Ohio River Valley
Water Sanitation Commission

WATER QUALITY MANAGEMENT OF PHENOLICS AND CYANIDE IN THE UPPER OHIO RIVER

Job Number: WSTN0010

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SECTION 1.0

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. Water column concentrations of phenolics and cyanides in the upper Ohio River often exceeded applicable ORSANCO and state criteria/standards in the mid to late 1970s and early 1980s. Concentration values were generally greatest in winter. There has been a substantial decline in water column concentrations from that period to the present.

2. Phenolics and cyanide wastewater loadings from permitted discharges show the same pattern during the period of study: high loadings in the late 1970s and early 1980s with a marked decline to present. Wasteloadings are generally substantially greater in colder months of the year corresponding to greater observed in-stream concentrations.

3. The available data base for observed in-stream phenolics and cyanide concentrations and wasteloading information is extensive but not completely sufficient for rigorous modeling analysis. The majority of wasteload data from the permitted discharges represents two to four measurements per month. These measurements are not necessarily made during the same time as in-stream monitoring measurements. Therefore, there is no necessarily direct correspondence between reported wasteloads and observed water quality. Further, almost no site-specific (upper Ohio River area) data are available on potential non-permitted discharges of phenolics and cyanide.

4. The vast majority of in-stream water quality data for phenolics and cyanide are monitored at various stations at a single location in the channel cross-section. Data from the February 1983 intensive survey for phenolics indicates, however, that substantial lateral stratification can exist which is not likely to be measured at the monitors. Therefore, in-stream concentrations substantially greater than those measured can exist in the upper Ohio River.

5. Due to the substantial lateral stratification observed in February 1983, a two-dimensional water quality model was constructed for analysis of data. The model consists of 63, two mile long longitudinal sections each of which is divided into five lateral segments. Model geometry was developed from detailed U.S. Army Corps of Engineers cross-section data; flow is taken from USGS measurements; dispersion coefficients are assigned from empirical measurements at similar sites; and phenolic and cyanide reaction coefficients were taken from studies performed by the State of Pennsylvania.

6. Analysis of the February 1983 intensive survey for phenolics, the best data set available, indicates that the two-dimensional model can realistically reproduce observed data. In-stream phenolic concentrations could not be explained satisfactorily with a laterally averaged one-dimensional approach.

7. Available ORSANCO monitoring data were reviewed to select a number of periods from 1977 to 1984 for data and modeling analysis. Twelve monthly periods were selected, both winter and summer, with both high and low in-stream concentrations. For each period, monthly in-stream monitor data were evaluated as follows: mean reported wastewater loads with mean boundary conditions; and maximum reported loads with maximum boundary conditions. These combinations were necessitated as there is no necessarily direct correspondence between reported loads and monitored water quality.

8. The modeling analysis of phenolics data is generally good within the limitations of the data. The results indicate that, in general, monitored concentrations can be satisfactorily accounted for with measured loadings from the permitted dischargers.

9. The modeling analysis for total cyanide is not as good as that for phenolics. Three reasons are possible: (1) the reaction rate coefficient for cyanide decomposition is overestimated; (2) the high observed in-stream concentrations were caused by correspondingly high waste inputs from permitted discharges which were not measured; or (3) there existed substantial other inputs of material from non-permitted sources.

10. Further analysis of the river data for cyanide during those periods when the model does not adequately account for in-stream concentrations indicates that the mass loading of cyanide, which is not accounted for, is in the order of 3000 to 6000 lbs/day. This magnitude of loading cannot nearly be accounted for by the estimated other potential loads which range from 160 to 263 lbs/day of total cyanide. It is therefore concluded that the most likely cause(s) of high in-stream cyanide concentrations which were not accounted for by calculations were greater loadings from the permitted (and perhaps other industrial) sources and/or lesser decomposition, most likely a combination of the two.

11. It is therefore concluded from the data and modeling analysis that the past excessive in-stream concentrations of phenolics and cyanide in contravention of ORSANCO and state criteria/standards were due primarily to wastewater loadings from the permitted dischargers with some possible input from non-permitted sources. The reported total wastewater loadings discharged from permittees during those periods selected for analysis when in-stream concentrations were in violation of standards greatly exceeded the total of current permit limitations.

12. On this basis, it appears that applicable stream water quality criteria for phenolics and cyanide can be maintained by point source control of permitted discharges. Analysis of existing wasteload allocations and permit limitations for low winter flow conditions including lateral stratification and in-stream reaction indicates, in general, that the limits are well-established and sufficient to maintain applicable water quality standards. A possible exception is a localized violation for phenolics below Weirton Steel under maximum discharge and critical low flow conditions due to incomplete lateral mixing. However, river quality should be within standards at the critical Wheeling Water Works. Even assuming the existence of other potential sources of cyanide and phenolics as estimated, and boundary concentrations from the major tributaries entering the mainstem with constituent concentrations at the levels of the standards, it is projected that water quality standards would be maintained for the ambient flow and temperature conditions specified.

13. Substantial amounts of cyanide and phenolics have been discharged historically from ALCOSAN. Values are much curtailed at present. However, given the continuing discharge of materials from this source, permit limitations may be considered from an equity and management standpoint.

14. No data were obtained on constituent concentrations in other industries of the region other than those with permit limits. Consequently, no potential load was assigned to this source. It may be appropriate to consider some surveillance monitoring to place a perspective on this potential source.

15. It is concluded that the elevated in-stream concentrations of cyanide and phenolics in the late 1970s and early 1980s were primarily due to mass loadings from permitted discharges which were greatly in excess of present permit limits. Lateral stratification which exists in the river may further exacerbate problems at critical locations such as the Wheeling Water Works. The recent depression of manufacturing productivity in the steel and other industries appears to be primarily responsible for recently improved water quality.

16. Given the existing depression of the steel industry and reduced wasteloads from permittees, violations of phenolics and cyanide water quality standards should not recur to any significant degree. If the steel industry recovers, however, consideration should be given to the following:

    a. location of monitoring stations closer to major discharges;

    b. lateral measurements in the cross-section;

    c. consideration of mixing zones;

    d. collection of rigorous in-stream and wasteloading data to improve modeling analysis;

    e. analysis of permit limits with validated model; and

    f. rigorous enforcement of permit limitations to maintain water quality standards.

SECTION 2.0

INTRODUCTION

The Ohio River Valley Water Sanitation Commission (ORSANCO) and the member states of Pennsylvania, Ohio and West Virginia have been concerned historically about concentration levels of phenolics and cyanide in the Ohio River, particularly in the upper 100 miles. In 1975, the Commission began a manual sampling program to monitor the river routinely for these and other water quality variables. Similarly, daily samples have been collected for a considerable period of time by personnel of the Wheeling, West Virginia Water Treatment Plant on the intake water and analyzed for phenolics which are associated with taste and odor problems. The historical data from these sources have indicated recurrent high concentration levels of these compounds in the past which interfere with the beneficial water uses of the region.

In 1976, a water quality criterion for phenolics of 10 μg/l was established by ORSANCO as part of recommended criteria for the Ohio River. This value, based on protection of public water supplies, was subsequently adopted by the State of Ohio. The States of Pennsylvania and West Virginia chose to adopt a standard of 5 μg/l for phenolics based on prevention of tainting of fish flesh. ORSANCO and the member states also have differing criteria/standards for cyanide. The Commission and Ohio use 25 μg/l for total cyanide while Pennsylvania and West Virginia have adopted 5 μg/l of free cyanide as a standard.

Historical monitoring data obtained by ORSANCO reveal concentration levels of phenolics and cyanide substantially in excess of the applicable water quality standards during certain periods. Phenolics and/or cyanide levels were observed to be particularly elevated during the winters of the mid to late 1970s, especially those which were particularly cold. Cyanide levels appeared to improve since 1979, but phenolics concentrations continued to be a problem into

1981. As a result, a number of studies were initiated in the early 1980s by ORSANCO in cooperation with the member states and the U.S. Environmental Protection Agency (EPA), Region III, to study the problem in greater detail. More recently, within the last three years, river concentration levels of phenolics and cyanide have been generally low and within standards.

It is of management interest to understand the reasons for the variability of constituent concentrations in the upper Ohio River. Water column concentration values are affected by a number of variables including phenolics and cyanide load inputs from permitted point sources, possible discharges from unpermitted point and non-point sources, tributary inputs, river base flow conditions, decomposition processes, water temperature, sunlight intensity, and biological activity. However, to this point, the deterministic cause and effect relationships among these factors and observed water quality have not been established. Therefore, the reasons for variations and trends in the observed concentration values of phenolics and cyanide over the last decade are not apparent.

It is possible that improved waste treatment, varying industrial productivity, meteorological factors, regulatory surveillance, and undefined sources have all had a bearing on the concentration of these substances over the period of interest. Effective water quality management is enhanced if the relative importance of the various factors which influence water quality can be determined. It is the purpose of this study to quantitatively determine the various factors which affect the levels of phenolics and cyanide in the upper Ohio River so that efforts can be directed to assure that previously observed problems do not recur.

2.1 DESCRIPTION OF THE STUDY AREA

The area to be included in the present study is that portion of the upper Ohio River from the confluence of the Allegheny and Monongahela River at Pittsburgh downstream to the Hannibal Locks and Dam at New Martinsville, West

Virginia as shown on Figure 2-1. The Ohio River in this region is approximately 126 miles long and is characterized by a series of six navigation control structures maintained by the U.S. Army Corps of Engineers. The width of the river is on the order of 1500 feet in the various pools. The principal tributary in this region is the Beaver River, which joins the mainstem approximately 25 miles below Pittsburgh. The long-term average annual flow at New Cumberland Locks and Dam is 36,700 cfs, with a minimum 7 day-10 year low flow of approximately 5200 cfs in the area. Time-of-travel through the study area at average annual flow is approximately five days increasing to greater than one month at critical low flow.

The study area is characterized by a heavy concentration of steel mills and chemical companies discharging treated wastewater containing concentrations of phenolics and cyanide. More than one dozen industrial operations discharge either or both of these compounds under permit. In addition, there are numerous though generally small, municipal discharges which may contribute some amount of material. The largest municipal discharge by far is the Allegheny County Sanitation District (ALCOSAN) Wastewater Treatment Plant located approximately three miles into the mainstem. Some of the municipalities are characterized by combined sewer overflows which result in periodic discharges of untreated sewage to the river. Storm drainage from municipal and industrial sites and discharges from numerous small tributaries also enter the river within the study area.

2.2 OBJECTIVES OF THE STUDY

The primary objective of this work is to better define the behavior of phenolics and cyanide in the Ohio River in order to support water quality management decisions regarding these compounds. Achieving this objective will involve the following:

1. determining the impact of permitted point source discharges on river concentration levels of phenolics and cyanide;

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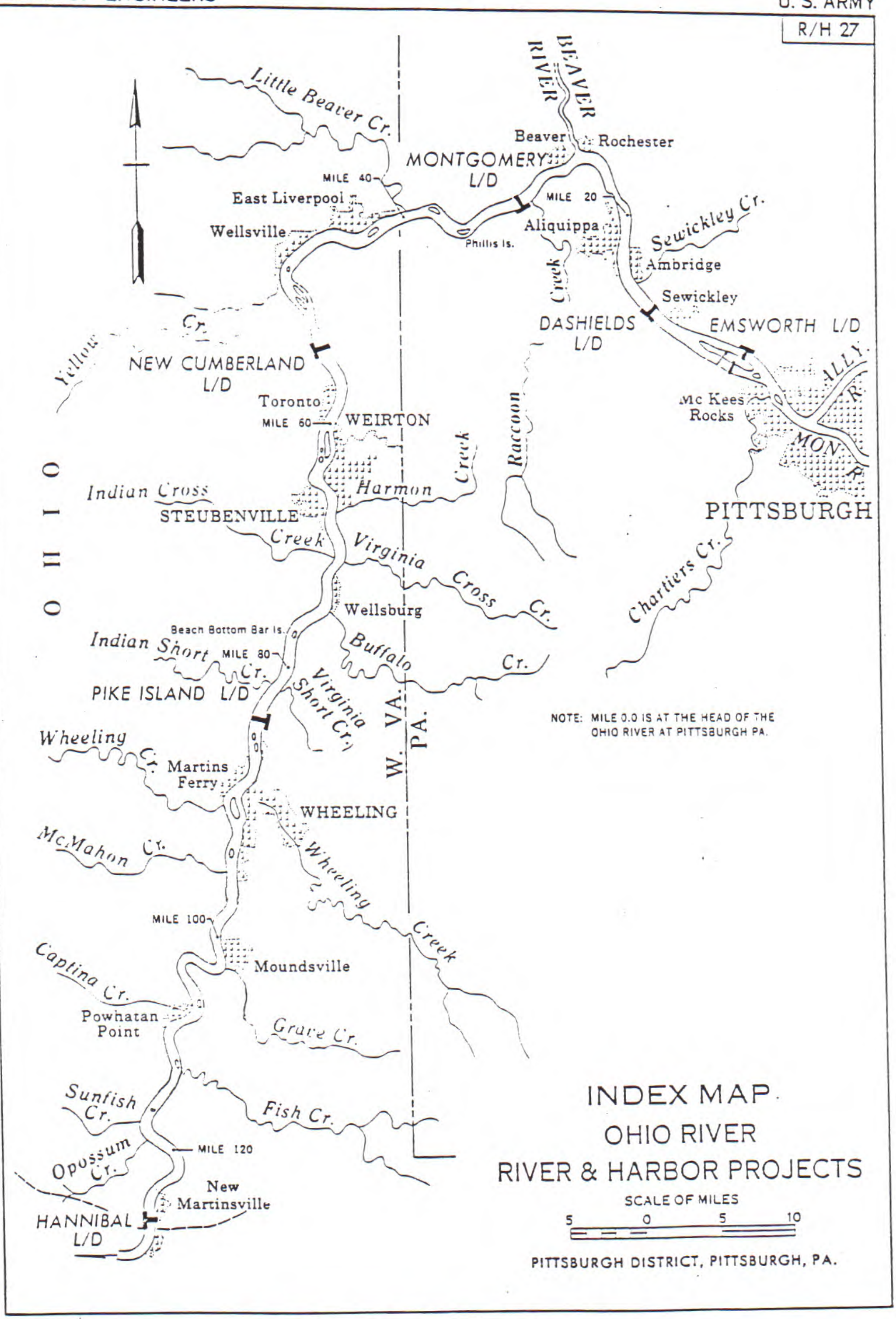


FIGURE 2-1. STUDY AREA

2. assessing the effectiveness of current control practices;

3. defining the presence and impact of additional sources such as unpermitted point and non-point sources, and contaminated runoff; and

4. developing alternative control strategies to maintain the applicable water quality standards for phenolics and cyanide as appropriate.

2.3 ORGANIZATION OF THE REPORT

The report is organized into a series of sections which summarize the results of various technical tasks which were undertaken to achieve the objectives of the study. A summary is presented of available data for phenolics and cyanide concentrations in the upper Ohio River from 1976 to date, together with information quantifying permitted wastewater loads. Information is also presented on potential unpermitted waste inputs and other relevant data necessary for the analysis. Wastewater inputs from permitted sources are then evaluated over the period 1976 to 1983 to ascertain compliance with permit limits and temporal trends. Estimates are provided and an assessment made of the significance of potential unpermitted waste inputs. The mathematical water quality model used to assess data from selected representative periods is described and the analysis of river data is discussed. Observations are provided on the principal reasons for observed historical high levels of the constituents of interest on the basis of the modeling analysis. Finally, the model is used to evaluate existing wasteload allocations for phenolics and cyanide loading to an assessment of current practices.

SECTION 3.0

SUMMARY OF AVAILABLE DATA

The mathematical water quality model subsequently used for problem analysis in this study requires several types of data including in-stream water quality, bathymetry, wastewater discharge, and advective flow. This section summarizes the availability of pertinent data.

3.1 OHIO RIVER WATER QUALITY DATA

The present study utilized ambient cyanide, phenolics, and temperature data for the 1976 to 1984 period in the 126-mile study area presented on Figure 2-1. Both spatial and temporal detail are necessary to establish a calibrated water quality model and to develop a predictive capability using this model. Available manual sampling and intensive survey data were used for these purposes.

3.1.1 ORSANCO Monitor Data

The most abundant source of ambient cyanide and phenolics data during the period of interest is the ORSANCO manual monitoring program. Data were collected routinely at South Heights, East Liverpool, Pike Island, Shadyside, and Hannibal (Figure 2-1) at a frequency of three to four times per month during the 1976 to 1980 period and one to two times per month thereafter. Additionally, cyanide and phenolics data were obtained at the same frequency in the Beaver, Allegheny, and Monongahela Rivers, which can contribute significant loads to the Ohio River. Temperature data, which are important in determining ambient reaction rates, are available for each of the preceding samples.

The manual monitoring program provides a comprehensive data base from which historical trends can be ascertained. For example, Figure 3-1 presents

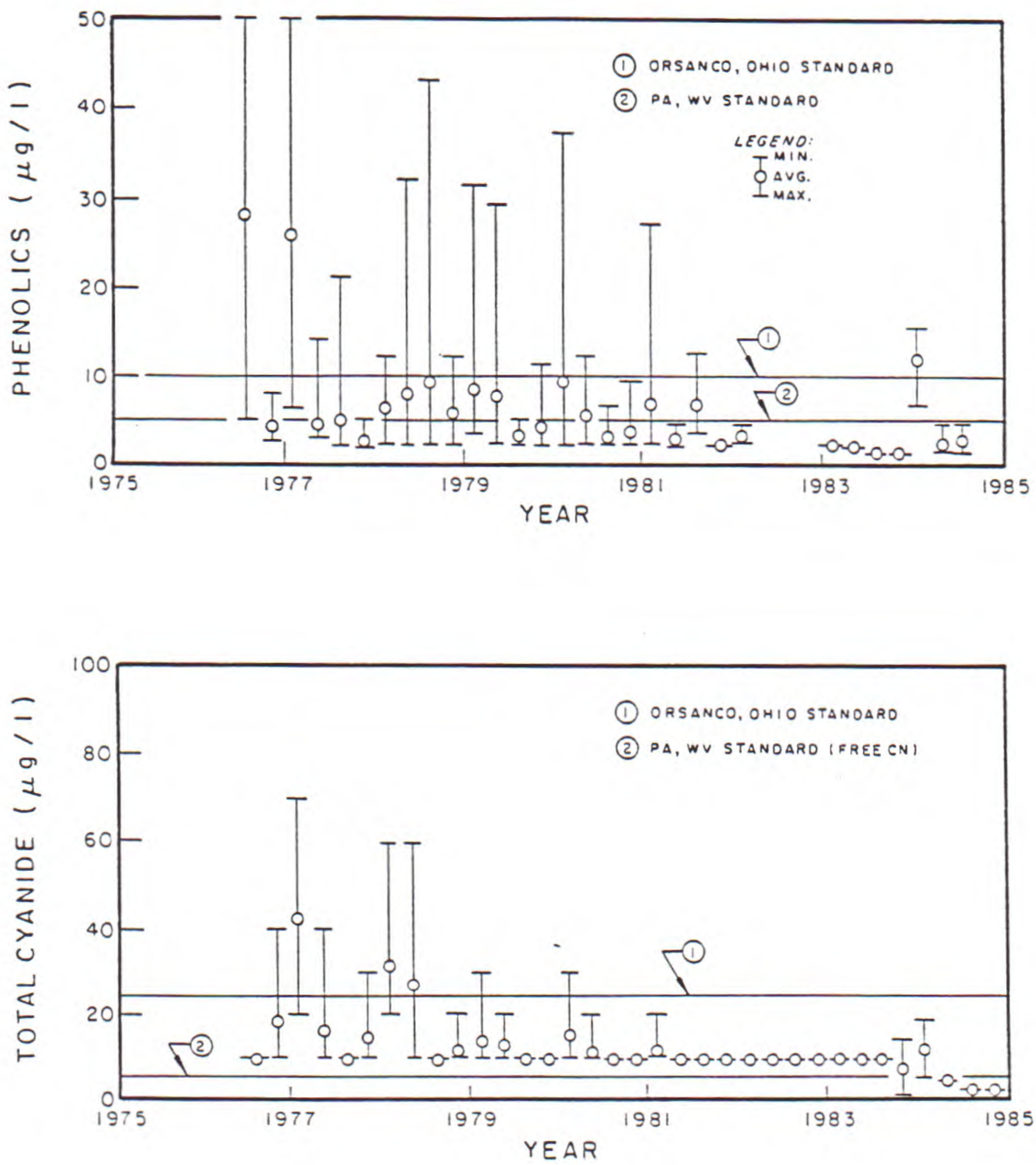


FIGURE 3-1. ORSANCO MONTHLY MONITORING DATA - SOUTH HEIGHTS

quarterly-averaged phenolics and cyanide data for the Ohio River at South Heights, milepoint 15.2. Lines depicting the ORSANCO and applicable state standards are also presented on this diagram. A general decline in phenolics concentration at this station is observed from peak values in excess of 50 µg/l in 1976 to peak values of less than 15 µg/l during 1983 and 1984. A similar decline in mean phenolics concentration is also observed. Peak and mean quarterly cyanide concentrations also decrease during the study period, with more frequent violations of both the ORSANCO and Ohio total cyanide standards occurring prior to 1981. It is difficult to ascertain the number of violations of the Pennsylvania and West Virginia standard of 5 µg/l of free cyanide because total cyanide (not free cyanide) is routinely monitored.

The monitoring data provides a uniform basis of comparison of historical cyanide and phenolics concentrations. It also provides a nominal amount of spatial coverage which, if augmented with data from other sources, could be used to calibrate a water quality model.

3.1.2 Special Phenolics Survey

An intensive phenolics survey was performed on the Ohio River by ORSANCO in February 1983. Water quality data were collected at approximately 25 stations in the Ohio River and its tributaries from milepoint 0.0 to milepoint 102.4 during a 3-day period. Phenolics data were obtained laterally (left, center, right) and with depth at each Ohio River station. Flow and temperature measurements were made at several locations.

The 1983 intensive survey provided the most spatial definition of ambient phenolics concentrations and was, therefore, used extensively to develop the water quality model. Survey data also revealed lateral variations in phenolics concentration downstream of the J&L Aliquippa discharge; since this has implications regarding standards violations, the water quality model was structured to allow computation of lateral concentration variations as subsequently discussed.

3.1.3 State Data

An intensive phenolic sampling survey was undertaken by the State of West Virginia, Department of Water Resources on March 16, 1981. The survey encompassed the Ohio River from milepoint 42.6 to 315.7. The majority of the ambient stations were downstream of the present study area; however, data collected at the seven stations between milepoint 42.6 and 126.0 are in general agreement with the ORSANCO monitor data collected during the same period.

Phenolics are monitored on a daily basis at the Wheeling Water Treatment Plant. Data have been obtained by HydroQual for the 1980 to 1984 period. As seen on Figure 2-1, this site is fairly close to the ORSANCO monitoring station at Pike Island, and measurements at these two sites compare favorably in most instances. The Wheeling data provide some indication of the degree of daily variablilty in phenolics concentration in the Ohio River; in recent years, this variation is fairly small.

3.1.4 STORET Data

A search for cyanide and phenolics data in the study area vicinity, was conducted using EPA's STORET database. Several stations were identified as having one or more cyanide or phenolics measurement during the period of interest; however, these measurements did not provide enough spatial coverage at any given time to allow model calibration from these data alone.

Data were also obtained from several of the Ohio River tribuataries to determine if significant background or naturally occurring concentrations of phenolics or cyanide compounds exist.

3.2 PERMITTED WASTEWATER INPUTS

There are presently 16 permitted cyanide and 12 permitted phenolics discharges to the study area as presented in Table 3-1.

TABLE 3-1. PERMITTED CYANIDE AND PHENOLICS DISCHARGES TO THE OHIO RIVER
(Milepoint 0.0 to 126.4)

Discharger	Milepoint	Permitted Loads (lbs/day) Cyanide Mean	Cyanide Maximum	Phenolics Mean	Phenolics Maximum
Pennsylvania					
Neville Chemical Co.	6.6			2.9	5.8
Shenango, Inc.	8.0	23	46	7.5	15.4
Jones and Laughlin Steel (Aliquippa)	17.5	1.0[a]	2.0[a]	16	48
Valvoline Oil Co. (Ashland Oil)	24.0			0.8	1.5
West Virginia					
Quaker State	45.2			1.1	2.3
Weirton Steel	62.2	85	220	48.3	142.4
Wheeling-Pittsburgh Steel (East Steubenville Coke)	68.8	41	73	7.8	23.4
Koppers Co.	69.3	1.8	3.5	6.3	12.3
Triangle PWC, Inc.	101.4	.14	.18		
Olin Corporation	105.0	2.3	3.1	6.9	22.8
LPC Chemical	105.2	-	0.2[b]		
Liquified Coal Development Company	113.0	-	0.2[b]	0.5[b]	1.0[b]
Mobay Chemical	119.0			5.4	10.9
Ohio					
East Liverpool WWTP	40.2			0.1	0.1
Wheeling-Pittsburgh Steel (Steubenville North)	68.7	5.9[c]	12[c]	15.0[c]	45.0[c]
Wheeling-Pittsburgh Steel (Steubenville South)	71.0	7.7[c]	15[c]	21.7[c]	65.1[c]
Wheeling-Pittsburgh Steel (Yorkville)	83.7			10.0[c]	30.0[c]
Consolidated Aluminum	124.0	0.4	0.8		
		172.24	383.58	149.8	425.0

[a]Free cyanide
[b]Effluent concentration in mg/l
[c]Draft permit values

In general, facilities report cyanide or phenolics discharges on a biweekly or monthly basis to the appropriate state agency or, in some cases, to EPA. The quantity of data available from each discharger varies according to the requirements and record retention habits of the permitting agency. Raw data or monthly mean data are available for many facilities; however, discharge records for several facilities are incomplete for the 1976 to 1984 period of interest.

3.2.1 Pennsylvania Sources

There are five permitted phenolics dischargers and two permitted cyanide dischargers to the study area from Pennsylvania. Mean monthly discharge data were available from November 1980 through March 1983 for J&L Aliquippa, U.S. Steel, and Neville Chemical. These data were obtained from the Pennsylvania Department of Environmental Resources (DER). No data were available for Shenango Inc. or Valvoline Oil. Discharge data prior to Novemeber 1980 are not readily available from this agency.

J&L Aliquippa and Valvoline Oil provided mean and maximum monthly discharge data for model calibration periods which were subsequently selected. Few data were identified for Shenango Coke and Iron for the study period.

3.2.2 Ohio Sources

Raw data records were available for the permitted Ohio dischargers from the Ohio EPA computer database. The discharge records for the Wheeling-Pittsburgh Steel facilities are fairly complete, although there are several periods for which data exceptions were noted in the database. Few data exist for the East Liverpool Wastewater Treatment Plant during the study period.

3.2.3 West Virginia Sources

Mean and maximum monthly data for the seven permitted cyanide and phenolics dischargers in West Virginia were readily available from the West Virginia Department of Natural Resources (DNR). Discharge records encompass the entire 1976 to 1984 period for almost all facilities, and some facilities sent additional information or confirmation of the state records for the calibration periods.

3.3 OTHER POTENTIAL INPUTS

Analysis of in-stream concentrations of cyanide and phenolics under present permit conditions requires the evaluation of all potential sources of these substances. Several other potential sources of cyanide and phenolics were evaluated using specific data where available and literature values to estimate those impacts for which data are unavailable. Both point and non-point sources were quantified.

3.3.1. Municipal Wastewater Treatment Plants

The presence of significant concentrations of cyanide and phenolics in a municipal treatment facility can arise from industrial discharges to sewer system and from urban runoff captured in a combined sewer system. The study area contains 39 municipal treatment facilities which do not have assigned effluent limits for cyanide or phenolics. These facilities, which are presented in Table 3-2, discharge approximately 260 million gallons per day (mgd) of wastewater to the Ohio River. The ALCOSAN Wastewater Treatment Plant, which discharges 200 mgd of wastewater, is the largest municipal facility in the study area. With the exception of the Wheeling Wastewater Treatment Plant (15 mgd), the rest of the municipal treatment facilities have discharges of approximately 5 mgd or less and are distributed in a fairly uniform manner along the river.

Most of these facilities do not routinely report effluent cyanide and phenolics concentrations; however, the ALCOSAN facility monitors these substances on a daily basis. Data are presently available for ALCOSAN from November 1980 through December 1983. Nationwide average literature values were used to estimate the impact of the remaining effluents.

3.3.2. Industrial Sources

There are presently 24 industrial dischargers to the Ohio River which are not required to monitor effluent cyanide and phenolics concentrations. These

TABLE 3-2. MUNICIPAL DISCHARGERS TO THE OHIO RIVER
(Milepoint 0.0 to 126.4)

Facility	River Mile	Q (mgd)
Alcosan	3.1	200.0
Coraopolis	10.2	2.3
Sewickley	11.8	1.4
Leetsdale	13.9	0.8
Crescent Heights	15.8	0.4
Ambridge	15.9	2.6
Hopewell	17.0	0.1
Aliquippa	20.0	3.4
Baden	20.3	0.5
Conway	21.6	0.5
Rochester	25.0	1.4
Monaca	25.4	1.2
Beaver	26.5	0.8
Vanport	28.0	1.6
Midland	37.3	1.3
Chester	43.3	0.5
East Liverpool	44.6	3.5
Newell	45.0	0.4
Wellsville	47.6	1.0
Stratton	55.0	0.1
New Cumberland	56.7	0.3
Toronto	59.1	1.0
Weirton	63.0	4.0
Steubenville	68.0	6.0
Follansbee	70.6	0.5
Wellsburg	74.0	1.3
Brilliant	74.4	0.3
Beech Bottom	78.0	0.1
Rayland	81.6	0.1
Tiltonsville	83.1	0.3
Wheeling	86.8	15.0
Benwood	93.0	0.2
Belmont	94.0	5.7
McMechen	96.2	0.3
Shadyside	98.0	0.6
Glendale	99.4	0.3
Moundsville	101.9	2.0
Powhatan	109.8	0.2
Total		262.0

dischargers, presented in Table 3-3, have a combined effluent flow of approximately 40 mgd. Only one discharger (St. Joseph Minerals) has a discharge flow in excess of 10 mgd, and most of the industries have discharges of less than 1 mgd.

TABLE 3-3. INDUSTRIAL DISCHARGERS TO THE OHIO RIVER
(Milepoint 0.0 to 126.4)

Facility	River Mile	Flow (mgd)
Vulcan	7.7	0.9
Pitt Forging	10.8	1.1
Armco Steel	15.9	2.1
HH Rovertson	16.9	0.1
Ampco-Pitts	23.9	0.0
St. Joseph Minerals	28.5	11.7
Taylor, Smith & Taylor	42.2	0.3
Celotex	42.4	0.1
Ohio Brass	45.0	0.6
Homer Laughlin China	45.1	0.5
Toronto Paperboard	59.1	0.9
Air Products and Chem	62.4	0.1
Apex Oil Terminal	64.9	0.4
S. George Company	73.8	0.2
Wheeling-Pittsburgh Beech Bottom	74.7	0.6
Shoemaker Mine	93.8	0.1
Standard Oil	102.0	0.0
Alexander Mine	102.2	0.0
Columbia Carbon	103.5	0.0
Allied Chemicals	105.0	3.5
Ohio Ferro Alloys	110.5	0.0
North American Coal	110.8	1.0
Ormet Corporation	117.0	4.7
PPG - Natrium	119.7	6.0
Total		38.8

Limited cyanide and phenolics data were found in the STORET database for Saint Joseph Mining and Vulcan. Data for other industries were not identified.

3.3.3 Stormwater Sources

Nationwide studies of non-point source pollutants[1,2] have shown that significant concentrations of cyanide and phenolics exist in urban runoff. Potential sources of storm drain and combined sewer overflow discharges in the study area are presented in Table 3-4. Twenty cities were identified by ORSANCO personnel as having combined sewer systems. The drainage area served by these systems is approximately 68 square miles. Additionally, the drainage area associated with six cities containing separate sewer systems were included as shown in Table 3-4. These cities have a combined drainage area of 16 square miles.

Using an annual average rainfall of 38 inches, the average daily runoff expected from urban areas is approximately 80 cubic feet per second (cfs). Nationwide average cyanide and phenolics concentrations were used in this study to estimate urban stormwater runoff contributions.

3.3.4 Background (Incremental Drainage)

The final potential source of cyanide and phenolics inputs to the Ohio River is that associated with basinwide runoff. Phenolic compounds are known to occur naturally,[3] and a basinwide STORET retrieval was performed to identify possible water quality conditions in a relatively pristine environment. Background data are also available from a previous study of the Monongahela River.[4]

3.4 OTHER AVAILABLE DATA

Other additional data necessary for use with the water quality model are summarized as follows:

TABLE 3-4. SOURCES OF URBAN RUNOFF

City	State	Population	Drainage Area (square miles)
Combined Sewers			
Aliquippa	PA	17,094	4.6
Ambridge	PA	9,575	1.5
Avalon	PA	6,240	2.0
Bellaire	OH	8,241	2.6
Bellvue	PA	10,128	3.2
Benwood	WV	1,994	0.6
Bridgeport	OH	2,642	0.8
Chester	WV	3,297	1.0
Emsworth	PA	3,074	1.0
Leetsdale	PA	1,604	0.5
Martins Ferry	OH	9,331	2.7
McMekon	WV	2,402	0.8
Mingo Junction	OH	4,834	1.5
N. Cumberland	WV	1,752	0.6
Pittsburgh	PA	423,938	20.0[a]
Rochester	PA	4,759	3.0
Sewickley	PA	4,778	2.0
Steubenville	OH	26,400	3.8
Weirton (50%)	WV	24,736	5.6
Wheeling	WV	43,070	15.0
Total			68.2
Separate Sewers			
Beech Bottom	WV	507	0.5
East Liverpool	OH	16,687	3.3
Moundsville	WV	12,419	2.9
New Martinsville	OH	7,109	2.4
Powhaten Point	OH	7,109	2.4
Toronto	OH	6,934	2.3
Weirton (50%)	WV	24,736	5.6
Wellsburg	WV	3,963	1.1
Total			15.7

[a]Includes only that portion of Pittsburgh adjacent to the Ohio River

3.4.1 Ohio River Flow Data

Ohio River flow data are available for the 1976 to 1984 period of interest at the USGS Station at Sewickley, Ohio (gauge #03086000) and subsequent to 1980 at Martin's Ferry (gauge #03111534). Data are also available for the Allegheny River (#03016000) and the Mongahela River (#03085000) close to the confluence with the Ohio River; these flow records are necessary to establish the upstream boundary conditions.

The Beaver River can be a significant source of flow and chemical loads to the study area. Discharge records are available for this tributary at Beaver Falls (#03107500) for the period of interest.

3.4.2 Channel Geometry

Geometry data are available for the Ohio River in several levels of detail from the U.S. Army Corps of Engineers. Cross-sections are available throughout the study area at 0.2 mile intervals. These data were averaged subsequently at appropriate intervals to develop the water quality model segmentation. The cross-sectional areas range from approximately 15,000 to 50,000 square feet and the depths range from 10 to 35 feet with the greatest depths observed immediately upstream of each dam.

SECTION 4

ANALYSIS OF WASTEWATER INPUTS

Estimates of cyanide and phenolic substance loadings to the Ohio River study area during the period of interest were made for both point and non-point sources. The primary sources of these substances during the 1976 to 1984 period were permitted dischargers, the upstream boundaries, and the Beaver River. The ALCOSAN wastewater treatment facility, which is not a permitted discharger, was also observed to be a relatively substantial source of cyanide and phenolics.

Available data indicate that both cyanide and phenolics discharges to the Ohio River have decreased significantly since 1976, although there are periods in both 1980 and 1981 during which total loads are comparable to those of earlier years.

4.1 PERMITTED WASTEWATER INPUTS (1976 to 1983)

A substantial amount of cyanide and phenolics data is available for the permitted dischargers. Histograms depicting mean and maximum monthly cyanide and phenolics loads were prepared for each major permitted discharger. These figures are presented in Appendix 1. Figure 4-1 presents a representative example monthly histogram showing Weirton Steel phenolics loads for the 1976 to 1984 period. Maximum loads range from approximately 2800 pounds per day in 1976, to less than 50 pounds per day during much of the post-1980 period. Mean loads have a range of approximately 500 pounds per day in 1976 and 1977 to less than 20 pounds per day for most of the latter monthly periods. Generally, phenolics loadings prior to 1979 were in excess of the existing permit limits of 48 to 142 pounds per day, the mean and maximum values, respectively. There is a noticeable decrease in phenolics discharge from this source in recent years; this trend is observed for most of the major dischargers.

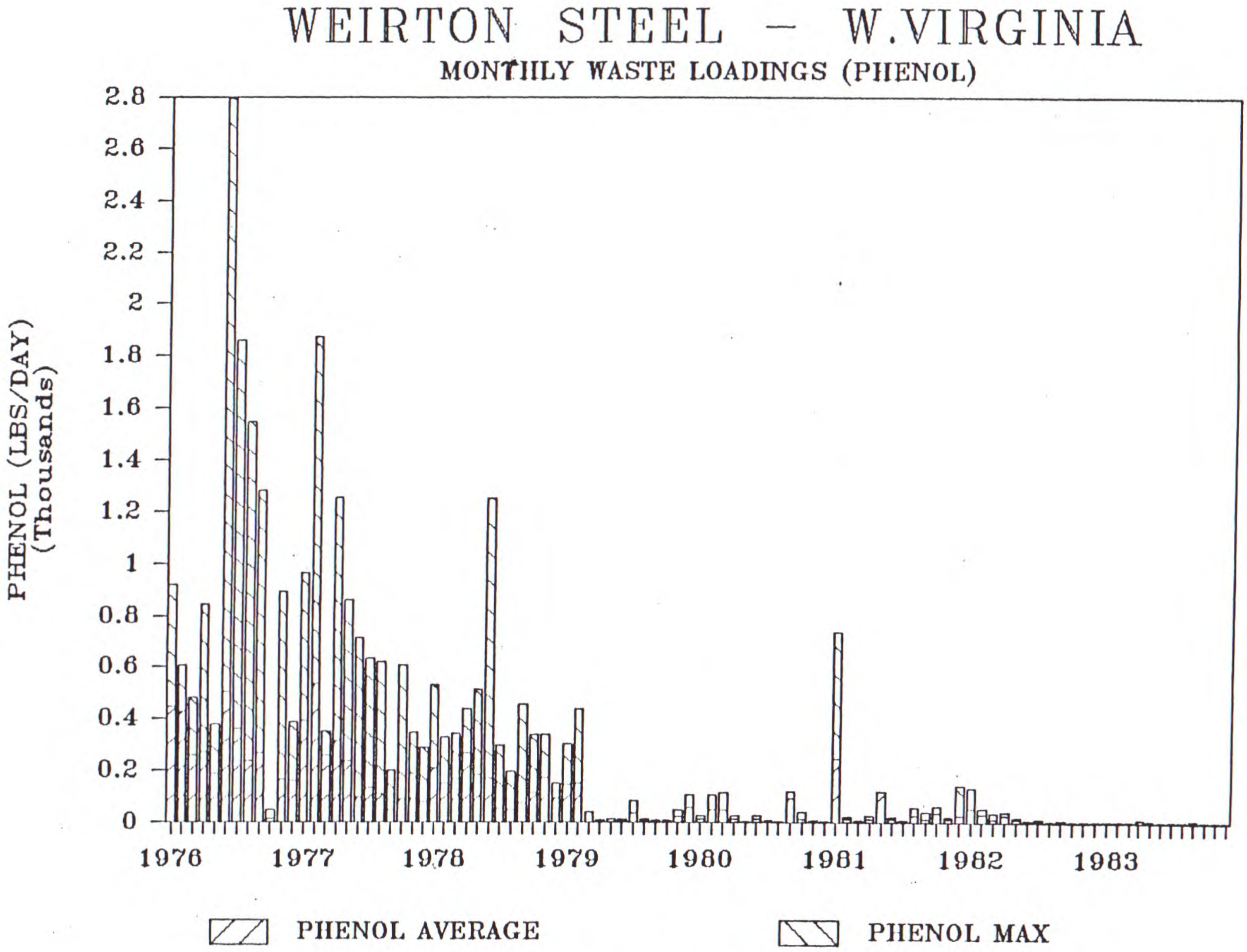


FIGURE 4-1. REPRESENTATIVE POINT SOURCE MONTHLY LOADING HISTOGRAM

Maximum monthly phenolics loads in excess of 1000 pounds per day have been reported for J & L Aliquippa, Shenango, Weirton Steel, and Wheeling-Pittsburgh Steel (West Virginia). Loads exceeding 100 pounds per day have been observed for Mobay Chemical, Olin, and Wheeling-Pittsburgh Steel (all Ohio dischargers).

Maximum monthly cyanide loads in excess of 1000 pounds per day have been reported for Wheeling-Pittsburgh Steel (Steubenville South), Weirton Steel, and Shenango. Cyanide discharges exceeding 100 pounds per day have been observed for Wheeling-Pittsburgh Steel (West Virginia).

Histograms depicting both mean and maximum annual cyanide and phenolics loads were also prepared for each permitted discharger. These figures are presented in Appendix 2.

4.2 TRIBUTARY INPUTS (1976 to 1983)

Monthly histograms of cyanide and phenolics loads from each of the major tributaries were created using the ORSANCO monitoring data. Mean and maximum monthly phenolics discharges for the Allegheny, Monongahela, and Beaver Rivers are presented on Figure 4-2. The Monongahela River has the greatest load in most instances, with mean monthly values in excess of 1000 pounds per day and maximum loads in excess of 2000 pounds per day on occasion. Phenolics loads from the Monongahela River show a marked decrease subsequent to 1981. The Beaver River exhibits occasional maximum and mean discharges in excess of 1000 pounds per day while the Allegheny River has a less significant impact than the other tributaries.

Mean and maximum cyanide discharges from these tributaries are shown in Figure 4-3. The Monongahela River is again the major load source in most intances, with peak concentrations often exceeding 5000 pounds per day prior to 1981. The Beaver River is sometimes a significant cyanide source, particularly so during the early months of 1981 when both mean and peak loads exceeding 10,000 pounds per day were observed. The Allegheny River does not exhibit high

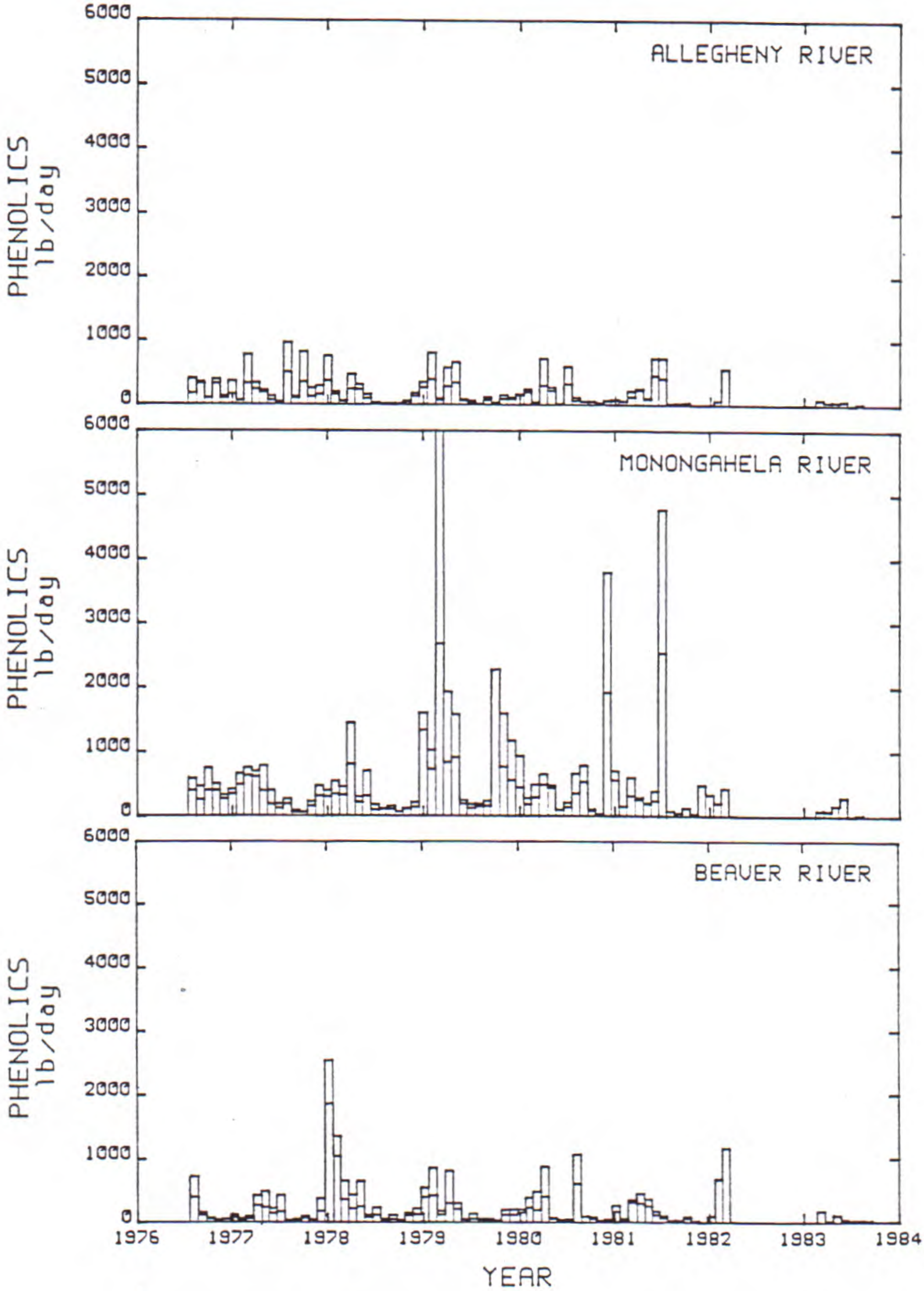


FIGURE 4-2. MONTHLY MAXIMUM AND MEAN TRIBUTARY PHENOLICS LOADS (1976-1983)

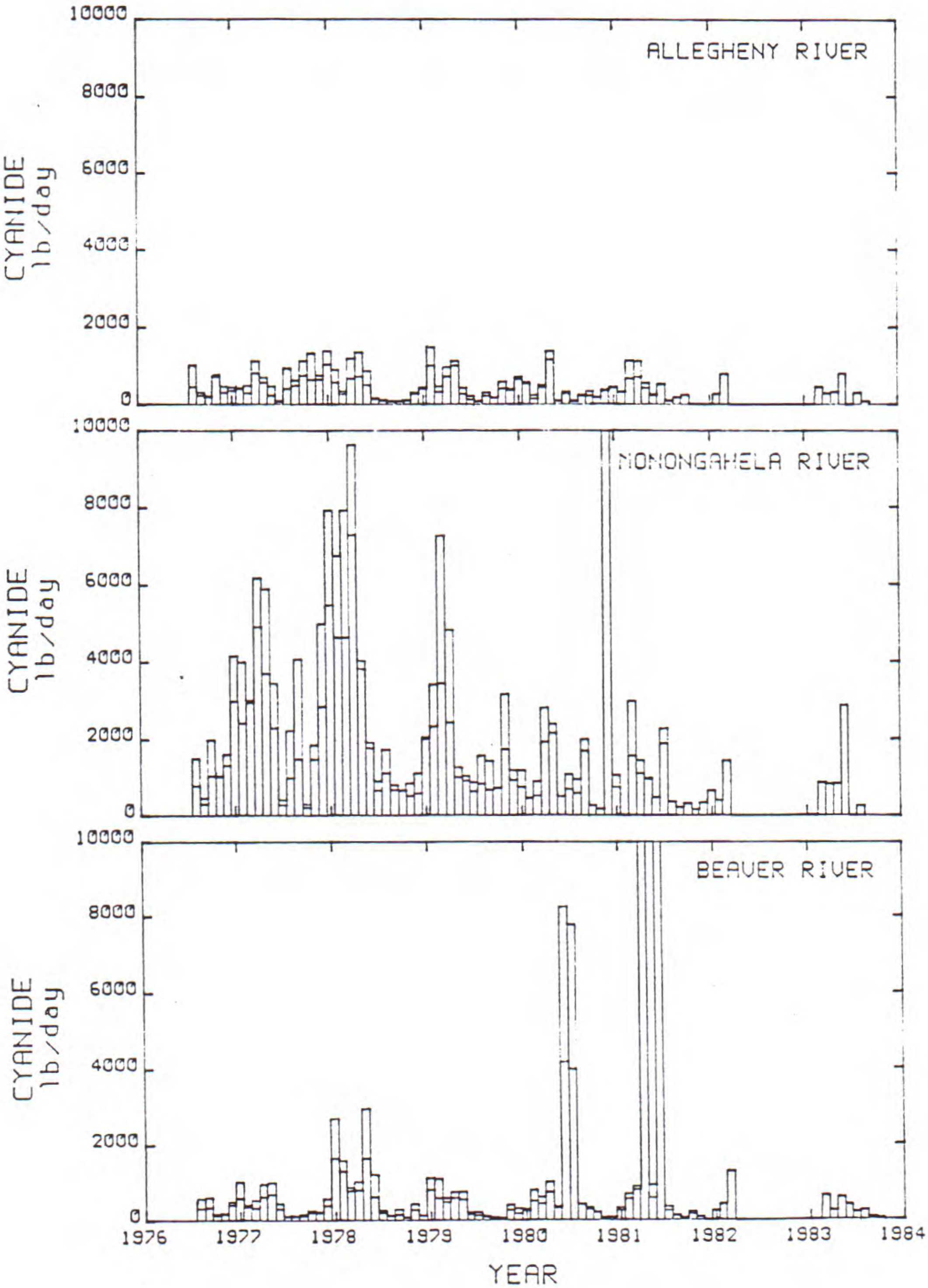


FIGURE 4-3. MONTHLY MAXIMUM AND MEAN TRIBUTARY CYANIDE LOADS (1976-1983)

peak or mean loads, but consistently discharges about 500 pounds per day to the study area on average. A trend toward lower cyanide loadings in the latter years is observed; however, the Monongahela River did exhibit a fairly high load of approximately 3000 pounds per day (based on 1 sample) during 1983.

4.3 UNPERMITTED WASTEWATER INPUTS

Additional sources of cyanide and phenolics are estimated from available literature data. These sources could become more significant relative to permitted discharges if the latter decrease in magnitude in the future.

4.3.1 Municipal

As discussed in Section 3, cyanide and phenolics data are available for the ALCOSAN wastewater treatment facility. ALCOSAN has periodically been a significant phenolics discharger, with mean monthly loads ranging from less than 10 pounds per day to approximately 200 pounds per day. Such loadings are on the order of values allocated to existing permittees. Daily maximum values of approximately 20 to 1500 pounds per day have also been observed. ALCOSAN is a less significant contributor of cyanide to the study area, with mean monthly loads ranging from appriximately 15 to 100 pounds per day and maximum loads ranging from 40 to 250 pounds per day.

The potential impact of the remaining municipal facilities within the study area is determined from available literature values. A nationwide USEPA survey of municipal facilities (5) showed that cyanide was present in 55.9 percent of all samples at concentrations ranging from 10 to 400 µg/l. Phenolics were detected in 26.7 percent of the samples at concentrations ranging from 1 to 35 µg/l. Excluding ALCOSAN, discussed previously, and East Liverpool, which is a permitted discharger, the remaining facilities discharge 59 mgd of treated effluent. Estimates of the potential impacts of these sources can be made by using the following equation:

$$W = Q * 8.34 * C / 1000 * P / 100 \tag{4-1}$$

where:

W = load (lb/day)

Q = wastewater flow (million gallons per day)

C = pollutant concentration (µg/l)

P = percent of samples in which pollutant was detected

The aggregate phenolic input from undocumented wastewater treamtment facilities is computed to be less than 4 pounds per day using the above equation while the cyanide input has a range of 3 to 106 pounds per day.

4.3.2 Industrial

The quantification of unpermitted industrial sources is extremely difficult do to the variety of industrial discharges in the study area and the lack of data associated with these discharges. A procedure which may be used to place some perspective on this potential source is to estimate the potential loading using an assumed reasonable effluent concentration for cyanide and phenolics and measured wastewater flow values. For effluent cyanide and phenolics concentration of 150 µg/l and a total combined waste flow of 38.8 mgd, the mass loading of each substance is on the order of 50 pounds per day. This loading is still much smaller than either the permitted industrial discharges or the tributary loads.

4.3.3 Stormwater (CSO and Urban Runoff)

The municipalities adjoining the study area have a CSO drainage area of 68.2 square miles. Using an annual rainfall of 38 inches and a runoff coefficient of 0.4, the average annual CSO flow is 76 cfs. Using the USEPA nationwide median cyanide concentration of 146 µg/l, a CSO load of approximately 60 pounds per day to the study area would occur. Similarly, the nationwide median phenolics concentration of 3 µg/l would result in an average runoff load of approximately 1 pound per day.

An additional urban runoff area of 19.0 square miles is associated with separate sewer systems; this drainage area is estimated to produce an annual average runoff flow of 21 cfs. Using USEPA nationwide estimates, a median cyanide concentration of 84 µg/l would result in a 7 pound per day load and a median phenolics concentration of 3 to 5 µg/l would result in an annual average load of less 1 one pound per day.

Both of these sources appear insignificant on an annual basis; however, they could have more important impacts during storm events. However, it is likely that these impacts would be attenuated by the increased river flow.

4.3.4 Background Inputs

The non-urban drainage area adjacent to the study area is roughly in the order of 10,000 square miles. This area would include areas draining into tributaries which in turn discharge into the study area. A runoff coefficient of 0.2 would result in an annual average runoff of approximately 5600 cfs. Background concentrations of cyanide and phenolics appear to be on the order of 3 µg/l. The resultant cyanide and phenolics loads are 90 pounds per day on an annual average basis. These loads would be expected to be greater during storm events.

4.4 DISCUSSION

The preceding information reveals that the permitted discharges and the tributary inputs constitute the majority of the cyanide and phenolics loads to the study area during the 1976 to 1983 period. The ALCOSAN municipal wastewater treatment facility produced significant phenolics inputs as well. Other municipal and industrial sources appear to be of lesser significance during this period.

The impact of the non-point source loads is of lesser significance during most of this period due to the distributed nature of these loads. While significant concentrations of cyanide and phenolics exist in CSO and urban runoff, the aggregate flow from the towns adjacent to the study area is not large enough to cause impacts such as those associated with the major point sources. The relatively low background concentrations result in similarly low average annual loading rates.

The relative importance of the unpermitted dischargers and the non-point source loads could assume greater significance in the future if control strategies or other circumstances bring permitted discharges and tributary loads (presumably from other permitted discharges) to lower magnitudes of pollutant discharge. Better quantification of non-point sources is necessary before final evaluations can be made on the potential significance of these inputs. It appears, however, that unpermitted discharges and non-point source loads were a relatively minor fraction of total cyanide and phenolics loadings to the study area during those critical periods when water quality problems were encountered.

SECTION 5.0

APPLICATION OF THE WATER QUALITY MODEL

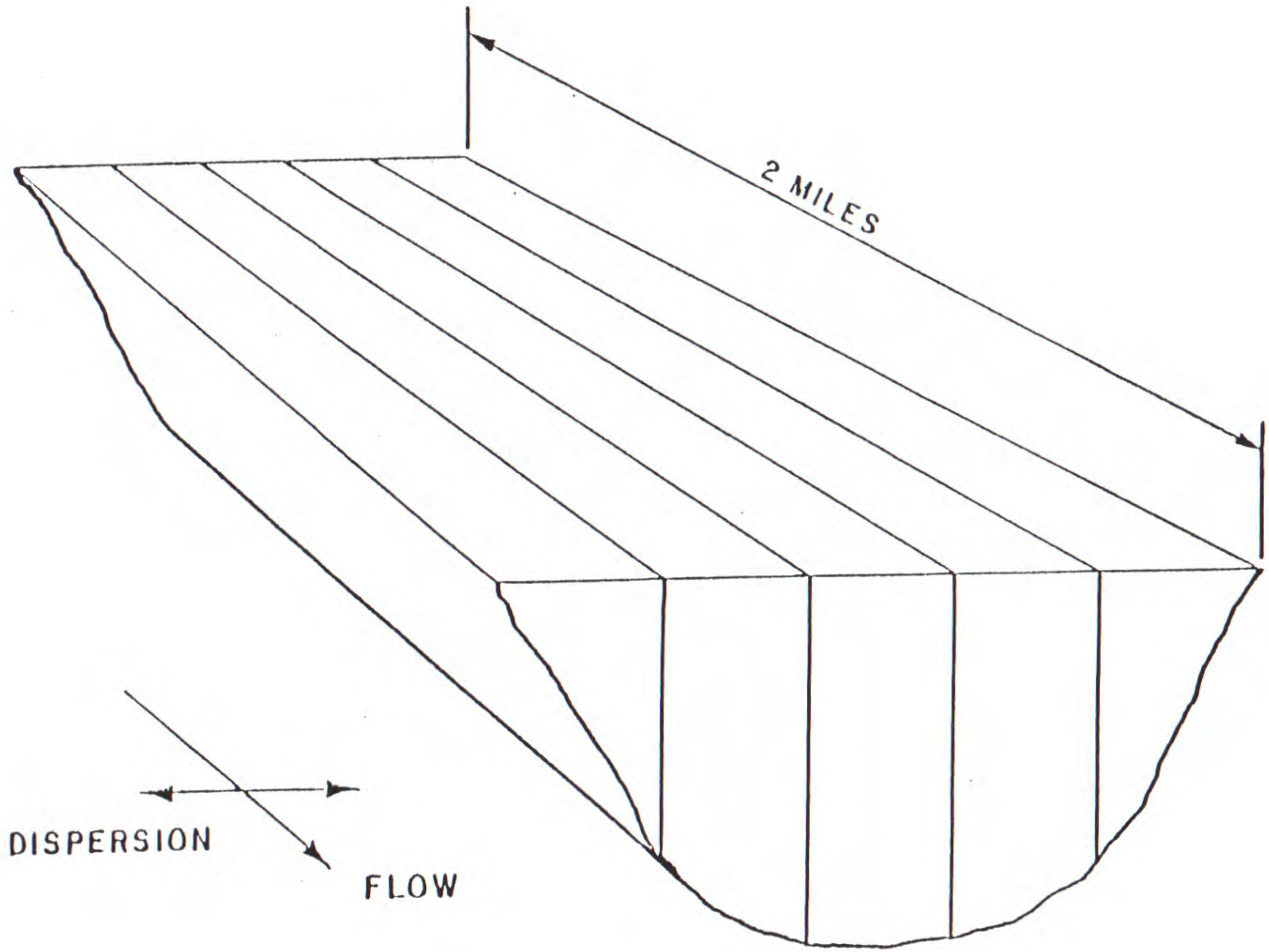
A mathematical water quality model of the upper Ohio River was constructed using the data discussed in Section 3.0. A two-dimensional, steady-state modeling framework was used to compute ambient cyanide and phenolics conditions using first order kinetics. The model is capable of depicting lateral variations in water quality associated with incomplete mixing.

The water quality model selected to meet the above requirements is SPAM, which was developed by Hydroscience, Inc. and enhanced by HydroQual, Inc. A discussion of this model is presented in Appendix 3.

5.1 MODEL SEGMENTATION

The water quality model is comprised of 315 segments encompassing the first 126 miles of the Ohio River from its inception at Pittsburgh to the Hannibal Locks and Dam. The model is divided into 63 longitudinal segments each of length two miles and is divided into 5 lateral segments throughout the study area as illustrated on Figure 5-1. The choice of segmentation reflects a compromise between model execution speed and provision for spatial detail should data availability improve in the future.

The physical characteristics of each model segment are presented on Figure 5-2 and tabulated in Appendix 4. The cross-sectional areas and depths depicted on this figure were computed by averaging the U.S. Army Corps of Engineers data over the length of the segment. Model cross-sectional areas range from approximately 15,000 to 50,000 square feet. Model depths range from approximately 10 to 35 feet. As expected, cross-sectional areas and depths are greatest immediately upstream of the six lock and dam systems.



Illustrative Model Segment

FIGURE 5-1. SCHEMATIC SEGMENT OF THE UPPER OHIO RIVER MODEL

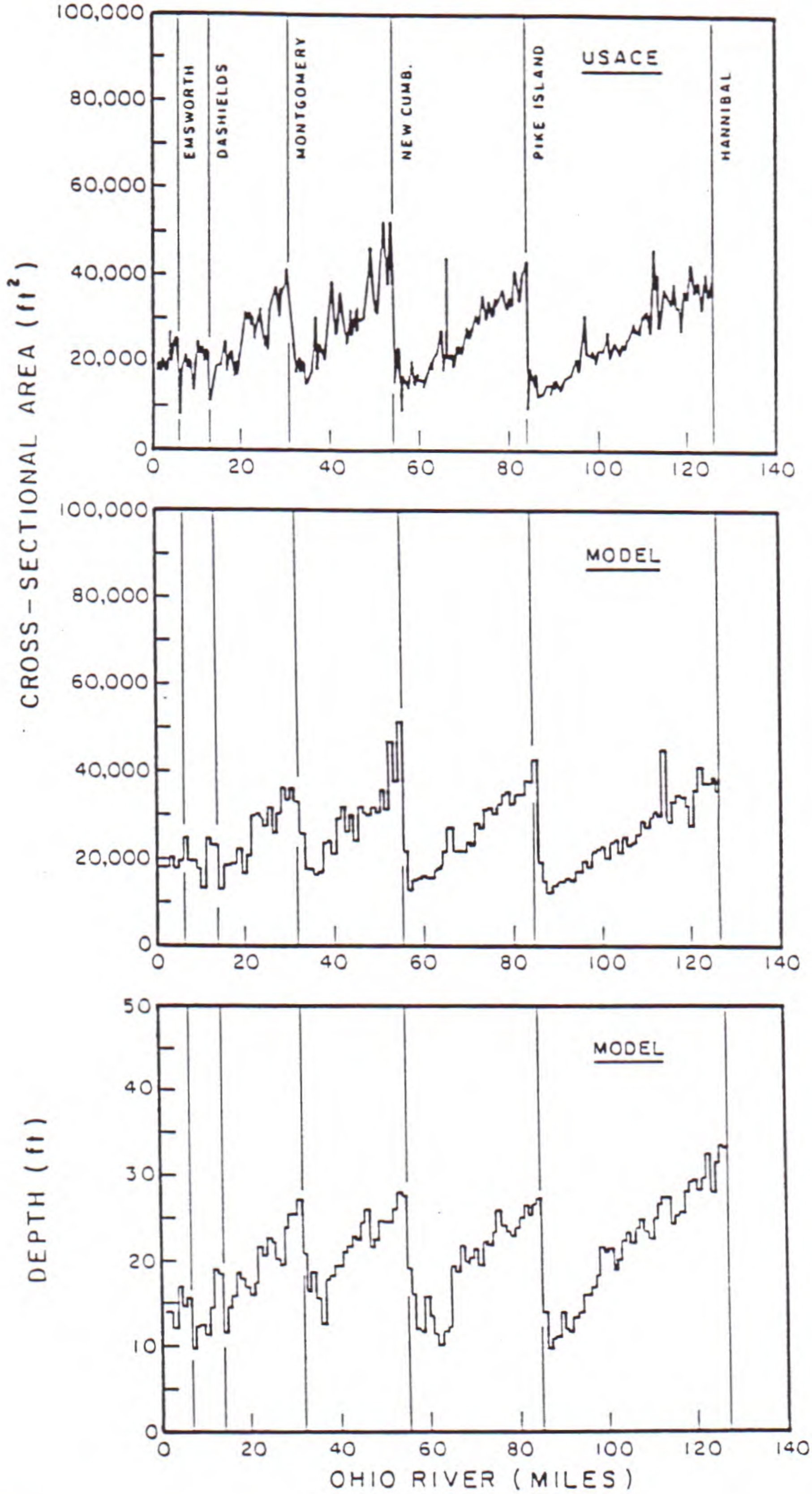


FIGURE 5-2. PHYSICAL CHARACTERISTICS OF THE UPPER OHIO RIVER AND MODEL

5.2 MODEL TRANSPORT

Both advective and dispersive transport were incorporated in the model framework. Computed time-of-travel and literature comparisons of appropriate dispersion coefficient ranges indicate that the transport structure adequately depicts water movement through the study area.

5.2.1 Time-of-Travel

The mean time-of-travel through the study area was computed for the water quality model from advective flow and volume considerations. Figure 5-3 presents the resultant travel times at flows ranging from 10,000 to 100,000 cfs. The figure shows a fairly good agreement between computed values and those developed by ORSANCO. It should be noted that longitudinal dispersion could significantly decrease these detention times; at low flows, this is in accordance with the short-circuiting often observed in river systems.

5.2.2 Dispersion

The 1983 ORSANCO intensive survey data indicate a considerable degree of lateral water quality variation near the major dischargers. This could be a significant factor in determining whether cyanide or phenolics standards are being met. To address this issue, lateral dispersion coefficients were assigned based on the work of Bansal[(6)] on several rivers. A lateral dispersion coefficient of five square feet per second was assigned throughout the study area in accordance with the literature values and preliminary computations. Present study data are not sufficient to verify this coefficient.

Similarly, a longitudinal dispersion coefficient of one square mile per day was assigned in the model based on previous studies. Additional data would be required to verify this coefficient.

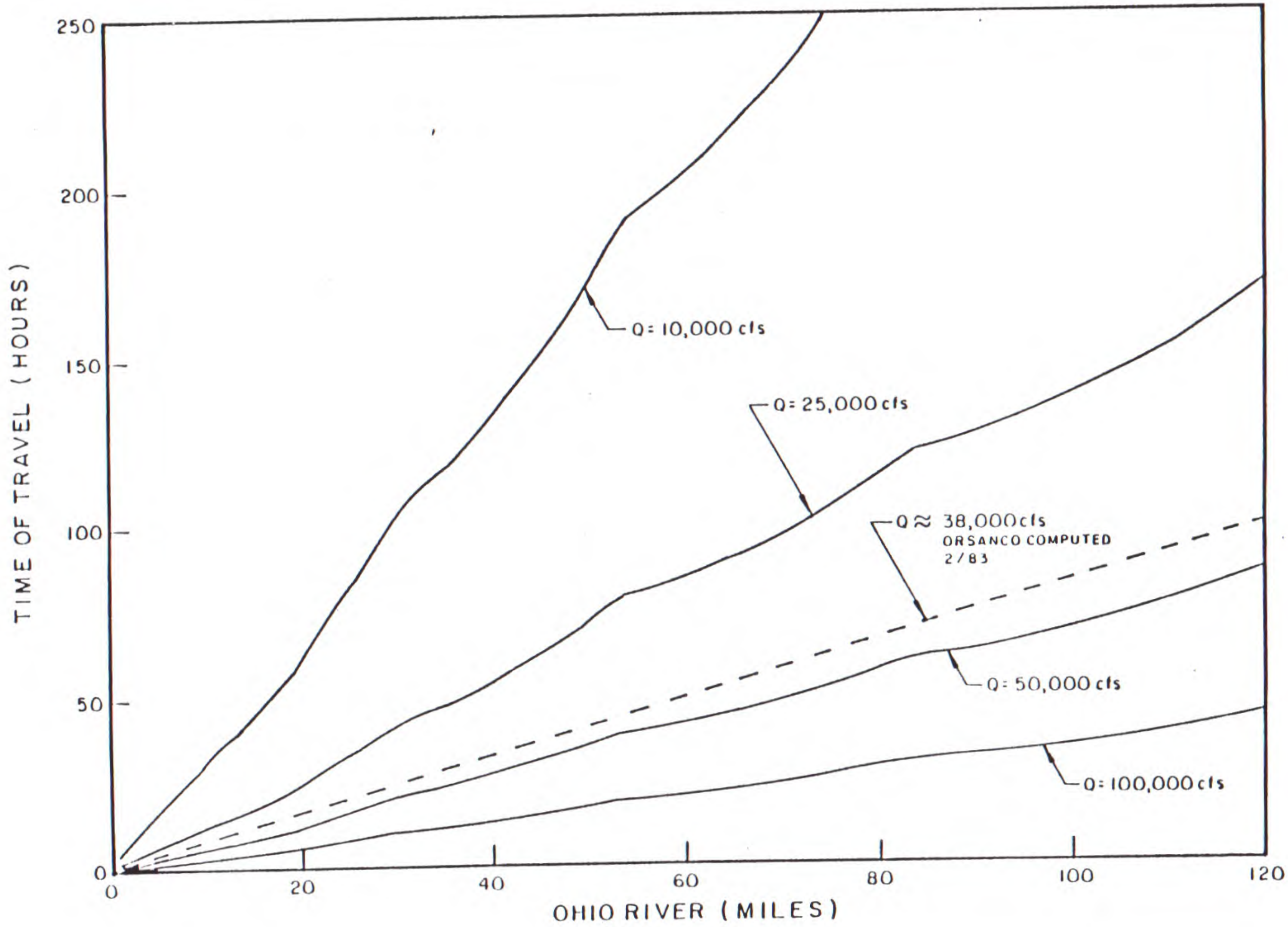
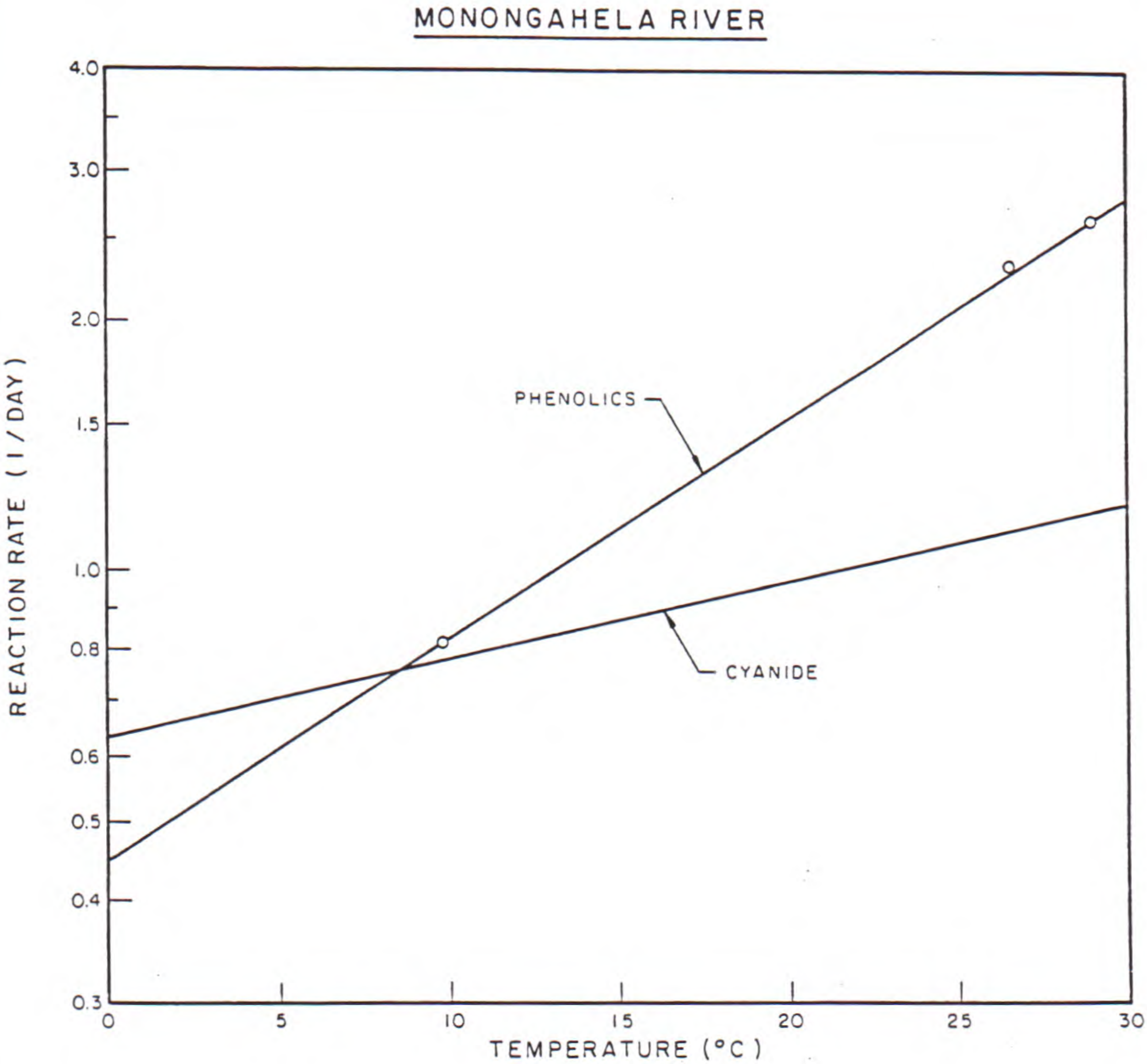


FIGURE 5-3. COMPUTED TIME-OF-TRAVEL IN THE UPPER OHIO RIVER

5.3 MODEL REACTION

Despite individual reactive pathways governing the fate of chemicals in natural waters systems, first-order reaction kinetics are often an adequate approximation of the overall removal rate of chemical compounds. This condition has been observed for cyanide and phenolics by Blumenschein,[4] in studies performed on the Monongahela River.

A temperature dependency was also noted for each substance as shown on Figure 5-4. The phenolics reaction rate is observed to decline sharply from 1.5/day at 20°C to about 0.45/day at 0°C. The cyanide reaction rate is somewhat less temperature-dependent, ranging from 1.0/day at 20°C to 0.65/day at 0°C.



REFERENCE: BLUMENSCHEIN, PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL RESOURCES (4)

FIGURE 5-4. CONSTITUENT REACTION RATES VERSUS TEMPERATURE

SECTION 6.0

ANALYSIS OF OHIO RIVER WATER QUALITY DATA

The water quality model discussed in Section 5.0 was used in conjunction with the known cyanide and phenolics sources to simulate ambient conditions. While this analysis is not rigorous due to a general lack of discharge data, the mathematical model compares favorably with observed data in most instances.

6.1 SELECTION OF PERIODS FOR ANALYSIS

The purpose of the modeling analysis is to quantify the degree to which recent reductions in in-stream concentrations of cyanide and phenolics are correlated to reductions in quantifiable discharge sources. ORSANCO monitor data were used to identify periods of interest. Since daily data are not available on a historical basis, an averaging interval of one month was selected for the analysis periods.

A total of 12 monthly periods were chosen from the available data base for model calibration. Periods were chosen to reflect a wide variety of physical and chemical conditions during periods for which discharge data are available. Ambient cyanide and phenolics data are routinely available only at the ORSANCO monitoring stations and the Wheeling Water Works intake during all periods with the exception of the February 1983 period. An intensive survey was performed by ORSANCO during this latter period, providing good spatial coverage of water quality conditions in the study area.

Physical conditions relating to the calibration periods are presented in Table 6-1. It is seen that the periods were chosen to provide a range of temperature and flow conditions, with average temperatures ranging from 1 to 26°C and monthly average flow at Sewickley ranging from 8700 to 47,800 cfs.

TABLE 6-1. PHYSICAL CONDITIONS FOR SELECTED SURVEY POINTS

Survey Period	Sewickley Flow (cfs)	Beaver Falls Flow (cfs)	Temperature (^{o}C)
February 1977	33700	4500	1
June 1977	8700	2300	24
November 1977	37800	4600	11
February 1978	23700	2800	1
February 1979	47800	5300	1
July 1979	11600	1500	25
February 1980	22200	2600	2
July 1980	22600	2400	26
January 1981	17900	2300	1
February 1983	37400	4800	2
June 1983	26100	2500	20

Cyanide and phenolics concentrations at the upstream boundary and from the Beaver River are presented in Table 6-2. Both mean and maximum monthly concentrations were used in the modeling analyses to assess the possible range of impacts from these load sources. The upstream boundary was assigned as a flow-weighted average of Allegheny and Monongahela river water quality conditions. A wide range of concentrations is observed for both compounds, with higher concentrations being more prevalent in the earlier years and the cold periods (when reaction rates are lower) and lower concentrations being more prevalent during the summer periods and more recent years.

Mean and maximum monthly phenolics and cyanide loads from known dischargers (both permitted and otherwise) are shown in Tables 6-3 and 6-4 respectively. In addition to the permitted discharges identified previously, Crucible Steel (which is presently inoperative) and the ALCOSAN wastewater treatment plant have significant discharges of these compounds.

The primary wastewater sources of phenolics shown in Table 6-3 are the steel mills at Aliquippa, Weirton, and Steubenville. It is observed that each of these facilities was capable of discharging several thousands of pounds of phenolics during the late 1970s and early 1980s; a curtailment of operations at many sites is apparent in 1983 and 1984.

TABLE 6-2. BOUNDARY CONDITIONS FOR SELECTED SURVEY PERIODS

	Cyanide ($\mu g/l$)		Phenols ($\mu g/l$)	
	Mean	Maximum	Mean	Maximum
Upstream				
February 1977	42	78	12	22
June 1977	16	23	8	11
November 1977	29	37	4	6
February 1978	60	72	6	9
February 1979	22	31	8	9
July 1979	32	68	5	7
February 1980	14	17	7	9
July 1980	10	10	5	7
January 1981	10	10	4	4
February 1983	16	16	2	2
June 1983	10	10	1	1
	Cyanide (lbs/day)		Phenols (lbs/day)	
	Mean	Maximum	Mean	Maximum
Beaver River				
February 1977	835	1192	170	191
June 1977	126	126	228	505
November 1977	418	502	192	401
February 1978	722	1082	252	355
February 1979	950	1142	247	285
July 1979	78	78	31	70
February 1980	607	1121	150	294
July 1980	133	133	280	346
January 1981	740	986	43	62
February 1983	229	229	69	69
June 1983	135	135	14	14

Similar trends are apparent in Table 6-4. Cyanide discharges from the major steel mills were the major source of point source loads in the 1977 to 1981 period, and discharges significantly decrease in many cases during 1983 and 1984.

TABLE 6-3. DOCUMENTED PHENOLICS DISCHARGED TO THE OHIO RIVER FOR SELECTED PERIODS

	February 1977		June 1977		November 1977		February 1978		February 1979		July 1979	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
J&L Aliquippa 001	199.0	394.0	116.0	153.0	105.0	215.0	142.0	217.0	395.0	740.0	-40.0	6.0
J&L Aliquippa 002	252.0	455.0	181.0	368.0	60.0	137.0	467.0	1529.0			458.0	658.0
J&L Aliquippa 003	1.0	3.0	6.0	26.0								
J&L Aliquippa 004	782.0	1095.0	480.0	834.0								
J&L Aliquippa 005			8.0	23.0								
J&L Aliquippa 018												
J&L Aliquippa 026											-56.0	5.0
J&L Aliquippa 102												
All Aliquippa	1234.0	1947.0	791.0	1404.0	165.0	352.0	609.0	1746.0	395.0	740.0	362.0	699.0
Neville							0.1	0.3	.15	.15	.24	.26
Shenango												
U.S. Steel												
Valvoline Oil	1.3	2.3	1.0	2.3	0.6	0.9	1.0	2.8	.2	.3	.2	.2
Quaker State	0.7	1.0	0.1	0.2	.0	0.1	0.1	0.3	0.1	0.3	0.1	0.1
Triangle PWC									N/A			
LCP Chemicals									N/A			
Olin					18.3	80.0	55.7	195.0	17.2	19.5	17.2	20.8
WPS-STB 001*			496.0	7170.0	12.2	122.0	755.0	1780.0	137.0	328.0	126.0	752.0
WPS-STB 201*	6.5	28.5	0.4	0.6	17.9	37.6	6.5	24.5	0.4	0.4	12.3	73.4
Weirton 001	0.2	0.3	0.4	1.3	0.3	1.0	5.8	67.4	11.3	74.2	0.2	0.3
Weirton 002	535.0	1830.0	94.7	716.0	92.5	348.0	147.0	3310.0	150.0	438.0	35.0	82.0
Weirton 102											0.1	0.1
Koppers	103.0	103.0	0.8	0.8	5.7	5.7	2.3	2.3	3.3	25.3	0.1	0.2
E. Liverpool												
Mobay	37.1	105.6	1.7	3.3	192.0	380.0	55.6	300.0	4.6	10.3	5.4	7.8
Crucible									6.8	9.9	27.1	99.9
WPS-SN601*	6.8	7.7	4.8	6.8	1.0	1.3	23.5	33.0	17.0	30.6	13.2	14.7
WPS-SN801*									15.8	65.0	3.6	5.9
WPS-SS004*	38.9	58.0	13.1	25.3	0.8	1.3	29.8	124.0	12.1	14.4	34.9	106.0
WPS-SS601*												
WPS-SS801*					AH	AH	AH	AH	10.7	17.0	11.0	18.0
WPS-YK002*	9.6	22.0	14.7	17.6					0.3	0.3	0.2	0.4
WPS-YK601*									2.4	3.7	26.7	49.7
WPS-YK801*	AH	AH	AH	AH	AH	AH	AH	AH	0.3	0.6	0.3	0.9
Alcosan	160	1470	15.7	54.7	8.3	21.1	9.4	52.2	6.7	18.0	8.7	41.3
Total	1973.0	4105.4	1418.7	9348.3	506.4	1329.9	1691.4	7585.5	784.3	1777.5	675.4	1901.2

*Wheeling-Pittsburgh Steel

TABLE 6-3. DOCUMENTED PHENOLICS DISCHARGED TO THE OHIO RIVER FOR SELECTED PERIODS (continued)

	February 1980		July 1980		January 1981		February 1983		June 1983		February 1984	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
J&L Aliquippa 001	-18.0	-4.0	-12.0	2.0	2.0	13.0	7.0	9.0	0.0	1.0	1.0	1.0
J&L Aliquippa 002	-29.0	45.0	-33.0	15.0								
J&L Aliquippa 003	20.0	33.0										
J&L Aliquippa 004	1501.0	3191.0	1469.0	3471.0	739.0	1715.0	915.0	1711.0	609.0	1394.0	6.0	9.0
J&L Aliquippa 005												
J&L Aliquippa 018			4.0	4.0			2.0	2.0				
J&L Aliquippa 026											2.0	2.0
J&L Aliquippa 102								0.0	0.0	0.0	3.0	18.0
All Aliquippa	1474.0	3265.0	1428.0	3492.0	741.0	1728.0	924.0	1722.0	609.0	1395.0	12.0	30.0
Neville	.19	.26	.06	.08	.1	.1	.34	.82	3.8	11.1	1.0	2.0
Shenango					233.0	624.0						
U.S. Steel	11.4	18.9	1.0	2.1	3.1	6.7						
Valvoline Oil	.8	1.5	0.2	0.5	0.4	1.3	0.3	0.6	0.7	3.2	0.3	0.4
Quaker State	0.1	0.1	0.1	0.1	0.1	0.4	.0	.0	.0	0.2	.0	0.1
Triangle PWC					0.2		0.2	<0.2	0.1	0.2	0.2	0.2
LCP Chemicals												
Olin	12.0	22.3	8.1	11.4	1.7	2.8	13.4	23.0	1.3	2.8	34.5	60.4
WPS-STB 001*	224.0	509.0	259.0	1260.0	58.0	98.7	11.3	15.7	7.0	20.8	23.0	51.5
WPS-STB 201*	13.7	19.5	5.1	53.6	0.4	1.6	0.8	2.7	0.4	0.6	0.4	0.6
Weirton 001	1.3	6.7	0.9	2.6	463.0	1330.0	0.0	0.0	0.0	0.0	0.0	0.0
Weirton 002	47.0	105.0	4.7	8.2	245.0	875.0	32.0	74.0	23.0	44.0	12.0	22.0
Weirton 102	0.1	0.1	0.1	0.3	0.3	0.4	0.0	0.1	0.2	0.7	0.9	1.8
Koppers	1.4	4.9	0.2	0.5	1.1	3.7	0.2	1.7	0.2	0.7	0.2	0.3
E. Liverpool												
Mobay	5.4	10.1	5.2	7.3	7.2	9.5	5.1	7.4	3.6	5.0	2.9	4.6
Crucible	30.6	113	9.5	29.6	11.4	18.1						
WPS-SN601*	91.1	159.0	0.0	0.0								
WPS-SN801*	3.5	5.0	3.0	3.0			AH	AH	AH	AH		
WPS-SS004*	18.3	23.2	8.2	17.3								
WPS-SS601*							0.0	0.0	0.0	0.1		
WPS-SS801*	6.3	6.3	22.8	38.4			AH	AH	AH	AH		
WPS-YK002*	0.5	1.4	3.1	5.7			0.2	0.5	0.0	0.0		
WPS-YK601*	9.7	15.9	61.5	198.0			6.2	8.1	18.6	59.2		
WPS-YK801*	0.4	0.7	0.5	1.0			0.2	0.2	0.2	0.4		
Alcosan	8.4	27.8	7.9	69.5	20.3	58.2	15.1	43.5	25.6	221	16.9	32.5
Total	1908.8	4154.2	1810.5	5099.4	1751.0	4674.1	993.6	1855.4	663.7	1529.5	86.1	171.3

*Wheeling-Pittsburgh Steel

TABLE 6-4. DOCUMENTED CYANIDES DISCHARGED TO THE OHIO RIVER FOR SELECTED PERIODS

	February 1977		June 1977		November 1977		February 1978		February 1979		July 1979	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
J&L Aliquippa 001	57.0	59.0	37.0	59.0	21.0	45.0	61.0	76.0	68.0	142.0	1.0	2.0
J&L Aliquippa 002	447.0	591.0	77.0	165.0								
J&L Aliquippa 003	9.0	16.0	40.0	107.0								
J&L Aliquippa 004	375.0	743.0	8.0	14.0								
J&L Aliquippa 005			0.0	0.0								
J&L Aliquippa 018												
J&L Aliquippa 026												
J&L Aliquippa 102					97.0	118.0	164.0	228.0	22.0	68.0	3.0	6.0
All Aliquippa	888.0	1409.0	162.0	345.0	118.0	163.0	225.0	304.0	90.0	210.0	4.0	8.0
Neville				N/A								
Shenango												
U.S. Steel												
Valvoline Oil												
Quaker State				N/A								
Triangle PWC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
LCP Chemicals	3.4	3.4	2.0	2.0	1.1	1.1	3.1	3.1	0.5	0.5	0.2	0.2
Olin				N/A								
WPS-STB 001*												
WPS-STB 201*					5.2	9.5	2.3	6.0	7.4	19.7	23.9	31.4
Weirton 001	27.0	59.0	16.5	29.0	39.0	82.0	11.0	18.0	102.0	586.0	25.0	41.0
Weirton 002	1040.0	1390.0	289.0	559.0	352.0	595.0	379.0	639.0	324.0	513.0	58.0	58.0
Weirton 102											2.0	3.6
Koppers	0.6	0.6	0.6	0.6	1.1	1.1	1.5	1.5	1.0	1.2	0.4	0.7
E. Liverpool												
Mobay				N/A								
Crucible									2.9	4.5	8.1	11.4
WPS-SN601*	295.0	374.0	43.5	71.0	85.3	165.0	5.0	5.5	AA	AA	239.0	358.0
WPS-SN801*									AH	AH	AH	AH
WPS-SS004*	188.0	263.0	103.0	185.0	306.0	737.0	49.1	72.4	AA	AA	176.0	343.0
WPS-SS601*												
WPS-SS801*			AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
WPS-YK002*	ND											
WPS-YK601*	ND											
WPS-YK801*	ND											
Alcosan	52.7	136	35.6	68.9	35.8	143	90.6	246	33.8	1.8	36.4	62.2
Total	2442.1	3499.1	616.7	1191.7	907.8	1753.8	676.1	1049.6	527.9	1335.0	536.6	855.3

*Wheeling-Pittsburgh Steel

TABLE 6-4. DOCUMENTED CYANIDES DISCHARGED TO THE OHIO RIVER FOR SELECTED PERIODS (continued)

	February 1980		July 1980		January 1981		February 1983		June 1983		February 1984	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
J&L Aliquippa 001	0.0	0.0	0.0	6.0	0.0	2.0	0.0	3.0	0.0	1.0	0.0	1.0
J&L Aliquippa 002	0.0	0.0					22.0	36.0	5.0	5.0	23.0	25.0
J&L Aliquippa 003	43.0	74.0										
J&L Aliquippa 004	46.0	123.0	46.0	174.0	24.0	44.0	16.0	32.0	7.0	17.0	1.0	2.0
J&L Aliquippa 005												
J&L Aliquippa 018			12.0	12.0			1.0	1.0	2.0	3.0	1.0	2.0
J&L Aliquippa 026												
J&L Aliquippa 102	24.0	54.0	8.0	30.0	50.0	106.0	0.0	0.0	0.0	0.0		
All Aliquippa	113.0	251.0	66.0	222.0	74.0	152.0	39.0	72.0	14.0	26.0	25.0	30.0
Neville												
Shenango					92.6	165.0						
U.S. Steel	2.8	4.9	9.4	27.2	8.0	16.0						
Valvoline Oil												
Quaker State												
Triangle PWC	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
LCP Chemicals	0.4	0.4	0.5	0.5	0.9	0.9	0.5	0.5	0.3	0.3	0.4	0.4
Olin												
WPS-STB 001*					37.0	50.0	1.1	1.1	18.0	23.0	24.0	43.0
WPS-STB 201*	53.7	89.4	39.0	45.0	14.0	46.0	32.0	58.0	14.0	16.0	16.0	32.0
Weirton 001	82.0	148.0	117.0	394.0	43.0	53.0	0.0	0.0	0.2	0.4	0.0	0.0
Weirton 002	152.0	152.0	35.0	35.0	385.0	385.0	32.0	74.0	23.0	44.0	322.0	540.0
Weirton 102	2.2	3.1	1.1	2.0	33.0	84.0	14.0	47.0	13.0	21.0	66.0	75.0
Koppers	1.0	1.5	0.8	1.3	1.1	1.5	0.6	1.0	0.3	0.6	0.3	0.6
E. Liverpool												
Mobay												
Crucible	8.0	21.8	7.5	30.5	2.8	7.5						
WPS-SN601*	181.0	260.0	0.0	0.0								
WPS-SN801*	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
WPS-SS004*	AH	AH	AH	AH			AH	AH	55.7	155.0		
WPS-SS601*							0.0	0.0	5.1	11.6		
WPS-SS801*	AH	AH	AH	AH			AH	AH	AH	AH		
WPS-YK002*												
WPS-YK601*												
WPS-YK801*												
Alcosan	26.7	104	14.3	36.0		NO DATA						
Total	585.3	905.4	259.4	699.8	680.6	937.4	119.3	253.7	143.7	298.0	453.8	721.1

*Wheeling-Pittsburgh Steel

The differences in physical and chemical conditions depicted in the preceding tables, when combined with highly variable discharges, result in a wide range of cyanide and phenolics concentrations in the study. The chosen surveys typify the wide range of water quality conditions.

6.2 SPECIAL PHENOLICS SURVEY (FEBRUARY 1983)

The special phenolics survey was of primary interest in calibrating the water quality model. The survey provides a fairly extensive phenolics database including measurements of lateral concentration variations at several stations. These lateral measurements provide information on the degree to which the Ohio River is mixed across the channel; this is important in determining the local impacts of a point source discharge.

It is observed from Table 6-1 that the temperature for this survey was approximately $2^{o}C$ throughout the study area and the Ohio River flow was 37,400 cfs at Sewickley. Boundary loads of phenolics were very low during this period, with both upstream and Beaver River boundaries having phenolics concentrations at the lower end of detectable limits. The primary source of phenolics during this period is apparently J&L Aliquippa, which produces over 90 percent of the known wastewater load during this period for both mean and maximum observed load conditions.

The results of the modeling analysis are presented in Figure 6-1. As discussed previously, the data reveal lateral variations in phenolics concentration downstream of the Aliquippa discharge. This variation persists for almost 10 miles, and the laterally-averaged concentrations are seen to decrease quickly due to the relatively high reaction rate (0.48/day) that exists even at this low temperature.

The top panel on Figure 6-1 shows results from the laterally-stratified model. Five spatial profiles are shown, one for each of the five lateral segments comprising the model. The peak concentration in the southern river

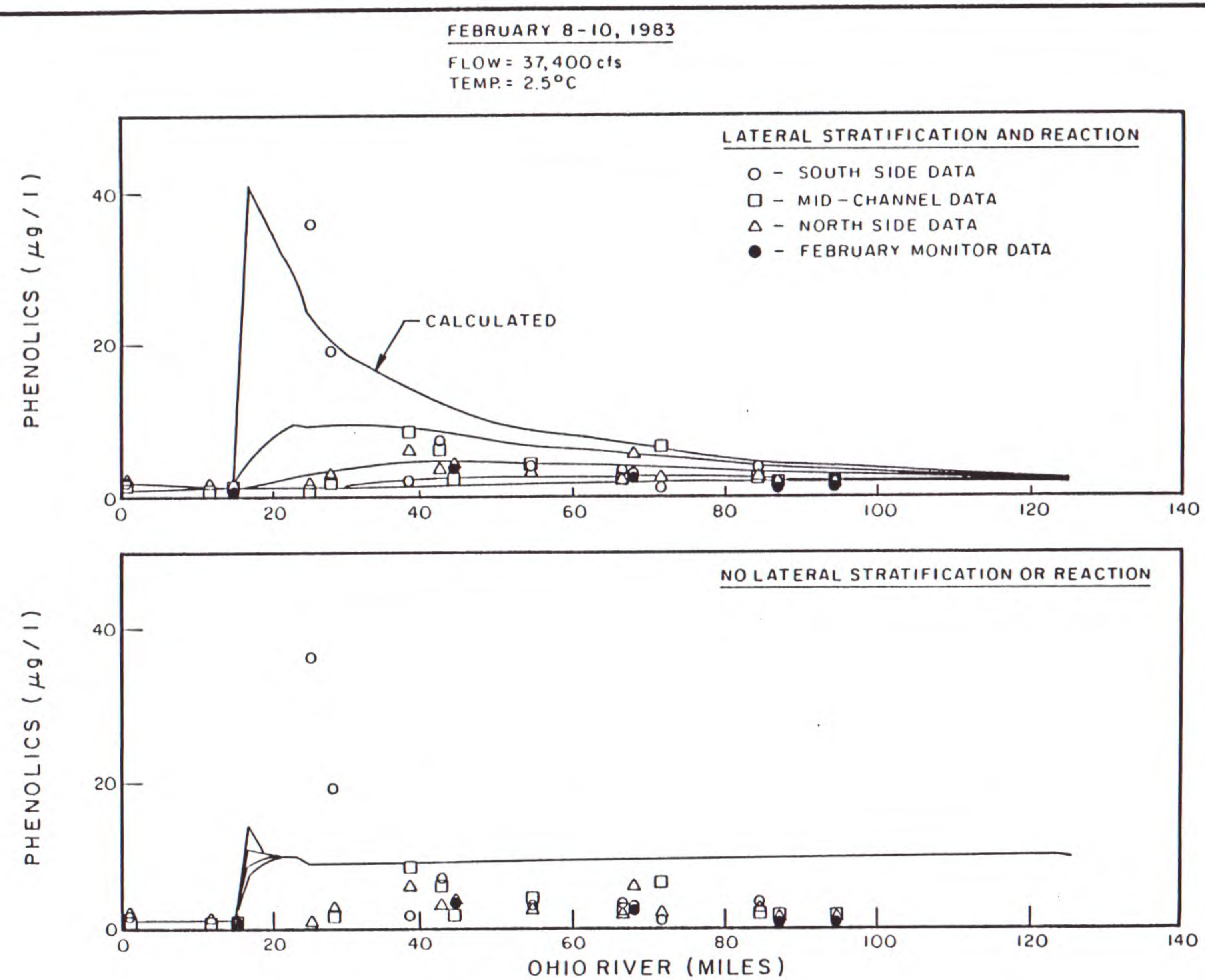


FIGURE 6-1. OBSERVED AND CALCULATED PHENOLICS CONCENTRATIONS

bank at the Aliquippa discharge declines rapidly in accordance with lateral mixing and decomposition. Concentration values in the other lateral segments tend to increase for some distance as waste is mixed laterally, and then decline due to decomposition. The bottom panel of Figure 6-1 presents the same computation assuming that complete lateral mixing occurs in the river.

In general, the laterally-stratified water quality model adequately reproduces observed conditions. The observed lateral variations are matched well by a combination of the lateral model segmentation and the selection of dispersion coefficients as discussed in Section 5.0.

6.3 HISTORICAL SURVEYS (1977 TO 1984)

The remainder of the cyanide and phenolics modeling effort was accomplished using ORSANCO monitor data and Wheeling Water Works influent data for a basis of comparison. It should be noted that the limited availability of point source discharge data concurrent with in-stream sampling severely limit the degree to which the water quality model can be calibrated and validated in the conventional sense. The model's utility in this analysis is that of a screening tool which is fully capable of performing a more detailed analysis should data become available in the future.

The results of the phenolics modeling for mean monthly load conditions are shown on Figures 6-2A and 6-2B. Three of the five computed model lines--south bank, mid-channel, and north bank—are displayed to increase the legibility of this and subsequent figures. The monthly mean monitor concentrations are presented, and these values are bounded by the observed concentration range in each period. Good agreement between observed and computed results is achieved in most instances of low concentrations; however, there are several periods in which mean ambient phenolics concentrations in excess of 20 μg/l could not be reproduced by the model. The February 1977 survey, which consistently has the highest concentrations, is not adequately depicted using mean discharges. It is

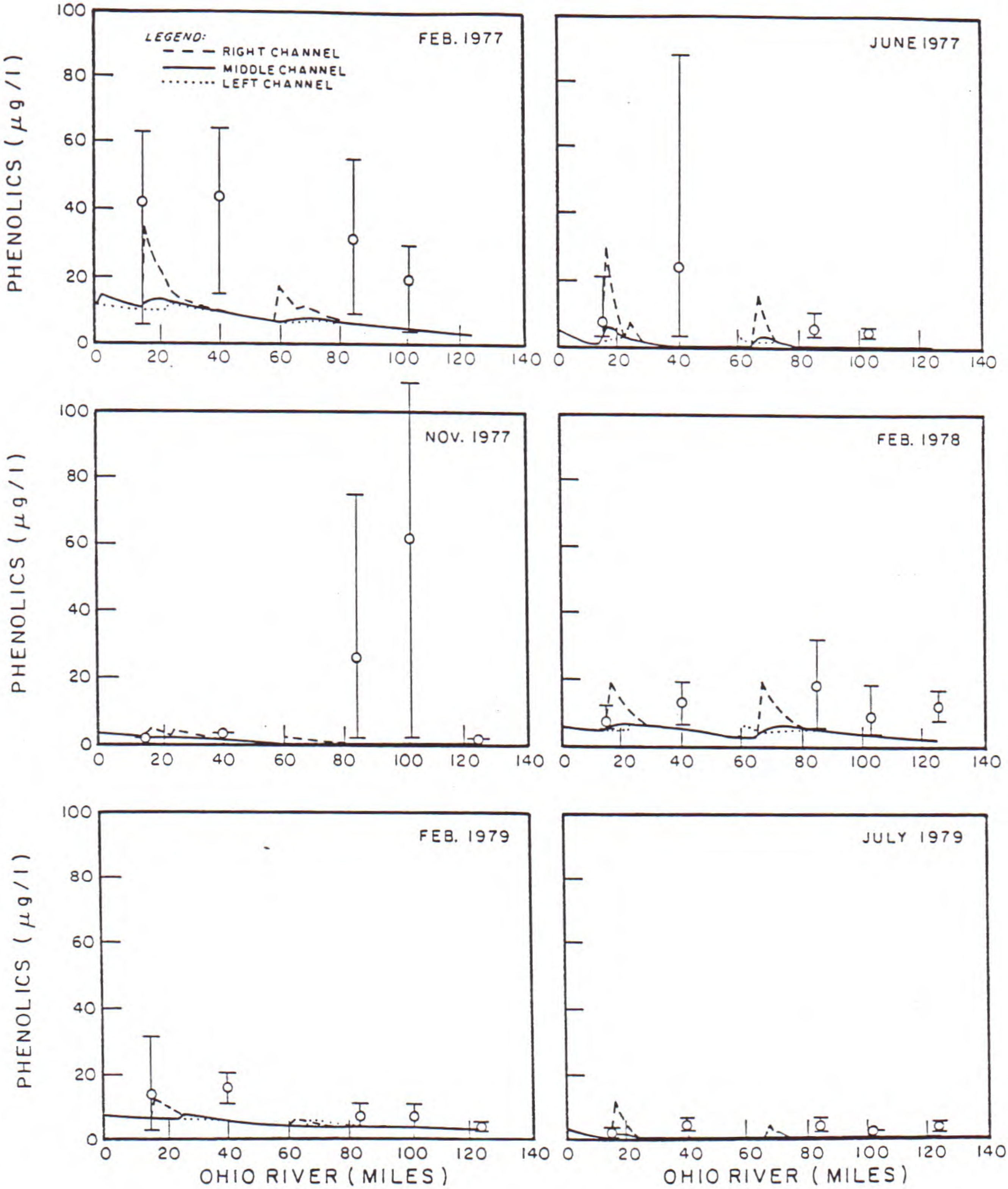


FIGURE 6-2A. OBSERVED AND CALCULATED PHENOLICS CONCENTRATIONS
(Mean Loads and Boundaries)

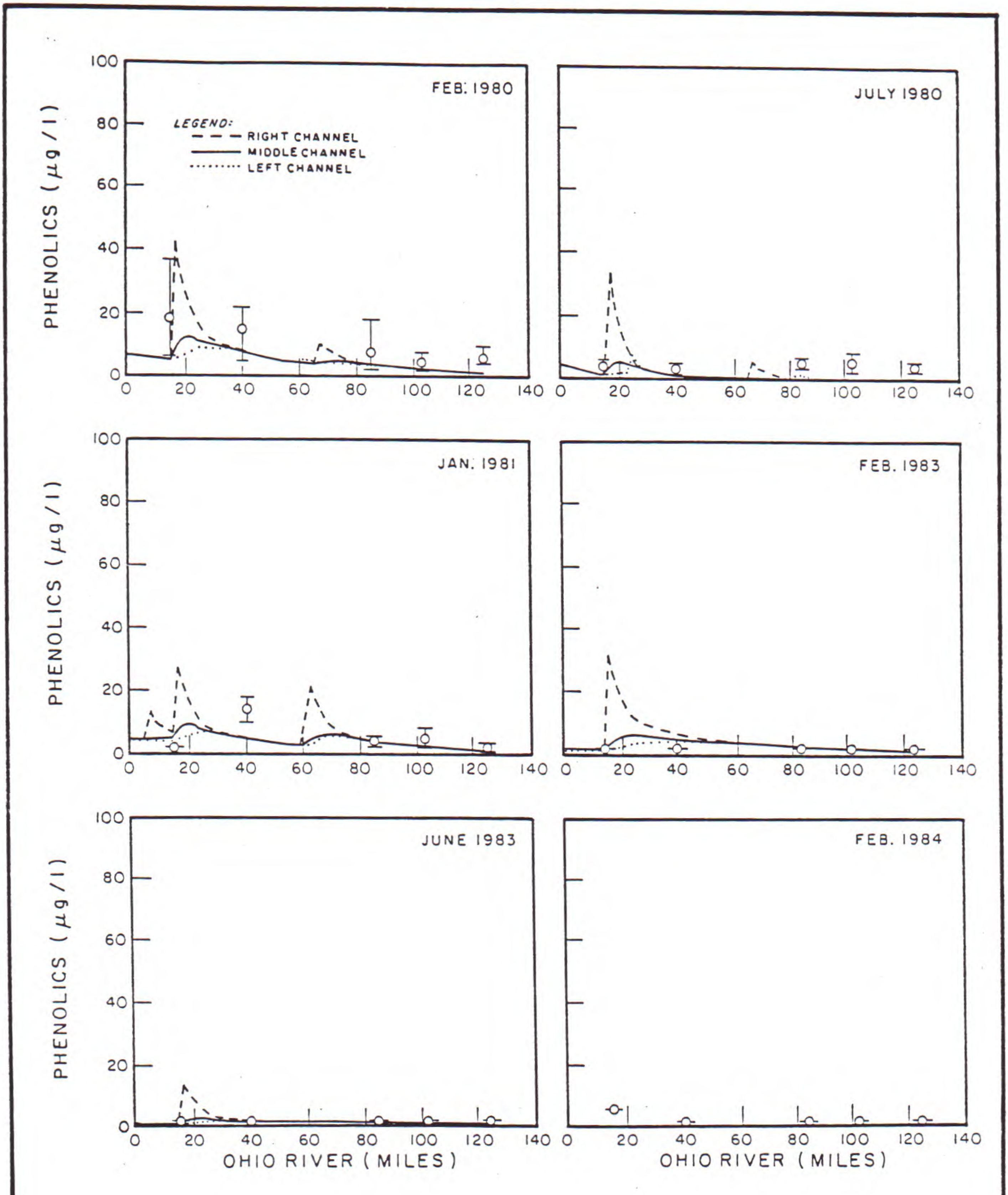


FIGURE 6-2B. OBSERVED AND CALCULATED PHENOLICS CONCENTRATIONS
(Mean Loads and Boundaries)

also noteworthy that the November 1977 data show two anomolous high values, indicating that a significant degree of load variably exists somewhere in this vicinity.

The water quality model was rerun using maximum known phenolics loads. As seen on Figures 6-3A and 6-3B, the resultant agreement between the observed and computed concentrations is improved in many instances. Comparison of the computed concentration profiles with those computed using mean loading conditions reveals that the model is sensitive to changes made within the range of the observed load data. The February 1977 calibration is noticeably improved.

The same modeling analyses were performed for cyanide. Concentrations computed using mean loads are presented on Figures 6-4A and 6-4B. The model and the observed data do not compare favorably in many instances at first glance, but it should be noted that the cyanide detection limit for the ambient monitoring program was 10 μg/l in most instances. For example, during the February and June 1983 calibration periods the monitor data are consistently at the detection limit; conseqently, the water quality model, which computes less than 10 μg/l of phenolics throughout the study area, compares well with the observed concentrations.

Cyanide model results from maximum load inputs are presented on Figures 6-5A and 6-5B. As was the case with phenolics, the agreement is improved for surveys having higher ambient cyanide concentrations. The majority of the improvement comes from the assignment of the maximum observed upstream boundary concentrations. In several instances data in the downstream area are consistently higher than the model prediction even under maximum load conditions (February 1977 for example). The reason for this is presently unknown, although the lack of recurrence of this phenomenon during more recent survey periods suggests the presence of unknown discharges which may presently be curtailed.

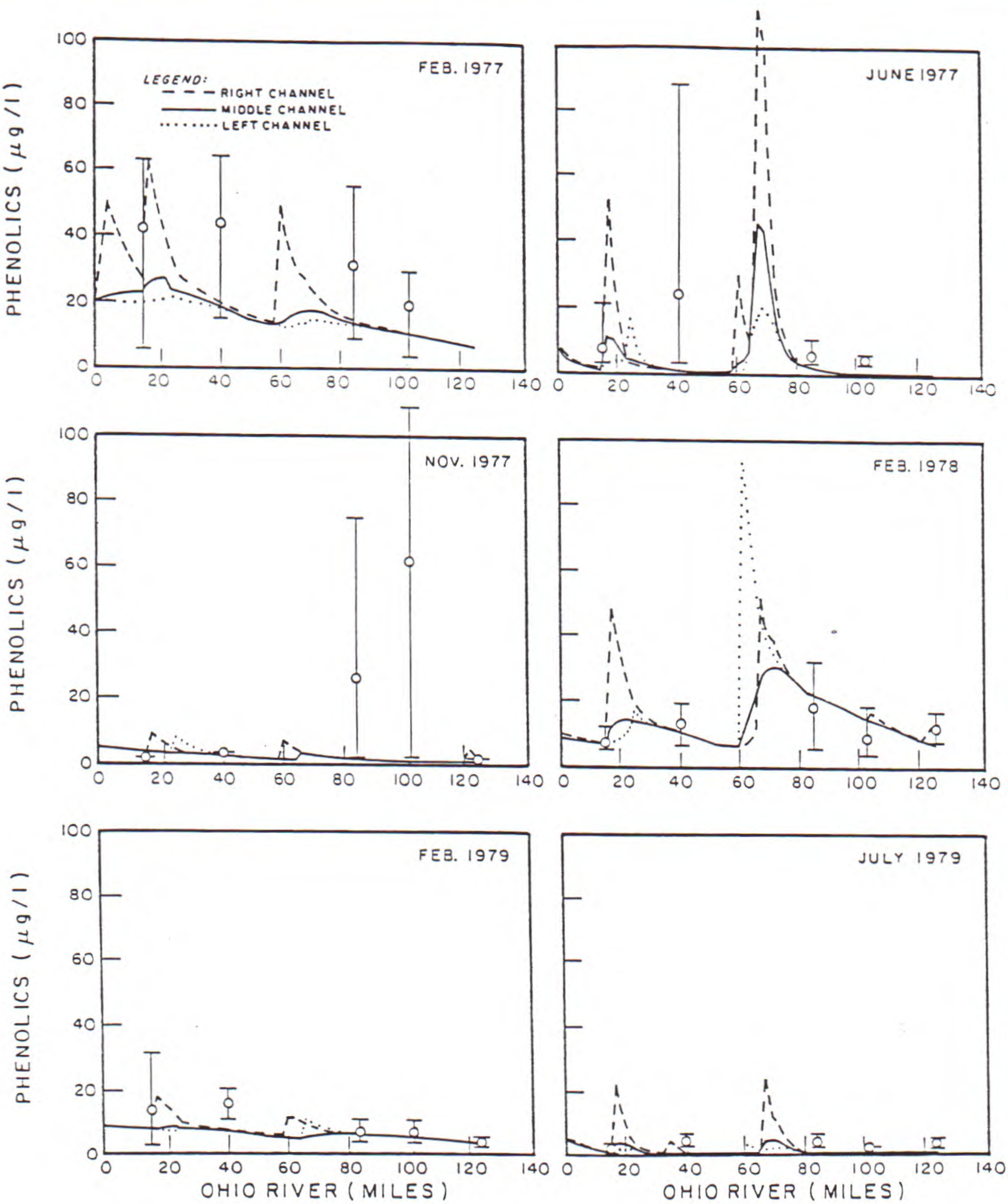


FIGURE 6-3A. OBSERVED AND CALCULATED PHENOLICS CONCENTRATIONS
(Maximum Loads and Boundaries)

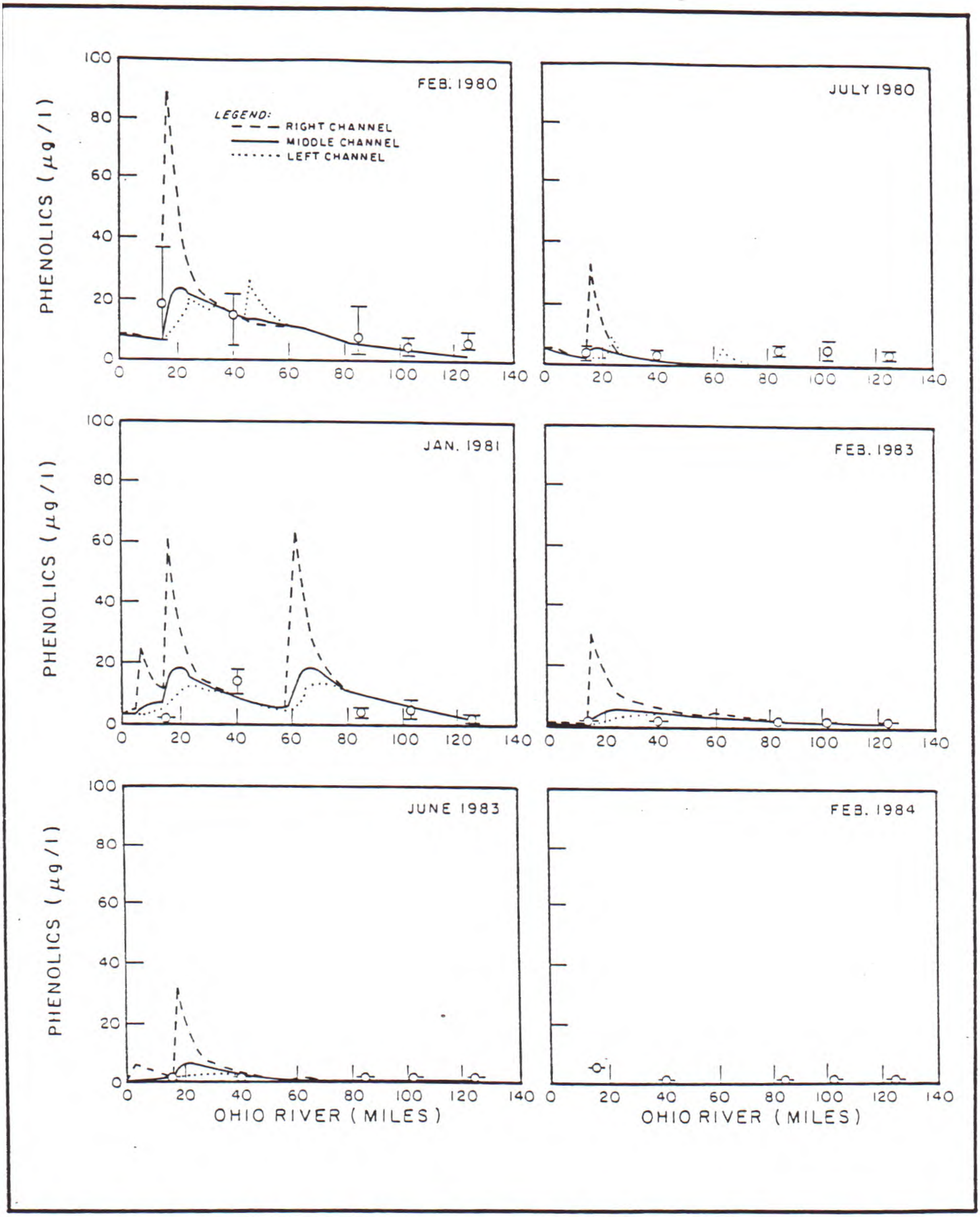


FIGURE 6-3B. OBSERVED AND CALCULATED PHENOLICS CONCENTRATIONS
(Maximum Loads and Boundaries)

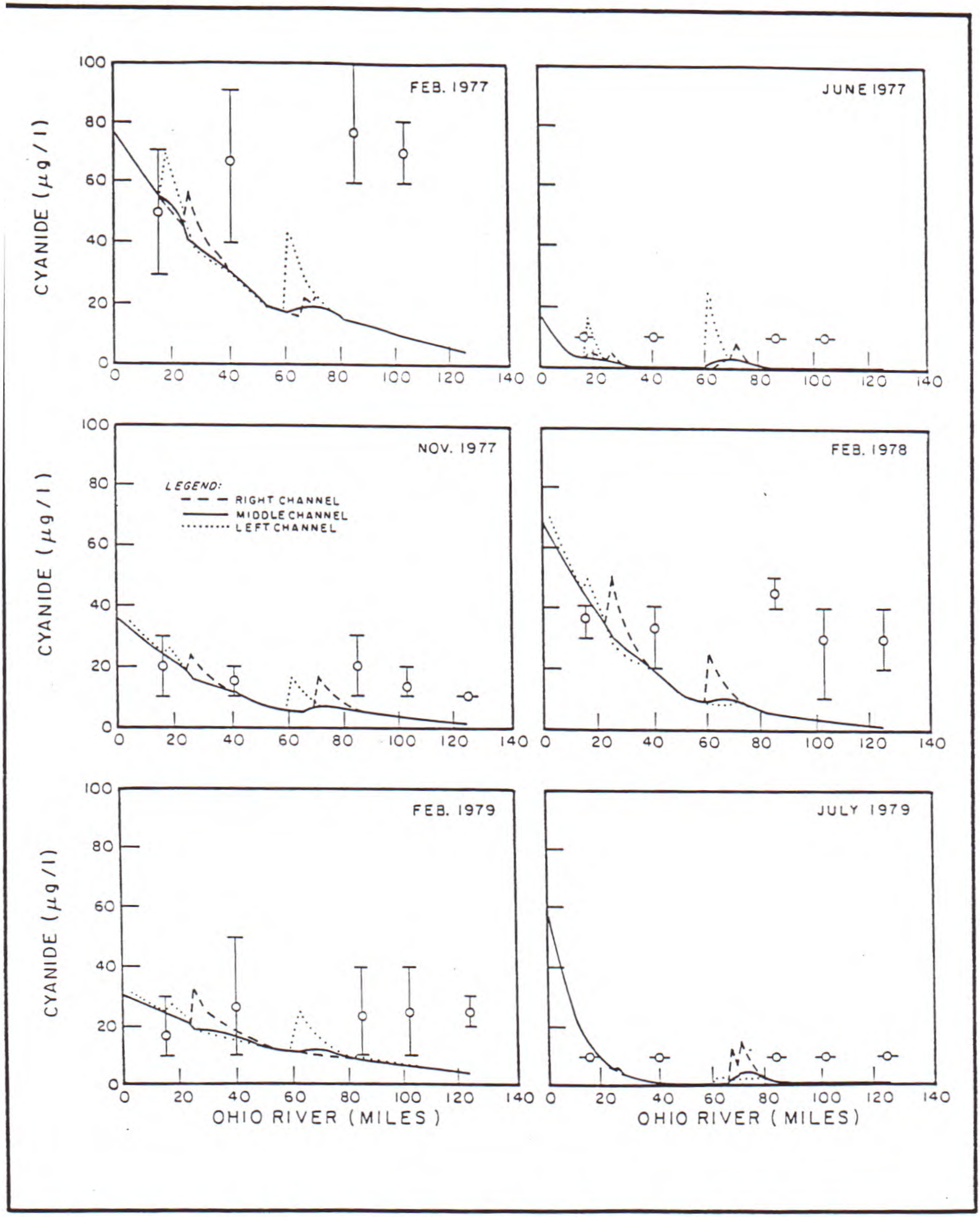


FIGURE 6-4A. OBSERVED AND CALCULATED CYANIDE CONCENTRATIONS
(Mean Loads and Boundaries)

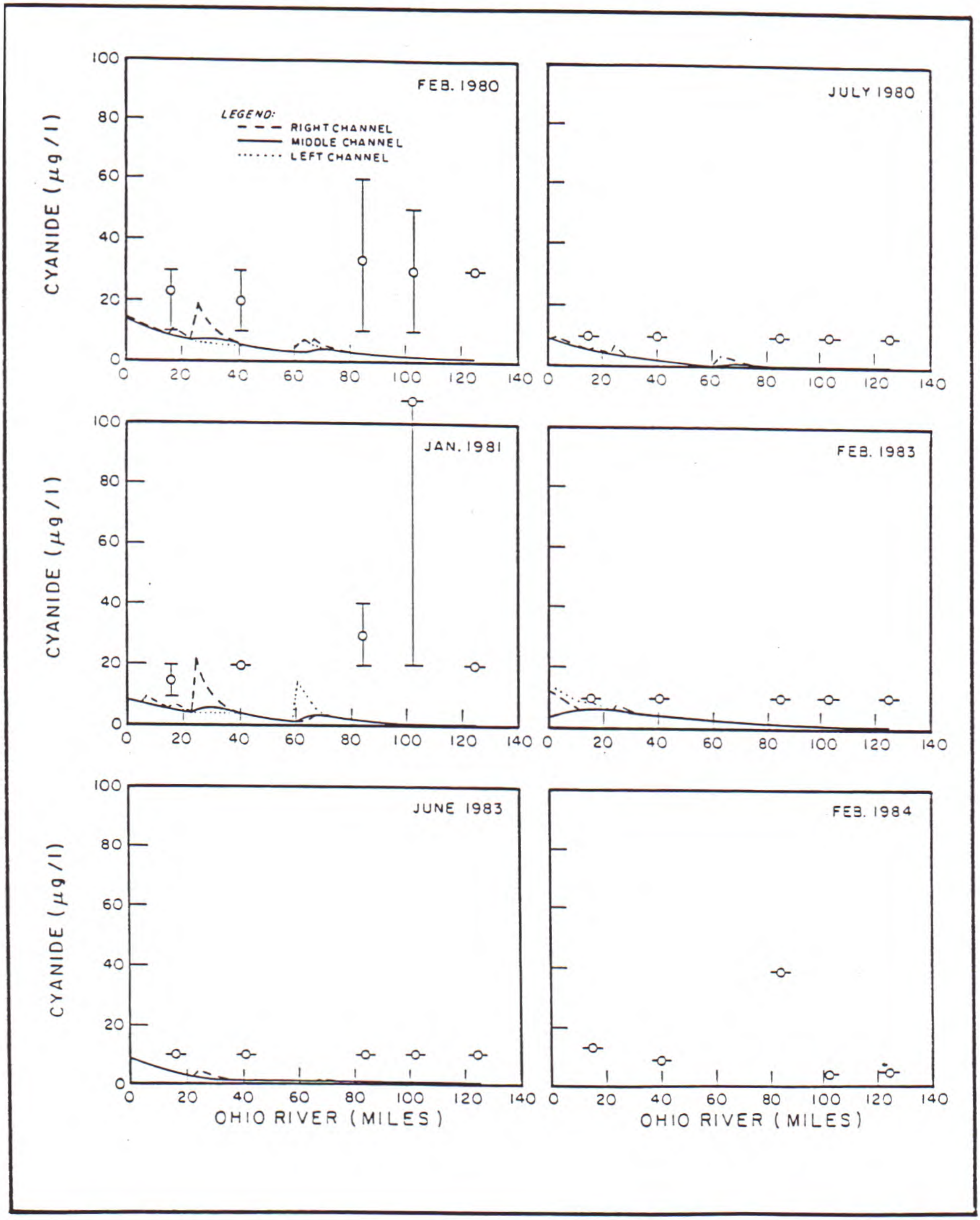


FIGURE 6-4B. OBSERVED AND CALCULATED CYANIDE CONCENTRATIONS
(Mean Loads and Boundaries)

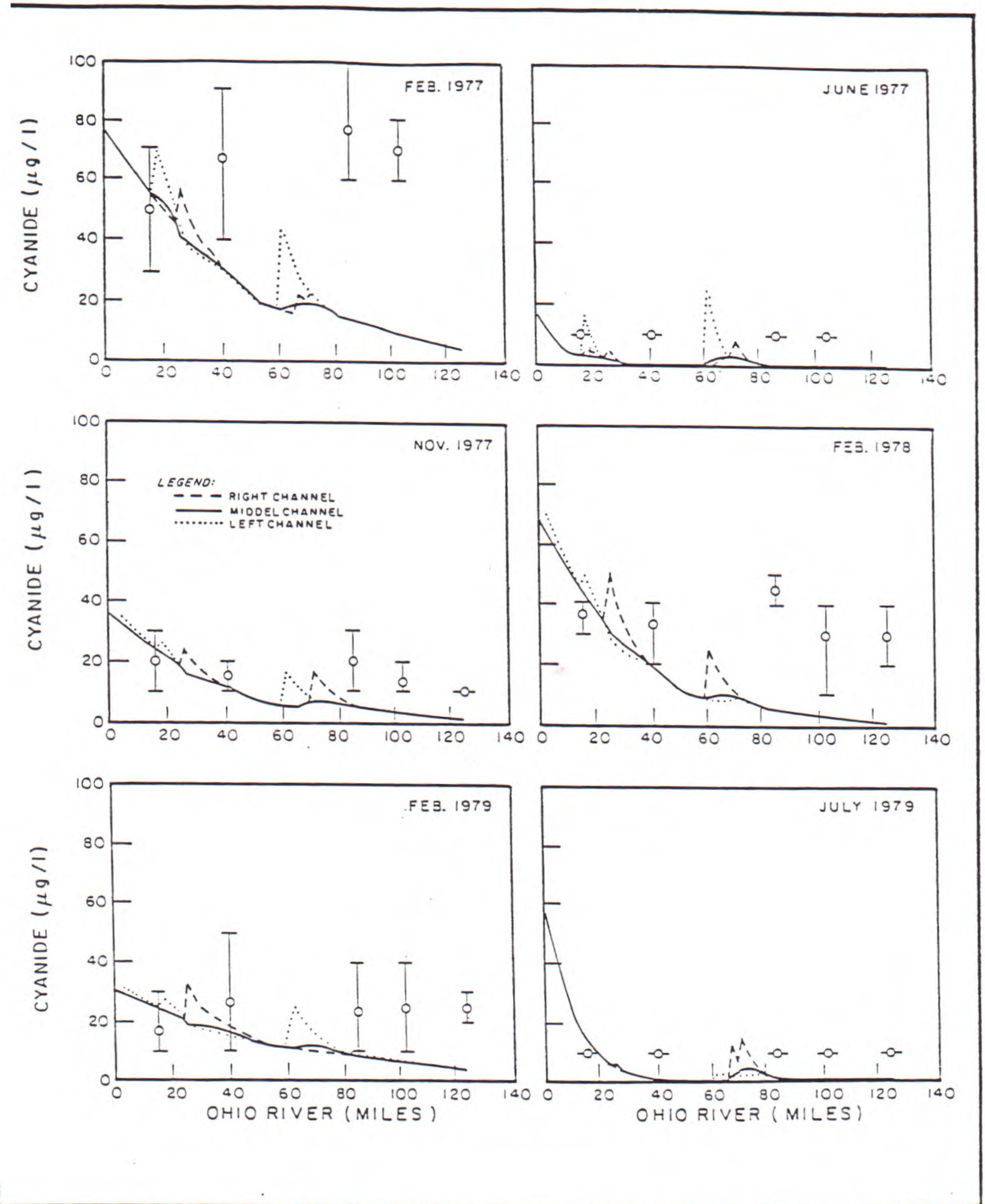


FIGURE 6-5A. OBSERVED AND CALCULATED CYANIDE CONCENTRATIONS
(Maximum Loads and Boundaries)

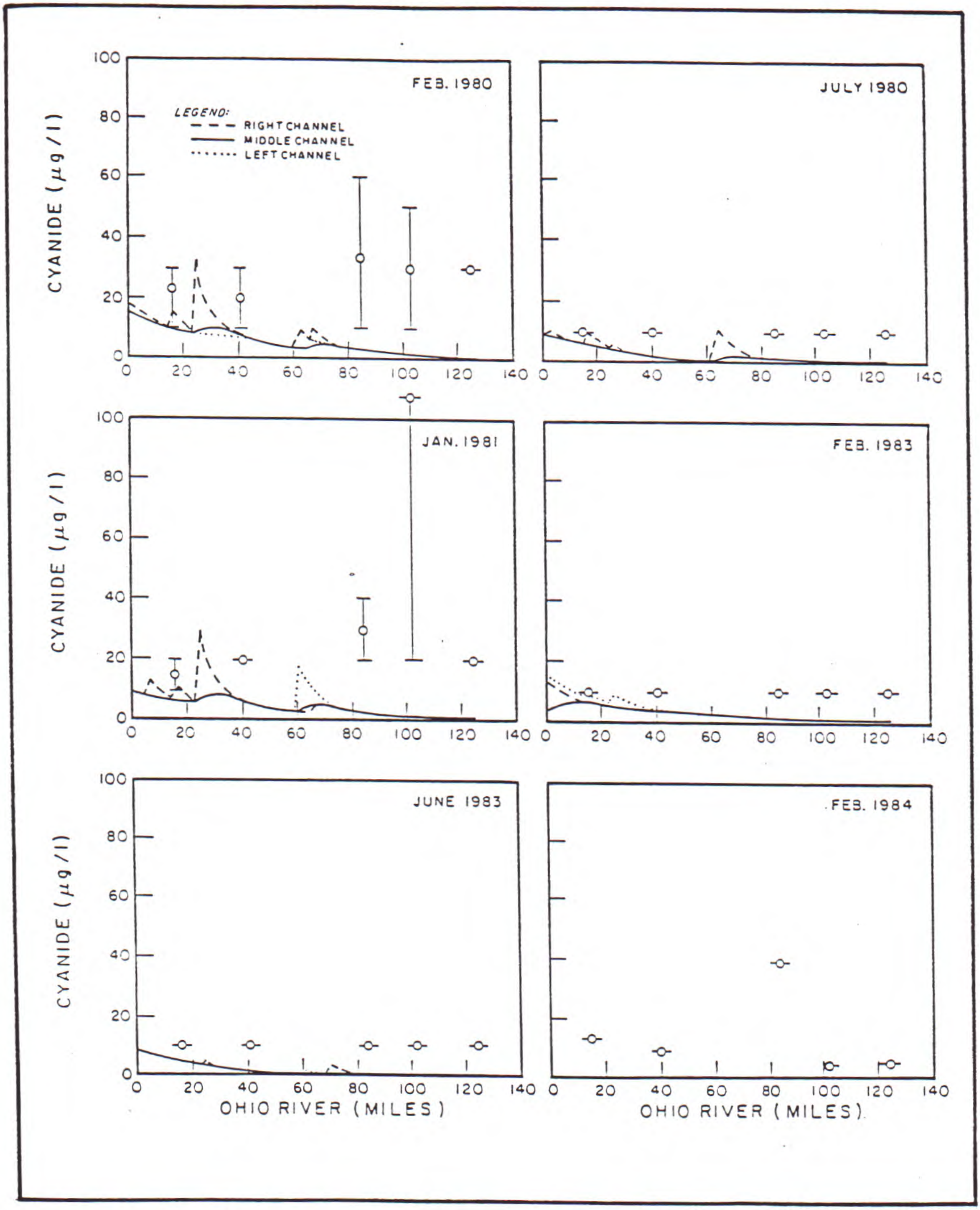


FIGURE 6-5B. OBSERVED AND CALCULATED CYANIDE CONCENTRATIONS
(Maximum Loads and Boundaries)

6.4 DISCUSSION OF RESULTS

As noted previously, the available data base for observed in-stream phenolics and cyanide concentrations and wasteloading information is extensive, but not completely sufficient for rigorous modeling analysis. The majority of wasteload data from the permitted discharges represents two to four measurements per month. These measurements are not necessarily made during the same time as in-stream monitoring measurements. Further, there are no good estimates of the monthly average loadings or in-stream water quality. Therefore, there is no necessarily direct correspondence between reported wasteloads and observed water quality. Further, almost no site-specific (upper Ohio River area) data are available on potential non-permitted discharges of phenolics and cyanide.

However, given the limitations of the data base, the modeling analysis of the phenolics data is generally good. The results indicate that, with certain exceptions, monitored in-stream concentrations can be generally accounted for with measured loadings from the permitted discharges. This is not to say that no other sources exist, but that by and large, the order of the permitted discharges account for the order of the in-stream concentrations. The modeling analysis for total cyanide is not as good as that for phenolics. Three reasons are possible: (1) the reaction rate coefficient for cyanide decomposition is overestimated; (2) the high observed in-stream concentrations were caused by correspondingly high waste inputs from permitted discharges which were not measured; or (3) there existed substantial other inputs of material from non-permitted sources.

To assess the potential significance of other potential sources, Table 6-5 is presented. The table presents a comparison of cyanide and phenolics loadings actually observed during the selected periods with existing permitted loads and estimated potential loads as discussed in Section 4.0. It is observed from the table that, on an annual average basis, it is estimated that unpermitted potential loads could account for 163 to 269 lbs/day of total cyanide and 93 to 96 lbs/day of phenolics. Regarding cyanide, the potential loading is an order

TABLE 6-5. COMPARISON OF DOCUMENTED, PERMITTED AND ESTIMATED LOADS

	Cyanide (lbs/day)	Phenolics (lbs/day)
1. Documented Loads (selected periods: 1977 to 1984)		
Permitted Loads (monthly average)	119 - 2442	86 - 1973
(daily maximum)	253 - 3499	171 - 9348
ALCOSAN (monthly average)	14 - 91	8 - 160
(daily maximum)	36 - 246	18 - 1470
2. Permitted Loads		
Monthly Average	172	150
Daily Maximum	384	425
3. Estimated Potential Loads		
Other Municipal[a]	3 - 109	<1 - 5
Other Industrial	Unknown	Unknown
CSO (annual average)[b]	60	1
Urban Runoff (annual average)[c]	10	<1
Background Runoff (annual average)[d]	90	90

[a]Total STP flow = 58.5 mgd
Reported national concentration ranges:
Cyanide = 10 - 400 μg/l @ 55.9 percent detection
Phenolics = 1 - 35 μg/l @ 26.7 percent detection

[b]Annual rainfall = 38 inches
Runoff coefficient = 0.4
CSO area = 68.2 square miles
CSO discharge (annual average) = 76 cfs
Reported national median concentrations:
Cyanide = 146 μg/l; phenolics = 3 μg/l

[c]Estimated urban runoff = 21 cfs
Estimated median cyanide = 84 μg/l
Estimated median phenolics = 3-5 μg/l

[d]Drainage area increase = 10,000 square miles
Runoff coefficient = 0.2
Estimated runoff = 5600 cfs
Cyanide, phenolics concentration = 3 μg/l

of magnitude less than the maximum values observed on the permitted discharges. Further, analysis of the river data for cyanide during those periods when the model does not adequately account for in-stream concentrations indicates that the mass loading of cyanide, which is not accounted for, is in the order of 3000 to 6000 lbs/day. This magnitude of loading cannot nearly be accounted for by the estimated potential loads in Table 6-5. It is therefore concluded that the most likely cause(s) of high in-stream cyanide concentrations which were not accounted for by calculations were greater loadings from the permitted (and perhaps other industrial) sources and/or lesser decomposition, most likely a combination of the two.

The relatively low estimated potential loads for phenolics is consistent with the better correlation of observed in-stream data with reported loads.

It is apparent from Table 6-5 that, during the 1977 to 1984 period and especially in the earlier years when water quality was poor, cyanide and phenolics loadings greatly exceeded existing permit values at times.

SECTION 7.0

ASSESSMENT OF EFFECTIVENESS OF CURRENT CONTROL PRACTICES

The purpose of the present permit limitations is to maintain ORSANCO and state water quality standards for cyanide and phenolics in the Ohio River. In this task, an assessment was made of the effectiveness of the existing permit limitations of cyanide and phenolics to maintain applicable water quality standards.

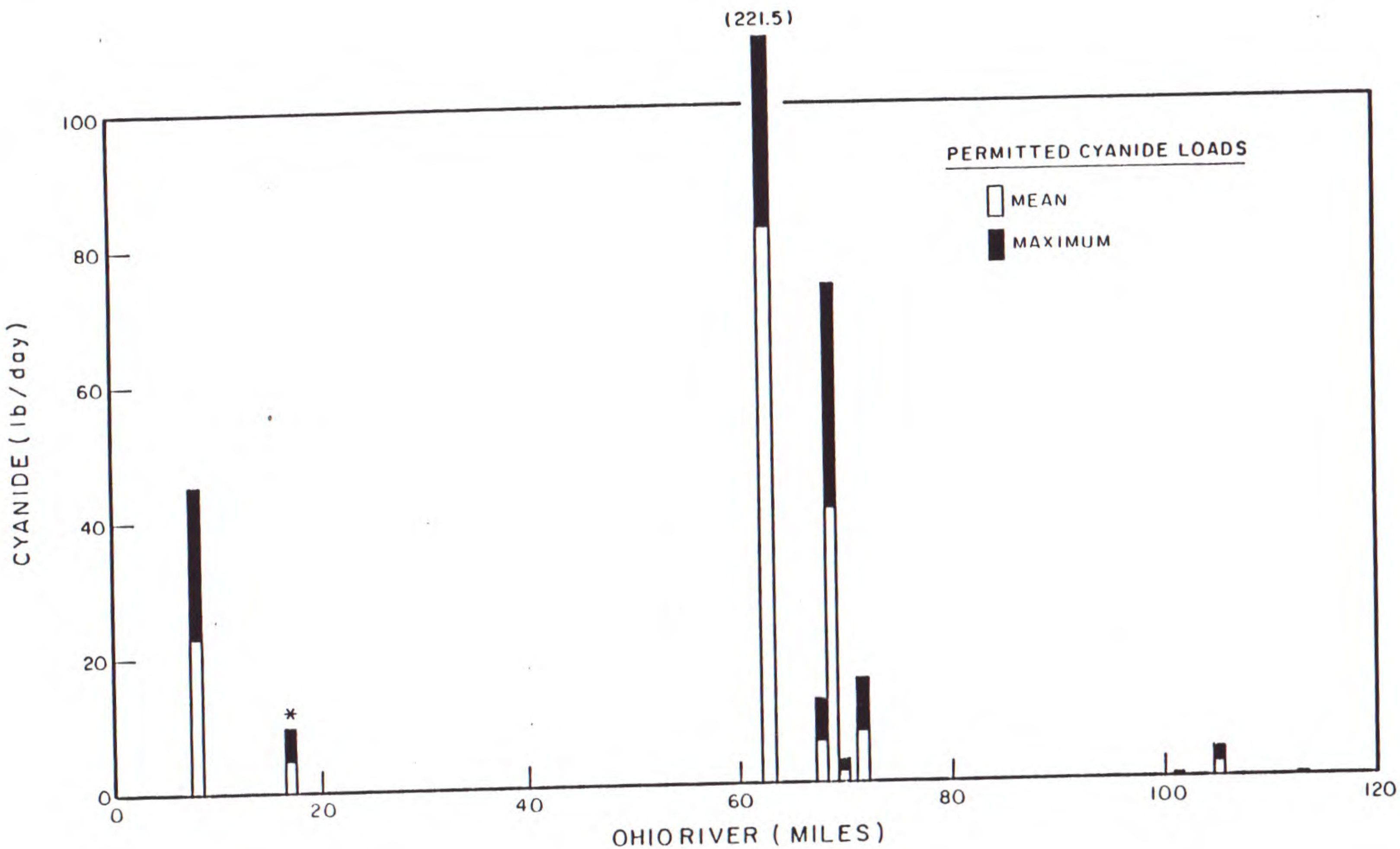
7.1 WATER QUALITY PROJECTIONS

The laterally-stratified mathematical water quality model of the upper Ohio River was used to assess the existing permit limitations for cyanide and phenolics to determine if water quality standards would be maintained under representative critical and average conditions.

7.1.1 Permitted and Unpermitted Loads

The presently permitted cyanide and phenolics discharges to the study area are presented in Table 3-1 and Figures 7-1 and 7-2. Both 30-day average and daily maximum loads are presented. The major discharger in each instance is Weirton Steel (milepoint 62). The Wheeling-Pittsburgh facilities (milepoint 68) and Shenango (milepoint 18) provide the next greatest loads of cyanide and phenolics. The mean monthly permitted discharges are in the order of 150 to 170 lb/day for both compounds, and the daily maximum values are approximately two to three times as great as the mean values in most instances.

Two major sources of unpermitted loads from the calibration periods - ALCOSAN and Crucible Steel - were not included in these analyses. The ALCOSAN load has been decreasing since 1980 and is of lesser significance; Crucible Steel is not operative at present. As noted previously, the above loads are



NOTE:
* ESTIMATED FROM FREE CYANIDE MEASUREMENTS.

FIGURE 7-1. LOCATION OF PERMITTED CYANIDE LOADS

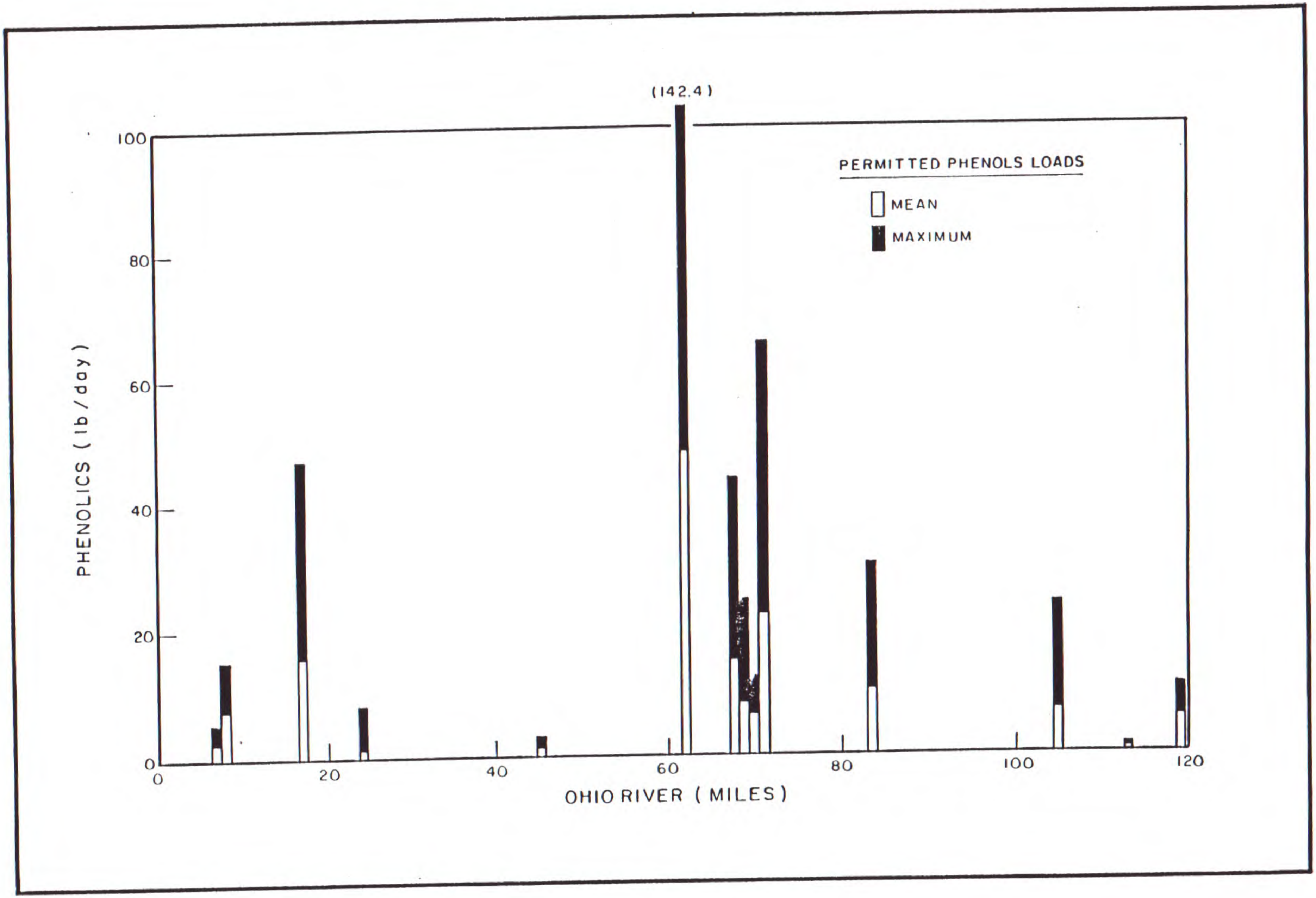


FIGURE 7-2. LOCATION OF PERMITTED PHENOLICS LOADS

significantly less than those actually discharged in the 1976 to 1984 period. In some instances, the permitted discharges are an order of magnitude lower than reported historical values.

7.1.2 Selection of Projection Conditions

Water quality projections using the existing permit limitations for cyanide and phenolics were made for both critical and average flow conditions for the month of January. The winter period was chosen due to the strong temperature dependency of the reaction kinetics for cyanide and phenolics. The low water temperatures prevailing during this month would result in the least decomposition of the constituents. Further, low and average flow conditions during this month are similar to those of other periods of the year. Water temperature was assigned as $1^{o}C$ and the critical low and average flow conditions at Sewickley were assigned as 4,800 and 44,800 cfs, respectively.

7.1.3 Projected Water Quality

The mathematical model was run using the specified flow and temperature conditions for both the mean monthly permit limits and the maximum daily discharge limits. The results of these analyses for phenolics and cyanide are presented on Figures 7-3 and 7-4 respectively.

The results of Figure 7-3 indicate that the phenolics standards of 5 µg/l (Pennsylvania/West Virginia) and 10 µg/l (ORSANCO/Ohio) are achieved at both average and low flows using mean monthly permit loads. Maximum concentrations are projected to be less than 2 µg/l in all cases. Permitted maximum daily discharges are projected to cause in-stream phenolics values to exceed the 5 µg/l standard and approach the 10 µg/l standard in the lateral segment closest to the Weirton Steel discharge under low flow conditions. Standards are projected to be maintained under average flow conditions.

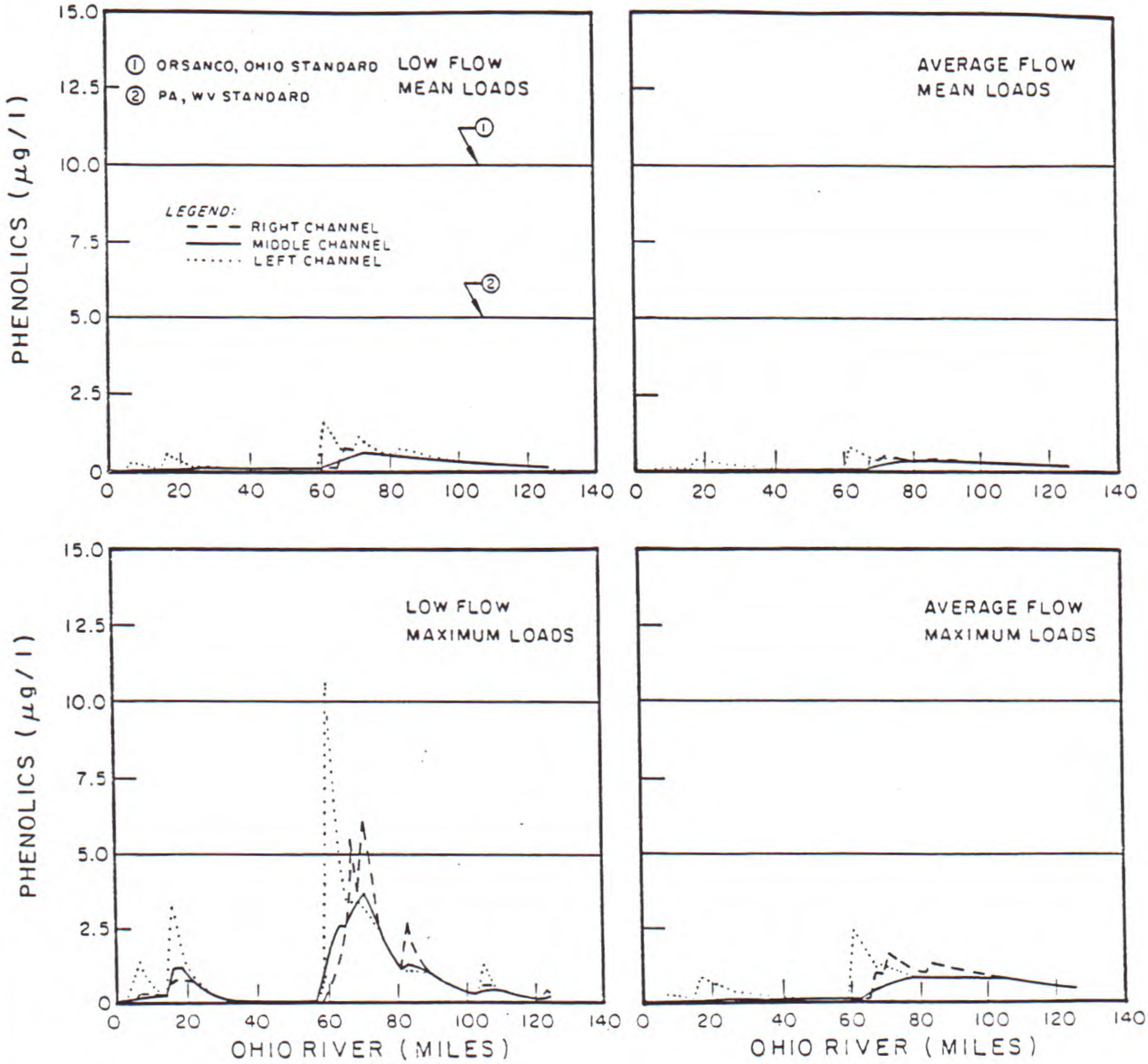


FIGURE 7-3. PROJECTED PHENOLICS PROFILES WITH PERMITTED LOADS
(January Conditions)

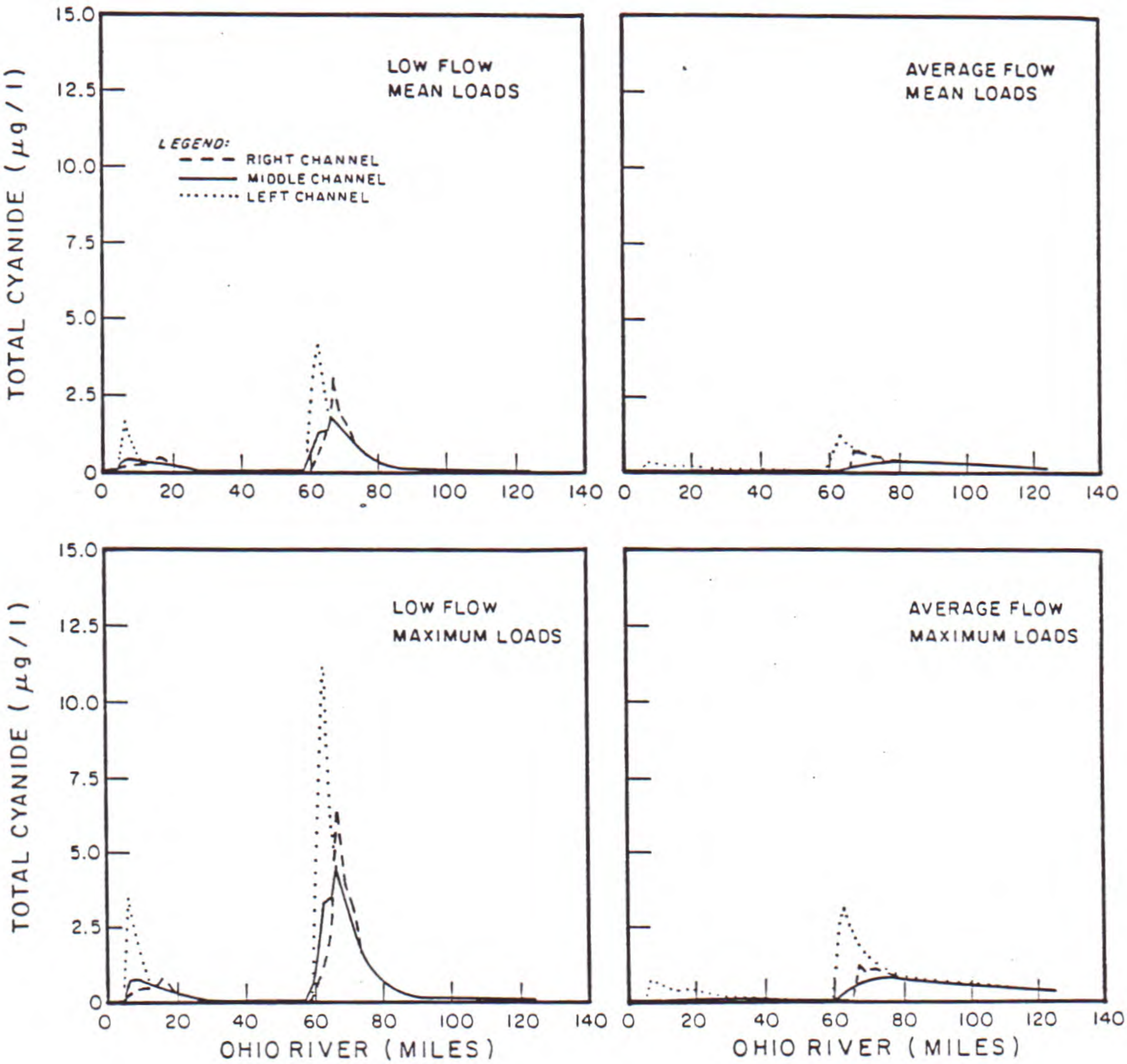


FIGURE 7-4. PROJECTED CYANIDE PROFILES WITH PERMITTED LOADS
(January Conditions)

Figure 7-4 indicates that the ORSANCO/Ohio water qualilty standard of 25 µg/l of total cyanide would be attained under all conditions of river flow and loading. The peak concentration observed at low flow is approximately 4 µg/l; at the average flow condition the peak concentration is on the order of 1 µg/l. Maximum permitted discharges result in peak concentrations of 12 µg/l at low flow and 3 µg/l at the average flow. Assuming that free cyanide is on the order of 20 percent of total cyanide from results reported elsewhere(7), it is estimated that the 5.0 µg/l standard for free cyanide of Pennsylvania and West Virginia will be maintained for these conditions.

It is noted that the modeling analysis of the historical data indicated the possibility that the decay coefficient for total cyanide may have been overstated. However, it is concluded that even if total cyanide behaves as a totally conservative substance, the existing permit limits would result in maintenance of water quality standards.

7.2 DISCUSSION OF RESULTS

The projected phenolics and total cyanide profiles of Figures 7-3 and 7-4 indicate that the existing permit limits for these substances are well-established and will result in maintenance of applicable water quality standards under critical conditions. A possible exception is a localized violation for phenolics below Weirton Steel under maximum discharge and critical low flow conditions due to incomplete lateral mixing. However, river quality should be within standards at the critical Wheeling Water Works. Even assuming the existence of other potential sources of cyanide and phenolics as estimated in Table 6-5, and boundary concentrations from the major tributaries entering the mainstem with constituent concentrations at the levels of the standards, it is estimated that water quality standards would be maintained for the ambient flow and temperature conditions specified. Most of the other potential sources are distributed throughout the study area and their impact is much less than an equivalent large point source. The principal possible exception to this estimation is for cyanide behaving as a totally conservative substance and entering the mainstem from the major tributaries (Allegheny, Monongahela and Beaver Rivers) with a concentration level already at standard. Under such a circumstance, there is essentially no additional assimilation capacity. As phenolics are certainly reactive, it is not likely that this potential exists for that substance.

It is noted that substantial amounts of cyanide and phenolics have been discharged historically from ALCOSAN. Values are much curtailed at present. However, given the continuing discharge of materials from this source, permit limitations may be considered from an equity and management standpoint.

It is noted that no data were obtained on constituent concentrations in other industries of the region other than those with permit limits. Consequently, no potential load was assigned to this source. It may be appropriate to consider some surveillance monitoring to place a perspective on this potential source.

In summary, it is concluded that the elevated in-stream concentrations of cyanide and phenolics in the late 1970s and early 1980s were primarily due to mass loadings from permitted discharges which were greatly in excess of present permit limits. Lateral stratification which exists in the river could further exacerbate problems at critical locations such as the Wheeling Water Works. The recent depression of manufacturing productivity in the steel and other industries appears to be primarily responsible for recently improved water quality. Maintenance of applicable standards and beneficial uses requires enforcement of existing permit limits.

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6. Bansal, Makendra K., "Dispersion in Natural Streams," Journal of the Hydraulics Division, ASCE, Volume 97, No. HY11, Proc Paper 8540, November 1971.

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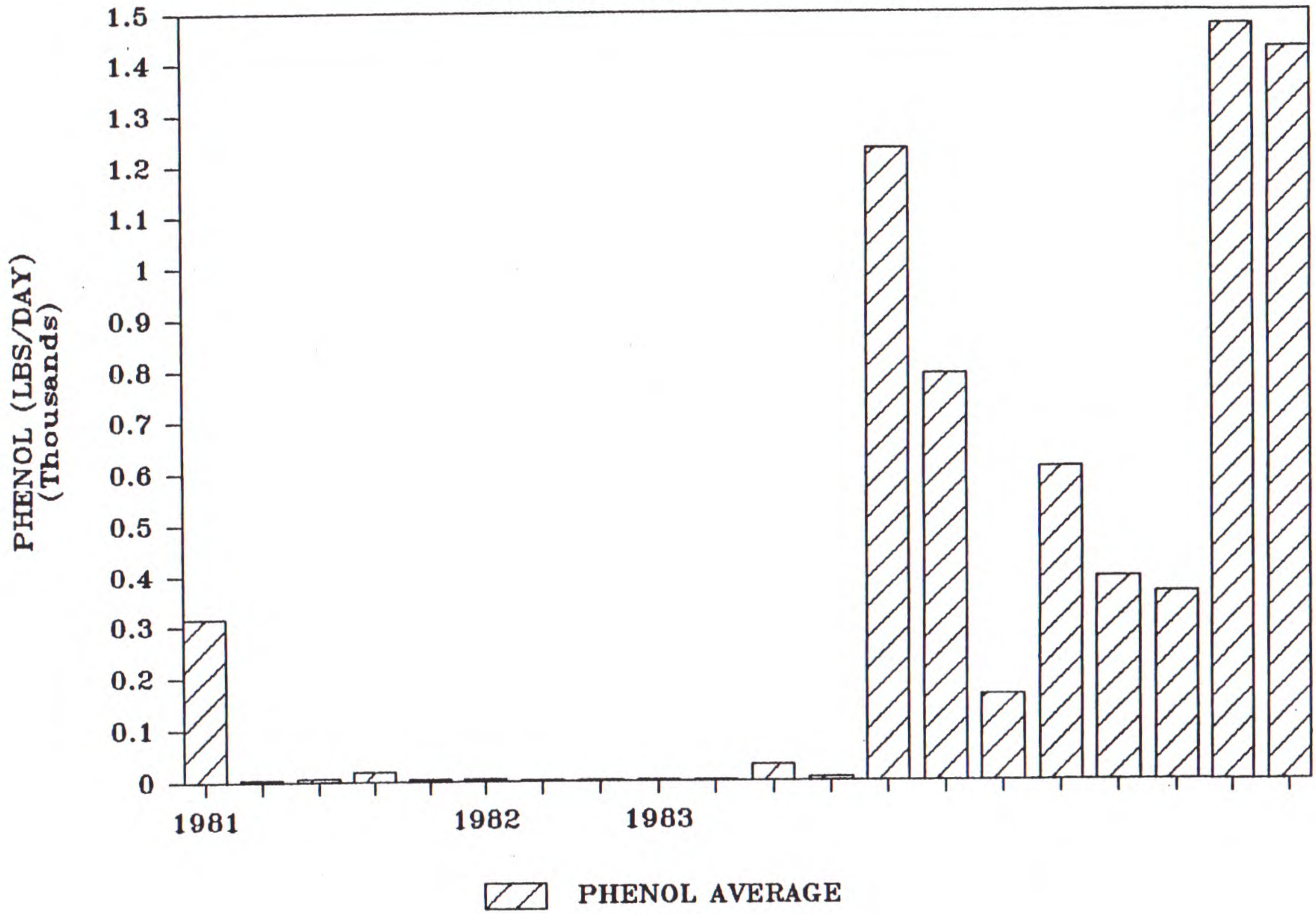
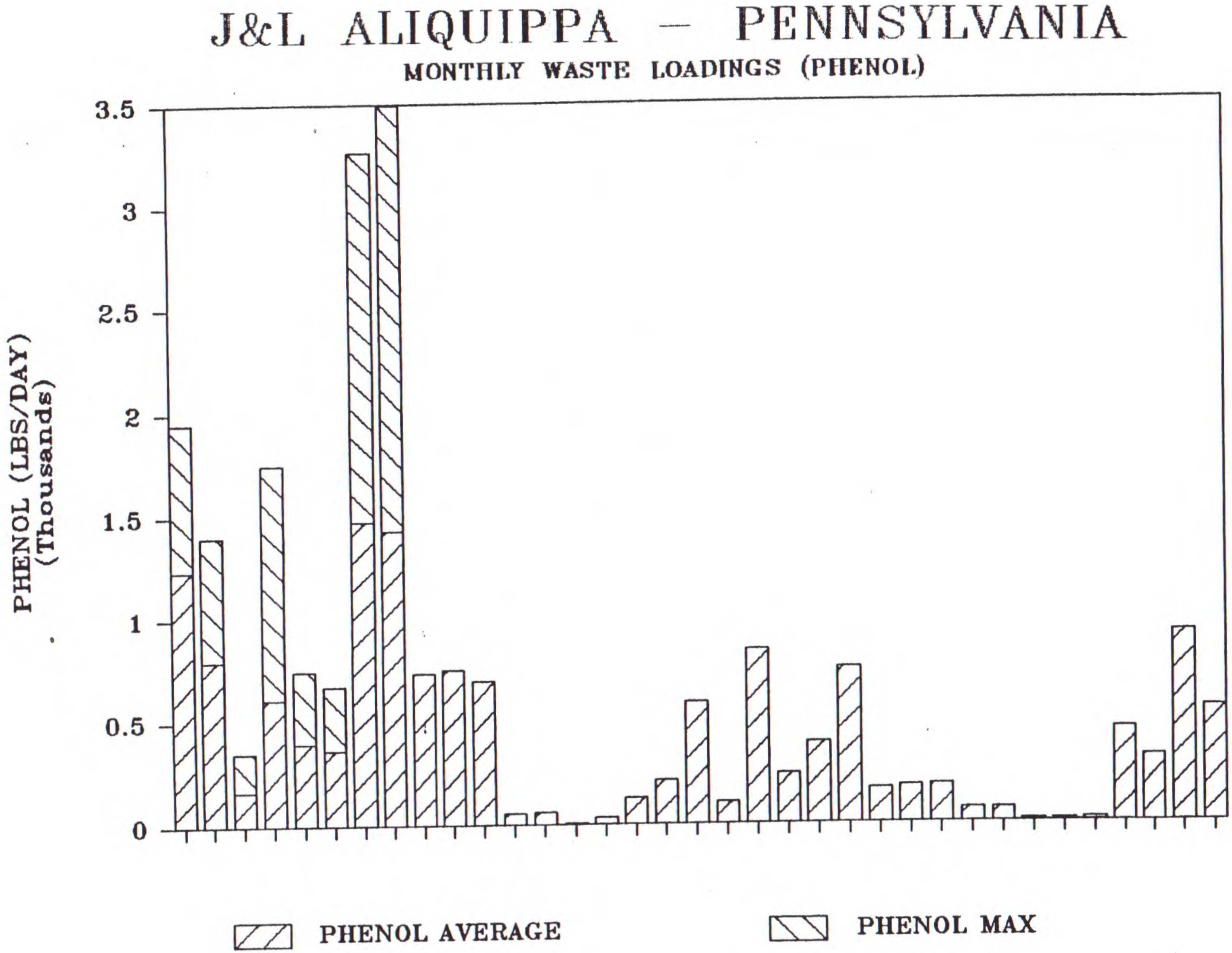
APPENDIX 1

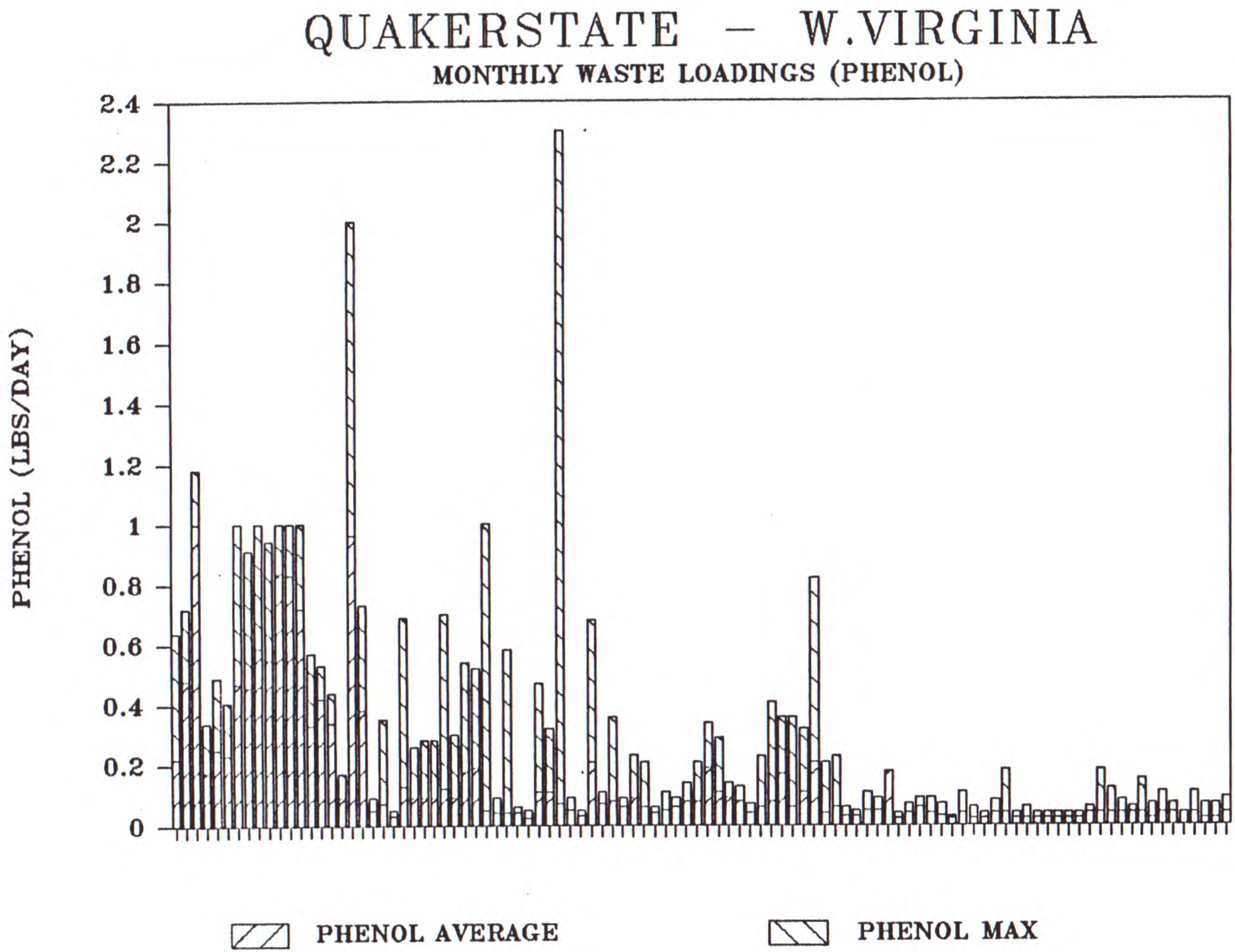
MONTHLY HISTOGRAMS OF MAJOR PERMITTED
CYANIDE AND PHENOLICS DISCHARGES

SHENANGO – PENNSYLVANIA

MONTHLY WASTE LOADINGS (PHENOL)

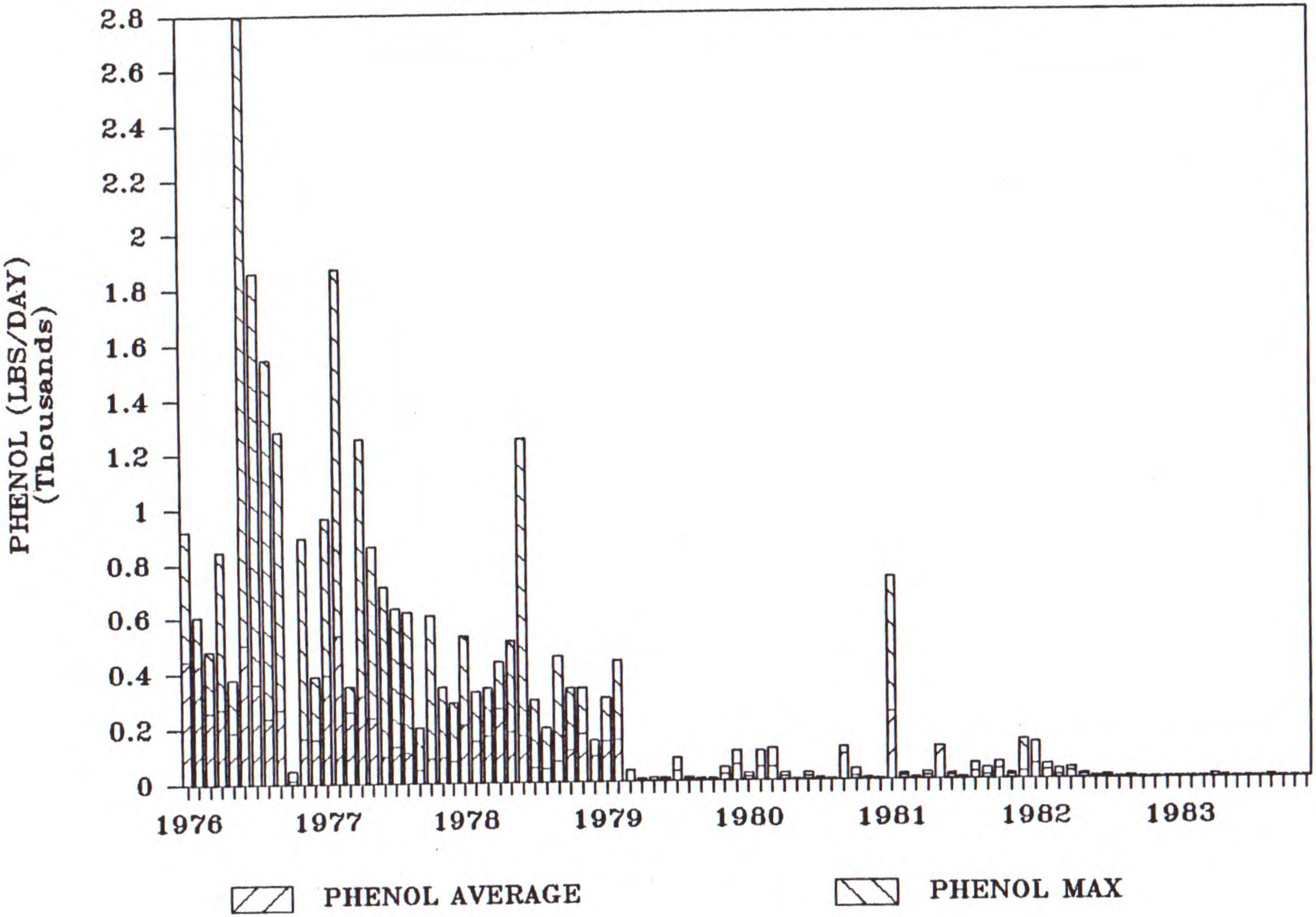


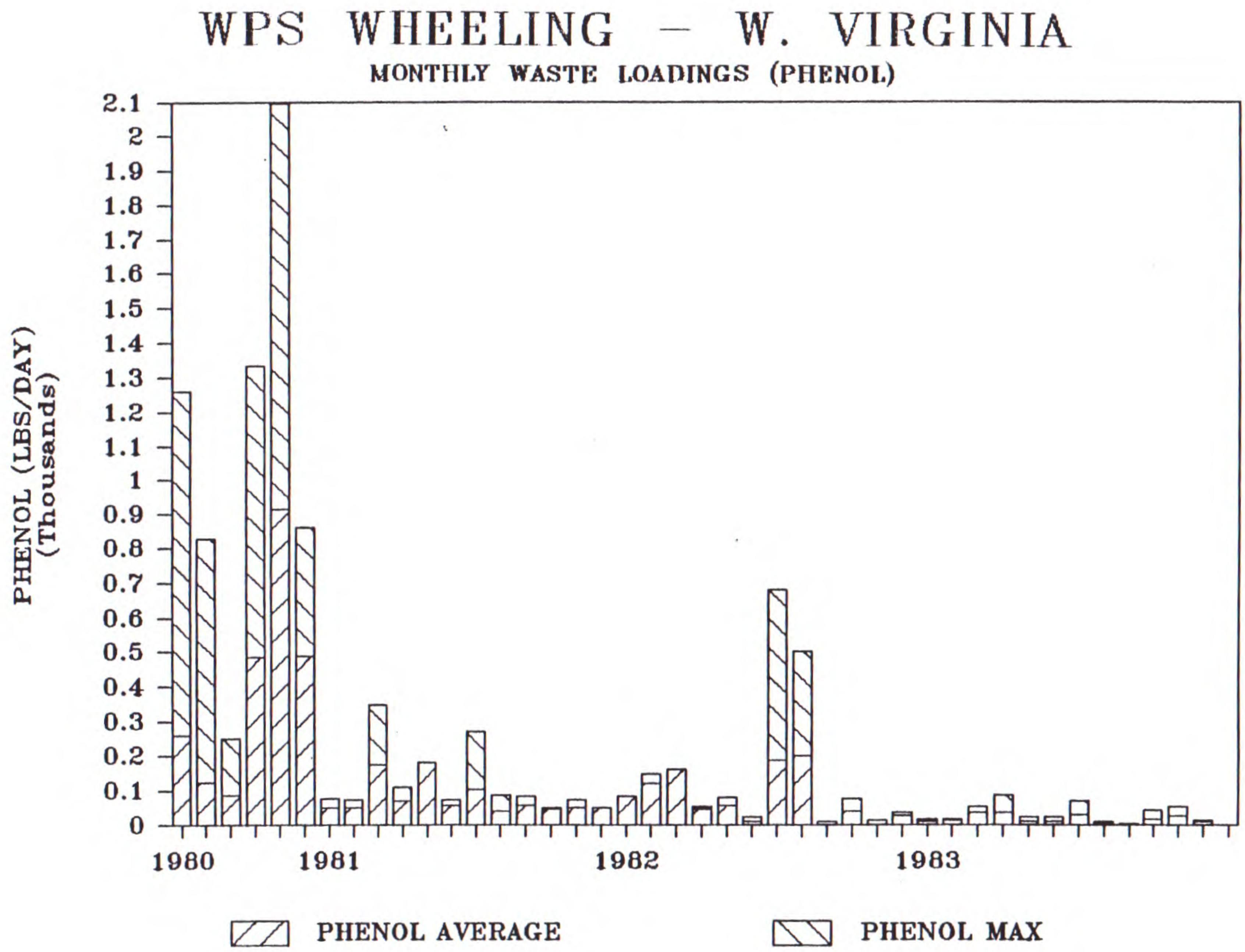

J&L ALIQUIPPA — PENNSYLVANIA
MONTHLY WASTE LOADINGS (PHENOL)
PHENOL (LBS/DAY)
(Thousands)
3.5
3
2.5
2
1.5
1
0.5
0
PHENOL AVERAGE
PHENOL MAX


QUAKERSTATE — W.VIRGINIA
MONTHLY WASTE LOADINGS (PHENOL)
PHENOL (LBS/DAY)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
PHENOL AVERAGE
PHENOL MAX

WEIRTON STEEL - W.VIRGINIA

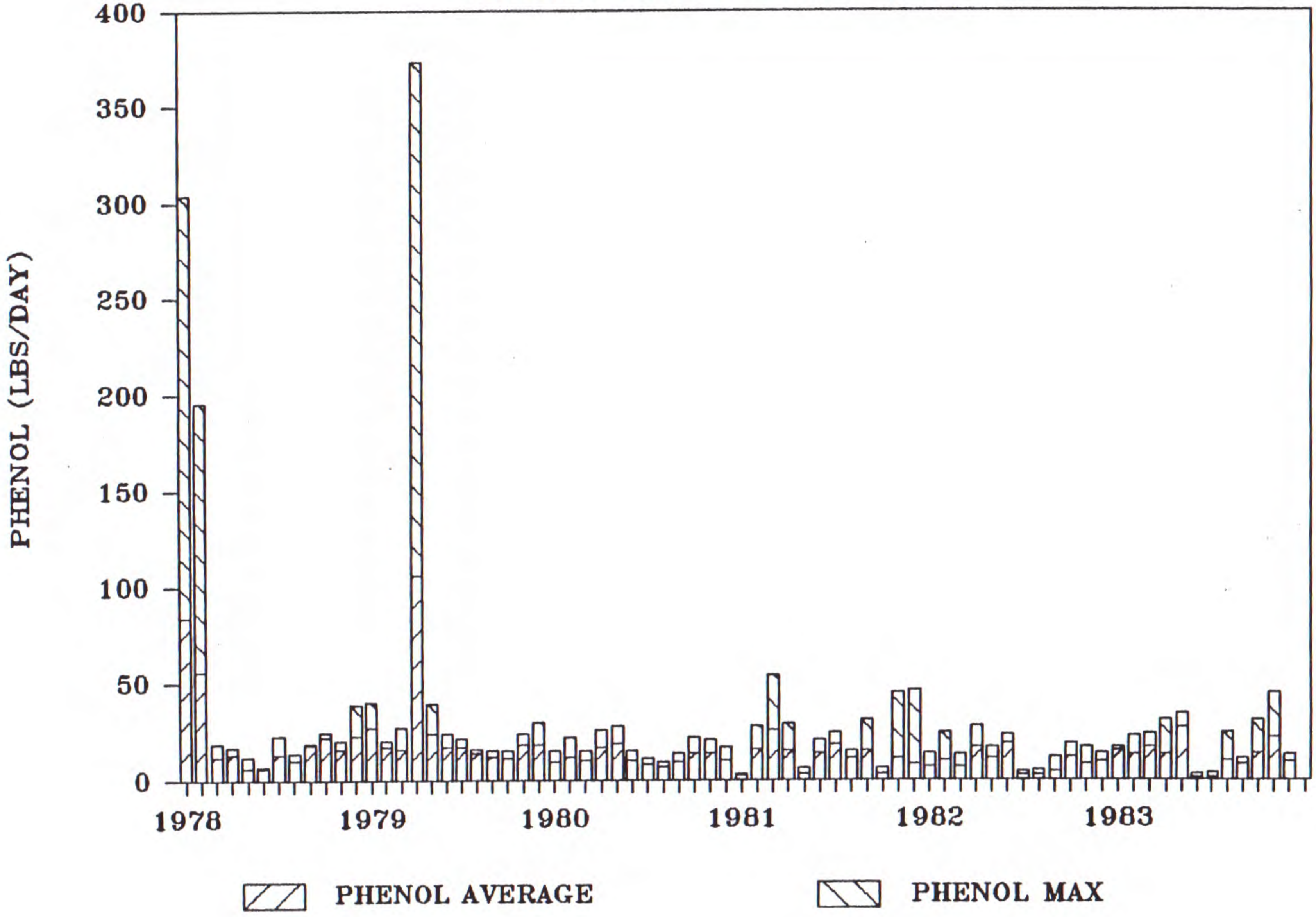
MONYHLY WASTE LOADINGS (PHENOL)





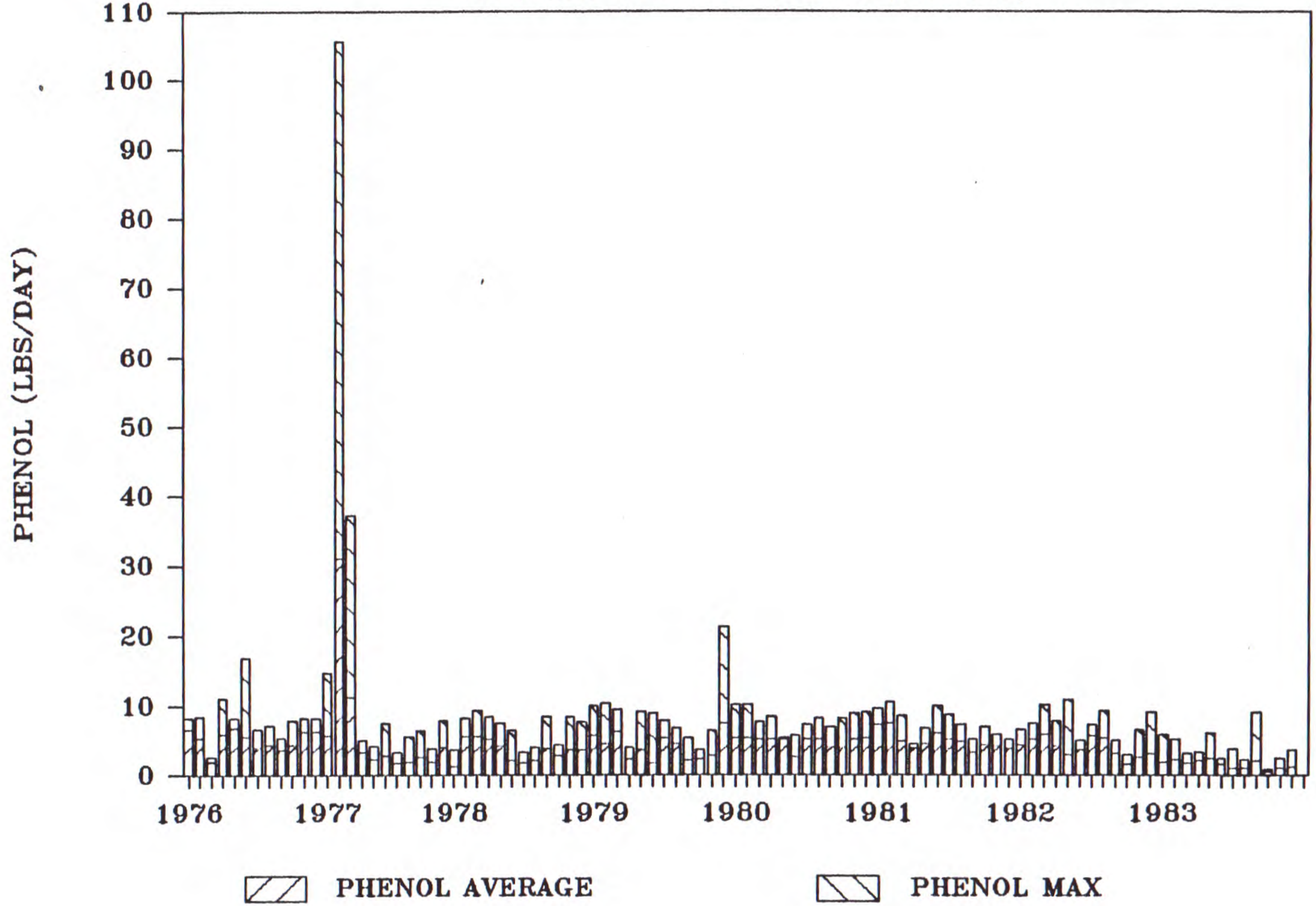
WPS WHEELING — W. VIRGINIA
MONTHLY WASTE LOADINGS (PHENOL)
PHENOL (LBS/DAY)
(Thousands)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1980
1981
1982
1983
PHENOL AVERAGE
PHENOL MAX

OLIN — W.VIRGINIA
MONTHLY WASTE LOADINGS (PHENOL)



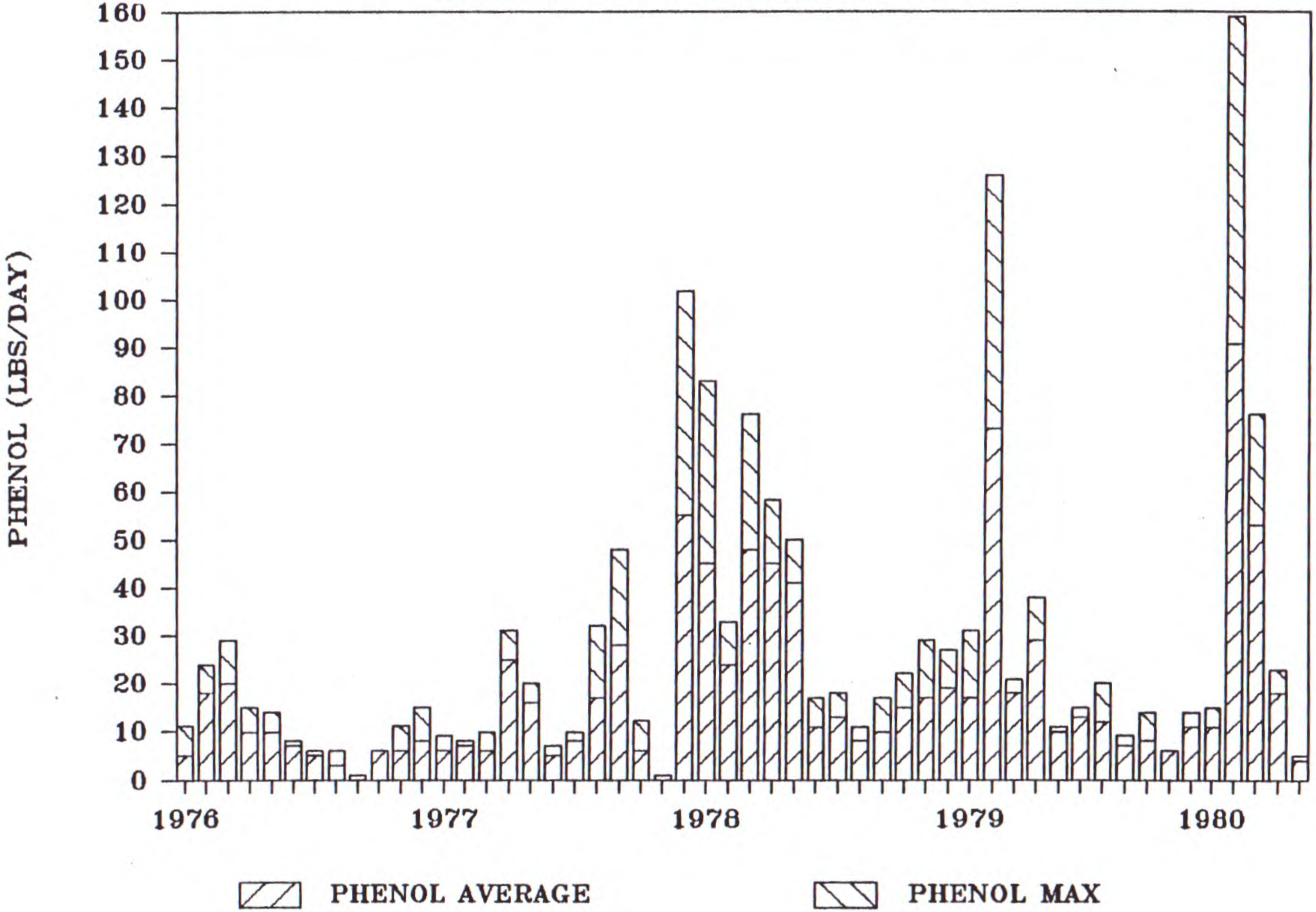
MOBAY CHEMICAL– W.VIRGINIA

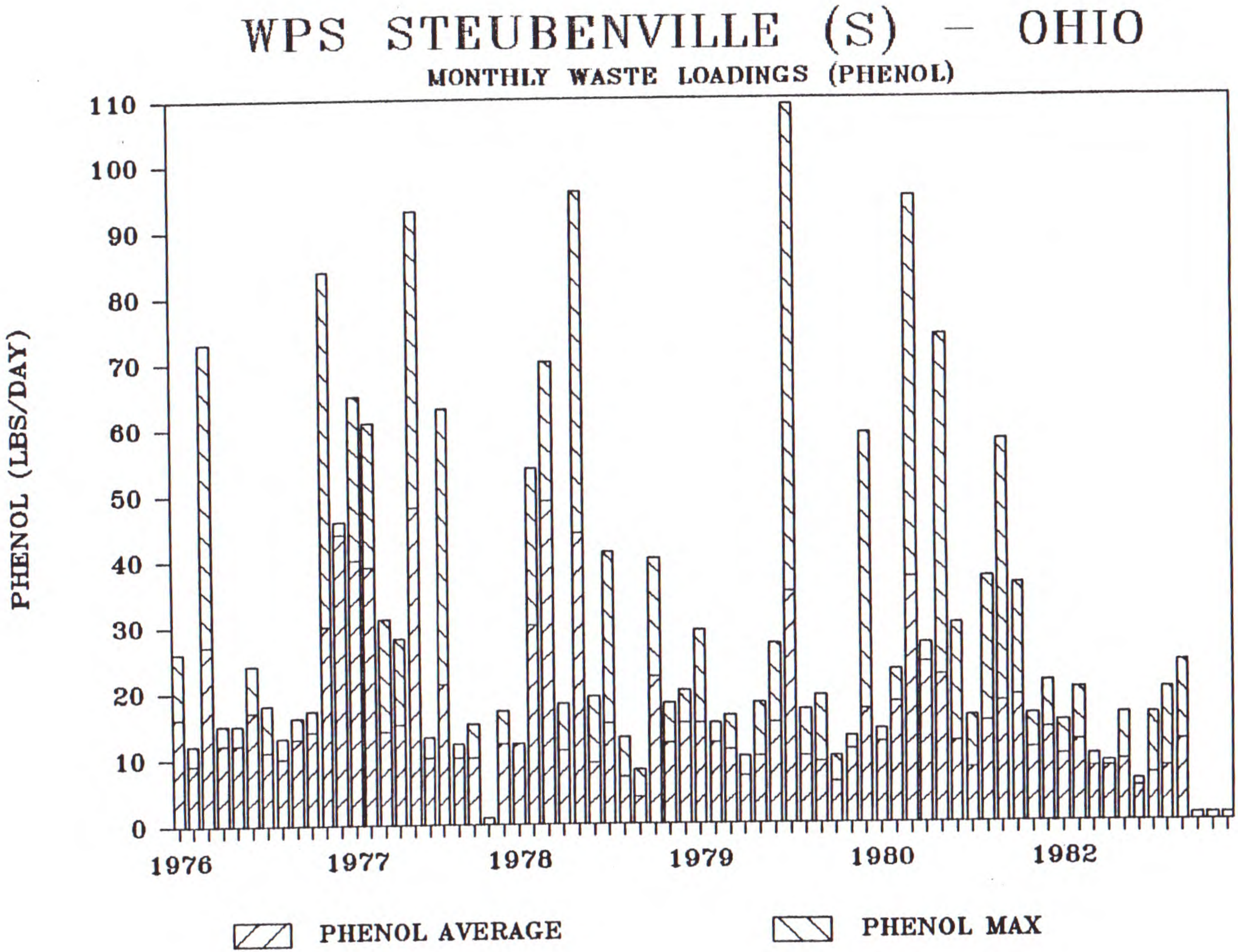
MONTHLY WASTE LOADINGS (PHENOL)



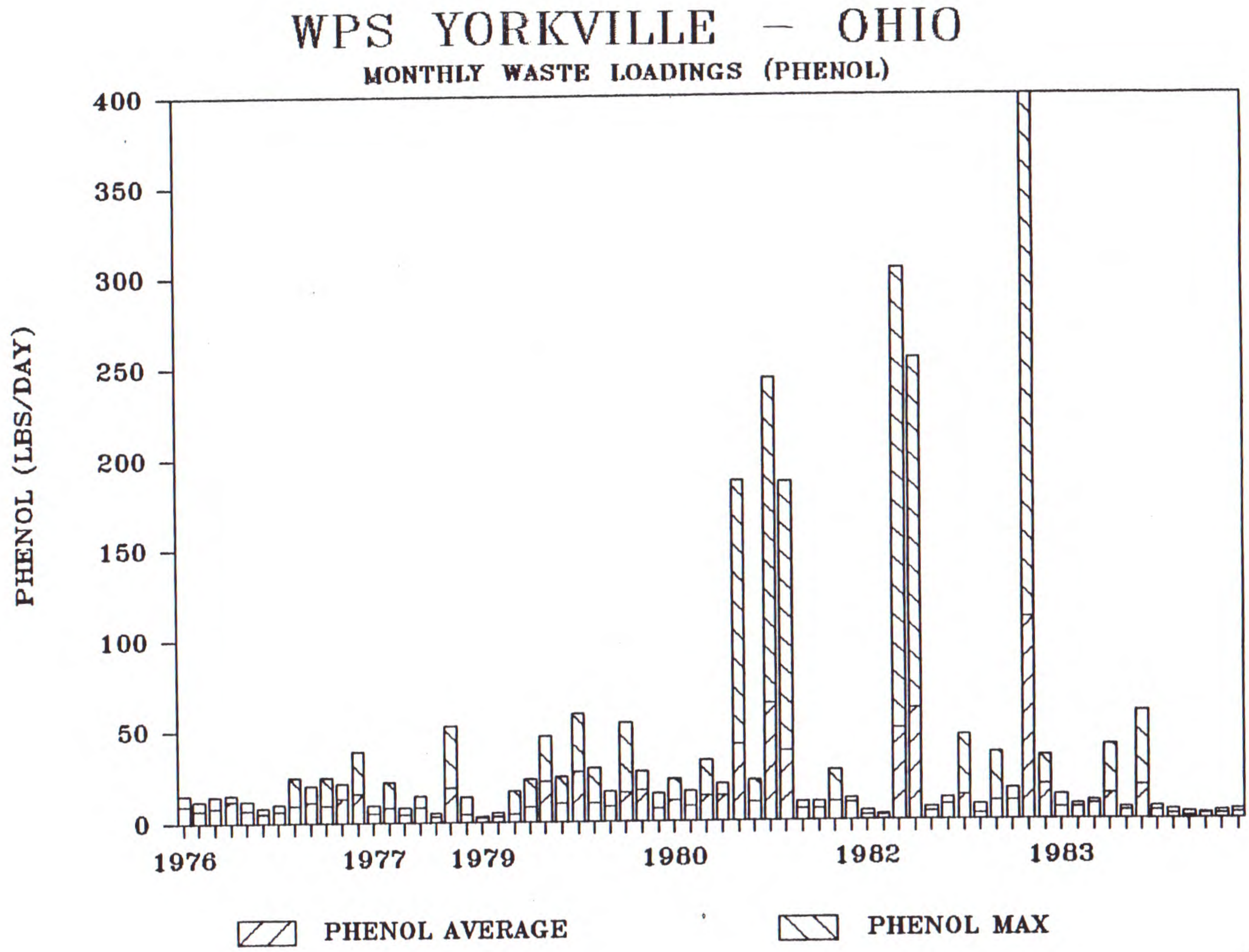
WPS STEUBENVILLE (N) – OHIO

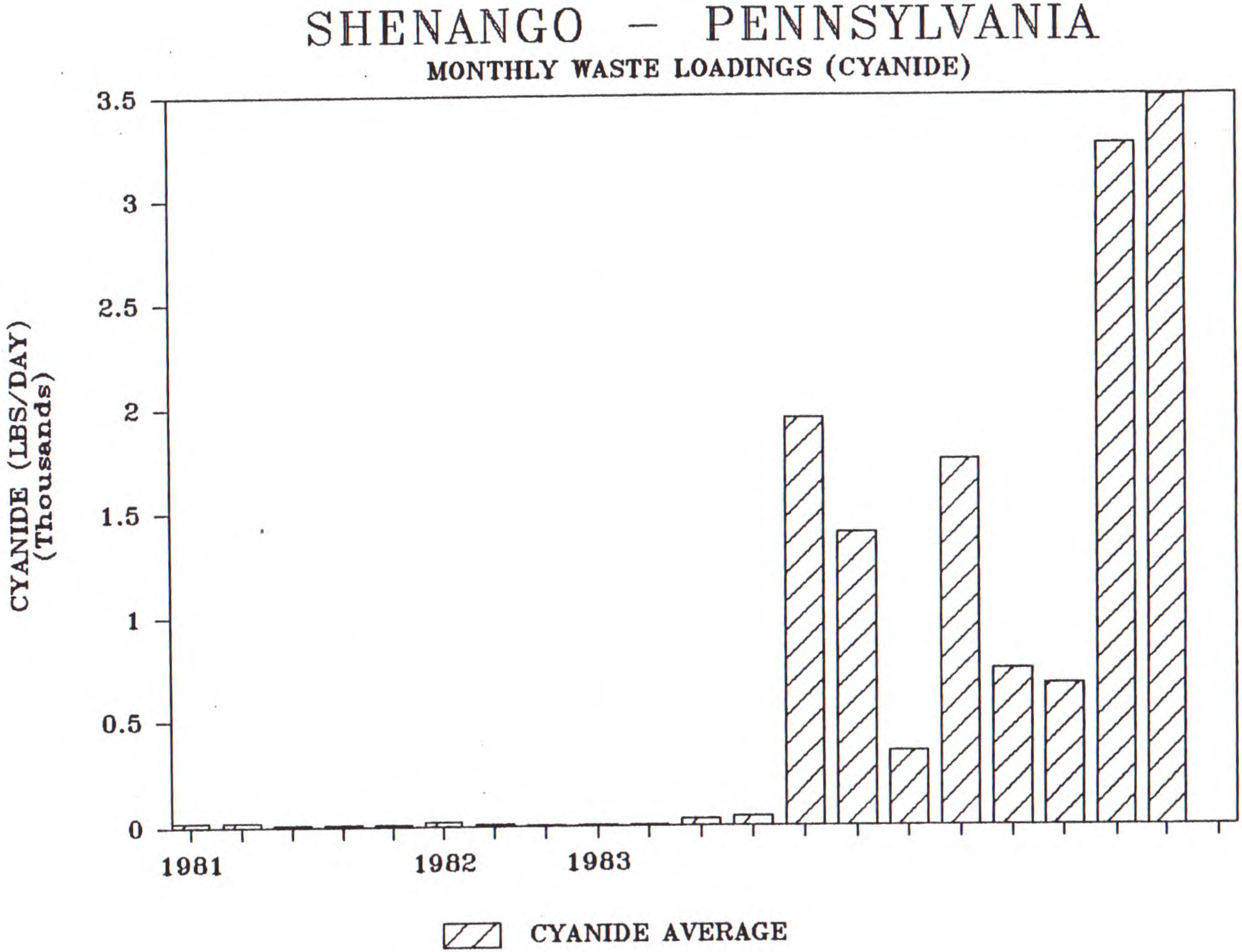
MONTHLY WASTE LOADINGS (PHENOL)





WPS STEUBENVILLE (S) - OHIO
MONTHLY WASTE LOADINGS (PHENOL)
PHENOL (LBS/DAY)
0
10
20
30
40
50
60
70
80
90
100
110
1976
1977
1978
1979
1980
1982
PHENOL AVERAGE
PHENOL MAX

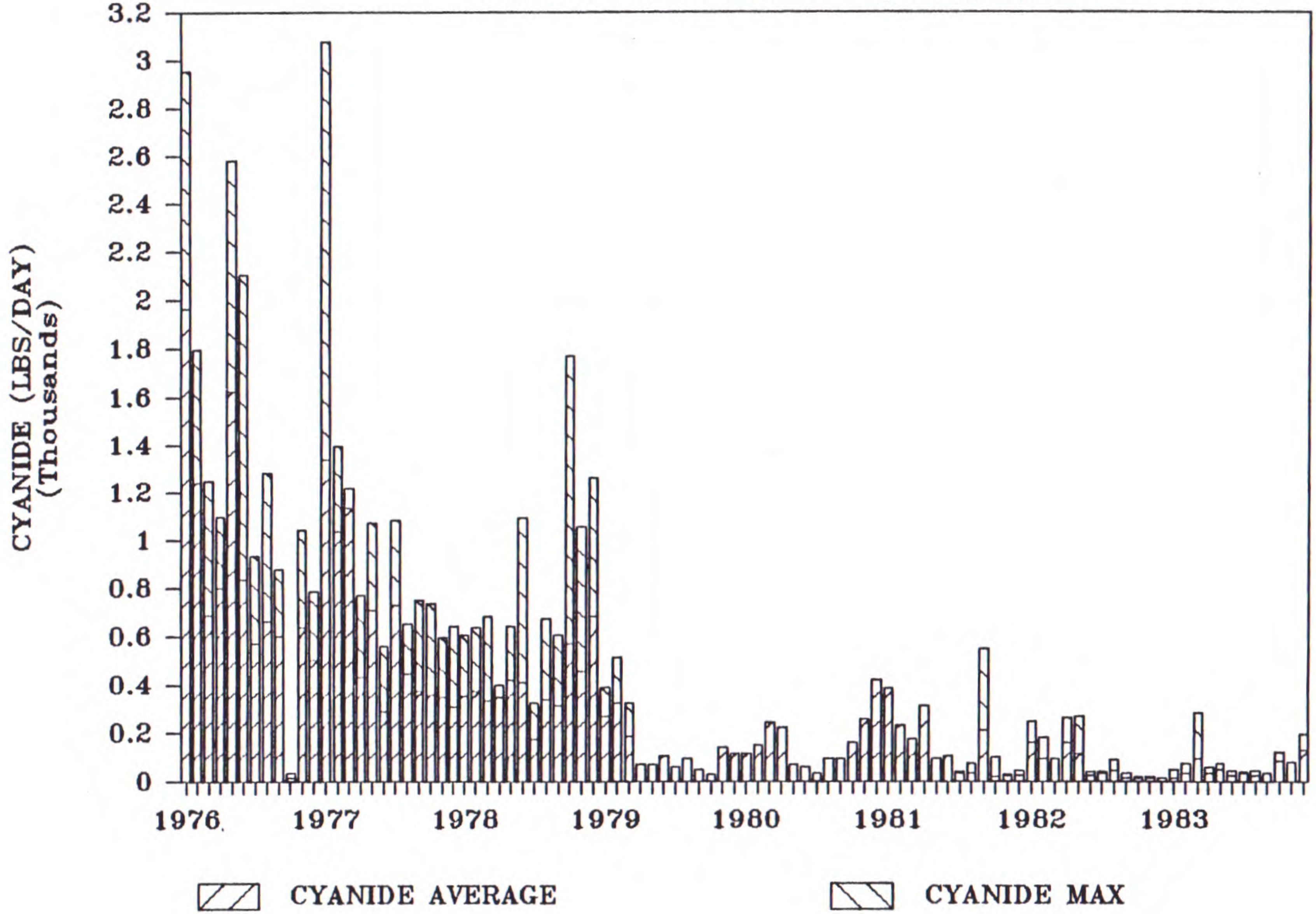

WPS YORKVILLE - OHIO
MONTHLY WASTE LOADINGS (PHENOL)
PHENOL (LBS/DAY)
400
350
300
250
200
150
100
50
0
1976
1977
1979
1980
1982
1983
PHENOL AVERAGE
PHENOL MAX

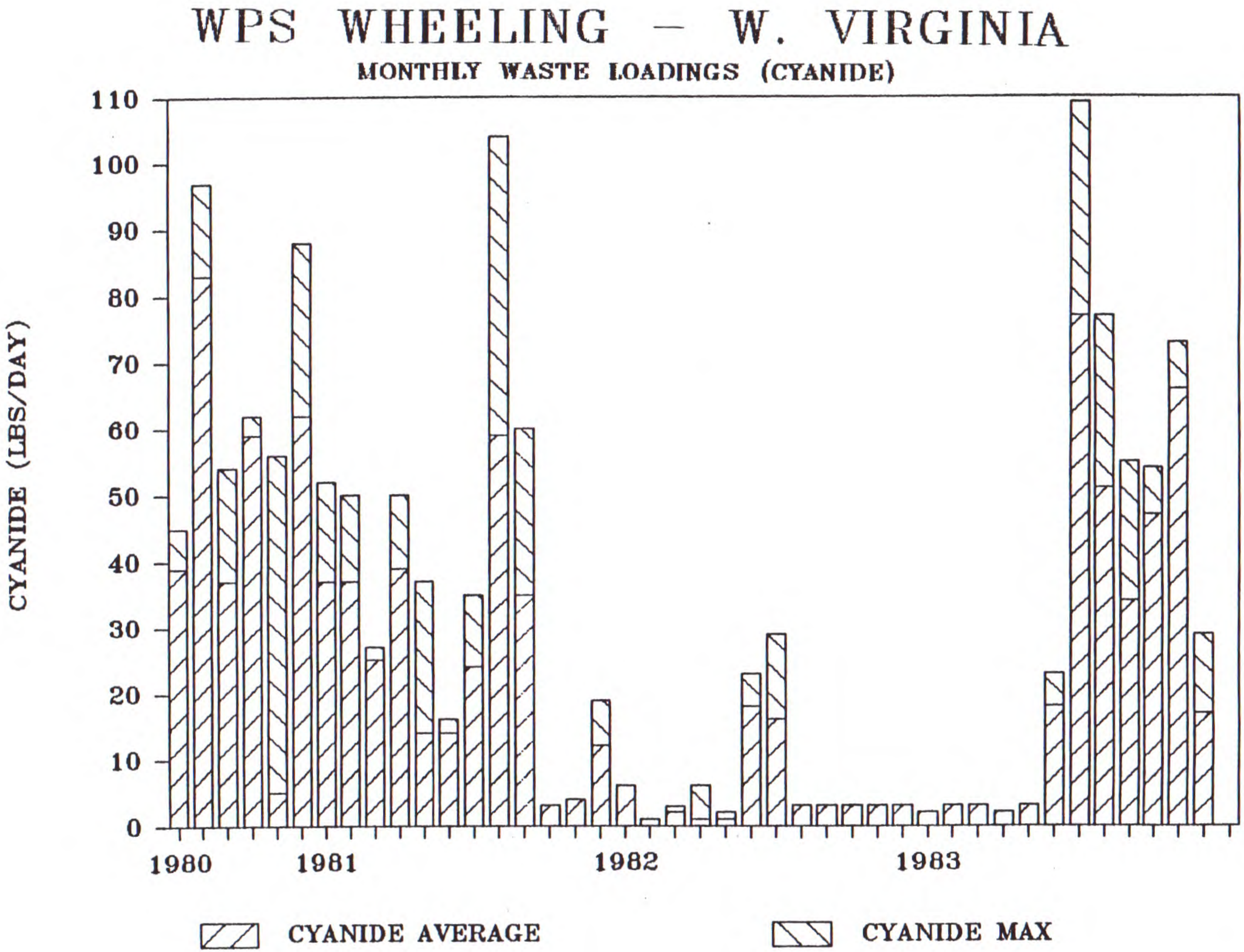


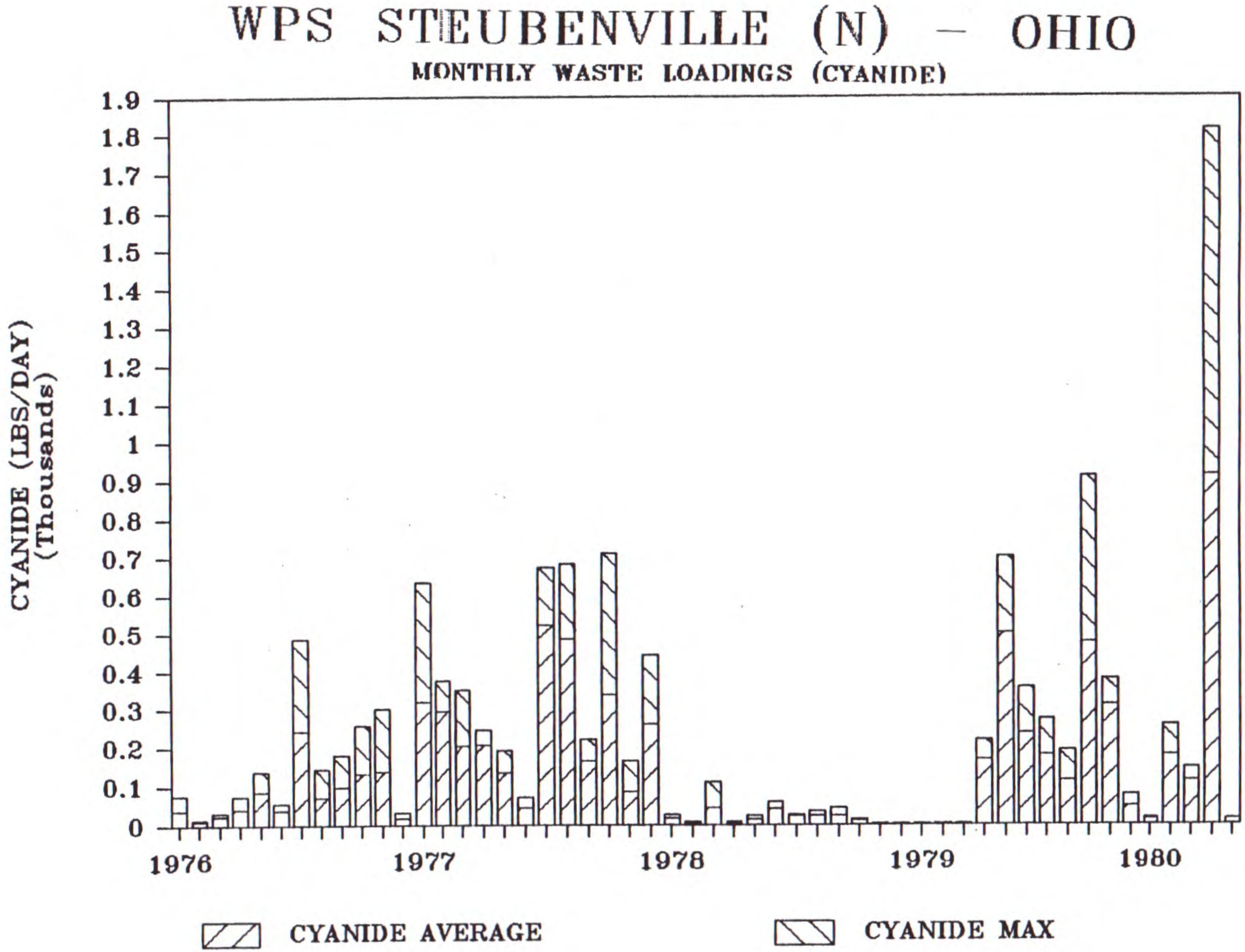
SHENANGO – PENNSYLVANIA
MONTHLY WASTE LOADINGS (CYANIDE)
CYANIDE (LBS/DAY)
(Thousands)
3.5
3
2.5
2
1.5
1
0.5
0
1981
1982
1983
CYANIDE AVERAGE

WEIRTON STEEL – W.VIRGINIA

MONTHLY WASTE LOADINGS (CYANIDE)

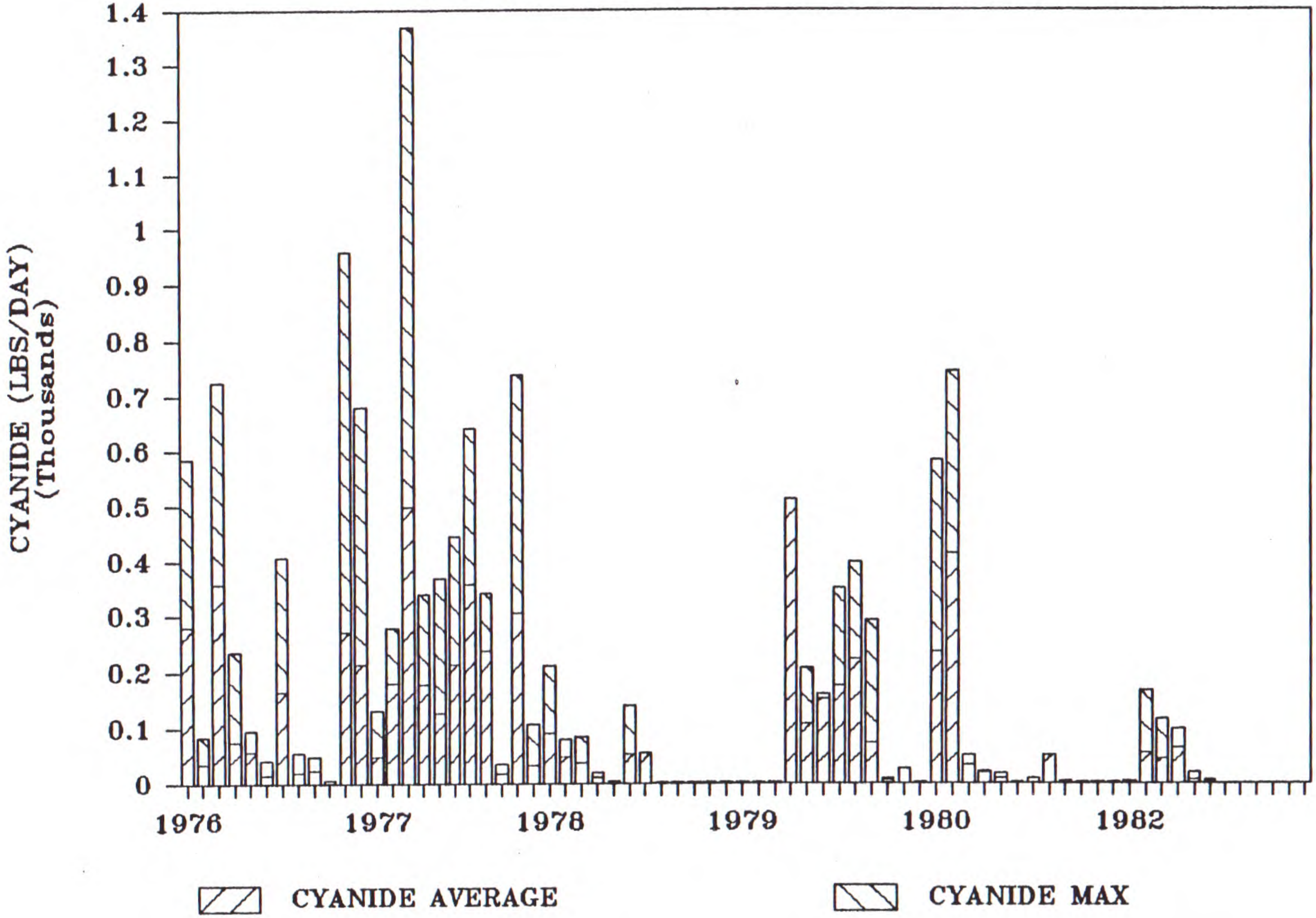



WPS WHEELING - W. VIRGINIA
MONTHLY WASTE LOADINGS (CYANIDE)
CYANIDE (LBS/DAY)
110
100
90
80
70
60
50
40
30
20
10
0
1980
1981
1982
1983
CYANIDE AVERAGE
CYANIDE MAX


WPS STEUBENVILLE (N) - OHIO
MONTHLY WASTE LOADINGS (CYANIDE)
CYANIDE (LBS/DAY)
(Thousands)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1976
1977
1978
1979
1980
CYANIDE AVERAGE
CYANIDE MAX

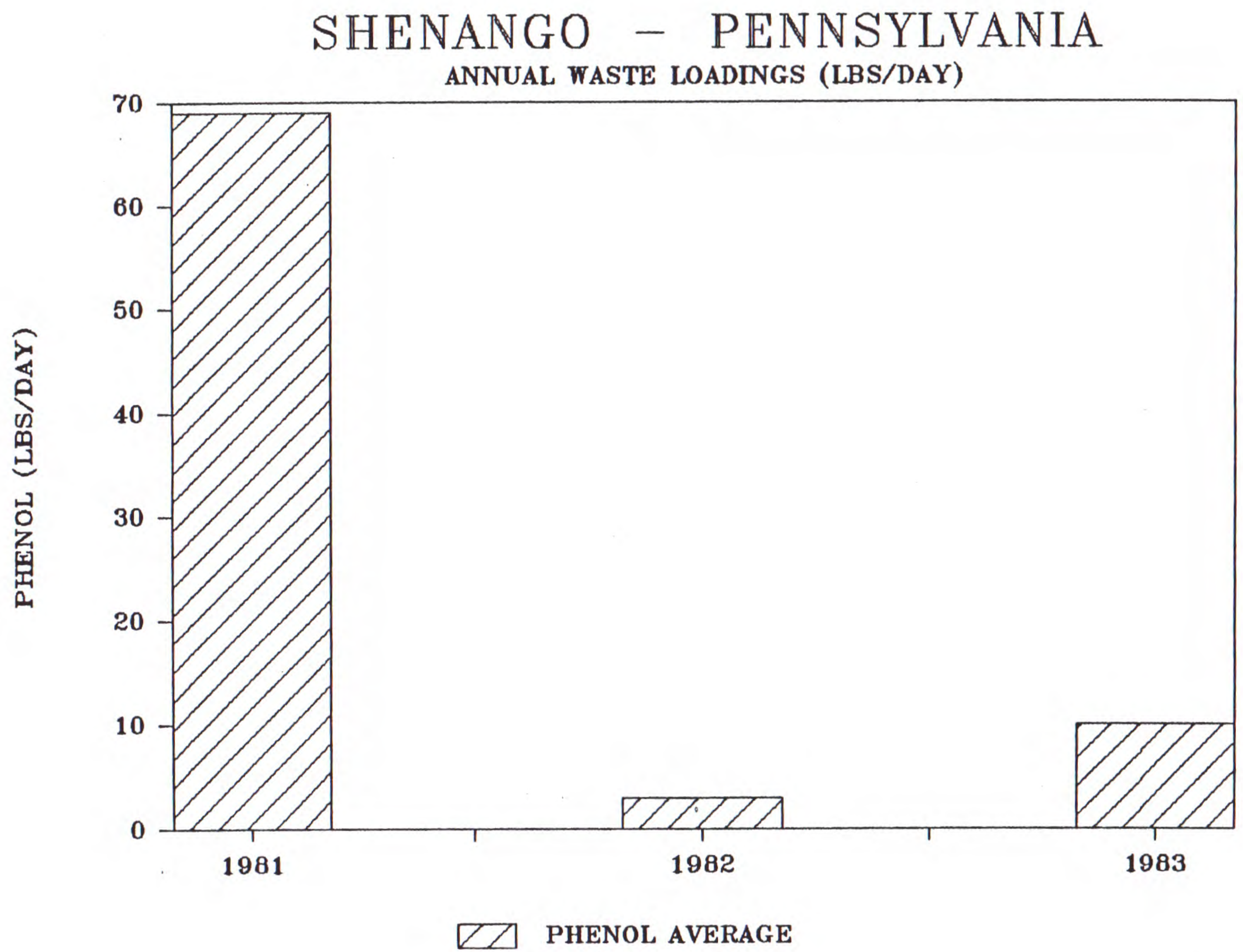
WPS STEUBENVILLE (S) – OHIO

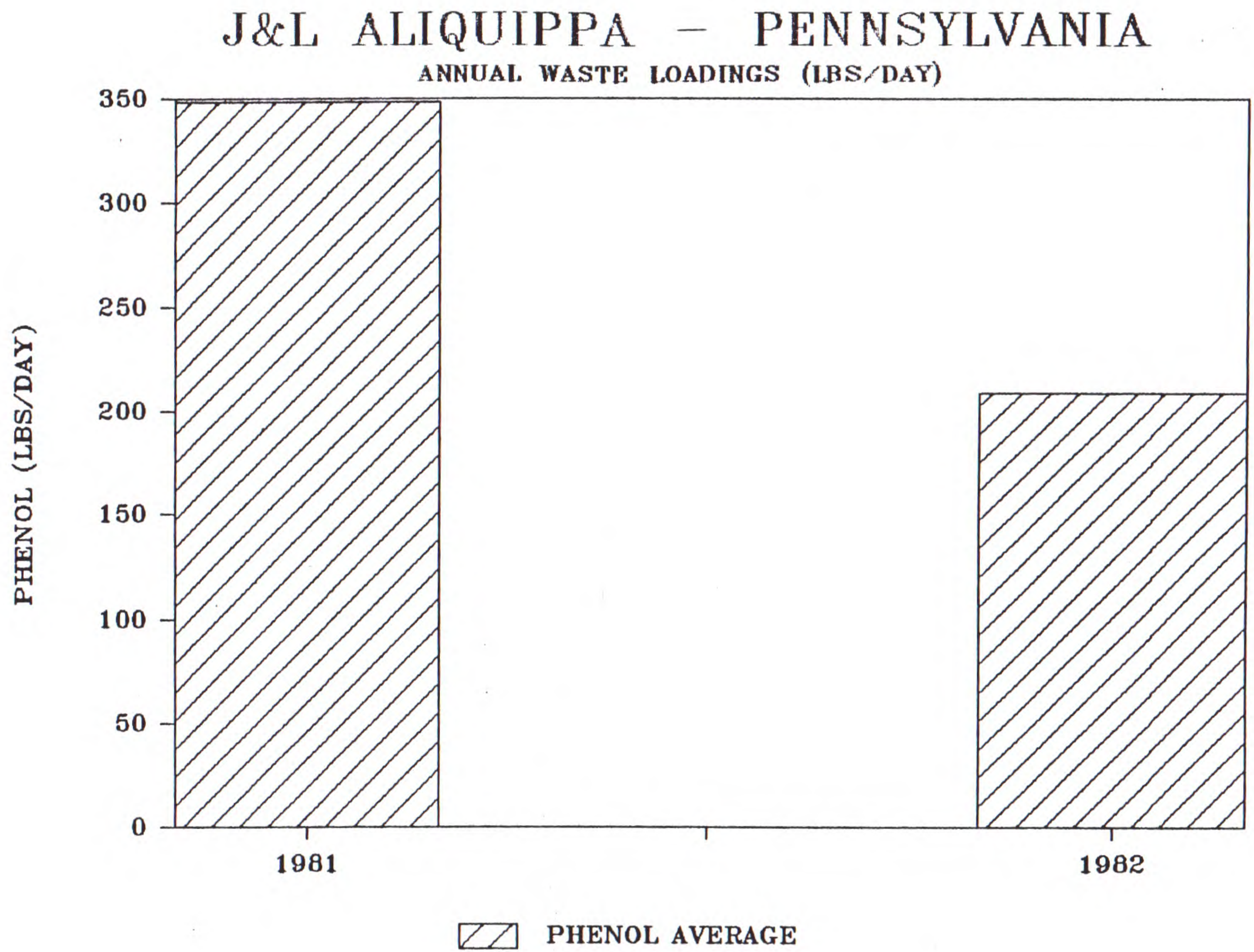
MONTHLY WASTE LOADINGS (CYANIDE)

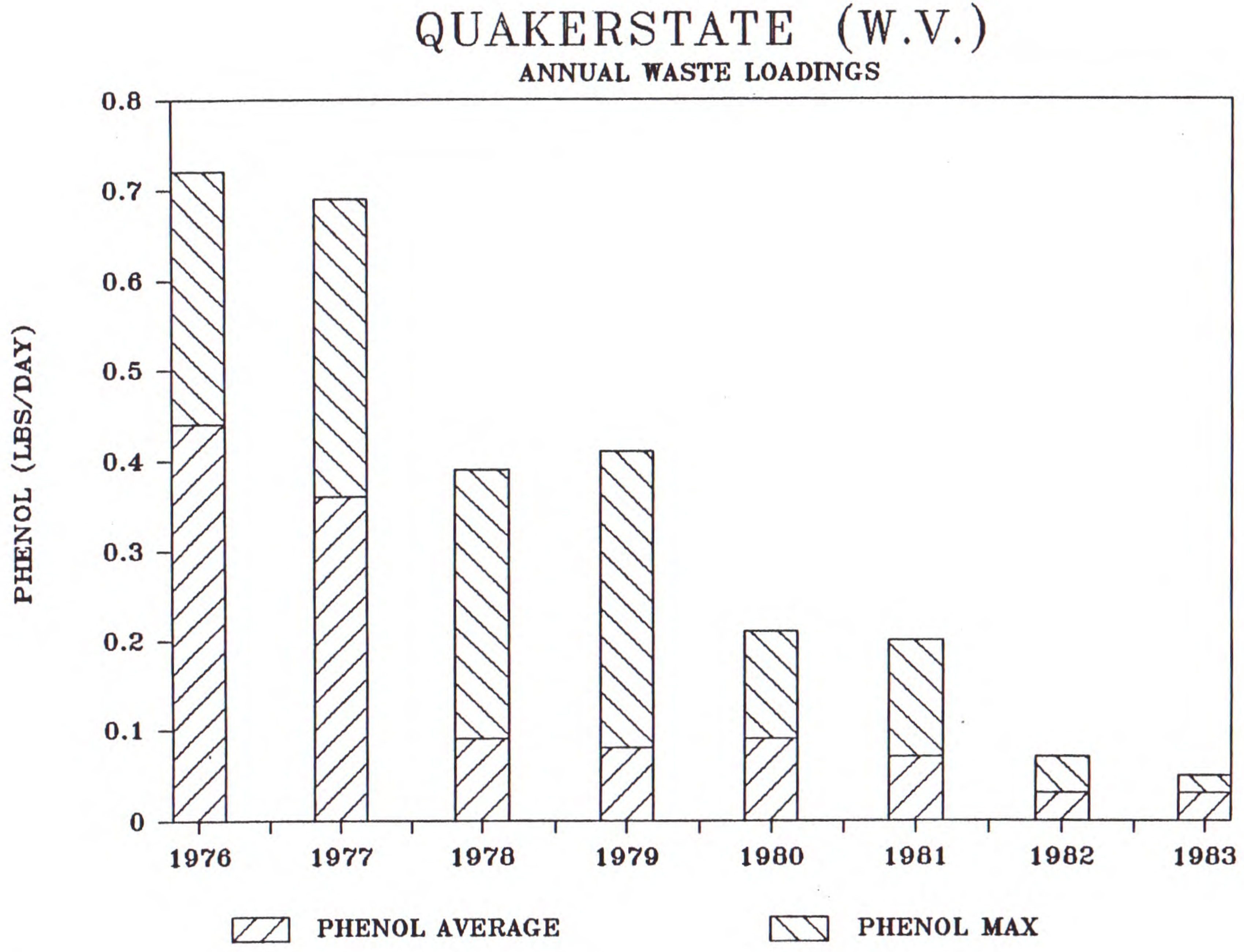


APPENDIX 2

ANNUAL HISTOGRAMS OF MAJOR PERMITTED CYANIDE AND PHENOLICS DISCHARGES

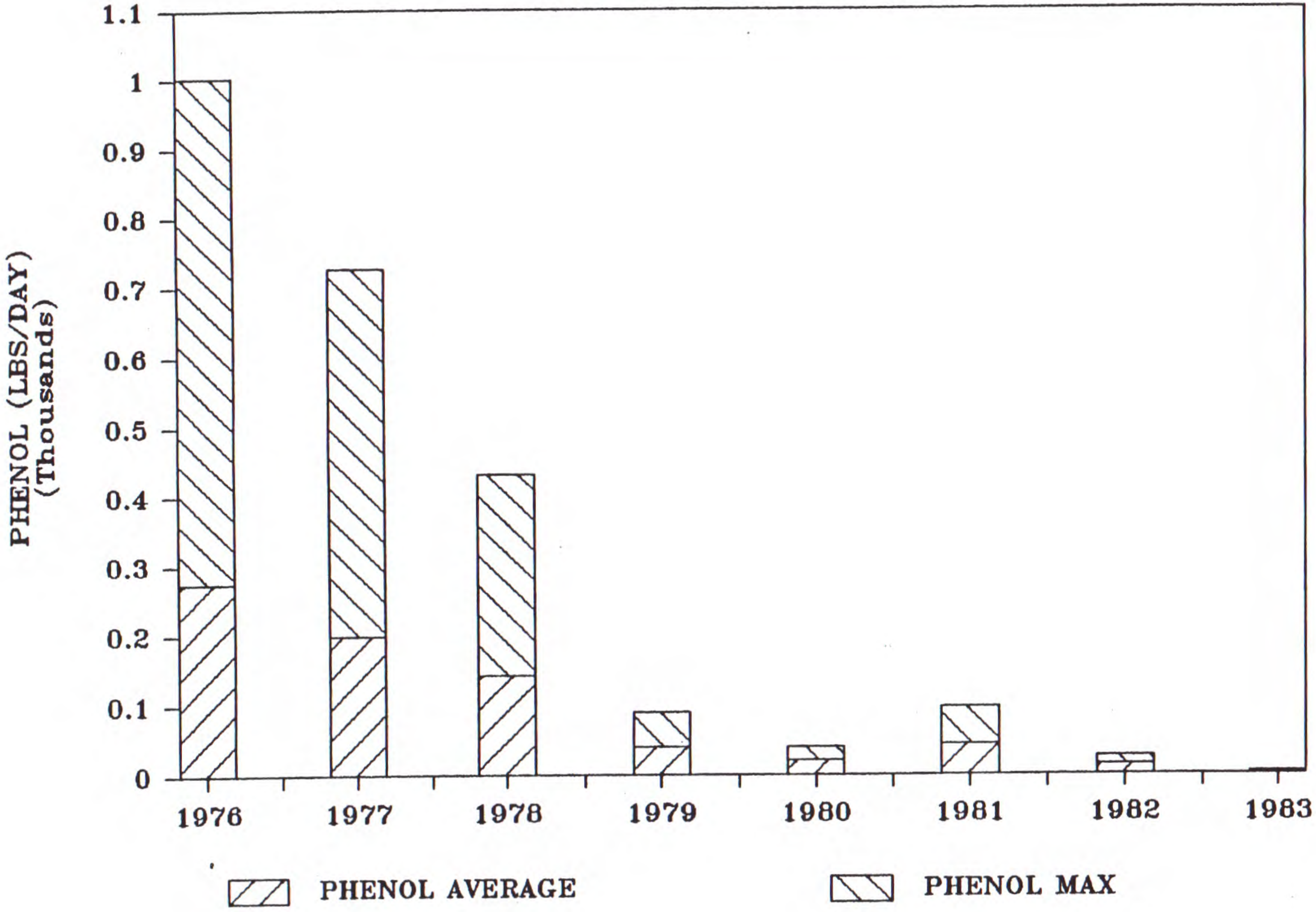

SHENANGO – PENNSYLVANIA
ANNUAL WASTE LOADINGS (LBS/DAY)
PHENOL (LBS/DAY)
0
10
20
30
40
50
60
70
1981
1982
1983
PHENOL AVERAGE

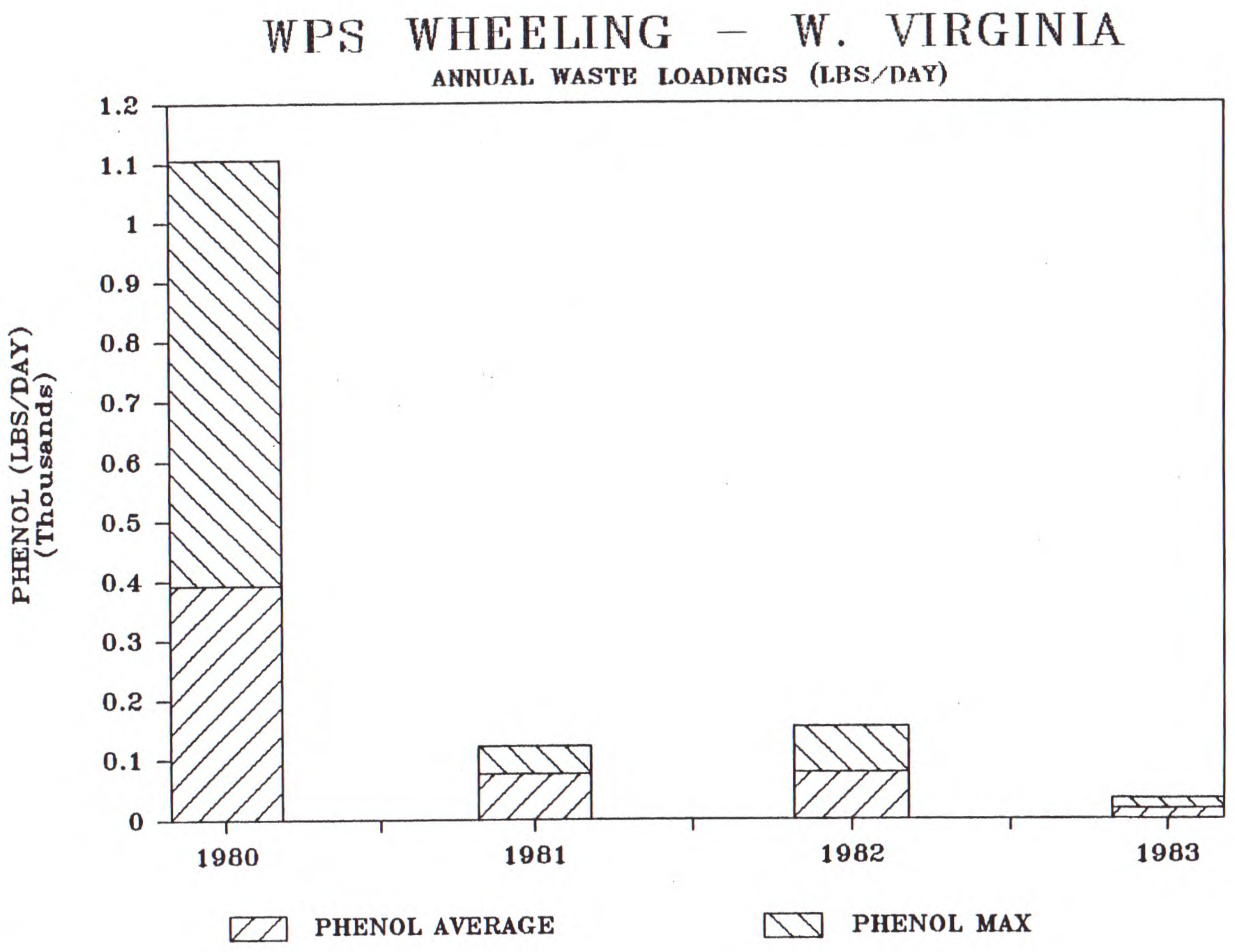

J&L ALIQUIPPA – PENNSYLVANIA
ANNUAL WASTE LOADINGS (LBS/DAY)
PHENOL (LBS/DAY)
350
300
250
200
150
100
50
0
1981
1982
PHENOL AVERAGE


QUAKERSTATE (W.V.)
ANNUAL WASTE LOADINGS
PHENOL (LBS/DAY)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1976
1977
1978
1979
1980
1981
1982
1983
PHENOL AVERAGE
PHENOL MAX

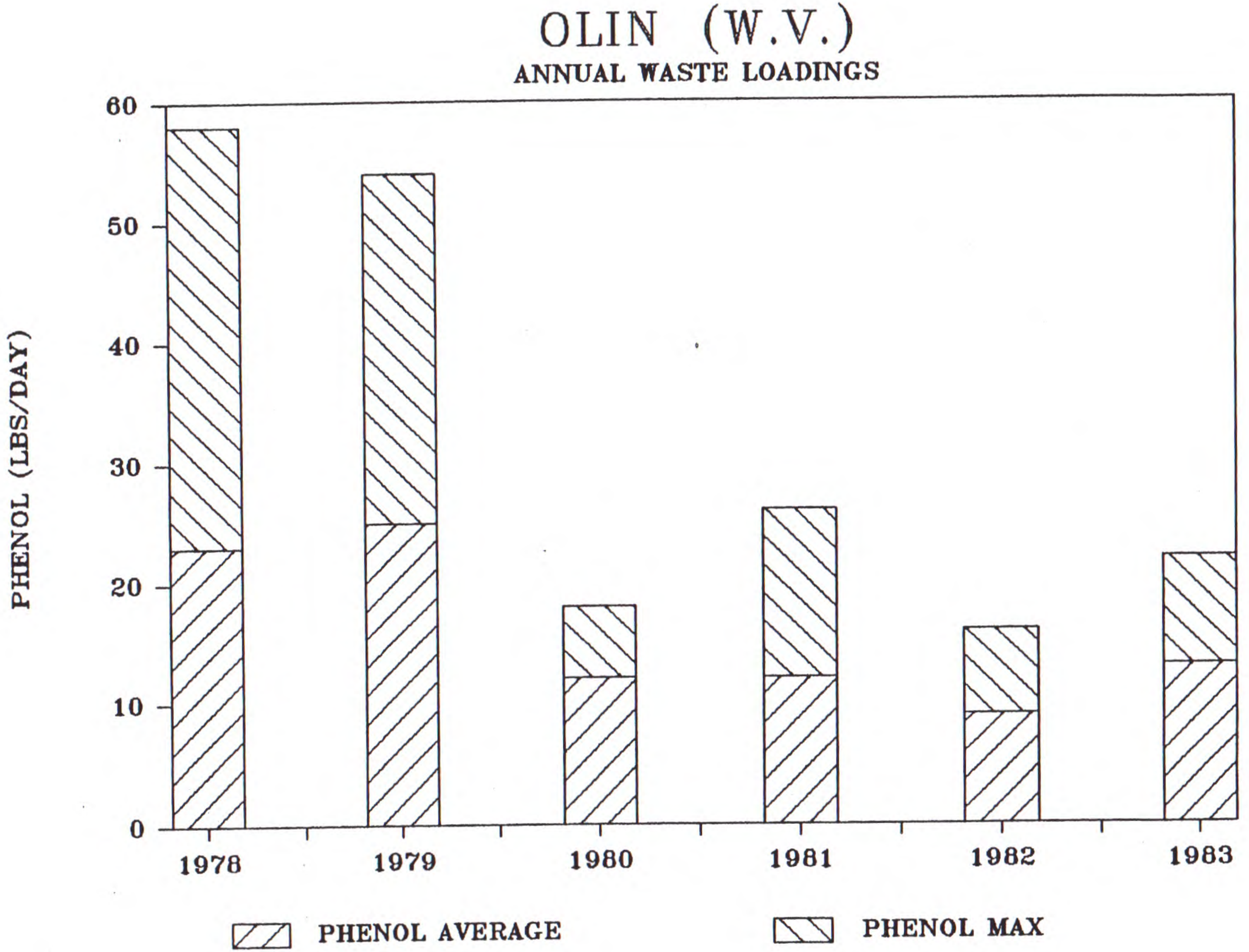
WEIRTON STEEL (W.V.)

ANNUAL WASTE LOADINGS



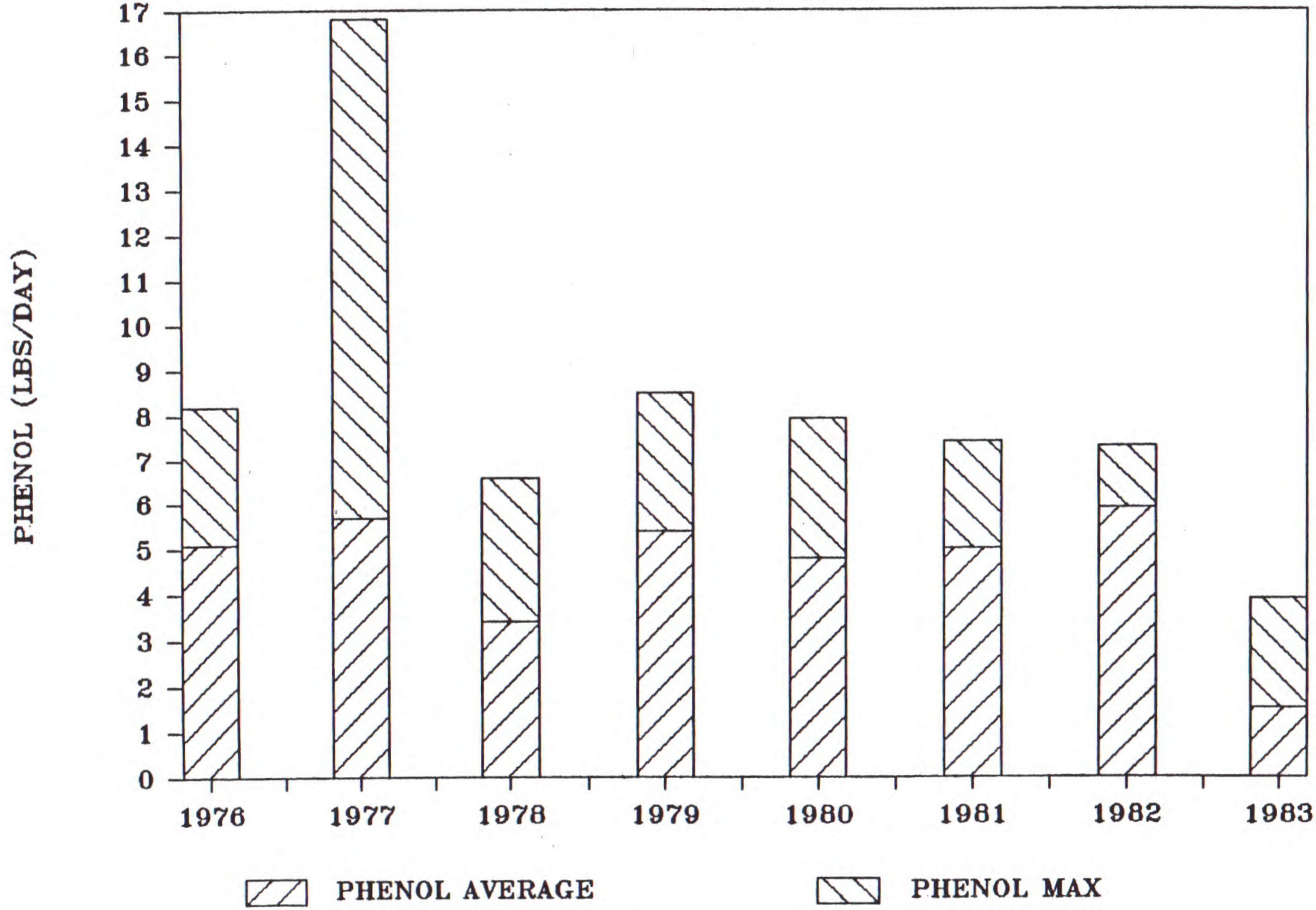


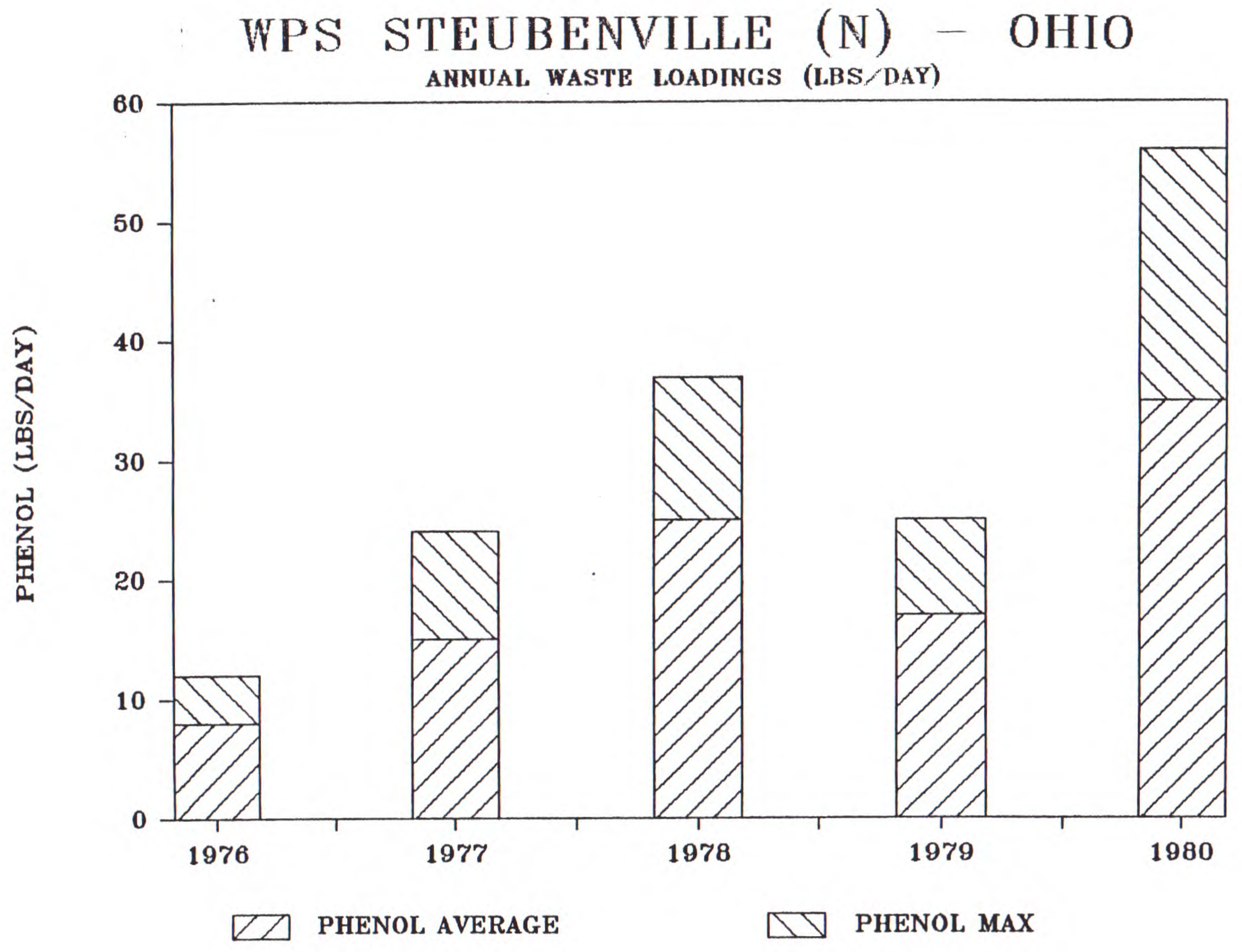
WPS WHEELING — W. VIRGINIA
ANNUAL WASTE LOADINGS (LBS/DAY)
PHENOL (LBS/DAY)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1980
1981
1982
1983
PHENOL AVERAGE
PHENOL MAX


OLIN (W.V.)
ANNUAL WASTE LOADINGS
PHENOL (LBS/DAY)
0
10
20
30
40
50
60
1978
1979
1980
1981
1982
1983
PHENOL AVERAGE
PHENOL MAX

MOBAY CHEMICAL (W.V.)

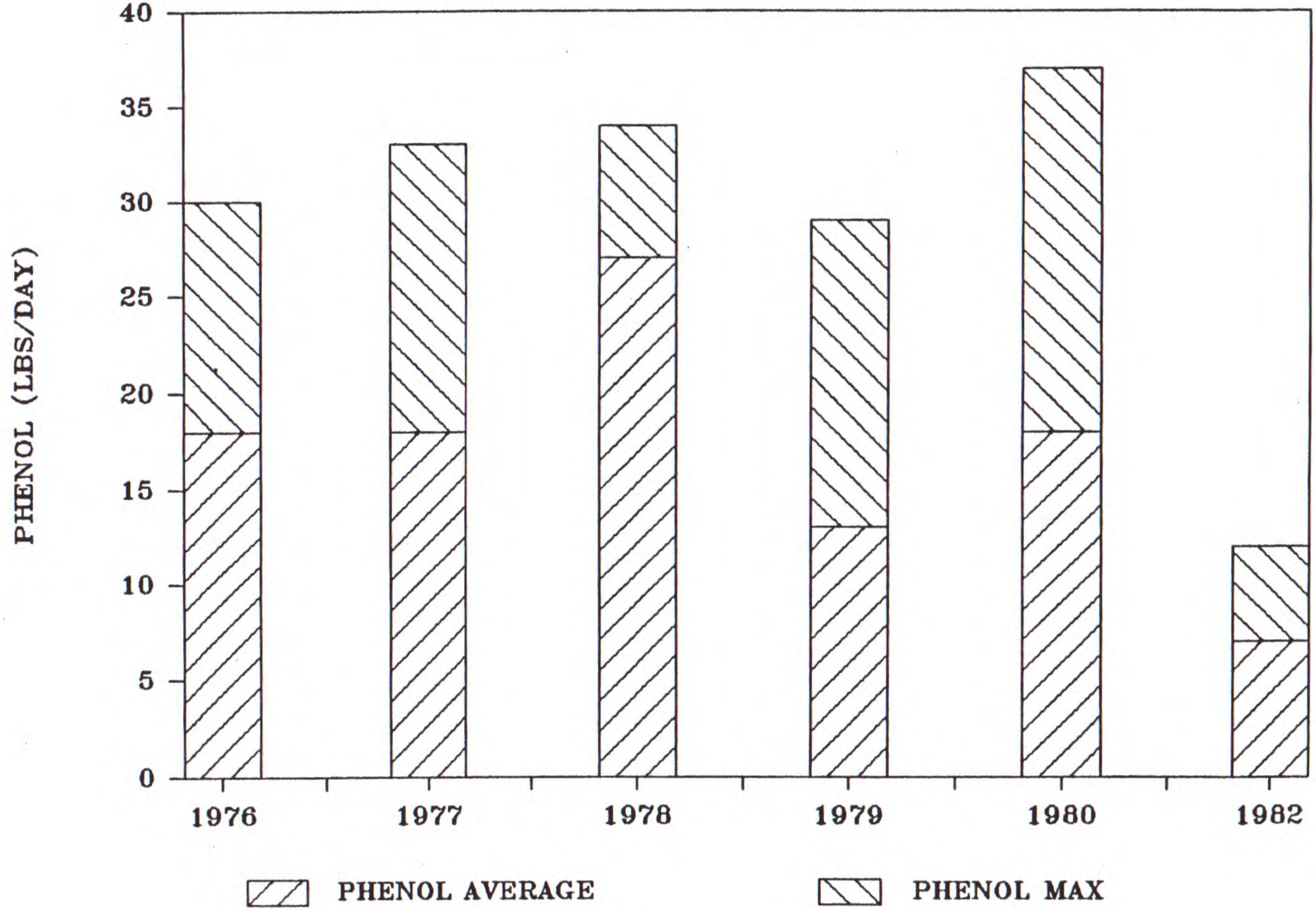
ANNUAL WASTE LOADINGS (LBS/DAY)

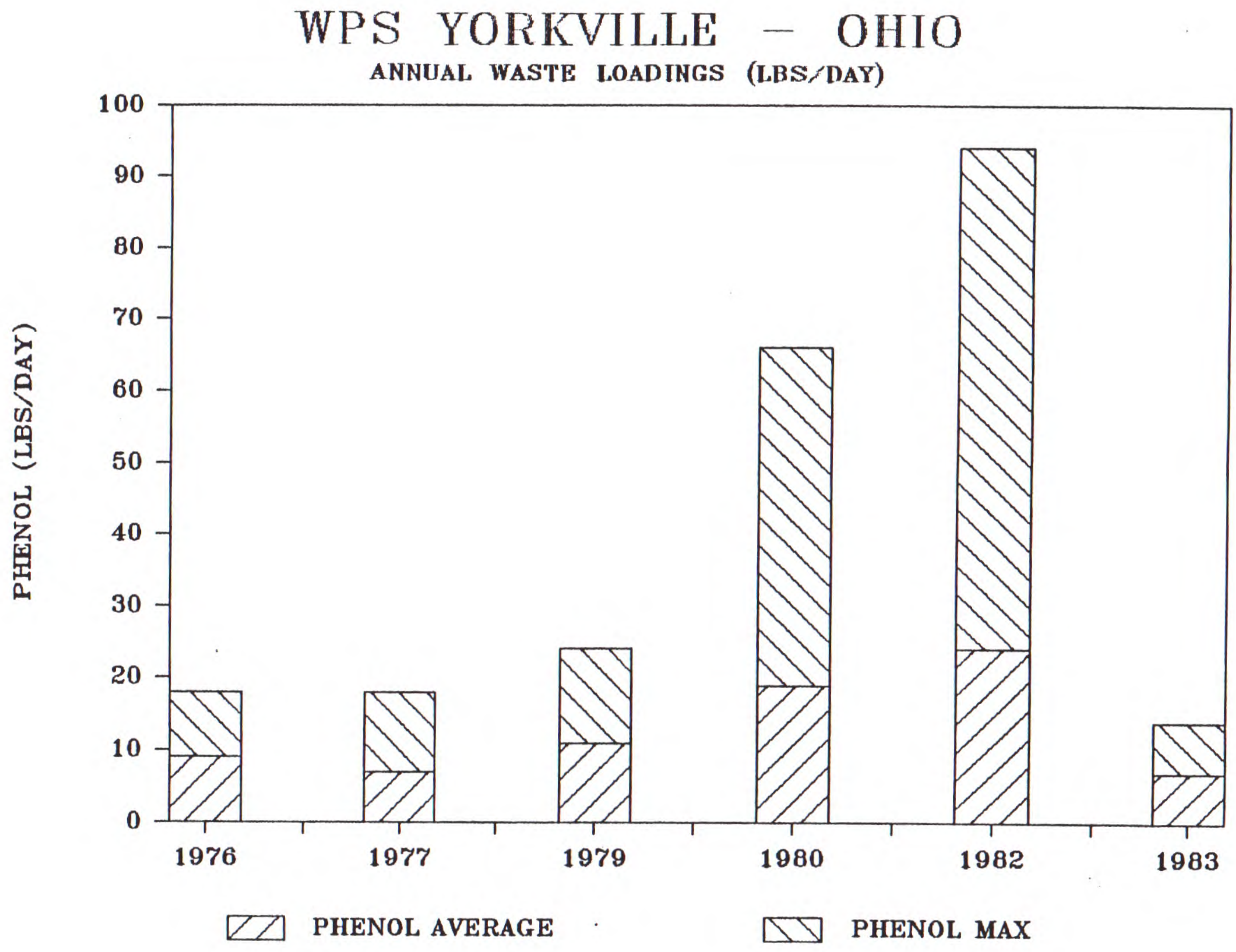


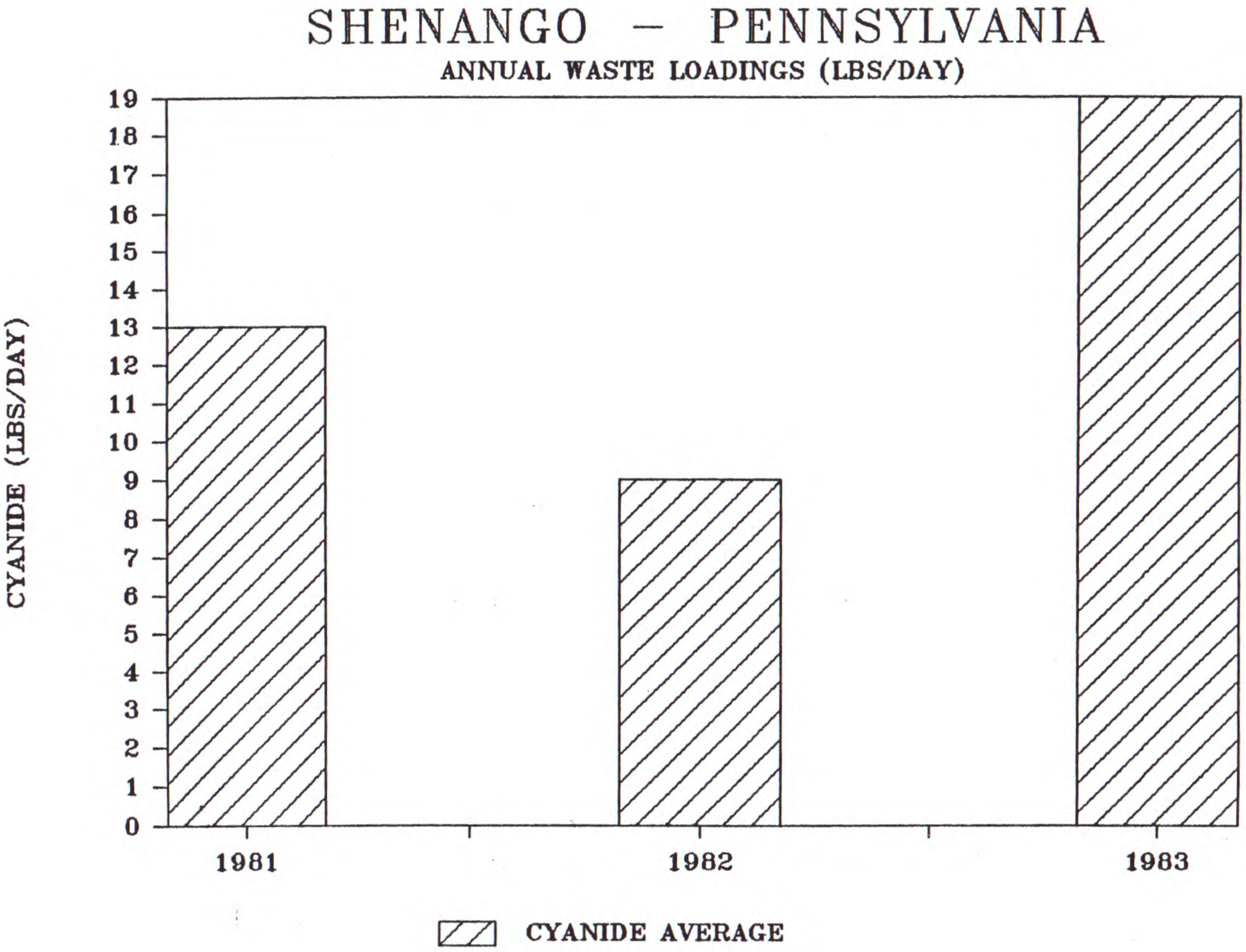

WPS STEUBENVILLE (N) - OHIO
ANNUAL WASTE LOADINGS (LBS/DAY)
PHENOL (LBS/DAY)
60
50
40
30
20
10
0
1976
1977
1978
1979
1980
PHENOL AVERAGE
PHENOL MAX

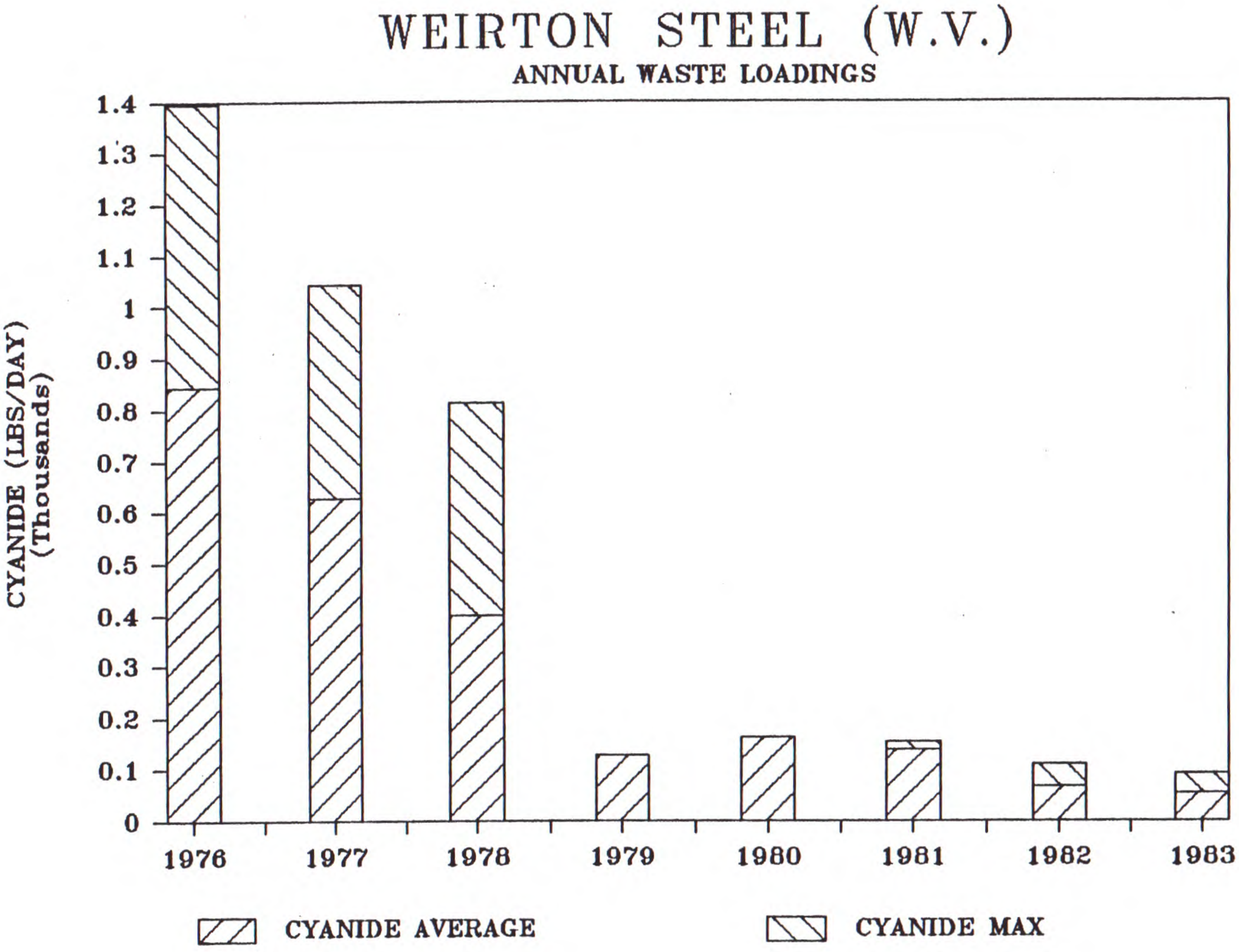
WPS STEUBENVILLE (S) – OHIO

ANNUAL WASTE LOADINGS (LBS/DAY)



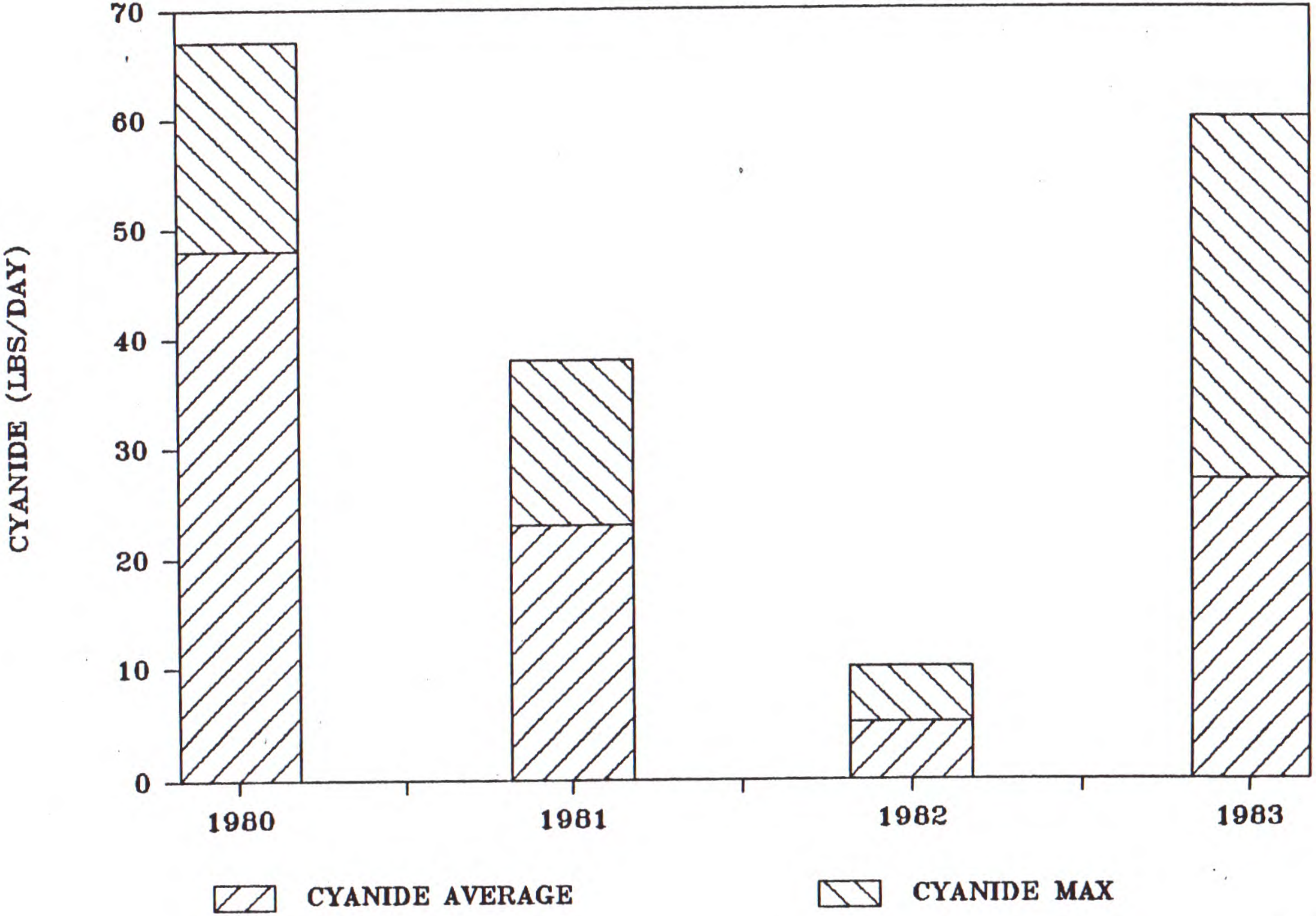

WPS YORKVILLE - OHIO
ANNUAL WASTE LOADINGS (LBS/DAY)
PHENOL (LBS/DAY)
100
90
80
70
60
50
40
30
20
10
0
1976
1977
1979
1980
1982
1983
PHENOL AVERAGE
PHENOL MAX


SHENANGO – PENNSYLVANIA
ANNUAL WASTE LOADINGS (LBS/DAY)
CYANIDE (LBS/DAY)
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1981
1982
1983
CYANIDE AVERAGE


WEIRTON STEEL (W.V.)
ANNUAL WASTE LOADINGS
CYANIDE (LBS/DAY)
(Thousands)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1976
1977
1978
1979
1980
1981
1982
1983
CYANIDE AVERAGE
CYANIDE MAX

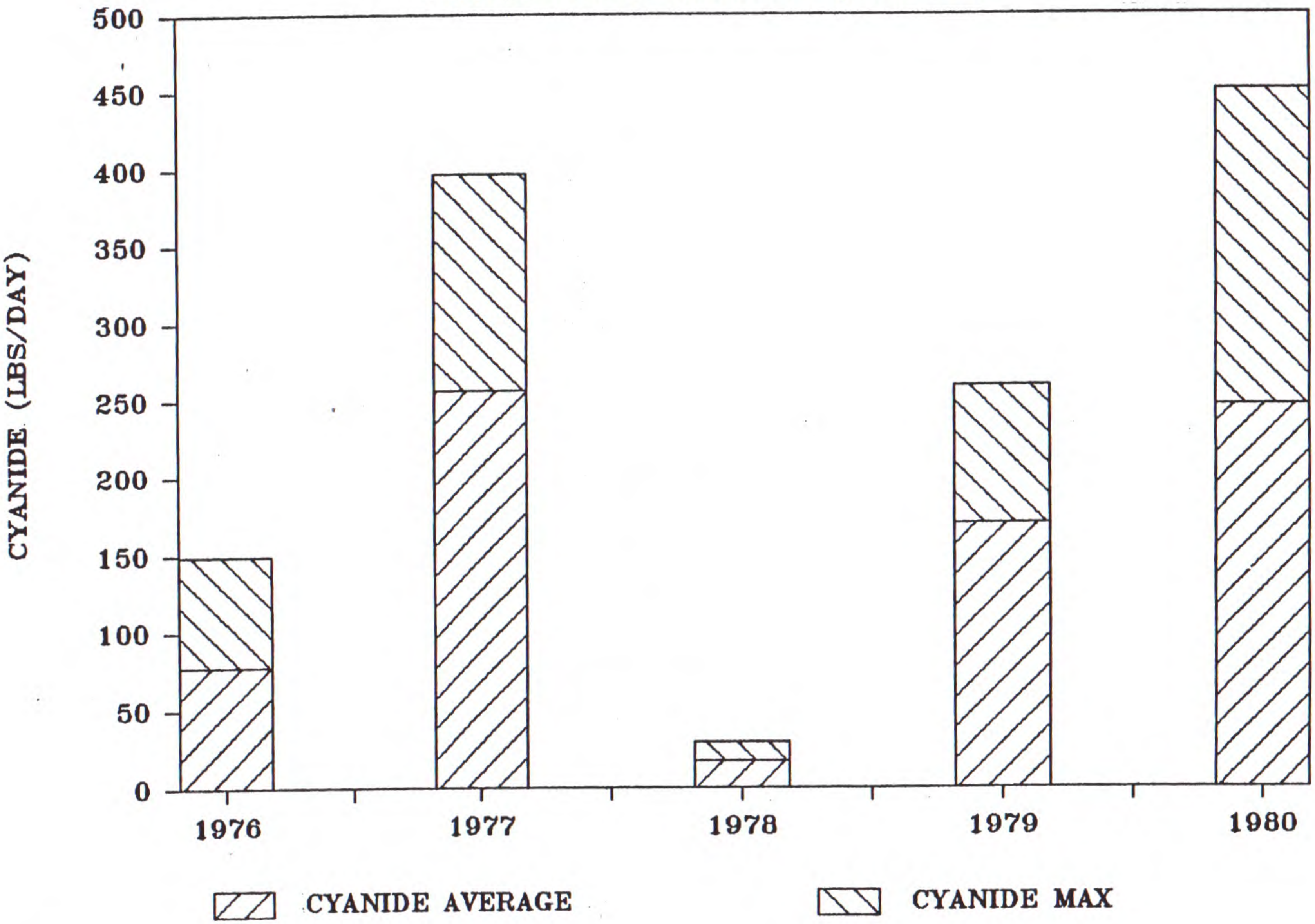
WPS WHEELING — W. VIRGINIA

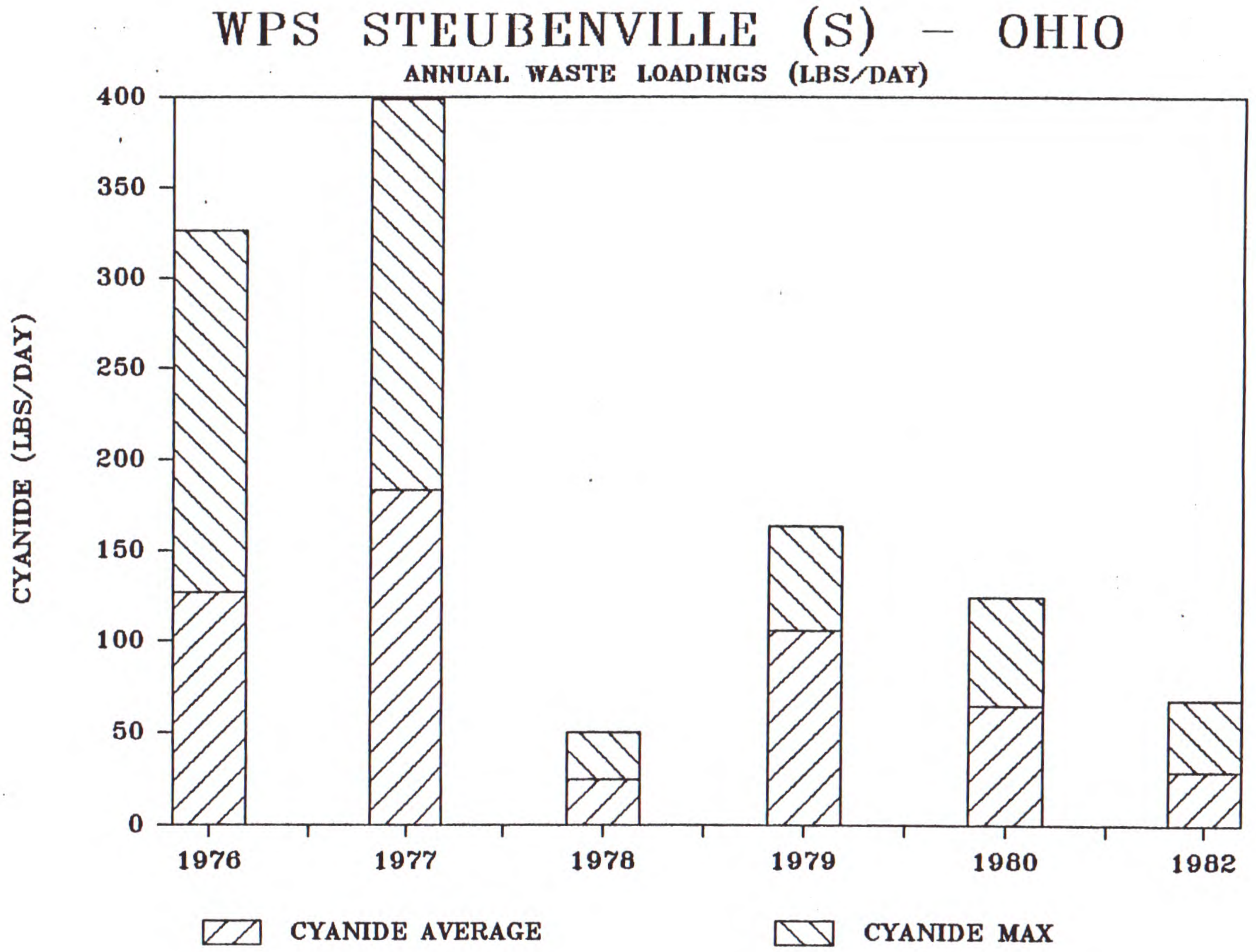
ANNUAL WASTE LOADINGS (LBS/DAY)



WPS STEUBENVILLE (N) - OHIO

ANNUAL WASTE LOADINGS (LBS/DAY)




WPS STEUBENVILLE (S) - OHIO
ANNUAL WASTE LOADINGS (LBS/DAY)
CYANIDE (LBS/DAY)
400
350
300
250
200
150
100
50
0
1976
1977
1978
1979
1980
1982
CYANIDE AVERAGE
CYANIDE MAX

APPENDIX 3

BASIC MODEL FRAMEWORK

APPENDIX 3

BASIC MODEL FRAMEWORK

The present study requires the use of a modeling framework which is capable of simulating first-order reactions in natural waters systems. Additionally, data indicate that lateral variations in water quality exist in the vicinity of major dishargers; consequently, the model must have a multidimensional transport structure. Ambient conditions will be computed on a steady-state basis, as insufficient data exist to justify the use of a more complex and costly time-variable model.

This model has been implemented on several computers including the IBM-PC/AT and is currently being used by several government agencies to analyze a variety of water quality problems.

SPAM is a steady-state, water quality simulation program. Although SPAM was originally designed for the BOD-dissolved oxygen balance, it is capable of handling water quality systems with similar reaction configurations. For example, SPAM can presently be used to model the following systems:

1. <u>conservative substances</u>: Any substance which does not decay or which can be approximated by zero decay, e.g., chlorides, total dissolved solids, total nitrogen, total phosphorus, etc.

2. <u>single reactive substances</u>: Any substance which decays according to first order kinetics, e.g., coliform bacteria, BOD, and ammonia.

3. <u>coupled reactive (feed-forward) substances</u>: Two (or more) substances reacting with first order kinetics in a feed-forward manner, e.g., BOD → dissolved oxygen deficit, organic nitrogen → ammonia → nitrate, and pH/alkalinity.

SPAM employs a simplified finite difference scheme based upon formulating a mass balance equation around each segment in a series of interconnected segments. A steady-state mass balance around a segment i is formulated as follows:

$$V_i \frac{dC_i}{dt} = 0 = \sum_j (\alpha Q_{ji} C_j + (1 - \alpha) Q_{ji} C_i) - \sum_k (\alpha Q_{ik} C_i$$

$$+ (1 - \alpha) Q_{ik} C_k) + \sum_j R_{ji}(C_j - C_i) + \sum_k R_{ik}(C_k - C_i)$$

$$- K_i C_i V_i + W_i - S_i \qquad \text{(A3-1)}$$

where:

C_i = concentration of the water quality constituent in segment i, (M/L^3)

C_j = concentration of the water quality constituent in segment j, (M/L^3)

V_i = volume of segment i, (L^3)

Q_{ji} = net non-tidal flow from segment j to segment i, (L^3/T)

R_{ji} = tidal exchange coefficient between segments i and j, (L^3/T)

$$R_{ij} = \frac{E_{ij} A_{ij}}{(\overline{L_i + L_j})} \qquad \text{(A3-2)}$$

where:

E_{ij} = tidal dispersion coefficient (L^2/T)

A_{ij} = cross sectional area of the interface between segments i and j, (L^2)

$(\overline{L_i + L_j})$ = average or characteristic length of segments i and j, (L)

K_i = first order reaction coefficient in segment i for the water quality constituent (1/T)

W_i = source of the water quality constituent in segment i, (M/T)

S_i = sink of the water quality constituent in segment i, (M/T)

α = is a weighting factor used in the differencing scheme

and where M, L, T are the mass, length, and time units, respectively.

Note that in Equation (1-a), the rate of change of mass in segment i (i.e., the time derivative) has been set equal to zero, which represents the steady-state condition. Equation (1-a), by rearranging terms, can be reduced to a set of simultaneous linear equations, presented in matrix form as follows:

$$[A]\ (C) = (W - S) \tag{A3-3}$$

where:

[A] = an n x n matrix, comprised of the transport and reaction terms of Equation (1-a)

(C) = an n x 1 vector of concentrations of the water quality constituent

(W - S) = an n x 1 (forcing function) vector of sources-sinks of the water quality constituent

The solution vector, (C), of segment concentrations may be obtained, formally, by inversion of the A matrix, i.e.:

$$(C) = [A]^{-1}(W - S) \tag{A3-4}$$

SPAM, however, takes advantage of the fact that the [A] matrix is sparse, and employs either a modified Gaussian elimination technique or a modified Gauss-Seidel iteration technique to solve for (C), rather than by direct matrix inversion. Both the Gaussian elimination and Gauss-Seidel iteration techniques provide reduced core requirements (allowing larger models) and reduced solution times over matrix inversion. Choice of the Gaussian elimination versus Gauss-Seidel iteration is dependent upon the size and configuration of the user's model, with Gaussian elimination being the faster of the two methods, but being restricted in model size capacity.

A4.1 Program Description

SPAM is comprised of a mainline program and 11 principal subroutines. A simplified flow chart showing the program flow is presented on Figure A3-1. SPAM controls the program flow, calling the subroutines in proper sequence.

SPAMA reads the dispersion coefficients, cross-sectional areas, characteristic lengths, and segment volumes. From the dispersion coefficients, areas, and lengths, it then calculates the exchange terms and α's, the weighting factors for the differencing scheme. SPAMA also reads the boundary conditions associated with the first system to be solved.

SPAMB reads the advective flows, and formulates the transport terms of the [A] matrix, and the forcing function vector.

SPAMC reads the segment temperatures, reaction rates and waste loadings (forcing function) associated with the first system to be solved.

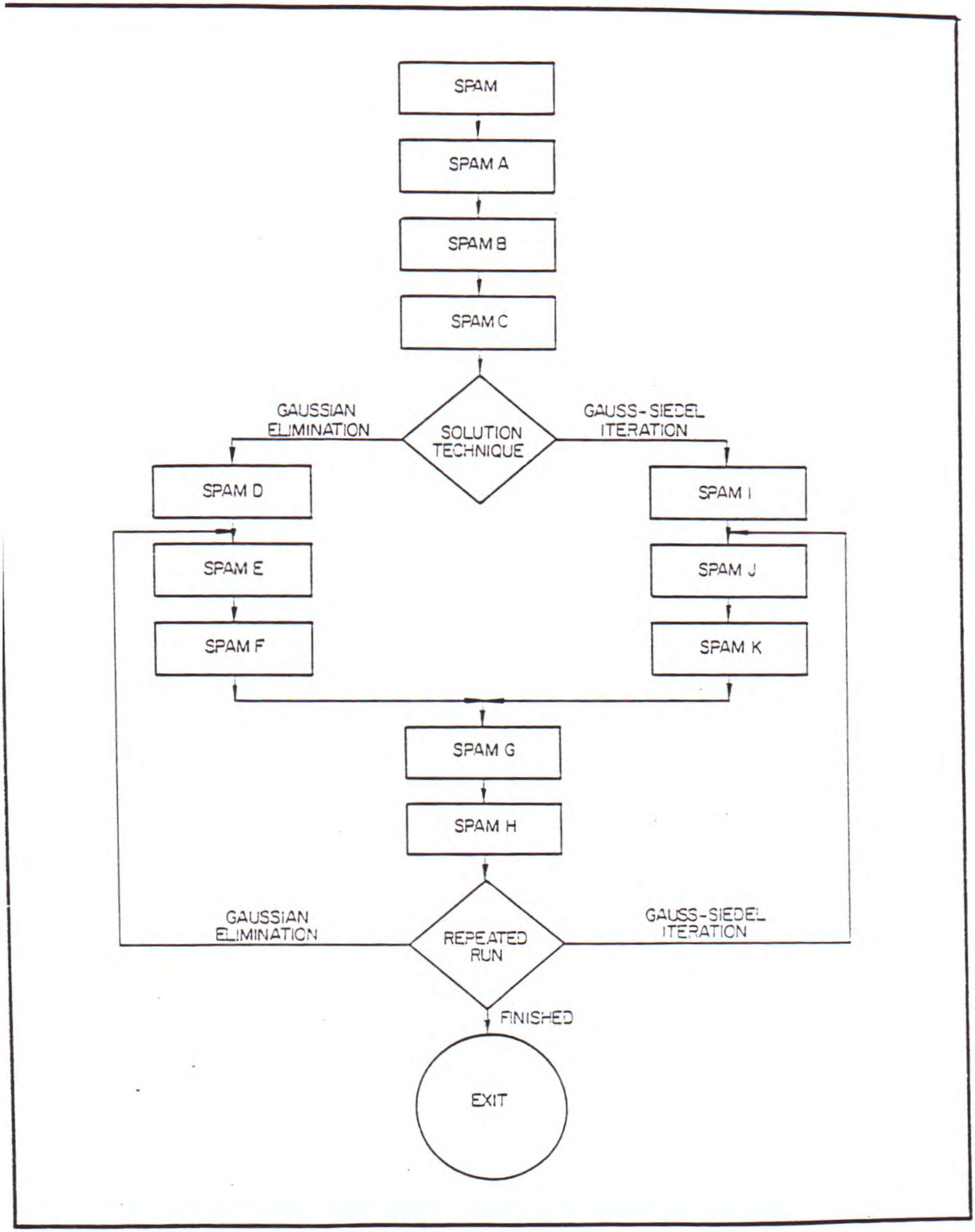


FIGURE A3-1. SIMPLIFIED PROGRAM FLOW

APPENDIX 4

COMPUTED GEOMETRY IN QUARTER-MILE INCREMENTS

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
1.00	1	17964.	706.00
1.25	1	73692.	706.00
1.50	1	18654.	706.00
1.75	1	17712.	706.00
2.00	1	18468.	706.00
2.00	2	18468.	706.00
2.25	2	19914.	706.00
2.50	2	20304.	706.00
2.75	2	17586.	706.00
3.00	2	20940.	706.00
3.00	3	20940.	706.00
3.25	3	20988.	706.00
3.50	3	20292.	706.00
3.75	3	19860.	706.00
4.00	3	17823.	706.00
4.00	4	17823.	706.00
4.25	4	21384.	706.00
4.50	4	21882.	706.00
4.75	4	27054.	706.00
5.00	4	20208.	706.00
5.00	5	20208.	706.00
5.25	5	26676.	706.00
5.50	5	24744.	706.00
5.75	5	23124.	706.00
6.00	5	25536.	706.00
6.00	6	25536.	706.00
6.25	6	14412.	692.00
6.50	6	9810.	692.00
6.75	6	8694.	692.00
7.00	6	19686.	692.00
7.00	7	19686.	692.00
7.25	7	15780.	692.00
7.50	7	17178.	692.00
7.75	7	19902.	692.00
8.00	7	20247.	692.00
8.00	8	20247.	692.00
8.25	8	22374.	692.00
8.50	8	18798.	692.00
8.75	8	19194.	692.00
9.00	8	17823.	692.00
9.00	9	17823.	692.00
9.25	9	20772.	692.00
9.50	9	16584.	692.00
9.75	9	18990.	692.00
10.00	9	13806.	692.00
10.00	10	13806.	692.00
10.25	10	20442.	692.00
10.50	10	20460.	692.00
10.75	10	20964.	692.00
11.00	10	25242.	692.00
11.00	11	25242.	692.00
11.25	11	23904.	692.00
11.50	11	21930.	692.00
11.75	11	22104.	692.00
12.00	11	23784.	692.00
12.00	12	23784.	692.00
12.25	12	20526.	692.00
12.50	12	20796.	692.00
12.75	12	23022.	692.00
13.00	12	23265.	692.00
13.00	13	23265.	692.00
13.25	13	12342.	682.00
13.50	13	11328.	682.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
13.75	13	12678.	682.00
14.00	13	13116.	682.00
14.00	14	13116.	682.00
14.25	14	14748.	682.00
14.50	14	15906.	682.00
14.75	14	19956.	682.00
15.00	14	19086.	682.00
15.00	15	19086.	682.00
15.25	15	19956.	682.00
15.50	15	19236.	682.00
15.75	15	21066.	682.00
16.00	15	19212.	682.00
16.00	16	19212.	682.00
16.25	16	21378.	682.00
16.50	16	25146.	682.00
16.75	16	25146.	682.00
17.00	16	19818.	682.00
17.00	17	19818.	682.00
17.25	17	18000.	682.00
17.50	17	19362.	682.00
17.75	17	20760.	682.00
18.00	17	22890.	682.00
18.00	18	22890.	682.00
18.25	18	19920.	682.00
18.50	18	20040.	682.00
18.75	18	21174.	682.00
19.00	18	16995.	682.00
19.00	19	16995.	682.00
19.25	19	18810.	682.00
19.50	19	20742.	682.00
19.75	19	17964.	682.00
20.00	19	21315.	682.00
20.00	20	21315.	682.00
20.25	20	20568.	682.00
20.50	20	23088.	682.00
20.75	20	23832.	682.00
21.00	20	30426.	682.00
21.00	21	30426.	682.00
21.25	21	29694.	682.00
21.50	21	31878.	682.00
21.75	21	31740.	682.00
22.00	21	30906.	682.00
22.00	22	30906.	682.00
22.25	22	29970.	682.00
22.50	22	32166.	682.00
22.75	22	28674.	682.00
23.00	22	29667.	682.00
23.00	23	29667.	682.00
23.25	23	30978.	682.00
23.50	23	25716.	682.00
23.75	23	27084.	682.00
24.00	23	27930.	682.00
24.00	24	27930.	682.00
24.25	24	6540.	682.00
24.50	24	31302.	682.00
24.75	24	31302.	682.00
25.00	24	32598.	682.00
25.00	25	32598.	682.00
25.25	25	27192.	682.00
25.50	25	23916.	682.00
25.75	25	16716.	682.00
26.00	25	26454.	682.00
26.00	26	26454.	682.00
6.25	26	23694.	682.00
26.50	26	24402.	682.00
26.75	26	24174.	682.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
27.00	26	31248.	682.00
27.00	27	31248.	682.00
27.25	27	33192.	682.00
27.50	27	35772.	682.00
27.75	27	34878.	682.00
28.00	27	37092.	682.00
28.00	28	37092.	682.00
28.25	28	37080.	682.00
28.50	28	37878.	682.00
28.75	28	34446.	682.00
29.00	28	33846.	682.00
29.00	29	33846.	682.00
29.25	29	30798.	682.00
29.50	29	38184.	682.00
29.75	29	38364.	682.00
30.00	29	36909.	682.00
30.00	30	36909.	682.00
30.25	30	36852.	682.00
30.50	30	41904.	682.00
30.75	30	37578.	682.00
31.00	30	33576.	682.00
31.00	31	33576.	682.00
31.25	31	36558.	682.00
31.50	31	31068.	682.00
31.75	31	6918.	664.50
32.00	31	26370.	664.50
32.00	32	26370.	664.50
32.25	32	23724.	664.50
32.50	32	21234.	664.50
32.75	32	22500.	664.50
33.00	32	18255.	664.50
33.00	33	18255.	664.50
33.25	33	20682.	664.50
33.50	33	21138.	664.50
33.75	33	22044.	664.50
34.00	33	18237.	664.50
34.00	34	18237.	664.50
34.25	34	19080.	664.50
34.50	34	21234.	664.50
34.75	34	20022.	664.50
35.00	34	16908.	664.50
35.00	35	16908.	664.50
35.25	35	15804.	664.50
35.50	35	16722.	664.50
35.75	35	17988.	664.50
36.00	35	17718.	664.50
36.00	36	17718.	664.50
36.25	36	19272.	664.50
36.50	36	17748.	664.50
36.75	36	19866.	664.50
37.00	36	24366.	664.50
37.00	37	24366.	664.50
37.25	37	30882.	664.50
37.50	37	18900.	664.50
37.75	37	19710.	664.50
38.00	37	25221.	664.50
38.00	38	25221.	664.50
38.25	38	24636.	664.50
38.50	38	24444.	664.50
38.75	38	24240.	664.50
39.00	38	21642.	664.50
39.00	39	21642.	664.50
39.25	39	23862.	664.50
39.50	39	21156.	664.50
39.75	39	22458.	664.50
40.00	39	30222.	664.50

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
40.00	40	30222.	664.50
40.25	40	25242.	664.50
40.50	40	34026.	664.50
40.75	40	38712.	664.50
41.00	40	32664.	664.50
41.00	41	32664.	664.50
41.25	41	35844.	664.50
41.50	41	31284.	664.50
41.75	41	27534.	664.50
42.00	41	27030.	664.50
42.00	42	27030.	664.50
42.25	42	29178.	664.50
42.50	42	30900.	664.50
42.75	42	36816.	664.50
43.00	42	31044.	664.50
43.00	43	31044.	664.50
43.25	43	26640.	664.50
43.50	43	25740.	664.50
43.75	43	29220.	664.50
44.00	43	24822.	664.50
44.00	44	24822.	664.50
44.25	44	27258.	664.50
44.50	44	28410.	664.50
44.75	44	28716.	664.50
45.00	44	32958.	664.50
45.00	45	32958.	664.50
45.25	45	26616.	664.50
45.50	45	29988.	664.50
45.75	45	28212.	664.50
46.00	45	31284.	664.50
46.00	46	31284.	664.50
46.25	46	27840.	664.50
46.50	46	33468.	664.50
46.75	46	30180.	664.50
47.00	46	30726.	664.50
47.00	47	30726.	664.50
47.25	47	30768.	664.50
47.50	47	31530.	664.50
47.75	47	29808.	664.50
48.00	47	32868.	664.50
48.00	48	32868.	664.50
48.25	48	30252.	664.50
48.50	48	36306.	664.50
48.75	48	35868.	664.50
49.00	48	31677.	664.50
49.00	49	31677.	664.50
49.25	49	47124.	664.50
49.50	49	32472.	664.50
49.75	49	39630.	664.50
50.00	49	37005.	664.50
50.00	50	37005.	664.50
50.25	50	31962.	664.50
50.50	50	33036.	664.50
50.75	50	31914.	664.50
51.00	50	32115.	664.50
51.00	51	32115.	664.50
51.25	51	35994.	664.50
51.50	51	39714.	664.50
51.75	51	50928.	664.50
52.00	51	48132.	664.50
52.00	52	48132.	664.50
52.25	52	53370.	664.50
52.50	52	48630.	664.50
52.75	52	46140.	664.50
53.00	52	38820.	664.50
53.00	53	38820.	664.50

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
53.25	53	23178.	664.50
53.50	53	42420.	664.50
53.75	53	51420.	664.50
54.00	53	52908.	664.50
54.00	54	52908.	664.50
54.25	54	23784.	644.00
54.50	54	18522.	644.00
54.75	54	16368.	644.00
55.00	54	22485.	644.00
55.00	55	22485.	644.00
55.25	55	24294.	644.00
55.50	55	20940.	644.00
55.75	55	16068.	644.00
56.00	55	13371.	644.00
56.00	56	13371.	644.00
56.25	56	10008.	644.00
56.50	56	18402.	644.00
56.75	56	16332.	644.00
57.00	56	15576.	644.00
57.00	57	15576.	644.00
57.25	57	15642.	644.00
57.50	57	14856.	644.00
57.75	57	9846.	644.00
58.00	57	16413.	644.00
58.00	58	16413.	644.00
58.25	58	21258.	644.00
58.50	58	21498.	644.00
58.75	58	17574.	644.00
59.00	58	17286.	644.00
59.00	59	17286.	644.00
59.25	59	16818.	644.00
59.50	59	16092.	644.00
59.75	59	18306.	644.00
60.00	59	16815.	644.00
60.00	60	16815.	644.00
60.25	60	16530.	644.00
60.50	60	16818.	644.00
60.75	60	16842.	644.00
61.00	60	16470.	644.00
61.00	61	16470.	644.00
61.25	61	15258.	644.00
61.50	61	17568.	644.00
61.75	61	17148.	644.00
62.00	61	18735.	644.00
62.00	62	18735.	644.00
62.25	62	18702.	644.00
62.50	62	19590.	644.00
62.75	62	21786.	644.00
63.00	62	19461.	644.00
63.00	63	19461.	644.00
63.25	63	20958.	644.00
63.50	63	20928.	644.00
63.75	63	22668.	644.00
64.00	63	22860.	644.00
64.00	64	22860.	644.00
64.25	64	23154.	644.00
64.50	64	23706.	644.00
64.75	64	26892.	644.00
65.00	64	28377.	644.00
65.00	65	28377.	644.00
65.25	65	21012.	644.00
65.50	65	18954.	644.00
65.75	65	20004.	644.00
66.00	65	22500.	644.00
66.00	66	22500.	644.00
66.25	66	46860.	644.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
66.50	66	21846.	644.00
66.75	66	13074.	644.00
67.00	66	22578.	644.00
67.00	67	22578.	644.00
67.25	67	23526.	644.00
67.50	67	22362.	644.00
67.75	67	20118.	644.00
68.00	67	22899.	644.00
68.00	68	22899.	644.00
68.25	68	25194.	644.00
68.50	68	23010.	644.00
68.75	68	23010.	644.00
69.00	68	24951.	644.00
69.00	69	24951.	644.00
69.25	69	24216.	644.00
69.50	69	23334.	644.00
69.75	69	24390.	644.00
70.00	69	23928.	644.00
70.00	70	23928.	644.00
70.25	70	27126.	644.00
70.50	70	28752.	644.00
70.75	70	26934.	644.00
71.00	70	29466.	644.00
71.00	71	29466.	644.00
71.25	71	27174.	644.00
71.50	71	26760.	644.00
71.75	71	27024.	644.00
72.00	71	28209.	644.00
72.00	72	28209.	644.00
72.25	72	30594.	644.00
72.50	72	27192.	644.00
72.75	72	31026.	644.00
73.00	72	32598.	644.00
73.00	73	32598.	644.00
73.25	73	31590.	644.00
73.50	73	31104.	644.00
73.75	73	30366.	644.00
74.00	73	33291.	644.00
74.00	74	33291.	644.00
74.25	74	36696.	644.00
74.50	74	31704.	644.00
74.75	74	35376.	644.00
75.00	74	31458.	644.00
75.00	75	31458.	644.00
75.25	75	8730.	644.00
75.50	75	31332.	644.00
75.75	75	35604.	644.00
76.00	75	34428.	644.00
76.00	76	34428.	644.00
76.25	76	32112.	644.00
76.50	76	33462.	644.00
76.75	76	31998.	644.00
77.00	76	36204.	644.00
77.00	77	36204.	644.00
77.25	77	21234.	644.00
77.50	77	34176.	644.00
77.75	77	35292.	644.00
78.00	77	36906.	644.00
78.00	78	36906.	644.00
78.25	78	37530.	644.00
78.50	78	34578.	644.00
78.75	78	38226.	644.00
79.00	78	33711.	644.00
79.00	79	33711.	644.00
79.25	79	33396.	644.00
79.50	79	33570.	644.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
79.75	79	33528.	644.00
80.00	79	36534.	644.00
80.00	80	36534.	644.00
80.25	80	35202.	644.00
80.50	80	34452.	644.00
80.75	80	35802.	644.00
81.00	80	35859.	644.00
81.00	81	35859.	644.00
81.25	81	37944.	644.00
81.50	81	42018.	644.00
81.75	81	38556.	644.00
82.00	81	39597.	644.00
82.00	82	39597.	644.00
82.25	82	39546.	644.00
82.50	82	40200.	644.00
82.75	82	36312.	644.00
83.00	82	38625.	644.00
83.00	83	38625.	644.00
83.25	83	41364.	644.00
83.50	83	41574.	644.00
83.75	83	43860.	644.00
84.00	83	44439.	644.00
84.00	84	44439.	644.00
84.25	84	11028.	623.00
84.50	84	11106.	623.00
84.75	84	20022.	623.00
85.00	84	20382.	623.00
85.00	85	20382.	623.00
85.25	85	16212.	623.00
85.50	85	18912.	623.00
85.75	85	16374.	623.00
86.00	85	15912.	623.00
86.00	86	15912.	623.00
86.25	86	14220.	623.00
86.50	86	18888.	623.00
86.75	86	13440.	623.00
87.00	86	13638.	623.00
87.00	87	13638.	623.00
87.25	87	15030.	623.00
87.50	87	14574.	623.00
87.75	87	14538.	623.00
88.00	87	15213.	623.00
88.00	88	15213.	623.00
88.25	88	15216.	623.00
88.50	88	16302.	623.00
88.75	88	17118.	623.00
89.00	88	16128.	623.00
89.00	89	16128.	623.00
89.25	89	16362.	623.00
89.50	89	17058.	623.00
89.75	89	13806.	623.00
90.00	89	16152.	623.00
90.00	90	16152.	623.00
90.25	90	17820.	623.00
90.50	90	15252.	623.00
90.75	90	17844.	623.00
91.00	90	16956.	623.00
91.00	91	16956.	623.00
91.25	91	16944.	623.00
91.50	91	17232.	623.00
91.75	91	15360.	623.00
92.00	91	16341.	623.00
92.00	92	16341.	623.00
92.25	92	15726.	623.00
92.50	92	18870.	623.00
92.75	92	16866.	623.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
93.00	92	18783.	623.00
93.00	93	18783.	623.00
93.25	93	17868.	623.00
93.50	93	18780.	623.00
93.75	93	17874.	623.00
94.00	93	18789.	623.00
94.00	94	18789.	623.00
94.25	94	11604.	623.00
94.50	94	8754.	623.00
94.75	94	19392.	623.00
95.00	94	21321.	623.00
95.00	95	21321.	623.00
95.25	95	22404.	623.00
95.50	95	22512.	623.00
95.75	95	20454.	623.00
96.00	95	19497.	623.00
96.00	96	19497.	623.00
96.25	96	22176.	623.00
96.50	96	20994.	623.00
96.75	96	21666.	623.00
97.00	96	22752.	623.00
97.00	97	22752.	623.00
97.25	97	31938.	623.00
97.50	97	25542.	623.00
97.75	97	23190.	623.00
98.00	97	23718.	623.00
98.00	98	23718.	623.00
98.25	98	23298.	623.00
98.50	98	23808.	623.00
98.75	98	40374.	623.00
99.00	98	24672.	623.00
99.00	99	24672.	623.00
99.25	99	22968.	623.00
99.50	99	23916.	623.00
99.75	99	24030.	623.00
100.00	99	21555.	623.00
100.00	100	21555.	623.00
100.25	100	25572.	623.00
100.50	100	23844.	623.00
100.75	100	24462.	623.00
101.00	100	25359.	623.00
101.00	101	25359.	623.00
101.25	101	24432.	623.00
101.50	101	23862.	623.00
101.75	101	24906.	623.00
102.00	101	26217.	623.00
102.00	102	26217.	623.00
102.25	102	28782.	623.00
102.50	102	28134.	623.00
102.75	102	22842.	623.00
103.00	102	22887.	623.00
103.00	103	22887.	623.00
103.25	103	22878.	623.00
103.50	103	24714.	623.00
103.75	103	26136.	623.00
104.00	103	26664.	623.00
104.00	104	26664.	623.00
104.25	104	60726.	623.00
104.50	104	25656.	623.00
104.75	104	26292.	623.00
105.00	104	24384.	623.00
105.00	105	24384.	623.00
105.25	105	23484.	623.00
105.50	105	23682.	623.00
105.75	105	26400.	623.00
106.00	105	25443.	623.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
106.00	106	25443.	623.00
106.25	106	11274.	623.00
106.50	106	24696.	623.00
106.75	106	27294.	623.00
107.00	106	27324.	623.00
107.00	107	27324.	623.00
107.25	107	27024.	623.00
107.50	107	28734.	623.00
107.75	107	29160.	623.00
108.00	107	30510.	623.00
108.00	108	30510.	623.00
108.25	108	27696.	623.00
108.50	108	31014.	623.00
108.75	108	29412.	623.00
109.00	108	28872.	623.00
109.00	109	28872.	623.00
109.25	109	29586.	623.00
109.50	109	28368.	623.00
109.75	109	29874.	623.00
110.00	109	31392.	623.00
110.00	110	31392.	623.00
110.25	110	33396.	623.00
110.50	110	31638.	623.00
110.75	110	30870.	623.00
111.00	110	32661.	623.00
111.00	111	32661.	623.00
111.25	111	33534.	623.00
111.50	111	31746.	623.00
111.75	111	28470.	623.00
112.00	111	31617.	623.00
112.00	112	31617.	623.00
112.25	112	32610.	623.00
112.50	112	33900.	623.00
112.75	112	37254.	623.00
113.00	112	47058.	623.00
113.00	113	47058.	623.00
113.25	113	37626.	623.00
113.50	113	33090.	623.00
113.75	113	41796.	623.00
114.00	113	30063.	623.00
114.00	114	30063.	623.00
114.25	114	39336.	623.00
114.50	114	32076.	623.00
114.75	114	33336.	623.00
115.00	114	35124.	623.00
115.00	115	35124.	623.00
115.25	115	39432.	623.00
15.50	115	39042.	623.00
15.75	115	34920.	623.00
116.00	115	36540.	623.00
116.00	116	36540.	623.00
116.25	116	36396.	623.00
116.50	116	34968.	623.00
116.75	116	35718.	623.00
117.00	116	35697.	623.00
117.00	117	35697.	623.00
117.25	117	39960.	623.00
117.50	117	34152.	623.00
117.75	117	35316.	623.00
118.00	117	34044.	623.00
118.00	118	34044.	623.00
118.25	118	34176.	623.00
118.50	118	35220.	623.00
118.75	118	33876.	623.00
119.00	118	29301.	623.00
119.00	119	29301.	623.00

River Mile	Model Segment	Area (sq ft)	Water SFC Elevation
119.25	119	36408.	623.00
119.50	119	37878.	623.00
119.75	119	38880.	623.00
120.00	119	37884.	623.00
120.00	120	37884.	623.00
120.25	120	36510.	623.00
120.50	120	37962.	623.00
120.75	120	38736.	623.00
121.00	120	43203.	623.00
121.00	121	43203.	623.00
121.25	121	44076.	623.00
121.50	121	41934.	623.00
121.75	121	40698.	623.00
122.00	121	38922.	623.00
122.00	122	38922.	623.00
122.25	122	37854.	623.00
122.50	122	39372.	623.00
122.75	122	40980.	623.00
123.00	122	39387.	623.00
123.00	123	39387.	623.00
123.25	123	37566.	623.00
123.50	123	37290.	623.00
123.75	123	33948.	623.00
124.00	123	40890.	623.00
124.00	124	40890.	623.00
124.25	124	41832.	623.00
124.50	124	42864.	623.00
124.75	124	40548.	623.00
125.00	124	37383.	623.00
125.00	125	37383.	623.00
125.25	125	37830.	623.00
125.50	125	38706.	623.00
125.75	125	39270.	623.00
126.00	125	39849.	623.00