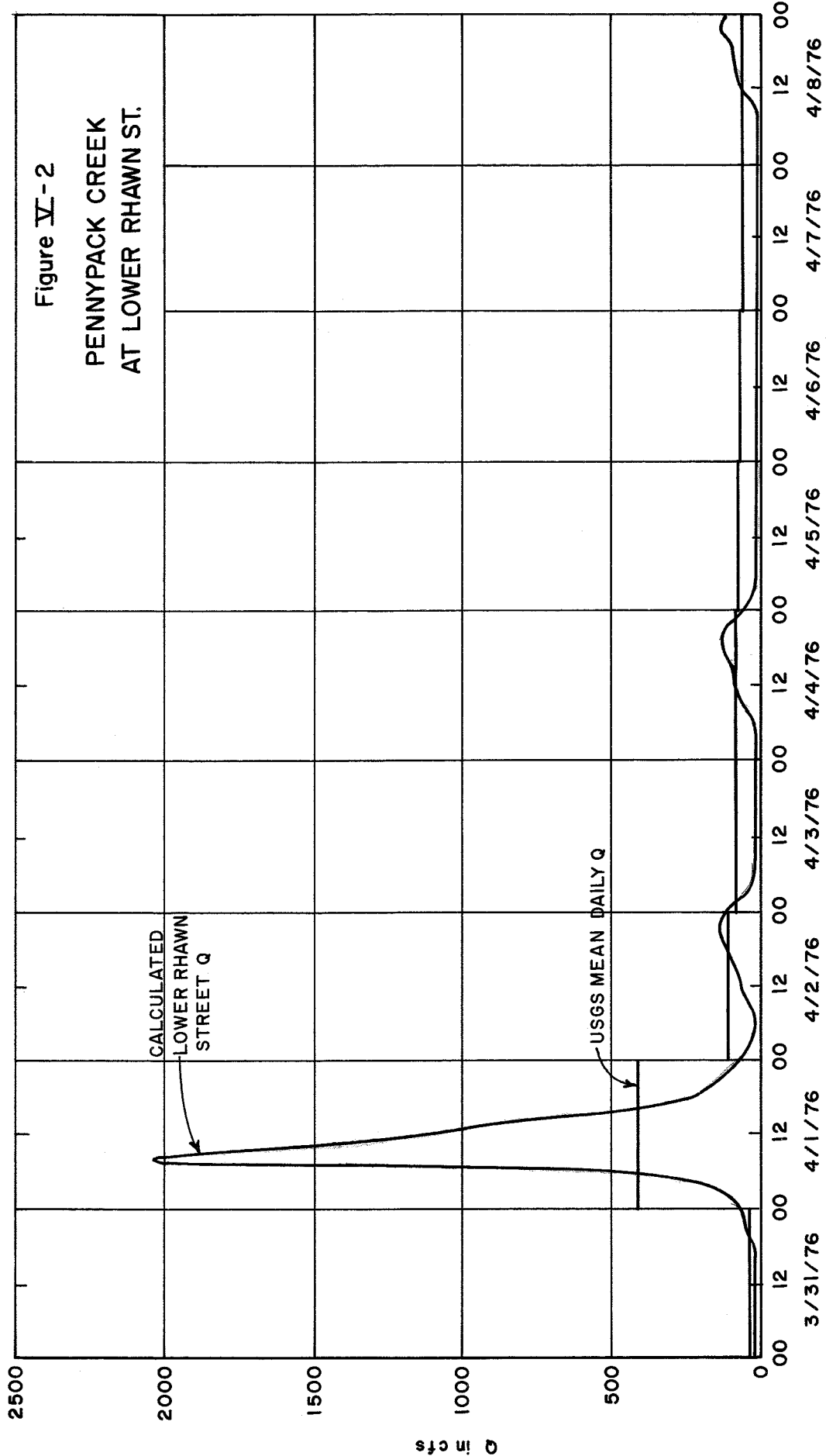


Figure V-2
 PENNYPACK CREEK
 AT LOWER RHAWN ST.

Quality Calibration

Once the quantity calibration is satisfactory, one can proceed with the water quality adjustments. The quality adjustments in STORM are a great deal more subjective since the method of computing quality loads is highly empirical and not physically based. The observed data did not really show the time-quality relationships assumed in the model (first flush effects), therefore, no real attempt was made to reproduce the time value of concentration for the measured events. Instead, the model parameters were adjusted to reproduce the mean value of the concentrations for each of the measured events.

The quality calibration for RWQM did not involve calibration during storms since no water quality data were available showing concentration magnitudes and/or time variations during storm events. Water quality data does exist on baseflow concentrations above the UMH treatment plant and effluent concentrations from the plant. These values were defined in Tables III-3 through III-5. Calibration of several model coefficients (e.g., deoxygenation rate) was performed using these input values and trying to reproduce the instream water quality profiles available from the sources referenced in Chapter III. Since some of these profiles were not observed during the study period, they were interpreted to represent "typical seasonal patterns". These data have been compared graphically against the final results in the next section.

Simulation Results

Nearly all judgments or decisions on water quality control measures should be made on the resultant water quality of the receiving water body. In this study the receiving water body was assumed to be Pennypack Creek, however it is recognized that the effects of certain constituents may have to be analyzed in the Delaware River or its estuary. Nevertheless, it is usually instructive to first compare land surface runoff quantity and quality for each subbasin for existing and future conditions.

Table V-1 shows the average annual runoff for existing and future conditions. It can be seen that the predicted average annual runoff changed from 18.42 inches to 20.97 inches, an increase of 14%.

Table V-2 shows the predicted pollutant loads for land surface runoff for each subbasin. The impact of changing land use can be evaluated for each subbasin by comparing existing and future conditions for the same parameter.

Table V-3 summarizes the loads from the land surface runoff, the treated sewage effluent and the base flow. Table V-4 shows a comparison of the loading components as a percentage of the total load. It can be seen that surface runoff contributes the majority of the CBOD and fecal coliform loadings while the sewage treated effluent is responsible for the majority of the NBOD and PO_4 . It is also shown that the tendency is for decreased impact from surface runoff and increased impact from sewage as future conditions A or B are approached.

TABLE V-1

PENNPACK CREEK

AVERAGE ANNUAL

SURFACE RUNOFF QUALITY

<u>SUBBASIN</u>	<u>EXISTING (inches)</u>	<u>FUTURE (inches)</u>
1	17.23	19.62
2	18.67	21.81
3	19.61	20.06
4	19.55	20.29
5	18.04	20.48
6	18.78	19.73
7	14.63	19.08
8	16.02	19.20
9	18.89	19.89
10	18.63	20.40
11	17.68	19.42
12	18.14	19.42
13	16.73	19.64
14	18.60	19.87
15	19.35	20.55
16	17.23	17.84
17	20.47	20.90
18	20.09	21.11
WEIGHTED AVG.	18.42	20.97

NOTE: AVG. ANN. PRECIP. = 36.23 INCHES

TABLE V-2
PENNYPACK CREEK
AVERAGE ANNUAL SURFACE RUNOFF LOADINGS (POUNDS)*

SUBBASIN NO.	EXISTING				FUTURE			
	BOD5	N	PO4	COLI	BOD5	N	PO4	COLI
1	31,662	600	1,710	781,835	48,042	793	3,090	1,02,796
2	40,658	633	1,645	587,006	59,038	766	2,615	768,363
3	64,640	982	3,790	1,354,447	67,640	1,015	4,062	1,418,070
4	44,453	672	2,536	894,191	45,794	689	2,708	960,275
5	33,242	509	1,632	636,780	42,361	601	2,837	885,479
6	70,300	1,137	4,342	1,690,619	88,217	1,345	5,374	1,969,920
7	3,294	103	144	59,216	8,467	194	770	241,617
8	6,423	134	343	176,621	10,202	181	810	327,163
9	20,236	317	1,228	648,341	21,556	343	1,495	676,277
10	53,417	1,047	2,656	1,301,699	69,288	1,167	3,713	1,672,337
11	31,317	554	2,050	687,531	35,922	668	2,682	820,229
12	8,996	168	634	228,411	10,667	179	764	304,810
13	23,817	463	1,366	468,498	36,843	510	2,145	1,003,864
14	8,255	128	512	195,444	8,821	130	588	234,701
15	37,782	583	2,108	802,028	45,019	646	2,475	932,323
16	48,751	762	2,828	1,052,420	54,995	785	3,172	1,205,297
17	51,296	788	2,943	1,016,820	53,560	803	3,080	1,105,222
18	<u>96,112</u>	<u>1,343</u>	<u>3,873</u>	<u>1,353,203</u>	<u>104,564</u>	<u>1,409</u>	<u>4,309</u>	<u>1,449,451</u>
TOTAL	674,651	10,923	36,340	13,935,110	810,996	12,224	46,689	17,000,194

* Coliform in Billion MPN

TABLE V-3
 PENNYPACK CREEK
 SUMMARY OF LOADING COMPONENTS

	CBOD	NBOD	PO ₄ -P	F. Coliform
<u>Existing Condition</u>	<u>(10³ lbs)</u>	<u>(10³ lbs)</u>	<u>(10³ lbs)</u>	<u>(10¹² MPN)</u>
Surface Runoff Quality	1011.9	25.0*	36.3	13,935
Sewage Treated Effluent	332.6	498.9	88.1	6
Base Flow Quality	<u>14.7</u>	<u>9.7</u>	<u>5.9</u>	<u>29</u>
Total Load	1,359.2	533.6	130.3	13,970
 <u>Future Condition</u>				
Surface Runoff Quality	1216.5	27.9*	46.7	17,000
Sewage Treated Effluent (A)**	575.5	863.2	152.5	12
Sewage Treated Effluent (B)**	1044.2	1566.3	276.7	21
Base Flow Quality	<u>14.7</u>	<u>9.7</u>	<u>5.9</u>	<u>29</u>
Total Load (With Sewage A)	1806.7	900.8	205.1	17,041
Total Load (With Sewage B)	2275.4	1603.9	329.3	17,050

* Assumed To Be Half of Total Inorganic Nitrogen times 4.57

** See discussion in text:

(A) UMH service area remains unchanged,

(B) UMH service area includes all of subbasins 1, 2, 4, and 5 but no change in other areas.

TABLE V-4

PENNYPACK CREEK

COMPARISON OF LOADING COMPONENTS

<u>Existing Condition</u>	% of Total Load			
	<u>CBOD</u>	<u>NBOD</u>	<u>PO4</u>	<u>F. Coliform</u>
Surface Runoff Quality	74.5	4.5	28.0	99.7
Sewage Treated Effluent	24.5	93.5	67.5	0.1
Base Flow Quality	1.1	1.8	4.5	0.2
 <u>Future Condition A*</u>				
Surface Runoff Quality	67.0	3.0	23.0	99.8
Sewage Treated Effluent (A)	32.0	96.0	74.0	0.0
Base Flow Quality	0.8	1.1	2.9	0.2
 <u>Future Condition B</u>				
Surface Runoff Quality	53.5	2.0	14.0	99.7
Sewage Treated Effluent (B)	46.0	97.5	84.0	0.1
Base Flow Quality	0.6	0.6	1.8	0.2

* See discussion in text:

(A) UMH service area remains unchanged,

(B) UMH service area includes all of subbasins 1, 2, 4, and 5 but no change in other areas.

Future condition A assumes that when the maximum development population increases, the UMH service area shown in Figure III-7, does not expand. Therefore future condition A includes only a portion of the total population increase. The waste from the remaining population increase is assumed to be transported from the basin. Future Condition B assumes that subbasins 1, 2, 4 and 5 are serviced entirely by the UMH plant while other subbasin service areas are not expanded due to either topographical or jurisdictional reasons.

Odd numbered Figures V-3 through V-13 show the maximum and/or minimum simulated profiles for each water quality parameter, while the even numbered Figures V-4 through V-14 show the value that occurs 50% of the time during the study period (i.e., January 1973 through June 1977). On all plots the proposed Pennsylvania State Instream Water Quality Standards^{11/} or local guidelines^{8/} have also been shown (i.e., if one exists) for reference purposes. The maximum simulated values were also compared to maximum pollutant concentrations measured in this country and other parts of the world^{12/} and found to be within the range of the observed values.

Water Temperature for Existing Condition

Figure V-3 shows that the maximum simulated temperatures do exceed the lower (spring) standard. From the general results it is not easy to determine whether they exceed the appropriate seasonal standards but all indications are that the results are within the seasonal standards. The

LEGEND:

- △ 21 Aug 78 - Observed Data.
- 5 Apr 76 - Observed Data.
- 6 Apr 78 - Observed Data.

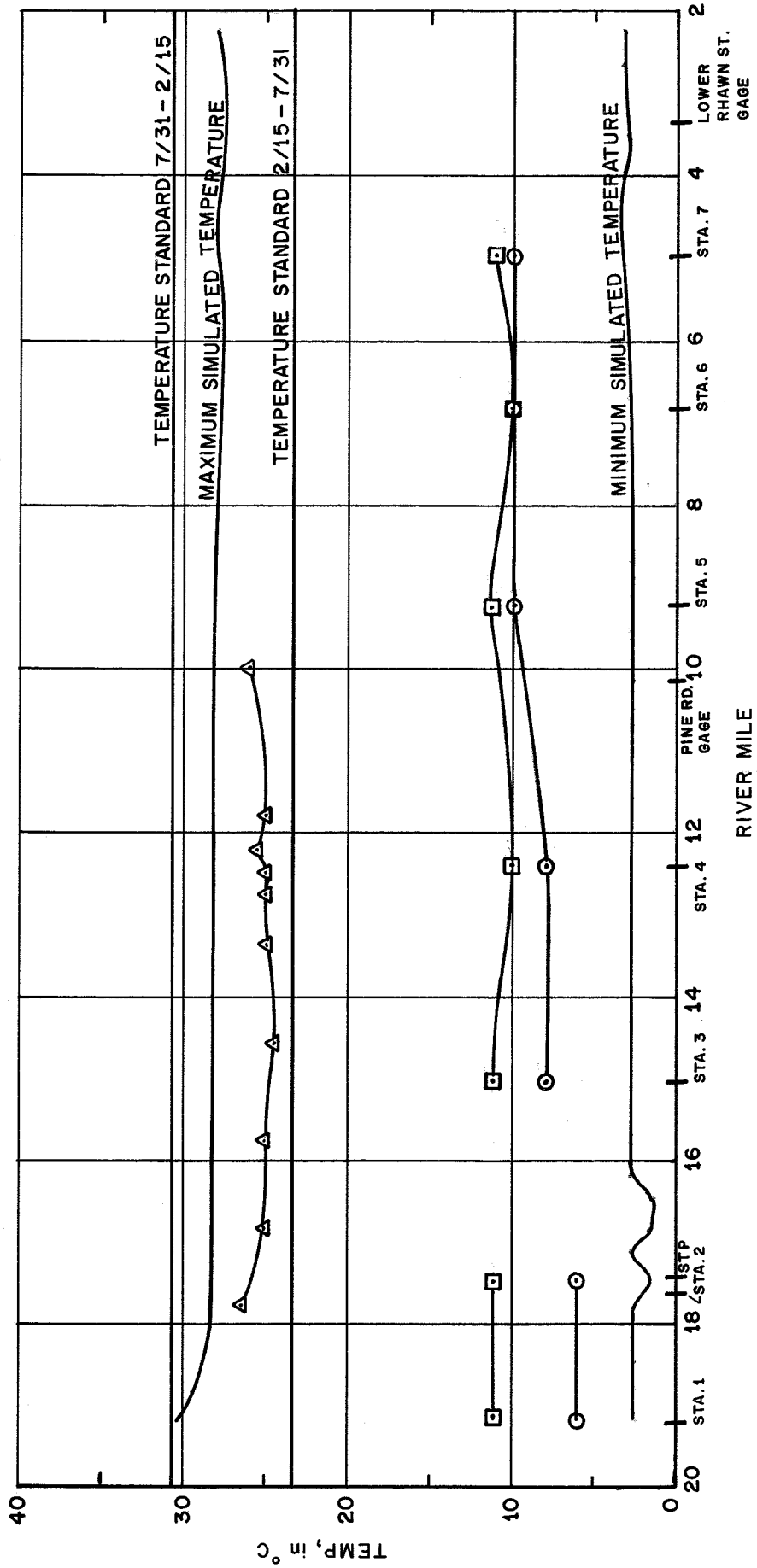


Figure V-3
 PENNYPACK CREEK
 WATER TEMPERATURE PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

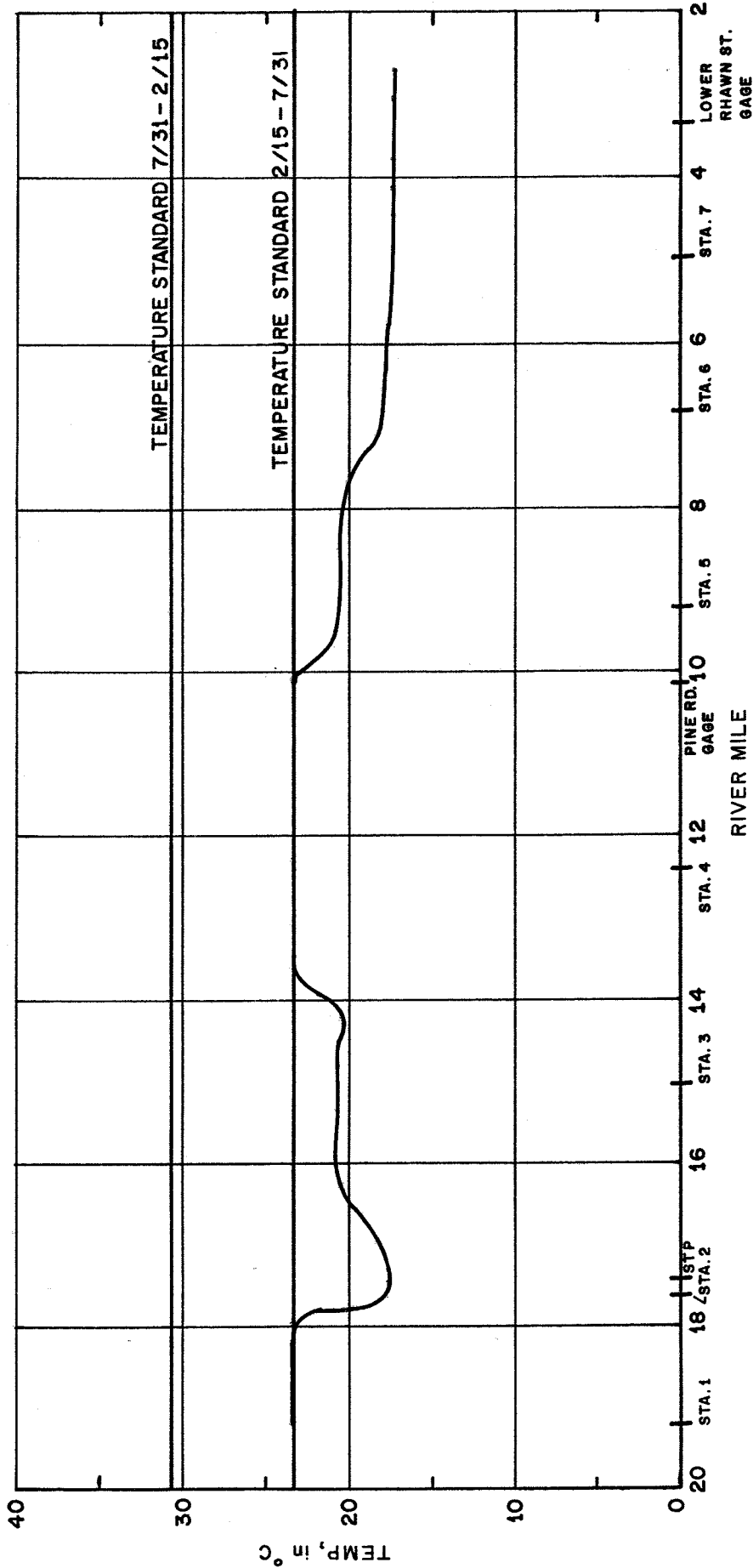


Figure V-4

PENNYPACK CREEK - 50 PERCENTILE
WATER TEMPERATURE PROFILE

FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

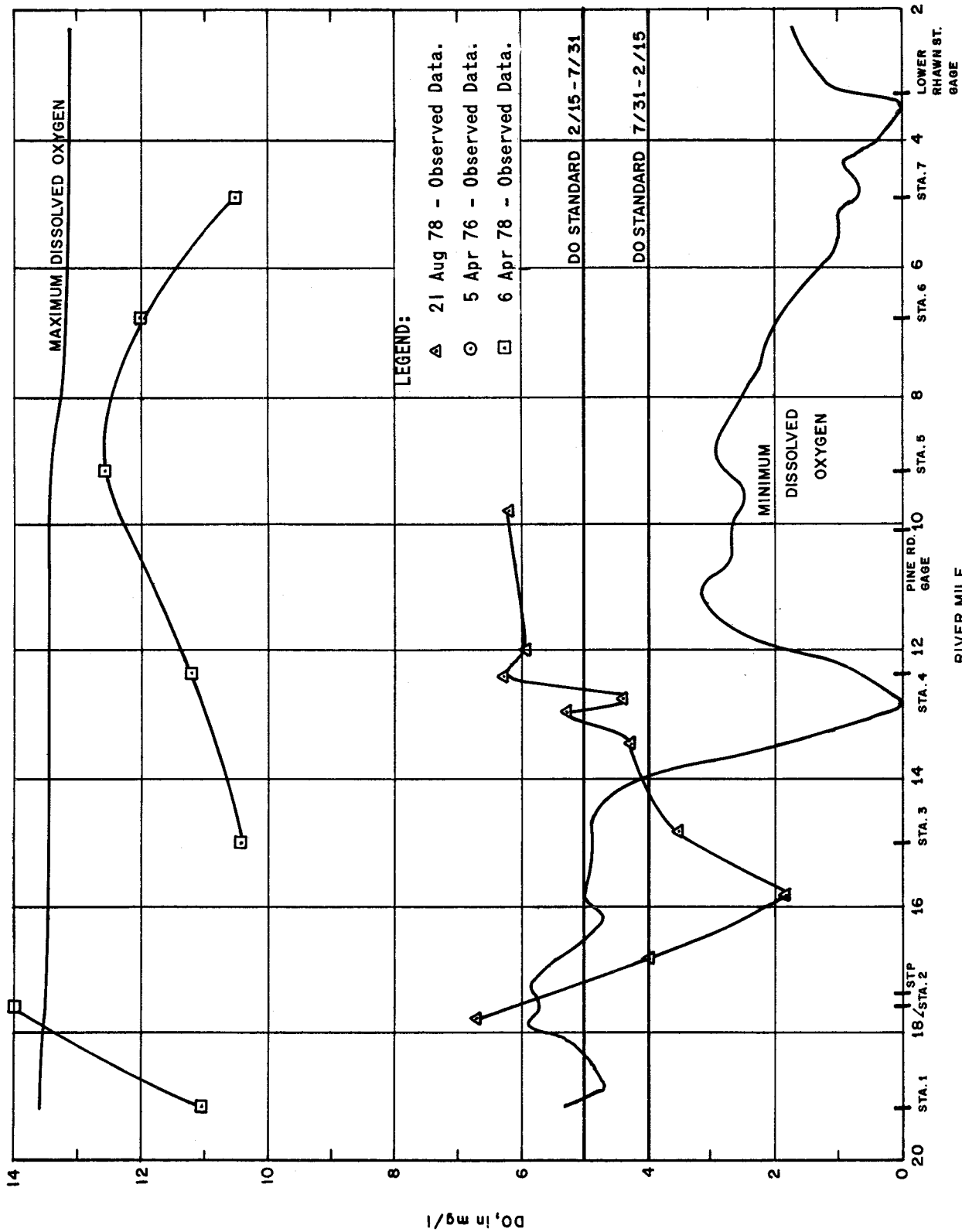


Figure V-5
 PENNYPACK CREEK
 DISSOLVED OXYGEN PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

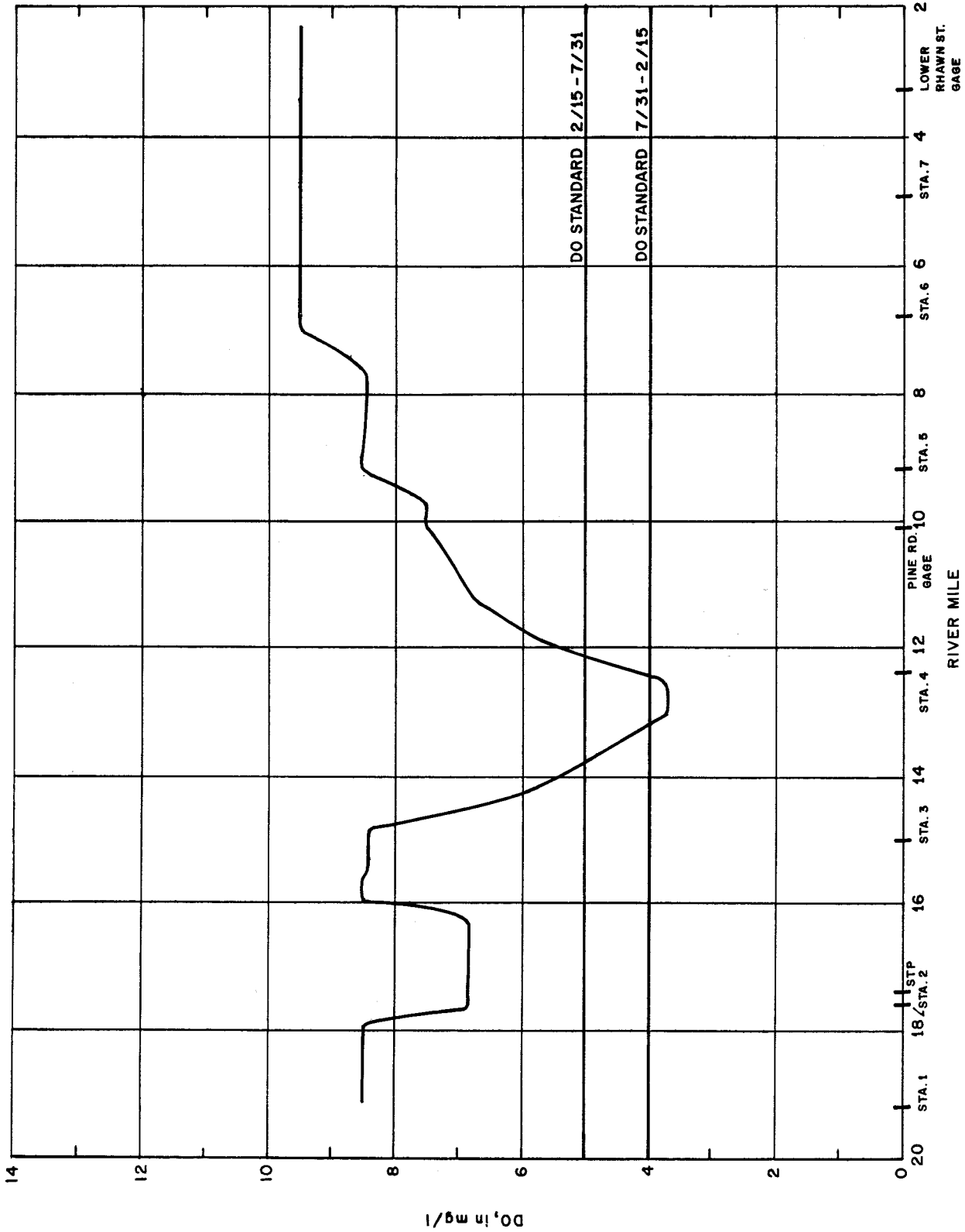


Figure V-6
 PENNYPACK CREEK - 50 PERCENTILE
 DISSOLVED OXYGEN PROFILE
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

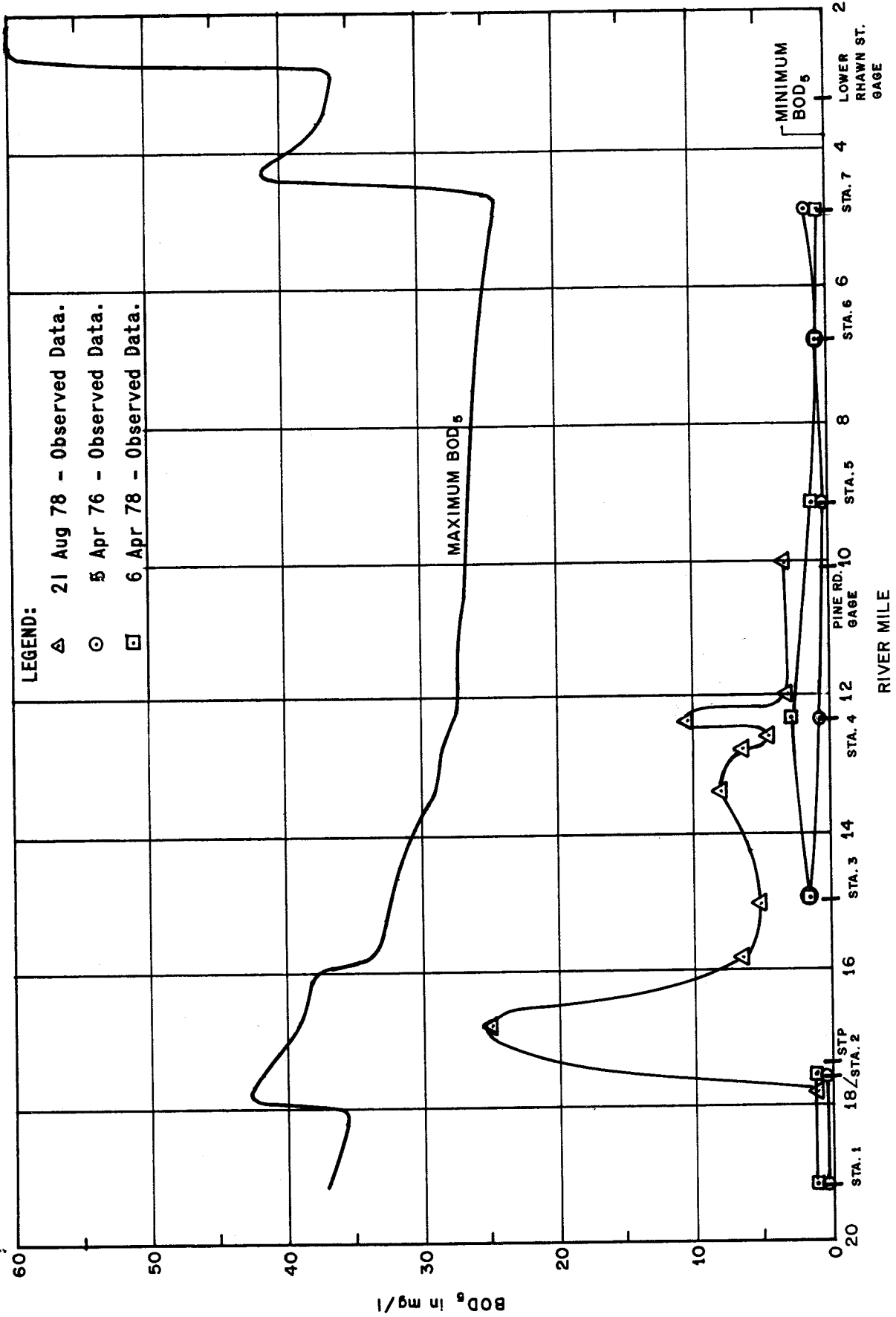


Figure V-7
 PENNYPACK CREEK - CARBONACEOUS BIOCHEMICAL
 OXYGEN DEMAND PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

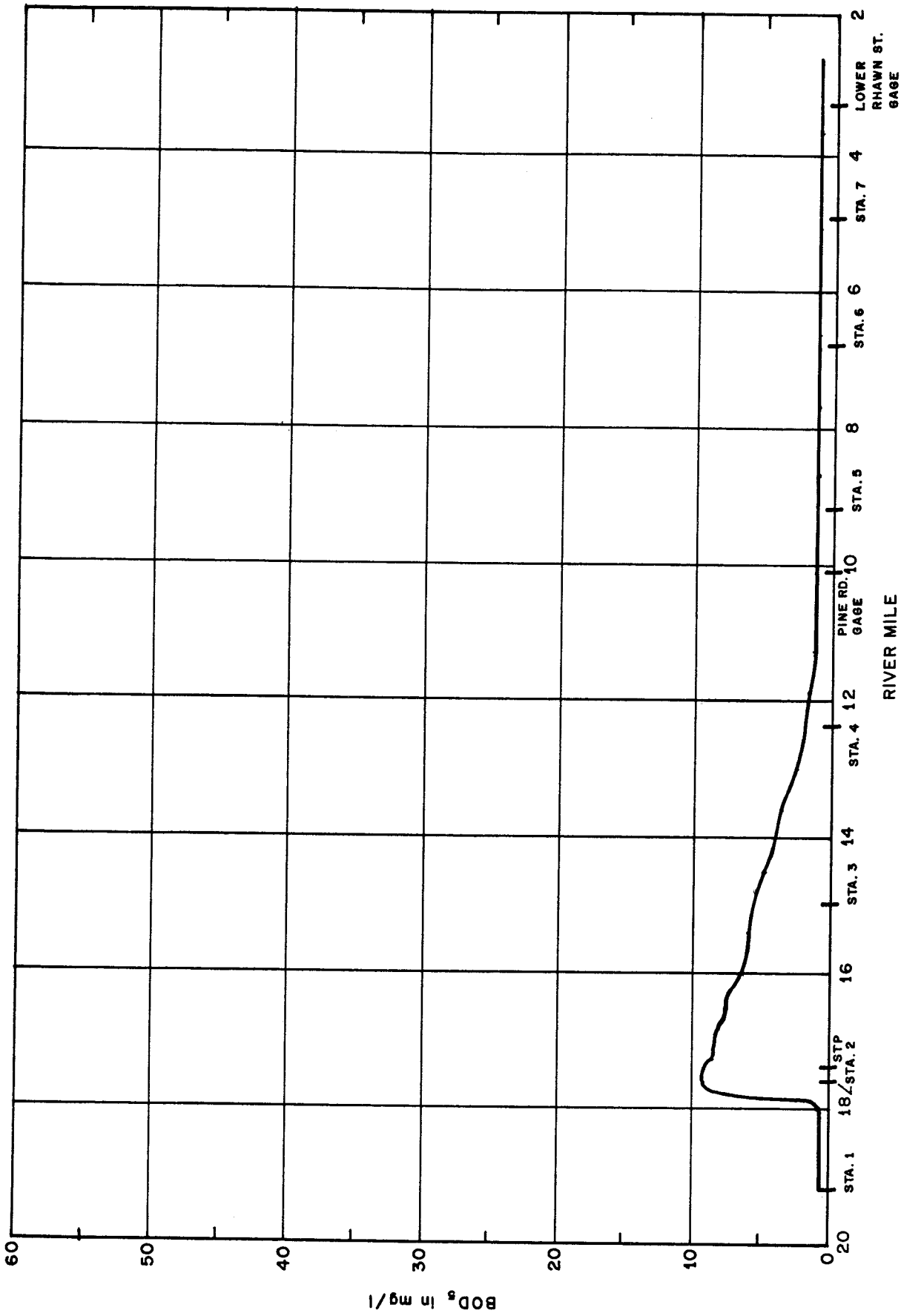


Figure V-8
 PENNYPACK CREEK - 50 PERCENTILE CARBONACEOUS
 BIOCHEMICAL OXYGEN DEMAND PROFILE
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

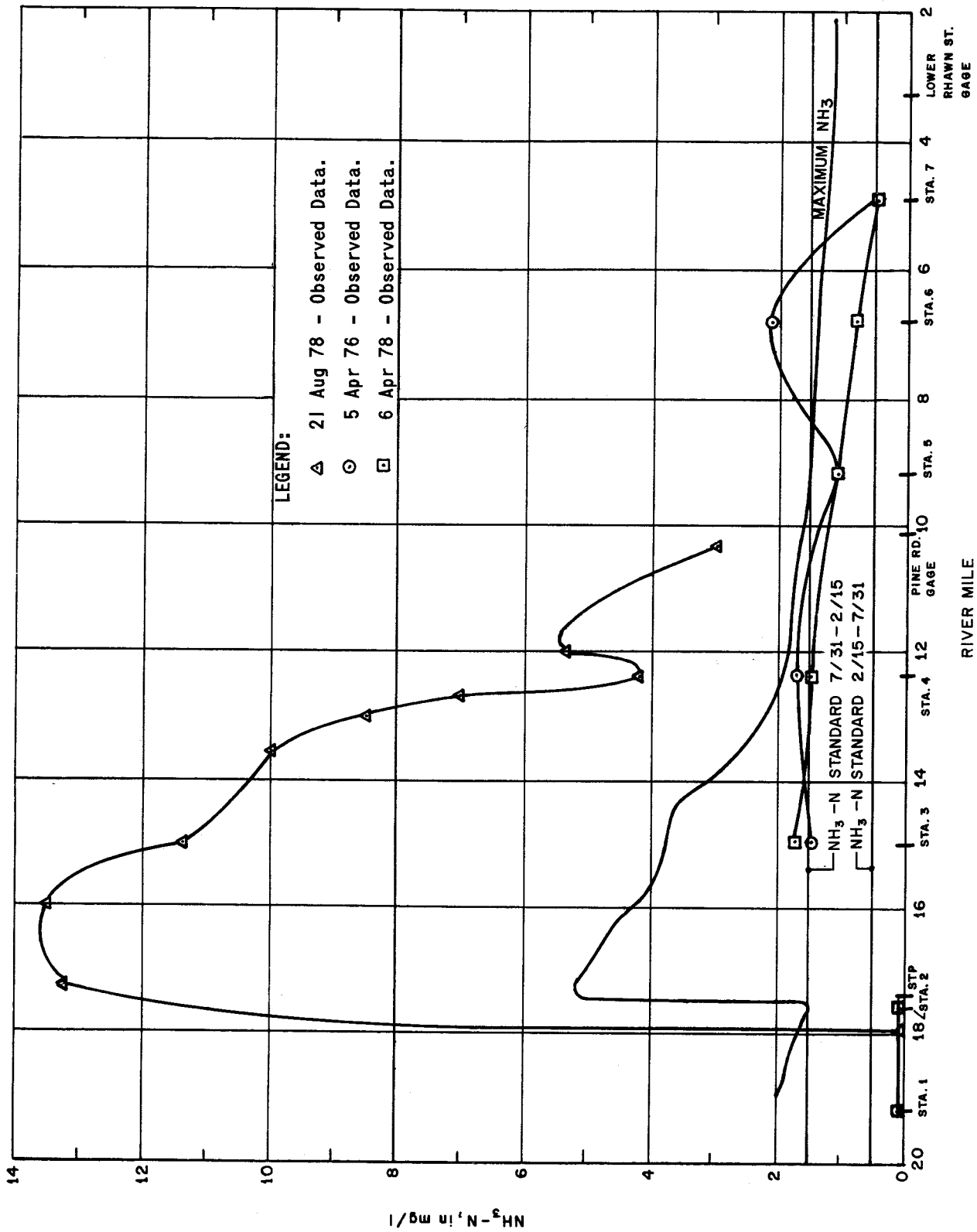


Figure V-9
 PENNYPACK CREEK
 AMMONIA NITROGEN PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

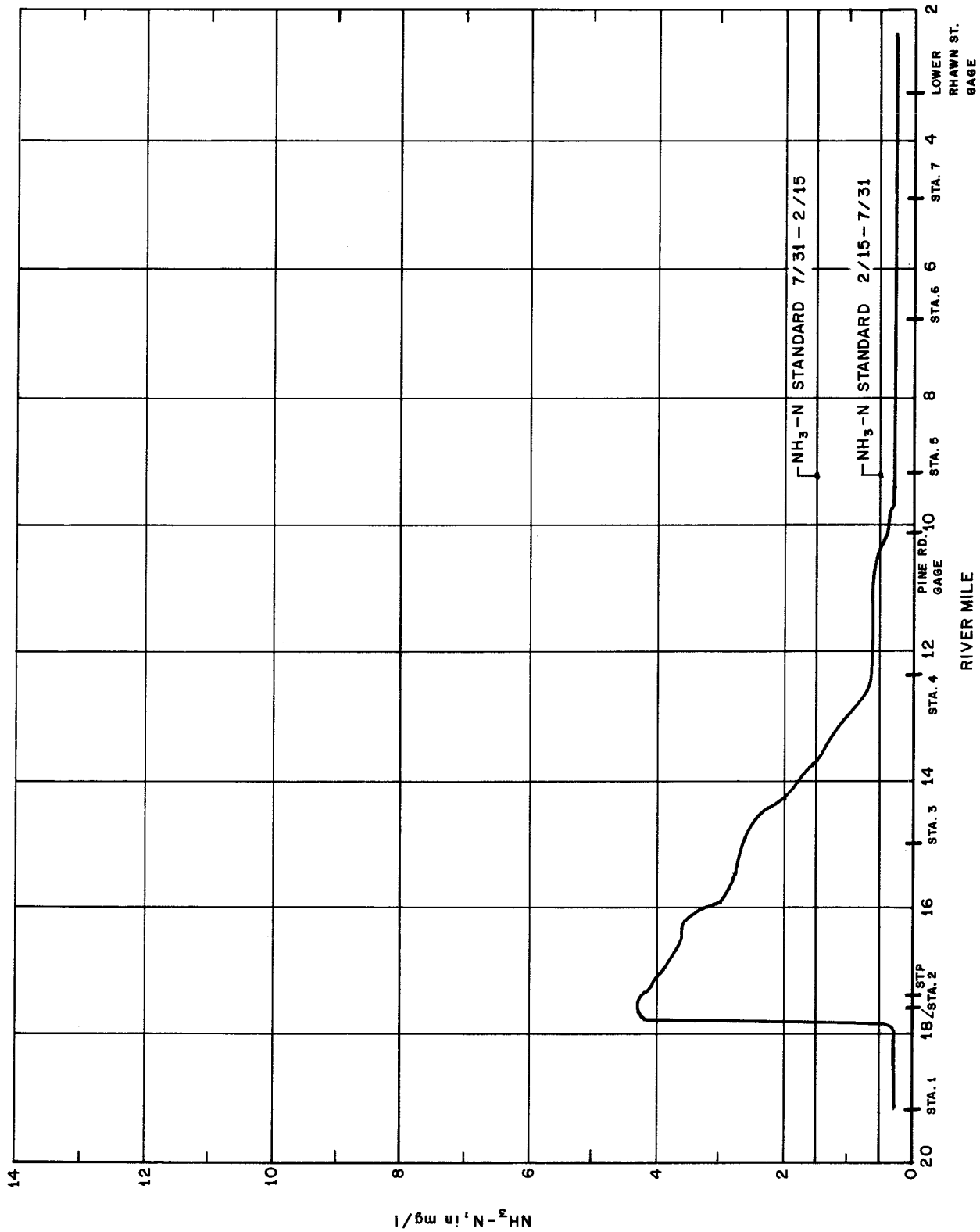
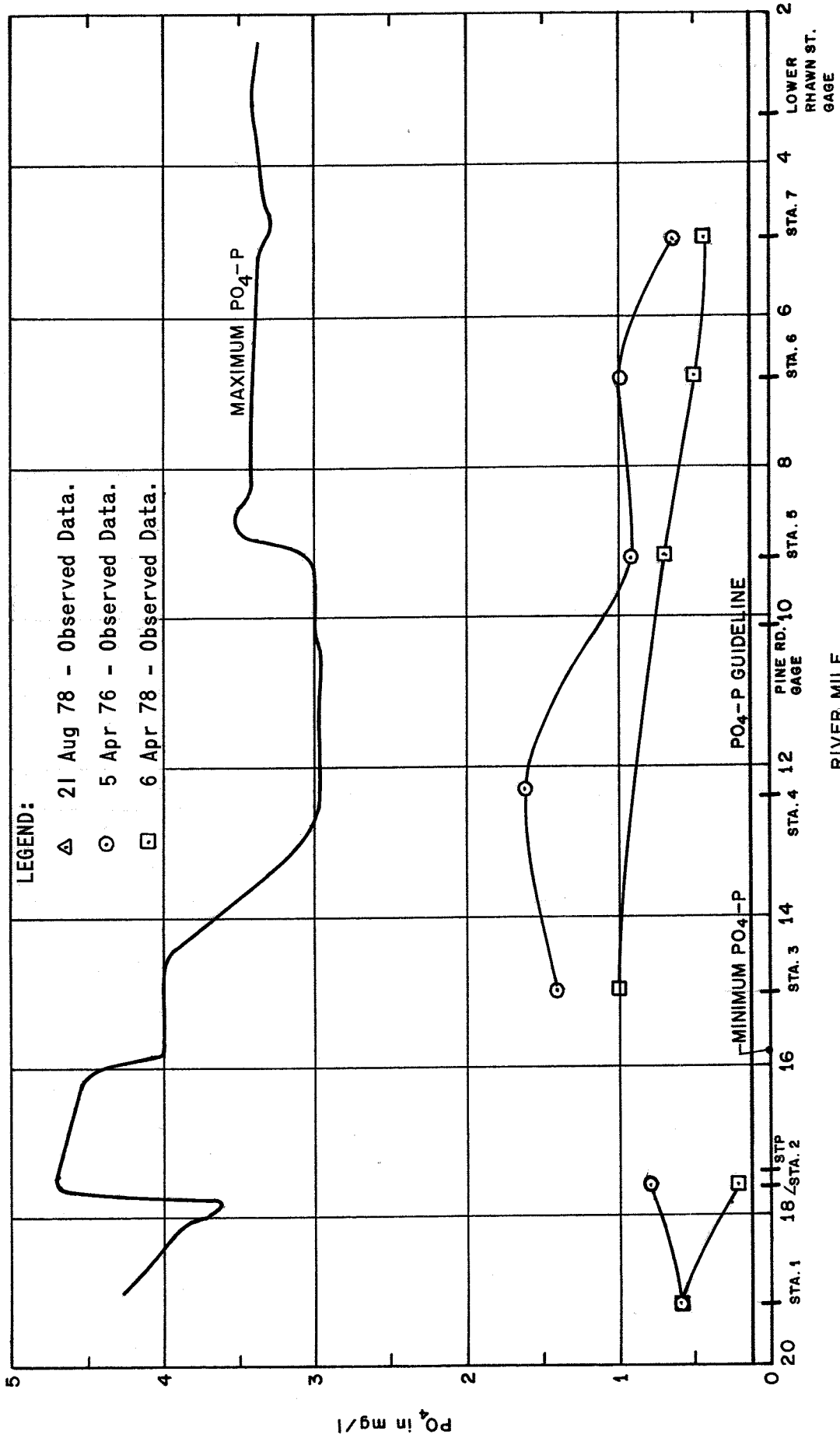


Figure V-10
 PENNYPACK CREEK - 50 PERCENTILE
 AMMONIA NITROGEN PROFILE
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77



RIVER MILE

Figure V-11
 PENNYPACK CREEK - ORTHOPHOSPHATE
 PHOSPHORUS PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

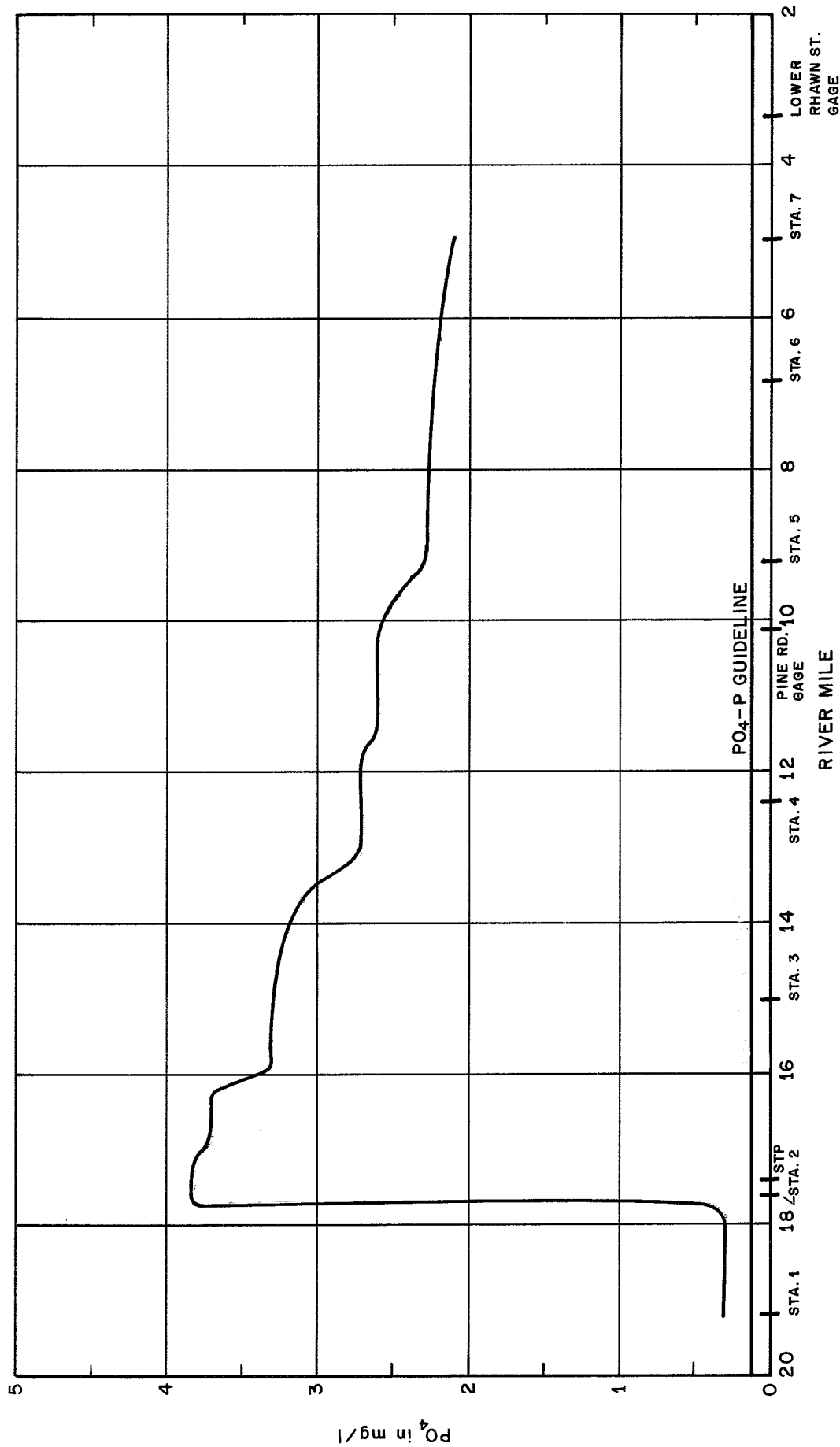


Figure V-12
 PENNYPACK CREEK - 50 PERCENTILE ORTHOPHOSPHATE
 PHOSPHORUS PROFILE
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

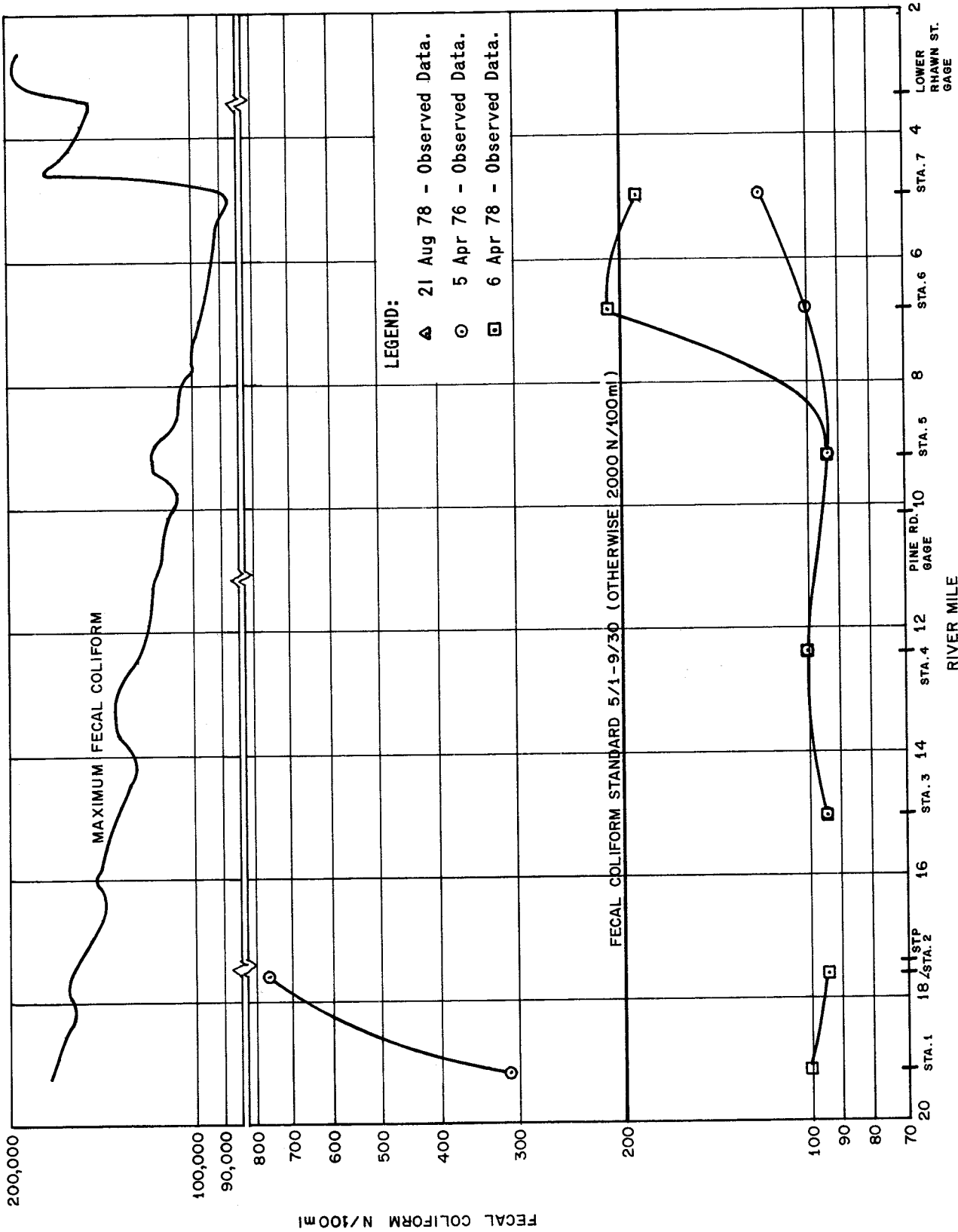


Figure V-13
 PENNYPACK CREEK
 FECAL COLIFORM PROFILES
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

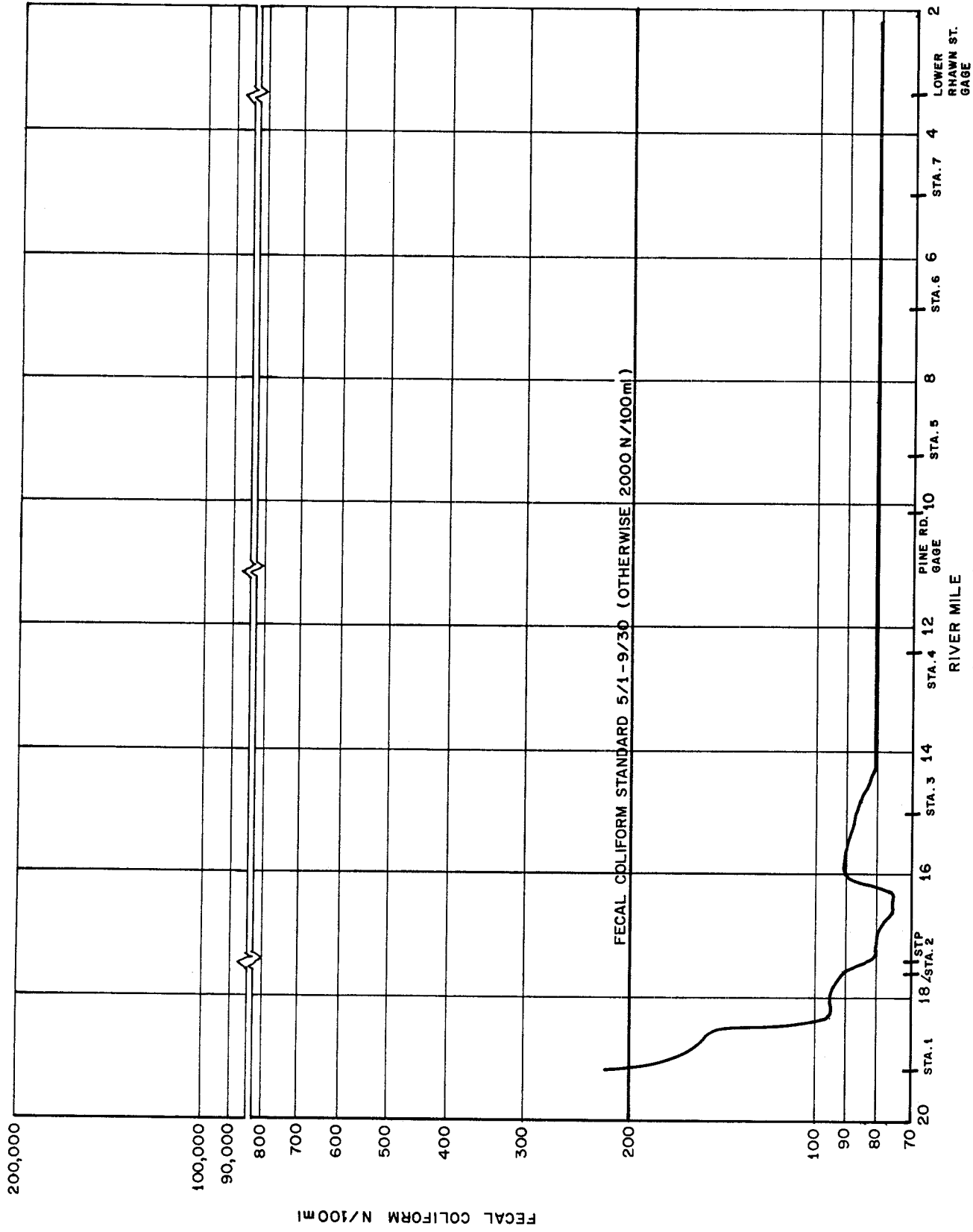


Figure V-14
 PENNYPACK CREEK - 50 PERCENTILE
 FECAL COLIFORM PROFILE
 FOR THE SIMULATION PERIOD JAN 73 TO JUN 77

50 percentile curve in Figure V-4 shows that 50% of the simulated values are below both seasonal standards. The results suggest that the water temperature is not generally a water quality problem. These results are confirmed by the limited available observed data.

Dissolved Oxygen for Existing Conditions

Figures V-5 and V-6 show that the simulated minimum dissolved oxygen does not always meet the stream standard and that 50% of the time it drops below both seasonal standards between river miles 12 and 14. While the simulated results define the DO sag point to be approximately 3 miles further downstream than observed values indicate, the authors are confident that the simulated magnitudes are approximately correct and indicate that a significant dissolved oxygen problem generally exists during the summer months between the Upper Moreland Hatboro (UMH) sewage treatment plant discharge and the downstream study boundary. This simulated impact is a combined effect of storm runoff and the UMH discharge. While great confidence cannot be placed in this specific simulation result, there is strong evidence from the observed field data that there are significant dissolved oxygen problems between the UMH discharge and the confluence with Huntingdon Valley Creek (approximately river mile 12). This measured impact is due to the UMH discharge.

Carbonaceous Biochemical Oxygen Demand for Existing Conditions

Figure V-7 and V-8 show that the simulation of CBOD is generally adequate. This conclusion helps develop confidence in the general adequacy of the dissolved oxygen profiles since there exists a direct relationship between the two parameters. The apparent error in location of the DO profile can be further shown to be caused in the model by the input data representing the geometric characteristics of the channel and not due to the CBOD or other loadings. CBOD standards or guidelines are apparently non-existent. The primary source of high CBOD is stormwater runoff.

Ammonia for Existing Conditions

Figures V-9 and V-10 show that while the simulated values are apparently low, the maximum simulated ammonia still exceeds the ammonia concentration standards. If the ammonia was to be increased, the dissolved oxygen would decrease. There is no apparent need to further decrease the dissolved oxygen profiles. Because of the average nature of many of the model inputs, there was also no apparent justification to try to increase the simulated values of the ammonia. The simulation results indicate that the UMH discharge causes significant increases in the ammonia concentrations and that they exceed the ammonia standard by a significant amount.

Orthophosphate for Existing Conditions

Since the observed nutrient concentrations suggest that the summer months are the season of high concentrations (see Figure V-9) and since observed orthophosphate was not measured during August 1978, it is difficult to determine the accuracy of the simulated PO_4 data. Some data from the City of Philadelphia shows that values in excess of 6 mg/l have been observed at Pine Road. Figures V-11 and V-12 show that the maximum simulated results are significantly higher than the local guidelines and the UMH discharge contributes significantly to the high concentrations. Any error made in the orthophosphate calculations has no impact on any other parameters.

Fecal Coliform for Existing Conditions

Figure V-13 shows that the maximum simulated fecal coliform colonies exceed, by orders of magnitude, both instream seasonal standards. The large magnitudes are due to stormwater runoff and constitute a significant problem during storm runoff periods. Figure V-14 shows that the 50 percentile curve only exceeds the summer standard in the headwater area (due to base flow estimates). The coliform problem is definitely related to the stormwater runoff simulation results and not to the sewage treatment plant. The UMH plant provides sufficient chlorination of their effluent to minimize the fecal coliform discharge from the plant. The UMH discharge is usually under 10 and under unusual conditions under 50 no. of colonies/100 ml.

Impact of Future Conditions

A comparison of existing and estimated future conditions water quality profiles are shown in Figures V-15 through V-20. The expected impact is summarized in Table V-5.

TABLE V-5
Comparison of Existing and Estimated Future Conditions

<u>Parameter</u>	<u>Impact of Future Conditions</u>
Temperature	No significant impact.
Dissolved Oxygen	Up to 1 mg/l decrease in DO in the headwater channel above the UMH discharge. No other significant impact between future and existing conditions. While the 1 mg/l would usually be considered significant change, since the remainder of the profile is so far below the standards, the upstream impact is generally inconsequential.
Biochemical Oxygen Demand	In general, about a 3 to 4 mg/l increase in BOD concentrations. This increase has no significant impact on the DO because the DO is already so low. If the existing conditions were improved, this BOD increase may be very significant.
Ammonia Nitrogen	In general, about 0.5 mg/l increase in the headwater channel and a 1 to 2 mg/l increase throughout the remainder of the channel. The largest impact is immediately downstream of the UMH discharge. This increase, like the BOD impact, has no significant impact on the DO because the DO is already so low. If the existing conditions were improved, this NH ₃ increase will be very significant, since the increase itself equals the NH ₃ standard.
Orthophosphate Phosphorus	In general, about 1 mg/l increase in the headwater channel and a 1.5 to 2 mg/l increase throughout the remainder of the channel. This is a significant increase which far exceeds the standard.
Fecal Coliform	In general 10 to 15% increase throughout the study area. This increase is insignificant compared to the magnitude of the existing condition.

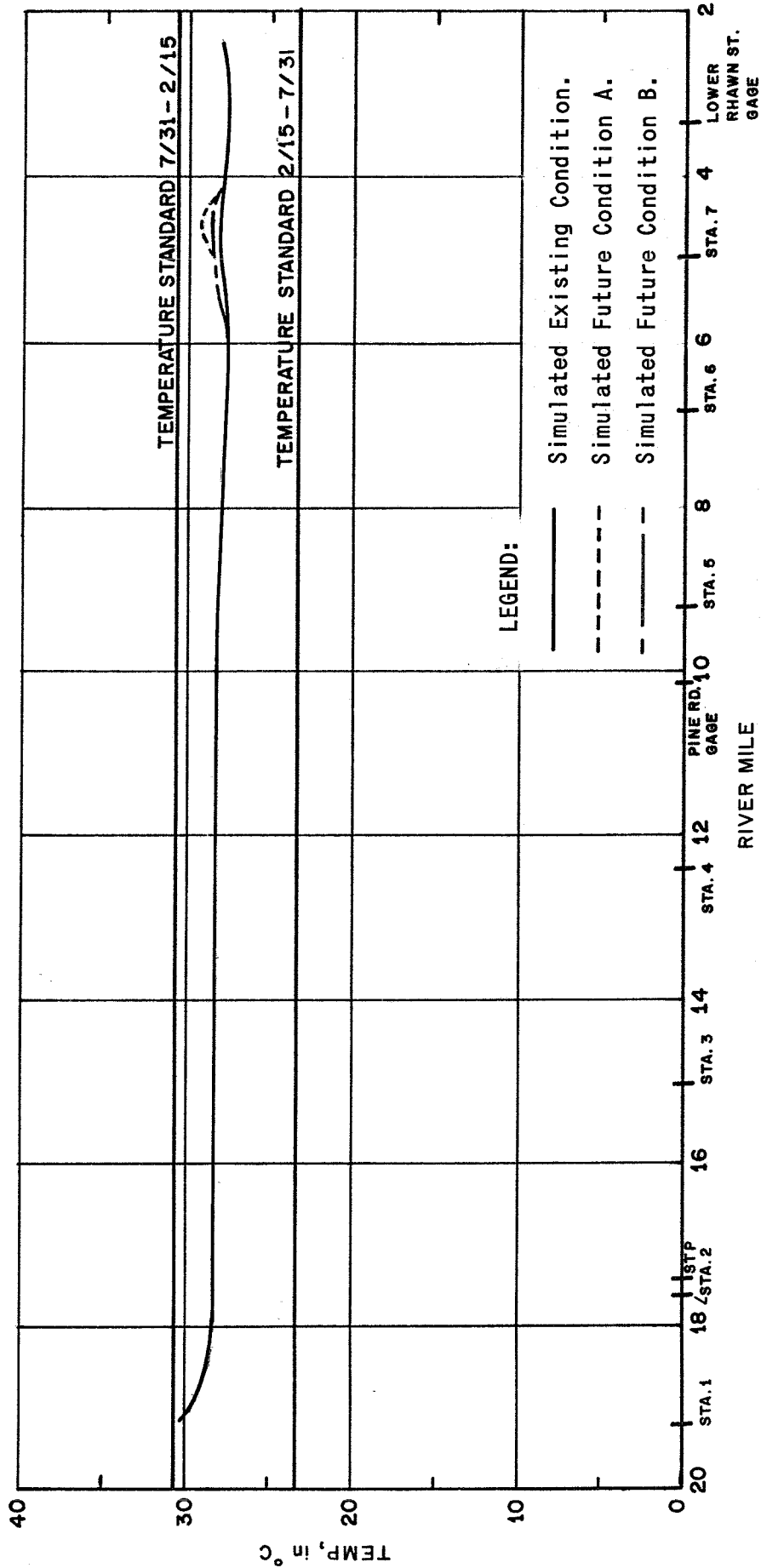


Figure V-15
 PENNYPACK CREEK - EXISTING AND FUTURE
 WATER TEMPERATURE PROFILES

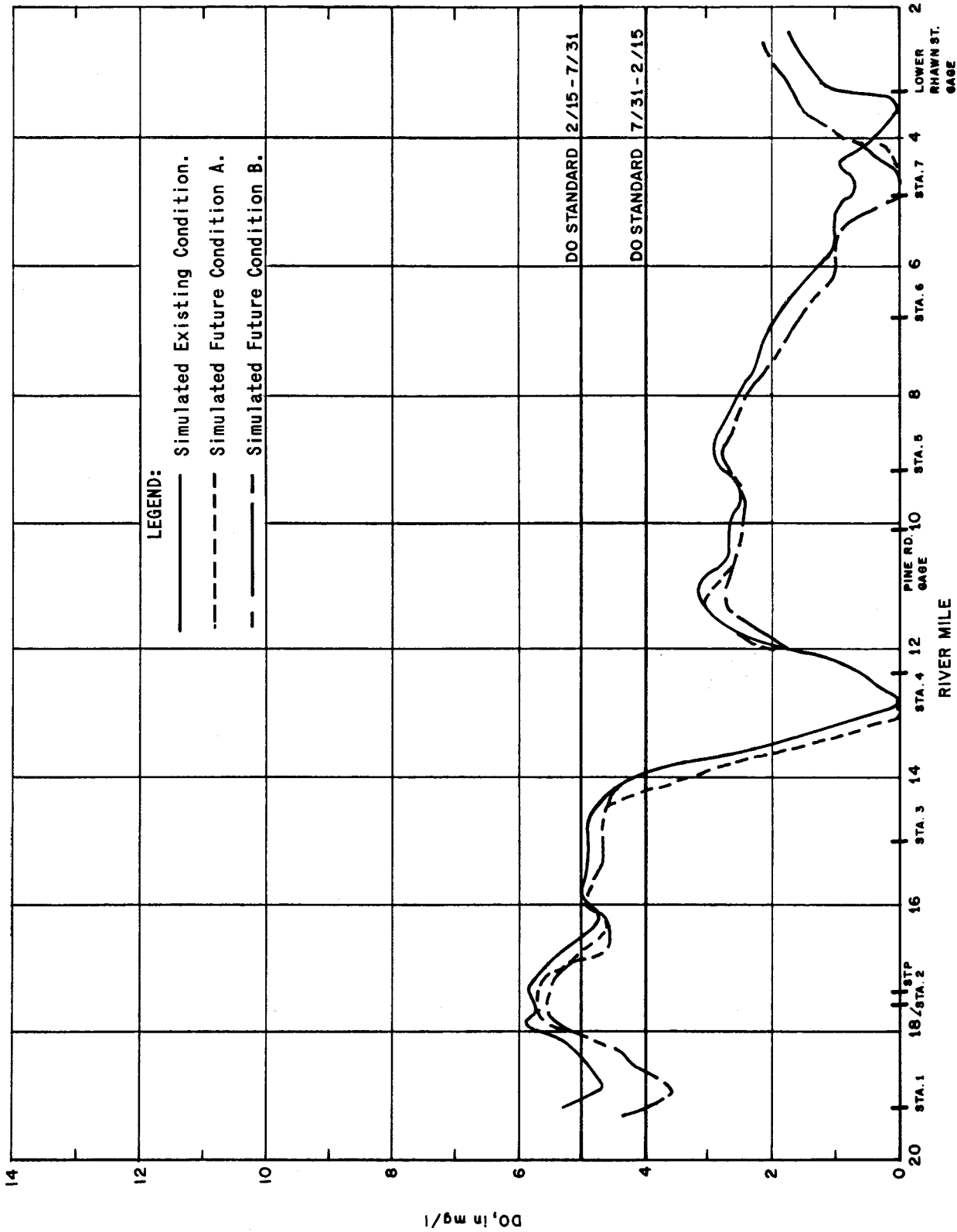


Figure V-16
 PENNYPACK CREEK - EXISTING AND FUTURE
 DISSOLVED OXYGEN PROFILES

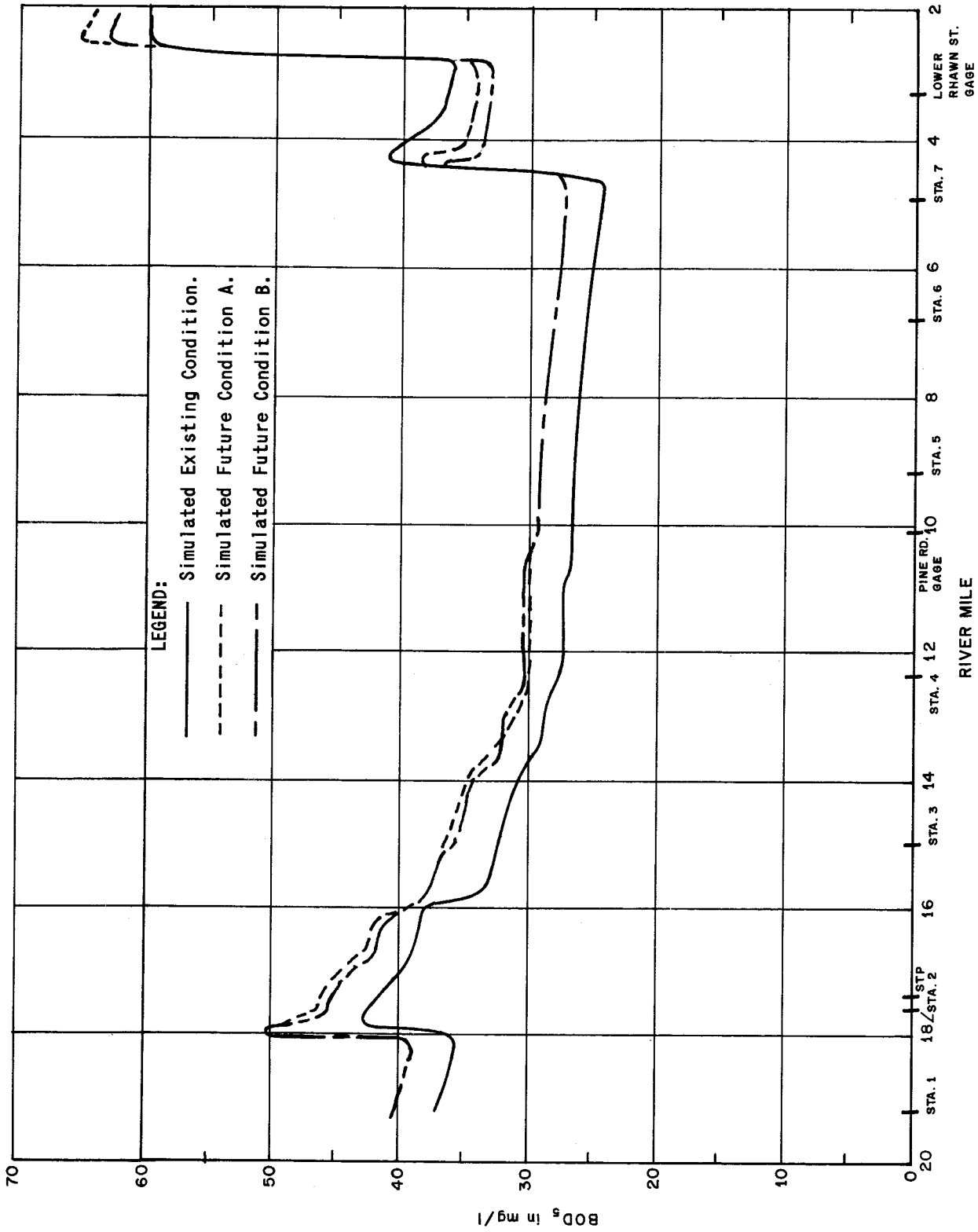


Figure V-17
 PENNYPACK CREEK - EXISTING AND FUTURE
 CARBONACEOUS BIOCHEMICAL OXYGEN DEMAND PROFILES

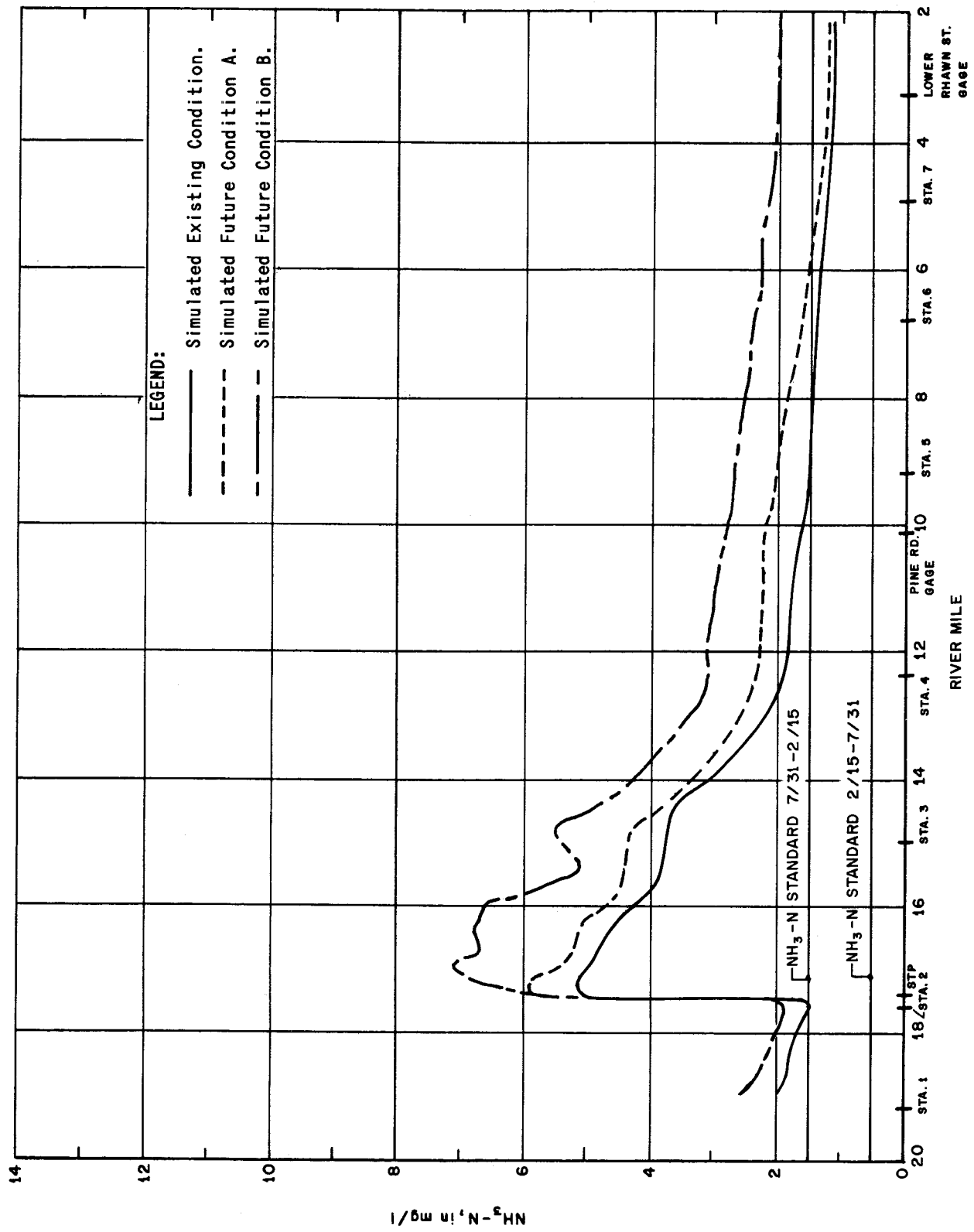


Figure V-18
 PENNYPACK CREEK - EXISTING AND FUTURE
 AMMONIA NITROGEN PROFILES

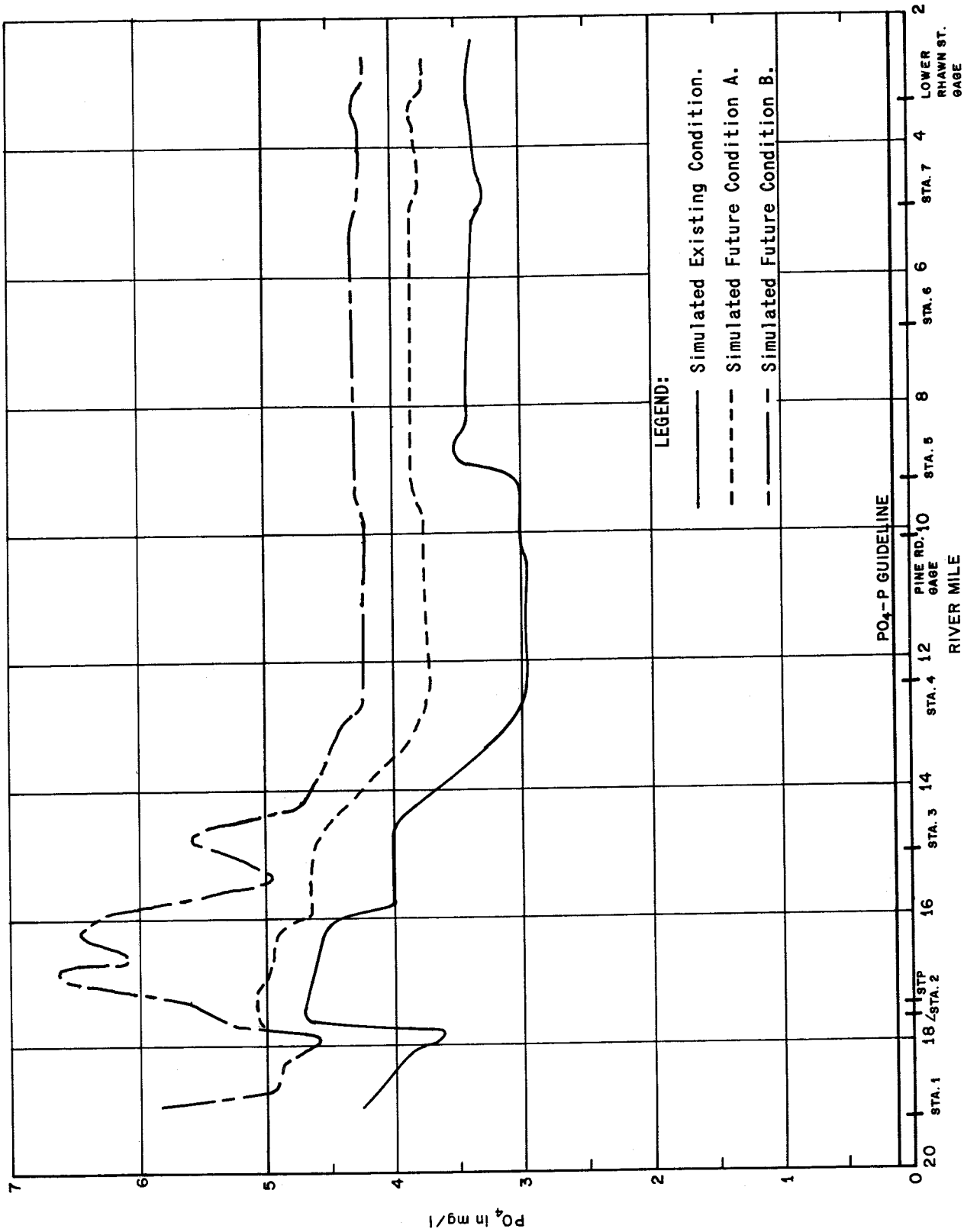


Figure V-19
 PENNYPACK CREEK - EXISTING AND FUTURE
 ORTHOPHOSPHATE PHOSPHORUS PROFILES

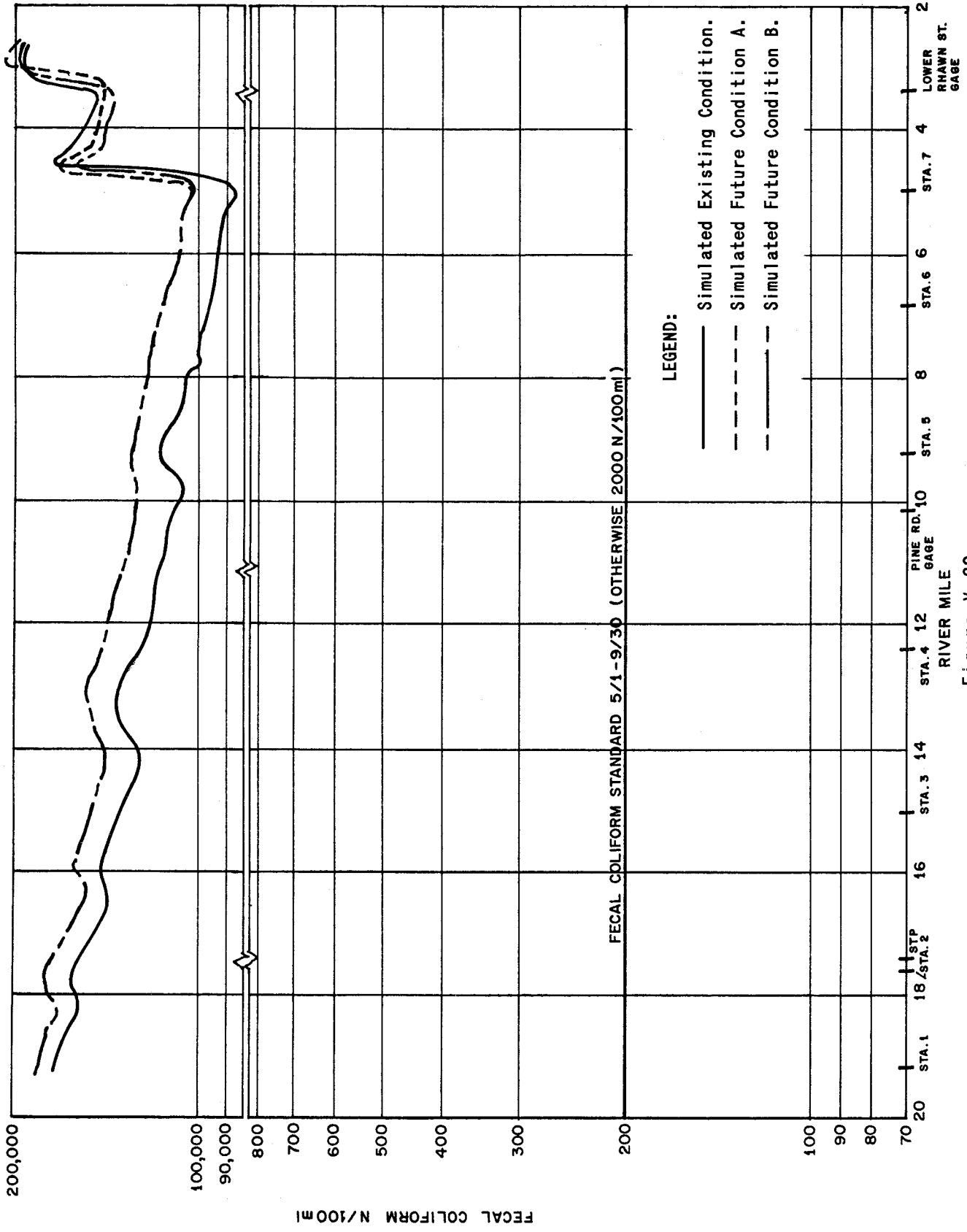


Figure V-20
 PENNYPACK CREEK - EXISTING AND FUTURE
 FECAL COLIFORM PROFILES

As shown in Table V-5, the impact of the changing land use for future conditions is a general increase in the nutrients in Pennypack Creek, especially below the UMH discharge. When the UMH service area is also increased in size, as in the future Condition B, the water quality condition with regard to nutrient concentrations is approximately double the increase without the service area enlargement. The reason for the apparent decrease in water quality due to increased service area (i.e., condition B) is that under condition A it is assumed that the waste from the population increase not within the service area is transported out of the watershed.

While the nutrient increase is significant, as is the increase in organic material (i.e., BOD), the integrated impact (i.e., dissolved oxygen) is minor except in the headwater channel above the UMH discharge. This lack of impact is caused by the high assimilative capacity of the channel. The real impact of the nutrient increases may be in the downstream receiving water (i.e., Delaware River) where detention times are increased and biotic problems may develop.

The increase in fecal coliforms is of minor impact compared to the estimated coliform counts from stormwater runoff under existing conditions.

VI REFERENCES

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5. Thackston, Edward L. "Effects of Geographical Variations on Performance of Recirculating Cooling Ponds," EPA Publication 660/2-74-085, November 1974.
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9. "Computer Program for Project Formulation," Soil Conservation Service Technical Release No. 20, U.S. Dept. of Agriculture, Washington D.C., 1965.
10. "HEC-1, Flood Hydrograph Package," Hydrologic Engineering Center, Computer Program Users Manual, January 1973.
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APPENDIX

Sources of Waste Treated Sewage

The sources of treated sewage within the Pennypack Creek Watershed have been sub-divided into municipal, industrial and non-municipal (e.g., apartments, churches, and schools) plants. An extensive list of all three were published by the Delaware Valley Regional Planning Commission in September 1977. The list was screened for all three types of plants and all dischargers within the basin exceeding a 0.035 MGD discharge are tabulated below in Table A-1.

TABLE A-1

<u>Facility</u>	<u>Current Capacity (MGD)</u>	<u>CBOD₅ (mg/l)</u>	<u>NH₃-N (mg/l)</u>	<u>PO₄-P (mg/l)</u>
MUNICIPAL PLANTS				
UMH	6.60	12.8*	6.6	5.3
Chapel Hill	0.12	12.8**	6.6	5.3
NON-MUNICIPAL PLANTS				
Meadowbrook Apts.	0.040	13.0***	7.0	6.0
Academy of the New Church	0.035	13.0***	7.0	6.0
INDUSTRIAL PLANTS				
Fischer & Porter (Cooling Water)	0.058	1.0****	0.3	0.6

* UMH effluent quality - annual average observed data

** Chapel Hill - assumed equal to UMH effluent

*** Non-municipal Effluents - assumed slightly worse than UMH

**** Industrial Cooling Water - assumed equal to Pennypack Creek headwater

Other sources of treated sewage are either smaller discharges than .035 MGD, are not operating or the sewage is transported out of the basin to another plant.

Personal communications in September 1978 with Mr. Dave Rider of the Pennypack Watershed Association suggested that all of the dry weather flow from the lower portion of the Pennypack Creek Watershed (i.e., the portion within Philadelphia County) is transported to the Philadelphia N.E. Plant which is outside the watershed. Some of the Philadelphia County's lines even extend into Abington and Lower Moreland. Mr. Rider also thought that the industrial sources do not have continuous outflow and that some of them are actually inoperative.

The sewage from the portion of the Warminster Township within the watershed is transported out of the basin.

The sources shown in Table A-1 are apparently the most significant ones remaining. Those sources have been evaluated as to their significance compared to the UMH plant. The results of that evaluation are shown in Table A-2.

The obvious conclusion from the results in Table A-2 is that no waste treatment source is more significant than 2% of the significance from that of the UMH plant effluent. This conclusion seems to be sufficient to justify using only the UMH effluent for evaluating impacts on the Pennypack Creek.

TABLE A-2

Facility	Q	% of UMH Plant Load		
		CBOD ₅	NH ₃ -N	PO ₄ P
UMH	100	100	100	100
Chapel Hill	2	2	2	2
Meadowbrook Apts.	1	1	1	1
Academy of the New Church	1	1	1	1
Fischer and Porter	1	0	0	0

