Integrated Water Management for River Transportation

JAMES R. HALL

A comprehensive water management plan that responds to adverse navigation conditions on the Mississippi River does not exist. An integrated approach to water management for navigation during low river flow conditions is suggested. An integrated approach would examine the combined capabilities of all basin sources to respond to low flow conditions on the Mississippi. Primary water sources that could augment flow of the Mississippi, and therefore the ones examined in this paper, include the Lake Michigan (Chicago) diversion, the Missouri River main stem reservoirs, and the Minnesota headwaters lakes. This paper is conceptual and therefore does not address all benefits or problems associated with the development of an integrated plan.

A comprehensive water management plan that responds to adverse navigation conditions on the Mississippi River does not exist. The need for such a plan was dramatically illustrated by the low Mississippi River flows resulting from the 1988 drought. These conditions actually halted river transportation for extended periods and greatly increased the cost of transportation. In addition, the low flow conditions caused untold damage to the ecological river community and left upstream cities facing the many problems associated with salt water intrusion.

An integrated approach to water management for navigation during low flow conditions is suggested in this paper. Such an approach would examine the combined capabilities of all basin sources to respond to low flow conditions on the Mississippi. Primary water sources that could augment flow of the Mississippi, which are therefore the ones examined in this paper, include (Figure 1)

1. The Lake Michigan (Chicago) diversion,
2. The Missouri River main stem reservoirs, and
3. The Minnesota headwaters lakes.

These sources will be discussed in more detail in later sections of this paper. This work is conceptual and therefore does not address all benefits or problems associated with the development of an integrated plan.

THE PROBLEM

Severe drought conditions during the spring and summer of 1988 resulted in record low stages on the nation's river transportation system. The U.S. Coast Guard imposed operating restrictions on the allowable draft, length, and width of tows. Operators often had to break up their tows and move smaller sections individually, a process known as "double tripping" or "triple tripping." Around-the-clock dredging was required to keep channels open. Shippers were turning to railroads and the Great Lakes/St. Lawrence Seaway for grain exports.

In July 14, 1988 testimony before the Senate Subcommittee on Merchant Marine, Robert W. Page, Assistant Secretary of the Army for Civil Works, described the problem: "The flow on the Mississippi River is 28 percent of the normal season flow at St. Louis and Memphis." Page testified that the Corps had reported 27 closures on the Mississippi and its major tributaries since early June. Of the more significant closures, he said:

> For instance, the closure at Greenville, Mississippi, had at one point in time 130 tows waiting. If each tow were configured with 30 barges, which is the common size of tows using the Mississippi River, 234,000 semitrailer trucks would have been required to move an equivalent amount of cargo; enough trucks to stretch from New Orleans to Portland, Oregon. This backup would equate to 58,500 railroad cars, enough to stretch from New Orleans to Kansas City.

Also in a July 1988 statement before the Senate Subcommittee on Merchant Marine, John Zick of Continental Grain Company said:

> Barges cannot be loaded to optimum draft—9′0″ or greater—but rather to just 8′6″, which reduces the volume, or bushels in a barge, by 10 percent. Secondly, tow sizes handled by each tow boat have been reduced in size from 25–30 barges per tow to just 16, again reducing capacity by nearly 50 percent. Thirdly, and most importantly, the turnaround time from St. Louis to New Orleans and back to St. Louis has gone from 16 days to 30 days, which means less barges for the system to load up river.

Zick stated further, "We estimate the additional costs of operating in this environment to be 5 to 10 cents per bushel, which ultimately is paid by the farmer in reduced prices for his grain."

RECOMMENDED ACTION

A comprehensive water management plan is needed to respond to low flow navigation conditions on the Mississippi River. The Corps of Engineers should press ahead with its proposed "drought contingency" study for the Mississippi River Basin. The Corps has proposed this study under authority of Section 216 of the Flood Control Act of 1970. The study should investigate how best to manage the basin's water resources for navigation and other purposes during periods of drought. The

Bureau of Policy and Information, Iowa Department of Transportation, Ames, Iowa 50010.

FIGURE 1 Mississippi River system.

proposal has been included in the Department of the Army budget request for Fiscal Year 1990. This study should accomplish the following:

- Provide an inventory and assessment of the Mississippi River Basin resources, problems, needs, and opportunities as they relate to inland commercial navigation.
- Review capacity constraints and inefficiencies in the system during low flows.
- Evaluate and develop structural and nonstructural alternatives to minimize low flow problems.
- Investigate reallocation of existing reservoir storage as well as development of potential new storage.
- Review environmental considerations and develop a systemwide environmental impact assessment.
- Review and evaluate legal and institutional constraints.

In the interim, while a long-range comprehensive plan is being developed, the Corps should use existing authority to augment low Mississippi River flows to the extent possible. The Corps has authority to make temporary changes in project operations under the broad authority granted the Secretary of the Army under 33 USC 1, which provides:

> It shall be the duty of the Secretary of the Army to prescribe such regulations for the use, administration, and navigation of the navigable waters of the United States as in his judgment the public necessity may require for the protection of life and property, or of operations of the United States in channel improvement, covering all matters not specifically delegated by law to some other executive department. Such regulations shall be posted, in conspicuous and appropriate places, for the information of the public; and every person and every corporation which shall violate such regulations shall be deemed guilty of a misdemeanor and, on conviction thereof in any district court of the United States within whose territorial jurisdiction such offense may have been committed, shall be punished by a fine not exceeding $500, or by imprisonment (in the cast of a natural person) not exceeding six months, in the discretion of the court.
>
> Any regulations prescribed by the Secretary of the Army in pursuance of this section may be enforced as provided in Section 413 of this title, the provisions whereof are made applicable to the said regulations.

POTENTIAL FOR LOW FLOW AUGMENTATION TO MISSISSIPPI RIVER

Increased diversions of 7,000 cubic feet per second (cfs) from Lake Michigan to the Mississippi River would provide an additional foot of water at St. Louis. Increased releases of 7,000 cfs over present navigation target flows from the Missouri River reservoir system would also provide an additional foot of water at St. Louis. The combined releases from these two sources, providing 2 ft of additional water at St. Louis, would go a long way toward solving problems experienced by commercial navigation during low flow conditions. However, the Minnesota headwaters lakes do not appear to be a viable source of water to the middle or lower Mississippi because of the small quantities of water available and extended water travel times.

There are many issues involved with the diversion or reallocation of water from any source. Most of these issues involve competing water uses for commercial navigation, hydroelectric power production, recreation, irrigation, municipal and industrial water supply, or for fish and wildlife needs. Any efforts to increase diversion of Lake Michigan water will require discussions with all the Great Lakes states and the Canadian federal and provincial governments. Also, inclusion of Mississippi River navigation needs in the Missouri River Reservoir Operating Plan must be accomplished with complete consideration of other water users.

The three possible sources of water to augment river flow during periods of low water are discussed in the following sections.

PROPOSED LAKE MICHIGAN (CHICAGO) DIVERSION

In a June 23, 1988, letter to the U. S. Army Corps of Engineers, Illinois Governor James R. Thompson recommended that the Corps authorize a temporary increase in diversion of water from Lake Michigan to aid shipping on the Mississippi River. The water would flow through the Illinois Waterway for 300 mi and then join the Mississippi just above St. Louis. This temporary diversion would have been in addition to the present diversion allowed by Illinois pursuant to a 1967 U.S. Supreme Court decision, which limits Illinois diversion to 3,200 cfs, although the hydraulic limit of the diversion structures approaches 10,000 cfs. It takes 14 days for Lake Michigan water to reach St. Louis.

The Governor's recommendation was denied because of the following determination by the Corps (personal communication, R. W. Page to Gov. J. R. Thompson, July 14, 1988):

> At this time, and in the foreseeable future, we believe that any additional water in the lower Mississippi resulting from

> the increased diversion of Lake Michigan water would not make a significant difference either in the navigability of the channel or in the need for continued dredging of the river crossings as shoaling occurs. . . . Based on discussions with the Department of Justice, we believe there is authority to support the proposed increase in the diversion from Lake Michigan were it determined that such an increase were appropriate. Prior to proceeding with any diversion, however, the Department of the Army would consult with the affected States and, in coordination with the Department of State, engage in appropriate discussions with the Government of Canada.

Table 1 shows the effects, as estimated by the Corps of Engineers, of an increased diversion of 7,000 cfs from Lake Michigan to the Mississippi River. Although Corps hydrologists concur that additional water would increase river stage, they emphasize the river's complexity and suggest that adding another foot of water does not necessarily equal 1 ft more in depth. According to the Corps, the river bottom can shift depending on the river's reaction to the rise (*1*).

The towing industry does not agree with the Corps of Engineers assessment that more water would not help. In July 14, 1988, testimony before the Senate Subcommittee on Merchant Marine, Joseph Farrell of the American Waterways Operators said:

> Some claim that such river level increases are insignificant. Pose the choice to a river pilot and you will discover that just one-half foot will significantly improve the ability to navigate and lessen the need for and extent of emergency dredging. These added inches increase the flow of the river—the scouring action so important to cleansing the siltation that otherwise builds up and results in channel blockages.

Lake Michigan (Chicago) Diversion

Water diversion from Lake Michigan to the Mississippi River Basin dates back to 1848 with completion of the Illinois and Michigan Canal. The canal, built primarily to serve transportation, provided a connecting watercourse between Lake Michigan and the Mississippi River System. Water diversion averaged about 500 cfs (*2*).

In the mid- to late 1800s, development of Chicago's drainage and sewer systems led to contamination of Lake Michigan waters. The newly constructed sewers moved water and wastes into the Chicago River, which in turn drained into Lake Michigan. In 1854 and 1885 large amounts of untreated sewage were carried into the lake by major storms. This contaminated water entered Chicago's water intakes and caused outbreaks of typhoid and cholera. It is reported that 90,000 people died in the 1885 epidemic (*3*).

TABLE 1 ESTIMATED EFFECTS OF INCREASING DIVERSION TO 7,000 CFS FOR 120 DAYS

Location	Base Flow cfs (30 June)	Flow Time (Days	Increase In Stage
St. Louis	70,000	14	1.0 ft
Cairo	103,000	15	0.6 ft
Memphis	118,000	18	0.6 ft
Vicksburg	150,000	22	0.5 ft
Drawdown of Lake Michigan/Huron			-0.06 ft

The Metropolitan Sanitary District of Greater Chicago took major steps to remedy this situation:

- In 1900 construction of the Sanitary and Ship Canal was completed, reversing the flow direction of the Chicago River (Figure 2). This new, larger canal followed the course of the old Illinois and Michigan Canal. The Chicago River Controlling Works (CRCW) was constructed at the mouth of the Chicago River in the early 1940s. The CRCW Lock serves shipping and regulates the amount of Lake Michigan water that is allowed to pass into the river. The structure also restricts river flooding from entering Lake Michigan.
- A second sanitary canal, the North Shore Canal, was completed in 1910. It extended for 6.14 mi to connect Lake Michigan at Wilmette to the Chicago River. Water flow from Lake Michigan is regulated by the Wilmette Controlling Works.
- A third canal, the Calumet Sag Canal, was completed in 1922. It connects Lake Michigan, through the Grand Calumet River, to the Sanitary and Ship Canal. The canal was constructed primarily to carry sewage, but also served transportation needs. The O'Brien Lock and Dam, located on the Grand Calumet River, regulates the flow of Lake Michigan water down the canal.

Diversion was originally limited through all channels to a combined total of 4,167 cfs. Diversion reached a high of 10,000 cfs by the late 1920s, but was reduced to a low of 1,500 cfs by subsequent court decisions. Today's diversion of 3,200 cfs was established in 1967. An increased diversion to 8,500 cfs was authorized by the Supreme Court for a 2½-month period in 1956–1957 to aid low flow conditions on the Illinois Waterway and Mississippi River due to a prolonged drought (*3*).

Present-Day Diversion at Chicago

Lake Michigan diversion at Chicago can be discussed in the following use categories: domestic water supply, direct diversion, and stormwater runoff.

Domestic water supply accounts for 52 percent of the present-day allowable 3,200-cfs diversion. Chicago alone withdraws about 1,500 cfs from Lake Michigan at its two water treatment plants. Thirteen other plants located along the Illinois shoreline also withdraw water.

Direct diversion to the Sanitary and Ship Canal from Lake Michigan provides for safe navigation and improves water quality in the canal system. Navigation diversions require about 215 cfs, and water quality diversions are set by law at 320 cfs. Structures control direct diversions at three locations:

- At the mouth of the North Shore Channel at Wilmette,
- At the mouth of the Chicago River, and
- At the mouth of the Calumet River.

Stormwater runoff of about 700 cfs, diverted by the reversal of the Chicago and Calumet rivers, is also included in the allowable 3,200 cfs.

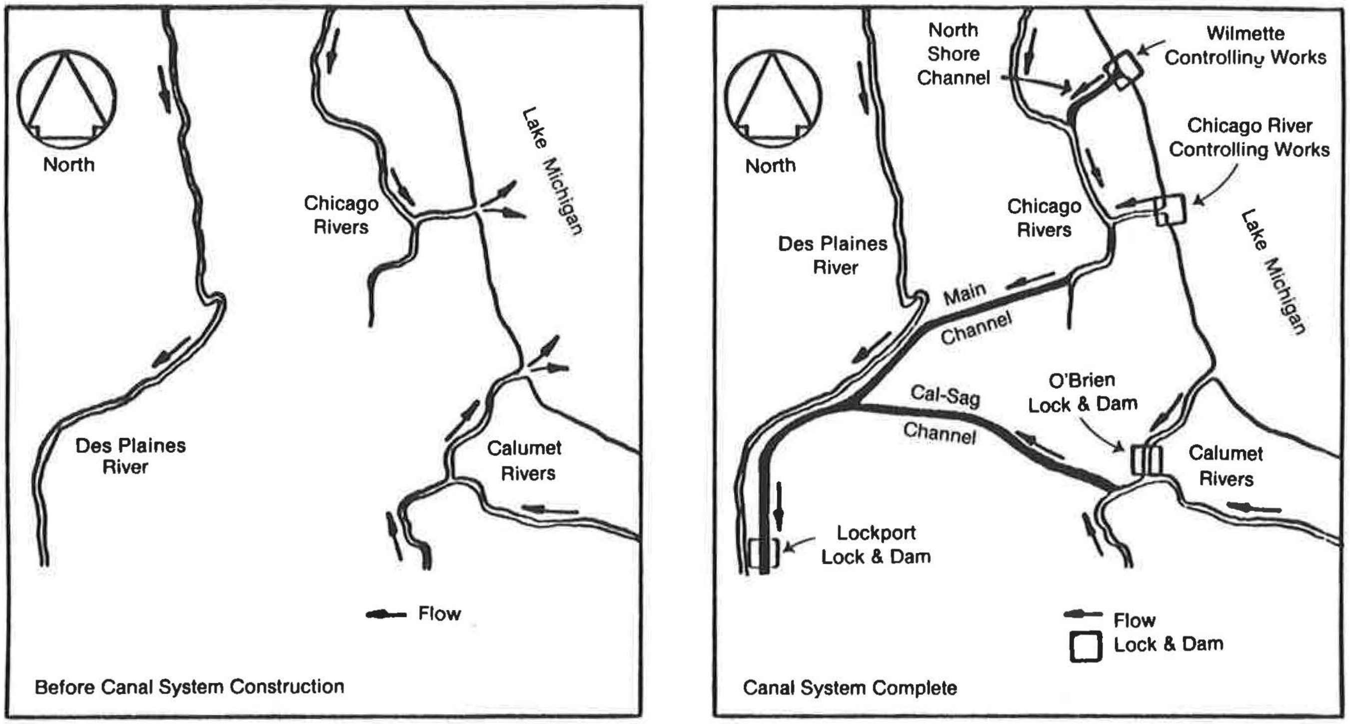

FIGURE 2 Lake Michigan (Chicago) Diversion. (Source: Division of Water Resources, Illinois Department of Transportation.)

Past Legal Decisions

Since its conception, diversion of Lake Michigan water has generated controversy between the Great Lakes states and lower Mississippi River states. The Supreme Court resolved issues on several occasions as follows (*2*):

- A 1925 decree allowed the Secretary of War to issue diversion permits. A permit to divert 8,500 cfs was issued in March 1925.
- A 1930 decree reduced the allowable diversion (in addition to domestic pumpage) to the following amounts:
  —6,500 cfs by July 1, 1930
  —5,000 cfs by December 30, 1935
  —1,500 cfs by December 31, 1938
- A 1956 decree authorized an increased diversion to 8,500 cfs for a 2½-month period to aid low flow conditions on the Illinois Waterway and Mississippi River due to a prolonged drought.
- A 1967 decree limited diversion to 3,200 cfs, including domestic pumpage, effective March 1, 1970. A five-year running average determined compliance with the 3,200-cfs limitation.
- A 1980 decree amended the 1967 decree to extend the averaging period from 5 to 40 years.

INCREASED MISSOURI RIVER FLOWS

Although the Missouri River provides up to 50 percent of the water supply for the Mississippi River at St. Louis, it is not managed to facilitate Mississippi River navigation. The potential for including Mississippi River navigation needs in the Missouri River operating plan was brought out by the extended drought of 1988. The Mississippi was experiencing low water problems from St. Louis south. At the same time, there were huge water reserves in the Missouri River reservoir system (Figure 3). To place the issue in perspective, reservoirs are generally maintained at about 63 million acre-feet (maf) of water. The river flow rate at Sioux City to maintain Missouri River navigation is 31,000 cfs, or about 21 maf per year. At this rate it would take nearly 3 years to empty the reservoir system, assuming no additional inflow. The Missouri River reservoirs can be managed to provide an additional foot of water on the Mississippi River at St. Louis in time of drought. However, historically the Corps has managed this water very conservatively, and for in-basin user needs only. In September 1981 the Missouri River Division Corps of Engineers completed a study on the Missouri River contributions to flow on the Mississippi (*4*). One conclusion presented by the study states:

> Travel time of releases from the main stem dams, in excess of 11 days, is too long to permit regulation for specific Mississippi low flow events. Therefore, the most viable regulation plan would be to revise the main stem operation criteria by reducing releases from April through July to provide increased discharge during the period of normally low Mississippi River flows, August through February.

Other conclusions deal with the effects on Missouri River users of altering the regulation plan. All conclusions need to be reevaluated in view of the Corps' increased amount of experience in reservoir management and because of the new economic perspective brought about by extended low flow on the Mississippi. For example, the argument that the 11-day travel time is too long is no longer valid.

A primary benefit to this suggested management proposal would be the additional establishment of need for Missouri

FIGURE 3 Missouri River Basin: 1987 (*8*).

River water for navigation. Several arid western states are interested in Missouri River water for irrigation purposes. The High Plains states irrigate 14.3 million acres from the underlying Ogallala aquifer through use of 170,000 irrigation wells. Although the aquifer receives some recharge each year, the quantity of water being withdrawn far exceeds the quantity being replaced. Over 5 million acres currently irrigated will be returned to dryland production or native vegetation by the year 2020 because of declining water supplies (*5*). The High Plains Ogallala Aquifer Regional Study, authorized by Congress in P.L. 94-587, looks at alternatives to increase water supply to the High Plains area. Figure 4 (*6*) shows interstate water transfer route alternatives, assessed by the Corps, to divert water to the High Plains area. Routes A and B consider diverting up to 3.4 maf of Missouri River water annually to this region (*5*). This would represent about 16 percent of the total Missouri River flow.

Missouri River Basin Development

The Missouri River flows for 2,300 mi from northwestern Montana to its confluence with the Mississippi River near St. Louis, Missouri. The Missouri River drainage basin covers parts of 10 states, comprising one-sixth of the nation's land area. Average annual precipitation ranges from 8 in. in areas of the northwestern plains to 42 in. in the lower basin. The

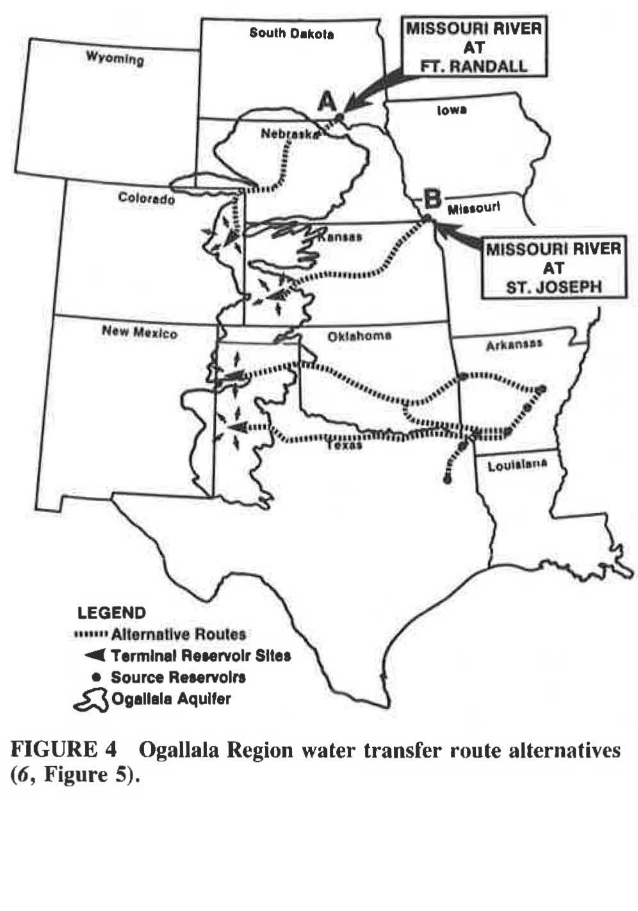

FIGURE 4 Ogallala Region water transfer route alternatives (*6*, Figure 5).

central two-thirds of the region receives about 20 in. of rainfall annually. The basin's drainage is via a system of streams and rivers that contributes to the flow of the Missouri River.

The comprehensive plan for Missouri River basin development was authorized by the Flood Control Act of 1944, commonly known as the Pick-Sloan Plan. The principal features are the six Missouri River main stem reservoirs, located in Nebraska, North and South Dakota, and Montana (Figure 3). These reservoirs have a total water surface area of 1.2 million acres and 5,940 mi of shoreline (7).

Reservoir Management

The reservoirs are managed for the Missouri River basin requirements of flood control, commercial navigation, hydroelectric power generation, irrigation, municipal and industrial water supply, water quality control, conservation of fish and wildlife, and public recreation.

The Missouri River reservoirs are operated according to a repetitive annual cycle. Most of the year's water supply is produced by winter snows and spring and summer rains, which result in increased storage. Runoff averages about 25 maf annually, although it can vary from a low of about 10 maf to a high of 40 maf. After reaching a peak between July and early August, storage declines until late in the winter when the cycle starts again. A similar pattern is found in releases from the system. From mid-March to late November, high levels of flow are required for navigation and to evacuate accumulated flood storage. This is followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats (*8*). The unpredictability of the weather sometimes creates problems for reservoir managers. For example, at a time when the reservoirs are at a record low of about 47 maf, the 1988 inflow to the system was only 12.7 maf. The Corps projects 1989 inflows of 21.4 maf.

The six main stem reservoirs contain a total storage capacity of 74 maf of water. Figure 5 shows the storage capacity in each reservoir. Note that 88 percent of the total capacity is contained in the three uppermost reservoirs (Garrison is the third largest reservoir in the United States). Gavins Point, the lowermost reservoir, contains only 0.5 maf.

If the six reservoirs were added together into one project, it would look like the diagram in Figure 6. The total 74 maf of storage is allocated into four separate storage zones as follows:

1. The lowermost (25 percent) is inactive—this zone provides an adequate head to generate hydroelectric power and to support a minimum fishery.
2. The multipurpose carryover (53 percent) is usable storage designed to support navigation, hydropower, and other functions during extended periods of drought. As of October 1988, 47.1 maf remained in the reservoir system. Water supply is projected to be at 46.1 maf by March 1, 1989. At this level of depletion, the three largest (uppermost) reservoirs are drawn down about 21 ft. However, they were designed for 70 ft of fluctuation.
3. The annual flood control and multiple use zone (16 percent) is intended for use annually. Water is stored in this zone during the flood runoff period, March through July, and evacuated during the balance of the year. According to present operating practices, this is the desired operating range.
4. The exclusive flood control zone, the top 6 percent, is reserved for remote floods only.

Specific Users

Figure 7 shows the time sequence of reservoir management events. Annual inflow and release requirements are projected, and regulation plans may vary to meet the multipurpose needs of the system. Reservoir managers often find themselves in the position of providing a balance between the needs of upstream and downstream users.

Flood Control

Flood control is the only authorized project function requiring evacuation of reservoir storage space; all other functions require storage of water. The high-risk flood season begins about March 1 and extends through the summer. The major portion of flood control space in the system must be evacuated before

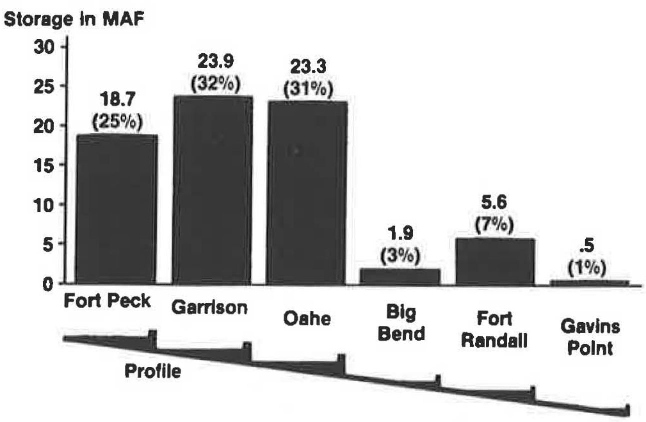

FIGURE 5 Missouri River main stem reservoirs: storage by reservoir. (Source: Missouri River Division, Corps of Engineers.)

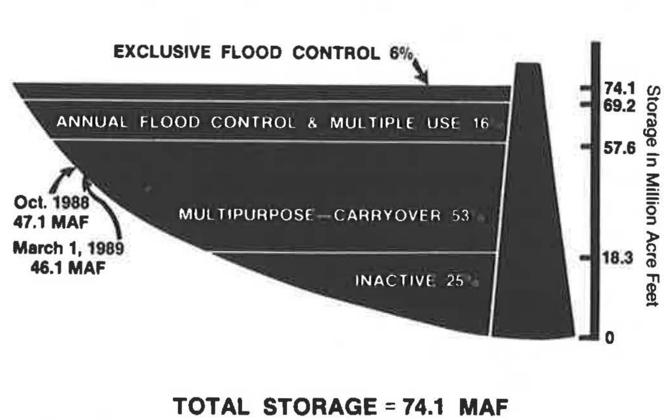

FIGURE 6 Missouri River main stem reservoirs: storage allocations. (Source: Missouri River Division, Corps of Engineers.)

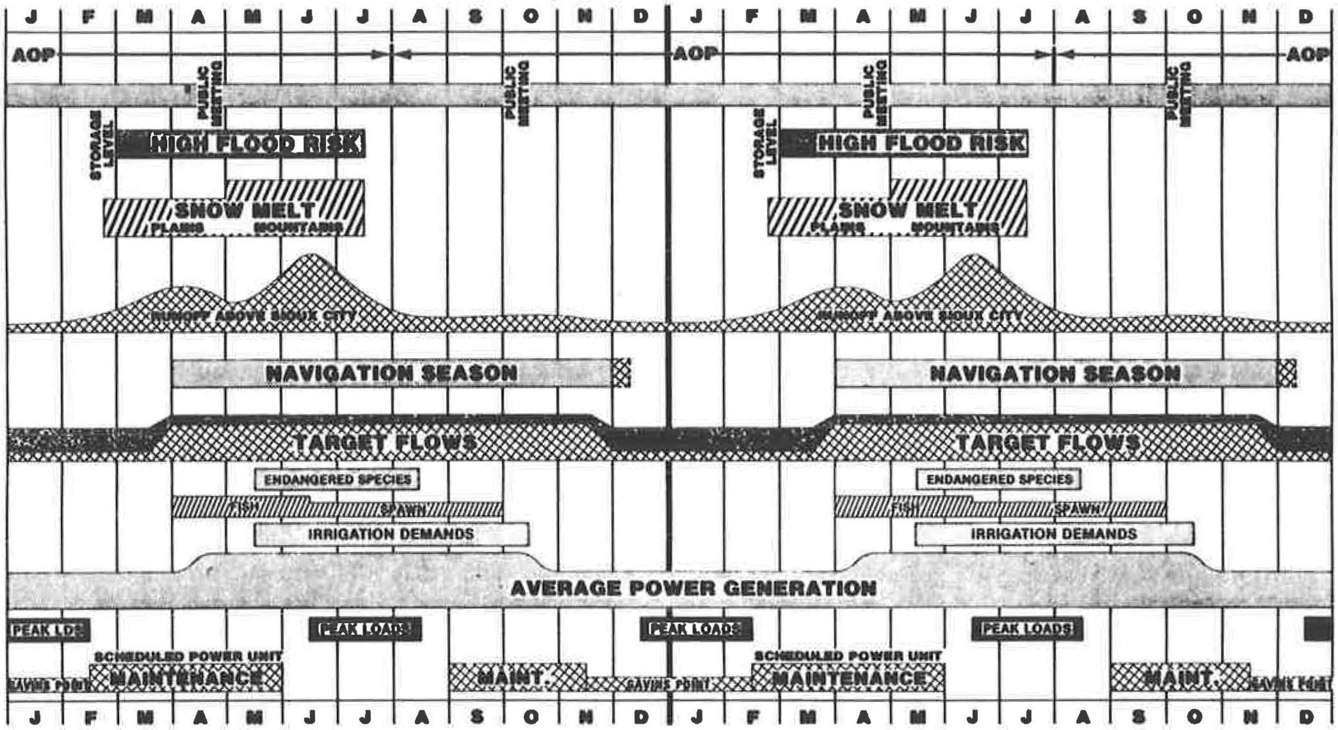

FIGURE 7 Water control calendar of events (*8*).

the winter season, when ice covers the Missouri. Maximum releases of 20,000 to 25,000 cfs can be maintained under ice conditions.

Severe Missouri River flooding occurred in 1844, 1881, 1903, 1908, 1909, 1915, 1927, 1932, 1942, 1943, 1951, and 1952. This type of flooding has been eliminated with development of the Missouri River Reservoir System, resulting in flood damage prevention of $2.7 billion (*7*).

Commercial Navigation

The Missouri is navigable for 732 mi from Sioux City, Iowa, to St. Louis, Missouri. Missouri River traffic has grown from about 300,000 tons in 1954 to a record high of 3.3 million tons in 1977. Since then, tonnage has steadily decreased to the level of 2.3 million tons in 1986.

Reservoir releases are scheduled to maintain Missouri River navigation target flows of 31,000 cfs at Sioux City, Iowa; 37,000 cfs at Nebraska City, Nebraska; and 41,000 cfs at Kansas City, Missouri. These flows generally provide a navigation channel 9 ft deep and 300 ft wide. The normal 8-month navigation season extends from April 1 through December 1. On the basis of perceived available water supply, the Corps often extends the navigation season by about 10 days. However, in times of severe drought, the target flows listed above are shortened by up to 6,000 cfs (*9*). The 1988 navigation season was shortened by 2 weeks and the 1989 season will be shortened by 5 weeks. Also, releases from Gavins Point Dam were cut to only 12,500 cfs during the winter of 1988–1989 to conserve water.

Hydroelectric Power Generation

Hydroelectric power is generated at all the main stem dams. Almost all of the water released from the reservoirs is used to generate hydroelectric power. Nearly 10 billion kilowatt hours of electricity are generated annually. This power serves 900,000 customers at a retail value of $485 million. The power is marketed by the Western Area Power Administration in the states of Colorado, Iowa, Minnesota, Montana, Nebraska, North and South Dakota, and Wyoming. Releases from the reservoirs are varied to allow generation of the greatest amount of energy at the times of greatest demand. Power generation is highest in the summer months and lowest in the winter.

Irrigation

Irrigation was a key purpose of the Pick-Sloan Plan. The original plan called for irrigation development of nearly 5 million acres of land (Table 2). However, irrigation development has been plagued with both economic and environmental difficulties, and only 8 percent of the planned development has occurred (*10*).

Today approximately 400 permits exist for irrigation withdrawals in the reservoir area, but these are relatively small. Irrigation, as developed today, does not significantly affect reservoir operation.

Section 1 of the Flood Control Act of 1944 (O'Mahoney-Millikan Amendment) gives priority to the use of water for irrigation and water supply over navigation. This amendment is strongly defended by upstream states still looking for the

TABLE 2 IRRIGATION DEVELOPMENT UNDER PICK-SLOAN MISSOURI RIVER BASIN PROGRAM

State	Acres Planned For Development	Acres Federally Developed	Percent
Montana	967,130	47,782	5
Wyoming	281,560	71,773	25
North D.	1,266,440	9,019	1
South D.	961,210	15,282	2
Colorado	101,280	0	0
Nebraska	989,445	177,230	18
Kansas	193,335	72,598	38
Total	4,760,400	393,684	8

development of irrigation. The amendment is viewed as counterproductive by downstream states that consider the development of new irrigation wasteful in this era of agriculture overproduction.

Water Supply and Quality

Numerous intakes are located along the Missouri to satisfy the needs of municipalities, irrigation, and thermal electric power plant cooling. Water supply needs do not significantly affect reservoir management. A minimum release rate of 6,000 cfs is required to facilitate water supply and water quality needs.

Fish and Wildlife and Public Recreation

Construction of the main stem reservoirs has contributed significantly to sport fishing in the Missouri River basin. Fish and wildlife needs are an important part of reservoir management. Reservoir levels and releases directly affect fish production, particularly during spawning periods. Water supply is not always adequate to allow the annual operation of each reservoir for optimum fish management. Therefore, to the extent possible considering other water needs, emphasis is given to the fishery management needs at one or two reservoirs each year. For example, water levels may be raised to where shoreline vegetation or rock spawning habitat is present during the spring spawning season.

Migrating waterfowl use the reservoirs in the fall months until the water freezes. Recreational use of the Missouri River increases each year. Nearly 12 million visitor days of use were recorded in 1986 (*7*).

In 1985 new challenges were introduced to operation of the Missouri River reservoirs with listing of the least tern and the piping plover as endangered and threatened species, respectively. These small birds nest on barren sandbars near the water's edge downstream from Garrison, Fort Randall, and Gavins Point dams. The nesting period is from May 15 through August 15. These nesting sites are prone to periodic inundation due to required reservoir management for flood control, hydroelectric power generation, and navigation.

The Endangered Species Act of 1973 requires federal agencies to ensure that their actions do not jeopardize the continued existence of threatened or endangered species or result in the destruction or adverse modification of their habitats (*7*). The Missouri River Division Corps of Engineers has outlined two basic options in managing the main stem reservoirs for the least tern and the piping plover:

- Stabilize river stages during the May–August nesting period.
- Provide nesting habitat at higher elevations (surveys are currently being conducted aimed at providing additional habitat).

During the 1988 period of low water flow in the Mississippi River, the Missouri River Division Corps of Engineers announced that the current release of 32,000 cfs from Gavins Point Dam was the maximum flow that could be sustained without significantly affecting the least tern and the piping plover (*11*). The maximum release rate from Gavins Point Dam is 45,000 cfs.

INCREASED FLOWS FROM THE MINNESOTA HEADWATERS LAKES

The Minnesota headwaters contain a relatively small amount of water (1.6 maf) when compared with the huge reserves of the Great Lakes and Missouri River main stem reservoirs. This lack of water supply, combined with excessive water travel times (2 months) from the headwaters to St. Louis, makes any plan for their use to supplement middle or lower Mississippi River flows infeasible. However, these reservoirs are important to provide regulated flow adequate for the operation of three navigation locks at St. Paul. Minimum releases of 350 cfs are required for uninterrupted service of the locks.

Minnesota Headwaters Development

The Minnesota headwaters were developed under the 1880 and 1882 River and Harbor acts. This development consists of a system of six reservoirs constructed by the Corps of Engineers between 1881 and 1913 (Figure 8). The reservoirs were originally authorized primarily to provide adequate flows for Mississippi River navigation from St. Paul to Lake Pepin (Pool 4). Later construction of the 9-ft channel and the lock-and-dam system on the Upper Mississippi significantly reduced the need for regulation of the reservoirs for navigation under normal conditions (*12*).

Today, with reduced need of releases for navigation, the reservoirs are operated for flood control, recreation and tourism, and fish and wildlife. Private property owners and resort interests have requested that the reservoirs be kept at uniform levels during the resort season. The reservoirs are also operated to support the production of wild rice, which is an economically and culturally significant resource for the Chippewa people. The regulated outflow from the reservoirs contributes to improved water supply, waste assimilation, stream habitat quality, downstream power generation, and industrial water supply.

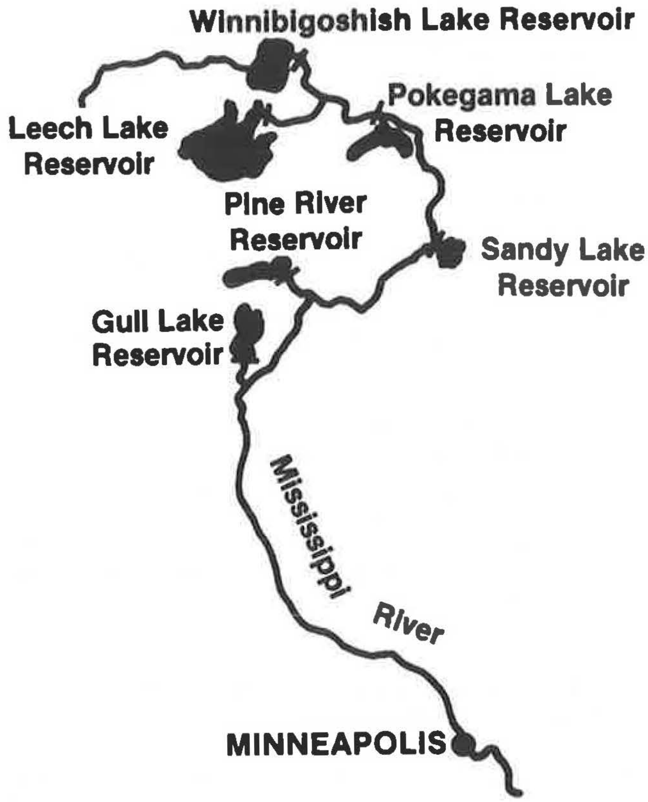

FIGURE 8 Minnesota headwaters lakes.

Regulation Plan

Through the 1888 River and Harbor Act, Congress gave the Secretary of the Army authority to develop regulations for operation of the headwaters reservoirs. These regulations were published in February 1936 and amended in January 1945. The published regulations indicate that the St. Paul District Corps of Engineers should regulate the headwaters reservoirs between the elevations shown in Table 3 whenever possible. (The normal summer regulation range is also shown for comparison.)

In addition, minimum flow releases have been established for each reservoir as follows:

Reservoir	*Minimum Release (cfs)*
Winnibigoshish	100
Leech	100
Pokegama	0
Sandy	20
Pine	30
Gull	20

Each of the reservoirs has a point of "mandatory minimum release" that coincides with the lower range of the "normal summer elevation" shown in Table 3. When a reservoir recedes below this stage, the regulations indicate that no release greater than the specified minimum should be made until the reservoir stage exceeds this level. If reservoir elevations decline further to the "minimum elevations" shown in Table 3, the release rates are reduced to 50 percent of the values shown above.

The total available storage in acre-feet, based on normal summer storage and the constraint of mandatory minimum release, is 177,180 for Winnibigoshish; 43,140 for Pokegama; 251,000 for Leech; 16,000 for Sandy; 48,400 for Pine River; and 20,000 for Gull. This results in total storage of 555,720 acre-feet available for flow augmentation from the headwaters projects under the present regulations for operation.

The most recent report on the headwaters reservoirs is the September 1982 feasibility study (*13*), which recommended only minor changes in reservoir operation that could be implemented under existing authorities.

REFERENCES

1. *Special Report: The Drought of '88*. Office of the Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C., Aug. 1988.
2. *Lake Michigan Diversion Accounting*. Chicago District Corps of Engineers, U.S. Army Corps of Engineers, Jan. 1988.
3. D. R. Vonnahme. *Lake Michigan Water Allocation and Diversion*. Illinois Department of Transportation, Chicago, April 1988.
4. *Missouri River Contributions During Periods of Low Flow on the Mississippi River*. Missouri River Division, U.S. Army Corps of Engineers, Omaha, Nebr., Sept. 1981.
5. *Summary of Results of the Ogallala Aquifer Regional Study with Recommendations to the Secretary of Commerce and Congress.*

TABLE 3 HEADWATER RESERVOIR REGULATION LEVELS

	Minimum		Maximum		Normal Summer
Reservoir	Elev.	(Stage)	Elev.	(Stage)	Elevation Range
Winnibigoshish	1294.94	(6.0)	1303.14	(14.2)	1297.94 - 1298.44
Leech Lake	1292.70	(0.0)	1297.94	(5.24)	1294.50 - 1294.90
Pokegama	1270.42	(6.0)	1276.42	(12.0)	1273.17 - 1273.67
Sandy	1214.31	(7.0)	1218.31	(11.0)	1216.06 - 1216.56
Pine River	1225.32	(9.0)	1231.32	(15.0)	1229.07 - 1229.57
Gull	1192.75	(5.0)	1194.75	(7.0)	1193.75 - 1194.00

Source: St. Paul District Corps of Engineers

High Plains Study Council (Governors of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas), Economic Development Administration, U.S. Department of Commerce, Dec. 1982.
6. *Water Transfer Elements of High Plains-Ogallala Aquifer Study*. U.S. Army Corps of Engineers, Jan. 1982.
7. *The Pick-Sloan Missouri Basin Program and Individually Authorized Projects: Seminar Proceedings*. Missouri River Basin Commission/Western States Water Council, Oct. 1980.
8. *Missouri River Main Stem Reservoirs Annual Operating Plan and Summary of Actual 1986–1987 Operations*. Missouri River Division, U.S. Army Corps of Engineers, Omaha, Nebr., Jan. 1988.
9. *A Review of the Missouri River Main Stem System Operation: Symposium Proceedings*. Missouri Basin States Association, Council Bluffs, Iowa, Jan. 1988.
10. *The Pick-Sloan Missouri Basin Plan: Conference Proceedings*. Missouri Basin States Association, Des Moines, Iowa, Aug. 1983.
11. *Newsletter to Missouri River Navigation and Recreation Interests*. (Missouri River Division, U.S. Army Corps of Engineers, Omaha, Nebr.), June 24, 1988.
12. *Alternatives Analysis, 1988 Drought Operation of Headwaters Reservoirs*. St. Paul District, U.S. Army Corps of Engineers, St. Paul, Minn. Aug. 1988.
13. *Mississippi River Headwaters Lakes in Minnesota: Feasibility Study*. St. Paul District, U.S. Army Corps of Engineers, St. Paul, Minn. Sept. 1982.

Publication of this paper sponsored by Committee on Inland Water Transportation.