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POTENTIAL THERMAL EFFECTS
OF AN EXPANDING POWER INDUSTRY:
OHIO RIVER BASIN I

D. E. Peterson and R. T. Jaske

February 1970

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POTENTIAL THERMAL EFFECTS OF AN EXPANDING
POWER INDUSTRY: OHIO RIVER BASIN ■

By

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ABSTRACT

Simulations of 1964 daily average stream temperatures of the Ohio River System were performed using the COLHEAT computer code. Average monthly direct cooling capacities of the Ohio River and its major tributaries (excluding the Cumberland and Tennessee Rivers) within a 5 °F envelope were calculated and found to range between 261,000 and 95,000 MW_T. Projected steam-electric loads and cooling facility trends for the Ohio Basin indicate that direct cooling water requirements will equal low monthly average direct cooling capacity by the year 1990. Ancillary cooling facilities for low flow periods could extend the use of direct cooling for a major part of the cooling requirements through the turn of the century.

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POTENTIAL THERMAL EFFECTS OF AN EXPANDING
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INTRODUCTION

In FY-1969, the Environmental and Sanitary Engineering Branch, Division of Reactor Development and Technology, U. S. Atomic Energy Commission, requested that Battelle-Northwest undertake a reconnaissance study of the thermal regimen of the Ohio River and its major tributaries. The purpose of the study was to continue testing and development of a regional simulation system, which was originally developed at the Pacific Northwest Laboratory to simulate the temperature distribution of the Columbia River.

In 1960 the population of the Ohio River Basin, excluding the Tennessee Basin, was approximately 19 million. This is expected to grow to 23 million by 1980 and to 29 million by the turn of the century.⁽¹⁾ This population is integrated with an economy that is one of the most diversified and highly developed in the United States.

Included within the Basin economy are significant segments of every major cooling water use category. In 1964 these categories included, on a nationwide basis:

Electric power	81.3%
Primary metals	6.8%
Chemical and allied products	. 6.2%
Petroleum and coal products	2.4%
Paper and allied products	1.2%
Food and allied products	0.8%
Machinery	0.3%
Rubber and plastics	0.3%

Transportation equipment	0.2%
Other	0.5%.(2)

In the case of electric power, at the close of 1963, 90% of the Ohio Basin steam-generating capacity of 28,000 MW used once-through cooling of plant condensers. By 1980 thermal capacity is projected, by the Federal Power Commission, to increase to 75,000 MW, a 17 year average annual growth rate of 6%. The growth rate is expected to continue near 6% through the decade of the 1980's and then slowly decline.(3)

In order to assess the potential impact of this projected power growth the study was modified to include simulations of average monthly capacities of the stream regimen to assimilate and dissipate heat within a temperature envelope of 5 °F. A 5 °F envelope was selected because it corresponds to a common, but not universal, constraint on temperature increases under various state water quality standards.(4)

This report summarizes the results of the study—the simulation of the 1964 thermal regimen of the Ohio River from Pittsburgh, Pennsylvania to Cairo, Illinois, a distance of 981 miles (Figure 1 and Table 1). Simulations of the Allegheny, Monongahela, Muskingum, Kanawha, Kentucky, and Wabash Rivers are also included. Two major tributaries, the Cumberland and Tennessee, which are part of the TVA system, were not studied as subbasins. Average monthly capacities of the tributaries and main stem to assimilate and dissipate heat are discussed in terms of projected thermal loads due to electric power generation in 1980 and in terms of projected power requirements for the year 1990. Low flow capacities were not examined by simulation in this study. However, the effects of low flow are treated briefly in the report. A subsequent report will examine minimum capacities in greater detail.

FIGURE 1. Ohio River Basin

TABLE 1. Summary of Average Annual Maximum and Minimum Cooling Capacities (MW_T) of Ohio River Basin Streams

	April, max.	Sept., min	Best 9 Months**	1970 Present Installations*
Allegheny River	15,400	1,600	4,500	5,800
Monongahela River	8,000	1,700	4,000	2,354
Muskingum River	5,600	<1,000	2,800	3,047
Kanawha River	12,400	2,600	3,600	932
Kentucky River	10,000	<1,000	3,600	650
Wabash River	20,000	5,200	9,100	5,200
Ohio River Basin	260,000	102,000	129,000	44,575

* In MW (electrical), includes some cooling tower plants

** Based on values sure to be exceeded 9 months of the year.

SUMMARY AND CONCLUSIONS

The principal objective, that of testing the COLHEAT simulation code under conditions which would yield predicted capability of an important river basin was achieved. The secondary objectives of assigning quantitative values to the thermal capability of the primary streams of the Ohio River Valley drainage area for average conditions were also carried out. For purposes of this study, the direct cooling capacity was arbitrarily defined as the quantity of heat that could be assimilated by the stream and dissipated to the atmosphere within a temperature envelope of 5 °F above background.

As a general conclusion it can be stated that under average monthly conditions, the thermal capacity of the Ohio River system is limited in September and October because of natural flow reductions. However, during 10 months of the year, sufficient capability exists to handle the majority of needs for thermal effluent disposal for most of the forecasted power

needs through the end of the century. Clearly, the power industry is faced with the problems of adapting more flexible design options which permit the advantages of low cost direct cooling during a majority of the year to be supplemented by ancillary cooling during the critical months.

Supplementary cooling would have to take the form of combinations of cooling ponds or cooling towers sited in such a manner as to permit optional, partial open circuit ancillary loops in order to meet summer load conditions. Such conditions could be met at operational points away from thermodynamic optima, such as high back-end loading, for these limited periods, with return to direct cooling and highly optimal cooling operation in the months with ample flow. In addition, the careful attention to scheduling of shutdowns and ancillary gas turbine systems offers additional possibilities while strengthening **system** reserves.

The study illustrates that, from a technological standpoint, sufficiently 'detailed methods exist for defining the cooling capability of any river in relation to any set of stream standards which may be adopted by states. There is an opportunity for both the regulatory agencies and the power industries to meet on common ground in the management of thermal loadings, similar to that carried out in the management of dissolved oxygen objectives in the operation of municipal waste treatment plants. The study reveals important avenues of approach in the future management of water resources systems which will permit all interested parties to derive the maximum benefit from technology without catastrophic impairment of traditional resources values for recreation and other uses, or the arbitrary assessment of increased operational costs throughout the year because of a short seasonal problem.

The following specific statements are derived from the study:

- Under average conditions, by 1980, the flow-through cooling requirements for single-stage, direct-cooled plants which could be sited on the Allegheny River will exceed the stream capacity in late summer and early fall. With systems using two-stage cooling combinations of topping ponds or topping towers, a considerable extension of the time could be achieved. A ratio exceeding 3.0 between average and minimum capability exists on the Allegheny; this ratio indicates that if supplementary cooling were employed on a flexible basis, sufficient capacity exists to handle all cooling requirements for the foreseeable future.
- The Monongahela River is capable of additional development on a flexible basis; however, under present once-through cooling designs, the capability is sufficient to match the 1980 requirements. Some allowance for continued use by other industry would also require factoring in a specific study directed to an actual allocation.
- On the basis of data collected for the study, it appears that the Muskingum River cannot attenuate present loads and remain within a 5 °F differential during September and October. This river could be a potential test basin for the development of flexible supplementary cooling methods with seasonal adjustments.
- The Kanawha River presently receives extensive heated effluent from chemical and primary metal production facilities in addition to electrical generating plants. Additional development of the river for direct cooling on a flexible basis could be accomplished, the flows being

sufficient to attenuate the projected average loadings through 1980 provided that supplementary cooling for the late summer and fall periods could be installed. Under single-stage, direct-cooled operation, the critical low flow capacity is under 250 MW_T.

- Conditions on the Wabash River are similar to other streams discussed. Some additional development appears possible; however,, the low flow extremes in summer and fall indicate the need for use of flexible systems or scheduled operation by 1980.

For the Ohio River Basin as a whole, considerable additional cooling capability exists below Evansville. This is expected to total at least 10 GW_e under average conditions during the summer and fall. With supplementary ponds or topping towers, as much as 40 to 50 GW_e could be handled within the study assumptions. The middle river, largely between Huntington and Cincinnati, which has few steam plants at present, is also a potential area for development. Again, possibilities for flexible design or operation exist. Under the maximum condition of development and with some partial supplementary cooling, the entire needs of the area could be accommodated through the foreseeable future. Without supplementary cooling, the available siting opportunities would be totally committed by 1984.

- The study reveals new and important opportunities in the use of dual purpose or supplementary cooling systems in which a portion of the thermal loading is handled by off stream processes such as cooling ponds or cooling towers during times when full river flows are not available to operate at thermodynamic optima. Such dual cooling permits the utility to use a better range of design practices as an alternative to the practice "high back-end

loading" resorted to when fuel is relatively cheap and equipment costs are relatively high. Dual purpose cooling systems permit the using utility to regulate the end quantity of heat disposed to the receiving stream or atmosphere throughout a range of operating conditions instead of requiring a firm and early choice of heat disposal method which may conflict with changes in effluent disposal policy on the part of regulatory agencies. Considerable additional research is needed to investigate the operating alternative open to a successful utility operation, particularly those involving fuel costs, reserve requirements, siting, and operational flexibility. Some excellent examples of the dual use of cooling lakes and power plants exist in combination with planned public joint use of the facilities. The study suggests additional opportunities for the building of public confidence by such dual cooled facilities.

- The study has developed additional opportunity to investigate the tendency to aggregate thermal capacity in "super" plants of very large rating. This aggravates the general problem of heat dissipation because of the limitations on the local temperature rise imposed by State Standards under the Water Quality Restoration Act of 1966, especially in the upper reaches of the study area. The data developed for the individual subbasins supplying the Ohio River Basin is especially useful in detailing the specific interdependence of plant size, load factor and seasonal stream capacity. These facts suggest that the optimization processes involved in plant size determination should include the entire system from water source to heat sink in the venture analysis supporting process selection. Such study should include review of such practices as high back-end loading. Though high back-end loading nominally

shows advantages in leveling the sensitivity of plants to changes in condenser temperature, it does so at the cost of higher total plant heat rate with attendant increases in overall heat discharge to the total environment. As a corollary, the study suggests the retention of lines of smaller, flexibly designed plants which could be used for regions which could incorporate direct cooling on smaller streams with appropriate electrical flexibility for low voltage regional systems.

- Finally, the study suggests the development of the concept of dynamic planning and management of stream temperature resources using the latest in computer simulation as an alternative to the use of rigid practices administered in an inflexible manner. Both the power industry and the regulatory agencies appear to have much to gain from the use of such practices in preservation of the quality of the environment and the low cost of power and other services to the ultimate consumer.

OBJECTIVES

The objectives of the Ohio River Basin study included the following:

- Continuation of testing and development of the COLHEAT computer program for the simulation of daily average temperature profiles of large river systems with regional input data: data which are available from a number of federal, state and local government agencies, as well as from private sources.
- Utilization of long term information to simulate the monthly average thermal capacity of the Ohio River within a set of constraints representative of current trends.
- Review Federal Power Commission projections of electric energy requirements for the Ohio Basin and analyze the potential long term significance of the projections with respect to the average thermal capacities of major basin streams.

SIMULATION MODEL

The COLHEAT simulation model, which was first utilized to simulate a reach of the Columbia River in August 1965, has been discussed in detail in a previous publication.⁽⁵⁾ The model applies a heat budget to a given section of a river, as follows:

$$\Sigma Q = Q_T = (Q_s - Q_r) - Q_b - Q_e \pm Q_h + Q_v$$

where

Net insolation

Q_s = incoming short wave radiation

Q_r = reflected short wave radiation from the water surface

Back radiation

$Q_b = 0.970 \sigma (T_w^4 - \beta T_a^4)$ Btu/ft²/hr

σ = Stefan Boltzmann radiation constant

β = atmospheric radiation factor derived from cloud cover and vapor pressure

T_w = temperature of water surface in °K

T_a = temperature of air in °K

Evaporation

$Q_e = 13.8 u (1_w - 1_a) \text{ Btu/ft}^2/\text{hr}$

u = wind speed in mi/hr

1_w = vapor pressure of water in inches of mercury

1_a = vapor partial pressure in inches of mercury

Conduction

$Q_h = 0.00466 kpu (T_a - T_w) \text{ Btu/ft}^2/\text{hr}$; 0.00466 is a constant derived from the **Bowen** ratio for quiescent lakes

k = correction factor varying between (1-3) for rapid streams

u = wind velocity in mi/hr

p = atmospheric pressure in inches of mercury

T_a = mean air temperature in °C

T_w = mean water surface temperature in °C

Advected energy

Q_v = varies with heat source

(Term used to input discharge heat from thermal effluents, and in special cases to handle ice, sleet, rain, etc.)

The water temperature for a river section is determined by means of the equation

$$T_w = \left[\frac{1}{V_r} \frac{Q_t A \theta}{62.5} + V_i (T_i - T_w) \right]$$

where

V_r = mean river section or reservoir volume

A = mean river section or reservoir surface area

θ = time increment

V_i = inflow volume per time increment

T_i = mean temperature of inflowing water

T_w = mean temperature of water in a given section of river or reservoir

Q_t = the net heat transport per time.

The above equation, which applies to homogeneous, isotropic media, is modified for nonhomogeneous media by incorporating it into a computational system which uses intermittent transport and mixing with respect to the ratios of mean travel times of water masses through a fixed volume. In the form of the model used in this study, the flow system is composed of an inner and outer trough with relative volumes B and (1-B), respectively (Figure 2). The model sets up a series of difference equations and iteratively computes the downstream temperatures as a function of the input data in the following manner:

$$T_{i+1,j+1} = (1-B) \left(T_{i,j} + T_{i,j}^{(1)} + T_{i,j}^{(2)} \right) + B \left(T_{i,j-1} + T_{i,j-1}^{(1)} + T_{i,j}^{(2)} \right)$$

where

$T_{i,j}$ = average water temperature of the beginning of the j^{th} flow increment at the end of the i^{th} time increment (flow day) °C

$T_{i,j}^{(1)}$ = the temperature change during the first half of the i^{th} time interval in the j^{th} flow increment as determined from surface heat exchange plus advected energy (heat budget) in °C

$T_{i,j}^{(2)}$ = same as above except for the second half of the i^{th} time interval, in °C

B = the fractional part of the water in the inner fast moving trough.

At the end of an i^{th} time interval the water in the inner and outer troughs of each section is mixed and an average temperature for the section is calculated. The process is then repeated for the $i + 1$ time interval.

Operation of the COLMEAT model requires the following data:

- River or reservoir dimensions reduced to equivalent non-parallel trapezoidal cross sections
- Water temperatures at the upstream end of reach under study and also at downstream locations

l VARIES AS RESERVOIR GEOMETRY AND FLOW
AND REPRESENTS A RESERVOIR LENGTH FOR THAT REGION
ONE FLOW DAY IN LENGTH

Neg 0695417

FIGURE 2. Model of Channel Flow at a Translational Instant

- Streamflow at inlet and outlet of each river section
- Meteorological data over the area of interest (wind velocity, mean air temperature, dew point, sky cover, incoming short wave radiation)
- Advected heat quantities.

These data requirements provide a topical outline for the following discussion.

STREAM PARAMETERS

River cross section charts and flow profiles for the Ohio River main stem between Pittsburgh, Pennsylvania and Cairo, Illinois were obtained from the U. S. Army Corps of Engineers. These data were reduced to equivalent trapezoidal sections for computational purposes; the surface area and total volume were conserved in the transformation, the water depth was taken as the average depth and the bottom width was calculated. Because of the reconnaissance nature of the study, in which local detail was not emphasized, any changes in the river due to scour and fill after the soundings were taken were assumed to be balanced.

The lock and dam system along the Ohio Waterway has undergone a number of modifications since 1964. Consequently, it was necessary to use two sets of cross sections for specific reaches of the river; one set for the 1964 simulation, when obsolete dams were still in operation, and a second set for calculations of mean monthly thermal capacities. The second set included changes in cross sections due to water level increases associated with the completion of nine locks and dams under construction or in preconstruction planning in 1965. Of those, four were situated in the Upper River, between River Miles 80 and 240, and five in the Lower Ohio, between River Miles 610 and 981. When the system is complete, the Ohio Waterway will have a total of 19 locks and dams in place of the regional system of 46, which was completed in 1929.

WATER TEMPERATURES

Water quality information in the Ohio Basin has been systematically collected since the early 1950's by the Ohio River Valley Water Sanitation Commission (ORSANCO), a Water Users Committee and the U. S. Geological Survey. ORSANCO, which represents the basin states, except Tennessee and Alabama, maintains a records center in Cincinnati, which collects data from all sources. Because of the large scale coordinated effort in the Ohio Basin, basic water quality data appear to be more complete and more readily available than in any other major river basin in the United States.

The daily average temperature data used in this study were obtained either directly from the ORSANCO records center or from publications of "Water Resource Data" of the U. S. Geological Survey. Observed 1964 daily average water temperatures were used for input data at the upstream end of each sidestream simulation and for comparisons with calculated temperatures at downstream locations in the system.

FLOW RECORDS

Daily average flow data for the 1964 calendar year were obtained from publications of "Surface Water Records" of the U. S. Geological Survey. Monthly average flows, which were utilized in determining the mean thermal capacities of the tributary streams and also of the Basin as a whole, were secured from "Water Supply Papers" of the U. S. Geological Survey.

METEOROLOGICAL DATA

The input meteorological data required for operation of the simulation system include the five major variables involved in the heat budget. Of these, solar radiation and dry bulb temperature are dominant factors; the others, in decreasing order of

importance, are dew point, wind speed, and cloud cover. The latter is involved only in the calculation of long wave (back) radiation exchange, since measured values of short wave (solar) radiation are used in the heat budget calculations.

The information was acquired largely from the National Weather Records Center at Asheville, North Carolina. Radiation data from three stations were utilized in the study, including: Huntington, West Virginia, Indianapolis, Indiana, and Hutsonville, Indiana. Weather data from Huntington, Cincinnati, Louisville, and Evansville were also used in the heat budget calculations.

ADVECTED HEAT

The term, advected heat, in the context of this report refers primarily to the waste energy resulting from condenser cooling of electrical generating plants. It can be utilized, however, to account for heat from other industrial or natural processes. For example, under low flow conditions groundwater seepage, which typically has a temperature that ranges only a few degrees about the mean annual dry bulb temperature, becomes a major source of inflow and energy to a stream; this is especially true in tributary basins of limited extent.

Daily average thermal loads for the 1964 simulation of stream temperatures were obtained largely through the cooperation of individual members of the Power Industry Advisory Committee. In isolated cases, where detailed information of the thermal load of specific plants was not available, proportionate loads were assumed, which were based upon the plant capacity in 1964, as indicated by the Federal Power Commission, and the ratio of plant capacity to daily load of nearby generating units for which data had been supplied by the Power Industry Advisory Committee.

Projections of future power requirements in the Ohio Basin were obtained from the Federal Power Commission. These forecasts indicate an increase from 163×10^9 kW-hr in 1970 to 316×10^9 kW-hr in 1980, a 10 year average growth rate of 6.8%. During the 1980's the growth rate is expected to decline slightly to 5.8%, so that by 1990 the power requirements in the Utility Market Area are projected to be 551×10^9 kW-hr.

Table 2 shows past and estimated future utility steam generating capacities (by subbasin) in the Ohio Basin for 1963, 1970, and 1980.⁽³⁾ Since the geographic distribution and the nature of electric power supply beyond 1980 or 1985 is uncertain, no detailed estimates have been included beyond those dates. In 1963, 90% (25,000 MW) of the thermal generating capacity used once-through cooling of plant condensers, 2200 MW used cooling towers and approximately 1000 MW utilized cooling ponds. Present estimates by the Federal Power Commission indicate that two-thirds (50,000 MW) of the 1980 thermal capacity will use once-through cooling. In the past, cooling towers or ponds have generally been required for mine mouth plants or plants located near load centers with a limited water supply.

SIMULATIONS

In a recently completed study by Battelle-Northwest of the thermal regimen of the Upper Mississippi River Basin,⁽⁶⁾ the calendar year 1964 was selected for simulation purposes because a paucity of complete sets of data existed for other years. In the case of the Ohio Basin, adequate information is available over a period of several years. However, potential future interties between Mississippi and Ohio Basin studies made manifest the desirability of a 1964 simulation.

TABLE 2. Distribution of Utility Steam Generating Capacity in the Ohio River Basin in 1963, 1970, 1980 in Megawatts (3)

<u>Subbasin</u>	<u>1963</u>	<u>1970</u>	<u>1980</u>
Allegheny	1,465	5,804	8,122
Monongahela	1,370	2,354	3,414
Beaver	645	743	653
Upper Ohio	5,331	9,927	20,755
Muskingum	2,101	3,047	2,871
Kanawha - Little Kanawha	1,101	932	1,491
Gyandot - Big Sandy	265	265	765
Scioto	411	274	198
Miami - Little Miami	1,197	1,161	1,495
Middle Ohio	3,346	4,813	9,223
Licking - Kentucky - Salt	632	632	1,632
White	1,148	1,864	3,256
Wabash	1,914	3,146	4,894
Lower Ohio	4,494	5,158	8,484
Green	1,672	3,067	4,067
Cumberland	<u>1,118</u>	<u>1,388</u>	<u>3,538</u>
	28,210	44,575	74,858

Ohio Basin flows in 1964 were slightly below normal with an average of 95% (244,700 to 257,600 ft⁵/sec) of the long term mean. The lowest average flows recorded along the main stem were 87% in the middle Ohio between Huntington (66,290 to 75,970 ft³/sec) and Louisville (110,400 to 177,200 ft³/sec). These near-normal flows were in marked contrast with the 62% (110,400 to 177,200 ft³/sec) of the long term mean registered at Thebes, Illinois on the Mississippi River, 43 miles above the confluence with the Ohio.

Air temperatures in the Ohio Basin were both above and below normal for 1964; the average for the Basin as a whole was approximately 0.1 °C above normal.

ALLEGHENY RIVER

The Allegheny River, which joins the Monongahela at the apex of Pittsburgh's Golden Triangle to form the Ohio River, drains an area of 11,730 square miles. The northernmost headwaters of the subbasin originate near Lake Erie in New York State; from there the Allegheny flows into and through the heavily forested uplands of western Pennsylvania in a general southwesterly direction toward the confluence with the Monongahela River.

Manufacturing has been and expects to continue as the major economic activity in the area, which lies in the region known as Appalachia. Dominant industries in the upper Basin are wood products, metals, machinery, and food products; metals, machinery, and apparel industries have been the most important in the lower Basin. Agriculture is dominated by dairying and livestock production. Bituminous coal mining continues to be a significant factor in the lower Basin economy. The upper Basin provided the first major production of petroleum in the world in the 1860's; its 1960 output was 5.3 million barrels of crude oil.

Mean annual precipitation in the subbasin ranges from 43 in. at Jamestown, New York to 36 in. at Pittsburgh. Despite the fact that precipitation in the area is below the average for the Ohio Basin as a whole, the average runoff is 23.2 in. per year, the highest yield of any tributary system.⁽⁷⁾ In 1964, the total precipitation at Pittsburgh was 38 in. Annual streamflow at Natrona, 24 miles above the Ohio River, was 18,090 ft³/sec (96% of normal) in 1964; the range for the year was between 188,000 ft³/sec and 1,610 ft³/sec. The minimum recorded at Natrona was 895 ft³/sec on October 22, 1963.

Cross section data were available for the Allegheny Waterway, a series of eight locks and dams, which provide slack water navigation in the lowermost 72 miles of the river.

Model Verification

Because the Allegheny River and its tributaries are used extensively for process and cooling waters, it was decided to restrict the simulation to the lowermost 50 miles of the Waterway for which adequate daily average water temperature records were available. Two major users of cooling water in this reach in 1964 were the 416 MW Springdale and the 262 MW Colfax Steam Plants. Daily average loads for each unit were made available for simulation input.

Results of the simulation are illustrated in Figure 3 (Allegheny River calculated and observed temperatures at Wilkinsburg, 1964). A least square simulated fit of calculated and observed temperatures indicated maximums, means, and minimums of 27.5, 14.1, 0.7, and 26.7, 13.9, and 1.1 °C respectively.

Projected Conditions

Federal Power Commission Projections (Table 2) indicate a growth in utility steam generating capacity in the Allegheny Basin from 1465 MW at the end of 1963 to 5804 MW in 1970 and

FIGURE 3. Allegheny River at Wilkinsburg

to 8122 MW in 1980. Nonutility steam capacity for 1964 was 68 MW; no projections for nonutility generation were available for 1980.

In order to assess the potential impact of this growth, the thermal capacity between River Mile 50 and the confluence with the Monongahela was calculated for conditions of mean monthly solar radiation and weather, and mean monthly flow for the 1950-60 period. Capacity was arbitrarily defined as the total heat that could be assimilated and dissipated within a temperature envelope of 5 °F (2.8 °C). Pennsylvania Water Quality Standards for Warm Water Fisheries specify that stream temperatures are not to exceed a 5 °F use above ambient temperatures or a maximum temperature of 87 °F, whichever is less. A further constraint was that no advected pulses less than 800 MW_T were admitted to the model (800 MW_T corresponds approximately to the average output of an 800 MW_e unit, with a 40% thermal efficiency and a capacity factor of 70%). The energy required to increase the stream temperature from a point on the decay curve to 5 °F was calculated only at the mouth for values less than 800 MW_T for inclusion in the total. Figure 4 represents the average assimilative plus the dissipative direct cooling capacity for the reach of interest; the lower two curves indicate average monthly local maximum inputs. Average total capacity ranges between 15,400 MW_T in April and 2400 MW_T in September; maximum input at Mile 50 ranges from 10,600 MW_T to 860 MW_T, and at Mile 0 from 13,300 MW_T to 1600 MW_T. In 1964 the steam generating capacity in the lower 50 miles of the Allegheny was approximately 700 MW_e. If it is assumed that the area will experience a growth in power demand proportional to the Allegheny subbasin as a whole, the generating capacity for 1980 will be 3900 MW_e. A check of Table 3 reveals that average direct cooling capacity for August, September, and October

FIGURE 4. Average Direct Cooling Capacity of Allegheny River

would be below or marginal to the cooling requirements for the area by 1980. Since it was assumed in the simulation that no residual heat from upstream sources entered the area under study, significant additions of any type would further limit the waste energy that could be assimilated within the given constraints.

TABLE 3. Average Direct Cooling Capacity [MW_T] of Allegheny River (RM 50 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 50</u>
January	11,500	10,300	8,100
February	11,300	10,100	7,900
March	14,100	12,800	10,300
April	15,400	13,300	10,600
May	10,800	8,900	7,000
June	6,000	4,600	3,600
July	4,500	2,900	2,200
August	3,500	2,200	1,600
September	2,400	1,600	900
October	3,800	2,700	2,000
November	6,000	4,800	4,100
December	9,200	8,000	6,600

The 10-year minimum direct cooling capacity at the mouth indicated in Figure 4 was calculated for monthly low flow during the period 1950-60. This value is only of short term interest because completion of potential watershed and reservoir projects in the basin is expected to provide a base flow of approximately $4000 \text{ ft}^3/\text{sec}$. The effect of future regulation will increase the direct cooling capacity in September from that indicated by approximately 1000 MW_T .

MONONGAHELA RIVER

The Monongahela River subbasin drains an area of 7390 square miles of western Maryland, northeastern West Virginia, and southwestern Pennsylvania. It flows in a general northerly direction from its origin in the Appalachian Plateau of West Virginia toward the confluence with the Allegheny River at Pittsburgh.

Coal mining continues to be the major industry over a greater portion of the subbasin. In general, mining predominates upstream of Mile 42 (Charleroi, Pennsylvania) on the main stem and manufacturing predominates in the Pittsburgh area, which lies downstream of that point. Dairying and livestock production are the primary agricultural activities in the region.

The Monongahela River is perhaps best known for its acidity. Oxidation of iron sulfides exposed to the atmosphere by coal mining operations and the associated drainage of sulfuric acid from the mines continues to cause the stream to have an unusually low pH. A range in pH between 3 and 4 has been relatively common during low flow periods of late summer and fall.

Mean annual precipitation ranges from 54 in. at higher elevations to 36 in. near Pittsburgh. Average runoff for the **subbasin** is 23.1 in, per year, which is approximately equal to runoff in the Allegheny subbasin. High and low values are **31.0** and 12.9 in., in contrast with 33.1 and 16.6 in. observed in the Allegheny subbasin. Annual streamflow at Braddock, 11 miles above the Ohio River, was 11,020 ft³/sec (90% of normal) for the 1964 calendar year; the range for the year was between 90,800 ft³/sec and 1620 ft³/sec. The minimum flow of record was 559 ft³/sec on 20, 22, 23 September 1946.

Cross section data were available for the Monongahela Waterway, a series of 15 locks and dams extending 132 miles upstream from the Ohio River.

Model Verification

Upstream of River Mile 90 (Pool No. 7) information on flow and stream temperatures was inadequate for simulation purposes; consequently, the study was initiated at that location. In general, major industrial usage of river water for process and cooling purposes occurs downstream of Charleroi (RM 42). The primary source of waste heat in the lower river in 1964 was from electrical generating plant condensers. Steam plant capacity between River Miles 42 and 0 totalled 1114 MW_e (units with a capacity of 5 MW_e or larger).

No observed temperatures were secured for the 1964 period at any point in the lower river. Therefore, comparisons between calculated and observed temperatures were made at Charleroi (Figure 5). A least square fit of a sinusoidal function to calculated and observed data indicated maximums, means, and minimums of 26.8, 13.8, 0.8 and 25.7, 14.0, 2.3 °C respectively.

Projected Conditions

Utility steam generating capacity (see Table 2) in the Monongahela subbasin is projected to increase from 1370 MW_e in 1963 to 3414 MW_e by 1980. In 1964 nonutility generating capacity was 245 MW_e; no projections of nonutility capacity for 1980 were available.

Since the section of the river simulated in this study (RM 90 to RM 0) lies within the State of Pennsylvania, a 5 °F temperature envelope was selected as one of the constraints on direct cooling capacity. It should be noted that West Virginia Water Quality Standards for Class C waters (propagation of fish, etc) and Class D waters (cooling and power) specify only that

FIGURE 5 Monongahela River at Charleroi

temperatures are not to exceed 93 °F at any time during the months of May through November and not to exceed 73 °F at any time during the months of December through April. ORSANCO uses criteria similar to the West Virginia Standards on temperature for aquatic life in their appraisal of quality conditions in the Ohio Basin.⁽⁸⁾ The second constraint placed on simulated average direct cooling capacity was that no heat pulse of less than 800 MW_T be input to the model in the reach of interest, with the exception that the energy associated with the difference between the residual temperature at the mouth of the river and 5 °F was included in the total capacity. In order to provide a consistent base for the entire Ohio Basin Study the above constraints were utilized throughout in calculating direct cooling capacities.

Figure 6 and Table 4 indicate the results of the simulation. Average monthly total capacity between RM 90 and RM 0 ranges from 8900 MW_T in February to 1700 MW_T in September. In 1964 the steam generating capacity in the lower Monongahela was 1114 MW_e. If growth proceeds in pace with the basin as a whole, the 1980 capacity will be approximately 2800 MW_e. The mean direct cooling capacity for both September and October falls below this level. Ten year minimum 7-day design flows at Braddock (RM 11) indicate a flow through assimilative capacity of 600 MW_T; since this figure does not include assimilative capacity due to storage and dissipative capacity (to the atmosphere), the total 10-year monthly minimum is unknown. However, even if the quantity is doubled to account for storage and atmospheric dissipation it becomes apparent that the stream capacity is marginal with respect to present requirements under low flow conditions.

The U.S. Army Corps of Engineers has identified 660,000 acre-feet of potential storage capacity in the Monongahela

FIGURE 6. Average Direct Cooling Capacity of Monongahela River

TABLE 4. Average Direct Cooling Capacity [MW_T] of Monongahela River (RM 90 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 90</u>
January	8,000	6,500	5,000
February	8,900	7,500	5,800
March	8,700	7,000	5,300
April	7,800	6,100	4,600
May	6,600	4,600	3,400
June	4,400	2,600	1,800
July	3,500	1,800	1,400
August	4,000	2,500	1,900
September	1,700	1,100	700
October	2,500	1,600	1,100
November	3,100	2,200	1,600
December	6,600	5,100	4,000

subbasin, which could be utilized to supplement streamflows during low flow periods. Present scheduling calls for an increased design flow at Braddock from the current value of 1820 to 2700 ft³/sec by 1980.

MUSKINGUM RIVER

The Muskingum River subbasin covers an area of 8040 square miles in Eastern Ohio. The northern and western parts of the region, which have been subject to continental glaciation, characteristically exhibit low topographic relief. The unglaciated areas are heavily wooded uplands bordering the Ohio River. The main stem Muskingum River is formed by the confluence of the Tuscarawas and Walhonding Rivers at Coshocton in the center of the subbasin; from there it flows for 110 miles to where it joins the Ohio River at Marietta, 172 miles downstream from Pittsburgh.

The economy of the area is diversified. Manufacturing is characterized by small facilities producing a large variety of products. Agriculture retains a significant position, with livestock production, dairying, and cash crop production as important components. Coal, clay, and petroleum production are all important features of the regional economy.

Mean annual precipitation ranges from 36 in. in the northern part of the basin to 41 in. near the Ohio River. Runoff averages 13.3 in. per year and ranges from 21.5 to 4.9 in.

Because of early flood problems, 17 artificial reservoirs have been constructed, largely in the headwaters. Ten potential reservoir sites have also been identified and may be developed in the future. The mean annual discharge at **McConnelsville** (approximately River Mile 50) is $7150 \text{ ft}^3/\text{sec}$. The 1964 mean flow was $6775 \text{ ft}^3/\text{sec}$; the maximum and minimum daily flows were 56,600 and $574 \text{ ft}^3/\text{sec}$ respectively.

The lower river contains an obsolete canal system, which presently is maintained by the State of Ohio, primarily for recreational purposes. Cross section data were available from the mouth to Dresden (RM 93).

Model Verification

Upstream of Dresden the input data were inadequate for modeling purposes; consequently, the simulations were initiated at that location. Two major steam generating plants were located in the reach of interest, Philo (500 MW_e) and Beverly (876 MW_e); both units are operated by the Ohio Power Company.

The results of the simulation are illustrated in Figure 7, a comparison of calculated and observed temperatures at Beverly (RM 24). No observed temperatures were available

FIGURE 7. Muskingum River at Beverly

downstream of Beverly. The results appear satisfactory except during the late winter and early spring when observed temperatures fluctuated more widely than calculated temperatures. The cause of the discrepancy is unknown. A least squares fit of a sinusoidal function to the calculated and observed data produced maximums, means, and minimums of 30.2, 16.2, 2.2, and 28.1, 16.8, 4.5 °C respectively. If calculated temperatures are used as synthetic values for the first four months of the observed data the sinusoidal maximum, mean, and minimum are 29.4, 15.8 and 2.3 °C respectively.

Projected Conditions

Table 2 indicates that utility steam generating capacity is expected to increase from 2101 MW_e at the end of 1963 to 2871 MW_e by 1980. Nonutility steam capacity in 1964 was 125 MW_e; no projections of 1980 nonutility capacity were available for the Muskingum subbasin. It should be noted that a 232 MW_e utility steam plant located in the nearby Hocking subbasin is included in the Muskingum total.

Figure 8 and Table 5 indicate the results of a simulation of mean monthly assimilative and dissipative capacity of the Muskingum River between River Miles 93 and 0. Total average direct cooling capacity ranges from a high of 5600 MW_T in February and March to a low of 1100 MW_T in September. On the average, the months of September and October have insufficient direct cooling capacity to assimilate the present loads and remain within a 5 °F differential with respect to background temperatures.

Maximum average local input capacity in September ranges from 500 MW_T at RM 93 to 600 MW_T at RM 0. For the low monthly average flow of the 1950-60 period the maximum local input would be 250 MW_T at RM 0.

FIGURE 8. Average Direct Cooling Capacity of Muskingum River

TABLE 5. Average Direct Cooling Capacity [MW_T] of Muskingum River (RM 93 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 93</u>
January	4,600	3,600	3,000
February	5,600	4,800	4,100
March	5,600	4,500	3,900
April	5,500	4,200	3,700
May	4,600	3,100	2,800
June	3,100	1,800	1,500
July	2,800	1,500	1,300
August	1,500	900	800
September		600	500
October		600-	600+
November	1,600	900	800
December	3,100	2,300	2,000

KANAWHA RIVER

The headwaters of the Kanawha River subbasin are situated in the Blue Ridge region of southern West Virginia, west central Virginia and northwestern North Carolina. From its southern extremity the subbasin trends in a north-northwesterly direction across West Virginia toward the Ohio River. The drainage area covers 12,300 square miles within the Appalachian Plateau; 8450, 3080, and 770 square miles of which are in West Virginia, Virginia, and North Carolina respectively. The main stem of the Kanawha River is formed by the confluence of the Gauley and the New River at Gauley Bridge, from there it flows in a northwesterly direction for 96 miles to Point Pleasant. Point Pleasant is 265 (Ohio River) miles downstream from Pittsburgh.

Manufacturing, mining, and agriculture are all important economic activities in the area. Dominant industries are chemicals, wood products, metal products, textiles, machinery, and food products. Coal mining and petroleum production continue as important extractive industries in the area. Farming is dominated by livestock production.

Mean annual precipitation in the subbasin ranges from 45 to 50 in. in the Blue Ridge region to 40 in. near the Ohio River. Average precipitation at Charleston (RM 54) is 44 in.; the 1964 average was 33 in. Runoff averages 18.7 in. per year. The range in runoff is between 27.2 and 11.4 in. Even though the Kanawha basin has 5% more area than the Allegheny basin its total runoff is only 85% of the total for the Allegheny. Mean annual streamflow at Charleston is $14,340 \text{ ft}^3/\text{sec}$. The 1964 average was $12,250 \text{ ft}^3/\text{sec}$ (85% of normal); the range for the year was between $111,000 \text{ ft}^3/\text{sec}$ and $1700 \text{ ft}^3/\text{sec}$. The minimum flow of record at Charleston was $1030 \text{ ft}^3/\text{sec}$ from 1 to 5 October 1953.

The Kanawha has been developed into a waterway from its mouth to River Mile 91, near Alloy, West Virginia. Cross sections were available for computer input to Kanawha Falls (RM 95).

Model Verification

Water temperatures and other data were incomplete above Mile 95. Therefore, simulation of the thermal regimen of the Kanawha River was initiated at that location.

A total steam generating capacity of 926 MW_e was in operation along the reach of interest at the end of 1963, 97% of which was upstream of/within the Charleston industrial complex. In addition, the major industry in Charleston for the period under simulation was chemicals and allied products, a significant producer of waste heat. A third major use of

cooling water was associated with the production of primary metals. The last two categories were important in that a paucity of data existed concerning their effective heat loads.

Figure 9 illustrates the results of the simulation, a comparison of 1964 calculated and observed temperatures of the Kanawha River at Charleston. Observed temperatures tended to be warmer than calculated temperatures except during period of high flow, by approximately 2 °C. The temperature difference corresponded approximately to an input of 600 MW_T. Since flows during 1964 low flow periods were generally estimated because of uncertain stage-discharge relationships, it appears probable that the difference between calculated and observed temperatures are as much a function of flow uncertainties as of unknown quantities of advected heat.

Projected Conditions

Table 2 indicates a growth in utility steam generating capacity from 1101 MW_e at the end of 1963 to 1491 MW_e by 1980. Nonutility capacity for 1964 was 275 MW_e; no projections of nonutility capacity for 1980 were available.

Figure 10 and Table 6 indicate the results of simulations of mean monthly thermal capacities of the Kanawha River from River Mile 95 to the mouth. The range is between a high of 12,400 MW_T in March to a low of 2600 MW_T in September. Maximum local inputs range between 1200 MW_T at the mouth to 1100 MW_T at RM 95 during September. In 1964 the steam generating capacity along the Kanawha River was 926 MW_e; if the capacity along the main stem increases in proportion to the subbasin as a whole the 1980 capacity would be approximately 1250 MW_e.

For 10-year monthly low flow conditions the maximum point assimilative capacity would be less than 600 MW_e.

FIGURE 9. Kanawha River at Charleston

FIGURE 10. Average Direct Cooling Capacity of Kanawha River

TABLE 6. Average Direct Cooling Capacity [MW_T] of Kanawha River (RM 95 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 95</u>
January	7,900	6,800	5,000
February	10,600	9,500	7,400
March	12,400	10,400	8,200
April	11,100	9,600	7,700
May	7,400	5,700	4,400
June	4,800	3,000	2,500
July	4,100	2,500	1,900
August	3,600	2,000	1,500
September	2,600	1,200	1,100
October	2,800	1,600	1,500
November	3,800	2,500	2,000
December	6,400	5,300	4,100

KENTUCKY RIVER

The Kentucky River subbasin drains an area of 6940 square miles of central Kentucky. The headwaters of the basin lie in the Appalachian Plateau sector of eastern Kentucky. From its origin the river traverses the lowland plateau of central Kentucky in a northwesterly direction to the confluence with the Ohio River, 545 (Ohio River) miles downstream of Pittsburgh.

Agriculture retains a dominant influence in the area, although manufacturing is increasing in importance. Coal mining and petroleum production are of importance only in the headwaters region of the Kentucky River.

Mean annual precipitation ranges from 48 in. in the headwaters to 44 in. near the Ohio River. The 1964 annual total at Lexington was 43 in. (97% of normal). The average runoff for the basin is 18.1 in.; the maximum and minimum runoff

of record are 32.0 and 5.7 in. respectively. The mean annual flow at Lockport (RM 31) is $8150 \text{ ft}^3/\text{sec}$. In 1964 the maximum, mean, and minimum flows at Lockport were 99,000, 7170, and $250 \text{ ft}^3/\text{sec}$ respectively. Because of the backwater effect from the Ohio River, no long term minimum has been established.

Cross section data were unavailable for the Kentucky Waterway, which extends 3 miles upstream from the confluence of the North and Middle Fork (Kentucky River Mile 259). Navigation charts, topographic maps, and flow data were utilized to estimate cross sections for computational purposes.

Projected Conditions

Observed temperatures were unavailable for the lower river; therefore, no verification was made of the Kentucky River model. The calculated mean direct cooling capacity between River Mile 96 (Lock and Dam No. 6) and River Mile 0 is summarized in Figure 11 and Table 7. The average total capacity ranges from $10,000 \text{ MW}_T$ in February to zero in August, September, and October. The zero minimum was biased by the fact that no input less than 800 MW_T was admitted to the model. The maximum monthly average local assimilative capacity for flow through conditions in October is 240 MW_T at the mouth and 200 MW_T at Lock and Dam No. 6. Thermal generating capacity for the Licking, Salt, and Kentucky basins is expected to increase from 632 at the end of 1963 to 1632 MW_e in 1980.

In 1964 the Kentucky basin steam generating capacity was 334 MW_e ; if growth is in proportion to the Tri-basin area as a whole, the 1980 Kentucky basin generating capacity would be approximately 860 MW_e .

WABASH RIVER

The Wabash River subbasin drains an area of 33,100 square miles, largely in the State of Indiana. The basin includes

FIGURE 11. Average Direct Cooling Capacity of Kentucky River

TABLE 7. Average Direct Cooling Capacity [MW_T] of Kentucky River (RM 96 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 96</u>
January	6,600	4,600	3,800
February	10,000	7,000	5,900
March	10,000	6,600	5,700
April	7,200	4,200	3,800
May	5,800	2,600	2,200
June	3,000	1,200	900
July	4,500	1,300	1,100
August		700	600
September		300	300-
October		200+	200
November	3,600	1,400	1,200
December	5,000	3,500	2,900

8560 square miles of eastern Illinois and 320 square miles of western Ohio. The region, which has been subject to continental glaciation, is characterized by flat or gently rolling topography, except in the southwest, where hilly terrain is more prevalent.

Precipitation ranges from 36 in. in the northern part of the basin to 44 in. near the Ohio River. In 1964 total precipitation at Indianapolis in the northern part of the basin was 36 in. (91% of normal); the 1964 total at Evansville, on the Ohio River, was 38 in. (91% of normal). Runoff averages 12.8 in. per year and ranges from 26.9 to 2.9 in. Streamflow at Mount Carmel, Illinois (RM 95) averages 26,270 ft³/sec per year. The low flow of record was 1620 ft³/sec on 27, 28, 30 September 1941. Mean annual flow for the 1964 calendar year was 18,370 ft³/sec (70% of normal); low flow for the year was 1800 ft³/sec.

FIGURE 12. Wabash River at Riverton

Agriculture and the associated food products industry is a dominant feature over much of the basin. Pharmaceuticals, pulp and paper, electrical machinery, and transportation equipment are industrial products of significance. Coal mining and petroleum production are important in the southwestern part of the basin.

Cross section data were available from the mouth of the main stem of the Wabash to River Mile 240. The original data were the result of surveys prior to 1935. Changes in meander patterns undoubtedly have voided the data in terms of local detail. Since the study was of a reconnaissance nature, it was assumed that the cross sections were representative of conditions along the river and thus could be used in the simulation.

Model Verification

No observed temperature information was obtained for the lower river. Therefore, the only locations where verification tests could be made were at Sullivan (RM 184), Hutsonville (RM 172), and Riverton (RM 162). Figure 12 indicates 1964 computed and observed temperatures at Riverton. A least squares sinusoidal fit to each set of data produced calculated and observed maximums, means, and minimums of 29.3, 16.2, 3.1 and 28.0, 15.5, and 3.0 °C respectively.

Projected Conditions

Figure 13 and Table 8 indicate the mean monthly direct cooling capacity of the Wabash River from River Mile 240 to the mouth. No dissipative capacity for the White River, which joins the Wabash near River Mile 128, is included in the total. The range in direct cooling capacity is between a maximum of 20,600 MW_T in April and a minimum of 5200 MW_T in September. Maximum local input ranges from 2100 MW_T at the mouth to 800 MW_T at Mile 240 for the low average capacity month of September.

FIGURE 13. Average Direct Cooling Capacity of Wabash River

TABLE 8. Average Direct Cooling Capacity [MW_T] of Wabash River (RM 240 to RM 0)

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 0</u>	<u>Maximum Input-RM 240</u>
January	13,400	10,800	3,500
February	19,900	14,600	5,200
March	20,400	15,400	4,800
April	20,600	14,900	5,600
May	17,900	10,600	4,100
June	17,500	10,900	4,600
July	13,200	9,700	3,300
August	7,800	4,200	1,600
September	5,200	2,100	800
October	5,800	2,600	1,200
November	9,100	5,400	2,000
December	12,200	8,700	2,700

Steam generating capacity is projected to increase from 1914 MW_e in 1963 to 4894 MW_e by 1980 in the Wabash subbasin (excluding the White River subbasin). Since 800 to 1000 MW_T may be contributed to the Wabash from the White River, the average cooling capacity during September and October would be below or marginal to the mean direct cooling capacity.

OHIO RIVER

Figures 14 through 21 are comparisons of 1964 calculated and observed temperatures at several locations along the Ohio River. In general, there is good agreement between computed and observed temperatures. The greatest difference was noted at South Heights (RM 15), in the Pittsburgh area, where observed temperatures tended to be warmer than calculated temperatures and also tended to exhibit a high degree of irregularity. A least squares sinusoidal fit of calculated

FIGURE 14. Ohio River at South Heights

FIGURE 15. Ohio River at East Liverpool

FIGURE 16 Ohio River at Huntington

FIGURE 17. Ohio River at Cincinnati

FIGURE 18. Ohio River at Markland Dam

FIGURE 19 Ohio River at Louisville

FIGURE 20 Ohio River at Evansville

FIGURE 21. Ohio River at Grand Chain

and observed temperatures at South Heights indicated maximums, means, and minimums of 27., 14.1, 1.2 and 27.5, 16.2, 4.9 °C respectively. Since good agreement of calculated and observed data was obtained both upstream and downstream of South Heights (see Figures 3, 5, 14, and 15), no parameter adjustments were made to achieve a better fit. Near Huntington (RM 304) calculated and observed sinusoidal maximums, means, and minimums were 27.9, 14.4, 0.9 and 27.4, 15.9, 3.4 °C respectively; at Louisville (RM 600) the temperatures were 30.3, 16.5, 2.0 and 28.6, 15.3, 2.7 °C respectively; at Grand Chain (RM 962, which is 19 miles above the mouth) 28.8, 17.0, 5.2 and 28.6, 16.0, 3.6 °C respectively.

Over the main stem as a whole maximum calculated temperatures were approximately 0.5 °C warmer, calculated means approximately 0.3 °C cooler, and calculated minimums 1.2 °C cooler than observed temperatures.

Projected Conditions

Figure 22 and Table 9 summarize the direct cooling capacity of the Ohio River Basin. The total indicated in the upper curve of Figure 22 includes the dissipative capacity for the tributary streams examined in this study. The average monthly direct cooling capacity ranges from a high of 261,000 MW_T in April to a low of 95,000 MW_T in October.

Table 2 indicates that Ohio Basin utility steam generating capacity is expected to increase from 28,210 MW_e in 1963 to 74,858 MW_e in 1980. By 1990 the total steam capacity is estimated from energy projections to be approximately 130,000 MW_e. The year when total direct cooling capacity in the Basin will equal steam generating capacity appears to be approximately 1984. Since only two-thirds of the 1980 total is expected to utilize once-through cooling, the actual full utilization of direct cooling capacity should be nearer to 1990.

FIGURE 22. Average Direct Cooling Capacity of Ohio River Basin

**TABLE 9. Average Direct Cooling Capacity [MW_T]
of Ohio River Basin**

<u>Month</u>	<u>Total</u>	<u>Maximum Input-RM 981</u>	<u>Maximum Input-RM 792</u>	<u>Maximum Input-RM 357</u>	<u>Maximum Input-RM 172</u>	<u>Maximum Input-RM 0</u>
January	208,000	120,000	64,400	48,900	26,300	17,400
February	247,000	176,000	93,100	65,400	29,600	18,700
March	251,000	163,000	92,100	65,800	31,100	20,700
April	261,000	143,000	80,000	59,000	30,800	20,600
May	198,000	100,000	55,700	44,800	21,900	14,200
June	168,000	63,000	29,000	20,600	11,400	7,500
July	176,000	51,000	22,400	16,200	8,400	4,900
August	129,000	40,000	16,800	12,900	7,600	4,900
September	102,000	26,000	8,900	7,100	4,400	2,900
October	95,000	29,000	11,000	9,300	6,200	4,500
November	123,000	51,000	21,500	15,300	9,300	7,100
December	195,000	98,000	49,600	36,000	19,500	13,600

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