ORBES

Volume III-G
Special Study Report

Issues Related to Water Allocation in the Lower Ohio River Basin

E. Downey Brill, Jr., Glenn E. Stout, Robert W. Fuessle,
Randolph M. Lyon, and Keith E. Wojnarowski
University of Illinois at Urbana-Champaign

May 15, 1977

PHASE I

OHIO RIVER BASIN ENERGY STUDY

OHIO RIVER BASIN ENERGY STUDY

Volume III-G

SPECIAL STUDY REPORT

ISSUES RELATED TO WATER ALLOCATION IN THE LOWER OHIO RIVER BASIN

E. Downey Brill, Jr.
Glenn E. Stout
Robert W. Fuessle
Randolph M. Lyon
Keith E. Wojnarowski

May 15, 1977

Prepared for
Office of Energy, Minerals,
and Industry
Office of Research and
Development
U.S. Environmental Protection
Agency
Washington, D.C.
Grant Number - US EPA R-804821

PREFACE

The report is based on the first nine months' progress in a special study of water allocation issues. It should be viewed as a preliminary analysis. Future work is planned for refining and extending the work described here.

We would like to thank the following people and agencies for supplying information: J. R. Villines and others from the Division of Water Resources, Department for Natural Resources and Environmental Protection, Kentucky; L. A. Martens, U.S. Geological Survey, Illinois; J. F. Blakey, Water Resources Division, U.S. Geological Survey, Ohio; W. G. Weist, U.S. Geological Survey, Indianapolis; the Illinois State Water Survey; and several representatives of the U.S. Army Corps of Engineers (Cincinnati, Louisville, and St. Louis offices). Much of the work of this report is based on earlier reports by all of these agencies. We also thank E. A. Joering of the Ohio River Basin Commission for supplying recent information, for suggesting sources of information, and for providing many helpful suggestions.

CONTENTS

TABLES

TABLES

FIGURES

1. INTRODUCTION

The objectives of this report are to describe the first stage of an ongoing analysis of water allocation issues related to energy development in the Ohio River Basin. The water resources of the Ohio River Basin Energy Study (ORBES) region are described in Chapter 3; average and low-flow conditions are considered. Projected water uses are given in Chapter 4; municipal, industrial, irrigation, navigation, and power-related uses are considered so that an overall balance between sources and supplies could be determined. Particular emphasis has been given to consumptive water losses since they are not available for other off-stream users or for maintaining water quality.

Municipal and self-supplied industrial uses were projected on a county basis for all states included in the ORBES region. Energy related uses were estimated by assuming that wet cooling towers would be utilized by plants specified by the four different ORBES scenarios. (Different cooling technologies will be examined in further studies.)

Two of the energy scenarios are based on projections by the Bureau of Mines (BOM). The BOM 80/20 and BOM 50/50 scenarios assume different ratios of coal-fired plants and nuclear plants for generating electricity; for example, the BOM 80/20 scenario assumes that 80% of the plants are coal-fired and 20% are nuclear. The other two scenarios, based on a Ford Foundation study, are referred to as the Ford Technical Fix (FTF 100/0 and FTF 0/100) scenarios. The FTF scenarios project much lower energy development than do the BOM scenarios.

The available water supplies and total projected water uses are compared in Chapter 2. Comparisons are made on a state basis and for the major river basins. For rivers, the ratio of cumulative consumption to the 7-day 10-year low flow was calculated for the different reaches; profiles are shown that give the ratios along the Ohio River. The methodology used to analyze the river basins is described in Chapter 5. Since excessive levels of consumptive use were estimated under the BOM scenarios, policy issues related to increasing water supplies and/or decreasing water consumption are also discussed in Chapter 2.

Many assumptions have been made in developing the water use estimates presented in this report. Many of the estimates can be readily modified to reflect different assumptions; for example, the aggregate water use levels could be changed (using a multiplicative factor) to correspond to a different consumptive use requirement for a power plant.

2. POLICY ISSUES RELATED TO WATER ALLOCATION AND USE

2.1 INTRODUCTION

Expected growth of population, industry, and energy demands will lead to increased demands on the finite water resources. This interrelationship is discussed in three main sections of this chapter. The first provides an overview of the magnitudes of water supplies and of present and projected water uses under the different ORBES scenarios. State totals are used which apply to the portions of the states within the ORBES region. The methods and data used are described in Chapters 3 and 4.

The second section provides a more detailed analysis of the effects of the consumptive water use on the major rivers; the methodology is described in Chapter 5. The approach is to express the cumulative consumption along a river as a percent of the 7-day 10-year low flow.

The third section provides a brief discussion of additional trade-offs and issues related to water allocation and energy development; research needs are also identified. In general, the interrelated nature of the water and energy systems is emphasized.

2.2. WATER USE PROJECTIONS IN RELATION TO WATER SUPPLIES: AN OVERVIEW

2.2.1 WATER SUPPLIES

Water supplies in the ORBES region are relatively abundant as indicated by the estimates of average rainfall, runoff, and inflow in Table III-G-1. During drought conditions, of course, supplies are much lower, as indicated by the low-flow estimates in the table. Runoff refers to the portion of actual stream flows originating within the region; the portion from outside the region is listed as inflow. Inflow is counted only where it enters the ORBES region; as an example, the inflow to Indiana is listed as zero since the actual streamflows into that state are listed as runoff or inflows to other states. Note that inflows to the region account for about 67% of the total average flow and for over 90% of the total low flow.

The reader is referred to Chapter 3 for a more detailed discussion of the water supplies.

Table III-G-1

WATER SUPPLY IN THE ORBES REGION[1]

Water Supply	Illinois	Indiana	Kentucky	Ohio	Total
Average Conditions					
Rainfall[2]	140,000	95,000	140,000	98,000	471,000
Runoff[2]	34,000[2]	28,000	50,000	30,000	140,000
Inflow[3]	160,000	0[3]	80,000	50,000	290,000
Total[4]	200,000	28,000	130,000	79,000	440,000
Low-Flow Conditions					
Runoff[2]	1,500	1,700	1,400	1,800	6,400
Inflow[3]	43,000	0[3]	31,000	4,500	78,000
Total[4]	45,000	1,700	32,000	6,300	85,000

[1] Data in cubic feet per second (cfs).
[2] Based on data from Ref. (1).
[3] Only inflow from outside the ORBES region is given here. Thus, the inflow to Indiana is listed as zero; the Ohio River, for example, is accounted for as a combination of runoff from the different states and inflow to Ohio.
[4] Total equals inflow plus runoff. Totals do not necessarily equal sums of column entries because of rounding.

2.2.2 WATER USE ESTIMATES

Estimates of the major water uses in 1970 are listed in Table III-G-2. Both withdrawal and "consumption" estimates are provided. The consumption estimates are of primary concern in this discussion; such water losses are not returned to the streams and are not directly available for other off-stream uses or for maintaining water quality.

Table III-G-3 provides projections of total water use in 1985. One major assumption is that all power plants use cooling towers--even existing plants which must be retrofitted. The estimates presented could easily be modified to reflect different cooling technologies.

One major trend is apparent from examining Tables III-G-2 and III-G-3; the water consumption estimates increase sharply, from 1000 cfs to 3000 cfs for the region as a whole. The major reason is the assumption that cooling towers would be employed by all plants. (Note that this trend is actually understated since the power-related estimates for 1970 include the parts of the states not in the ORBES region). A related trend is that the water withdrawal estimates decrease because of the assumption that cooling towers replace once-through cooling.

Another trend is that the relative proportions of consumptive use change. For the 1970 estimates, municipalities and industries accounted for approximately 90% of the total consumption, but for the 1985 estimates they account for only 37% with power-related consumption accounting for the remaining 63%. Irrigation, discussed in a following section, is not considered here.

The trends described above also hold in examining water use estimates for the four ORBES scenarios for 2000 (see Tables III-G-4, III-G-5, III-G-6 and III-G-7). Under the BOM scenarios, power-related water consumption could be as much as 75% of the total projected consumption.

The two BOM scenarios project significantly higher energy demands and lead to much higher estimates of water use than do the FTF scenarios. The difference between the BOM 80/20 and BOM 50/50 scenarios is relatively small; the total water consumption estimate for the BOM 50/50 scenario is approximately seven percent greater because of the larger cooling requirement of nuclear plants. The estimate for the FTF 0/100 scenario is only three percent greater than for the FTF 100/0 scenario.

Table III-G-2

WATER USE IN 1970[5]

	Illinois	Indiana	Kentucky	Ohio	Total
Water Withdrawal					
Municipal[6]	430	720	480	1,400	3,000
Industrial[6]	1,500	400	450	3,300	5,600
Power[7]	18,000	6,500	5,900	21,000	51,000
Total	19,000	7,600	6,900	26,000	60,000
Water Consumption[8]					
Municipal	86	140	96	270	600
Industrial	87	24	27	200	330
Power[7]	7.7	7.7	33	22	70.4
Total	180	180	160	490	1,000

[5] Data are in cfs. Municipal and industrial estimates are for the areas of each state within the ORBES region. Power estimates are for the entire state.

[6] See Chapter 4.

[7] From Reference (1).

[8] Estimated at 20% of withdrawals for municipalities and at 6% for industries.

Table III-G-3

PROJECTED WATER USE IN THE ORBES REGION

IN 1985[9]

	Illinois	Indiana	Kentucky	Ohio	Total
Water Withdrawal					
Municipal	470	790	560	1,500	3,400
Industrial	2,500	730	770	3,700	7,700
Power	720	560	510	1,000	2,800
Total	3,700	2,100	1,800	6,300	14,000
Water Consumption					
Municipal	95	160	110	310	670
Industrial	150	44	46	220	460
Power	480	370	340	670	1,900
Total	720	570	500	1,200	3,000

[9]Data in cfs. See Chapter 4 for a discussion of the method used to calculate these estimates.

Table III-G-4

PROJECTED WATER USE IN THE ORBES REGION
UNDER THE BOM 80/20 SCENARIO FOR 2,000[10]

	Illinois	Indiana	Kentucky	Ohio	Total
<u>Water Withdrawal</u>					
Municipal	540	910	660	1,700	3,800
Industrial	3,800	1,200	1,200	6,000	12,000
Power	1,600	1,500	1,400	2,600	7,000
Total	5,900	3,600	3,000	10,000	23,000
<u>Water Consumption</u>					
Municipal	110	180	130	340	760
Industrial	230	71	71	360	730
Power	1,000	1,000	930	1,700	4,700
Total	1,400	1,200	1,100	2,400	6,200

[10] Data in cfs. See Chapter 4 for a discussion of the method used to calculate these estimates.

Table III-G-5

PROJECTED WATER USE IN THE ORBES REGION

UNDER THE BOM 50/50 SCENARIO FOR 2000[11]

	Illinois	Indiana	Kentucky	Ohio	Total
Water Withdrawal					
Power	1,700	1,600	1,500	2,800	7,600
Total of Municipal, Industrial, and Power Withdrawals	6,000	3,700	3,400	10,000	24,000
Water Consumption					
Power	1,100	1,100	1,000	1,900	5,100
Total of Municipal, Industrial, and Power Consumption	1,500	1,300	1,200	2,600	6,600

[11] Data in cfs. See Chapter 4 for a discussion of the method used to calculate these estimates.

Table III-G-6

PROJECTED WATER USE IN THE ORBES REGION
UNDER THE FTF 100/0 SCENARIO FOR 2000[12]

	Illinois	Indiana	Kentucky	Ohio	Total
Water Withdrawal					
Power	750	620	580	1,200	3,200
Total of Municipal, Industrial, and Power Withdrawals	5,100	2,700	2,400	8,900	19,000
Water Consumption					
Power	500	420	390	810	2,100
Total of Municipal, Industrial, and Power Consumption	840	670	590	1,500	3,600

[12] Data in cfs. See Chapter 4 for a discussion of the method used to calculate these estimates.

Table III-G-7

PROJECTED WATER USE IN THE ORBES REGION

UNDER THE FTF 0/100 SCENARIO FOR 2000[13]

	Illinois	Indiana	Kentucky	Ohio	Total
Water Withdrawal					
Power	760	660	620	1,300	3,400
Total of Municipal, Industrial, and Power Withdrawals	5,100	2,800	2,500	9,000	19,000
Water Consumption					
Power	500	440	410	880	2,200
Total of Municipal, Industrial, and Power Consumption	840	690	610	1,600	3,700

[13] Data in cfs. See Chapter 4 for a discussion of the method used to calculate these estimates.

2.2.3 COMPARISON BETWEEN CONSUMPTIVE LOSSES AND AVAILABLE SURFACE-WATER SUPPLIES

A comparison between consumptive water estimates and available surface-water supplies during low-flow conditions is given in Table III-G-8. Under each state the incremental consumption from 1970 is given for 1985 and for the two extreme scenarios (BOM 50/50 and FTF 100/0). This consumption is also expressed as a percent of the total runoff and as a percent of the total flow (runoff plus inflows to the ORBES region). Under the BOM scenario, the average percent of total flow is estimated at seven percent for the ORBES region; the large variations from state to state result in large part from the fact that inflows were counted only where they enter the ORBES region.

When the total consumption estimates for the BOM scenario are compared to the estimated low-flow runoff from within the region, however, the percents are much larger. The percent for the ORBES region is 87%; the maximum percent is 115% and occurs for Ohio. These amounts highlight the degree to which the states could depend on inflows from outside their boundaries. The estimates for Illinois, for example, indicate that the incremental consumption is only three percent of the total flow but that it is 87 percent of the runoff from within the state. The large difference results from the very large flow in the Mississippi River. Future development in adjacent regions, however, could lead to competition for that resource. In particular, there is a large potential for irrigation in the Missouri Basin which drains into the Mississippi River. Similar conditions hold for the other states. Note that the dependence on inflow is much less under the FTF scenario.

2.2.4 POTENTIAL ROLE OF IRRIGATION

Irrigation has not been considered in the above discussion of water consumption because of the many questions surrounding its development in the region. Presently there is very little irrigation in the ORBES region. Recently, however, supplemental irrigation during drought periods has received increasing attention.

Water consumption estimates for irrigation in the year 2000 are presented in Tabel III-G-9; low, moderate, and high levels of irrigation are assumed. The low estimate is based on data for irrigated acreage in recent periods and assumes no additional development. The moderate and high estimates correspond to significant expansion of irrigated acreage. (Projections and factors affecting irrigation development are discussed in Section 4.6.)

Table III-G-8

INCREMENTAL WATER CONSUMPTION FROM 1970 IN RELATION TO LOW-FLOW SUPPLIES

State	Scenario 1985	BOM 50/50	FTF 100/0
ILLINOIS			
Incremental consumption (cfs)	544	1276	657
(As % of runoff)	37	87	45
(As % of total flow)	1	3	1
INDIANA			
Incremental consumption (cfs)	393	1141	489
(As % of runoff)	23	67	29
(As % of total flow)	23	67	29
KENTUCKY			
Incremental consumption (cfs)	341	1083	431
(As % of runoff)	24	75	30
(As % of total flow)	1	3	4
OHIO			
Incremental consumption (cfs)	715	2077	1018
(As % of runoff)	39	115	56
(As % of total flow)	11	33	16
TOTAL			
Incremental consumption (cfs)	2003	5587	2605
(As % of runoff)	31	87	40
(As % of total flow)	2	7	3

Table III-G-9

WATER CONSUMPTION IN 2000 FOR IRRIGATION

IN COMPARISON TO OTHER WATER USES[14]

State	Irrigation Consumption (cfs)			Scenario Consumption (cfs)	
	Low	Moderate	High	BOM 50/50 [15]	FTF 100/0 [15]
Illinois	170 (33)	530 (100)	1,100 (200)	1,500 (0)	840 (0)
Indiana	110 (20)	530 (100)	1,100 (200)	1,300 (0)	670 (0)
Kentucky	110 (20)	210 (40)	320 (60)	1,200 (0)	590 (0)
Ohio	110 (20)	800 (150)	1,300 (250)	2,600 (0)	1,500 (0)
Total	500 (93)	2,100 (390)	3,800 (710)	6,600 (0)	3,600 (0)

[14] Irrigated acreages, in thousands of acres, are given in parentheses.

[15] Estimates are for municipal, industrial and power uses.

The consumption rate is assumed to be 59% of withdrawals; this rate is the national average and is well below the high levels experienced in the region at present. An application rate of 1.5 inches per week is assumed to occur simultaneously in all areas in calculating totals. This unlikely condition corresponds to a severe and widespread drought.

The estimates in Table III-G-9 indicate that irrigation development could entail significant levels of water consumption, relative to the total consumption estimates for municipal, industrial, and power-related uses under the two extreme ORBES scenarios. Irrigation demands would be met from some combination of groundwater and surface water sources. Depending on the extent to which surface water is used, the impact (in conjunction with that of the other uses) on the 7-day 10-year low flows could be significant. Extensive groundwater utilization should be studied carefully because of the interrelationship with surface water and because safe-yield estimates are not known in many areas.

2.3. EFFECTS OF WATER CONSUMPTION ON THE MAJOR RIVER BASINS

2.3.1 INTRODUCTION

The local effects of increasing levels of consumption have been examined through an analysis of surface water supplies and incremental surface water use levels. Incremental use levels were examined because of the assumption (made by this investigation) that 7-day 10-year low flows take into account present levels of water use. Wet cooling towers have been assumed for all new plants. Retrofitting of existing plants was not considered in the analysis described in this section.

Surface water usage was considered for the following reasons:

1) ground water records are poor for most of the region,
2) power facilities use surface water almost exclusively, and
3) power generation has been projected to be the major consumer of water in coming years.

Irrigation was not considered in this analysis because the projections of water use and acreage are highly variable. Extensive irrigation, however, would compound the problems noted below.

In this analysis it is also assumed that the present fraction of demand met by surface supplies would continue through 2000. Further assumptions and the methodology are discussed in Chapter 5. The consumption estimates presented here do not account for increases in consumption in adjacent areas (e.g., upper Ohio River Basin). Thus, they should be viewed as incremental consumption from uses in the ORBES region. Where excessive levels of consumption are indicated, the implication is that some combination of storage, increased groundwater utilization, and reduced water consumption is necessary.

2.3.2. CONSUMPTION RATIOS FOR THE MAJOR RIVERS IN THE ORBES REGION

Tables III-G-10, III-G-11, III-G-12, and III-G-13 describe the ratios of the cumulative consumption to the 7-day 10-year low flow--hereafter referred to as the consumption ratio--for different reaches of the major rivers under each energy development scenario. The impact of consumption on the major rivers is arbitrarily defined as light, moderate, or heavy if the average consumption ratio is .05 or below, between .05 and .25, or over .25, respectively. Due to incoming tributaries and changing use, the ratio changes along the rivers. Under the BOM scenarios, only three basins are considered to have relatively light consumption while in the FTF scenarios, eight or nine basins have light consumption.

Figures III-G-1 and III-G-2 give detailed profiles of the consumption ratio along the Ohio River Main Stem under the BOM and FTF scenarios, respectively. For the BOM 50/50 and 80/20 scenarios, the Ohio River has maximum consumption ratios of .14 and .12 and an average consumption ratio of .10 and .09, respectively. For the FTF scenarios with much lower projections of energy use, the Ohio River consumption ratios are only a few percent.

2.3.3. SELECTED EFFECTS OF CONSUMPTION BY STATE

2.3.3.1. ILLINOIS

Taking into account only plants in the ORBES region in Illinois, the consumption ratios along the Mississippi River are very low. The average consumption ratio is less than .03 for the BOM 50/50 scenario, even if all power plants are assumed to be operating simultaneously at full capacity.

In contrast, the Kaskaskia and Big Muddy River Basins are projected to face very high levels of consumption. The Big Muddy River is estimated to lose a significant amount of its low flow just from projected municipal and industrial usage and from the scheduled power plant additions.

The Illinois River Basin is projected to have an average consumption ratio of only 5% in the BOM 80/20 scenario. Under the BOM 50/50 scenario, three nuclear plants have been sited in the upper reaches of this system--e.g., Iroquois and Livingston Counties--where low flows are projected to be seriously affected by plant operation. Although one nuclear plant operating at full capacity consumes approximately 42 cfs, even if all potential reservoirs were built for both counties, the total 10-year net-yield would still be only 30 cfs (see Reference 2). Similarly, for Hamilton County the total 40-year safe yield would be only 10 cfs with the additional reservoirs (see Reference 3). Plants sited in this county, however, under the BOM scenarios would consume 55 cfs and withdrawals would be 83 cfs.

Table III-G-10

RIVER BASIN CONSUMPTION RATIOS-BOM 80/20

River Basin	Number of Plants	Minimum Ratio	Maximum Ratio	Average Ratio for All Reaches	Relative Impact
Muskingum, Oh.	5	.12	.19	.16	Moderate
Big Sandy, Ky.	0	.02	.02	.02	Light
Scioto, Ohio.	9	.45	1.45	.86	Heavy
Licking, Ky.	0	.18	.18	.18	Moderate
Great Miami, Oh.	9	.41	.96	.60	Heavy
Little Miami, Oh.	3	2.06	2.06	2.06	Heavy
Kentucky, Ky.	2	.03	.37	.20	Moderate
Salt, Ky.	0	--[16]	--[16]	--[16]	Heavy
Green, Ky.	4	.12	.19	.15	Moderate
Wabash, Ind.	22	.11	.34	.20	Moderate
Saline, Il.	2	23.00	35.00	29.00	Heavy
Cumberland Ky.	4	.03	.26	.11	Moderate
Ohio River	134[17]	.009	.12	.08	Moderate
Kaskaskia, Il.	2	.65	.65	.65	Heavy
Big Muddy, Il.	1	1.10	1.10	1.10	Heavy
Illinois, Il.	16	.02	.10	.05	Light
Mississippi River	22[17]	.007	.04	.018	Light

[16]Ratios were not calculated since the 7-day 10-year flow is zero.

[17]All power plants in the ORBES Region are taken into account in calculating the consumption ratios for the Ohio River. Only plants in the ORBES portion of Illinois were considered for the Mississippi River.

Table III-G-11

RIVER BASIN CONSUMPTION RATIOS-BOM 50/50

River Basin	Number of Plants	Minimum Ratio	Maximum Ratio	Average Ratio for All Reaches	Relative Impact
Muskingum, Oh.	5	.12	.20	.16	Moderate
Big Sandy, Ky.	0	.02	.02	.02	Light
Scioto, Oh.	8	.43	1.45	.83	Heavy
Licking, Ky.	0	.18	.18	.18	Moderate
Great Miami, Oh.	8	.41	.96	.58	Heavy
Little Miami, Oh.	0	0	0	0	Light
Kentucky, Ky.	2	.03	.37	.20	Moderate
Salt, Ky.	0	--[18]	--[18]	--[18]	Heavy
Green, Ky.	2	.008	.14	.11	Moderate
Wabash, Ind.	18	.01	.23	.14	Moderate
Saline, Il.	2	23.00	35.00	29.00	Heavy
Cumberland, Ky.	5	.02	.26	.10	Moderate
Ohio River	135[19]	.006	.14	.10	Moderate
Kaskaskia, Il.	2	.65	.65	.65	Heavy
Big Muddy, Il.	0	.33	.33	.33	Heavy
Illinois, Il.	15	.02	11.49	1.79	Heavy[20]
Mississippi River	24[19]	.007	.05	.026	Light

[18]Ratios were not calculated since the 7-day 10-year flow is zero.

[19]All power plants in the ORBES Region are taken into account in calculating the consumption ratios for the Ohio River. Only plants in the ORBES portion of Illinois were considered for the Mississippi River.

[20]Rated light for all but two of the upstream reaches which are rated heavy.

Table III-G-12

RIVER BASIN CONSUMPTION RATIOS-FTF 100/0

River Basin	Number of Plants	Minimum Ratio	Maximum Ratio	Average Ratio for All Reaches	Relative Impact
Muskingum, Oh.	1	.04	.07	.055	Moderate
Big Sandy, Ky.	0	.02	.02	.02	Light
Scioto, Oh.	2	.13	.64	.33	Heavy
Licking, Ky.	0	.18	.18	.18	Moderate
Great Miami, Oh.	4	.15	.30	.19	Moderate
Little Miami, Oh.	1	.63	.63	.63	Heavy
Kentucky, Ky.	0	.02	.03	.03	Light
Salt, Ky.	0	--[21]	--[21]	--[21]	Heavy
Green, Ky.	0	.008	.008	.008	Light
Wabash, Ind.	3	.01	.13	.07	Moderate
Saline, Il.	0	∿0	∿0	∿0	Light
Cumberland, Ky.	0	.01	.01	.01	Light
Ohio River	22[22]	.002	.03	.02	Light
Kaskaskia, Il.	0	.06	.06	.06	Moderate
Big Muddy, Il.	0	.33	.33	.33	Heavy
Illinois, Il.	2	.01	.06	.03	Light
Mississippi River	2[22]	0	.01	.005	Light

[21]Ratios not calculated since the 7-day 10-year flow is zero.

[22]All power plants in the ORBES Region are taken into account in calculating the consumption ratios for the Ohio River. Only plants in the ORBES portion of Illinois were considered for the Mississippi River

Table III-G-13

RIVER BASIN CONSUMPTION RATIOS-FTF 0/100

River Basin	Number of Plants	Minimum Ratio	Maximum Ratio	Average Ratio for All Reaches	Relative Impact
Muskingum, Oh.	2	.12	.19	.155	Moderate
Big Sandy, Ky.	0	.02	.02	.02	Light
Scioto, Oh.	0	.04	.30	.14	Moderate
Licking, Ky.	0	.18	.18	.18	Moderate
Great Miami, Oh.	0	.06	.06	.06	Moderate
Little Miami, Oh.	0	0	0	0	Light
Kentucky, Ky.	0	.03	.03	.03	Light
Salt, Ky.	0	--[23]	--[23]	--[23]	Heavy
Green, Ky.	0	.008	.008	.008	Light
Wabash, Ind.	1	.05	.11	.05	Light
Saline, Il.	0	∿0	∿0	∿0	Light
Cumberland, Ky.	0	.02	.13	.06	Moderate
Ohio River	14[24]	.004	.04	.03	Light
Kaskaskia, Il.	0	.06	.06	.06	Moderate
Big Muddy, Il	0	.33	.33	.33	Heavy
Illinois, Il.	1	.01	.07	.04	Light
Mississippi River	1[24]	0	.01	.005	Light

[23]Ratios not calculated since the 7-day 10-year flow is zero.

[24]All power plants in the ORBES Region are taken into account in calcuating the consumption ratios for the Ohio River. Only plants in the ORBES portion of Illinois were considered for the Mississippi River.

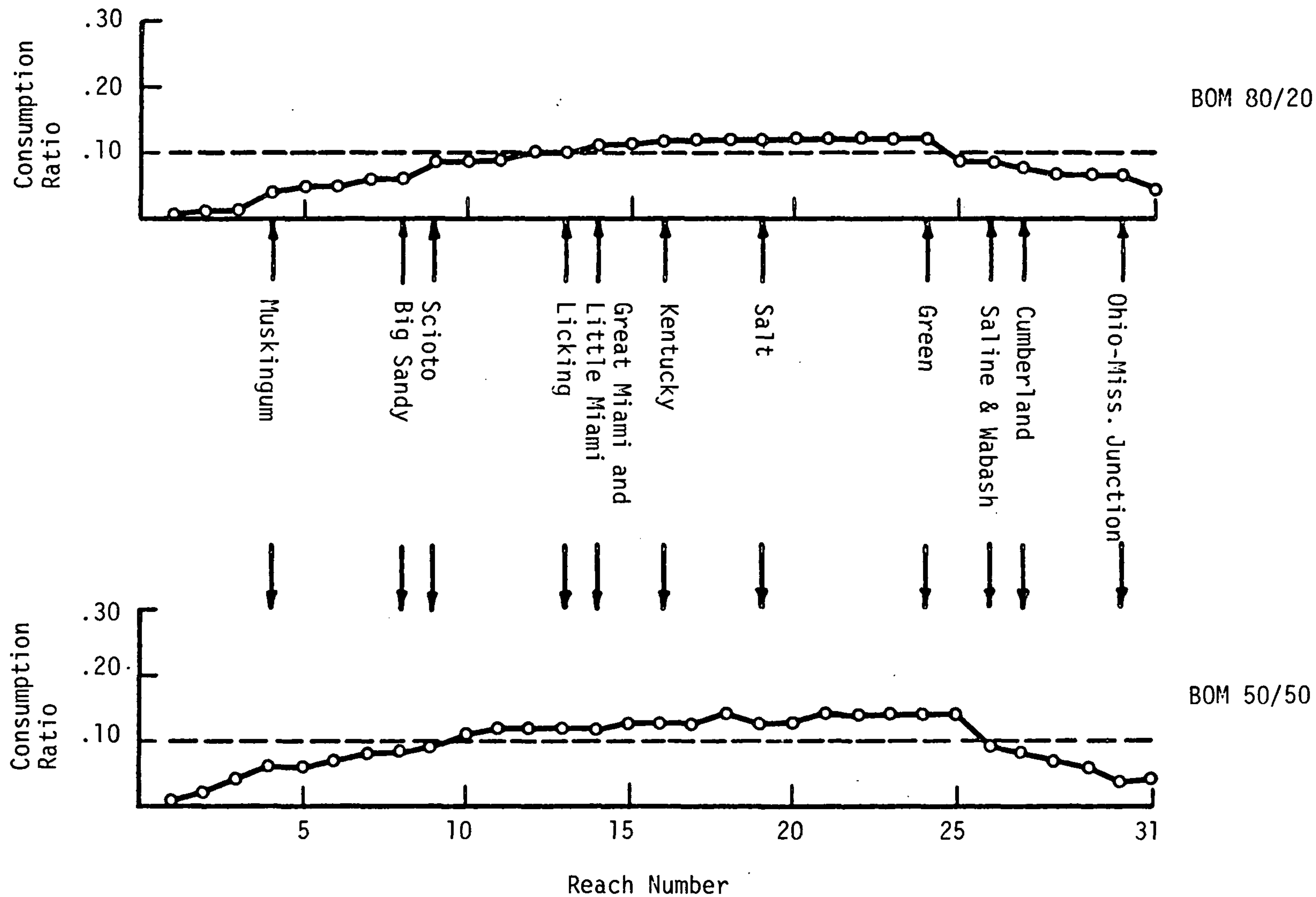


Figure III-G-1. CONSUMPTION ALONG THE OHIO RIVER FOR THE BOM SCENARIOS

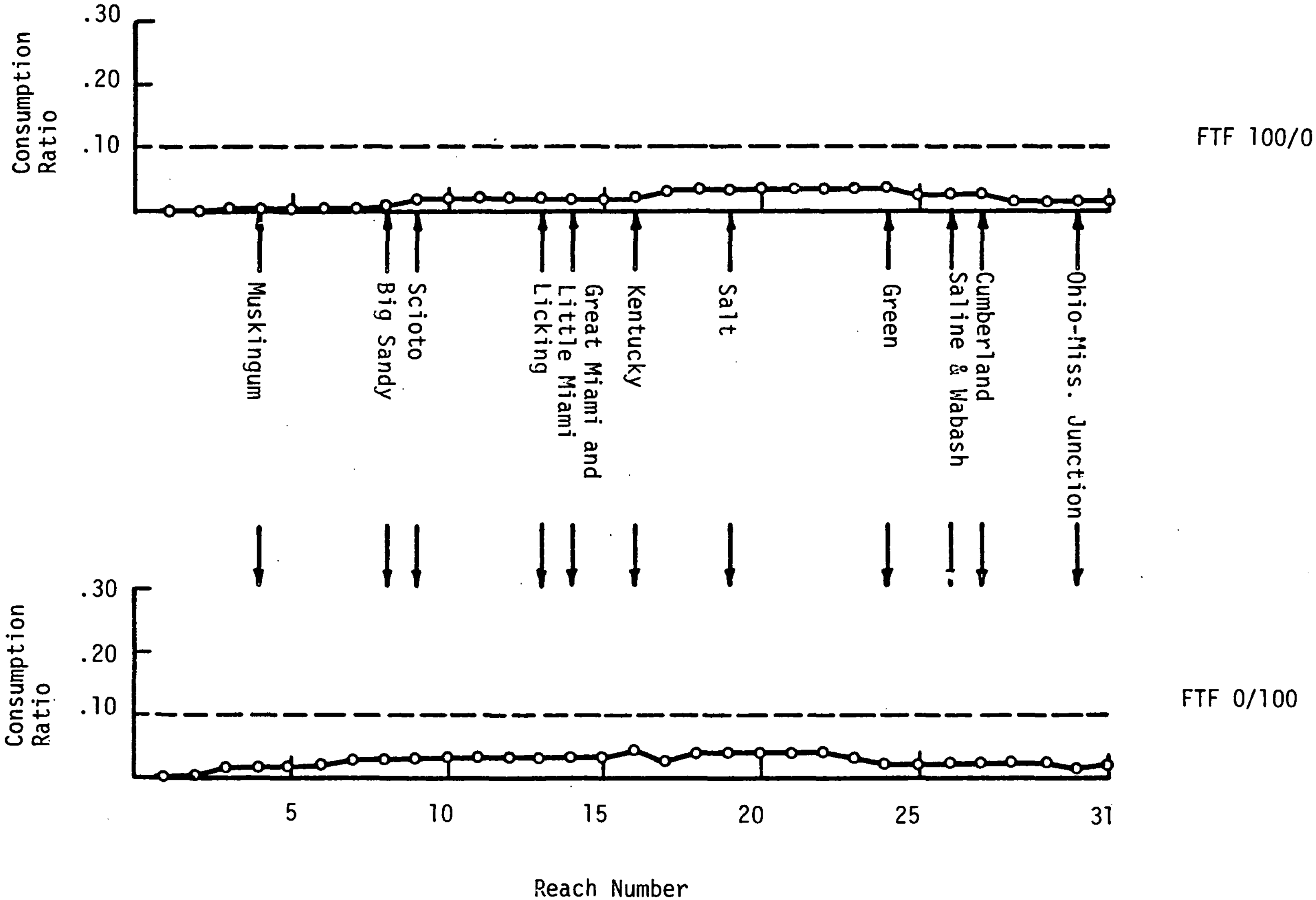


Figure III-G-2. CONSUMPTION ALONG THE OHIO RIVER FOR THE FTF SCENARIOS

2.3.3.2. INDIANA

Indiana has an extensive system of rivers in the Wabash Basin. A number of plants are located along this system as well as along the Ohio River in the ORBES scenarios. In general, the maximum consumption ratio in the Wabash River Basin is about .30 for the BOM scenarios and about .08 for the FTF scenarios. The highest figures in the basin are encountered when plants are sited on the upper reaches of the East and West Fork of the White River.

2.3.3.3. KENTUCKY

In Kentucky, most plants sited by the ORBES scenarios are close to the Ohio River Main Stem. No plants have been located on the interior rivers in the FTF scenarios. For the BOM scenarios, plants are located on the Kentucky, Green and Cumberland Rivers, and these rivers have average consumption ratios ranging from .10 to .20. Although no plants were sited in the Salt and Licking Basins, these basins are projected to have consumption ratios above .10 because of municipal and industrial water usage alone.

2.3.3.4. OHIO

Ohio is projected to have the largest power-related water use of all the states in the ORBES region. Plants are heavily distributed along the Ohio, Great Miami, Scioto, and Muskingum Rivers in the BOM scenarios. The minimum ratio in the BOM scenario for all of these basins except the Ohio is above .10. Plant sitings on the Little Miami in the BOM 80/20 and FTF 100/0 scenarios are also projected to have considerable impacts. Local problems may also exist for the Scioto River Basin under the FTF scenarios. In general, however, the FTF scenarios have less impact on low flows in Ohio's rivers than do the BOM projections.

2.4. POLICY TRADE-OFFS AND RESEARCH NEEDS

2.4.1. INTRODUCTION

The preceding sections describe the relative magnitudes of water supplies and projected water uses. Estimates of water consumption for the ORBES scenarios represent high percentages of the low flows in many of the major river basins, and the cumulative consumption represents a significant percentage of the low flow in the Ohio River under the BOM scenarios. The preceding section also describes the importance of the large inflows to the ORBES region and notes the potential for competition from adjacent regions.

The situation described above for the BOM scenarios is represented by the top corner point on the triangle in Figure III-G-3. It is a rather extreme position in the infinity of futures since the estimated level of water consumption is so high. Excessive water consumption can exacerbate existing water quality problems and can cause new ones. Where problems occur, extreme and costly measures could be undertaken during low-flow periods to control both non-point and point sources of pollution. Excessive consumption can also preempt other water use activities. For example, supplemental irrigation could be restricted in the future in some areas where it would cause additional decreases in nearby stream flows.

Directions of change are indicated by the other two corners of the triangle. Available water supplies can be increased by constructing reservoirs or by greatly increasing groundwater use. Or, the level of water consumption can be reduced, although this change would almost certainly have to be in the dominant power sector. (If large-scale irrigation is developed, conservation can be effected there, also.) Policy alternatives and some of the trade-offs between them are discussed below. The triangle does not imply that there are only three alternative policies for the future; an overall strategy based on some mixture of them is most likely the best.

2.4.2. AUGMENTING SUPPLIES: RESERVOIRS AND GROUNDWATER UTILIZATION

Increasing available supplies is fraught with unknowns and potential impacts. Reservoirs run counter to the current trend in water resources planning in the ORBES region because of their many potential environmental, social, and economic impacts. Such projects can, however, serve multiple purposes (e.g., recreation and municipal supply) and could be used as cooling lakes for power plants. (Also, preliminary calculations have indicated that water losses would be less than for cooling towers.) Reservoir sites in the region have been identified, but safe yields from them have not yet been estimated (except for Illinois).

In Section 2.3 and in Chapter 5, groundwater utilization for municipal and industrial uses is assumed to grow in proportion to surface water use. The ORBES region apparently contains areas with abundant groundwater sources; their safe yields, however, are not generally known (except for some areas of Illinois). A policy of greatly increased use should be preceded by a program of groundwater mapping and analysis to prevent "mining" (i.e., depletion). The interrelationship between a given groundwater source and the nearby streamflows should also be analyzed. In many parts of the ORBES region, high-yield sources are along the major rivers, and extensive development of them might cause a major decrease in the flows of the corresponding rivers during low-flow periods Note that these groundwater related issues will become especially important if large-scale irrigation materializes since that source is commonly used.

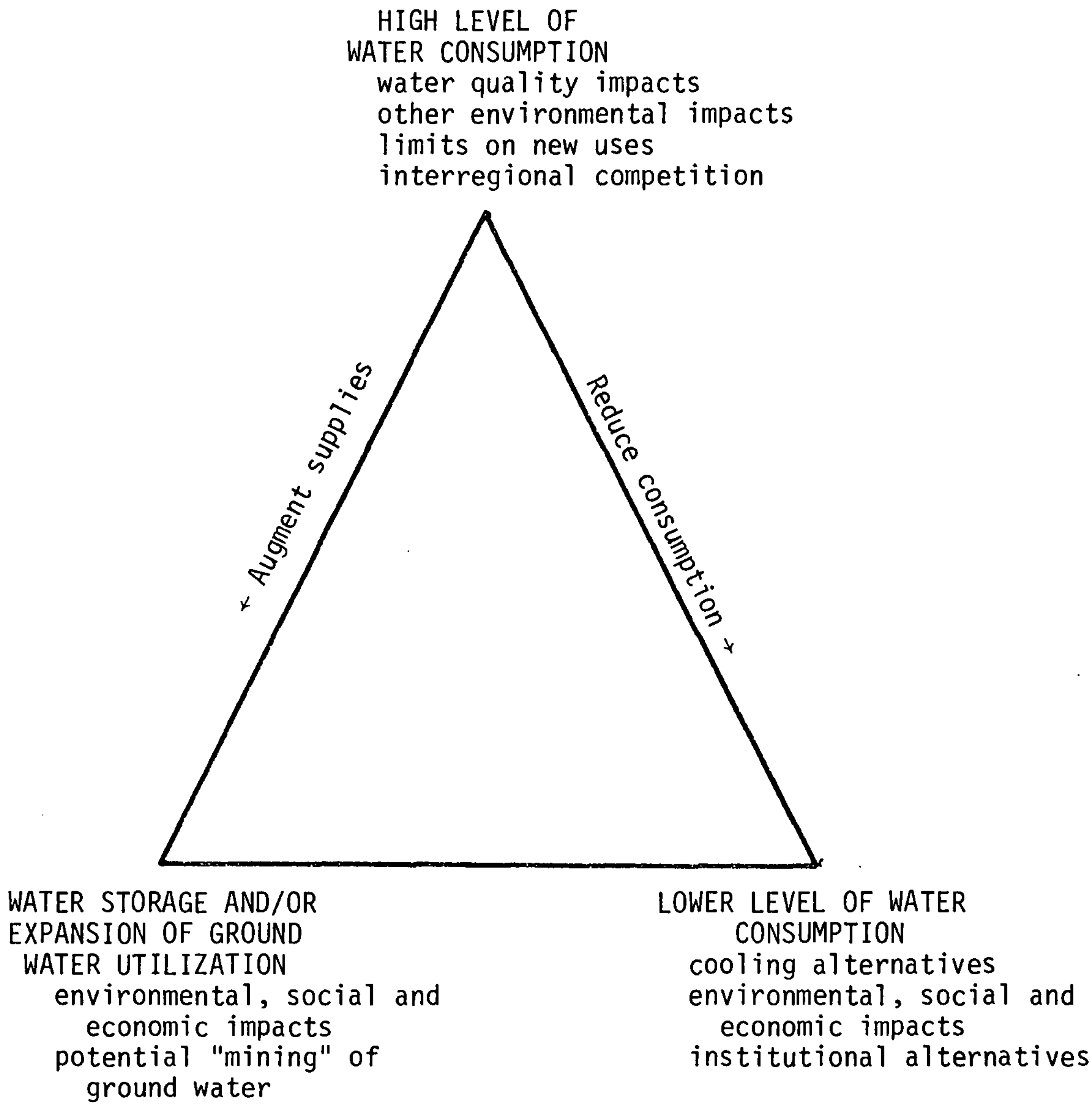


Figure III-G-3. POLICY TRADE-OFFS RELATED TO WATER CONSUMPTION

2.4.3. REDUCING CONSUMPTION: ENERGY CONSERVATION, COOLING ALTERNATIVES, AND INSTITUTIONAL CHANGES

Rather than storing water or greatly increasing groundwater utilization, the level of water consumption can be decreased. Significant decreases must be in the power sector since even stringent conservation in the municipal and industrial sectors would not significantly alter the relationship between water supply and use on a regional basis. On a local basis, of course, water conservation can be effective in all sectors. Water consumption in the power sector can be reduced by energy conservation and/or by alternative cooling technologies.

Employing energy conservation can take different forms. Power-plant capacities can be limited--either individually or in total. Or, during periods of low streamflow, reduced electricity use or even "brown-outs" could be employed to minimize streamflow depletion by power-plant cooling systems; lower power plant efficiencies could also be accepted during those periods to reduce consumptive losses. Institutional arrangements would be needed, of course, to implement such a program. This approach could even be carried farther. For example, if large-scale supplemental irrigation systems are developed, power use could also be curtailed during critical periods when the water is needed for crops.

Water consumption by power plants could also be reduced by utilizing cooling systems other than cooling towers (assumed in the calculations in this report). As discussed in Chapter 4, the other technologies (cooling lakes, once-through, and dry towers) produce less consumptive loss than cooling towers. Also, small reservoirs could be used in conjunction with cooling towers; total losses would increase, but stored water could be used during low-flow periods.

As an extreme case, water consumption could be minimized by locating all power plants on the largest rivers (e.g., Ohio and Mississippi Rivers) and by employing once-through cooling. As trade-offs in this extreme case, however, thermal pollution in the region's waterways and the SO_2 air pollution in the Ohio River Valley would also tend to be maximized. Additional research is needed, however, to explore the trade-off between consumptive losses and thermal pollution for all of the cooling technologies.

There are other technological approaches to optimizing water use since the level of use is variable. New cooling-towers can be designed to reduce the levels of consumption although there are generally cost penalties. Also, variable cooling technologies and plant-operating procedures can be used to minimize water consumption or thermal pollution during critical periods (at the expense of decreased plant efficiency, most likely). Wet-dry towers are one example. Other approaches to optimizing water and energy use include multiple-purpose reservoirs, or cooling lakes, as mentioned above where recreation and aquaculture are possible uses (4).

Another approach is to use cooling water discharges for district heating (5). Water reuse by municipalities and industries is a part of many water and energy optimization approaches. Reuse itself, however, tends to have little effect on total consumption. Reuse of thermal effluents of power plants could reduce heat loadings on the receiving waters since heat losses would occur during multiple uses (e.g., district heating, or warming agricultural soil to extend growing seasons).

There are also alternate institutional approaches to optimizing water use. For example, in addition to existing allocation methods, user fees could be applied to consumptive losses, or consumption "rights" could be auctioned. In general, the different approaches to managing environmental externalities could be applied to manage water consumption.

2.5. CONCLUSIONS

The water resources and energy systems are highly interrelated; there are significant trade-offs in many directions, leading to many far-reaching policy issues. It has been demonstrated that the consumption losses under the BOM scenarios could have a major impact on the available streamflows under the assumption that cooling towers are employed exclusively. The severity of this impact is much less for the FTF scenarios.

For the BOM scenario, the estimates of consumptive losses are extremely high for many of the tributaries of the Ohio River. For the main stem of the Ohio River, the highest ratio of cumulative consumption to 7-day 10-year low flow is .14. That ratio is quite significant, especially since future increases in consumption upstream of the ORBES region are not taken into account. Growth in water use after the year 2000, of course, would add to these problems. Also, extensive development of supplemental irrigation could increase the impact.

Inflows of the ORBES region are critical to maintaining adequate streamflows for water quality maintenance. Future development in nearby regions (e.g., for irrigation) could lead to increased competition for these water resources and to interregional political conflicts.

It is also clear that under the BOM scenario, at least, new water allocation mechanisms would be needed--to contend with drought conditions--on an interregional basis, within the ORBES region, and within the states of the region. Such mechanisms require new legislation and new institutional arrangements. Groundwater allocation mechanisms will be especially urgent if that resource is developed extensively beyond current practice.

REFERENCES

1. C. Richard Murray and E. Bodette Reeves. Estimated Use of Water in the United States in 1970. U.S. Geological Survey Circular 676. Washington, D.C., 1972.

2. Julius H. Dawes and Michael L. Terstriep. Potential Surface Water Reservoirs of North-Central Illinois. Illinois State Water Survey Report of Investigation 56, Urbana, 1966.

3. William C. Ackermann. Potential Water Resources of Southern Illinois. Illinois State Water Survey Report of Investigation 31, Urbana, 1962.

4. J. Karlcheck, J. Powell, E. Beardsworth. "Prospects for District Heating in the United States." Science, Vol. 195 (March 1977): 948-955.

5. Charles C. Coutant. "How To Put Waste Heat To Work." Environmental Science and Technology, Vol. 10, No. 9, (1976): 868-871.

3. OVERVIEW OF WATER RESOURCES IN THE ORBES REGION

3.1 INTRODUCTION

The analysis of water supplies and use levels, discussed in Chapter 2 for the ORBES region, is based on supply estimates presented below and described in more detail in a project memorandum (1). Water supplies are viewed here as the sum of river inflows to the region and sources originating within the region. The inflow distinction is made because it leads to an analysis (in Chapter 2) of the potential dependence (by the ORBES region) on water resources that originate outside the region.

Sources originating within the region are classified as streamflow runoff, groundwater, and potential reservoirs. Estimate of 7-day, 10-year low-flows in the major rivers are presented along with average flow data because they are commonly used in planning to represent critical periods for water quality analyses.

3.2 PRECIPITATION AND RUNOFF

Average precipitation and runoff in the ORBES region is described in Table III-G-14. The average water supplies, listed in Chapter 2, are based on the estimates of average runoff and on the areas shown.

Runoff during low-flow conditions is defined in this study as the flow of water from the region at the boundaries. The estimates (given in Table III-G-15) were made by simply summing the 7-day, 10-year discharges of the major rivers (and subtracting any inflows to the region through these rivers). The discharges of these rivers are given in a following section of this chapter. Although the low-flows do not occur simultaneously, this method was used as a conservative first approximation. Note also that some runoff is actually available for use within the region but evaporates before reaching a boundary.

3.3 INFLOW TO THE ORBES REGION

The major streams flowing into the ORBES region are listed in Table III-G-16; average and 7-day, 10-year low-flows are given. As an example, the Mississippi River flow at the north-west corner of the region is an inflow since it originates outside the region. South of that point, the runoff to the Mississippi River from outside the region is estimated by the discharges of the major rivers (e.g., the Iowa River). As in the case of streamflows within the region, the 7-day, 10-year low-flows were simply summed--providing a first approximation.

3.4 WATER SOURCES WITHIN THE ORBES REGION

Streamflows, groundwater sources, and potential reservoir sites in the ORBES are described below. These individual water sources are considered in the analysis of the local impacts of each ORBES scenario.

3.4.1. STREAMFLOWS

Average and 7-day, 10-year low-flows of the major rivers within the ORBES region are listed in Tables III-G-17, III-G-18, III-G-19, and III-G-20(one for each state). Figures III-G-4 , III-G-5 , III-G-6 , and III-G-7 , show the locations of the gauging stations listed in the tables (with a few exceptions).

The Ohio River is highly regulated, and its flow characteristics must be estimated. Table III-G-21presents two sets of estimates of the 7-day, 10-year low-flow. The second set, prepared by the Corps of Engineers and used by the Ohio River Basin Commission, were used in the calculations in Chapter 2. Flow data for some of the minor tributaries of the Ohio River are also given in Table III-G-21.

The reader is directed to References (5, 9, 11, and 12) for additional streamflow data for the region.

3.4.2. GROUNDWATER SOURCES AND POTENTIAL RESERVOIR SITES

The major groundwater sources and potential reservoir sites in Illinois are described in Figure III-G-8 , a map supplied by the Illinois State Water Survey (ISWS). In particular, the water yields from these sources were estimated and are indicated on the map. Additional data describing these sources has also been published by the ISWS [Ref (13)].

Groundwater information for Indiana, Kentucky, and Ohio was obtained from References (7, 14, 15, 16, 17, and 18) and is described in a project memorandum (1). In general, the groundwater in areas adjacent to the major rivers (shown in Figures III-G- 5, III-G- 6, and III-G-7 above) can support wells yielding 500 gallons per minute (1.1 cfs). Of course, these sources and the river flows are highly interdependent. Safe yields from the aquifers in these states are not known, and a major research need is to develop such a data base.

Potential reservoir sites for Indiana, Kentucky, and Ohio are described in Tables III-G-22, III-G-23, and III-G-24, respectively. The approximate locations are shown in Figures III-G- 9, III-G-10, and III-G-11, respectively. Safe yield estimates are not available; another research need is to develop such estimates to complete the inventory of water sources in the region.

3.5 FUTURE WORK

The information presented in this chapter represents a first-cut effort. It is anticipated that after additional review by state and federal agencies the material will be augmented and revised. Additional research needs are discussed in Chapter 2.

Table III-G-14

PRECIPITATION AND RUNOFF IN THE ORBES REGION[1]

State	Acreage in ORBES Region	Average Annual Rainfall (in.)	Average Annual Runoff (in.)
Illinois	29,831,680	40	10[2]
Indiana	20,515,360	40	12
Kentucky	25,376,000	48	17
Ohio	21,343,360	40	12

[1]From Ref. (2), unless otherwise indicated.

[2]From Ref. (3).

Table III-G-15

ESTIMATED RUNOFF UNDER 7-DAY 10-YEAR LOW-FLOW CONDITIONS

State	Total Runoff (cfs)	Rivers Included
Illinois	1500	Illinois, Kaskaskia, Big Muddy, Embarass Little Wabash, Saline
Indiana	1700	White, Wabash
Kentucky	1400	Licking, Kentucky, Green, Big Sandy,[3] Cumberland[4]
Ohio[5]	1800	Little Miami, Great Miami, Scioto, Muskingum, Mill Creek

[3]It was estimated that only 65% of the Big Sandy River basin lies inside the ORBES region, and 65% of the discharge was assumed to be runoff.

[4]Runoff from the ORBES area was estimated as follows: (low-flow at Smithland, Ky.) - (low-flow at Dover, Tenn.) + (low-flow at Rowena, Ky.).

[5]The Beaver River basin was evaluated in the same manner as the Big Sandy River basin (see footnote 3).

Table III-G-16

INFLOW TO THE ORBES REGION UNDER AVERAGE AND LOW-FLOW CONDITIONS

River	Flows (cfs)	
Inflow to Illinois:[6]	Average	7-day 10-yr
Mississippi	46910	13970
Wapsipinicon	1344	90
Iowa	6253	540
Skunk	2233	19
Des Moines	5254	124
Fox	219	0
Wyaconda	209	0
N. Fabius	249	0
Middle Fabius	211	0
S. Fabius	348	0
North	207	0
Missouri	79650	24500
Salt	1511	0
Meramac	2964	285
Rock	5237	1306
Green	528	49
Illinois	10710	2196
Subtotal	164037	43079
Inflow to Kentucky:[7]		
Tennessee	67320	27900
Cumberland	13090	3010
Subtotal	80410	30910
Inflow to Ohio:[8]		
Ohio	32740	3100
Big Sandy	1480	21
Guyandotte	1573	20
Kanawha	10367	1200
L. Kanawha	2100	4
Beaver	1419	139
Subtotal	49679	4484
TOTAL INFLOW	294126	78473

[6]From Ref. (4).

[7]The average inflow of the Tennessee River is based on the average flow at Paducah (5). The 7-day 10-year low flow of the Tennessee River is

Table III-G-16

INFLOW TO THE ORBES REGION UNDER AVERAGE AND LOW-FLOW CONDITIONS

(footnotes, continued)

calculated from the 7-day 10-year low flow of the Ohio River at Metropolis and Golconda (1) and from the flow of the Cumberland River at Smithland, Kentucky (2). Cumberland River inflow estimated by subtracting the flow at Dover, Tennessee, from the flow at Celina, Tennessee (2).

[8] Since approximately 35% of Big Sandy River Basin lies outside the region, 35% of the flow is assumed to be inflow. Similarly, approximately 60% of the Beaver River basin lies outside the ORBES region, and 60% of the flow is assumed to be inflow. That inflow is added to the Ohio River inflow which is estimated as the flow at Sewickley, Pennsylvania. All flow estimates are from Ref (2).

Table III-G-17

FLOWS OF MAJOR RIVERS IN ILLINOIS

River	Location[9]	Avg. Disch.(cfs)[10]	7-day, 10-yr low flow (cfs)[11]
Mississippi	Clinton, IA (1)	46,910	13,970
	Keokuk, IA (2)	61,100	15,170
	Alton, IL (3)	93,130	21,470
	St. Louis, MO (4)	174,000	45,970
	Chester, IL (5)	174,700	46,840
	Thebes, IL (6)	177,600	47,810
Ohio	Golconda (7)		12,610
	Metropolis (8)	262,200	44,820
Chicago Sanitary and Ship Canal	Lockport (9)	5,455	1,700
Illinois	Marseilles (10)	10,710	3,240
	Kingston Mines (11)	13,430	3,000
	Meredosia (12)	19,590	3,500
Rock	Rockton (13)	3,702	795
	Oregon (14)		1,100
	Como (15)	5,024	1,097
	Joslin (16)	5,237	1,306
Pecatonica	Freeport (17)	878	181
S. Branch Kishwaukee	DeKalb (18)		.10
Kishwaukee	Belvidere (19)	273	34.3
	Perryville (20)	568	62.3
Des Plaines	Russel (21)	104	0
	Des Plaines (22)	210	4.3
	Riverside (23)	368	18.4
Fox	Algonquin (24)	760	51
	Dayton (25)	1,506	198
DuPage	Warrenville (26)	102	13.6
	Shorewood (27)	217	45
Green	Amboy (28)		4.9
	Genesco (29)	528	49.2
Kankakee	Momence (30)	1,820	411
	Wilmington (31)	3,740	451

Table III-G-17 (cont.)

River	Location	Avg. Disch. (cfs)	7-day, 10-yr low flow (cfs)
Iroquois	Chebanse (32)	1,583	16.6
Vermilion	Lowell (33)	722	7.3
	Pontiac (34)	374	.2
Mackinaw	Congerville (35)	435	.54
	Green Valley (36)		25.2
Spoon	Wyoming (37)		1.2
	Seville (38)	967	19
Sangamon	Monticello (39)	398	2.1
	Riverton (40)		37.2
	S. Fork at Kincaid (41)		.84
	Oakford (42)	2,929	206
LaMoine	Colmar (43)	441	.78
	Ripley (44)	739	9
Vermilion	S. Fork at Sidney (45)		13.5
	Danville (46)	927	33
Kaskaskia	Ficklin (47)		.70
	Vandalia (48)	1,401	25.7
	New Athens (49)	3,654	93
Embarass	Newton (50)		13.2
	Lawrenceville (51)		35
Little Wabash	Clay City (52)	882	.47
	Carmi (53)	2,493	5.7
Big Muddy	Mt. Vernon (54)		1.3
	Benton (55)	454	30.6
	Murphysboro (56)	1,787	35.2
Saline	Harrisberg (57)		1.1[13]
	Junction (58)	1,211[12]	2.4[13]

[9]Locations of guage stations are indicated by numbers in circles on the Illinois map in Fig. III-G-4.

[10]From Ref. (4), unless otherwise indicated.

[11]From Ref. (6), unless otherwise indicated.

[12]From Ref. (7).

[13]From Ref. (8).

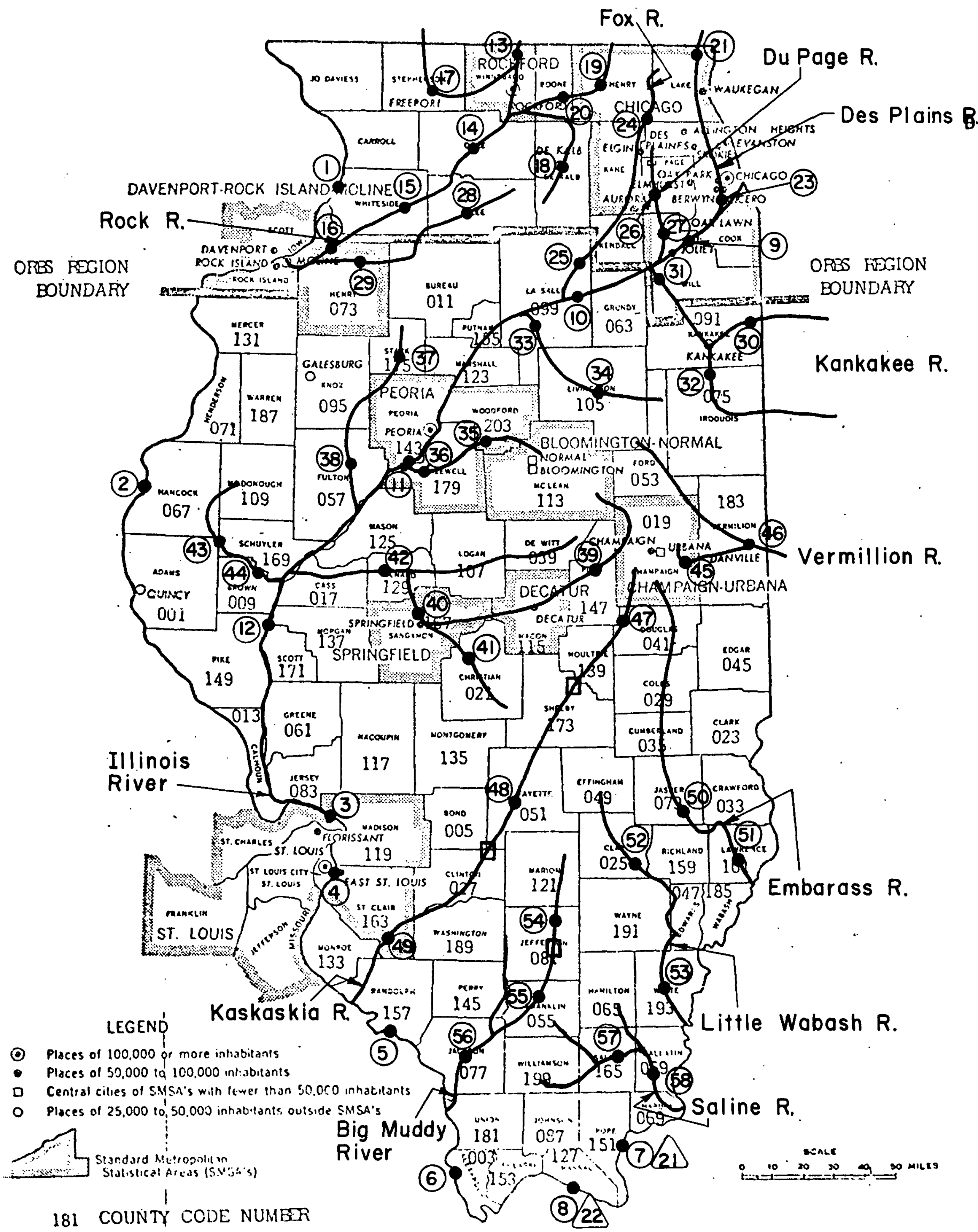


Figure III-G-4. STREAM-GAUGING STATIONS IN ILLINOIS

Table III-G-18

FLOWS OF MAJOR RIVERS IN INDIANA

River	Location[14]	Avg. Disch (cfs)[15]	7-day, 10-yr low flow (cfs)[10]
Wabash	Huntington (1)	536	9
	Peru (2)	2,294	87
	Logansport (3)	3,205	190
	Lafayette (4)	6,203	535
	Covington (5)	6,936	630
	Terre Haute (6)	10,200	900
	Vincennes (7)	11,240	1,060
Eel	N. Manchester (8)	347	31
	Logansport (3)	704	95
Tippecanoe	Oswego (9)	97.8	2.6
	Ora (10)	779	130
	Monticello (11)	1,451	166
	Delphi (12)	1,573	188
Mississinewa	Ridgeville (13)	125	.9
	Eaton (14)	271	2
	Marion (15)	625	16
	Peoria (16)	671	20
Salamonie	Portland (17)	64.5	.9
	Warren (18)	356	5.2
	Dora (19)	495	20
Wildcat Creek	Jerome (20)	103	1.1
	Kokomo (21)	203	8.5
	Owasco (22)	351	15
	Lafayette (4)	690	43
Big Monon Cr.	Francesville (23)	135	10
Vermilion	Danville (24)	889	12.8
	Catlin (25)		11.2
Sugar Cr.	Crawfordsville (26)	458	4.4
	Byron (27)	624	19
Big Raccoon Cr.	Fincastle (28)	438	30
	Coxville (29)	122	2
White	Anderson (30)	367	36
	Noblesville (31)	801	61
	Indianapolis (32)	1,056	70
	Martinsville (33)	1,344	44
	Spencer (34)	2,971	210
	Newberry (35)	4,490	275
	Petersberg (36)	11,230	685

Table III-G-18 (cont.)

River	Location	Avg. Disch. (cfs)	7-day, 10-yr low flow (cfs)
Fall Cr.	Fortville (37)	161	14
Eagle Cr.	Zionsville (38)	91.3	0
Eel	Bowling Green (39)	825	17
E. Fork White	Columbus (40)	1,786	100
	Seymour (41)	2,346	155
	Bedford (42)	3,438	182
	Shoals (43)	5,289	222
Muscatatack	Deputy (44)	337	0
Vernon Fk.	Vernon (45)	215	0

[14] Locations are indicated by numbers in circles on the Indiana map in Fig. III-G-5.

[15] From Ref. (7).

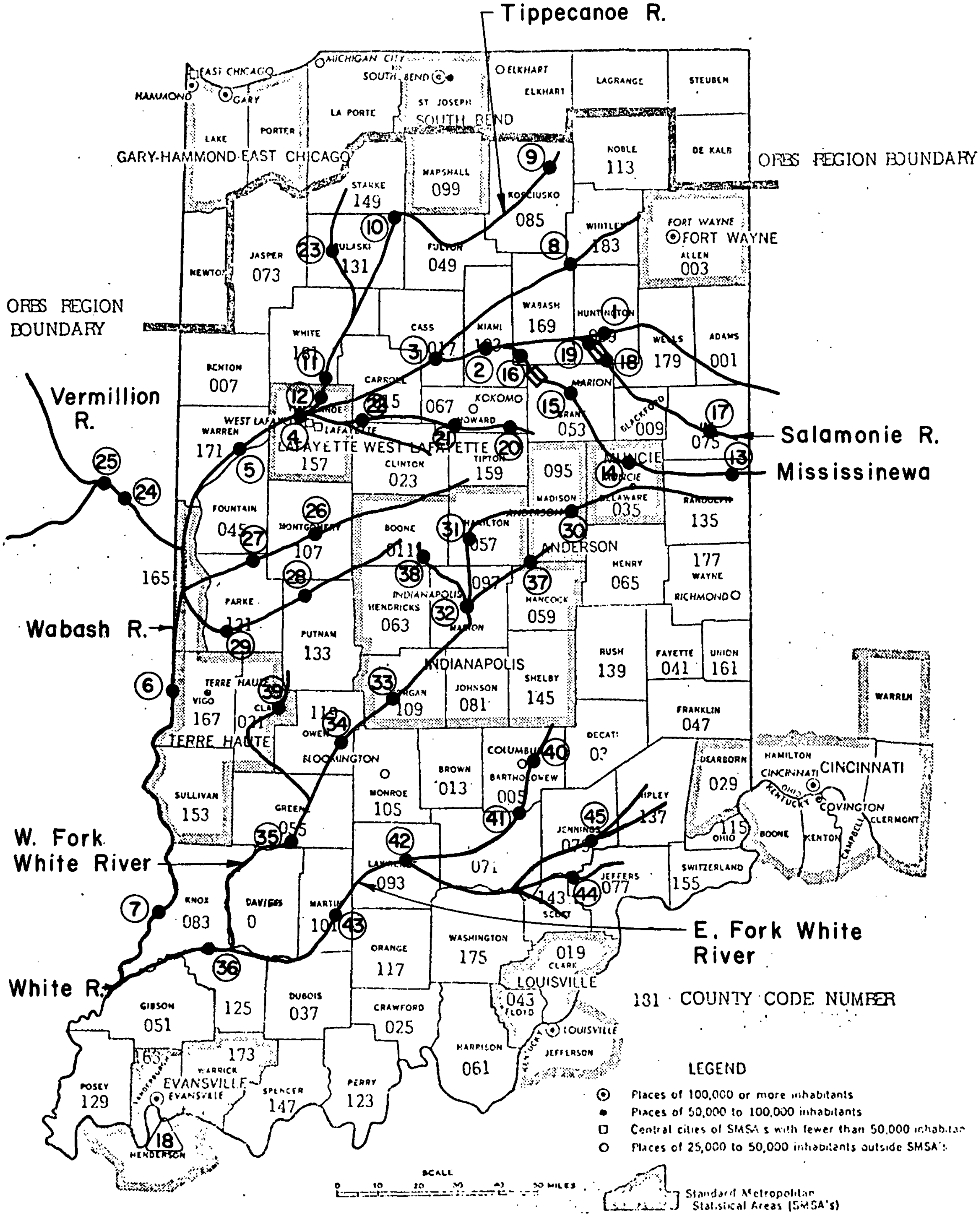


Figure III.G-5. STREAM-GAUGING STATIONS IN INDIANA

Table III-G-19

FLOWS OF MAJOR RIVERS IN KENTUCKY

River	Location[16]	Avg. Disch. (cfs)[17]	7-day, 10-yr low flow (cfs)[17]
Kentucky	Winchester (1)	5,223	33
	Frankfort (2)	7,023	112
	Lockport (3)	8,247	163
	N. Fork at Hazard (10)		1.5
	N. Fork at Jackson (11)	1,293	2.2
	S. Fork at Booneville (12)	1,028	
	Middle Fork at Talega (13)	700	
	Elkhorn Cr. Nr. Frankfort (14)	599	
Salt	Shepherdsville (4)	1,533	
Rolling Fork	Boston (5)	1,720	1.3
Licking	Farmers (6)	1,076	3.1
	McKinneysburg (7)	3,038	
	Catawba (8)	4,131	10
	S. Fork at Cynthiana (9)	751	.7
Green	Greensburg (15)	1,086	1.7
	Brownsville (16)	4,136	141
	Woodbury (17)	7,979	241
	Livermore (18)	10,850	306
Barren	Bowling Green (19)	2,464	53
Rough	Dundee (20)	963	11.1
Cumberland	Barbourville (21)	1,722	8.3
	Williamsburg (22)		8.6
	Cumberland Falls (23)	3,146	16
	S. Fork at Stearns (24)	1,767	
Tradewater	Olney (25)	329[11]	0[7]
Big Sandy	Louisa (26)	4,228	59
	Levisa Fk. at Pikesville (27)	1,353	3.9
	Levisa Fk. at Paintsville (28)	2,385	15

[16] Locations are indicated by numbers in circles on the Kentucky map in Fig. III-G-6.

[17] From Ref. (2).

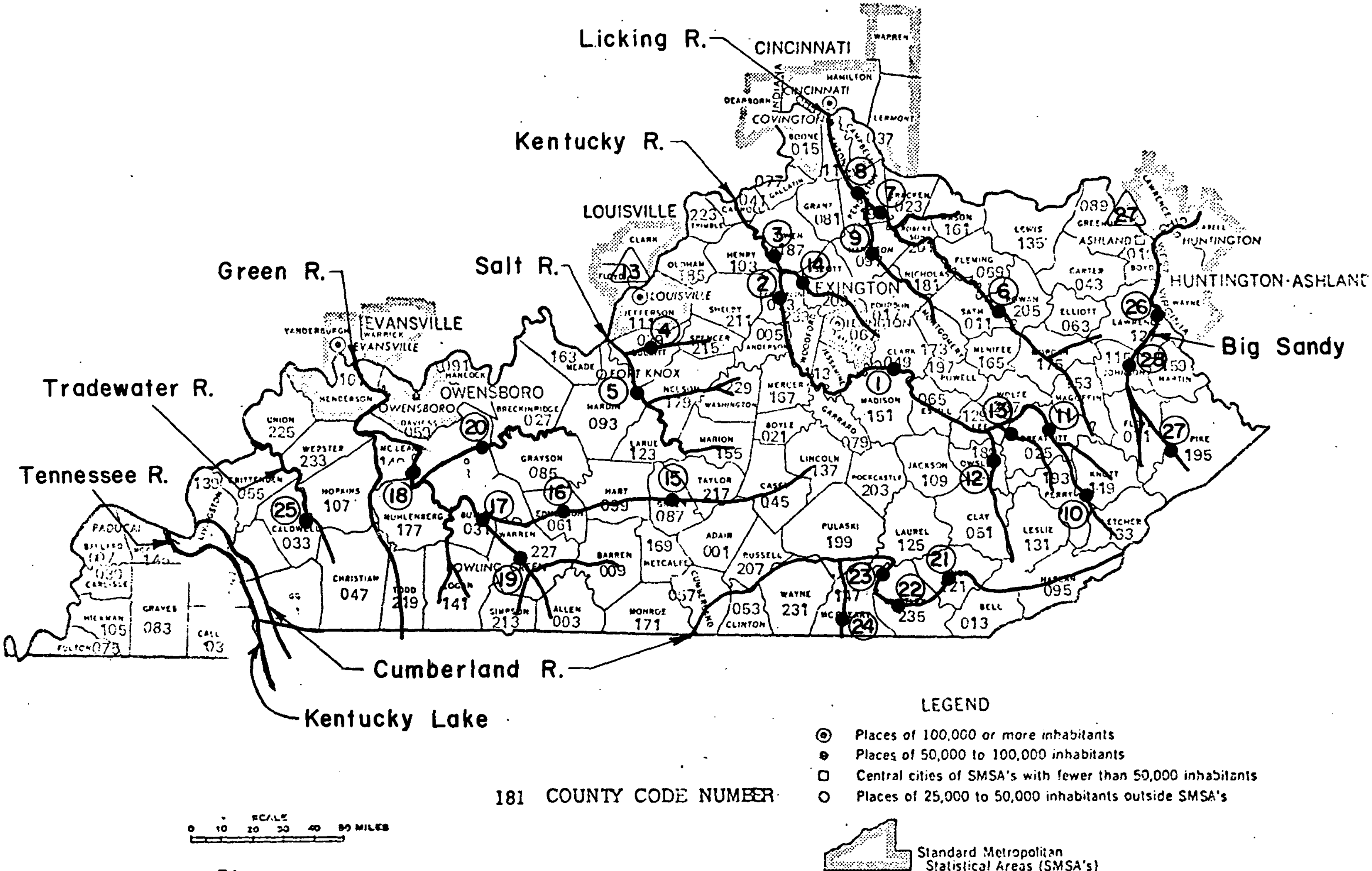


Figure III-G-6. STREAM-GAUGING STATIONS IN KENTUCKY

Table III-G-20

FLOWS OF MAJOR RIVERS IN OHIO

River	Location[18]	Avg. Disch. (cfs)[19]	7-day, 10-yr low flow (cfs)[20]
Little Miami	Milford (1)	1,205	45
	E. Fork at Perinton (2)	547[21]	1.0
	Oldtown (3)	107	7.3
	Caesar Creek, Harveysburg (4)	210[21]	.2
	Caesar Creek, Wellman (5)	235[21]	1.3
	Todd Fk, Roachester (6)	224[21]	.2
	E. Fork, Williamsburg (7)	277[21]	0
	E. Fork, Batavia (8)	415[21]	.4
Mill Creek	Carthage (9)		4.2
Great Miami	Sydney (10)	473	18[19]
	Taylorsville (11)	995	46[19]
	Dayton (12)	2,083	175[19]
	Miamisburg (13)	2,295	223[19]
	Hamilton (14)	3,203	281[19]
Mad	Urbana (15)	140	33[19]
	Springfield (16)	481	115[19]
Stillwater	Englewood (17)	571	12[19]
Whitewater	Alpine, IN (18)	545	45
	Brookville, IN (19)	1,274	82
	E. Fork at Brookville, IN (19)	423	19
Scioto	Columbus (20)	1,336	41
	Circleville (21)	3,294	128
	Chillicothe (22)	4,370	147
	Mouth of the Scioto (23)		600
Big Walnut Creek	Rees (24)	487	7
Big Darby Creek	Darbyville (25)	438	6.2
Olentangy	Delaware (26)	Reliable records not available due to Delaware Reservoir.	
	Prior to Delaware Reservoir construction	348	1
Paint Creek	Bourneville (27)	788	7.8

Table III-G-20 (cont)

River	Location	Avg. Disch. (cfs)	7-day, 10-yr low flow (cfs)
Muskingum	Coshocton (28)	4,855	464
	Zanesville (29)	6,926	550
	McConnelsville (30)	7,282	565
	Mouth of Muskingum (23)		790
Tuscarawas	Dover (31)	1,375	159
	Newcomerstown (32)	2,422	210
Walhonding	Nellie (33)	1,457	
Mohican	Green (34)	879	
Licking	Tobosco (35)	672	50
Nimishillen Cr.	N. Industry (36)	166	23[19]
Mohoning	W. Branch at Newton Falls (37)	98.7	4.1[19]
	Youngstown (38)	844	200
	Lowellville (39)	1,078	290

[18] Locations are indicated by numbers in circles on the Ohio Map in Fig. III-G-7.

[19] From Ref. (2), unless otherwise indicated.

[20] From Ref. (8), unless otherwise indicated.

[21] From Ref. (9).

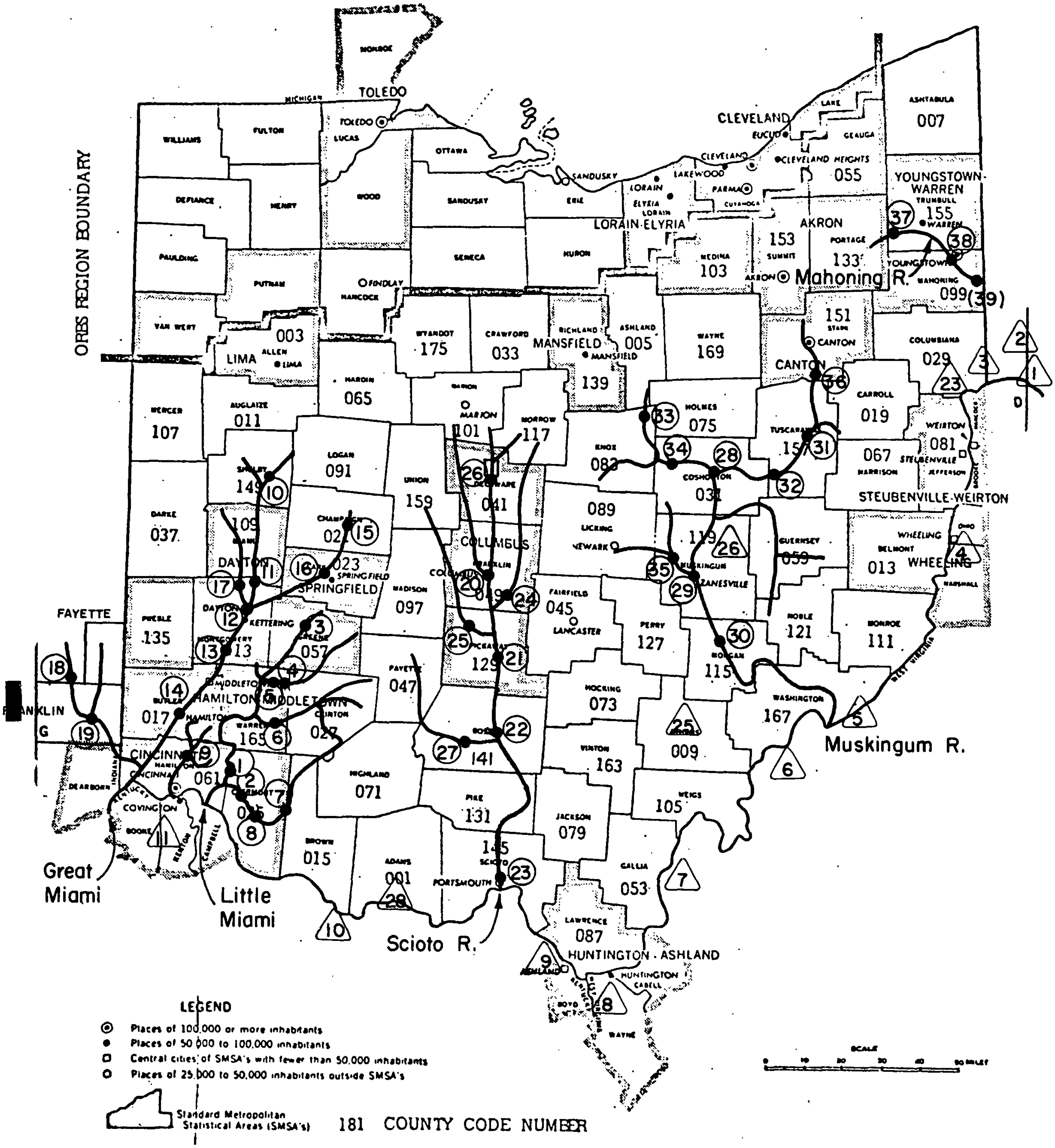


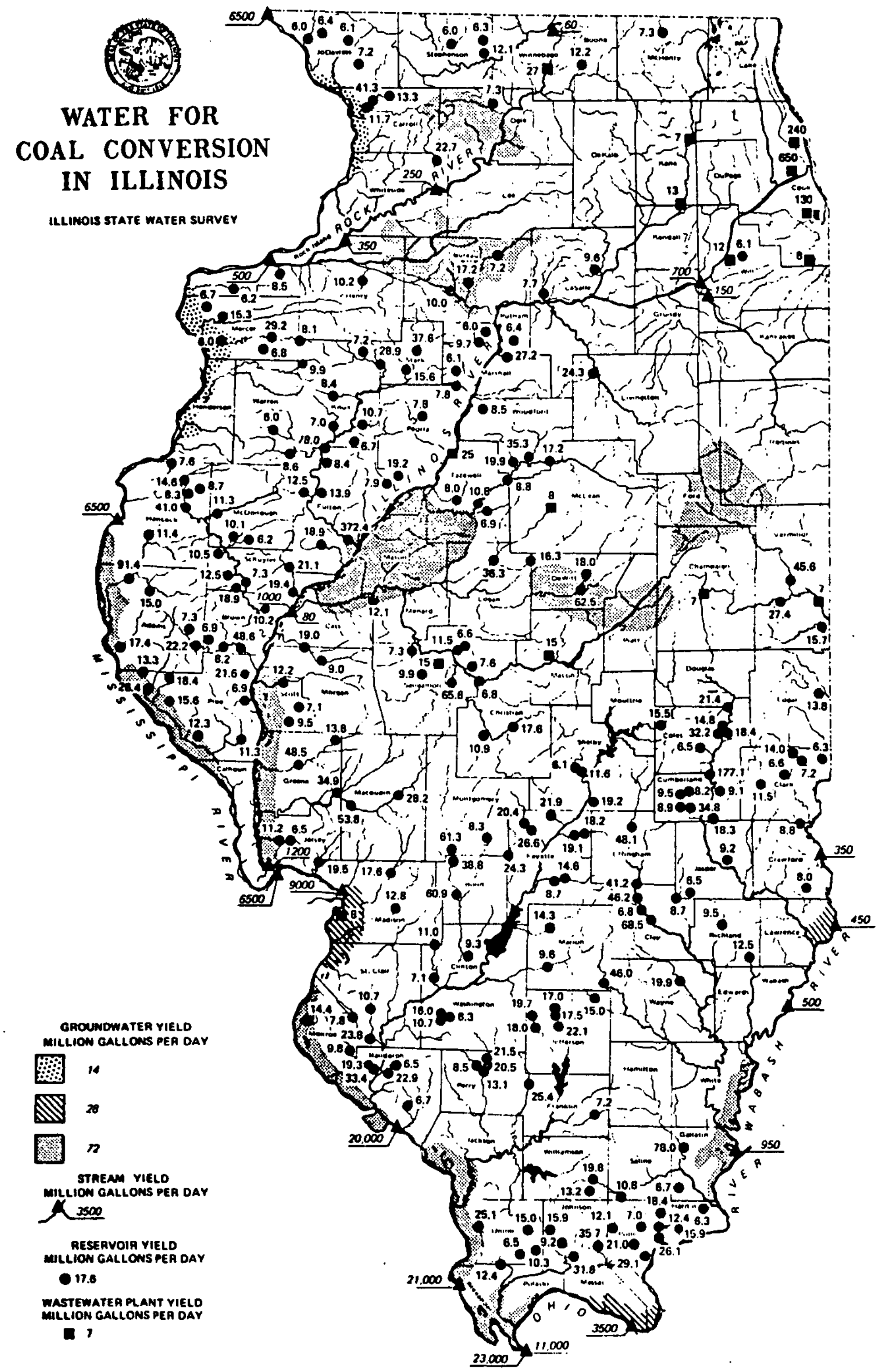
Figure III-G-7. STREAM-GAUGING STATIONS IN OHIO

Table III-G-21

FLOWS OF THE OHIO RIVER AND MINOR TRIBUTARIES

River	Location [22]	Avg. Disch (cfs) [23]	7-day 10-yr Low Flow Estimates (cfs) [24]	7-day 10 yr Low Flow Estimates (cfs) [25]
Ohio	Pittsburgh, PA (1)		3,100	6,555
	Sewickley, PA (2)	32,740	3,100	
	Ohio-PA State line (3)		3,600	
	Wheeling, W. VA. (4)		3,700	6,820
	St. Marys, W. VA (5)		4,000	
	Parkersburg, W. VA (6)	50,730	4,900	8,055
	Pt. Pleasant, W. VA (7)		6,600	
	Huntington, W. VA (8)	77,620	6,900	9,950
	Ashland, KY (9)		7,400	
	Maysville, KY (10)	91,550	7,800	11,150
	Cinn., OH (11)	96,810	7,900	12,130
	above Kentucky R. (12)		8,100	
	Louisville, KY (13)	113,700	8,200	14,265
	Dam 43 (14)		8,800	
	Dam 45 (15)		9,100	
	Dam 46 (16)		9,200	
	Dam 47 (17)		9,300	
	Evansville, IN (18)	133,900	11,000	16,635
	Dam 48 (19)		11,000	
	Dam 49 (20)		11,000	
	Golconda, IL (21)		14,000	
	Metropolis, IL (22)	258,500	46,000	47,230
Little Beaver	E. Liverpool, OH (23)	522	18	
Hocking	Enterprise, OH (24)	435	29	
	Athens, OH (25)	978	43	
Raccoon Cr.	Adamsville, OH (26)	655	3.4	
Tygarts Cr.	Greenup, KY (27)	304	.2	
Ohio Bush Cr.	West Union, OH (28)	442	.2	
Mill Cr.	Carthage, OH (20)		4.2	
Blue	Whitecloud, IN (30)	617	12	

[22]Locations are indicated by numbers and triangles on Fig. III-G-4, III-G-5, III-G-6, and III-G-7.
[23]From Ref. (2).
[24]From Ref. (8).
[25]From Ref. (10).



Stream Yield = Minimum daily flow once in 50 years.

Reservoir Yield = 1/2 the capacity during a once-in-40-years drought.

Figure III-G-8. WATER DATA FOR ILLINOIS

Table III-G-22

SELECTED RESERVOIRS IN INDIANA[26]

Location No.[27]	Reservoir[28]	Drainage Area (sq. mi.)	Total Storage (ac-ft)
1	Big Pine (P)	331	210,500
2	Lafayette (P)	787	331,800
3	Mississinewa (E)	809	368,400
4	Salamonie (E)	553	263,600
5	Huntington (E)	707	153,100
6	Mansfield (E)	216	132,800
7	Cagles Mill (E)	295	228,100
8	Monroe (E)	441	441,000
9	Big Blue (P)	269	85,700
10	Downeyville (P)	276	86,400
11	Clifty Creek (P)	140	56,370
12	Patoka (E)	168	301,600
13	Azalia (P)	250	69,920
14	Deputy (P)	294	147,000
15	Parker (P)	175	133,000
16	Fall Creek (P)	242	223,100
17	Crawfordsville (P)	423	161,170
18	Maltersville (P)	62	23,200
19	Upper Martinsville (P)	2,110	420,000
20	Deer Creek (P)	280	90,000
21	Denver (P)	680	263,000
22	Pipe Creek (P)	167	68,800
23	Delphi, Upper (P)	4,136	514,000
24	Coal Creek (P)	256	170,250
25	Big Walnut (P)	197	160,700

[26] Ref. (7).

[27] Locations are indicated by number on state map in Fig. III-G-9.

[28] Potential (P) or existing (E).

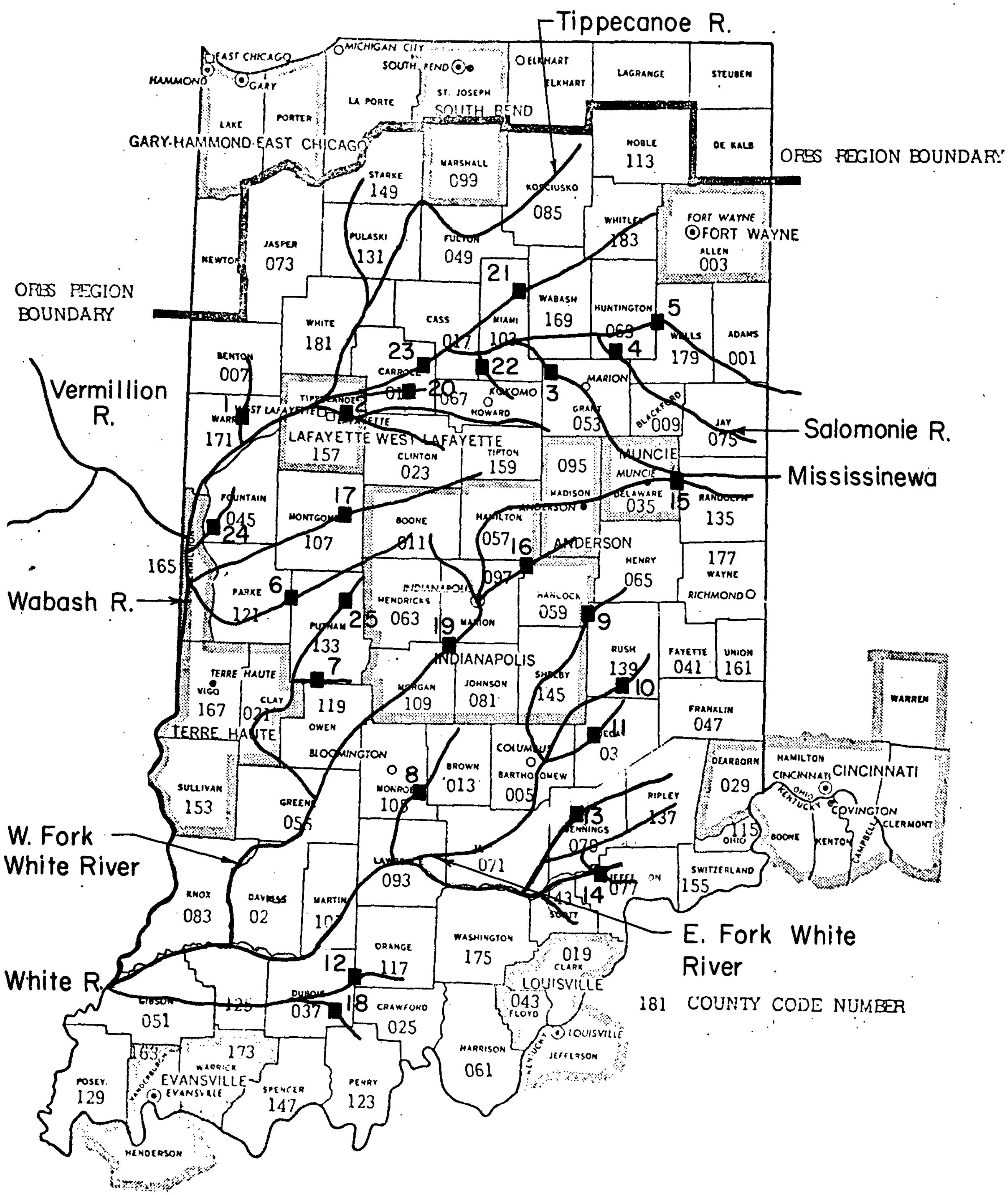


Figure III-G-9. SELECTED RESERVOIR SITES IN INDIANA

Table III-G-23

SELECTED POTENTIAL RESERVOIRS IN KENTUCKY[29]

LOCATION NO.[30]	RESERVOIR	DRAINAGE AREA (sq. mi.)	TOTAL STORAGE (Ac-ft)
1	Drakes Creek	500	307,000
2	Camp Ground	438	448,600
3	Floyds Fork	42	139,500
4	Howardstown	384	369,300
5	Taylorsville[31]	354	399,100
6	Cutshin Creek	84	69,000
7	Ford	2,503	840,000
8	Greasy Creek	51	30,200
9	Kingdom Come	131	73,000
10	Leatherwood Creek	49	35,000
11	Line Fork	64	62,000
12	Little Goose Creek	38	30,000
13	Red Bird River	115	90,000
14	Station Camp Creek	95	290,000
15	Troublesome Creek	201	112,000
16	Walkers Creek	1,260	180,500
17	Falmouth	1,505	898,300
18	Hinkston Creek	174	128,000
19	Royalton	76	47,300
20	Paintsville[31]	92	76,400
21	Yatesville[31]	208	99,800

[29] Ref. (2).

[30] Locations are indicated by number in state map in Fig. III-G-10.

[31] Under construction.

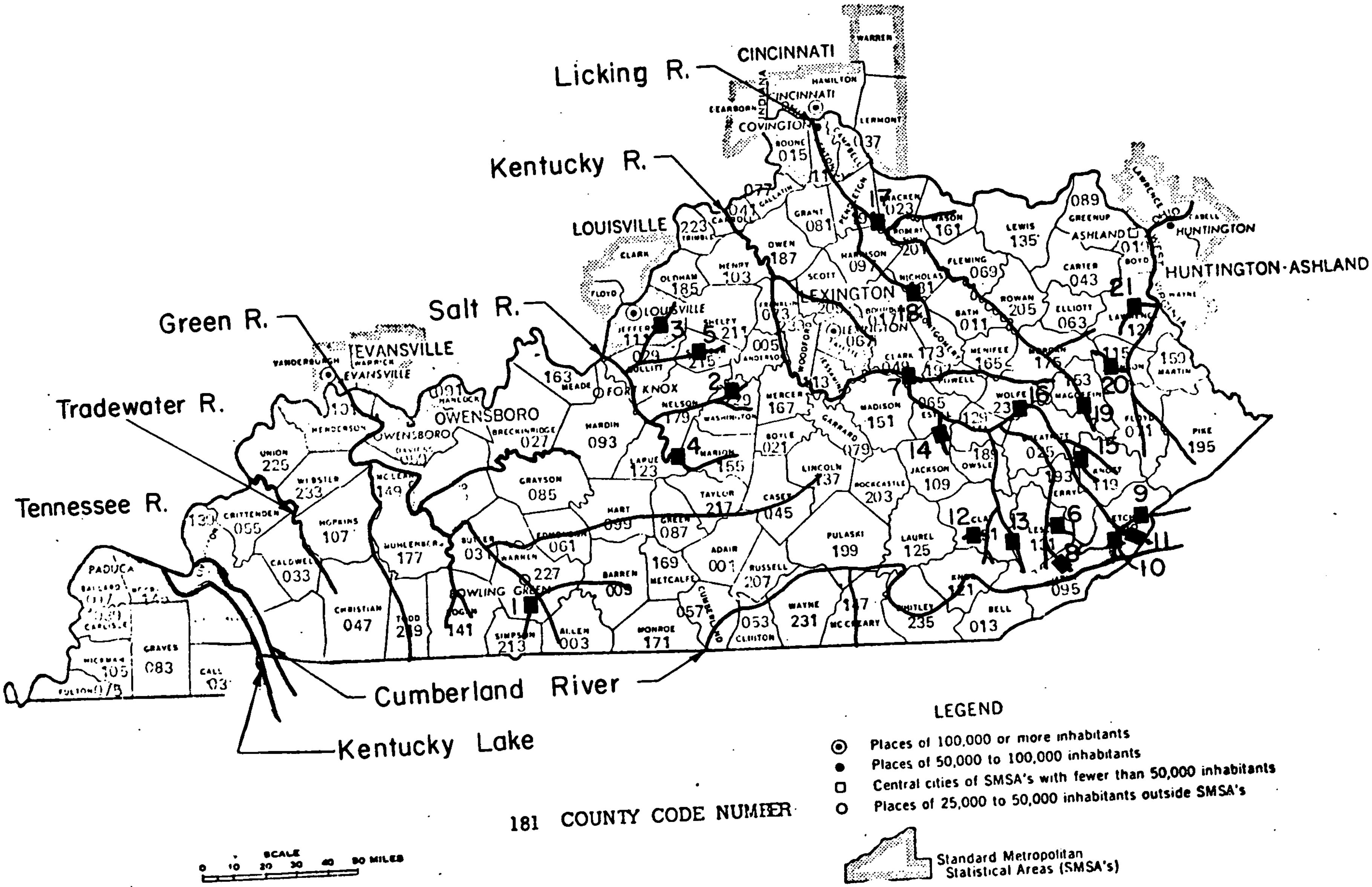


Figure III-G-10. SELECTED RESERVOIR SITES IN KENTUCKY

Table III-G-24

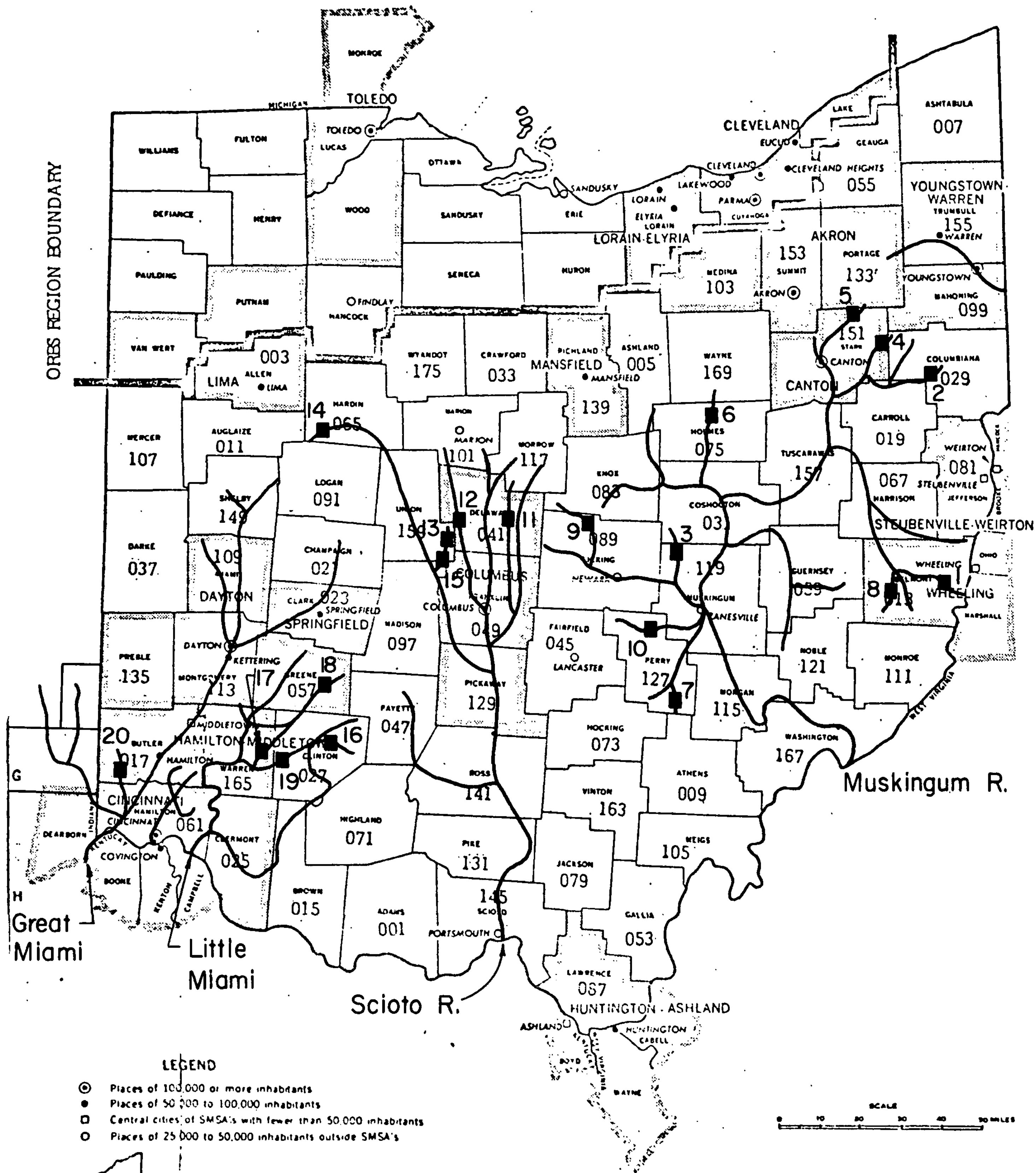
SELECTED POTENTIAL RESERVOIRS IN OHIO[32]

Location No.[33]	RESERVOIR	DRAINAGE AREA (sq. mi.)	TOTAL STORAGE (Ac-ft)
1	Boggs Fork	15	5,000
2	Conser Run	15	5,100
3	Frazeysburg	62	62,000
4	Hugle Run	9	8,200
5	Middle Branch	27	9,300
6	Millersburg	381	77,000
7	Ogg	12	8,500
8	Skull Fork	46	15,000
9	Utica	114	82,000
10	Valley Run	25	15,100
11	Alum Creek[34]	123	124,000
12	Bellepoint	736	88,200
13	Mill Creek	181	92,500
14	Roundhead	34	11,900
15	Upper Darby	239	32,500
16	Cowan Creek	51	14,000
17	Morrow	685	244,000
18	Washington Mills	308	61,000
19	Todd Fork	245	95,000
20	Dry Fork	45	37,000

[32] Ref. (2).

[33] Locations are indicated by number in Fig. III-G-11.

[34] Under construction.



LEGEND

- ◉ Places of 100,000 or more inhabitants
- ● Places of 50,000 to 100,000 inhabitants
- ◘ Central cities of SMSA's with fewer than 50,000 inhabitants
- ○ Places of 25,000 to 50,000 inhabitants outside SMSA's
- Standard Metropolitan Statistical Areas (SMSA's)
- 151 COUNTY CODE NUMBER

Figure III-G-11. SELECTED RESERVOIR SITES IN OHIO

REFERENCES

1. Project memorandum submitted to P. Haag (for distribution to project members) from E. D. Brill, February 18, 1977. Attachment submitted May 15, 1977, lists major assumptions. A copy is on file at the Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801.

2. The Corps of Engineers, U.S. Army Engineer Division, Ohio River, in cooperation with the Department of Agriculture, Department of Commerce, Department of H.E.W., Department of the Interior, FPC, and participating states, Ohio River Basin Comprehensive Survey, App. D, K, Cincinnati, Ohio,1967.

3. Illinois Technical Advisory Committee on Water Resources, Water For Illinois, a plan for action, Springfield, March, 1967.

4. U.S. Department of the Interior, Federal Water Quality Administration, Great Lake Region, Chicago and Minneapolis Offices, Upper Mississippi River Comprehensive Basin Study, App. H, 1970.

5. U.S. Geological Survey. Water Resources Data for Kentucky Water Year 1975, Louisville, 1975.

6. Singh, Krishan P. and John B. Stall. The 7-Day 10-Year Flows of Illinois Streams, Illinois State Water Survey Bulletin 57. Urbana, 1973.

7. U.S. Army Corps of Engineers, Louisville District, in cooperation with Member Agencies of the Wabash River Coordinating Committee, Wabash River Basin Comprehensive Study, Main Report, App. C, F, 1971.

8. Personal communication from William G. Weist, Jr., Chief of Hydrologic Studies Section, U.S. Geological Survey, Indianapolis, Indiana, October, 1976.

9. U.S. Geological Survey, Water Resources Data for Ohio Water Year 1975. Columbus, 1975.

10. Personal communication from Richard C. Armstrong, Acting Chief, Planning Division, U.S. Army Corps of Engineers, Cincinnati, Ohio, April 5, 1977.

11. U.S. Geological Survey, Water Resources Data for Illinois Water Year 1975.

12. U.S. Geological Survey. Water Resources Data for Indiana Water Year 1975. Indianapolis, 1975

13. Smith, William H. and John B. Stall. Coal and Water Resources for Coal Conversion in Illinois, Cooperative Resources Report 4, Illinois State Water Survey and Illinois State Geological Survey. Urbana, 1975.

14. U.S. Geological Survey, Hydrologic Atlas Series, Nos. HA15-HA38. 1960-1962. Available from Kentucky Geological Survey, 307 Mineral Industries Building, Lexington, Ky. 40506.

15. Ohio Department of Natural Resources, Division of Water. Water Inventory of the Muskingum River Basin and Adjacent Ohio River Areas, Report No. 21, Columbus, 1968.

16. Ohio Department of Natural Resources, Division of Water. Water Inventory of the Scioto River Basin, Report No. 17, Columbus, 1963.

17. Ohio Department of Natural Resources, Division of Water. Water Inventory of the Little Miami River and Mill Creek Basins and Adjacent Ohio River Tributaries, Report No. 18, Columbus, 1964.

18. Ohio Department of Natural Resources, Division of Water. Water Inventory of the Mahoning and Grand River Basins and Adjacent Areas in Ohio, Report No. 16, Columbus, 1961.

4. WATER USE CALCULATIONS AND PROJECTIONS

4.1. INTRODUCTION

This chapter contains water use projections for the ORBES region. Projections of municipal and industrial use have been made on a county basis for 1975, 1985 and 2000 for all 350 counties in the Study area. Water use for power generation, irrigation and navigation has also been investigated.

This chapter is a much condensed version of a more detailed report (1), which includes the county projections. State totals are presented in this chapter; they represent only the portions of the states within the ORBES region.

Water use is difficult to measure and it is even more difficult to project, since projections depend on population, income, relative prices, and technological developments. Thus, the figures presented here should be interpreted cautiously; they are more likely to represent orders of magnitude than specific values. This is especially true, of course, for the longer range projections.

The municipal and self-supplied water use sections are probably the most reliable. The projections of water use for power generation, irrigation and navigation are less certain. Finally, the reader should keep in mind that projections for withdrawals and consumption are based on present technologies and life-styles. The use projections should not be considered identical to "requirements" because of the major potential for water conservation.

4.2. MUNICIPAL WATER USE

4.2.1. PROJECTION METHODOLOGY

Municipal use was calculated in this study by multiplying county population by a per capita use figure for the county (See Table III-G-25). This technique has a few drawbacks. The total population of a county is not actually served by municipal systems. Also, income and price factors are not considered in these projections. Because of life-style differences, the entire population of a county does not use water at exactly the same rate as the population served by municipal systems. Additionally, municipal systems support industrial, civic and commercial users, and often have significant leakage. The method employed here, however, can be justified for strong reasons:

1. While rural families may use less water than urban ones--for income and life style reasons--water <u>is</u> used for livestock. This may partly outweigh the demand placed on municipal systems by nondomestic uses (e.g., industrial, civic).

Table III-G-25

MUNICIPAL WATER USE PROJECTIONS
IN MILLION GALLONS PER DAY[1]

State	1960	1975	1985	2000	2020
Illinois	280	300	310	350	--
Indiana	420	500	510	590	700
Kentucky	290	330	360	430	--
Ohio	790	920	990	1100	1200

[1] 1 million gallons per day = 1.55 cubic feet per second.

2. Assuming a slightly high level of use is appropriate for cautious planning.

3. For this study one important consideration is incremental demand, i.e., the change in demand from one period to the next. The result of the technique used here is very similar to that of the Great Lakes Basin Framework Study (GLBFS) (2). Although the authors of the GLBFS comprehensively investigated rural water demand, for planning purposes they assumed that all new population would use municipal systems.

4. Based on a preliminary econometric study, the effect of income on per capita municipal use in the region is thought to be negligible.

4.2.2. PER CAPITA USE

Per capita figures for municipal demand have been taken predominantly from the Ohio River Basin Comprehensive Survey, Appendix D (ORBCS) (3) which was prepared in 1967. This source contains per capita usage rates based on the population served by municipal water supply systems. These rates include some industrial, commercial and public uses as well. Several counties in each state are outside the actual Ohio River Basin, though they have been included in the ORBES region. In these cases, per capita use figures have been derived from other sources. Many Illinois counties and Jasper County, Indiana, are covered by the Upper Mississippi River Comprehensive Basin Study (UMRCBS) (4) which is analogous to the ORBCS. For many of the northern counties in Indiana and Ohio, approximate data have been taken from the GLBFS.

In this analysis the per capita use figure has been kept constant at the base level suggested by the data source. There are two potential problems with this approach. First, in a few cases the ORBCS figure is excessively high to be considered a reasonable county-wide figure. For example, a few per capita figures are above 200 gallons per capita daily (gpcd). The other problem may be that the per capita consumption of water may be growing somewhat. A study of a region similar to the Ohio River Basin (2) suggests that per capita use may increase to 108 gpcd at an annual rate of 1% and thereafter at an annual rate of .25% to the level of 130 gpcd.

For more detailed descriptions and analysis of municipal demands, the reader is directed to Reference (1).

4.2.3. POPULATION PROJECTIONS

The specified dates for the ORBES scenarios are 1975, 1985, and 2000. Except for Ohio, recent official state projections of county populations for these dates are contained in the ORBES Task 1 report (5). For Ohio only the figures for 1985 were provided, so projections were performed for 1975, 1985, 2000 and 2020 based on a disaggregation of data from another source (6). This is specifically discussed in Reference (1). Similar projections were made also for Indiana before the Task 1 report was received. For Indiana, however, the Task 1 figures are used for all projections except for 2020.

4.2.4. CONSUMPTION

Consumption of municipal water is estimated to be approximately 20 per cent of withdrawals (7).

4.3. SELF-SUPPLIED INDUSTRIAL WATER USE

4.3.1. PROJECTION METHODOLOGY

Self-supplied industrial withdrawals account for approximately 90% of all industrial withdrawals (2, p.v.); the remaining percentage is municipally supplied. In this report, and in all studies cited, discussions of industrial withdrawals exclude the power generation industry. Projections for self-supplied industrial use in the ORBES region are presented in Table III-G-26. These projections are based on industrial earnings projections contained in Reference (6). Two other methods for making projections were also tried, and will be mentioned below. The data base for self-supplied industrial withdrawals for almost all counties in this study is the <u>ORBCS</u>. This survey calculated industrial withdrawals based on figures for water use per employee for different industries. For the few counties not covered by the <u>ORBCS</u> or the <u>UMRCBS</u> special calculations were made. Special calculations were also made to incorporate recent United States Geological Survey data for Ohio (8).

Manufacturing earnings are used as a measure of industrial growth in counties. Industrial water withdrawals are assumed to be directly correlated to industrial growth. Manufacturing earnings are projected by OBERS (Office of Business Economics and the Economic Research Service) (6) for SMSA's (standard metropolitan statistical areas) and non-SMSA portions of economic areas. The economic areas typically consist of several counties whereas SMSA's are smaller, being generally one to three counties. OBERS projects earnings for 1980, 1985, 1990, 2000 and 2020. It also has data for 1962 and 1970. Ratios of future earnings to those of 1962 have been calculated. A typical vector of ratios for 1970 earnings, 1980 earnings, etc., looks as follows:

1970	1980	1985	2000	2020
1.4226	2.1916	2.5810	4.2043	7.4579

Table III-G-26

SELF-SUPPLIED INDUSTRIAL WATER USE PROJECTIONS

IN MILLION GALLONS PER DAY[2]

State	1960	1975	1985	2000	2020
Illinois	640	1200	1600	2400	4100
Indiana	180	330	470	770	1300
Kentucky	190	360	490	760	1300
Ohio	1600	1700	2400	3400	5200

[2] 1 million gallons per day = 1.55 cubic feet per second.

OBERS does not project data for 1975. Earnings in 1975 are assumed to be a linear interpolation of 1970 and 1980 earnings. Note that earnings ratios and industrial water use projections for 2020 are included even though this year is not specified for the ORBES project. These projections have been included since they could be readily generated.

Under this technique growth of industrial water withdrawals is assumed to be strictly proportional to the growth of manufacturing earnings. In Illinois, for example, separate earnings ratios were calculated for 17 different areas in the state--10 non-SMSA economic areas and 7 SMSA's. Each county falls into exactly one of these 17 regions, and its self-supplied industrial water use was projected to grow accordingly.

Water use projections have also been made using total earnings instead of manufacturing earnings as the measure of industrial growth. The total earnings data are obtained from OBERS projections and all calculations are exactly analogous to those with manufacturing earnings. Total earnings, however, include data from government, agriculture and other sectors which do not indicate industrial growth. So, manufacturing sector earnings would seem to be a better indicator of self-supplied industrial water use than total earnings. Total earnings projections were made because of some minor inconsistencies in the OBERS data base. Projections using total earnings growth rates give state-wide totals which are essentially the same as projections based on only manufacturing sector growth. A more detailed comparison of these two projections is contained in Reference (1).

A problem with using earnings projections of either type, however, is that they lead to large--perhaps unrealistic--increases in water withdrawals. A similar observation was noted by the authors of the GLBFS, who used "value added in manufacturing" as their measure of industrial growth. They project a 600% increase of value added from 1970 to 2020 in the Great Lakes region. They assert that industrial water withdrawals cannot be projected to increase at such a high rate, though consumption may increase in these magnitudes. Furthermore, they suggest industrial water withdrawals may decline during the coming years. After a period of decline in withdrawals while industrial plants are improving their efficiency levels, it is expected that withdrawals will begin to increase because of industrial growth. Thus, withdrawals in 2000 may be generally equal--depending on the subarea of the Great Lakes basin--to those in 1970. By 2020 withdrawals may be about 10% more than 1970. This picture would be complicated, of course, by changes in wastewater treatment requirements and by additional reuse caused by local water shortages. For this study, it is believed that rather than planning on a decrease in withdrawals, the more cautious planning approach would be to assume a constant level of withdrawals from 1975 through 2000.

4.3.2. CONSUMPTION

Anti-pollution discharge regulations and the spread of cooling towers both are expected to contribute to decreasing withdrawal rates. This trend has been observed recently, for example, by officials at the United States Geological Survey in Ohio. Still, as emphasized by the authors of the GLBFS, consumption *is* expected to increase and this could have significant impacts upon the region's water resources.

Consumption projections can be based on industrial withdrawal projections of the earnings growth variety using a constant consumption rate. The *1972 Census of Manufactures* (9), for example, suggests an average 6% level of consumption for industry. Murray and Reeves (7) find a 10% national level of industrial consumption. The 6% value was used in the calculations in Chapter 2.

4.4. COMPARISON WITH OTHER WATER-USE INVESTIGATIONS

The municipal and industrial projections presented in this report have been compared with projections and water use inventories from a number of different sources. Especially beneficial have been recent data received from the Division of Water Resources, Kentucky Department for Natural Resources and Environmental Protection (10, 11, 12) and from the United States Geological Survey in Columbus, Ohio (8). Also useful have been *Water for Illinois: A Plan for Action* (13), a paper by C.S. Csallany (14) and the *Wabash River Basin Comprehensive Study* (15).

The state-wide aggregations presented here have been checked for consistency with the above materials, and a modification was made for one county in Ohio. Generally, when data for recent years have become available, they are quite close to the projections presented here.

4.5. ENERGY-RELATED WATER USE

4.5.1. WATER USE FOR ELECTRIC-POWER GENERATION

Water consumption and withdrawal for electric-power generation are projected in this investigation based on a formula for estimating water use with present technologies. The condenser cooling water flow rate is estimated (5, pp. 1d-20, 1d-21) as follows:

$$W = \frac{3.71666 \times 10^{-2} (L) (C) [H (1-S) - 3413]}{8.34 (\Delta T)} \qquad (1)$$

where:

W = water flow rate required (in cfs),

L = load factor (as a percentage of capacity),

C = generating capacity (in megawatts),

H = heat rate, which is directly related to thermal efficiency (in BTU/kWh, British thermal units per kilowatt hour),

S = stack heat loss (as a percentage of heat rate), and

ΔT = temperature rise across the condenser (in degrees Fahrenheit, °F).

Based on the following assumptions, estimates of water use are given below:

L = 100%

C = 1000 MW, except in FTF 100% coal scenario where the plant capacities are 600 MW,

H = 9500 BTU/kWh for coal-fired plants,

H = 10,500 BTU/kWh for nuclear plants,

S = 15% for coal-fired plants,

S = 0 for nuclear plants, and

ΔT = 15°F

In the first phase of this study it is assumed that all plants will employ wet cooling towers. For a plant using such towers it is estimated (5, p. 1d-22) that 2% of the total condenser flow would be lost to evaporation and drift (these losses are termed consumption), and that 1% of the total flow would be required as blow down. In total, 2% of the total flow calculated by Equation 1 would be needed as make-up. For example, a 1000 MW coal-fired (nuclear) plant operating at full capacity would have a condenser flow of 1380 cfs (2100 cfs), a withdrawal rate of 41 cfs (62 cfs), and a consumption rate of

28 cfs (42 cfs). In the calculations described in Chapters 2 and 5, and in Section 4.5.3 of this chapter, a load factor of 55% is assumed in determining aggregate water use estimates for large areas; the estimates listed above are reduced proportionally for each plant.

4.5.2. WATER USE FOR COAL GASIFICATION

The estimated withdrawal and consumption for coal gasification plants operating at full capacity are shown in Table III-G-27, based on Reference (16). A unit size high-BTU plant--as defined by ORBES--produces 250 x 10^6 standard cubic feet per day (SCFD) of pipeline quality gas. A unit size low-BTU plant produces 1500 x 10^6 SCFD.

4.5.3. TOTAL ENERGY-RELATED WATER WITHDRAWAL AND CONSUMPTION

Estimates are presented for the 1970 level of use and for projected water uses in 1985 and 2000 in Table III-G-28. Note that the estimates for 1970, from Reference (7), reflect state totals instead of totals for the ORBES portions of the states. Only the ORBES counties were included, however, in the projections of use in 1985 and in 2000 for the different scenarios.

The 1985 projections were prepared in the following manner. A list of existing plants and plants scheduled for completion between 1975 and 1985, along with their respective generating capacities, is provided in Reference (5). Using the assumptions stated above (including a load factor of 55%), water withdrawal and consumption were estimated for 1985. The estimates were summed on a state by state basis. Projections for 2000 were made in a similar manner; the ORBES scenarios provide the proposed number of plants and their respective capacities. The estimates for the two BOM scenarios in Table III-G-28 include projected withdrawal and consumption by coal-gasification plants. Only one high-BTU and one low-BTU plant are located in each state, however, and the projected water use for coal gasification accounts for only a very small portion of the total energy-related water use. The other ORBES scenarios do not forecast gasification plants.

As noted above, wet cooling towers were assumed for all plants, implying a switch from once-through cooling in existing plants by 1985. As shown in Table III-G-28, a very small percentage of the withdrawal in 1970 was consumed. According to the projections, however, consumption will increase greatly as cooling towers are used. This trend already has been observed, for example, by the U.S. Geological Survey in Ohio; data for that state (8) indicate a 455% increase in consumption from 1970 to 1975, accompanied by an 11% decrease in withdrawal.

Table III-G-27

ESTIMATES OF WATER WITHDRAWAL AND CONSUMPTION

BY COAL GASIFICATION PLANTS

Plant Type	Withdrawal (cfs)	Consumption (cfs)
High BTU	38	29
Low BTU	22	18

Table III-G-28

WATER WITHDRAWALS AND CONSUMPTION

FOR ENERGY-RELATED USES IN CUBIC FEET PER SECOND[3]

	Scenario					
State[4]	1970	1985	BOM(80/20)	BOM(50/50)	FTF(100/0)	FTF(0/100)
Illinois	18,000 (7.7)	720 (480)	1,600 (1,000)	1,700 (1,100)	750 (500)	760 (500)
Indiana	6,500 (7.7)	560 (370)	1,500 (990)	1,600 (1,100)	620 (400)	660 (440)
Kentucky	5,900 (33)	510 (340)	1,400 (900)	1,500 (1,000)	580 (390)	620 (410)
Ohio	21,000 (22)	1,000 (670)	2,600 (1,700)	2,800 (1,900)	1,200 (810)	1,300 (880)
Totals[5]	51,000 (70.4)	2,800 (1,900)	7,000 (4,700)	7,600 (5,100)	3,200 (2,100)	3,400 (2,200)

[3]Consumption figures are in parentheses.

[4]For 1970, the state figures are for the entire state, from Ref. (7); for future years figures are for the ORBES portions of the states assuming cooling towers are on all plants.

[5]Totals do not always equal the sums of the column entired due to round-off error.

Any combination of cooling technologies could be assumed instead of the uniform adoption of wet cooling towers. Water withdrawal and consumption would depend on the mix. Only preliminary calculations for different technologies have been made as part of this study, but they tend to support the trend indicated by the following estimates of consumptive losses made by the Federal Power Commission (17) for 1000 MW coal-fired plant operating at full capacity: 28 cfs for wet cooling towers, 16 cfs for cooling ponds, and 12 cfs for once-through cooling. Dry cooling systems have very small consumptive losses (18).

4.6. WATER USE FOR IRRIGATION

4.6.1. INTRODUCTION

Professionals' views vary widely concerning the prospects for irrigation in the ORBES region. Projections of irrigation based on historical trends show continuing, yet moderate, growth. Some experts have suggested that there is the potential for major expansion of irrigation in the region. In contrast, other investigators believe much of projected--and even present--irrigation will not be economically profitable (19).

Presently, the ORBES region is characterized by a virtual absence of irrigation. The percentage of agricultural land which is irrigated is one of the lowest in the nation (20), and the rich farm soils often show a surplus of water. Hence, some recent publications dealing with the region's water resources have not looked heavily into irrigation. Recently, however, irrigation has increased rapidly in some parts of the region. If the extreme projections hold, irrigated acreage in the region could increase more than ten fold by the year 2020.

4.6.2. PROJECTIONS

Projections of irrigated acreage and peak water use are presented in Table III-G-29. In a number of cases projections have been made by river basin or by state rather than by areas within the ORBES boundaries. Still, the values presented give an idea of the wide range in projections, and the relative irrigation possibilities in the ORBES region. The acreage projections have been taken from a number of sources, and are briefly described below.

For Illinois, different projections of irrigated acreage have been derived as follows:

Case 1 (33,000 acres) is a 1967 estimate of row crop acreage in the counties in the ORBES region (21). Also, see Reference (20) for 1969 figures.

Table III-G-29

PROJECTIONS OF IRRIGATION IN THE ORBES REGION

State	Acreage	Peak Week Use (cfs)	Annual Use[6] (Thousand Acre-Ft.)
Illinois			
Case 1	33,000	290	Not Available
Case 2	200,000	1,800	Not Available
Case 3	800,000	7,200	Not Available
Indiana			
Case 1	20,000	180	19
Case 2	61,000	550	57
Case 3	220,000	2,000	140
Case 4	1,500,000	14,000	Not Available
Kentucky			
Case 1	20,000	180	Not Available
Case 2	32,000	290	28
Case 3	64,000	570	55
Ohio			
Case 1	20,000	180	32
Case 2	54,000	480	32
Case 3	270,000	2,400	210

[6] From different sources than peak week use figures

Case 2 (200,000 acres) is an estimate for the ORBES counties in 2020 based on trends in the late 1960's which project 250,000 acres for the entire state (22). For the ORBES region the 1985 projection is about 95,000 acres; the 2000 projection is roughly 140,000 acres.

Case 3 (800,000 acres) is an estimate for the ORBES counties based on a potential of from 1 to 1.2 million irrigated acres in the entire state at some time in the future (23, 24).

For Indiana the following cases are presented:

Case 1 (20,000 acres) is an estimate of irrigated acreage in 1967 in the ORBES region (25). Also, see Reference (20) for statewide 1969 figures.

Case 2 (65,000 acres) is a projection for 2020 based on historical trends (25). Similar trends are suggested in Reference (15).

Case 3 (220,000 acres) is the estimated economic potential for irrigation in the Wabash River Basin (which includes part of Illinois and excludes parts of Indiana) in 2000 (3).

Case 4 (1.5 million acres) is a projection of the amount of economically feasible irrigated acreage by 2020 in the Wabash River Basin (15).

The following cases are presented for Kentucky:

Case 1 (20,000 acres) is based on Census of Agriculture figures for 1969 (20).

Case 2 (32,000 acres) is a projection of economically feasible acreage in the Kentucky, Salt and Licking River Basins in 1980 (3). This includes most of the irrigated acreage in Kentucky except for the portion which falls into the Ohio River Main Stem region.

Case 3 (64,000 acres) is a projection of economically feasible acreage in the Kentucky, Salt and Licking Basins in 2000 (3).

For Ohio the following cases are presented:

Case 1 (20,000 acres) is the estimated total for the ORBES region based on figures for irrigated water use in 1975 (8) and statewide acreage figures for 1969 (20).

Case 2 (54,000 acres) is the sum of projections of economically feasible acreage in the Muskingum, Scioto, and Little and Great

Miami River Basins in 1980 (3). This does not include acreage in the Ohio River Main Stem region.

Case 3 (270,000 acres) is a projection for 2000 for the same region as Case 2 (3).

4.6.3. PEAK IRRIGATION RATES

Two types of estimates for water use are presented in Table III-G-29. Peak week levels have been calculated in cubic feet per second based on irrigation of all acreage at a level of 1.5 inches per week. This method is described below. Where projections (or actual data for Case 1 for Ohio) on water use are available (3, 8, 15, 25), they are also presented. Figures from other sources are in acre-feet, but it should be noted that almost all irrigation occurs over the summer months. Therefore, the levels of acre-feet presented are low in the sense that they average the water use over the entire year.

The quantity and time of irrigation in the region will vary because of crop, soil type and climatic differences. In a given region, however, corn and soybeans require similar amounts and timing of irrigation. Since these are among the most important crops in the ORBES region they are central to the derivation of peak week irrigation rates. For corn, the critical period in Illinois is typically the last two weeks in July--i.e., about 65 days after seedling emergence--when the plants are undergoing silk emergence. At this time the plants have the greatest water need, and this is also the period during which rainfall is least probable. During these weeks as much as 1.5 inches of water might be applied by irrigation. Total irrigation over the three summer months is in the range of one foot, half of which might come in one month (23).

4.6.4. CONSUMPTION

Water use in irrigation is highly consumptive due to large losses from transpiration and evaporation. According to Murray and Reeves (7), more than 90% irrigation water in the ORBES region may presently be consumed. They note that their data for some regions may be poor, but even the lowest consumption rate in the nation is above 33%. The average rate of consumption of irrigation water in the U.S. was 59% in 1970 (7). This average can be applied to the different projections given in Table III-G-29 to obtain estimates of total consumption that could occur in the ORBES region.

4.6.5. FACTORS AFFECTING PROJECTIONS

Projections of irrigation are affected by both agronomic and economic factors. Among the most important agronomic factors is the soil type, and its ability to retain water in drought periods. In Illinois, projections of major potential increases in irrigation are largely for areas of sandy soils; soils with hard clay beneath the surface may also be conducive to supplemental irrigation (23).

Economic factors, however, will ultimately determine the extent of irrigation. As Vernon Ruttan notes in his discussion of resource combinations in agriculture, "The most striking feature about agricultural development in the United States is not its stability but the way in which it responds to economic and technological changes." (26, p.8).

Among the important economic factors are the relative prices of such inputs as land, labor, fertilizer, energy and water. Crop prices and accessibility to markets also play important roles in determining the extent of irrigation. The changing structure of the agricultural sector may also affect irrigation development patterns. Agribusiness may have more funds to invest and may have a longer planning horizon than single family farmers. Successful irrigation in the ORBES region will also require sound management techniques. These techniques are likely to become increasingly common due to rising levels of agricultural education and agribusiness.

While trends of rising levels of management expertise, land prices, crop prices and agribusiness indicate increased potential for irrigation, other factors may moderate or counteract them. Importantly, irrigation at present entails increased inputs of energy, labor, fertilizer and water. Costs per unit output may in fact rise with irrigation, and the prices of the increased inputs may rise as fast--or faster--than land or produce prices. For these reasons not all experts are convinced that increased irrigation in the ORBES region--and other relatively humid regions--will be profitable or should be encouraged. Additional research in this area is needed.

4.6.6. IRRIGATION IN NEIGHBORING BASINS

Major increases in irrigation in neighboring regions have also been projected by some investigators. Because water use for irrigation is very consumptive, major increases in irrigation in neighboring regions could significantly affect the inflow of water to the ORBES region. In Iowa, for example, irrigated acreage may double this year. Irrigated acreage in Nebraska may increase from 6.5 to 10 million acres by the 1980's, and may eventually reach 15 million acres (24). These large developments are likely to affect the water balance of the Missouri River Basin, and therefore of the Mississippi River, which is the western boundary of the ORBES area.

4.7. NAVIGATIONAL WATER USE

In general it appears that even major increases in water use--and consumptive losses--over the next few decades will not seriously affect navigation in the rivers of the ORBES region. The Ohio River, the Mississippi River above St. Louis, the Illinois Waterway, and the Green and Barren Rivers in Kentucky are all locked and dammed (3, 4) to an extent that ensures adequate channel depth during low-flow conditions. Based on brief discussions with U.S. Army Corps of Engineers, it appears that the effects of increased consumption on the Mississippi River south of St. Louis would also be minimal. During low-flow conditions dredging is presently increased to maintain nine foot channel depths, and barges are restricted in their movements outside the channel.

In addition to increased dredging activity, lighter loading of barges may accompany these periods. Such measures may be increasingly necessary, as barge traffic is expected to grow througout the coming decades (3, 4). Also, increased mining and use of coal would add to the traffic projections made in the late 1960's (4), which foresaw coal use remaining steady or declining.

A brief discussion with a Corps of Engineers representative in St. Louis suggested the following rule of thumb for looking at the effects of water losses on the navigation along the Mississippi River. At the low water level of 54,000 cfs at St. Louis (i.e., the 9-foot channel depth), every 1000 cfs decrease in flow lowers the channel depth approximately 1/2 inch. A decrease of 10,000 cfs would lower the river stage roughly 8 1/2 inches. As a comparison, the 7-day 10-year low flow of the Mississippi River at St. Louis is 45,970 cfs (see Chapter 3).

The above discussion suggests that, in general, the impacts of increased water consumption on navigation may be slight. It is possible, however, that large increases in heavily consumptive uses could have significant effects on navigational water levels. Particularly important in this regard would be extensive development of irrigation and power generation outside as well as within the ORBES region. The Upper Mississippi River Comprehensive Basin Study, for example, notes that "future consumptive demands for water for irrigation in the Missouri River Basin could significantly reduce the Missouri River's contribution" to the Mississippi during low flow (4, p. J-11). The Missouri River, which is outside the ORBES region, presently contributes 24,000 of the 54,000 cfs needed to maintain a nine foot channel depth in the Mississippi River at St. Louis. Power generation could also affect water levels in the Mississippi, through the cumulative effects of plants in the Upper Mississippi, and Missouri, and Ohio River Basins.

4.8. SUMMARY

Water withdrawal and water consumption are related yet distinct aspects of water use. Even for a given sector they do not necessarily increase at the same rate. Municipal withdrawals and consumption are both likely to increase proportionately with population growth. Industrial withdrawals may remain fairly constant or grow slowly, but consumption is projected to increase at the rate of industrial growth. It should also be noted that municipal and industrial usage levels presented in this study are averages. Peak levels are typically 20% greater (15).

Water use for irrigation and power generation may entail major consumptive losses. With the spread of closed system cooling technologies, power withdrawals are decreasing, but consumption is increasing sharply. The extent of irrigation growth over the coming decades remains a question; experts' opinions range from forecasting little growth to vast expansion.

Major increases in water consumption--related to power generation and irrigation--could adversely affect navigation, but even during low-flow periods these effects might be slight.

Water quality maintenance, wildlife, and recreational water uses have not been extensively considered in this investigation. Rather, the aim has been to concentrate on consumptive uses of water, which could affect these other uses. Non-consumptive uses, however, should also be given explicit consideration in water allocation decisions.

REFERENCES

1. Project memorandum submitted to P. Haag, ORBES Project Office, (for distribution to project members) from E.D. Brill, February 18, 1977. Attachment submitted May 15, 1977. A copy is on file at the Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801.

2. Great Lakes Basin Commission, Water Supply Group. Great Lakes Basin Framework Study, App. 6. Ann Arbor: Great Lakes Basin Commission, 1975.

3. The Corps of Engineers, U.S. Army Engineer Division, Ohio River, in cooperation with the Department of Agriculture, Department of Commerce, Department of H.E.W., Department of the Interior, FPC, and participating states. Ohio River Basin Comprehensive Survey, App. D, F, L. Cincinnati, Ohio, 1967.

4. U.S. Department of the Interior, Federal Water Quality Administration, Great Lakes Region; U.S. Army Engineer Division, North Central; and U.S. Department of Agriculture, for UMRCBS Coordinating Committee. Upper Mississippi River Comprehensive Basin Study, App. H, J, N. 1970.

5. Project memorandum received from ORBES Project Office, Task I Report, "Development of Plausible Future Regional Technology Configurations." October 18, 1976.

6. Bureau of Economic Analysis, U.S. Department of Commerce and Economic Research Service, U.S. Department of Agriculture for the U.S. Water Resources Council. OBERS Projections: Regional Economic Activity in the U.S., Vols. 1, 5, 6. Washington, D.C.: U.S. Government Printing Office, April, 1974.

7. C. Richard Murray and E. Bodette Reeves. Estimated Use of Water in the United States in 1970. U.S. Geological Survey Circular 676. Washington, D.C., 1972.

8. Personal communication from James F. Blakey, District Chief, Water Resources Division, U.S. Geological Survey, Columbus, Ohio. Water use inventories by county for 1975 were provided for the following categories: municipal, self-supplied industrial, power, rural (including livestock), and irrigation. February 2, 1977.

9. U.S. Bureau of the Census. Census of Manufactures, 1972 Special Report Series: Water Use in Manufacturing, Washington, D.C.: U.S. Government Printing Office, September 1975.

10. Mull, D.S. et al. Public and Industrial Water Supplies of Kentucky, 1968-69. Information Circular 20, Kentucky Geological Survey, Lexington, Kentucky, 1971.

11. W.E. Gates and Associates. "Projection of Self Supplied Industrial Water Demand - ORBC Level 'B' Study Area - State of Kentucky." prepared for the Ohio River Basin Commission, Cincinnati, Ohio. August, 1976.

12. Personal communication from James R. Villines, Division of Water Resources, Bureau of Natural Resources, Department for Natural Resources and Environmental Protection, Frankfort, Kentucky 40601. Included computer output of municipal and industrial withdrawal permit data. January, 1977.

13. Illinois Technical Advisory Committee on Water Resources. Water for Illinois: A Plan for Action. Springfield, Illinois, March, 1967.

14. Csallany, S.C. "Water Demand for Illinois Counties." Urbana: Illinois State Water Survey, mimeograph, November, 1972.

15. U.S. Army Corps of Engineers, Louisville District, and U.S. Department of Agriculture in cooperation with Member Agencies of the Wabash River Coordinating Committee, Wabash River Basin Comprehensive Study App. F, H, 1971

16. Stout, Glenn E., "Proceedings of the Workshop on Research Needs Related to Water for Energy.: Research Report No. 93, Urbana: Water Resources Center, University of Illinois, November, 1974.

17. Federal Power Commission. The 1970 National Power Survey, Part 1. Washington, D.C.: U.S. Government Printing Office, December, 1971.

18. Dynatech Research and Development Company. A Survey of Alternate Methods for Cooling Condenser Discharge Water; Large Scale Heat Rejection Equipment. EPA Water Pollution Control Research Series 16130 DHS. 1969.

19. Personal communication from Loyd K. Fischer, Professor, Department of Agricultural Economics, The University of Nebraska-Lincoln, Lincoln, Nebraska, April 8, 1977.

20. U.S. Bureau of the Census. Census of Agriculture, 1969. Washington, D.C.: U.S. Government Printing Office, 1972.

21. Illinois Conservation Needs Inventory Committee, Illinois Soil and Water Conservation Needs. Urbana: University of Illinois, 1970.

22. Illinois Department of Business and Economic Development. Technical Appendix to the Report on Priority and Planning Elements for Developing Illinois Water Resources. Springfield, Illinois, 1970.

23. Personal communication from Marlowe D. Thorne, Professor, Department of Agronomy, University of Illinois at Urbana-Champaign, Urbana, Illinois, March 1977.

24. William Prater, "Drought, Land Prices Yield Corn Belt Irrigation Interest." The Champaign-Urbana News-Gazette, March 21, 1977.

25. Kemp, Kenneth. Predictions of Agricultural Irrigation for Indiana. Indianapolis: State of Indiana Department of Natural Resources, 1970.

26. Ruttan, Vernon W. The Economic Demand for Irrigated Acreage: New Methodology and Some Preliminary Projections, 1954-1980. Baltimore: The Johns Hopkins Press, 1965.

5. METHODOLOGY FOR EXAMINING SURFACE-WATER USE ALONG MAJOR TRIBUTARIES

5.1 INTRODUCTION

This chapter describes the methodology used to examine the total surface water use throughout 16 major drainage areas within the ORBES region. The cumulative water use of each river was estimated moving from the uppermost power plant site to the downstream reaches. Specifically, the cumulative "consumptive" use (that water not returned to the water source) was calculated taking into account the municipal, industrial, and power requirements. Irrigation was not included in this analysis because of the wide variations in projections.

It is shown that the cumulative water consumption estimates are extremely high when compared to the 7-day 10-year low flows in many of the rivers. The implication is that large water storage projects would be needed or that different development patterns would be required.

5.2 METHOD OF ANALYSIS

The rivers were divided into reaches by the power plant sites since significant increases in water use occur there. Only plants specified by the ORBES scenario under study were taken into account, in defining reaches. The exact location of a dividing point is defined to lie at the downstream boundary of the county containing the corresponding plant.

Water requirements were assumed to be met continuously from the major river sources. Water storage was not considered, but the need for it was identified.

5.2.1. MUNICIPAL AND INDUSTRIAL WATER USES

The municipal and industrial water requirements are the same for the four different ORBES scenarios. The county projections made as part of this project, and referenced in Chapter 4, were to estimate incremantal withdrawal levels. These needs were assumed to be supplied from surface water and groundwater--based on the proportions established by the historical trend.

Consumptive use levels were estimated (as discussed in chapter 4) at 20% of the withdrawals by municipalities and at 6% of the withdrawals by industries.

5.2.2. POWER WATER USES

Different types of power plants were assumed to use water consumptively at the rates indicated in Chapter 4. The planned additions and removals of power plants by 1985 and the plants specified under each ORBES scenario were considered.

Note that cooling towers were assumed for all energy facilities in this analysis. It is shown, however, that water storage would be required in many areas if the if the specified requirements were to be met.

Another assumption, a conservative one, is that the first two power plants in the most upstream reaches of each tributary were assumed to operate at their full rated capacities. After a third plant was added, however, a 55% load factor was applied in calculating the cumulative water consumption (except that the cumulative estimates were not allowed to drop below the level specified by the first two plants).

5.2.3. WATER CONSUMPTION RELATIVE TO THE 7-DAY 10-YEAR LOW FLOWS

For each river basin the total water consumption was first calculated for the most upstream reach. The water requirements for all counties which drain to this reach were included in this calculation. The resulting consumptive loss was then expressed as a ratio of the 7-day 10-year low flow in that reach. Such ratios are termed consumption ratios in this report.

The second reach and the other downstream reaches were then analyzed in turn using the cumulative consumptive water loss. The consumption ratio values provide a profile of the water loss along each river.

In carrying out the analyses of the Ohio River and the Mississippi River, the consumption ratios were calculated taking into account the consumptive losses from their tributaries in the ORBES region. Also, for these rivers, water utilization for municipal and industrial purposes was included for the nearby areas in Pennsylvania, West Virginia, Missouri, and Iowa that are contained in the main-stem drainage basins. These areas are described in References (1) and (3), which also provide the necessary water use projections.

5.3. IMPACT OF WATER LOSSES FROM MAJOR TRIBUTARIES

The ratios of consumptive water losses to 7-day 10-year low flows of the major rivers are described in Tables III-G-10, III-G-11, III-G-12, and III-G-13 for the BOM 80/20, BOM 50/50, FTF 100/0, and FTF 0/100 scenarios, respectively. These tables are contained in Chapter 2 where a discussion of impacts and issues is also provided. Figures III-G-1 and III-G-2, also given in Chapter 2, illustrate the profile of the consumption ratios for the Ohio River under the different ORBES scenarios.

REFERENCES

1. The Corps of Engineers, U.S. Army Engineer Division, Ohio River, in cooperation with the The Department of Agriculture, Department of Commerce, Department of H.E.W., Department of The Interior, F.P.C., and participating states. Ohio River Basin Comprehensive Survey, App. D,K. Cincinnati, Ohio, 1967.

2. U.S. Army Corps of Engineers, Louisville District, in cooperation with Member Agencies of the Wabash River Coordinating Committee. Wabash River Basin Comprehensive Study, Main Report, App. C,F. 1971.

3. U.S. Department of The Interior, Federal Water Quality Administration, Great Lake Region, Chicago and Minneapolis Offices. Upper Mississippi River Comprehensive Basin Study, App. H. 1970.

4. Personal communication from James F. Blakey, District Chief, Water Resources Division, U.S. Geological Survey, Columbus, Ohio, February 2, 1977.

5. Project memorandum submitted to P. Haag, ORBES Project Office, (for distribution to project members) from E. D. Brill, February 18, 1977. Attachment submitted May 15, 1977, Lists major assumptions. A copy is on file at the Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801.

6. Project memorandum received from ORBES Project Office, Task 1 Report, "Development of Plausible Future Regional Technology Configurations." October 18, 1976.