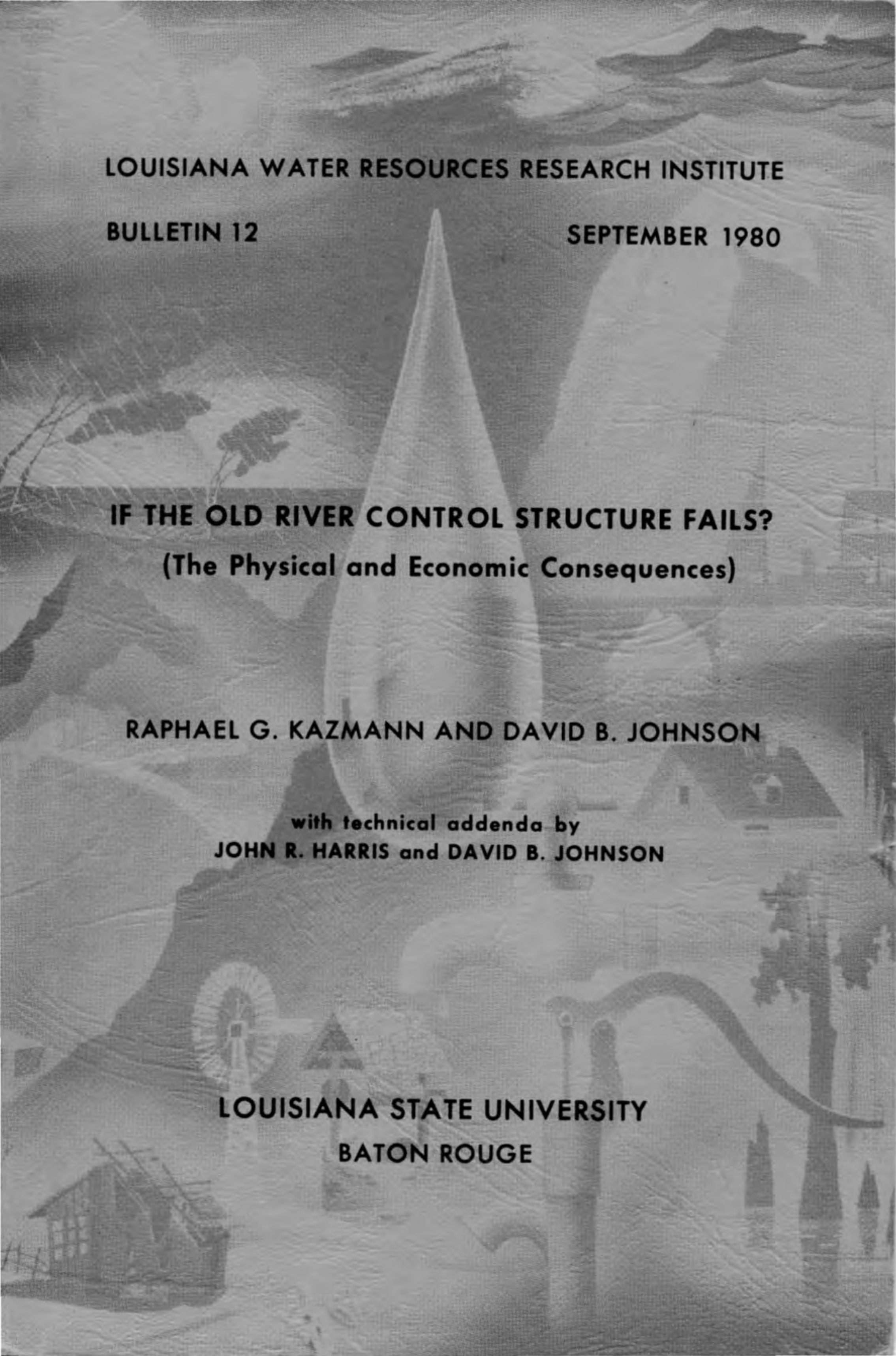

LOUISIANA WATER RESOURCES RESEARCH INSTITUTE

BULLETIN 12 SEPTEMBER 1980

IF THE OLD RIVER CONTROL STRUCTURE FAILS?

(The Physical and Economic Consequences)

RAPHAEL G. KAZMANN AND DAVID B. JOHNSON

with technical addenda by
JOHN R. HARRIS and DAVID B. JOHNSON

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RAPHAEL G. KAZMANN
PROFESSOR OF CIVIL ENGINEERING

DAVID B. JOHNSON
PROFESSOR OF ECONOMICS

with technical addenda by
JOHN R. HARRIS and DAVID B. JOHNSON

LOUISIANA STATE UNIVERSITY

BATON ROUGE, LOUISIANA 70803

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IF THE OLD RIVER CONTROL STRUCTURE FAILS?

DESCRIPTORS: Water Policy, *Louisiana, Future Planning, Control Structure, Lower Mississippi River, Atchafalaya Diversion, Alternate Water Supplies, Conjunctive Use, Priorities, Economic Impacts, Pipe Line Breaks, Floods, Salt-water Wedge

IDENTIFIERS: Old River Control Structure, Low Sill Structure, Artificial Recharge, River Morphology, New Orleans Water Supply, Low Sill Structure, Auxiliary Structure

A B S T R A C T : The flood of 1973 almost undermined the Old River Control Structure (located about 40 miles north of Baton Rouge, La.). The O.R.C.S. is the device that prevents the Atchafalaya River from becoming the principal distributary, the new outlet, of the Mississippi River. The Corps of Engineers is now (1980) making plans to build an auxiliary structure near the O.R.C.S. to reduce the flow through the existing, damaged, structure. The threat of a major diversion of the Mississippi River is real and immediate and the estimated cost of the auxiliary structure is approximately $200 million.

Were a major flood to destroy the ability of the O.R.C.S. to control the distribution of flow between the Lower Mississippi River and the Atchafalaya River, then major flooding would occur in the Atchafalaya Basin, highway and railroad bridges would be destroyed, gas pipelines severed, and industrial production along the Mississippi River between Baton Rouge and New Orleans would be reduced. The dry weather period following the flood would result in reduced discharges in the river between B.R. and N.O. This would permit salt water from the Gulf of Mexico to fill what is now the main stem of the river. The present channel would become a salt water estuary of the Gulf of Mexico. The economic impact of the disaster is generally evaluated and a plan to replace the potable water supply of the B.R.-N.O. complex is outlined along with some preliminary cost estimates.

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I

SUMMARY

The Old River Control Structure (ORCS), placed in operation in 1962, is the control valve of the Mississippi River. It controls the distribution of flow between the Mississippi and Atchafalaya Rivers (Figure 1). In 1973 the low-sill structure, which is part of the ORCS, was almost undermined and destroyed. Had this event occurred the entire flood control program of the lower Mississippi River would have been jeopardized. The Corps of Engineers, recognizing the vulnerability of the existing ORCS has started to work on an auxiliary structure which would reduce the flow of water through the existing structure and still enable the Corps to control the distribution of flow.

This study and the related addenda discuss the hydrologic and geomorphic forces at work on the ORCS and provide some estimates of costs that would result from a failure of the ORCS. A failure of the ORCS could have impacts on the rail and road transportation system in Louisiana, on the availability of fresh water for industries and municipalities, on the availability of electricity and natural gas and it could cause flood damage on private and public property. Table 1A presents a quantitative summary of the costs discussed. Table 1B is an abbreviated list of probable costs for which no estimates have been made in this study.

Probably the most important single conclusion reached by this study is that in the long run the Atchafalaya River will become the principal distributary of the Mississippi River and that the current main-stem will become an estuary of the Gulf of Mexico. Just when this will occur cannot be predicted: it could happen next year, during the next decade, or sometime in the next thirty or forty years. But the final outcome is simply a matter of time and it is only prudent to prepare for it.

The local and national consequences of the failure of the ORCS, which would result from the situation described in the preceding paragraph, would be realized immediately and in the long term. It is possible that land transportation across the Atchafalaya Basin would be interrupted for an indefinite period of time because of the undermining of the footings of bridges that cross the Atchafalaya River. There would be widespread flooding in the Basin since large stretches of the protection levees are below the required grade. Many of the gas and oil pipelines that cross the Basin will probably be broken or damaged. Most of the land animals in the Basin will probably drown. New land and new opportunities will be created in Upper and Lower Atchafalaya Bays by the deposition of sediment.

The economic consequences of the failure of the ORCS have been examined in some detail. The reader is referred to the technical addenda for a discussion of the methodologies, assumptions and qualifications attached to each estimate in Table 1. If the ORCS does not fail, or if it fails and none of the physical consequences occur, the loss will, of course, be zero. Our low estimates are based on the assumption that some damage will occur in all of the categories. The high/low estimates in the transportation section are based on differences in the number and location of the bridges which might fail as a result of scouring activities. The low estimate of $213 million assumes that I-10 and U.S. 190 would be closed to traffic for one year. The high estimate of $1.1 billion assumes that all four major roads across the Basin are closed for one year.

FIGURE 1. The Relationship Between the Mississippi and Atchafalaya Rivers. Note the location of the Old River Control Structure.

The high estimate of private property losses within the Basin is based on the total assessed value of private property within the Basin. In the event of an ORCS failure and subsequent periodic flooding, this property would not lose all value. The high estimate of $380 million is really a conservative estimate of total private property value in the Basin. The low estimate of $228 million is based on the assumption of a 60% loss in private property values.

The pipeline replacement costs are based on the costs of constructing the aerial pipeline for Florida Gas Transmission Company in 1973, adjusted to 1977 prices. Each pipeline across the Atchafalaya River costs about $2 million (1977 prices). A conservative low estimate is $4 million for two pipelines lost and a conservative high estimate is $14 million for replacing seven pipelines.

The high estimate of $1.5 billion in reduced incomes in the Louisiana and 27 other southern and eastern states is based on the assumption that all major pipelines crossing the Basin are disrupted for 180 days. The low estimate of $208 million assumes that the two pipelines in Category III are disrupted for 180 days. Not shown in Table 1 is the unemployment associated with the high estimate: 88 thousand; and the unemployment associated with the low estimate: 12 thousand.

The necessary replacement of municipal and industrial water supplies is discussed in detail in Addendum A. The maximum capital cost (1976 prices), which includes replacing the fresh water supply of Bayou Lafourche, is approximately $730 million. The minimum cost, where the fresh water of Bayou Lafourche is allowed to become brackish, is almost $600,00,000, all at 1976 prices. Of course the plan provides potable water for the communities that now (1980) use the Bayou as their source of water.

Also included in Table 1 is an abbreviated list of losses that might result from the failure of the ORCS or by a major flood in the Basin, losses that cannot presently be quantified in monetary terms.

TABLE 1

CONSEQUENCES OF ORCS FAILURE

A. Losses For Which Quantitative Estimates Have Been Made

	Millions of $ (1977 Prices) High	Millions of $ (1977 Prices) Low
Transportation		
Damages to Bridges, Approach & Roadways	$ 74	$ 44
Additional Operating Costs (one year)	573	75
Value of Time Loss (one year)	418	56
Additional Operating Costs of Railroads	38	38
Transportation Totals	$1,103	$ 213
Flood Damage		
Private Property Losses Within Basin	$ 380	$ 228
Private Property Losses Outside Basin	34	34
Public Sector Losses	271	271
Flood Damage Totals	$ 685	$ 533
Pipeline Failure		
Replacement of Pipelines	$ 14	$ 4
Reduction in State Incomes	$1,505	$ 208
Replacement of Municipal and Industrial Water*	$ 730	$ 600
TOTAL	$4,037	$1,558

*1976 prices

B. Losses for Which No Quantitative Estimates Were Made

1. Relocation costs of residents and movable property located in the Basin;
2. Capital costs of water conservation equipment, mostly cooling towers, in the Baton Rouge-New Orleans industrial corridor and subsequent increased operating cost.
3. Construction and maintenance of additional levees and flood control measures in the Basin and possible increases in dredging;
4. Disruption of oil and gas production and exploration in the Basin and damage to the facilities due to flood waters;
5. Possible brownouts or selective blackouts due to the salt water wedge immobilizing electric generating plants located along the Mississippi River south of the ORCS. Also, there would be additional costs in retrofitting these plants for saline water;
6. High mortality rates for deer, rabbits, squirrels and other animals domiciled in the Basin.
7. High mortality rates for shrimp and oysters in central Louisiana in the first and second year following the failure but possibly greater harvests in the long run.
8. Shoaling in the Mississippi immediately downstream from the O.R.C.S., which would hamper, or even eliminate barge navigation.

There are a number of steps that might be taken to ameliorate or delay the destruction of the ORCS and the resulting damage. The first of these is to complete at the earliest date the auxiliary ORCS structure now being planned by the U.S. Corps of Engineers. This will, at least, restore most of the original capacity of the structure to control the flow into the Atchafalaya River. Other steps include the strengthening of the foundations of the highway and railroad bridges that cross the Atchafalaya, the construction of pipe lines across the Atchafalaya that will be less susceptible to destruction by flood water, the construction of ring levees around municipalities and industrial plants to reduce the damage that would otherwise be caused by flooding, and construction of replacement water supplies for municipalities and industries located on the banks of the Mississippi River between Baton Rouge and New Orleans. Of course the long process of retrofitting each plant or industrial process so that the quantity of cooling water required will be decreased should be started immediately.

All of these steps, and more, will be needed to reduce the inevitable impact of the diversion of the Mississippi River into the present course of the Atchafalaya River and the transformation of the present lower Mississippi River into an estuary of the Gulf of Mexico.

II

INTRODUCTION

"Old Man River...he keeps on rolling along" Oscar Hammerstein II.

The Mississippi River, memorialized in songs and literature, is the longest and, economically, the most important river on the North American continent. It is a major north-south transportation artery and a water-borne link, via the ports of New Orleans and Baton Rouge, to the world's ports. It provides fresh water to, and carries away waste products from, municipalities and industries located astride its banks; it is a continual source of nutrients to the oyster beds and fishing grounds located adjacent to its mouths in the Gulf of Mexico. The river is also a recreational outlet for boating enthusiasts and for those who ride the excursion boats. This river of Hammerstein and Twain, of industry and recreation, is getting ready to write another chapter in its colorful history by drastically altering its course in the lower 300 miles of its length.

The point of immediate interest is the continued efficacy of the Old River Control Structure, located about 45 miles north by northwest of Baton Rouge (Figure 1). The primary function of this structure is to maintain the distribution of the flow of the Mississippi River between the main stem and the Atchafalaya River. At the present time, the goal is to maintain an approximate distribution of 70 percent of the flow down the main stem of the Mississippi and 30 percent down the Atchafalaya.

During the flood of 1973, which resulted from climatic conditions estimated to occur on an average of once in 25 years, there was a distinct possibility that the structure would be undermined or bypassed. If this had happened, some 70 percent or more of the flow of the Mississippi would have been diverted down the Atchafalaya Basin and only the remainder of the flow would have followed the present course of the Mississippi to the Gulf of Mexico.

Such a diversion could have had several significant effects: communities located in, or adjacent to, the Atchafalaya Basin would have been flooded; all major highways, including Interstate 10, and railroads crossing the Basin might have lost their high bridges, and east-west traffic would have been disrupted for several months; many industrial firms using fresh water from the Mississippi for cooling and processing purposes would have discovered during the following low-flow period that the saline content of their water had increased considerably; many sections of the East Coast, as far away as New York and New Jersey, would have received appreciably lower supplies of natural gas.

The purpose of this report is to explain the physical sources of the threat, to explain the consequences, and to suggest some actions that might ameliorate or prevent some of the consequences. Finally, and most importantly, the purpose of this report is to alert responsible legislators and administrators to the situation so that they, in turn, will understand that this is not a parochial problem confined solely to flood control in the lower Mississippi Valley (important though this may be) but will directly or indirectly affect a sizable proportion of the population of the United States. It is indeed a national problem, one that will be with us for the next three or four decades, and one that must be discussed and solutions found within this decade.

The scope of this study has been limited both by time, availability of personnel, and money. We make no claims that this is a definitive study - that remains to be accomplished by others who may be more qualified and can devote more effort to it. This should be considered a pilot study, one which surveys the terrain and which sets the stage for a national effort to prevent general economic losses to a sizable proportion of the population and to stimulate local efforts to protect the lives and property of the people directly affected.

The study was funded by the Office of Water Research and Technology of the U.S. Department of the Interior under the Water Resources Research Act of 1965 P.L. 89-380. The study was administered under the allotment program of the Louisiana Water Resources Research Institute as Project A-040-LA. The illustrations were prepared by Mrs. Norma B. Duffy, Chief Draftsman of the Division of Engineering Research. Final copy was prepared by Ms. Carolyn Sharp.

The cooperation of officials from the major natural gas pipeline companies and electric utilities was most helpful as was the assistance of the consulting firm of Pyburn and Odom on the evaluation of pipe line crossings. The work would never have been accomplished without the help of all of those mentioned, and many others who assisted in obtaining and analyzing the data. If this report is a success, they deserve a full share of credit. However, any errors or conclusions are attributable solely to the authors.

III

THE PHYSICAL SETTING

The physiographic setting of the Old River Control Structure has been described by Hebert (1967) and Horne (1976). Briefly, the Old River was a channel that connected the Mississippi and Red Rivers. The Red River flowed directly to the Gulf during its periods of low flow and into the Mississippi, via Old River, when the Red River was at a high stage and the Mississippi River was at a low stage. The Atchafalaya River is formed at the junction of the Red and Old Rivers and it is a continuation of the Red River but, since it receives flow from the Mississippi, it has a much larger discharge than the Red River. Figure 1 shows the relationships between the Mississippi, Red, and Atchafalaya Rivers.

From historic times until the latter part of the 19th century, the Atchafalaya was plugged by a huge raft of logs which impeded the passage of water and kept the discharge down to a hydraulic minimum. In an effort to improve the navigability of this river, repeated efforts were made to remove the logs and other impediments to flow. In the 1880's these efforts were finally successful; the log raft was removed and hydraulic conditions improved. The channel then began to get deeper and it became apparent to some engineers that sooner or later the Atchafalaya would capture the bulk of the discharge of the Mississippi unless something were done. Despite several unsuccessful attempts which were made to control the flow from the Mississippi, the percentage of water diverted through the Atchafalaya slowly increased.

One major reason for the gradual increase in discharge through the Atchafalaya is that the water flows a shorter distance from Old River to the Gulf via the Atchafalaya than it does when it travels down the main stem of the Mississippi. A second reason is that the surface geology of the Atchafalaya Basin is not well-consolidated clay, as is the channel of the main stem, but is a mixture of recent clays and silts and therefore is more friable and less resistant to the action of water.

The result of the hydraulics of the situation is that the upper portion of the Atchafalaya channel is degrading (cutting or getting deeper) whereas the lower portion of the channel, starting a few miles south of the I-10, is slowly filling up with sediment. The increased discharge, which is concentrated at the two outlets located at Morgan City and Wax Lake, is slowly widening and deepening these outlets.

Another important aspect of this geomorphologic process has been the drainage of some swamp lands in the upper reaches of the Basin (since the bottom of the main Atchafalaya channel was decreasing in elevation and beginning to provide an outlet for local drainage) while simultaneously, due to sedimentation, the shallow lakes and swamps further south were being filled in. Those who are presently (1980) petitioning the Corps of Engineers to "save the Basin", and their traditional hunting and fishing grounds, overlook the fact that the source of the change is the sediment from an area of continental size and that there are limits to what engineers can achieve in the face of such geologic forces. As a counter-balance, the deposition now underway in the Atchafalaya Bays is beginning to produce more land which will ultimately replace the Basin as an area for hunting and fishing.

In order to keep the Mississippi River from being diverted into the Old River, the Congress, in 1954, authorized and directed the U.S. Corps of Engineers to build a control structure at the head of Old River, in order to keep the discharge within a range of 25 to 30 percent of the total flow of the Mississippi at Vicksburg. With the expenditure of about $100 million and much time and effort, the ORCS was opened in 1962 and the increases in diversion were brought under temporary control.

The control of an alluvial river is probably the most difficult task that can be undertaken by civil engineers. Over a long period of time such controls have never been successful, although they might be operable for periods of up to 100 or 150 years. Ultimately the forces, which move hundreds of millions of tons of silt and half a trillion tons of water annually at the rate of, possibly, an average of 3 ft. per second, are too powerful to contain. Most of the erosion occurs during periods of flood, when the carrying capacity of the river is the highest and the flow velocities are the greatest. Deposition occurs immediately after the velocity decreases.

As the duration of time since the last flood increases, more and more sediment is deposited in the channel, the carrying capacity of the channel is decreased, vegetation grows on the banks and in the channel to further impede flow, and the stage is set for the next flood. When this flood occurs, water levels are slightly higher at the same discharge rate than they were at the end of the previous flood.

In summary, the Atchafalaya Basin and its outlets constitute the area of the continental United States and Canada where the forces of geology and geomorphology are most active. It is not the place where the works of man have a great prospect of a long life; nor is it the place where ever-increasing expenditures to counteract the forces of geomorphology should be made except that, on a short-term basis, some expenditures may be economically justified.

To add to the problems, the entire delta area is slowly subsiding as the sediments compact due to the added weight of the deposits of silt and sand. Although no definitive studies have been accomplished, the land in and around Morgan City is probably subsiding at the rate of more than 1 ft per century (the subsidence rate in the New Orleans area, in which the surface geology is slightly older, is approximately 0.4 ft per century (Kolb and Van Lopik, 1958, p. 104)). More likely, the actual subsidence in the Lower Atchafalaya Basin is approximately 2 ft per century. Thus, even without the deposition of new sediments in the Basin, flood heights will tend to get higher, relative to land surface, because the land, itself, is sinking. Some of these associated problems are only now being recognized and answers being sought. Not the least of these problems is the fact that the determination of land surface elevations with respect to sea level is uncertain.

The study referred to in the previous paragraph was based on mean sea levels determined at tidal stations but the problem is that the land surface elevations at these tidal gages may not remain constant. They may be subsiding. Nor is there any reason to believe that the sea level of the entire north coast of the Gulf is at the same mean elevation. Because currents are always flowing in the Gulf, differences in water level elevation, exist from place to place. The National Geodetic Survey is now reviewing the matter of "sea level elevation" in order to determine, nationwide and consistently, differences in elevation between points. The use of "sea level", which is based on the assumption that the mean level over a period of years is the same at all points, has proved to be erroneous in precisely determining the gradients of rivers that debouch into the oceans. For this reason, among others, areas subject to flood in which the terrain is smooth and almost horizontal cannot be precisely shown on maps.

The Atchafalaya Basin is the scene of the most active geomorphic processes in the entire North American continent. Local changes in land surface elevation due to deposition of sediment are frequent. Channels of rivers are unstable, cutting their beds deeper in some places and depositing silt and raising their beds in other areas. Throughout these geologically unstable areas are located oil and gas fields, major highways, pipelines, small cities and much potentially rich agricultural land, most of it currently undrainable. In addition, this area is the scene of a direct confrontation between the United States Government and the Mississippi River: the government wishes to control the river which is stubbornly resisting these efforts. In 1980, the government's efforts are focused on the Old River Control Structure, which prevents the Mississippi River from utilizing the Atchafalaya River as its main distributary instead of the present main-stem which passes Baton Rouge and New Orleans on its way to the Gulf. The success of the efforts to save the ORCS will depend on the willingness of the Congress to fund the work (in this instance to repair the existing structure and to initiate the construction of an auxiliary or a replacement structure) and the whim of fortune: if another flood equalling or exceeding the flood of 1973 does not occur before the construction program is completed the potential disaster can be possibly averted for a few decades.

It is difficult to envision and to enumerate the consequences of a flood larger than that of 1973 yet smaller than the "project flood" utilized by the Corps of Engineers for its design and planning. However, some discussion of possible consequences is necessary if citizens and policy making officials are to comprehend the potential seriousness of the situation in the absence of corrective measures.

Such a flood could happen next year, during the 1980's or 1990's, or possibly even later. There is no assurance that it will not occur next year. The following scenario is presented in order to assist the nontechnical reader in understanding the possible effects of a sudden failure of the ORCS. Not every one of the impacts in this scenario has an equal probability of occurring but some impacts which have a low probability are so serious that we decided to include them. We cannot state that a flood of such a significant magnitude will occur during the 1980's or the 1990's, but we do know such a flood is possible during the next 20 years, and that eventually one will occur. In the following hypothetical scenario, we assume it will occur in 198X.

when the Mississippi River at the Carollton gage in New Orleans reached bank-full (11 ft mean sea level) on December 3 and slowly rose to 14 ft by New Year's Eve. The river rose to 15 ft in January and, although it dropped to 14 ft by the end of the month, it rose again in February. In response to rains in the Ohio valley and the Upper Mississippi valley the river erratically rose even higher in March. By late March the river had reached 18 ft at New Orleans, and the Corps of Engineers was fully mobilized for the flood fight. The Bonnet Carre spillway was opened and, although all of the sediment deposited in the spillway during the preceding flood had not been removed, an estimated 200,000 cubic ft per second moved through the spillway and the elevation of the river at New Orleans was stabilized at 18 ft.

The rains continued to accelerate the snow melt in the upper Mississippi valley and the river at St. Louis rose steadily: at the Market Street gage in St. Louis the stage rose above 30 ft and the continuous rains made the prediction of 35 ft or more seem only too likely. By the end of March the TVA reservoirs were full and the spillways were discharging at capacity. A flow of over 2 million cubic feet per second was being measured at Vicksburg, and the Yazoo River was flooding nearby low areas.

The need to divert water away from New Orleans necessitated the opening of the Overbank Structure of the Old River Control Structure. The Low Sill Structure, that had almost been undermined in 1973, was discharging almost 600,000 cubic feet per second as a result of the relatively low stage of the Red River. The Red River watershed received very little rain and the flooding that did occur was the result of back water from the Atchafalaya-Old River system.

Things were far from quiet in the Atchafalaya Basin. The total discharge of the Atchafalaya River at Krotz Springs in mid-March was almost 800,000 cfs, the lower parts of the guide levees were under water and persons living in the floodway had been forced to evacuate their residences. Several of the gas pipelines and one oil pipeline had been cut, caused basically by the undermining action of the water. The river had simply scoured holes beneath the pipelines (which had been laid down in deep trenches for the river crossings) and shook the lines back and forth until, ultimately, some gave way. The gas and oil flows were immediately shut off and very little hydrocarbon pollution occurred. At the same time, the companies with pipelines crossing the Basin cooperated and made alternate arrangements to transport the gas across the Basin through the pipelines that were still intact. There were some short term shortages of gas for electric utilities and some industrial firms but the electric utilities switched to more expensive fuels and the general public noticed very little differences in their gas and oil deliveries.

The pipelines that cross the Atchafalaya Basin were not all ruptured at the same instant. As the reports of pipeline failures came in a hasty study was undertaken which showed that a number of states in the South and East received a large porportion of their natural gas from pipelines crossing the Basin. If this interrupted gas could not be rerouted, states such as

Connecticut, Florida, Georgia, Massachusetts, New Jersey, New York, North and South Carolina, Pennsylvania, Rhode Island, and South Carolina would be without natural gas deliveries within a few days. Emergency allocations were put into effect but, fortunately a combination of warm weather on the east coast, which reduced demand, and rapid deployment of gas through other pipelines had the happy effect of reducing the impact of the pipe line breaks on most of the industries. Here and there a few plants had their deliveries of natural gas temporarily curtailed.

In mid-April some drivers of passenger cars and trucks that traveled on the portion of I-10 that crosses the Basin noticed that the Whiskey Bay bridge seemed to tremble. The Louisiana Department of Transportation was notified and they sent an engineer to investigate the bridge. After completing a preliminary investigation he recommended that the bridge be closed to all traffic. This was promptly done and all traffic was now diverted to congested U.S. 90 to the south and U.S. 190 to the north. On April 18 one of the piers of the Whiskey Bay crossing was undermined and the bridge collapsed.

It was on the same day that the Old River Control Structure began to vibrate even more violently than it did in 1973. The flow through the ORCS complex was estimated at 800,000 to 900,000 cfs. The thousands of cubic yards of stone that had been brought in to replace the failed left abutment began to vanish and re-appear on the right side of the structure. There was evidence that a large hole downstream of the low sill structure was enlarging and it was hypothesized that a new hole was being gouged beneath the structure from the upstream side. The Morganza floodway, down stream of the ORCS, was opened fully to relieve the pressure on the low-sill structure. An estimated 200,000 cfs was being discharged at Morganza by April 25, bringing the total discharge at the fallen I-10 bridge to more than 1,200,000 cfs. The rains in the Ohio Valley continued. In the Missouri basin, runoff from rain and snow-melt filled the flood storage portions of the reservoirs and each of the reservoirs, from Fort Peck downstream to Ft. Randall, was discharging water at the maximum practicable rate short of overtopping the down-stream levees.

In New Orleans the Corps continued to build small "potato levees" on the main levees of the river and to fill and place sand bags to control bank erosion and to contain sand boils. As early as April 20, plans were underway to dynamite a portion of a downstream levee to protect the city. Everyone fervently hoped that there would be no wind from the Gulf to raise river levels.

As the swollen Ohio and flooded Mississippi rivers joined, the combined discharge did not raise the mainstream water levels smoothly: at first the river stage would go up for a few days, then go down a little, then up again some more, and then down a foot or so followed by another rise. In response to the laws of hydraulics, the river stage kept on rising although the actual discharge had not changed much. Although the total flow was almost 20 percent less than the hypothetical maximum, the original design flow lines for the hypothetical project flood were being approached all along the Mississippi River from Cairo to Vicksburg. Construction crews, assisted by volunteers, attempted to raise the levee a foot or two at the many danger spots and worked to build set-back levees where bank caving seemed to be occurring.

The Old River Control Structure collapsed on May 1 and it was conservatively estimated that 70% of the Mississippi River flood water was diverted down the Atchafalaya River. None of the road or rail bridges spanning the Atchafalaya had been designed to withstand the deep erosion produced by this greatly increased discharge. The original design flow lines for the hypothetical project flood were being approached all along the Mississippi river from Cairo to Vicksburg. The bridge at Krotz Springs collapsed as did one of the major east-west railroad bridges. In addition, Morgan City, located astride an outlet of the Atchafalaya to the Gulf, was largely inundated.

The ORCS's low sill structure, which had been undermined and had finally collapsed, remained in place, broken-backed, partially blocking the Old River channel. When it collapsed, the blockage had created a small flood wave about 5 or 6 ft. high at the structure and this was reflected in downstream stages of the Mississippi. The most immediate effect was to overtop and breach the levee downstream from the structure just above the site of the new auxiliary low sill structure still under construction by the Corps of Engineers. Although the flood fighters had more than one emergency to handle as the flood wave worked its way down the main channel, no other levees were overtopped.

The crevasse at the levee enlarged rapidly and uncontrollably. Flood stage predictions for points in the Atchafalaya Basin were made public four times a day and notice was given to the remaining residents of Morgan City and the surrounding area that they would have to evacuate. The National Guard, aided by contingents from the Army, Navy, and Coast Guard, policed the entire area after the Governor of Louisiana declared martial law for the affected areas. The citizens of Houma and its environs were warned that some of the streets would have several feet of water covering them and that U.S. 90 would become impassable. It was unofficially estimated that at least 70 percent of the flow of the Mississippi was going down the Atchafalaya and discharging at the Morgan City-Wax lake outlets. The stages of the lower Mississippi River downstream from the diversion began to fall slowly, and an effort was made to reduce the Atchafalaya flood by closing the Morganza floodway. This action did not help appreciably. The river adjusted to this situation and more water poured through the upstream crevasse. See Figure 2 for a map of the flooded area.

Heroic efforts in reinforcing and raising the low spots of the ring levee around Krotz Springs managed to keep water out of that locality, although water from internal drainage produced by rainfall accumulated in the areas at low elevation since pumping power was in short supply. The discharge of the Atchafalaya River, now the new main-stem of the Mississippi, at the latitude of Krotz Springs was estimated at almost 1.6 million cfs. Houma, Raceland, and Thibodeaux were first isolated and then flooded. Many of the residents loaded their most portable belongings in their fishing boats and sought safety in higher ground. Schools in Baton Rouge, New Orleans, and some small towns were converted into dormitories and mass kitchens were set up for those fleeing from flooded lands.

Compounding the problem was the shortage of electric power that resulted from the natural gas cut-off. Fortunately Waterford 3, a nuclear unit, was just completing its full power tests and was brought on line about the time that the gas shortage was curtailing the output of other generating plants along the Mississippi River. The coal-fueled Big Cajun Station at New Roads was surrounded by a hastily constructed levee that was tied into the main Mississippi River levee. It, too, continued to generate power.

Now all three major east-west highways (U.S. 90, U.S. 190, and I-10) were closed to traffic due to bridges being washed out and all traffic from the Gulf Coast states to southwestern Louisiana and southern Texas had to travel at least 220 miles out of their way. Because the detour involving the shortest distance consisted of crowded two lane roads, those travelling from the area east of the Basin to and from points west of the Basin used I-55, I-20, and Highway 59 in Texas for a total additional distance of 615 miles.

During the summer, a long dry spell ensued. By September the discharge at Vicksburg was down to 300,000 cfs. and the combined flow at the two outlets, at Morgan City and Wax Lake, totalled slightly over 200,000 cfs.

New deposits of silt, some over twenty feet in depth, covered what had formerly been shallow lakes in the Basin. New islands appeared and a total of more than 20 square miles of new marsh land appeared in the Atchafalaya Bays. The ship channel from Morgan City to the Gulf was silted up as was a large part of the Intracoastal Waterway for some distance east and west of Morgan City. Industrial sites near Morgan City, where many of the larger oil platforms had been constructed, were still shut down and the availability of transporta-

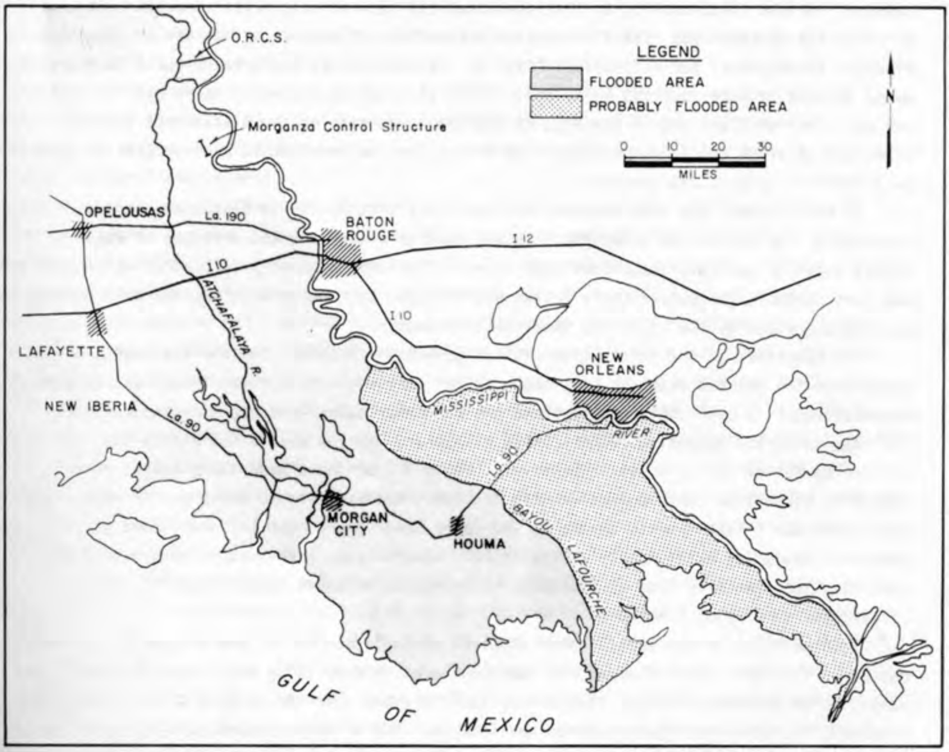

FIGURE 2. Map showing flooded and probably flooded area.

tion and housing was severely limited. The beginnings of renewed economic activity could be seen in Houma, as many of the small industries reopened and the oil industry slowly picked up the pieces and went on with the business of finding and producing oil offshore. The fishing fleet had resumed activity, but a sufficiency of ice to preserve the catch remained a hope rather than a reality.

The Corps of Engineers and the U.S. Geological Survey started to make weekly salinity traverses of the Mississippi River, beginning just downstream from the Carrollton intake of the City of New Orleans. As a result of the low flow in the Mississippi River, the movement of a dense tongue of salt water from the Gulf known as the "salt water wedge" was precisely charted. An old computer program that predicted the rate of salt water movement upstream based on the duration and rate of discharge was dusted off and run. The results generated dismay: by December, the Mississippi River as far upstream as New Orleans would have a salt water content of more than 500 parts per million of chloride (normally there are less than 100 parts per million) and in January, if the discharge rate of the Mississippi did not rise, the chloride content would double or triple and the front would have progressed upstream past Kenner, Laplace, and Gramercy.

At Baton Rouge, the flow measured approximately 100,000 cfs in September, and was still decreasing. By the middle of October, it was down to 75,000 cfs and problems of water supply began to manifest themselves down river. The first community to observe water problems was Port Sulphur: the water supply became undrinkable, with 40 or 50 times the salt content maximum suggested by the Louisiana Department of Health.

The operators of the Taft nuclear-fueled generating station, the one that had provided power when the gas had been cut off, began to get worried. Their river intake was pumping brackish water to cool the condensers and the condenser tubes were beginning to corrode. The same thing was happening to oil-fueled plants and the few gas-fueled plants that had resumed operation on the Mississippi river. Thus, all of these generating plants were forced to curtail or cease operation when the tubes became corroded and began to leak. All shut downs would last from 18 months to two years until new condenser tubes, made of corrosion-resisting metal, could be installed. Nonetheless, there was no alternative to operating the plants as long as possible. Warnings were issued to decrease the use of electricity to prevent blackouts.

The operators of the public water supplies of Jefferson Parish and Orleans Parish were caught on the horns of a dilemma: if they continued to pump salty water into the mains, the water, while drinkable for the time being, would corrode domestic water heaters and do other mischief, including making any coffee undrinkable. But if they stopped pumping, water would not be available for sanitary purposes and fire fighting. They also recognized that the situation would tend to get worse as the discharge diminished in the old main stem channel of the Mississippi River, below the defunct control structure.

Emergency efforts were made upstream to divert more water to New Orleans and these were partly successful in that they prevented an additional decrease in the fresh water flow. Orders were issued to open all spillways of all upstream reservoir systems to maintain the low flow of the Mississippi River as high as possible while, simultaneously, regaining some flood storage capacity. The power generation schedules of TVA and the Corps of Engineers were badly disrupted by these orders and the orders were challenged in the courts by local citizens' groups.

The water supply of New Orleans was degraded even further, pipe corrosion increased, and the long line of water trucks crossing the Causeway over Lake Pontchartrain bringing well water to the citizens for drinking purposes continued to operate. Every available water truck was diverted from contruction projects and fire duty and pressed into service to deliver water to the citizens. The water ration which started at one quart a day later increased to two quarts and still later to a gallon a day per person. But even these small rations required the use of all available tank trucks and at one time a daily total of 2000 loaded water trucks was counted crossing the Lake into New Orleans.

The citizens slowly adapted to a two-source water supply; one supply for drinking, (mostly bottled water) and the other for washing and sanitary purposes.

By late February of the year following the flood, the salt water wedge passed Donaldsonville and the river intake there, which supplied water to Bayou Lafourche, had nothing but salty water to contribute. The inhabitants of the banks of the bayou got used to drinking bottled water and sugar cane growers worried about processing sugar in the fall.

In the reach of river between Baton Rouge and New Orleans the impact of a brackish water supply was not felt uniformly. Upstream of Donaldsonville many of the industries used ground water as the source of supply. Although their aquifers were connected to the river and their well fields would ultimately suffer the infiltration of salty water to the aquifers which would degrade their water source, this would take several years. In the meantime it was businesss as usual, albeit with unusual efforts to reduce the use of fresh water. Industries that drew water from deeper aquifers were not affected by the change in the river water's mineral characteristics.

Many of the industries located along the Mississippi used river water primarily for thermo-electric cooling. Their condenser pipes began to corrode and replacements became increasingly difficult to obtain. The net effect on the industrial complex could be visualized as something similar to someone slowly pouring very fine sand into the gears of a machine: the machine still worked but not as efficiently, and with frequent, ever-longer, periods of down-time. The prices of polyethelene pipe, plastic wrap, polyvinyl, and other products of the river-based petrochemical industry began to rise as production diminished.

Curiously enough, the movement of ships up as far as Baton Rouge was not affected by the change in the relative flow of water. After a brief period of intensive dredging at the mouth of the Mississippi River, it was found that the accumulation of silt and sediment at the river outlet practically ceased because most of the sediment was being diverted down the Atchafalaya River. An unforseen by-product of the disaster was that it became possible to maintain, at relatively low cost, a 50 ft. channel from the Gulf to Baton Rouge.

Still unsolved, however, was the problem of barging materials upstream past the shoal that formed for a distance of about 10 miles down stream of the ORCS. Some people suggested that a canal lock and dam be built to by-pass the ten miles of shoal water; others suggested a dredging program. After holding hearings, the House Committee on Public Works inserted an authorization into pending legislation to enable the Corps to determine the desirability of a canal and the long process of technical studies, benefit cost studies and environmental impact statements was started.

Probably the most keenly-felt effect by the lovers of sea food was the destruction of the oyster beds and shrimp nurseries from Morgan City eastward. Some oyster beds were destroyed by a decrease in salinity of the water due to the flood; others, just to the west of New Orleans, were destroyed by an increase in salinity due to lack of sufficient fresh water; still others were hurt by the deposition of silt in formerly clear brackish water. Oyster production decreased. Many shrimp nursery areas were similarly affected.

Although the harvest of shrimp and oysters decreased, and would be lower than normal for a year or two, the long term effect of the deposit of sediments throughout the area adjacent to the lower portions of the Basin was expected to eventually result in a larger area becoming suitable for the production of shrimp and oysters. The net long-term effect on shrimp and oyster production was expected to be beneficial.

The great Atchafalaya swamp was bereft of its deer, squirrel, and rabbit population, mostly by drowning, although a few deer survived and so did the alligators. All of the areas set aside for hunting, either for private rental or public use, were changed by the deposition of silt and the total alteration of drainage patterns. In general, the area covered by lakes decreased and the fishing success declined accordingly. When the flood subsided, many of the land owners found themselves possessors of a fairly good agricultural property that, with some drainage work, could produce crops of soy beans or even rice.

The Upper and Lower Atchafalaya Bays took on the appearance of the former "Lower Basin". Islands coalesced, swamp vegetation appeared as did marsh grasses. A new fishing area manifested itself. The State of Louisiana acquired additional lands and the usual arguments ensued as to how to "manage" it.

V

HYDROLOGY AND GEOMORPHOLOGY

General

The preceding scenario, which attempted to capture some of the implications of the major flood coupled with the ORCS failure, is based on a synthesis of many disciplines. Two of the most important are Hydrology and Geomorphology.

Hydrology is the study of the action of water from its evaporation from the ocean, to its watering of the earth in the form of rain and snow, its movement in the earth (where it accumulates and moves in the form of ground water), and to the surface of the earth where we see it as stream flow and in lakes and swamps.

In the field of surface water, the attention of the hydrologist is particularly directed to the extreme occurances of floods and droughts. These constitute the limiting parameters on any human development. It requires only one flood to make people homeless, and a day completely without water supply is sufficient to shake the foundations of a city.

The devastating flood of 1927, which gave birth to the Lower Mississippi Valley flood control program, was probably not the worst flood witnessed by people of European descent. In fact the reason that the citizens of Louisiana, Mississippi and Arkansas speak English, not Spanish, is probably the result of a monstrous flood of the Mississippi River:

It is a matter of record that Hernando Desoto, former Lieutenant to Cortez and Pizarro, camped on the Mississippi River bank at a site in what is now Tunica County, Mississippi, probably during March of 1543. There he witnessed a flood that did not peak for 40 days and he saw an immense expanse of water that he estimated was about 60 miles wide (Harrison, 1961, pp 51, 52).

In his posthumous report to the Spanish King, this senior Con quistador and daring explorer undoubtedly advised his ruler that all the land to the southwest was the Mississippi River and that included all the land in the flood plain south of Tunica (or, say, Memphis). Such a report by a trusted and senior commander undoubtedly cooled the interest of the Spanish throne in conquering, and taking over, the flood-prone land described by Desoto. This shift in interest enabled the French, about 150 years later, to explore the lower Mississippi and, in 1699, to claim for the French Crown the area from its mouth to the latitude of Old River. The French Settlement, particularly the settlement of New Orleans, was flooded in 1718, even while the first levees were being built by Le Blond de la Tour.

The reason for the sparse human settlement in the flood plain of the Mississippi before Europeans arrived in the area is undoubtedly to be found in its flood history. The impact of floods in the area south of the ORCS must have been particularly great. The point to be made is that floods are nothing new, that very great floods have occurred from time to time, and there is no reason to believe that such floods will not occur in the future. In fact, we can state with complete certainty, that sooner or later, a flood greater than that ever recorded or witnessed will occur. There is no way to prevent it nor is there any way to protect against it.

The Corp of Engineers has devised a project flood to be used as the basis for designing and building flood control projects. This flood is three million cubic feet a second to be distributed between the three principal Gulf outlets of the Mississippi River. But the Corps has never said, or even hinted, that this was the maximum possible flood. They have said that probably such a flood would not be exceeded more than once in a thousand years. But they have never said that it would not be exceeded next year. And since the selection of the project flood in the early 1930's, much has happened to the river with the result that these figures might well be called into question, not particularly as regards magnitude, but primarily as to frequency of occurrence.

Come of the concepts that will be discussed in the following pages may seem unusual. However, it would be well to remember that the report you are reading is written in English and not in Spanish, and Hernando Desoto knew a flood when he saw one. The 198X scenario described above and the following discussion might actually understate rather than overstate the situation.

Hydrology

One of the basic assumptions of classical hydrology is that any measurement of river level or discharge is the product of a unique set of antecedent conditions and, given the same conditions, the same measurements would be recorded again and again. The antecedent conditions include the season of year, distribution of rain, condition of the watershed (is it vegetated or barren; dry, moist or wet; resistant to erosion or subject to erosion, etc.), and the underlying geology. Any periodic measurement, such as the daily river stage, is but one item of what is termed "an infinite stationary series" and that at any future time, when antecedent conditions are identical, the same values of stage and discharge should recur and be recorded.

It is on this basis that the extreme occurrences of stage and discharge are evaluated. This is the basis for computations of recurrence intervals, confidence limits, frequency and other statistical measures. Thus, the effect of a dam in decreasing the recurrence of floods and increasing the availability of water during dry periods can be evaluated, and the probable flood heights, which determine the needed levee elevations, can be computed. Zoning maps can be prepared to show the area flooded by a flood of given recurrence interval, for example, once every twenty-five years or once every one hundred years (an interval beloved by various federal agencies that sell "flood insurance"). All of these computations are based on the assumption that each periodic measurement is a representative one and can be treated as a sample of an infinite series of measurements that will reflect the underlying hydrologic reality.

Man-made changes:

To the dismay of the hydrologist, the underlying assumptions of the science are being undermined by the very success of applying these statistical methods and constructing projects in the field of water resources. For instance, once a river is dammed and a major reservoir formed, the flow downstream is not a hydrologic event governed only by antecedent natural conditions. The discharge of the river is determined in part by the will of the operator of the dam and the capacity of its spillway or outlet. If it is a dam for hydropower, the discharge will vary through the day as the demand for power varies. If water is removed from the reservoir for purposes of irrigation, the overall flow of the river below the dam will be less than it would have been in its absence because not only will water have been removed to irrigate farms and subsequently be consumed by plant evaporation, but also water will directly evaporate from the lake surface, thus additionally reducing the overall river flow. Any measurements of river discharge and stage will be affected not only by natural forces but also by unpredictable human action.

The discharge from the reservoir will be clear, not silty, and the river will tend to degrade, or scour its bed as it dissipates the energy of the water. As far as the river hydrologist is concerned, the discharge measurements are those of a different stream, the watershed of which is drier, with different sediment characteristics, different mineralogical and thermal characteristics, and much greater extremes. The flow could be zero if the reservoir operators desire but the flow could be far greater than any recorded on the natural stream if the dam were breached when the lake was full and the spillway was overflowing. Thus, the statistical validity of the data obtained at downstream points has been degraded and the uncertainties increased in the design of water-associated facilities downstream.

A similar situation on a larger scale exists with regard to the entire drainage system of the Mississippi River. Large reservoirs on the upper Missouri River have more than enough storage capacity to hold the entire average annual flow of the Missouri river. There are large flood control and navigation reservoirs on the Tennessee and Cumberland rivers. These reservoirs also produce power in their capacity as generators of electric power that is used for peaking purposes. Consequently, the flow goes from zero to maximum capacity of the turbines in 24 hour periods. There are many flood control reservoirs on tributaries of the Ohio and in the delta area of the state of Mississippi. There are also large flood control - sediment storage reservoirs on the Arkansas River. Within broad limits the discharge from all of these rivers is under the control of the units of the Federal government to the extent of their legislative authorizations, which are not necessarily consistent with one another.

A further reduction in the validity of the statistical data is caused by the small, but persistent navigation improvements which have been made in the channel of the Mississippi River. These improvements have consisted in dredging the sand bars and creating cut-offs where bends in the river channel made this desirable, constructing groins and stabilizing the eroding portions of the bank by the installation of articulated concrete blankets. As a result, the hydraulic efficiency of the channel has been increased and some normal sources of sediment have been blocked off.

The average difference in elevation between the land surface of the drainage area of the Mississippi River and the Gulf has remained the same. Thus, even allowing for the increased evaporation of water from the reservoirs and the irrigated areas, the total energy of the river water is virtually unchanged. It is, however, directed differently. During low flows the discharge is concentrated in a relatively narrow hydraulically efficient channel, and the river elevation for a specified discharge has gone down. In turn, formerly hard-to-drain lands now drain more easily, and articulated concrete mattresses that protect erodible banks are more easily undermined.

Construction of levees for the protection of riparian lands has constricted the alluvial river to a small fraction of its former flood plain. Thus flood heights, for the same discharge, have a tendency to become increasingly higher. For example, at the Market Street Gage in St. Louis, a measured discharge in 1940 of 850,000 cubic feet per second produced a stage of 39.2 ft. In 1973, the same discharge produced a stage of 43 ft. In New Orleans, a discharge of 1.1 million cfs in 1890 produced a gage height of 15.3; by 1922 it had risen to 18.6 ft (M.R.C. 1925, p. 160). The stage of 18 ft. is the maximum now permitted by Corps of Engineers procedures which use spillways like the Bonnet Carre to reduce the stage and discharge at New Orleans.

Flood Occurrence:

The problem is not one of flood-height prediction, because the hydrologist can adjust his models to the changing conditions and produce useful short-term predictions. The real problem, however, is that the design and construction of permanent flood protection works, which may cover decades, must strive to hit a moving target. Even if the hydrologist can predict the maximum discharge with reliability, there is no way of determining the proper elevation to use in the design. Even if the design is correct for 10 years after the works are completed, subsequent floods of similar discharge most likely will be associated with higher elevations, the precise magnitude of which will become known only after the flood occurs.

An additional complicating parameter is the time of concentration of the watershed. This is a hypothetical construct which expresses the duration of rainfall needed before the drop of water falling on the most remote point of a watershed reaches the gaging station, or the point where measurements are to be made. No one has ever measured a time of concentration in the field, but the concept is a useful one because it integrates all of the hydraulic and climatic parameters and is a convenient way of expressing complicated and interrelated processes.

For example, consider a small watershed which is untouched by man. If it rains one inch an hour (possibly the equivalent of 200 cubic ft. per second at the outlet of the watershed) it might require 10 minutes of rain before the flow at the outlet reached the 200 cfs rate. If a dam were built which created a lake just upstream of the natural outlet and if a one-inch/hr. rain occurred during a period when the reservoir were empty, the discharge at the natural outlet might never reach 200 cfs. The time of concentration could be considered infinite or indeterminable. If, however, the one inch rain occurred when the reservoir was full and the spillway were already discharging water, the 200 cfs discharge might well be reached at the end of 5 minutes. It is altogether possible that the 1-inch rain might produce a discharge far greater than 200 cfs if additional water were being released through a pipe at the base of the dam just before the rain.

Linsley and his associates (1949, p. 612) described the same process as it occurs on a larger scale: "Far more serious, however, is the tendency for an increase in flood-peak flows... Reservoirs greatly reduce the time of travel of flood peaks moving through them, and a system of reservoirs may cut several days from the normal time from headwaters to outlet ... with resulting higher flood peaks in the lower basin ... Even if peak flows (downstream) are not increased, the reduced time to peak decreases the opportunity to take protective measures downstream." No information has been accumulated in the last 30 years that would cause us to modify this evaluation.

On an even larger scale, the urbanization that has occurred in the drainage area of the Mississippi River has increased the rapidity of runoff because it takes less time for water to drain from a smooth concrete surface than it does for it to run off from a field or forest. Drainage districts have improved the drainage of farm land and reduced the time that water spends on agricultural land. Also channel straightening and deepening has occurred throughout the land on a piecemeal and uncoordinated basis. No one can measure, much less predict, the change in concentration time of the drainage area. Consequently, an identical pattern of rainfall and snowmelt, all antecedent conditions being the same, will now produce a flood peak more rapidly, and very likely a higher one, than it did in the past. Just how much greater cannot be predicted. Previously, the chance that flood peaks from the major tributaries would coincide and create a great flood on the Mississippi was relatively small; it has become more likely that a single vast storm system will produce flood peaks from each tributary almost simultaneously due to the improvements in hydraulic efficiency and the existence of large reservoirs in series along major tributaries. Although no definitive studies have yet been published, the climatic conditions that produced the 1973 flood, with a total peak discharge of 2,300,000 cfs at the Gulf outlets was an event with a recurrence interval of possibly as little as 25 years.

Drought and the Saltwater Wedge:

The reverse of the flood coin is drought. As we have seen, construction of a reservoir for any purpose, from the viewpoint of persons downstream, dessicates, or dries up, the watershed. Another dessicating effect is that the normal drainage of any surficial sands, or other porous deposits, is stopped by the construction of the dam and the creation of the reservoir. The normal ground-water flow that maintains the discharge of streams during dry weather is cut off, as far as the watershed below the dam is concerned. If the operators decide to release water during dry periods, water will flow down stream, but if they are endeavouring to conserve water, the dry weather flow released will be a matter for deliberate governmental decision. This, in turn, depends on the decisions of the agency operating the reservoir which are not easily predictable.

Even before the construction of reservoirs along the Missouri, Arkansas, Ohio, and Tennessee rivers, the New Orleans area occasionally suffered from the occurrence of saline water at the river intakes. In 1936, 1939, 1940, 1952, 1953, and 1956, which were a few of the years of protracted periods of low discharge in the Mississippi River, the drinking water of the citizens of New Orleans became appreciably salty (Kazmann and Arguello, 1973, pp 4-9 to 4-11). The discharge of the river at New Orleans during such periods ranged from 90,000 to 150,000 cfs as compared with an average discharge of 300,000 cfs or more.

A brief discussion of the movement of salt water upriver is probably in order. The bed of the Mississippi River is below sea level as far upstream as Old River. Near New Orleans the deepest part of the "thread", or "thalweg", of the river are from 130 to 180 ft below sea level. Thus salt water from the Gulf, once it crosses the bars in the passes of the Mississippi River, has a constant potential for moving upstream. Because salt water is denser than fresh water, it advances upstream on the river bed. The vanguard, shaped some what like a long, blunt wedge, is pushed forward by an increasingly thick layer of saline water, much the way that a wedge used as a door stop is pushed under a door to hold it ajar.

Counteracting this advance is the turbulence of the river water, which continuously erodes the tip and upper surface of the wedge. The rate of erosion depends on the velocity, and hence the discharge, of the fresh river water. Normally the erosion rate prevents upstream penetration much beyond Venice, La. However, during long periods of low flow the wedge has reached Kenner and even points further upstream. There is no reason to believe that the salt water could not go further upstream, even to Baton Rouge, should the discharge remain low for a sufficient time.

Any diminution of dry weather flow, whether due to drought or to diversion of water through the ORCS, would promote the arrival of salt water at the municipal intakes of the New Orleans area. Such a period of low flow, whether or not the ORCS survives, will produce a direct, political confrontation between those citizens who rely on the Atchafalaya River for water supply (Morgan City, Houma, et. al.) and those citizens who rely on the main stem of the Mississippi (the New Orleans Metropolitan area, cities between New Orleans and Baton Rouge, and the entire population that resides on the banks of Bayou Lafourche). Nor are political compromises possible under these circumstances. If the water goes down the Atchafalaya, the New Orleans citizens will have salt in their water supply, and the generating plants that rely on the river for cooling water will contend with corrosive salt water. If the ORCS is closed, the inhabitants of the Basin will have similar problems.

Geomorphology

Geomorphology is the study of topographical features of the earth and how they have been produced. If we exclude major earth upheavals such as those produced by earthquakes (and this is quite an exclusion for the Mississippi Valley, in view of the 1811 New Madrid earthquake), then most of the changes in the topography have been produced by the action of water. On the main stem of the lower Mississippi River there has been a tendency toward equilibrium: the flat gradient of the river, combined with a large, stable cross section with depths ranging from 50 to 200 ft, forces water into the Gulf. The elevation of the Gulf, although it fluctuates with the tide and wind, controls the water level.

The Atchafalaya's path to the Gulf is only about half as long as the present main stem of the lower Mississippi River. If there were no ORCS the steeper gradient would mean that the water would flow in the Atchafalaya faster, and contain more kinetic energy than it does in the present main stem. This additional energy would tend to scour the downstream river bottom deeper and this alteration would probably lower the river bed upstream far beyond the ORCS location. As time went on, more and more flow would be diverted from the present main stem and river scour would occur further upstream until, finally, a new equilibrium would be reached.

The concrete floor of the ORCS was built at an elevation of five feet below sea level (-5 ft msl) at that point. The river immediately upstream from the structure has a bottom elevation of from -30 to -40 with holes as deep as -100 ft msl. A concrete pavement was constructed that essentially prevents the river from cutting below the pavement of the ORCS in response to the energy that is potentially available in the water.

The bed is being cut increasingly deeper and deeper as the Atchafalaya strives to find an equilibrium between the bed load, the discharge, and the difference in elevation. There will be a tendency, at the same time, for the channel not only to cut deeper, but to become more tortuous.

In the upper reaches of the Basin, lands that abut the Atchafalaya will become drainable during periods of low river flow as the channel bottom deepens. In the lower part of the Basin much of the sediment carried by floods will be deposited and will raise the surrounding land surface, as the history of the present main outlet of the Mississippi River is repeated at another location. Thus, the lakes and depressions will be filled in, the channel will meander more, the lower Basin will be transformed to dry land, and new land will be created in what is now called Atchafalaya Bay. This is the work of water, termed geomorphology, and in the long run, man cannot change it although, by vast expenditures of treasure and energy, he can modify or delay it for a time.

Overview

The discussions of hydrology and geomorphology, brief though they are, are needed so that the specific deductions reached later can be understood. The frequency of the recurrence of a major flood for instance, depends on the interpretation and evaluation of hydrologic data. It has been shown that the validity of the data base has been reduced by the construction and operation of such mundane works as rural storm drainage systems, channel straightening, bank stabilization, and reservoir construction and operation. All of these activities have resulted in a decrease of small, annual losses that would otherwise have occurred to those persons and communities benefitting from the projects. As an unintended side-effect, the hydrogist finds that evaluation of new downstream projects has become increasingly difficult and uncertain.

Identical weather conditions now produce floods of greater magnitudes and higher river stages. On the other hand, dry weather discharges have become lower and water levels in rivers during periods of low flow have become lower.

In effect the water velocities and flood discharges to be handled by the ORCS during its lifetime are likely to be higher and more frequent than computations based on the original observational data would indicate.

The low-flow discharges provide a mirror-image picture: The low flows will be lower and the resulting invasion of the main stem of the Mississippi River by salt water is likely to become more frequent and more severe than earlier analyses might indicate. This implies that shortages of fresh water will occur at the intakes of municipalities and industries.

The geomorphology of the river is affected by the aforementioned changes in hydrology. The degradation of the Atchafalaya River bed below the ORCS not only changes the drainage characteristics of lands in the upper Basin, it also threatens all river crossings as well as the integrity of the control structure itself. At the lower end of the Basin silt deposition and flooding must inevitably occur, probably at a more rapid rate than had previously been calculated.

The time-frame is, therefore, short. At present the ORCS, the Basin, and industrial, commercial, or municipal structures along the lower Mississippi River are in immediate danger. The Corps of Engineers is planning to build an auxiliary structure to purchase more time. The questions are "How much time?" and "What do we do?", "What happens if we do nothing?" and "What happens if a flood occurs before the auxiliary structure is finished?"

VI

CONSEQUENCES

Introduction

Those factors which will cause an eventual failure of the ORCS were discussed in the previous section. The purpose of this section is to discuss some of the consequences of the failure. It should be noted that many of these effects could occur even if the ORCS did not fail. For example, if a flood slightly greater than the 1973 flood were to occur, then, even if the ORCS were to remain intact, there would still be extensive flooding and damage in the Basin. Other impacts, such as salt water intrusion and extensive silting of the Mississippi River below the ORCS would occur only if the structure were to fail.

The discussion of the consequences in the following pages is not an exhaustive one because of time and resource constraints. Where possible, we have tried to provide quantitative estimates but, in many cases, we could only describe the consequences in qualitative terms.

Salt Water Intrusion

The bed of the Mississippi River is below sea level for more than 350 river miles above the Head of Passes (AHP), to about the latitude of Natchez, Mississippi. The thread of the channel, usually called the "thalweg", does not descend smoothly. It is a winding, undulating surface which, in the latitude of Old River, ranges in elevation from 10 ft below sea level to almost 100 ft below sea level. The channel scours during floods and fills as the flood waters recede. So much silt is deposited at the mouth of the Mississippi that continuous dredging is required. Hence, once the Mississippi River is diverted, the silt will then be deposited at the outlets of the Atchafalaya.

Salt water from the Gulf, once it crosses the bars, or deposits of sediment, in the passes of the Mississippi, has a constant potential for moving upstream. Because salt water is denser than fresh water, it advances upstream on the river bed. The vanguard, shaped somewhat like a long blunt wedge, similar to a rubber door-stop, is pushed forward by an increasingly thick layer of saline water.

Counteracting this advance is the turbulence of the river water, which continuously erodes the tip and the upper surface of the wedge and carries the resultant mixture downstream. The rate of salt water erosion depends on the velocity, and hence the discharge, of the fresh river water. Normally the erosion rate prevents upstream penetration by the salt water wedge much beyond Venice, La. However, during long periods of low water the salt water wedge may reach Algiers, Kenner, or points even further upstream. Should the discharge remain low for a sufficiently long period of time (from 6 to 9 months) there is no reason to believe that the wedge would not reach Baton Rouge.

There is nothing in the foregoing discussion that will be news to those familiar with the Mississippi River. The Corp of Engineers and the U.S. Geological Survey make periodic salinity traverses of the Mississippi River during periods of low discharge in order to determine the precise position of the tip of the salt water wedge and its rate of movement upstream. The positions of the saline water interface for the years of significantly low discharge are available from the New Orleans District Office of the Corp of Engineers and the information concerning a typical movement of the salt water wedge based on the Corp's data was published in 1973 (Kazmann and Arguello, Fig. 4.3).

The year after the postulated destructive flood and the failure of the ORCS, there will be nothing to stop most of the fresh water from going into the Atchafalaya. If only 70 percent of the water is diverted, then in a normal year when the low flow at Vicksburg might be below 250,000 cfs, only 75,000 cfs might be available in the main stem to erode the wedge. This would be a flow that is equivalent to the lowest discharge on record at New Orleans and there is no doubt that the saline water would reach the intakes of New Orleans, Kenner, and some points upstream. If this situation continued for more than 6 months, saline water might ultimately reach the Baton Rouge area.

The salty river water poses innumerable problems for the citizens, and the industries that are their source of livelihood. A brief listing includes the drinking water supply, water supply for industrial processes, and the supply of cooling water for all purposes, including the production of electricity. Less immediate is the inevitable contamination of much of the alluvial ground water by the encroachment of salty river water as it replaces the water drawn by the water supply wells.

The Mississippi River is the source of drinking water for most of the residents of the industrial corridor from Donaldsonville downstream. This includes the entire population of Bayou Lafourche, including the City of Thibodaux, as well as the citizens of Orleans and Jefferson Parishes. A few towns located along the Mississippi, such as Baton Rouge and LaPlace, obtain their drinking water from deep wells.

When the water becomes contaminated by salt, all of the river intakes will have to continue to operate and to pump salty water into the mains. City water pressure must be maintained for fire-fighting purposes. However, since salty water is corrosive, the devices using river water where the water is heated (boilers, domestic hot water heaters, etc.), will tend to corrode first. The water mains will begin to leak in many places somewhat later. A direct cost of the salt water will be the ruination of irrigated lawns and home gardens.

There are ample sources of drinking water that could, and would, be used in an emergency. In the New Orleans area, the geologic formation known as the 700-foot sand already produces potable, but colored, water. Water distribution points would be set up near those industries that now operate wells producing from this sand and drinking water would be available. The 400 ft sand formation in some parts of Jefferson and Orleans Parishes, might also be used as a source of local water supply. In addition, water could be trucked in from St. Tammany Parish. The price of a gallon of water would increase by at least a factor of 100 as compared with the present (1980) cost of pumping it from the river, treating it, and putting it into the mains for distribution. The containers and transportation costs alone would mandate most of the price increase. Well drillers will probably be in great demand.

On the East Bank of the river the drinking water situation would be eased by the availability of ground water in certain areas around the Shell plant at Norco to some areas upstream. Although the quality might be lower than desirable because of the presence of iron in some of the ground water, it would be drinkable and available locally, thus eliminating long hauls and making every water truck much more effective. Ground water in the Baton Rouge area has been studied intensively (Rollo, 1969; Kazmann, 1970; Smith, 1979; Whiteman, 1979). Information on the availability of groundwater elsewhere has been published jointly by the La. Dept. of Conservation (Now part of the Dept. of Natural Resources) and the La. Dept. of Public Works (now a unit of the La. Dept. of Transportation), the La. Geological Survey and the United States Geological Survey (Long, 1965; Rollo, 1966; Winner, Forbes and Broussard, 1968; Harder, Sauer, and Broussard, 1968; Hosman, 1972; and Whiteman, 1972).

Industrial Water:

It is difficult to describe adequately the effects on industrial production and employment should the river water become salty. Downstream from Moissant Airport, or Kenner, it will not be feasible to replace river water by well water except in certain limited areas, underlain by the 400 ft sand or the 700 ft sand formations. In most of the area the underlying formations contain saline water, especially under the West Bank. Thus, plants that use water for the production of steam, or in the industrial process itself, may face difficulties in adequately treating the water, which carries the implication that they must either shut down or sharply reduce output.

The steam-electric generating plants that use processed river water for boiler-feed will have trouble with the excessive salt content in the river water. Upstream from Kenner the area is underlain by some aquifers containing saline water, and others containing fresh water. Thus for plants that seem to be favorably situated such as the Little Gypsy generating plant of Louisiana Power and Light Company, for example, wells might be drilled to produce fresh water in ample supply for boiler feed.

Even if the process and boiler feed water sources could be replaced, the major problem would be the quality of the supply of cooling water available for plant use. Although saline water is currently used elsewhere for the cooling of condensers in steam-electric generating plants, including nuclear-fueled generating stations, these are all located on or near the coast line and corrosion resistant materials were used in the construction of these plants.

The industries and the steam-electric generating plants situated along the Mississippi River were designed to use fresh river water for cooling and make-up purposes. Some of the industries, especially those between Donaldsonville and Baton Rouge, utilize wells as their source of water supply and sometimes use cooling towers in conjunction with the ground-water supply. This is done because of the relatively high initial expense of a river intake and the hazards connected in maintaining and operating it. The industries and generating plants that are based on river water will find that their operating problems are compounded when the water turns salty. Corrosion of the heat exchangers will mean that extensive retrofit expenditures will replace the former relatively low cost of maintenance. The cost of enforced shut downs is likely to be the most significant cost.

Even more serious is the problem posed by the successive reuse of water by many industries. At present (1980) the discharge of the river is so large that the increase in water temperature due to the discharge of spent cooling water is difficult to measure at a distance of a mile or two downstream from the discharge point. But when the flow of the river decreases, due to the diversion of water down the Atchafalaya, the velocity of the water will decrease dramatically and the temperature of the water in the vicinity of the intakes will tend to rise, not only from the addition of heated water from upstream plants, but also from the "short-circuiting" of the heated water discharged from the plant itself to its river intake.

Thus the sea-change in the hydrology must inevitably cause changes in the industrial processes and these changes will increase costs and decrease productivity even if all other conditions remain the same.

Collapse of Highway and Railroad Bridges

One of the most significant potential effects of ORCS failure would be the collapse of the highway and railroad bridges crossing the basin. There are four major highways and four railroad lines either crossing the basin at approximately right angles, or approximately paralleling the basin in a southeast to northwest direction.

Although no bridge is very likely to fail as a direct result of the velocity of the water, it is quite possible, as explained in a previous section, that the major piers of the bridges could be undermined by the scouring activity of the Atchafalaya River. The bridge most likely to fail is the Interstate 10 bridge over Whiskey Bay. During the 1973 flood a scour hole deeper than the depth of the centerline pier (-185 ft) was observed progressing toward the I-10 bridge.

The next bridge most likely to fail is the one carrying US 71 and US 190 traffic across the Atchafalaya, at Krotz Springs, Louisiana. Louisiana Highway #1 which crosses the Atchafalaya at Simmesport is subject to scouring and it has about the same probability of failure as the US 190/71 bridge. Least likely to fail would be the US 90 bridge across the Atchafalaya located near Morgan City, but portions of the road bed would be flooded and subject to erosion.

If the ORCS fails, the failure would probably occur during the height of a severe spring flood and considerable scouring would occur in those sections of the Atchafalaya where the river bed is sandy and where the river is constrained within a narrow channel. Although the conditions in the vicinity of the I-10, US 190/71 and Louisiana Highway 1 are relatively more favorable for serious scouring than they are in the vicinity of the US 90 bridge, we cannot state that they definitely will fail; nor can we estimate the probability of failure very accurately. We do know, however, that there is a definite possibility that they will fail. Consequently, some of the costs of such failures should be examined.

Three types of costs are associated with any bridge failure. One is the cost to the state and federal governments (the general public) of replacing the bridge, and the second is the additional cost to the driver and vehicle owner resulting from the need to detour around the bridge, the third is the cost, in time, of delays and trips, not taken for this reason.

The estimated cost of replacing the five bridges (US 90, US 190, La. 1, and the I-10 bridge) is $65 million in 1977 prices. Because some roadways and approaches of the highways crossing the Basin might also be damaged, it is estimated that the total cost of the ORCS failure on all four major roads crossing the basin would be $75 million. Because US 90 would most likely not be significantly damaged, except for roadside erosion, the estimated cost of the four bridges failing on the three ramaining major roads is approximately $60 million (1977 prices).

In addition to the cost of replacing major public highway facilities, private citizens and firms, and other public agencies, would have to bear the cost of detouring around the Basin. The worst case would involve the closure of all four major highways across the Basin; a more probable case would involve the closure of I-10, US 190, and La 1. We estimated the cost under two scenarios. One was the failure of I-10 and US 190; the other was the closure of all four roads.

Two distinct types of additional costs will exist in the event of a failure. One is the additional cost associated with the vehicle: maintenance, fuel and tires and oil. Based on 1977 estimates provided by the U.S. Department of Transportation and the Hertz Corporation, the variable cost per mile of operating a car in 1977 was 12.2 cents and the variable cost of operating a truck was 24.4 cents per mile. Utilizing traffic counts of automobiles and trucks crossing the Basin on each of the four highways we were able to estimate the additional operating costs in the event that all four highways were closed.

The most heavily travelled highway is US 90 which carries 14,000 automobiles and 3,800 trucks each day [1977 data]. I-10 carries 10,200 automobiles and 3400 trucks each day. US 190 and La 1 each carry approximately one-half of the volume of I-10. Total detour mileage varies from 302 miles for those utilizing US 90 to 159 miles for those using La 1. These detours are calculated on the basis of utilizing suitable two lane roads. Traffic from points east of New Orleans which is traveling to destinations west of the Louisiana/Texas state line, or the reverse, will probably use the interstate system which involves a longer detour but on better roads. In the latter case, the detours would involve 315 miles.

Should four major highways be blocked, the total additional operating costs imposed by the shortest detour are $1 million per day for automobiles and $553 thousand per day for trucks. If the detour period lasted 6 months, the additional operating costs would be $280 million.

More important than the additional resource operating costs involved in the detours is the value of additional time spent by the occupants of the vehicles. This time has a positive value to those who are traveling on business and to those traveling on leisure. Using conservative estimating techniques the value of the lost time of the drivers of medium and large trucks amounts to $409 thousand per day and that of automobile occupants totals $736 thousand per day. The total value of time lost is $1.1 million for each day. Total value of time lost during a six month detour period would be approximately $206 million, and if the detour should last a year the total cost would be approximately $418 million.

A third category of costs would be those imposed on the general public by delays in transportation or trips not taken. We made no estimates of such costs because it was assumed in the foregoing estimates that all trips taken on these highways in 1977 would be taken on the detour routes. Of course some trips would not be worth the additional cost of the detour and would not be undertaken. The upper bound of the loss incurred by those not taking the detours are included in the detour cost estimates and if they were to be estimated separately there would be double counting. Total costs of additional operations and value of time lost would be approximately $2.7 million per day or $500 million for a six month detour period, and $1 billion for a one year detour period.

It is unlikely that the bridge piers of all four major highways would be undermined. A more likely scenario would involve only the closure of I-10 and US 190. The additional operating costs for automobiles would be $124 thousand per day and for trucks it would be $65 thousand per day. The value of time lost in detouring would by $155 thousand per day for trucks and automobiles. Total detouring costs would be $360 thousand per day or $66 million for six months, and $132 million for one year.

Although there are four railroad bridges crossing the Basin, only two are currently in service. Based on operating cost data provided by the Association of American Railroads, we estimate the daily detour costs to be $103 thousand with costs of a one year detour period equal to $38 million. Both bridges were built in the early part of this century and we could not estimate the replacement costs because such bridges are not being built today.

Flood Damages

There would be two flood related consequences of the failure of the Old River Control Structure. First, there would be a rapid flooding of the lands within and adjacent to the Basin immediately following the ORCS failure. Second, until new flood protection measures were put into place there would be periodic floodings during the Spring season. Approximately 140,000 people and three million acres are located within the flood-prone area. Principal towns affected by the flood include Morgan City, Berwick, Melville, Krotz Springs and portions of Franklin, Houma and Thibodaux.

The land within the Basin will be flooded at the time of the ORCS failure and would be subject to frequent, if not permanent, inundation after that. This area contains approximately 60,000 residents and private real property wealth of $380 million. Many of the buildings and other forms of permanent construction situated on the land would lose virtually all value, although the land in some areas, especially that land which would drain between the floods, would retain some positive value for grazing, fishing and hunting purposes. Also, as pointed out in a previous section, the geomorphological changes will result in some land being drained more efficiently. This newly drained land, however, will be subject to periodic flooding.

Total private property losses inside the Basin are likely to amount to about 40 to 80 percent of total value. If the mean of 60% is utilized, total losses in 1977 prices will be $228 million.

Certain lands outside of the Basin would be subjected to the initial flood and subsequent periodic flooding until flood protection systems could be improved. During the 1973 flood, some lands located outside the Basin were underwater for two months. Approximately 81,000 people live in the area which has an estimated total property value of approximately $480 million. During the 1973 flood, damages were equal to approximately seven percent of the property value in the area flooded. Applying this seven percent to the larger areas which could be flooded yields an estimate of approximately $34 million. This estimate, unlike the one for the losses within the Basin, is for the one time flood. Subsequent floods would cause additional damages.

The estimate of $34 million is based solely on the damages expected to result from the first flood. Subsequent floods could occur which would have the effect of significantly increasing the estimate of the cost of flood damages outside of the Basin. The damage estimates for the area within the Basin were based on the premise that the area would be subject to constant flooding and that the initial drop in property values would reflect these periodic but frequent inundations.

Total losses inside and outside the Basin are estimated to total $262 million. St. Mary Parish would be most seriously affected with losses of $168 million.

In addition to the losses of private property, the failure of the ORCS would result in considerable losses to the public sector. According to the 1973 Post Flood Report of the Corps of Engineers, the principal categories of expenditures for flood-related activities included the strengthening of levees and floodwalls, raising of the Atchafalaya Basin guide levees, sand bagging, plugging culverts, emergency pumping operations and patrolling. Governments also expended funds to repair damaged roads and highways, to provide relief to refugees and to issue emergency food stamps. Total damages sustained in the Atchafalaya Basin were nearly $37 million, of which government damages and expenditures were $11.5 million, or about 31 percent of the total. Losses in the Mississippi-Atchafalaya Basin to the east were approximately $2 million or 12 percent of total damages suffered in the area.

In the event of an ORCS failure, much of the land will be perennially and possibly permanently inundated. Government funds might be used to evacuate the Basin and to provide possible levee construction for Morgan City and other inhabited areas within the Basin. The major losses would be the capital losses of those public facilities located within the Basin. Data which could be used for estimating capital losses do not exist, and could not be developed for this study.

Total estimated private property losses outside the Basin are $34 million. Applying the same percentage as that which existed for the area inside the Basin during the 1973 flood (31%) would yield estimated public sector damages of $11 million.

Included in the losses to the government might be the replacement values of the ORCS complex which is conservatively estimated to be $200 million. Total public sector losses, excluding those within the Basin, would total more than $271 million.

Fishing Industry

One of the major sources of income to the residents of southern Louisiana is the fishing industry. The total value of fish and shellfish landings in Louisiana during 1977 was $139 million of which 63% were shrimp landings and 7.5% were oyster landings. Forty-six million dollars of shrimp and four million dollars of oyster landings were reported for the central district of Louisiana, which includes the coastal and bay areas extending from Bayou La Fourche to Bayou Teche. Thus, $50 million in landings could be affected by changes in the characteristics of the water flows in the Atchafalaya Basin.

Both shrimp and oysters are affected by the temperature and salinity of the water. A decrease in either the salinity or the temperature of the water could destroy the shrimp nurseries and oyster beds. The primary danger is that the failure of the ORCS would result in a greatly increased flow of fresh and cold water in the Atchafalaya Basin. The influx of these waters into the brackish waters of the lower basin and adjacent coastal areas would very definitely increase the mortality rate of oysters and shrimp. Oystermen with leases on beds in the affected areas and those shrimpers who traditionally shrimp in particular bay areas would suffer some losses. The extent of these losses would depend on the time of failure and on the ability of shrimper and oystermen to harvest their catch before th high mortality rates are realized. In the short run (1-2 years), it can be expected that there will be a lower harvest, although the resulting higher prices might cushion the losses to the shrimpers and oystermen. A number of empirical studies have found the retail price elasticity of demand to be price inelastic. The estimated elasticity coefficient ranges from -0.05 to 0.63. The consistent finding of price inelasticity is important because it means that a decrease in supply will result in an increase in total revenue spent on shrimp.

Despite short run losses, the net long run effect on the supply of shrimp and oysters will most likely be positive because the tons of sediment and nutrients which are currently deposited into the deep sea off the mouth of the Mississippi River will be distributed throughout the central and western coastal region of Louisiana. Unlike the Mississippi River, which is constrained into a narrow channel until it meets the deep sea bed, the lower Atchafalaya is unconstrained and its overflows very quickly spread throughout the area of shallow marshland. This process will enlarge the fertile brackish area in which oysters and shrimp can thrive. The long term increase in the shrimp and oyster nursery areas appears to be the only significant positive result due to an ORCS failure, aside from improved navigation on the lower Mississippi River.

Natural Gas Pipeline Failure

The seven major interstate gas pipelines which cross the Atchafalaya Basin are vulnerable, in some degree, to disruption by flood waters subsequent to an ORCS failure. These pipelines provide major portions of the natural gas delivered to several eastern and south eastern states. For example, Georgia, Rhode Island, North and South Carolina, Florida, Connecticut, and New Jersey receive much of their natural gas supplies through these pipelines.

The primary threat to the continued viability of the pipelines is the scouring action of flood waters which produce large holes in the river bed. These may expose the pipelines to the impact of debris and vibrations. One major and four minor pipelines in the Basin were ruptured during the 1973 flooding.

All of the major pipelines crossing the Basin are not equally vulnerable to the failure. The age and condition of the pipeline, the type of crossing (aerial or submerged), depth of submerged crossings, subsoil characteristics, and the width of the channel at the point of crossing are all important parameters. Based on these characteristics the pipelines can be arrayed into three categories of relative likelihood of failure.

The two pipelines which are least likely to fail constitute Category I; the pipelines which are considered next most likely to fail constitute Category II; and those pipelines which are most likely to fail constitute Category III.

Data on the quantity of natural gas crossing the Basin and the distribution of this gas among the states east of the Mississippi were difficult to obtain. Piecing together information from the gas pipeline companies and the Federal Energy Regulatory Commission, it is estimated that 15 percent of the natural gas consumption in 28 eastern and southern states passes through the Basin. If all of the pipelines crossing the Basin should fail, there would be a daily shortage of 3.8 million mcf with a value of $3.5 million (1977 prices). The value of the gas lost is not a direct loss to society because only the gas in the vicinity of the break would be lost. The gas which is not delivered could be stored in abandoned wells, salt domes, and other storage facitlities until the line was repaired or rerouting arranged. The economic effects, to the extent they occurred, would be realized initially in those sectors of the economy in which the natural gas was distributed or used as boiler fuel or fuelstock. Utilities, petrochemicals and similar industries would be affected in the first round of impact, but as the income and profits of those employed in these industries decreased other industries would sell less, and the incomes of those employed in the industries affected by this secondary round of impacts would also decrease.

In order to estimate the decrease in state gross output, employment and income a technique known as input-output analysis was utilized. Employing this technique we were able to estimate the economic impact on each state. Input-output analyses are subject to numerous conceptual and data limitations so the results should be viewed with caution. Input-output analyses were applied to each of three seperate assumptions about pipeline failure. The first assumption is that the pipelines in all three categories will fail. The results on a daily basis of this worst case scenario are presented below:*

	Per Day
Shortage of Natural Gas	3,800,000 mcf
Reduction in Gross Output	$6,900,000
Reduction in Income	$8,400,000
Unemployment	88,000

* See Addendum B for additional details and for the estimated impacts on the various states.

The most seriously impacted states, with their percentage of natural gas consumption crossing the Basin shown in parenthesis, are: North Carolina (52.1), New Jersey (46.7), South Carolina (42.1), Delaware (40.9), and Georgia (39.4). The states with the greatest employment impact are New York (11,000), Pennsylvania (11,000), Georgia (8,600), and New Jersey (8,200).

The second scenario is one in which the five pipeline systems in Categories II and III fail:

	Per Day
Shortage of Natural Gas	2,400,000 mcf
Reduction in Gross Output	$4,500,000
Reduction in Income	$5,400,000
Unemployment	56,000

The states which would be most significantly affected, and the percentage of their natural gas consumption shown in parenthesis, are Georgia (33.5), Alabama (27.7), South Carolina (26.7), and Connecticut (23.0).

The third scenario is one in which it is assumed that only the two pipelines in Category III will fail:

	Per Day
Shortage of Natural Gas	500,000 mcf
Reduction in Gross Output	$ 900,000
Reduction in Income	$1,200,000
Unemployment	12,000

One of the most indeterminate aspects of this research was evaluation of the capability of the pipeline companies with ruptured pipelines to reroute their natural gas to their intended destinations. Pipeline companies have many interconnection points with other pipeline companies and, where none exist, connections of crossing pipelines can be made within a couple of days. Obtaining properly sized compressors could require six months. The principal difficulty is equallizing the pressure between two lines to be interconnected.

When Florida Gas Transmission Line was ruptured during the 1973 flood, the company was able to reroute the gas without any appreciable loss in gas deliveries in Florida. If only the two pipelines in the most vulnerable category were to be ruptured, it would be possible to reroute the natural gas, but if the three pipelines in the next most vulnerable category were to be ruptured, it is uncertain whether rerouting alternatives would have sufficient capacity to insure continuation of deliveries. Generally, distribution companies maintain a supply of natural gas in storage sufficient to make up as much as several days of normal use and it is unknown whether alternative routes could be identified and utilized within such a period of time. Construction of a new pipeline across the Basin would take approximately 6 months to a year and would have to be accomplished during a period of low water.

The only conclusion we can reach is that some natural gas pipelines are vulnerable to rupture in the event of an ORCS failure. Some locations, especially southeastern Louisiana might experience at least temporary shortages of natural gas and possibly electricity. Widespread and prolonged disruption in natural gas deliveries are unlikely unless most of the major pipelines are severed.

Losses for Which No Quantitative Estimates were Made

Despite our best efforts there remain a number of economic losses, or costs, to which, we have been unable to attach dollar values. Some of these are impossible to quantify. For example: what dollar value is to be placed on the extensive kill of land animals that will occur as the direct result of flooding the Basin? Some of the other consequences, like the decline in the production of shrimps and oysters, are temporary in nature but it is not feasible to place a price tag on the losses: neither the duration of the period of low production nor the extent of loss is determinable.

There are other types of losses that could be quantified if sufficient data were available. For instance, the costs of additional cooling tower equipment to enable industries to utilize smaller amounts of water for purposes of heat exchange and heat sink. Another example: if enough data were available it might even be possible to determine the relocation costs of residents, and of moveable property, located in the Basin.

Probably the simplest method of summarizing the losses that cannot be quantified at this time is a simple listing:

Table 2

Partial List Of Losses That Have Not Been Quantified

1. Prelocation costs of residents (and moveable property) located in the Basin.

2. Capital cost of water conservation equipment, mostly cooling towers and water treatment equipment, in the Baton Rouge - New Orleans industrial corridor.

3. Losses due to the disruption of oil and gas production in the Basin and damage to facilities due to flood waters. Approximately one half of the 800 producing wells were shut-in for some period of time during the 1973 flood. After the initial flooding, the generally higher water levels in the lower Basin might necessitate the raising of controls on some wells or the construction of new or higher levees around the existing facilities.

4. Disruption of oil and gas exploration, development and production in Louisiana and the Gulf of Mexico because of loss of support facilities caused by extensive flooding in the Morgan City-Houma area.

5. Temporary or permanent shut down of construction facilities for the building of off shore platforms.

6. Effects of possible brownouts or selective blackouts due to the saltwater wedge which would interfere with the production of electricity by plants located on the Mississippi River south of the ORCS. There would be additional costs involved in retrofitting these generating plants for the use of brackish and salty water or for the use of cooling towers or cooling ponds.

7. Construction and maintenance of ring levees and pumping plants and other flood protection measures in and near the Basin.

8. The possible construction of a lock and dam around the reach of the Mississippi just downstream of the ORCS, a reach that is expected to shoal shortly after the diversion of the discharge down the Atchafalaya.

9. Possible replacement of high voltage transmission towers that cross the Basin. Although the cost of a single tower ranges from $500,000 to $1,000,000, the number that might be affected is indeterminate.

10. The cost of replacement of the wildlife (rabbits, deer, squirrels, etc.) that drowned during the flood.

11. The costs and disruption that will follow the decrease in shrimp and oyster production.

A related concern of the research team was that there could be serious shortages of electricity in some parts of the East and the South if a number of pipelines in the Basin were ruptured. Except for Southeastern Louisiana, Mississippi, and Florida, this concern seems to be unwarranted. Most eastern states use natural gas to generate less than one percent of their electricity, which means a total cessation of natural gas deliveries would have relatively little impact on the availability of electicity. Southeastern Louisiana, Mississippi, and Florida could feel some impact if many of the seven pipelines were ruptured but the ability to convert some of their gas-based generating units to oil and their ability to purchase power would lessen the impact of all but total cessation of natural gas deliveries.

VII

OPTIONS & ALTERNATIVES

General

The time scale of any process is of utmost importance to those who must live through it. In terms of conventional geology, a century is only an instant and millenium is not much longer. In terms of human existence, a century is a long time: sufficent for four generations to participate in adult activities. The gas and oil provinces that produce the resources that are presently transported across the Basin are not likely to maintain production for more than 30 or 40 years under the most optimistic estimates of reserves. Thus if we use 30 years as our time frame for this preliminary look at possibilities for mitigating or averting disasters, our time-scale is applicable and reasonable.

Many of the impacts of an ORCS failure were summarized in previous sections. Viewed over a 30 or 40 year time scale, the problems we confront become manageable, in principle, if our goal is to overcome temporary difficulties and make ourselves more secure. Thus the suggestions, and discussions of alternates, found in the following pages are aimed at modifying the physical arrangements (and probably a few economic arrangements) from the present condition of extreme and immediate hazard to one that is more susceptible to being maintained. Stating it differently, the Citizens would have to abandon their conflict with the forces of geomorphology and undertake to adapt themselves to the action of these forces.

It is a truism that since all things cannot be done at once, choices must be made. Recognizing that the available information is neither detailed nor extensive enough for definitive choices, the following items are listed in terms of tentative priority. If the writers had to make personal decisions on priorities, this is the order that projects would be undertaken. This listing should not be interpreted as meaning that one project must be completed before another project is started because the projects might overlap. In absence of funds to do everything at once, some priorities have to be established.

The Old River Control Structure

The first priority must be to prolong the effective life of the Old River Control Structure. The Corps of Engineers is already working on the design of an auxiliary low-sill structure just downstream from the existing structure and the new facility, when completed, will remove some of the stress from the existing complex. The auxiliary structure would be operated in conjunction with the existing low-sill structure thus restoring the complex's capability to handle its orginally designed flow. The estimated cost, as of August 1979, was $185,000,000. Specifically the new unit will a) reduce the discharge per foot of width at the existing low-sill structure by from 30 to 40 percent and reduce the potential for scour damage; b) reduce the liklihood of marine accidents; and c) facilitate routine inspection and maintenance and make possible major repairs on the existing structure. Construction is tentatively planned to start in 1982, and will require approximately 3 1/4 years to complete if all work proceeds according to plan.

The Pipeline Crossings

One low cost alternative of minimizing the impact of pipeline failure would be the development of a plan of joint cooperation among the various pipeline companies. Where pipelines physically cross each other or come fairly close to one another, it would be relatively simple and inexpensive to make interconnections on both sides of the Atchafalaya Basin. It might be a desirable form of insurance to stockpile compressors to equalize interconnection pressures. As an alternate, some organization should be made responsible for determining, currently, where the proper compressors could be found. This simple procedure would increase the flexibility of routing natural gas through alternative pipelines in the event that one or more pipelines were severed.

Another, but more costly alternative, would be the construction of aerial crossings of the Atchafalaya River designed specifically to withstand flows of 2,000,000 cfs or more in the river. The operators of pipelines are already turning toward aerial crossings of the Atchafalaya River in lieu of submerged pipelines. It seems likely that in the normal course of events, as the time comes to replace the sub-river crossings, the replacements will be aerial crossings. It would, however, be highly desirable for individual pipeline companies and the Federal Energy Regulatory Authority to actively promote intercompany cooperation in the building of a number of aerial crossings, to allow several companies to use the same piers and suspension bridges, and to allow such increases in rates as will prove necessary to accomplish these improvements at the earliest possible data. This aerial crossing construction project is nothing more than an insurance policy which should be put in place at the earliest possible moment.

A more costly alternative to aerial crossings would be the joint construction of a pipeline on the west side of the Atchafalaya protection levees which would cross the Mississippi north of the Old River Control structure and then proceed southward to interconnect with the various pipelines crossing the Atchafalaya.

Another option would be for the consortium to directionally drill (from the surface) a tunnel far under the Atchafalaya River bed, say to a depth of 250 ft below the present river bed, a depth which would probably make it safe from even the deepest scour holes. A large diameter pipeline would be placed in such a tunnel. Although not yet widely used, directional drilling of deep pipeline crossings is a technology that is proven. As this is written, in 1980, the firm of Reading and Bates is placing a 30-inch steel pipeline under the Profitt Island Chute of the Mississippi River by the use of directional drilling techniques. This could be done for major pipelines that cross the Atchafalaya.

Highway and Rail Transportation

The potential for undermining of the piers and pile foundations of the highway and railroad bridges by the Atchafalaya River has already been observed (Horne, 1976 pp. 11-19). By actual measurement, the bottom of the river some 800 ft. downstream of the Whiskey Bay crossing of Interstate 10 in 1975 was about 5 ft. below the base of the channel piers. Similar data is available for other highway crossings and there is no reason to believe that bridge piers of railroads that cross the Atchafalaya, and which were constructed decades ago, are immune from undermining.

In principle, there are at least two possible methods of preventing these various sets of bridge piers from being undermined. The first would be to build another set of piers near the first, with the base elevation of the new piers set much deeper than those now in existence. Then the bridge loads would be transferred from the existing piers to the new ones. Although the writers know of no such transfer of load involving bridge piers, similar transfers of load have been accomplished by firms such as Spencer, White and Prentiss, in replacing the foundations of multistoried structures. It is at least possible that this could be accomplished and the possibility should be investigated.

The second method would involve the in-situ solidification of the sands surrounding and underlying the present bridge piers. This would consist of the injection of solidifying agents such as the one formerly produced by the American Cyanamid Company, AM-9, through wells drilled in the vicinity of each foundation. The solidification would extend from the present river bed down to, possibly, 100 ft. below the present piers and should probably encompass a circle with a radius of possibly 200 ft. with the pier in the center. Although such solidification of unstable ground has been used by the mining industry in shaft sinking and in the pushing of drifts through water-saturated broken rock or sand, the application to bridge pier stabilization, has not, to the knowledge of the writers been attempted.

There are other methods of protecting bridge piers from undermining, such as the placing of sheet piles to the required depth, but no attempt has been made to delve deeply into the possibilities since the need for obtaining the required technical expertise was not forseen when the study was originally planned.

Flood Protection

The magnitude of a flood that is contemplated in the 198X scenario is not one that will be contained by the Atchafalaya protection levees at their present grades. Admittedly there are physical problems with constructing the levees to any particular grade because of the nature of the underlying soil in certain areas. There are also financial problems, although the cost of earthwork has not escalated as rapidly as other construction activities due to improvements in earth moving equipment and the increased efficiency and productivity associated with these advances. It would probably be wise for each municipality that may be subject to flooding in and near the Basin to provide for its own protection through the construction of a ring levee.

Federal funds from existing programs might be available to finance part of the cost of local ring levees although in the absence of available Federal funds, communities such as Thibodeaux and Houma could and should protect themselves from flooding.

The problems of Morgan City and its environs are of such magnitude that the writers believe that probably nothing less than a third Gulf outlet can save the community from a disaster in the time-frame with which we are dealing. A ring levee of adequate height together with the needed pumping facilities would provide some added protection to Morgan City but on a longer-term basis it is doubtful that any community located in this area, or in any area of similar geomorphology, can survive. The sediments under it are compacting, the land surface surrounding it is slowly rising in elevation due to sedimentation, and the river levels for a given discharge are, and have been, increasing. Lacking a third major outlet for the Atchafalaya, there is little prospect that Morgan City will survive the next major flood - and should the ORCS be destroyed or by-passed, the chances approach zero.

In a somewhat parallel fashion, the major industries and steam-electric generating plants should organize to protect their physical plants by means of levee construction. It should be made clear that ring levees in themselves will not prevent flooding - they must be supplemented with pumping stations to get rid of internal drainage due to storm water. The organization of levee districts and the construction of ring levees where needed is not something to be accomplished overnight. A time frame of 5 or 10 years is more realistic.

Water Supply

Even if the ORCS is destroyed or by-passed the physical facilities along the present main-stem of the Mississippi river should survive essentially undamaged. This statement would apply to the East Bank and possibly to the West bank, depending on the efficacy of the ring levees that might be available to protect the cities and industrial sites. The real stress on this area, after all the power failures and transportation problems have been overcome, will come during the first low-water period after the flood subsides.

As with other floods, dredging the mouth of the Mississippi to restore the silted outlet would be undertaken to restore navigation at the earliest possible moment. As mentioned in the scenario, navigation on the Mississippi should be no problem once the silt is dredged out of the passes. However, another very serious problem will manifest itself as the discharge through the present main-stem decreases, both because of diminished drainage from the Mississippi's water shed and the increased diversion of water through the Atchafalaya outlet via Old River. The saltwater "wedge" will move upstream. When the transition from a freshwater channel to a saline estuary has been completed, all persons and organizations using the freshwater of the Mississippi River will confront the same situation - lack of an adequate and dependable potable water supply. The dimensions of the problem can be outlined by the presentation of some statistical information on water use.

In 1975 industrial and municipal pumpage of surface water from the Mississippi River downstream of St. Francisville, La. totalled approximately 2.6 billion gallons a day; pumpage for thermo-electric plants totalled 3.7 billion gallons a day (Cardwell and Walter, 1979). Translated into terms of cubic ft. per second, the total is approximately 9700 cfs. By way of comparison, the low flow of the Ohio River at Cincinnati has been less than 10,000 cfs many times during the period of record which means that the equivalent of the low flow of the Ohio River would be needed to replace current water supplies. This rate of pumpage would have constituted about 13 percent of the flow below Old River on November 4, 1939 (75,000 cfs) which is the lowest flow recorded at that point. In the event of a failure of the ORCS the writers do not believe that it is realistic to plan to deliver this quantity of water, uncontaminated by salt, to the thermo-electric, industrial plants and municipalities now situated on the river banks.

As part of this study, Professor John R. Harris, a professional engineer, has evaluated the problem of alternate water supply. He has assumed that if freshwater were made available, cooling towers, that require only make-up water, could be constructed to replace the once-through cooling systems now in use by the various plants. He has also prepared a preliminary engineering analysis of the problems involved in finding, developing, and providing alternate fresh water supplies to the entire industrial complex as replacements for municipal supplies that are river-based. His report constitutes Addendum A of this Bulletin and is being published separately as Bulletin 12A.

Professor Harris has evaluated two alternate plans for providing potable water to replace the Mississippi River as a water source. Figure 3 summarizes the plans. The New Orleans metropolitan area, including the population centers downstream to Venice, would be supplied from the Pearl River by means of a long pipeline, details are shown in Figure 8, Addendum A. Inasmuch as the low flow of the Pearl River is inadequate to supply the total demand during periods of low flow and simultaneously prevent saline water from intruding to just below the river intake site, it is proposed that a well field and small water treatment plant be built and operated as part of this project. The well field would supply the total water demand of the area during periods of low flow and the treatment plant would supply water for well replenishment during periods when more than enough water is available in the Pearl river. The raw water treatment plants now used in the New Orleans metropolitan area would remain in use there since in the normal course of operation raw Pearl River water would be brought to the present river intakes; thus there would be no need to build new treatment plants. Nor would it be necessary to modify present distribution networks. It might also be possible to augment the local water storage facilities by storing treated river water in underlying waterbearing formations (Kimbler, et. al., 1975) near the areas of use and thus provide insurance for possible interruptions of the pipe lines, either caused by pipeline breaks or for planned shutdowns to effectuate maintenence and repairs as might be needed. Figure 3, prepared on the basis of Addendum A, shows the approximate locations of river intakes and pipelines.

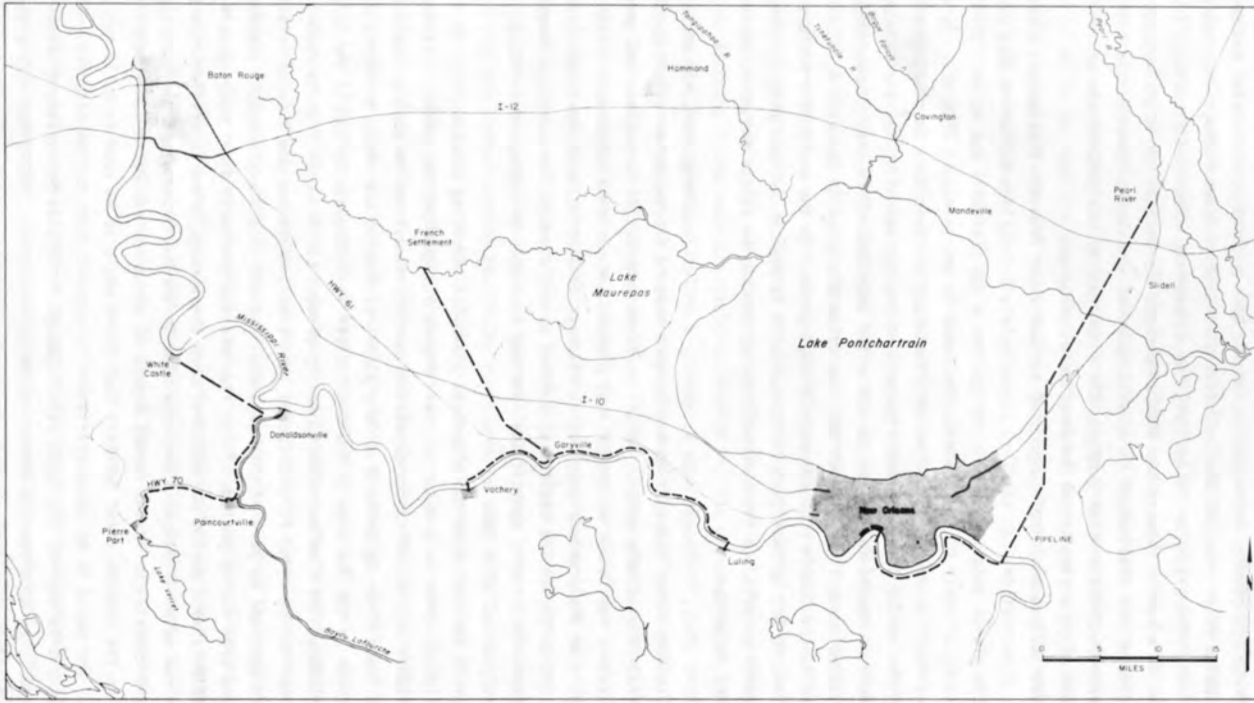

FIGURE 3. Map showing principal pipe lines connecting new sources of water with major areas of use.

The Middle River parishes on the West bank would be served by a pumping station on the Atchafalaya and a pipeline along Highway 70 from the intake near Pierre Part all the way to White Castle, via Donaldsonville. Needed river crossings might be made to supply some industrial needs along the East bank. It is possible that one of the rivers, the Amite River for example, might be used as a source of municipal water for the East Bank area upstream from New Orleans. Details of such a project were left to further study.

The problem of supplying Bayou Lafourche with sufficient water to maintain navigation below Thibadaux was also studied in connection with Segment 2. The solution was to build a much larger pumping station on the Atchafalaya and to pump some 200 mgd into the Bayou. An alternate possibility might be to dredge the Bayou deep enough so that water from the Gulf would reach Thibadaux. Time and funds were was insufficient to investigate such possibilities in detail although a cost estimate was made of supplying Bayou Lafourche with 200 mgd as part of the Segment 2 project.

The East Bank, from Luling to Gramercy and Lutcher would be supplied by a combination of a river intake on the Amite River near French Settlement and a battery of wells that would be used during periods of low discharge and replenished during periods of high discharge. The installation would be similar to that proposed at the Pearl River intake.

The conclusion of the report was that it is indeed feasible to replace the Mississippi River by alternate sources as the source of water for the consumptive use of commercial and industrial establishments and the potable water use by municipalities. In fact, since most of the alternate water supplies would be of better quality than Mississippi River water, the writers believe that there might be justification for undertaking such replacements even without the spur of a looming diversion of discharge from the present main stem to the Atchafalaya.

Cost estimates during an inflationary period are both unreliable and misleading. Using 1976 figures for water cost based on 1976 prices and 7% funding, costs of water from the different segments ranged from 23 to 26 cents per 1000 gallons of water delivered. However, these figures do not reflect the alternate of supplying Bayou Lafourche with 200 mgd - when this alternate is included costs range from 23 to 45 cents per kilogallon of water. Total capital cost ranges from 600 million to 700 million dollars to implement such plans.

VIII

CONCLUSIONS

The conclusions reached as a result of this study can be grouped into four categories: a) those dealing with geomorpologic effects on the future of Mississippi-Atchafalaya flow distribution; b) those dealing with the consequences of failure of the ORCS on the physical facilities involved, including the transportation network, power facilities and water supply; c) those dealing with the economic impact of the failure, including the short and long range economic consequences in Louisiana and in the rest of the Nation; and d) those dealing with possible actions to ameliorate the catastrophe.

A. Geomorphology of the Mississippi-Atchafalaya System.

It is concluded that:

1. The most important, single concept resulting from the study reported upon herein is that in the long run the Atchafalaya River will become the main distributary of the Mississippi River and the current main-stem will become an estuary of the Gulf of Mexico. This will likely come about after a major flood.

2. The frequency of occurrence of major floods, otherwise known as the "return period", cannot be reliably assessed even by the most sophisticated methods now available. Improvements in the hydraulics of the rivers which are tributaries of the lower Mississippi River have unpredictably altered the hydrologic characteristics of the entire watershed so that the extremes of flood and drought increasingly deviate from the historical record even though the weather conditions may be approximately unchanged. Thus the observed, historical, synchronization of flood peaks is not likely to be repeated even if identical weather conditions, by some miracle, were to recur at a later date. In addition, there is the increasing impact of inadvertent weather modification, produced by the heated air and the tonnages of particulates and chemicals that enter the atmosphere from cities and industrial sources. Although this topic is not discussed in this report, it is being studied in many parts of the country.

3. Despite the wholehearted and competent efforts of the Corps of Engineers the basic hydrologic problem will remain. This problem consists of trying to maintain the Mississippi River in a path 300 miles long whereas the natural tendency of the river is to use the short route to the Gulf via the Atchafalaya River. This physical tendency focuses its hydraulic power immediately downstream from the structure where the bed is being cut deeper and huge local holes have been formed.

Each year the upstream channel of the Atchafalaya will be cut a little deeper and the sediment will be deposited downstream in what used to be Grand Lake and the adjacent overflow areas and in the Atchafalaya bays. As a result of deposition, especially during floods, the land surface in the lower Basin will slowly rise. Associated with this rise in land elevation the flood height in the lower Basin will rise higher and higher, for the same discharge.

The time scale is one unknown factor. It might take one or several major floods to produce the final results. Since the future is unpredictable, no valid estimates can be made: a ten-year wet period might do the job. But on the other hand, this wet period might be preceded by a 20 year period of dry weather. The first flood could come next year or the year after or it might be delayed a decade or two. But the final outcome is simply a matter of time and this should be knowledged.

B. Physical Consequences of the Failure of the ORCS.

It is concluded that:

1. The immediate consequences of a major flood, with or without failure of the ORCS will be:

(a) The footings of some of the bridges, both highway and railroad, that cross the Atchafalaya may be undermined, thus causing collapse of the structures.

(b) Many, if not all, present pipeline crossings of the Atchafalaya could suffer breaks, cutting off the supply of oil and gas to some southern and eastern states.

(c) The Atchafalaya protection levees will be overtopped causing widespread flooding.

(d) The Morgan City area will probably be flooded and sediment deposited in the city itself and its environs.

(e) The low-lying land within the Basin will be covered with a new layer of sediment during the flood, reducing the recreational opportunities for water-based activity, and reducing the hunting of land creatures such as deer and squirrels since many of these animals will have been drowned.

(f) New land, and new opportunities for water-based recreation, will be created in what are now the Lower and Upper Atchafalaya Bays.

2. All of the long range consequences of a flood coupled with the failure of the ORCS cannot be visualized. However, the most important of these is believed to be the transformation of the Mississippi River channel below the ORCS from a fresh water zone to a saline estuary of the Gulf. This, in turn, will mean that present (1980) water sources for municipalities and industries (including plants for the generation of electric power) will be saline and totally unsatisfactory for the purposes for which they are now being used.

It is concluded that entirely new sources of water supply will be needed for the Baton Rouge - New Orleans industrial complex and that, simultaneously, the use of river water for once-through cooling of condensers, will have to be abandoned. Instead, it will be necessary to use cooling towers and other means of heat transfer in order to minimize the quantities of water needed. Arrangements will also have to be made for disposal of waste water and sludge, although this topic was not studied or reported upon here.

C. The Economic Consequences of an ORCS Failure.

It is concluded that:

1. Depending on the resistence of existing structures to the erosion and undermining caused by the increase in flooding due to the destruction of the ORCS, the capital losses that can be quantified will amount to a total between 1.5 and 4 billion dollars (1977).

2. A direct increase in unemployment of from 12,000 to 88,000 will result immediately.

3. A direct increase in transportation costs will result from the need to use long detours instead of highway and railroad bridges that have been undermined by the flood. The additional costs of operating trucks and automobiles is estimated at approximately $600 million dollars a year.

4. Using conservative estimating techniques, the value of time lost by drivers of medium and large trucks and drivers and occupants of private automobiles, is believed to be approximately 400 million dollars a year.

5. A significant fraction of the total economic loss is embodied in individual losses for which no quantitative estimates can presently be made. Such losses would include increased dredging, relocation costs for residents of the Basin, increased costs to those remaining in the Basin and in the Baton Rouge-New Orleans industrial corridor as a result of degradation of the water supply by salt water intrusion, disruption of oil and gas exploration and

production, and destruction of most of the animal life in the Basin.

D. Possible Actions to Ameliorate the Catastrophe.

It is concluded that a number of measures can be taken to delay or ameliorate the results of a failure of the ORCS. Among these actions are:

1. The completion, at the earliest possible moment, of the auxiliary structure at Old River proposed by the U.S. Corps of Engineers and now (1980) in the planning stage.

2. Strengthening the foundations of the highway and railroad bridges that span the channels of the Atchafalaya River.

3. Construction of new pipeline crossings of the Atchafalaya River that will be less vulnerable to river scour. These could either be aerial crossings or could be constructed using directional drilling techniques which would place the completed pipeline some 200 or 250 ft below the present river bed.

4. Protection of individual cities and plant sites by the construction of ring levees and the necessary pumping stations by the municipalities and industries threatened by flooding.

5. Initiation of the first steps to replace the present River based water supplies in the Baton Rouge-New Orleans industrial corridor by the industries and municipalities that would be affected. The suggestions found in Addendum A of this report could be used as a preliminary basis for discussion.

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BULLETIN 12 Addendum A

ALTERNATE WATER SOURCES FOR THE BATON ROUGE - NEW ORLEANS INDUSTRIAL CORRIDOR

JOHN R. HARRIS

Department of Civil Engineering

SEPTEMBER 1980

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ALTERNATE WATER SOURCES FOR THE BATON ROUGE-NEW ORLEANS INDUSTRIAL CORRIDOR

DESCRIPTORS: New Orleans, Atchafalaya River, Old River Control Structure, Disasters-floods, Salt-water Wedge, Conjunctive Use, Alternate Water Sources

IDENTIFIERS: Pearl River Supply, Low Flow Augmentation, Well Fields, Water Shortage, Water Replacement, Water Supply, Water Utilization

A B S T R A C T : The Lower Mississippi River is the source of fresh water for most of the municipalities and industries located along its banks below East and West Baton Rouge Parishes. The Flood Control Act of 1954 authorized the construction of a complex at Old River, above Baton Rouge, to divert part of the flood waters from the Mississippi River to the Atchafalaya River-the Old River Control Structure (O.R.C.S.)

During a major flood in 1973 the left wing wall of the low-sill structure collapsed. A cavity 55 ft deep had been scoured in the inflow channel under the structure. It is likely that the same or similar conditions will recur and that a failure of the O.R.C.S. is a possibility. Should the structure fail the Mississippi River would be lost as a source of fresh water below this point due to the intrusion of salt water from the Gulf of Mexico during the first period of low water. The many users below East and West Baton Rouge Parishes would have to find alternate sources of supply.

The consequences of the failure are described in detail and alternate sources are proposed. The New Orleans area and the municipalities and industries downstream would be supplied with water from the Pearl River. During periods of low discharge in the Pearl, a well field would supply the demand. This well field would be replenished with the use of filtered Pearl River water during periods of high water. The West Bank and Bayou Lafourche would be supplied with water from the Atchafalaya River. The remainder of the area would use water from the Amite River supplemented with water from a well field near French Settlement. Estimated cost of raw water delivered to the intake of the user, 1976 prices, about 25¢/kilogal.

REFERENCE: Harris, John R., ALTERNATE WATER SOURCES FOR THE BATON ROUGE-NEW ORLEANS INDUSTRIAL CORRIDOR *Louisiana Water Resources Research Institute*, Bulletin 12 A, Louisiana State Univ., B.R., Sept. 1980.

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I

INTRODUCTION

Mississippi River water is the source of fresh water for most industries and towns in the Louisiana Parishes located along the Mississippi River below Baton Rouge. The Lower Mississippi, with an average flow of some 300 billion gallons per day, provides about 95% of the fresh water requirements in this area.

The economic advantages provided by the Mississippi River, as the terminus of a 12,350 mile waterway transport system, coupled with nearby mineral resources have attracted billions of dollars of industrial development into the area downstream from Baton Rouge. New Orleans, the second largest port in the nation and Baton Rouge, the seventh largest, are both located on this stretch of the river. Accompanying the industrial growth has been an increase in the use of fresh water. Total water pumpage in the parishes along the Mississippi River below Old River increased from 3.2 billion gallons per day in 1965 to alomost 7.0 billion gallons per day in 1975.

A structure was constructed at the Old River to control the volume of water which flows from the main stem of the Mississippi River into the Atchafalaya Basin. Scour around the main flow control structure and the shifting of the Mississippi River channel toward the structure have increased its vulnerability to destruction and have raised questions concerning the consequences that might result from the failure of the structure.

A failure of the structure and the consequent loss of control over the flow at Old River would probably result in the diversion of the main flow of the Mississippi River to the Gulf of Mexico via the Atchafalaya River. Such a diversion could cause a shortage of fresh water in the Mississippi below Old River. The fresh water would be replaced by salt water entering the Mississippi River at its mouth at the Gulf of Mexico and moving northward up the channel. As the amount of fresh water flowing downstream decreased, the channel would fill with salt water from the Gulf up to the diversion point at Old River. Those who depend upon the Mississippi River for fresh water would have to develop alternative sources of supplies.

The primary purpose of this study is to evaluate the potential consequences caused by the failure of the control structure to the users of fresh water, who are located on the stretch of river between the Old River Control Structure and the Gulf of Mexico. Another purpose was to study several possible alternative sources of water supply and produce order-of-magnitude cost estimates of each. Such costs for alternative fresh water supplies would be directly attributable to the failure of the Old River Control Structure. Thus the benefits of preserving the control structure at Old River, if this is in fact feasible, would be partly expressed by these cost estimates.

This paper, and the studies leading to its development, were funded by the Louisiana Water Resources Research Institute, at Louisiana State University in Baton Rouge as project A-040-LA.

The work was started by Dr. E. Barcus Jernigan while he was Assistant Professor of Civil Engineering at L.S.U. Dr. Jernigan completed an extensive literature search. In

addition the basic concept of Alternate A and the complicated Wang computer program for obtaining cost data were developed by Dr. Jernigan before leaving Louisiana State University. These have been used with his permission.

Professor Raphael G. Kazmann, Professor of Civil Engineering, Louisiana State University, was very helpful in the hydrologic evaluations, that include the mass curve analyses, well field calculations and aquifer yields. The author is grateful to Professor Kazmann for this invaluable assistance, and for his general review of the paper.

Figures 6 through 10 were prepared by Mrs. Norma Duffy, Head of the Drafting Department, Division of Engineering Research, Louisiana State University from rough sketches prepared by the author and her contribution is gratefully acknowledge.

II

THE MISSISSIPPI RIVER BELOW OLD RIVER

The Mississippi River System drains 1.24 million square miles of central United States. This includes most of the area from the Rocky Mountains in the West to the Appalachians in the East. The Mississippi River discharges into the Gulf of Mexico through two major distributaries, the Lower Mississippi River and the Atchafalaya River. The distribution of flow between these two rivers is controlled by the structure at Old River just below mile 315 above Head of Passes (AHP) on the Mississippi River. The structure was designed to divert about 25% of the Mississippi River discharge to the Atchafalaya River. The mean annual discharge through the Lower Mississippi and Atchafalaya are about 465,000 cubic feet per second (cfs) and 187,000 cfs respectively.

Little of the flow discharged through the Lower Mississippi River originates below the latitude of Old River. Drainage in Southeastern Louisiana, east of the Atchafalaya Basin, is generally away from or parallel to the river. No tributaries enter the Mississippi River below Baton Rouge.

The most devastating flood recorded on the Lower Mississippi River occurred in 1927. Maximum flow on the Mississippi at Vicksburg was computed to have been 2,280,000 cfs on May 4, 1927. Seventeen million acres were flooded and property damage equivalent to over one billion dollars (in 1977 dollars) was incurred along the Mississippi. The Mississippi River levee below New Orleans had to be breached by dynamite in order to prevent flooding of New Orleans. After the flood the U.S. Congress authorized the Mississippi River Commission and the U.S. Army Corps of Engineers to develop a unified flood control plan for the Mississippi River Valley. This project, entitled the "Mississippi River and Tributaries Flood Control Plan", was to "protect the alluvial valley of the Mississippi from the maximum flood predicted as possible" (U.S. Army Corps of Engineers, 1973, unpaginated). This "maximum flood" has become known as the Project Flood. The Project Flood flows would be about one-third greater than the 1927 flood, with a total flow of 3,030,000 cfs in the Mississippi and Atchafalaya Rivers below the latitude of the Red River Landing.

Elements of the project included levees to contain flows, floodways to bypass excess flows, stabilization of the river channel, and control of drainage from tributaries by dams and reservoirs. According to the plan for the Project Flood, half the total flow, about 1,500,000 cfs would pass through the Lower Mississippi River to the Gulf of Mexico and the remainder would pass through the Atchafalaya Basin.

The Old River Control Structure (ORCS) is a vital element in flood protection plans for both the Lower Mississippi River and the Atchafalaya Basin. In order to prevent the channel capacity in the Lower Mississippi from being exceeded, water must be diverted through the ORCS, the Morganza Spillway and the Bonnet Carre Spillway, the last being located several miles north of New Orleans.

III

THE OLD RIVER CONTROL STRUCTURE

The Atchafalaya River offers a shorter course to the Gulf of Mexico from Old River than does the Lower Mississippi. The average water surface slope to the Gulf in the Atchafalaya is almost twice that of the Lower Mississippi River. Until the late 1890's, the Atchafalaya had not developed sufficiently to accomodate large flows and the Atchafalaya was nothing but a minor outlet for Mississippi River water. In response to civil works intended to improve navigation and reduce flooding, the proportion of the flow of the Mississippi River diverted by Old River into the Atchafalaya began to increase steadily.

As the flow through Old River to the Atchafalaya increased, it soon became apparent that some action would be necessary to prevent the eventual capture of the Mississippi by the Atchafalaya. The construction of low sill concrete dams in the upper Atchafalya in 1928 in order to reduce, if not eliminate, the increase in the rate of water diversion, proved ineffective.

On September 3, 1954, the 83rd Congress enacted the Flood Control Act of 1954, Public Law No. 780, which authorized construction of a complex at Old River to maintain the Mississippi River in its present course by controlling the rate at which flow is diverted into the Atchafalya River. The structures were to maintain diversion at the rate which existed in 1950, when approximately 25% of the total flow of the Mississippi discharged through Old River.

Two structures to control discharge were constructed just above Old River at mile 315 AHP on the West Bank of the Mississippi. In addition to the diversion control structures, a navigation lock at Old River was authorized to provide for navigation between the Mississippi and Atchafalaya. These structures were to be operated, 1) to provide for controlled diversion of water from the Mississippi during low and normal flows at the rates which existed in 1950, 2) to maintain navigation between the two rivers, and 3) to divert flood flows from the Mississippi to the Atchafalaya as prescribed by the Mississippi River Commission flood control plan for the Lower Mississippi River.

Construction of the low sill structure, and its inflow and outflow channels were completed in 1959. The structure has a total span of 566 feet with 11 bays each having a width of 44 feet. The three center bays have a weir crest elevation of minus five (-5) feet Mean Sea Level (MSL). The other eight bays have a weir crest elevation of 10 feet MSL. Each bay is equipped with a vertical steel lift gate. A mobile gantry crane provides a means of opening and closing the bays independently. A short inflow channel from the Mississippi River to the low sill structure and an outflow channel about seven miles long from the structure to the Red River at mile 12 above its mouth, were excavated. The bearing piles supporting the structure were set at elevation -90 feet MSL. Steel sheet pilings for seepage control were set to elevation -36 feet MSL.

A second control structure, the overbank structure, was also completed in 1959. It consists of 73 gated bays, each with a width of 44 feet between piers, giving a total width of 3,356 feet. The weir crest of these bays is 52 feet MSL. Flow through the bays can be controlled by hinged timber needles operated by two traveling cranes. The natural Old River channel was closed with an earthen dam in October, 1963.

Total cost originally estimated for the project in 1953 dollars was about $46,750,000 initial cost or $1,880,000 in annual charges, excluding the cost of the navigational lock and channels. Minimum annual tangible benefits were estimated at $14,600,000, for a benefit-cost ratio of 7.7 to 1 (House of Representatives Document No. 478, 1954, PP. 22-23). This does not include intangible benefits such as preventing the loss of the Mississippi as a water supply for the Baton Rouge - New Orleans industrial complex and the probable expense of channel maintenence and bank stabilization due to increased meandering of the Mississippi River. As of 1975, the current estimated Federal cost of the ORCS was $81,200,000 and the project was 83% complete (Mississippi River Commission document, 1976, pp 42-48).

Scouring Around the Structure

The record of Scour in the diversion channel at Old River is well known (Hebert, 1967, p. 51 and Horne, 1975, pp. 1-15). Scour was anticipated by the Corps of Engineers in the original project design and provision was made to place revetment along the banks of the inflow and outflow channels. The designers also recognized that downstream raveling could also be a problem. The finally selected site was chosen because at this point the channel would have to pass through clay deposits and the clay has properties that would make the channel easier to protect against raveling (Graves, 1958, p. 1147). Although problems with scour had been anticipated, the severity of the problems was underestimated. The initial operational test of the structure was accomplished in 1961. Shortly thereafter, in 1962, scour protection and repair activities in the immediate vicinity of the low sill structure were required. Additional work was undertaken in 1963, 1964, 1966, 1968, 1973 and 1974 (Corps of Engineers Annual Reports, 1962-74).

After three months of operation in 1961, a scour hole 30 feet deep (to -40 feet MSL) was formed in the outflow channel just downstream from the structure. The hole was filled with stone and riprap, but when operations were resumed in 1962 the scour hole reformed in the channel to a depth of -90 feet MSL. The hole was again repaired and the riprap paving was extended in an attempt to reduce the erosion in the outflow channel. The problem seemed solved until a rise in 1964 deepened the cavity to -140 feet MSL, and caving occurred along the banks of the outflow channel. The maximum flow through the low sill structure in 1964 was about 300,000 cfs on March 24th when the Mississippi River stage was 42.5 feet MSL. Repairs were made with articulated concrete matting and about 150,000 tons of stone and riprap (Corps of Engineers Annual Reports, 1962-74).

Discharges Through the Structure

The hydraulic analysis of the final design of the Old River complex (Graves, 1958, pp 1148, 1149) indicated that a maximum of 700,000 cfs would flow through the low sill and overbank structures during the Mississippi River and Tributaries Project Flood, with the Mississippi River stage at 64.0 and the stage downstream from the structures at about 62.5 MSL. About 325,000 cfs of the 700,000 cfs were to pass through the low sill structure during this projected flood. Since the actual discharge through the ORCS depends on the actual upstream and downstream stages during a flood, this 325,000 cfs figure cannot be considered the "design capactiy". However, this figure should be noted as being one of the highest expected discharges since it was assumed to occur during the Project Flood.

The flood of 1973 was a major flood for the Lower Mississippi River. The maximum flow in the Mississippi above Old River was 2,041,000 cfs. The peak flow in the Mississippi below Old River was 1,498,000 cfs. This was equal to the maximum flow for which flood protection works had been designed and which could be safely passed without endangering New Orleans and other areas along the Lower Mississippi.

During this major flood, the left wing wall of the inflow channel to the low-sill structure collapsed. Investigations revealed a cavity 55 feet deep had been scoured in the inflow channel under the structure. This cavity exposed the supporting pilings down to elevation -50 feet MSL. The tips of the pilings are set at -90 feet MSL. Figures 1 and 2 show cross sectional views of the scour hole at the structure as measured in May, 1973 (cross-sections developed based on contour map presented by Horne, 1976, pp. 13 and 15, after U.S. Army Corps of Engineers drawings). In the outflow channel, the scour hole had been re-opened to a depth of -50 feet MSL. Following the collapse of the wing wall the Corps of Engineers acted quickly to reduce the flows through the low sill structure by lowering the stage of the Mississippi River at that location as much as possible. This was accomplished by opening the Morganza control structure about 35 miles downstream.

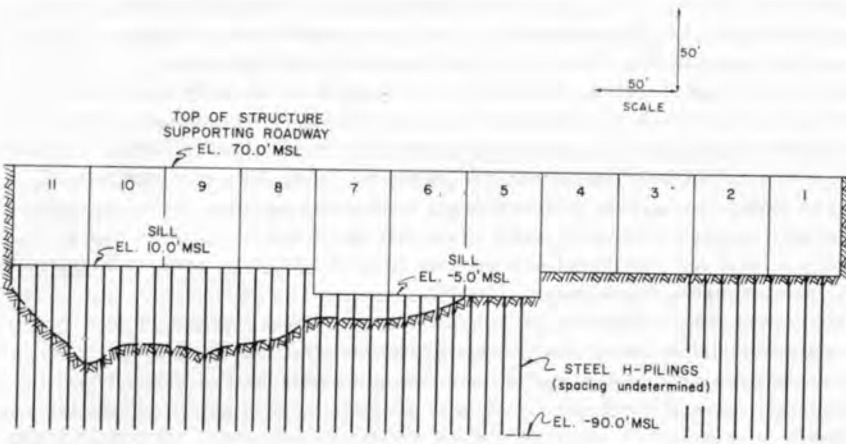


FIGURE 1. LONGITUDINAL SECTION-LOW SILL STRUCTURE
(Looking downstream)
1973

Adopted from Horne, 1976, p 10

Although the Mississippi continued to rise at the ORCS through the following month, the rise was not as great as would have occurred without the opening of these other structures. The stage at the upstream face of the low sill structure was about 60.1 on May 15, with a downstream stage near 59.3. The resulting discharge through both of the Old River control structures under these conditions was the highest to date; about 610,000 cfs (Corps of Engineers, 1973). About 390,000 cfs of this discharge was through the low sill structure (Mississippi River Commission, design Memo No. 4). The Corps of Engineers reported a maximum discharge of 500,000 cfs through the low sill structure on this date. This estimated discharge is approximately 50 percent higher than the 325,000 cfs which was expected to pass through the low sill structure according to the anticipated Mississippi River and Tributaries Project Flood.

Future Scour

There are some indications that the conditions which produced high discharge and turbulent flows, similar to those that caused the scouring in the Old River diversion channel, will become more severe in the future. With the existing physical arrangement at the low

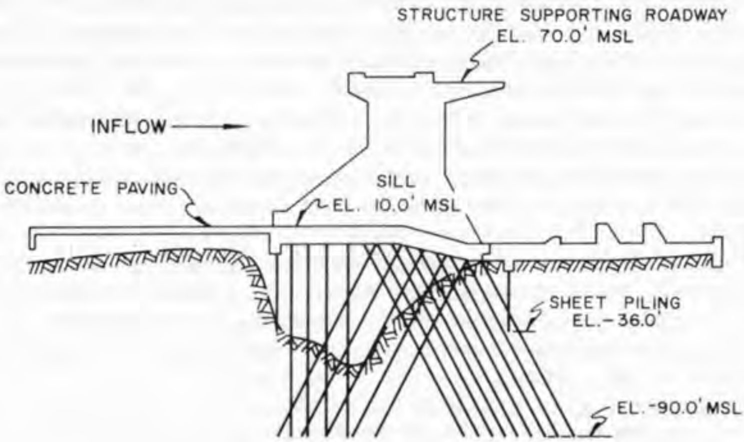


FIGURE 2. CROSS SECTION-LOW SILL STRUCTURE
(At bays 10/11)
1973

Adapted from Horne, 1976, p.10

sill structure, the velocity and discharge through the structure are determined by the water surface elevations in the Mississippi River and in the diverson channel downstream from the structure. As would be expected, large differences in elevation of the water surfaces produce high discharges and velocities through the structure. High discharges may result from several combinations of stage changes such as an increase in the Mississippi stage, a decrease in the downstream stage of the channel, or both. Observed trends in deposition and degradation seem to simultaneously result in a gradual increase in Mississippi River stages and gradual decreases in downstream stages at Old River.

The flood of 1973 revealed the fact that the hydraulic efficiency of the Mississippi River channel seemed to have deteriorated throughout its lower length. Stages were higher for a given discharge than they had been in the past. For example, a 1,800,000 cfs flow at Vicksburg in 1950 resulted in a stage of 43.7 feet. In 1973, this same discharge resulted in a stage of 50.6 (or 6.9 feet higher). A brief post flood report by the Army Corps of Engineers on the 1973 flood explained this deterioration in the lower Mississippi channel as follows (Corps of Engineers, Mississippi River and Tributaries, Post Flood Report, 1973, pp. 63 & 65):

> "Channel efficiency has diminished thoughout the lower Mississippi River due to changes arising from the dynamic nature of the alluvial river, the persistent tnedency of the river to meander, the instability introduced by the cutoff program, and a generally incomplete river stabilization program."

Further,

> "Some deterioration or loss in flow capacity has occurred continuously since 1950...As channel stabilization works are currently estimated to be 58 percent complete within the middle reach, some additional deterioration can be expected...."

While the stages of the Mississippi River side of the Old River control structures appear to be rising, on the downstream side, both in the Red River backwater area and in the upper reaches of the Atchafalaya River, the stages appear to be declining (Horne, 1976, p 25). As predicted by Fisk (1952, pp 26-28) the Atchafalaya River has been deepening and enlarging its channel's cross sectional area in the upper segment, which enables it to carry the same amount of water as in earlier years at a lower gradient. Since the water surface elevation at the lower end remains nearly constant, the result is a decrease in stage at the upper reaches of the river (the channel is degrading).

The end result of this tendency for the Mississippi stages to increase, and the stages of the downstream side of the Old River control structures to decrease, is to produce an increase in the overall discharge through the structures and, presumably, higher discharges as time goes on. The prospect is that the scouring in the vicinity of the structures will grow worse.

Published reports of the Corps of Engineers and public statements by the Chairman of the Mississippi River Commission indicate that they are quite concerned over the stability of the low sill structure. In testimony before the Senate Committe on Appropriations in February, 1976, the President of the MRC, General F. P. Koish stated (U.S. Senate Committe on Appropriations Hearings, 1976)...

> "The item which I consider to carry the highest priority in my total program, is the remedial work that is required to insure the integrity of the Old River low sill and overbank structures and ultimately the Mississippi River and Tributaries flood control system. If I had to select a single feature as being the most important to the viability of the Mississippi River and Tributaries project it would be these structures."

Possible Failure of the Low Sill Structure

In the preceding section of this report the problems with scour at the low sill structure were outlined and evidence has been presented to show that the discharges through the structure are increasing over the years. Under these circumstances, failure of the low sill structure is possible, and it is appropriate to discuss the potential consequences that would result from this failure.

The phrase "failure of the low sill structure" as used herein refers to any circumstance which would result in uncontrolled diversion of water from the Mississippi River into the Red and/or Atchafalaya Rivers at the Old River site. Failure could result from events such as collision by river traffic as occurred in April, 1964 and again in December, 1965; from acts of sabotage or war; from the undermining of the foundation by scour with subsequent settlement or total collapse; from the scouring out of an unobstructed channel under or around the edge of the structure; or by any set of combinations of these possibilities.

The intent of this study was to concentrate on the consequence of catastrophic failure of the structure. No attempt has been made to discuss such topics as the probabilities associated with the various modes of failure, various possible river conditions on the Mississippi, Red, and Atchafalaya Rivers at the time of the failure, the possible remedial actions that might be undertaken or the conditions resulting from these actions.

The scenario for this study is to suppose that the failure did in fact occur, and the occurrence took place during a major flood. The resulting diversion of flood waters through the outflow channel, down the Red River channel and thence down the Atchafalaya would develop a much larger channel immediately. The main channel of the Atchafalaya would enlarge its cross section in a short period of time to a dimension adequate to carry the main flow of the Mississippi. While some flow would continue in the main lower Mississippi channel during subsequent periods of high water, the discharge of the Mississippi River would essentially be captured by the Atchafalaya. During low flow periods that would occur after the flood, the discharge to the Lower Mississippi River channel might be negligible. All of this would take place in spite of efforts which might be taken to restrict the diversion at Old River and keep the Mississippi River channel open.

Consequences of Failure of Low Sill Structure

Some of the economic burdens that would result from the capture of the Mississippi River, and the probable benefits to be derived from preventing it, were outlined for Congress in 1954 by the then Secretary of the Army in a recommendation for the construction of the ORCS (House Document 478, 83rd Congress, 1954, pp 16-17). The Secretary pointed out that if the Atchafalaya continued to capture an ever larger portion of the Mississippi's flow, the Mississippi River channel would eventually fill with silt for a considerable distance below Old River and the total flow of the river would pass through the Atchafalaya except during floods. Navigation on the Mississippi would have to be routed through the Atchafalaya River system and the intracoastal waterway to New Orleans, unless a lock and dam were constructed below Old River and a dredged channel were maintained from the lock to near Baton Rouge. The cost of the first alternative would be high because of the improvements that would be required in the Gulf Intracoastal Waterway and in the Atchafalaya River. Construction of a lock and dam and dredging to maintain a navigation channel would likewise be costly.

In addition to the economic burden pointed out by the Secretary, other effects of the diversion of the Mississippi River at Old River would be the disturbance of equilibrium conditions in the river as far upstream as Vicksburg, and increased flooding in the Atchafalaya basin. Increased stream velocities upstream from Old River (and lower stages) would result from the increased gradient through the Atchafalaya. The increased stream velocity would cause the river to meander more and would make navigation more difficult. Many of the present locks, flood-gates, levees and floodwalls would be ineffective for the altered stages along the Mississippi and Atchafalaya. Existing transportation facili-ties and communication and utility lines across the Atchafalaya Basin might be severed during increased flows.

The major effect on the quality of the water would be an increase in the extent and frequency of salt water intrusion from the Gulf into the main stem of the Mississippi River. Salt water encroachment would tend to make the river an unreliable source of fresh water for the many industries and municipalities located south of Baton Rouge along both banks of the Lower Mississippi River. If fresh water flow stopped completely, the river would become a slack water, salty estuary of the Gulf of Mexico, with all that this implies for industries, municipalities and nuclear-fueled power plants that now use, or plan to use, river water as their supply.

IV

EFFECTS OF FAILURE ON WATER QUALITY

Salt Water Intrusion

The quality of the water of the Lower Mississippi River would be changed by the loss or significant reduction in flow of water following the failure of the Old River control structure. The most important effect would be the change in salinity caused by salt water intrusion into the channel as the fresh water was displaced by salt water entering from the Gulf of Mexico. This change would be more than merely a slight increase in salinity from its present level. It would tend to be a total conversion from fresh to salt water.

Uner existing conditions there is a dynamic equilibrium in the Mississippi channel between the fresh water flowing downstream and the salt water of the Gulf of Mexico. The dense salt water tends to displace the fresh river water and flow upstream along the river bottom. The flow of fresh water erodes the salt water - fresh water interface and retards the salt water intrusion. Thus, the continuing intrusion results in a wedge of salt water along the bottom of the channel, with its narrow end upstream.

The interface between the salt and fresh water in the Mississippi River is well defined. It has been found that the salinity content changes from fresh water with concentrations of a few hundred parts per million (ppm) chloride to saline water which contains 10,000 to 15,000 ppm of chloride with a depth change of a few feet. There is little mixing along the interface at the small end of the wedge. Maximum chloride concentration in the Mississippi River upstream from the salt water wedge is about 50 ppm (Everett, 1971, p. 25).

Because the thalweg of the Mississippi is below sea level, salt water intrudes into the mouths of the river at all times except during the largest floods. The extent to which salt water penetrates depends upon the discharge from the stream, tidal conditions and the elevation of the bottom of the river channel.

Analytical methods of predicting the length of the salt water wedge above the mouth of the river have not been successful because of the changes in the forces which influence the extent of the intrusion (Everett, 1971, pp. 22-28; Kazmann and Arguello, 1973, p. 43). The discharges, depth and width of the river, tides and the distribution of flow in the river's various outlets to the Gulf are all factors in determining the extent of salt water intrusion.

The maximum recorded intrusion occurred in October, 1939, when the river discharge reached a record low of 75,000 cfs and ranged from 75,000 to 100,000 cfs for thirty consecutive days. The upper end of the salt water wedge reached Norco, Louisiana which is 120 miles from the Gulf and 15 miles above New Orleans. In October, 1940, the wedge penetrated past Kenner Hump at mile 115 (AHP) though flow was less than 100,000 cfs for only a few days. Concentrations of chloride have been as high as 620 ppm at the Algiers water treatment plant intake at mile 95.5 (AHP) (Everett, 1971, pp. 22, 29).

Whereas low discharges in the Mississippi permit a salt water wedge to penetrate upstream along the channel bottom, the complete loss of freshwater flow into the Lower Mississippi River at the latitude of Old River would result in the present channel completely filling with salt water. The heavier salt water would flow inland from the Gulf of Mexico along the bottom of the channel, displacing the freshwater and forcing it up to the surface, thus forming a two-layered stratified system. The freshwater on the surface would move downstream, its total depth decreasing as it moved downstream. Eventually all the fresh water would be lost and the channel would become completely filled with salt water to an elevation approximately equal to the Gulf level. This resulting water body would be tidal at its lower end, with positive and negative waves alternatively traveling up the old channel as the Gulf tides rose and fell.

The present channel bottom of the Mississippi is below sea level upstream from the Gulf to a point well above Old River, as shown on Figure 3. At some locations between Baton Rouge and New Orleans, the salt water would be well over 150 feet deep.

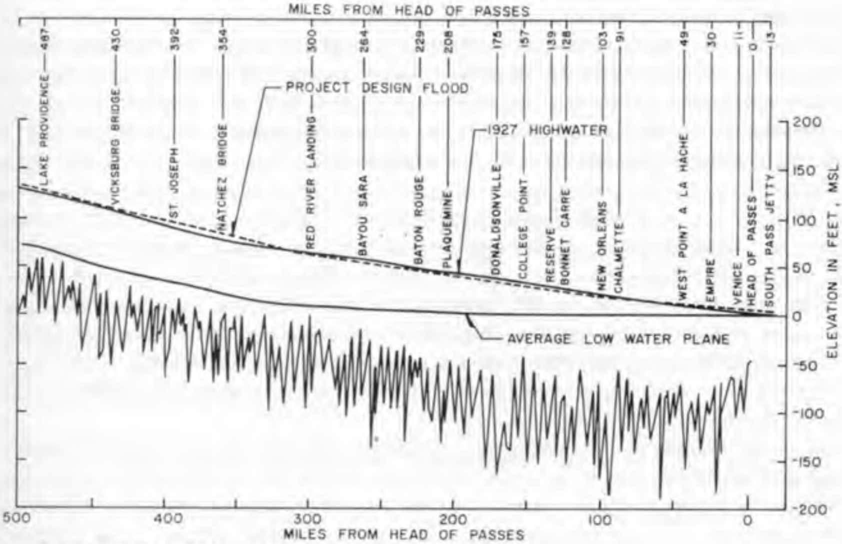


FIGURE 3. PROFILE OF THE LOWER MISSISSIPPI RIVER FROM THE GULF OF MEXICO TO MILE 500 FROM HEAD OF PASSES

Even if there were a complete diversion at Old River, fresh water flow into the present channel of the Mississippi River would not stop altogether. Precipitation falling between the levees would pass down-stream. Also, there are two minor tributaries to the Lower Mississippi: Thompson Creek and Bayou Sara. These streams, that drain an area of approximately 425 square miles, enter the river just above Baton Rouge at Miles 256 (AHP) and 266 (AHP) respectively. The streams are ungaged, but an estimate of their flow can be made by assuming their discharges would be similar to other gaged streams in the area. The mean annual discharge of similar streams in this area is about 1.4 cfs per square mile of watershed. The two tributaries would thus contribute an annual flow averaging approximately 600 cfs to the Mississippi Channel. It is also quite possible that, in time, runoff from lands which now drain away from the river might be redirected into the channel, since the water level in the channel would be at sea level, and thus lower than the land to be drained.

With a complete cessation of fresh water flow at Old River, the quantities of fresh water entering the river from all other sources would not be enough to cause a significant reduction in the salinity of the water from the Gulf.

Pollution

The Mississippi River receives wastes produced in about 41 percent of the area of the Continental United States. Bacteria, nitrogen and phosphorous compounds, pesticides, organic chemicals and various heavy metals from countless sources are all present in ever-varying concentrations. A number of recent publications have discussed the water quality of the Lower Mississippi and have described the variations in concentration of specific pollutants and indicators of water quality (EPA, 1972, 1974; LSCC, 1973, 1974, 1977). Loss of the flow from up river would divert these materials away from the channel of the Lower Mississippi. However, the overall mass of materials carried to Louisiana's wetlands and the Gulf of Mexico would remain unchanged.

Pollutants from minor creeks, rivulets and overland flow are not a significant problem on the Mississippi River below Old River because the continuous flood protection levees along its bank prevent drainage into the river.

The Mississippi does receive waste waters from most of the industries and communities along its banks. The concentrations of various polutants resulting from these discharges depend on the quantities discharged, the volume of receiving water with which they are mixed, the rate of transport of the waste away from the point source and the rate at which the material is removed from the water or is changed in form.

Significance of Water Quality Changes

The change of water quality in the Lower Mississippi River from fresh to saline would be more than a variation in water quality. It would be a complete change in character. This change would affect all of the industries and municipalities which depend on the Mississippi as a source of fresh water. The loss of the Mississippi River as a fresh water source for even a few weeks each year would cause severe problems to the users, such as potability and pipe corrosion, because of the absence of readily available alternative fresh-water sources.

This change in water quality would not, of course, affect navigation or recreation on the the Mississippi River.

There would be other effects: industries that use river water for once-through cooling would find that their river intakes and the outlets for spent water were too close together. Consequently the cooling water would be contaminated by water that had passed through the condensers and was much hotter than normal river temperatures. The effect would be to reduce the production of power.

Industries and municipalities that dispose of treated wastes into the river might find that the degree of treatment was inadequate. On the other hand, industries that produced waste streams of chlorides or other minerals found in sea water would find that they had, effectively, stopped polluting the river: if the water is already too salty, a little more salt would not be noticeable.

V

FRESH WATER USAGE AND REQUIREMENTS

Present Uses

Below Old River the quantity of water pumped from the Mississippi River for industrial and power generation uses is equal to approximately 65% of the total water pumped for these purposes in the entire state of Louisiana. The river below Baton Rouge provides almost half the quantity of water used for public supply in Louisiana. More than 150 industries, power plants and municipalities pumped water from the Lower Mississippi in 1975. Large industrial plants utilizing the river's water included almost fifty chemical plants, some twenty synthetic rubber and plastics producers, more than twenty petroleum refineries and about twenty processors of food and kindred products (U.S. Geological Survey unpublished data, 1977).

Table I shows total pumpage for public supplies and thermoelectric and industrial uses by parishes along the river. Lafourche Parish is included since fresh water from the Mississippi is pumped into Bayou Lafourche at Donaldsonville and provides fresh water for this parish. Fresh water pumpage for thermo-electric uses accounts for 57% of the total pumpage. Table II lists industrial use of fresh water by type of industry. The chemical and plastics industries account for 85% of the total industrial usage.

TABLE I
PUBLIC SUPPLY, INDUSTRIAL AND THERMOELECTRIC PUMPAGE IN 1975
(Parishes along the Mississippi River Downstream from Old River, Rounded to the nearest MGD)

	Public Supply		Industrial		Thermoelectric	
Parish	Ground	Surface	Ground	Surface	Ground	Surface
Ascension	1	1	1	115	0	0
Assumption	0	2	0	10	0	0
East Baton Rouge	40	0	85	114	8	5
Iberville	1	0	30	643	1	388
Jefferson	0	58	2	34	3	1498
Lafourche	0	8	0	29	0	0
Orleans	0	131	19	0	16	594
Plaquemines	0	6	0	51	0	0
Point Coupee	1	0	5	1	0	0
St. Bernard	0	9	0	566	0	0
St. Charles	0	5	2	604	0	1541
St. James	0	2	4	275	0	0
St. John the Baptist	1	1	3	88	0	0
West Baton Rouge	4	0	3	0	0	0
West Feliciana	2	0	2	35	0	0
TOTAL	50	223	156	2565	28	4026

Total Ground Water = 235 MGD   Total Surface Water = 6814 MGD   Grand Total = 7049 MGD

Figures based on U.S. Geological Survey files for water pumpage in 1975.

Total withdrawal of fresh water in 1975 in the parishes below Old River using the Mississippi River's water was more than 7.0 billion gallons per day (BGD). Of this amount, slightly more than 6.8 BGD was taken from surface sources, with almost all of this being taken from the Mississippi. Approximately 6.4 BGD of the water used was returned to the river as wastewater.

TABLE II
FRESHWATER WITHDRAWALS, IN MILLIONS OF GALLONS A DAY FROM THE LOWER MISSISSIPPI FOR VARIOUS INDUSTRIES IN 1975

	Ground water	Surface water	Total
Chemical, plastics and synthetic rubber	78	2224	2302
Petroleum refining and petroleum products	21	179	200
Food and kindred products	37	32	69
Wood and paper products	3	58	61
Others or industrial withdrawals not identified by type product	18	71	89
TOTAL	157	2564	2721

Source: U.S. Geological Survey data for water pumpage in 1975.

Table III is a list of the major power generation facilities along the Mississippi below Old River in 1975. All but two of the facilities withdrawing water in 1975 used cooling water, once through. Additionally, small municipal power plants are located along this reach with a total capacity of 100 MW as well as private industrial generating plants having a total capacity in excess of 400 MW. Total pumpage for power generation was 4 BGD in 1975, almost all of which was from the Mississippi River. At least one nuclear fueled power plant, owned by the La. Power & Light Company at Taft, La., will be utilizing river water for cooling by 1984. As of this writing (1980) it is more than 50 percent complete and making application for permission to load fuel.

TABLE III
ELECTRIC GENERATION FACILITIES ALONG THE MISSISSIPPI RIVER BELOW OLD RIVER

Plant	Owner[3]	Approximate 1975 capacity (MW)	Fresh water withdrawals (MGD)[1,2] Ground	Surface
Big Cajun[4]	Cajun Electric	230	17	0
Louisiana	GSU	428	5	5
Willow Glen	GSU	1586	1	388
Little Gypsy	La. P&L	1251	0	930
Market Street	NOPSI	96	2	112
Nine Mile Point	La. P&L	1917	0	1500
Waterford	La. P&L	860	0	605

Source: Lower Mississippi Region Comprehensive Study, 1974, Volume D-11, pp. 292, 410.
1. U.S. Geological Survey, unpublished data of pumpage of water in Louisiana, 1975, unpaginated.
2. Corps of Engineers, 1975, p. 161.
3. Owners: GSU--Gulf States Utilities, inc.; La. P&L--Louisiana Power & Light, Inc.; NOPSI--New Orleans Public Service, Inc.
4. Projected maximum withdrawal rate, Environmental Impact Statement Bovay Engineers, Inc.,--Burns and Roe Inc., 1975. p. 4-20.

Effects of Loss of Fresh Water Flow on Water Use

Since the water withdrawn from the Mississippi is used for a myriad of purposes, the required quality of the raw water and the treatment requirements are not uniform. In some instances brackish or saline water could be used in place of fresh water with few, if any, problems. Total dissolved solids over about 500 ppm, including 250 ppm of chlorides, would make the water undesirable for public consumption according to drinking water standards. There are, in addition, many industrial processes in use along the lower Mississippi which require water of higher quality than that suitable for public water supply.

To further complicate the analysis of the effects of the failure of the ORCS on water use on the lower Mississippi is the likelihood that in the years immediately following failure, the salinity of the river would be quite variable throughout the year and along the length of the channel. To reduce the complexity of this problem to a worst-case basis the assumption was made that the flow of fresh water had stopped completely. Provisions would then have to be made to satisfy water demand by developing alternate sources.

As in any study dealing with water supplies, the first requirement is to determine water demands. The major difference between this study and other studies is that demand projections have been based on the assumptions that water usage would decrease rather than increase. The basis for this assumption is discussed at length in the following pages.

Recent federal regulations have forced industries to reduce the quantities of waste materials discharged into receiving waters, and the expressed goal of "zero discharge" is to eliminate the discharge of all pollutants and make the streams suitable for swimming and fishing. If this goal, unrealistic as it may be, remains in effect, and there is, at present, no reason to assume otherwise, the recycling of water would approach 100 percent by the mid 1980's and the only water demand would be to replace water actually consumed or lost by evaporation.

Should the fresh water flow in the Mississippi cease, the cost of obtaining fresh water would clearly increase. In many instances, it might be more economical to recycle wastewater than to develop alternate sources. If recycling were already being practiced in response to federal requirements, the demand would remain nearly constant at the present level of consumption. If recycling were not yet practiced by industries, the necessity to develop an alternate source coupled with the federal requirements, would be a strong incentive to reduce water demands to the maximum extent.

An increase in the price of water could be expected to reduce the municipal demand. It has been observed that water consumption in communities decreased by approximately 6 percent for a 10 percent increase in price (Clark, 1976, p 372). Thus the total demand on the public water supplies along the Mississippi could be expected to decrease somewhat, even with a slight increase in population. An assumption that requirements of municipal water supply systems would remain constant is therefore reasonable.

In summary then, water demands have been based on the assumptions that (1) municipal requirements would not change, and (2) industrial requirements would reflect the actual consumptive use requirements.

Consumptive use requirements differ widely between different industrial categories and even between plants using the same basic processes. In thermoelectric power generation consumptive losses are approximately one and one half percent of the condenser flow for plants using cooling ponds, and about two percent for plants using evaporative cooling towers and spray ponds. The average condenser water requirement for fossil-fueled, steam electric power plants was about 40 gallons per kilowatt-hour in 1965 (Water Resources Council, 1968, p. 4-3-3). Using these figures and assuming condenser cooling water will be passed through evaporative cooling towers, it is possible to estimate the consumptive water requirements for the thermoelectric plants on the lower Mississippi. Of the 7550 MW capacity shown in Table III, the capacity of the plants dependent on the Mississippi for fresh water is about 6370 MW. The consumption of these plants, based on the two percent of 40 gallons per kilowatt-hour would be approximately 120 MGD.

Most water used by industry is for cooling purposes, and the plants located along the lower Mississippi are no exceptions. Reductions in water use can be accomplished by reusing water by the use of cooling devices such as forced or natural draft cooling towers or cooling ponds.

While each plant has its own characteristics and potential for water conservation, generalizations can be made concerning the overall level of consumption, or minimum water requirements. The U.S. Environmental Protection Agency published an estimate of water intake and consumption in 1968 for a number of standard industrial classes. This information, presented in Table IV, shows the wide variation which would be expected, with from 6.2% to 21.2% of the total volume of intake actually being consumed.

TABLE IV.
VOLUME OF INTAKE AND PERCENT CONSUMED BY INDUSTRY GROUPS, 1968

Industry	Intake, Billion gallons	% Consumed
Food & Kindred Products	811	7.2
Lumber	118	21.2
Paper	2252	7.7
Chemicals	4476	6.7
Petroleum & Coal	1453	15.2
Stone, clay, glass	251	13.1
Primary metals	5005	6.2
All manufacturers	15467	9.6

Source: US EPA "The Economics of Clean Water", Vol I, 1972, p. 37.

In general, the consumptive use by an industry would increase somewhat when it changed from once-through cooling systems (which increase the temperature of cooling water but do not directly evaporate any) to closed-cycle cooling systems because of the evaporative losses associated with most cooling processes. Once-through cooling systems have essentially no water losses. Cooling towers consume about 0.2 percent of the recirculated volume through spray losses, and about 1.0 percent through evaporation for each 10½ F decrease in cooling temperature (Durfor, 1963, p 236). Thus, the consumption data presented above would have to be increased somewhat if all industries practiced closed-cycle cooling.

It was assumed that the minimum water requirements of various industries using the Mississippi as a fresh water source would be 20 percent of the total water usage for wood products, 15 percent for petroleum refineries, and 10 percent for the remainder. Applying these percentages to the figures for 1975 industrial surface water pumpage shown in Table I, gives a total consumption of 270 MGD for all industries using the river as a source of supply.

The total public water supply obtained from surface streams was 227 MGD. Assuming this full amount would have to be provided, along with the consumptive requirements of thermoelectric generating plants and industries, the total demand for fresh water by present users of the Mississippi below Old River would be some 620 MGD. This is the demand used for cost estimates in this study. Despite the seeming accuracy of the figures, no guarantee is given or implied that the second and third significant figures are reliable. It is possible to round off these numbers to 200 MGD and 600 MGD respectively without losing accuracy.

VI

POSSIBLE FRESH WATER SOURCES

General

Should the discharge of the Mississippi River be essentially captured by the Atchafalaya, the flow in the Lower Mississippi would progressively decrease as the channel just below the point of diversion filled with sediments. Salt water intrusion into the entire river channel would probably occur during the first period of low discharge that occurred after the failure of the low-sill structure. Thus in a relatively short period of time the fresh water flow in the lower Mississippi would cease almost entirely and alternate sources of fresh water would be needed to satisfy the present users of fresh water. Other sources of surface water, as well as ground-water supplies, are the most likely alternatives. Less likely, but possible, are the desalting of brackish or saline waters, the capture and storage of local runoff, and water reclamation and reuse.

Exclusive of the Mississippi River, the most important sources of surface water in southeastern Louisiana include the Atchafalaya River, the streams flowing into Lake Pontchartrain and Lake Maurepas, and the Pearl River. The area between the Atchafalaya basin and the Pearl River covers over 13,000 square miles of which about 11,000 square miles is land. The runoff from this area averages from 18 to 24 inches per year.

In the same area there is an abundance of fresh ground water, although its distribution is not uniform. Vast quantities of potable ground water are available in the parishes east of the Mississippi and north of Lake Pontchartrain. Below Baton Rouge, along the banks of the Mississippi, the ground water is usually potable. In the vicinity of New Orleans and further south, the salinity of the ground water is too high for most uses.

River and stream beds in southeast Louisiana are below sea level from their outlets for some distance upstream. Consequently near the outlets of such rivers the channels contain saline water at times. For this reason the quantity of fresh water which may be withdrawn is often limited by the upstream movement of salt water into the river--the "Salt Water Wedge".

Surface Waters

East of the Mississippi

East of the Mississippi river and south of Lake Pontchartrain, the bayous are characterized by low minimum flows and intrusion of salt water into the streams and marshes. The bayous drain low wetlands that are very flat, and such lands are subject to flooding by tides. Major hurricanes may produce tides in many of these areas in excess of 10 feet MSL. Such streams must be excluded from consideration as sources of fresh water.

The major streams east of the Mississippi that are potential sources of fresh water are the Amite, Tickfaw, Tangipahoa, Tchefuncte and Pearl Rivers.

The Amite River drains an area of 1,819 square miles from its source in southwestern Mississippi to Lake Maurepas. Principal tributaries include Bayou Manchac and the Comite River. The annual average discharge of the Amite River is about 2,600 cfs at its mouth. The mean flow of the river at Denahm Springs is 1,900 cfs. The minimum flow recorded for the Amite between 1938 and 1976 at Denham Springs was 271 cfs, from a drainage area of about 1,280 square miles (U.S. Geological Survey, 1976, p. 231).

The Tickfaw River also originates in southwestern Mississippi and flows into Lake Maurepas. Principal tributaries are the Blood, Natalbany, and Pontchartrain Rivers. Average annual discharge is approximately 1,300 cfs from a drainage area of 945 square miles. Minimum flow recorded at Holden, Louisiana for a period from 1940 to 1976 was 65 cfs from a drainage area of 247 square miles. This minimum flow occurred in October, 1969 (U.S. Geological Survey, 1976, p. 196).

The Tangipahoa River has an average flow of about 1,300 cfs at its mouth. The source of the river is in southwest Mississippi and it drains approximately 771 square miles. The minimum recorded flow of 245 cfs in the Tangipahoa, for the period from 1938 to 1976 occurred at Robert, Louisiana where the drainage area is 646 square miles, from October 30 to November 3, 1968 (U.S. Geological Survey, 1976, p. 192). To prevent the movement of salt water upstream, the minimum flow required twelve miles upstream from the mouth of the Tangipahoa is approximately 100 cfs. This requirement means that, at low flow, the maximum rate of withdrawal should not exceed 150 cfs.

The Tchefuncte River's mean flow at its mouth at Lake Pontchartrain is about 700 cfs from a drainage area of 450 square miles. The mean flow at Folsum, Louisiana for the period of record 1943-1976 is 159 cfs. The minimum recorded flow of the Tchefuncte near Folsum was 26 cfs in September, 1968 where the drainage area is 95.5 square miles. (U.S. Geological Survey, 1976, p. 190).

The Pearl River, which flows along the state line between south-eastern Louisiana and southwestern Mississippi drains an area of 6,630 square miles at Bogalusa, Louisiana and has an average flow of 9,300 cfs at that point. Below Bogalusa, the Pearl River consists of a system of tributary, distributary and interconnecting channels. About 15 miles south of Bogalusa the Bogue Chitto joins the Pearl from the west. Farther downstream the channel branches into the Pearl River and a western branch, appropriately called the West Pearl River. Still farther south, the Middle Pearl River distributary leaves the West Pearl River. Minimum flow in the West Pearl River at U.S. Highway 11 above the junction with the Middle Pearl distributary is 1,300 cfs, which is approximately 75% of the total flow of the system during minimum flows (Cardwell, et. al, 1966, pp. 13-14).

Development of the Pearl River as a source of water for towns and industries along the Mississippi River is presently restricted by a Louisiana State Stutute prohibiting transport of water from St. Tammany Parish. The Louisiana Revised Statute Act of 1968, No. 284 paragraphs 1 and 2 as amended by an Act of 1972, No. 42, paragraph 1 provides that:

> No person, firm, corporation, public body, quasi-public body or political subdivision shall transport underground or surface water from the Parsih of St. Tammany to any person, firm, corporation, municipality or city located outside of said Parish; provided, however, that the provision of this section shall not be construed to prohibit any person, firm or corporation engaged in the business of selling or furnishing to consumer bottled water from wells which are situated within the said Parish.

Revision of this law would be required prior to embarking on any project to export water from the Pearl River or ground water from St. Tammany Parish.

Salt water intrusion may be a critical parameter on the lower Pearl River. For a withdrawal rate of 150 cfs from the West Pearl River below U.S. Highway 90, salt water could be expected to intrude to the point of withdrawal and remain for a seven-day period at least once every six years and remain for a fourteen-day period at least once every 7½ years (Cardwell, et. al, 1967, pp. 44-47). Withdrawals made farther upstream on the Pearl River would be limited by minimum flows rather than salt water intrusion. Above mile 29.9 on the Pearl River, where a lock is located, withdrawals equal to the minimum flow could be made. As a result of large and sustained withdrawals, however, the river downstream from the lock would become a salt water estuary during low flows.

West of the Mississippi

Surface drainage in the basin lying between the west bank of the Mississippi and east of the Bayou Lafourche ridge is characterized by sluggish canals and bayous. The Barataria Bay Basin extends from Donaldsonville, Louisiana, from mile 175 AHP down to the Gulf of Mexico. The dominant water bodies in the area are Barataria Bay at the lower end, Lakes Salvador and Cataouatche, and Lac des Allemands, which is near mile 130 AHP on the Mississippi. The water level record of the gaging station on Bayou des Allemands, which is about seven miles below Lac des Allemands, shows that flows into and out of the lake are tidally influenced. The water surface at the gaging station normally ranges between -0.5 and 2.0 feet MSL. Water surfaces in the swamps and marshes south of Lac des Allemands would be even closer to the level of the Gulf of Mexico. There are no surface water supplies in this basin which could provide a significant amount of fresh water suitable for a potable water supply on a continual basis.

Between the Bayou Lafourche ridge and the East Atchafalaya Basin Floodway Levee sources of surface water closely resemble those in the Barataria Bay basin. Sluggish bayous and drainage canals carry surface water to the Gulf. North of Donaldsonville the land is low and wet except for the natural levee banks of the Mississippi. The narrow strip of land between the Mississippi River and the Atchafalaya Basin is drained through a random pattern of bayous and drainage canals, none of which could qualify as a major source of fresh water.

The Atchafalaya will become a principal source of fresh water in south Louisiana should the Old River Control Structure be destroyed. A system of channels, pipelines and pumping stations to divert water from the Atchafalaya to satisfy the demands of the existing municipal and industrial users on the Lower Mississippi would be feasible.

Quality

The water in streams which flow into Lakes Pontchartrain and Maurepas is of satisfactory quality for use as sources of potable water. High rates of discharge are derived from surface runoff while dry weather flows consist of ground-water discharge. The concentrations of dissolved solds are generally lower than such concentrations in Mississippi River water and the water is generally softer. Color, turbidity and sediment are present (Cardwell, 1967, pp. 47-74), but pose no unusual water treatment problems.

The quality of the fresh water in the Atchafalaya basin would be essentially that of the Mississippi River. Any difference in quality would be caused by inflows from the Red River.

Ground Water

General

Three principal aquifer groups have been identified in southeastern Louisiana. They are the Miocene-Pliocene sands, Pleistocene sands, and the Mississippi River alluvium. Miocene and Pliocene sands form a vast aquifer complex in southeastern Louisiana. The system of sand layers formed by these deposits consists of fine to medium well-sorted sands with interbedded layers of clay. The Mio-Pliocene sands outcrop in Mississippi and dip and thicken to the south where they are covered by Pleistocene deposits. Sand layers range in thickness from 50 to a few hundred feet. Transmissivities usually range from 100,000 to 300,000 gpd per foot. The unconsolidated formations are many thousands of feet thick, but fresh water is found only to a maximum depth of 3500 feet in Tangipahoa Parish. Southward from Lake Pontchartrain the base of fresh water becomes increasingly shallow and is underlain by saline aquifers (LMRC, 1974, Vol. C-II, pp. 477, 481, pp. 528-531).

Pleistocene deposits overlie the Mio-Pliocene sands throughout southeastern Louisiana. These sands have not been completely flushed of salt water, and south of New Orleans they generally contain saline water. The sands are not well sorted and their transmissivities are less than 200,000 gpd per foot. Well yields of fresh water are generally low to moderate, possibly a few hundred gallons per minute. Larger yields are often obtained where the local aquifer is hydraulically connected to, and recharged by, the Mississippi River alluvium and the point-bar deposits which receive water from the Mississippi.

Total Potential Supply

Figures 4 and 5, taken from the Lower Mississippi Region Comprehensive Study, summarize the groundwater situation in the lower Mississippi Region. This study contains an estimate that the potential yield of the aquifers in Water Resources Planning Areas 8 and 10 (which include most of southeastern Louisiana from the Atchafalaya Basin to the Pearl River and a part of Amite, Wilkinson and Pike Counties, Mississippi) is 460 MGD from water table aquifers and 850 MGD from artesian aquifers (LMRC, 1974, Vol. C-1, p. 150). Pumpage of fresh ground

FIGURE 4. GEOLOGIC SOURCES OF GROUND WATER

water in southeastern Louisiana was about 415 MGD in 1975. The estimate of groundwater requirements in the area for 1980 is more than 600 MGD (Louisiana Department of Public Works, 1971, pp. 46, 48). Estimates of potential yield were based on pumping rates which would cause a lowering of water levels an average of 200 feet, or to the top of the aquifer in artesian aquifers, and water level declines of forty feet in water table aquifers after fifty years of pumping. The decline of water levels assumed in these estimates of potential yields included such parameters as increases in pumping costs as water levels decline, land subsidence, contamination by salt water and the effect of lowered water levels on the outcrop or recharge area. The estimates obtained are crude average values for all of southeastern Louisaina and should be used with this qualification in mind at all times.

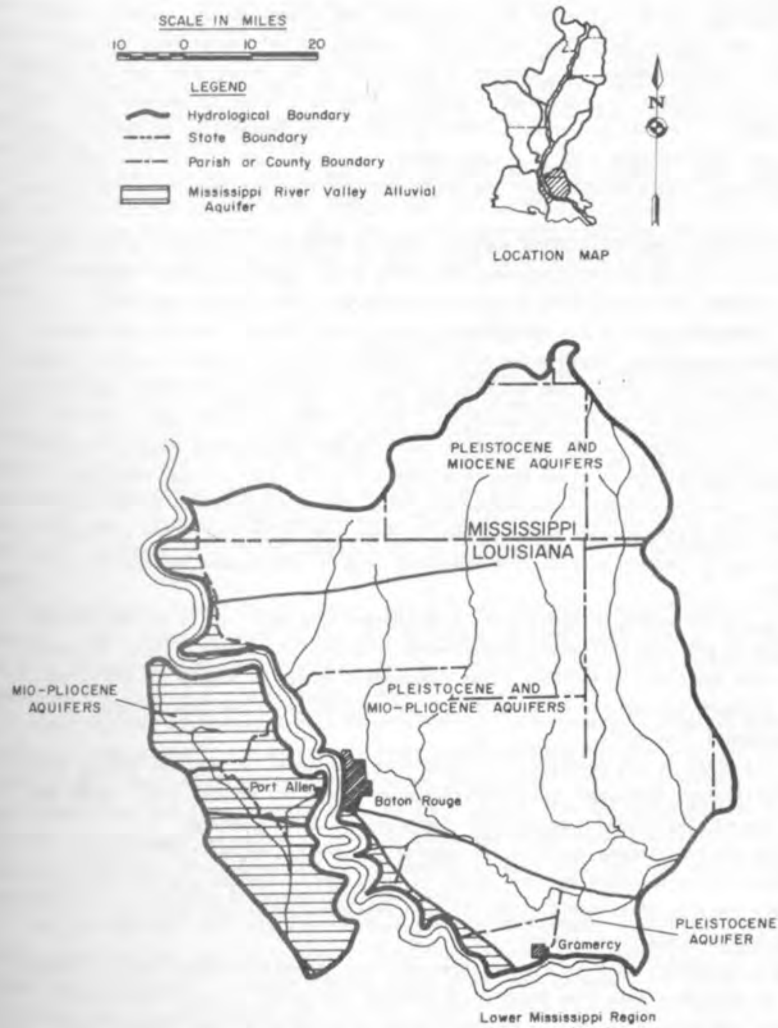


FIGURE 5. GEOLOGIC SOURCES OF GROUND WATER

In the Florida Parishes, the area north of Lake Pontchartrain, vast groundwater resources exist and flowing wells are common. There is an estimated 2×10^{14} gallons (two hundred thousand billion gallons) of fresh water underground, enough to fill a lake 100 times the area of Lake Pontchartrain to a depth of 15 feet (Winner, 1963, p. 19). These artesian aquifers have been developed as sources of fresh water for public supplies, industrial use, irrigation and rural domestic use. The fresh water aquifers are underlain by salt water throughout Louisiana. In the Florida Parishes, the deepest fresh water bearing sand is about 3500 feet below MSL. Under most of the area fresh water occurs to a depth of at least 2400 feet below MSL.

Lake Pontchartrain lies just south of the Florida Parishes. Aquifers under this lake contain both fresh and saline waters. The interface between salt water and fresh water decreases from a depth of about 3000 feet near the north shore of the lake to about 1000 feet in the south.

As in other areas where salt water and fresh water are in equilibrium, removal of the ground water in the Pontchartrain areas could cause movement of salt water into the sand presently containing fresh water. As pumping is increased in the fresh water portion of the aquifer a hydraulic gradient is created which causes nearby salt water to advance toward the point of withdrawal. A report by Cardwell (1967, p. 70) on the feasibility of use of groundwater in the Lake Pontchartrain area as a supplemental supply for New Orleans concluded that any large withdrawals should be made near the north shore of the lake to minimize salt water encroachment.

In the New Orleans area the shallow aquifers consist of small, isolated sand deposits including the point bar and distributary deposits found along abandoned stream channels. These shallow aquifers are unimportant as public or industrial fresh water supplies.

The most important aquifers are designated as the 200-ft, 400-ft, 700-ft, and 1200-ft sands. The 200-ft sand yields fresh water only in certain areas of Jefferson and St. Charles Parishes, and the water is colored and not used for public supplies. The 400-ft sand yields moderate quantities of water of varying qualities. Rollo (1966, p. 20-21) found chloride contents generally to range from 250 ppm to less than 500 ppm and hardness ranging from 80 to 268 ppm. Large quantities of water have been pumped from the 700-ft sand, which has resulted in water level declines in the New Orleans area and some subsidence of the land surface (Kazmann and Heath, 1968). Water in the 700-foot sand is yellowish and although potable is not used for public supply. The 1200-foot sand is rarely used because of its chloride content.

Although a limited amount of fresh water is withdrawn from aquifers in the New Orleans area the quality is poor and salt water encroachment is a constant threat. Thus, the ground water in this area would not be suitable as an independent source of supply for the metropolitan area, although the aquifer could be recharged with filtered and treated water which could later be pumped from wells.

Fresh ground water is not available in significant quantities outside the natural levee ridge of the Mississippi from above Donaldsonville down to the New Orleans area. Below New Orleans there are no significant quantities of fresh ground water anywhere.

Inasmuch as the Pleistocene aquifers are generally connected hydraulically to the Mississippi River Valley alluvial aquifer, which is in hydraulic contact and recharged by the Mississippi, these aquifers would ultimately be contaiminated by salt water were the Mississippi to become brackish or saline.

In general, it appears that large quantities of fresh ground water would only be available north of an east-west line from Baton Rouge through the center of Lake Pontchartrain. Even though vast underground reservoirs of fresh water exist north of Lake Pontchartrain, continuous withdrawals at rates large enough to meet all or a substantial part of the demand along the Mississippi River could eventually deplete the aquifers unless artificial recharge were undertaken.

In order to provide for a permanent water supply and to maintain water levels in the wells, the aquifers would have to be recharged artificially through a system of injection wells. Essentially, equilibrium would have to be created between withdrawal and injection. This requirement of artificial recharge increases the costs of ground water supply systems.

A fresh water surface source capable of producing at a rate equal to the total demand must be located (including the water to be used for recharge to replenish the water taken from storage). Since the water injected into aquifers must be free of solids, filtration of the water from the surface source must be provided. Finally, a transmission network and a series of injection wells would be required. It is, of course, possible that some of the wells used to produce water could be utilized as injection wells.

A ground-water production and injection system such as this would be equivalent to a normal surface water supply. It would produce water at the mean rate, with a storage reservoir of sufficient capacity to meet fluctuations in demand. In this instance the storage reservoir would be the aquifer. However, the system would have to pay an operating cost not normally experienced in surface water treatment and storage systems: lifting the water the vertical distance from the water level in the well to the ground surface. There would be some compensating advantages as compared to a surface reservoir in that the water stored in the aquifer would not suffer evaporation losses, be subjected to pollution, and the reservoir capacity would not be dimished by siltation.

<u>In this study, wherever ground water is withdrawn from an aquifer to satisfy a requirement for fresh water, it is planned that an equivalent amount of treated surface water would be injected into the formation so that over an extended period of time the net ground water withdrawal would be zero.</u> The aquifer is to be used as a flow balancing reservoir and is not to be mined.

Desalination

Desalination has been studied intensively in recent years, especially since the Office of Saline Water (now, in 1980, a part of the Office of Water Research and Technology) was established in the 1950's. A number of processes for providing potable water and water for industrial usages from saline or brackish water have been developed and improved. In 1971 there were 301 desalting plants in the United States with a total capacity of over 43 MGD of which eight were rated at 1 MGD or greater. Eleven desalting plants on the lower Mississippi River had an average capacity of about 90,000 gallons per day (U.S. Department of the Interior, 1970).

Most desalting plants distill water, but some use freezing, reverse osmosis, or electrodialysis. Among other parameters, the cost of producing fresh water from salt water depends on daily throughput, the cost of energy, the type of process used, the quality of feed water, and the quality of the finished product.

About one half of the total cost of desalination is for energy. About 25 percent of the energy requirement is for electrical power and 75 percent for steam generation. Cost estimates were obtained by the Office of Saline Water using electricity costs of 6.2 mils per kilowatt hour and steam heating costs of $0.22 per million BTU based on a 50 MGD unit. The cost to desalinate sea water in 1965 was estimated to be about $.47/kilogallon. The equivalent 1976 cost would have been approximately $1.25/kilogallon. An approximate estimate for 1980 would be between $2.00 and $3.00 per kilogallon.

These estimates yield cost figures that are very much higher than the present cost of potable water on the lower Mississippi. Desalination would be economically feasible as a fresh water source only in remote coastal areas where surface waters are salty or brackish, the ground water highly mineralized, and the costs of water transmission from other locations prohibitive.

Water Reuse

Continuous water reuse is already practicied in a number of processes such as in closed cycle cooling towers and in the steam generation-condensation cycle. It may find an even more widespread application if effluent limitations for wastewater discharges become more restricive. However, direct recycling of a community water supply by the use of treated sewage effluent is so rare as to be virtually nonexistent. Treated industrial waste-water could be used as a community water supply in some instances, and treated municipal wastewater could be used by some industries, but recycling of a community water supply through a waste-water treatment system would be practiced only if no other alternative were available.

There are several advanced methods of water and wastewater treatment available which can make almost any water source safe to drink. However, these methods are quite expensive and are generally considered to be practical only in the most unusual circumstances (Metcalf and Eddy, 1972 and Clark et. al, 1977).

If the Mississippi River's flow should be diverted, industries using river water would be forced to practice reuse by recycling their water supplies to the maximum extent possible because the cost of fresh water would increase, and this added cost would improve the economic desirability of conservation. It is, however, highly unlikely that any of the communities along the lower Mississippi would attempt to recycle wastewater for municipal use since alternate sources of fresh water are available.

VII

ALTERNATE FRESH WATER SUPPLIES

Introduction

Most of the industries and population centers in southeastern Louisiana which utilize the fresh water of the Mississippi are located along its banks and on the narrow natural levees of Bayou Lafourche. Few alternative surface water sources have been developed because the Mississippi has been a dependable source in the past, although ground water is used in limited quantities through the region.

The demand for fresh water is unevenly distributed along the river banks from just above Baton Rouge to below Venice. Consequently, the feasibility of alternatives varies from place to place along the river. The immediate solution to a fresh water crisis would most probably consist of a number of local solutions rather than a single, regional one. It is possible that in time a water authority might be established to develop a region-wide supply, but this would be accomplished by the cooperation of local organizations in response to economic and physical circumstances.

This study addresses the initial problems that would be studied by any planning organization whose task it would be to delineate feasible alternate, and permanent, water supplies for the large numbers of users along the Mississippi. This study is actually an initial screening of possible alternative sources of fresh water to determine which of them might be suitable for more detailed investigation.

The dominant geologic feature of the region is the Mississippi River trench. With the freshwater flow reduced or eliminated, scour and deposition would virtually cease and the River would no longer be a formidable barrier to water transmission lines. Water could be transferred from one side of the river to the other with few complications. This would eliminate the necessity of having to maintain a strict division between supplies for the East bank and West bank.

Clearly a number of alternative arrangement can be made to transfer various quantities of fresh water from several locations to the customers. Although no attempt has been made to determine the optimum course of action, preliminary cost estimates have been made for some of the more feasible alternatives.

North of Baton Rouge and in the Baton Rouge Metropolitan area, ground water is a logical alternative source of the total fresh water supply for both public and industrial consumption because of its quality and availability. It is already the principal source of potable water as shown by the pumpage data in Table I. In East and West Baton Rouge Parishes, West Feliciana, and Point Coupee, all 47.0 MGD of the public water supply is derived from ground water. For industries and electric generating stations, about 40 percent of the water used was ground-water. If total demand by industry were reduced by 90 percent through various conservation practices, the present rate of groundwater withdrawals would, theoretically, meet the total industrial and thermo-electric consumption requirements. The water is available in the aquifers but wells would have to be installed in locations where the water is used, or it would have to be piped from existing well sites to the consumer.

In the Baton Rouge area and the parishes upstream, the replacement of the Mississippi as a surface water source would pose no serious problems, nor would it be an expensive matter.

Two alternative approaches to the problem of supplying fresh water to users of the Mississippi River downstream from the Baton Rouge area were considered. Both alternatives consisted of providing water from several sources. The fresh water supply for the New Orleans metropolitan area and those consumers downstream from New Orleans would be obtained from the Pearl River, supplemented by well fields northeast of Lake Pontchartrain. This source was the same in both alternatives.

Alternate Water Supply Plan A

For this analysis the region below East and West Baton Rouge Parishes was divided into four segments as shown in Figure 6. Segment 1 encompasses the New Orleans metropolitan area: the parishes of Jefferson, Orleans, and St. Bernard. Segment 2 consists of both banks of the Mississippi in St. James, Ascension, Assumption, Plaquemines, and Iberville Parishes, and Bayou Lafourche. Segment 3 is composed of the sparsely populated areas along the Mississippi south of New Orleans. St. Charles and St. John the Baptist Parishes made up Segment 4. Breakdown of water demands by parishes and segments, as well as type are shown in Tables V and VI.

TABLE V.
WATER REQUIREMENTS BY PARISH AND TYPE

Parish	Public	Industrial	Thermoelectric
Ascension	1.8	12.7	0.0
Assumption	1.6	1.1	0.0
Iberville	1.4	73.4	11.8
Jefferson	58.4	3.9	45.3
Lafourche	7.6	3.2	0.0
Orleans	131.3	2.1	18.4
Plaquemines	6.4	5.5	0.0
St. Bernard	9.0	61.7	0.0
St. Charles	5.0	66.1	46.5
St. James	1.7	30.4	0.0
St. John the Baptist	2.4	9.9	0.0
Totals	226.6	270.0	122.0

Requirements given in MGD (Million gallons per day)

Source: U.S. Geological Survey Files for Water Pumpage in 1975.

TABLE VI.
WATER REQUIREMENTS BY SEGMENTS
(Million Gallons a Day, Rounded Figures)

Segment No.	Public	Industrial	Thermoelectric	Total
1	200	70	60	330
2	15	120	10	145
3	5	5	0	10
4	10	75	45	130
TOTALS	230	270	115	615

Combined by segments from Table V.

Segment No. 1 - New Orleans Metropolitan Area

As shown in Table VI, the New Orleans metropolitan area would have an average requirement of approximately 330 MGD. Municipal requirements would be 200 MGD, industrial 70 MGD and thermoelectric 60 MGD.

Ground water and alternate surface water supplies have been studied intermittently as sources to satisfy the fresh water requirements of the New Orleans Metropolitan area. The total dependence of the metropolitan area on the Mississippi River has caused operational problems in the past because of salt water intrusion from the Gulf to the river intakes on the Mississippi during periods of low flow in the river. Moreover there exists a constant

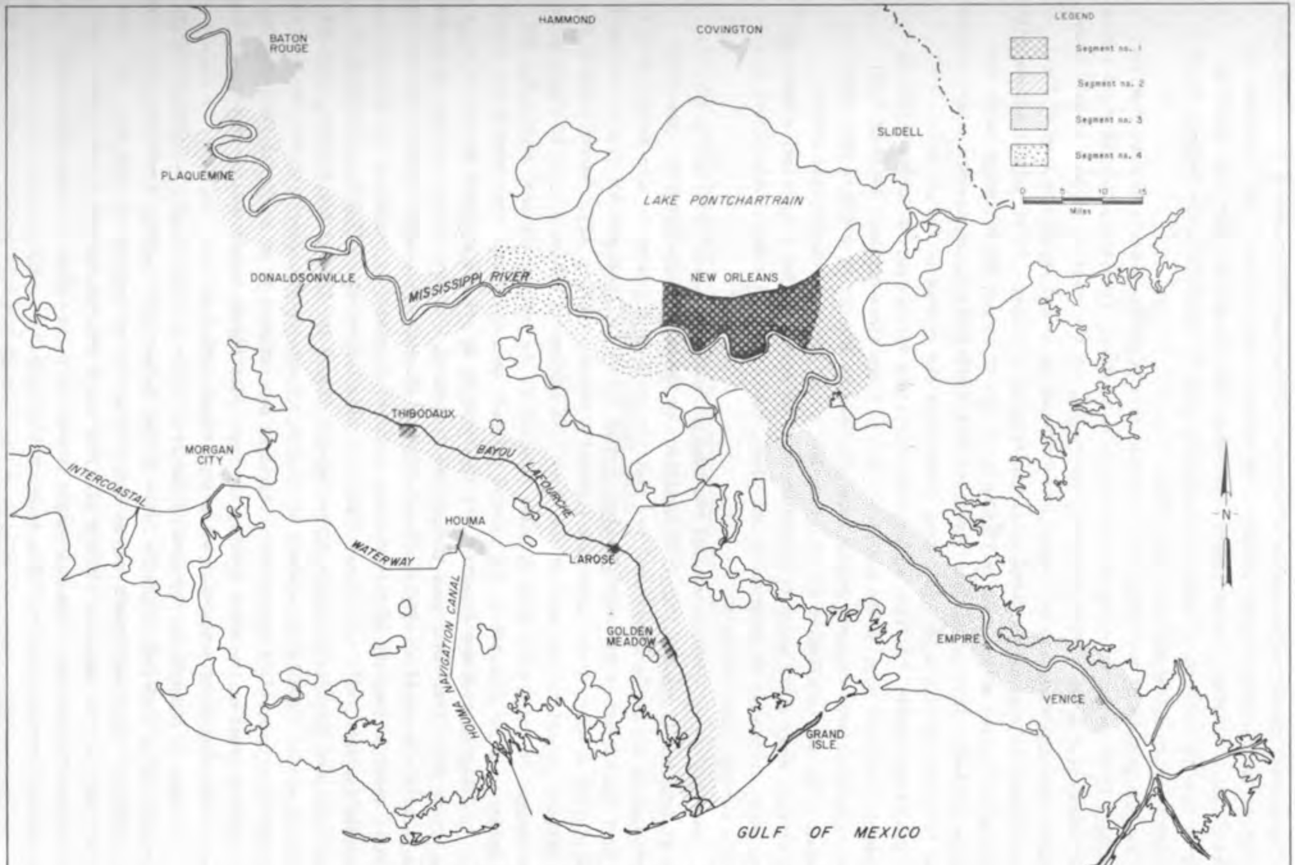


FIGURE 6. ALTERNATE WATER SUPPLY - PLAN A

hazard from pollution due to industrial or shipping accidents, not to mention the gradual increase in concentration of various pollutants in the river water, despite the best efforts of local, state and Federal agencies.

The nearest surface water source of interest is the Pearl River, which is located about 35 miles to the northeast of New Orleans. The average flow at Pearl River, Louisiana is slightly over 6,100 MGD. The necessary fresh water for the metropolitan area could be obtained from this stream, if provisions could be made for augmenting the surface supply with ground water during period of low flow.

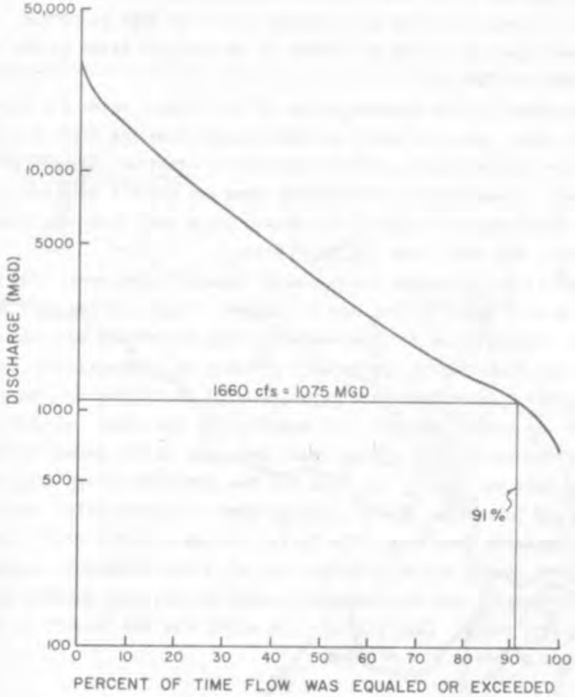
For the purpose of this study it is assumed that withdrawals would be made from the West Pearl River in the vicinity of the town of Pearl River, Louisiana, located about twelve miles above the U.S. 90 highway crossing. Below U.S. 90 the river is subject to salt water intrusion from the south and salt water could intrude up to and beyond the town of Pearl River if the discharge were reduced below the recorded minimums. It is further assumed that withdrawals of river water would be limited so as not to reduce the discharge below the recorded minimum. This assumption is necessary in order to limit the maximum extent of salt water intrusion to that which would have occurred in the absence of the project.

Discharge records for flows at Bogalusa, Louisiana for the period October, 1938 to September, 1975 were used in the analysis. Stream flows since October, 1963, at Pearl River, Louisaina were compared to the Bogalusa flows by the use of a double mass curve. Although a dam was constructed on the river during the period of record near Jackson, Mississippi, above which water is withdrawn from the reservoir for a municipal supply, and below which wastewater is returned to the river, there has been a negligible effect of the monthly average river discharge.

The ratio of the drainage area at the town of Pearl River, Louisiana to the drainage area at Bogalusa is about 1.3 to 1. Examination of the double mass curve for cumulative discharges at the two locations confirms that the ratio of discharge is also about 1.3 to 1. The West Pearl River is estimated to carry almost 95% of the total minimum flow of the Pearl River system at Pearl River, Louisiana (Cardwell, et. al, 1967, p. 43). During flood flows, the eastern channel carries most of the flow. The pumpage of 300 or 400 MGD to supply water requirements in the project area is small compared to the average and peak discharges, and the amount of water diverted to the eastern channel, once withdrawal requirements are satisfied, is unimportant to the anlyasis. At low flows it is assumed at least 85% of the total flow in the Pearl River will pass through the West Pearl. If this estimate proves to be too high or if the proportions of flow in each channel changed in subsequent years, the amount of water diverted into the West Pearl River could be increased by placing sills in the diversion channels. Since the total flow in the Pearl River at Pearl River, Louisiana is about 1.3 times the flow at Bogalusa, and because 85% of the flow at Pearl River, Louisiana at low to medium flows can be counted on to pass through the West Pearl channel, the flow in the West Pearl channel at Pearl River, Louisiana was computed to be about 1.3 times 85%, or 1.1 times as great as the total flow at Bogalusa. Additional details of the analysis of the flow in the Pearl River are presented in Appendices A and B.

As shown in Appendix A, the flow of the Pearl River at Pearl River, Louisina should not be reduced below 1470 cfs. With the ratio of flow between Pearl River, Louisiana and Bogalusa to be 1.3 to 1 this requirement reduces the minimum flow at Bogalusa to 1340 cfs. This flow of 1340 cfs plus the demand of 530 cfs (330 MGD and 12 MGD for segments 1 and 3 respectively) can be satisfied when the flow at Bogalusa exceeds 1870 cfs. This flow has been equalled or exceeded 91% of the time since 1938, as shown in Figure 7.

One of the undesirable side effects of long term declines in ground-water levels is the gradual subsidence of the land surface. Consequently any scheme of surface water use which involves the use of ground-water storage should include the replenishment of the aquifers when surplus surface water is available. Thus over relatively short periods, say five



FLOW DURATION CHART
PEARL RIVER AT BOGALUSA, LA.
1938-1975
FIGURE 7.

years, major water-level declines would be avoided and no significant subsidence would occur. Moreover, as the well field would be located in a rural, unurbanized area, the slight amount of subsidence that might occur would be of little economic significance. To avoid side-effects such as subsidence, the proposed Pearl River water supply is based on the conjunctive use of ground water and surface water. The writer recognizes that some legislation will have to be altered in order to permit the construction and operation of such a conjunctive system. The following analysis was prepared by Professor Kazmann.

During the driest period of record, between 1954 and 1957, the monthly flow of the West Pearl River was less than the required discharge rate to meet the minimum water requirements during several long periods. Had the system been in operation, the cumulative production from the well fields, partly offset by artificial recharge through injection wells, would have been some 60 billion gallons. However, by 1960 all of the water withdrawn from storage would have been replaced, bringing water levels to approximately their pre-pumpage position. This condition would have been produced by operation of a treatment plant of 55 MGD capactiy and injection wells capable of accepting water at that rate. By way of comparison, the Los Angeles County Flood Control District's injection well barrier to salt water encroachment has injected water from the Metropolitan Water District at rates of up to 40 MGD with no operating difficulties. Of course if a larger treatment plant were built, recharge could be maintained at a higher rate and the cumulative amount taken from groundwater storage would be less. The exact size of the treatment plant will have to be determined after detailed studies have been completed.

The only treatment required at the Pearl River site would be for that water which must be injected to replenish the aquifers from which ground water had been withdrawn. This water treatment plant and injection system would have to be designed based on the long term average replenishment rate: 55 MGD.

The hardness and dissolved solids concentrations of Pearl River water are lower than those of the Mississippi River. Potable water can be produced from the Pearl River with the application of coagulation, sedimentation, filtration and disinfection. As the existing water treatment plants in the New Orleans metropolitan area are capable of producing a water of satisfactory quality from raw Mississippi River water, these same treatment plants could readily be adapted to treat raw water from the Pearl River.

This study has aimed at providing the average water demand to the area: 330 MGD. In order to satisfy the peak hourly, daily, and monthly demands, local storage will be required in the New Orleans area. The existing finished-water storage reservoirs near the New Orleans treatment plants and in the distribution system will probably be inadequate for anything except hourly or daily peaks. Adidtional, and major, storage facilities will be needed.

The use of parts of the saline aquifers that underlie the East Bank and West Bank of the New Orleans area for the storage of treated fresh water may be the answer to the storage requirement. A study of this possibility was made for the Jefferson Parish Water Department (Kazmann et. al., 1974) and such local aquifer storage seems to be feasible. Bulletin 10 of the La. Water Resources Research Institute, "The Cyclic Storage of Fresh Water in Saline Aquifers", gives details of such a system (Kimbler, et. al. 1975). However, the capacity and location of each storage site and the equipment needed so that peak demands can be met are beyond the scope of this study. Each storage site would have the capability of storing one or two billion gallons of water as a minimum.

Costs

Water from Pearl River and from wells in St. Tammany Parish would have to be treated, delivered, and paid for by the water users in the project area. A preliminary general estimate of the cost of such a project is useful in comparing the cost of this alternative water source to other possible actions which may be taken to insure that an adequate supply of fresh water is always available.

Cost data were obtained from several sources. Estimates from contractors and actual construction estimates from bids on facilities comparable to portions of this project were used. A local utility company provided a schedule of rates which was used to compute power costs. Additional cost information is presented in Appendix C.

The system would have to deliver the 330 MGD for Segment 1, and 10 MGD for Segment 3 to the New Orleans metropolitan area. A possible location for the transmission pipe lines from Pearl River to the metropolitan area is shown in Figure 8. A dual pipe line would run from the Pearl River about 1.1 miles above the U.S. Highway 11 bridge, to the southeast shore of Lake Pontchartrain in the vicinity of Little Woods. It would then follow Parish Road south across the Intracoastal Waterway to Chalmette where it would supply the St. Bernard Water Works and local industries. Also at this point the requirements for Segment 3 would be obtained from the feeder line. The dual main lines would then cross the Mississippi and follow the west bank levee right of way upstream to serve the Algiers, Gretna, Westwego and Marrero Water Works, and the various industrial users along this reach. The lines would continue upstream to the vicinity of Nine Mile Point where they would supply the water for the power generating plant, then cross the Mississippi back to the East Bank to supply the Carrollton Water Works (New Orleans Metropolitan area treatment plant) and the Jefferson Parish Water Works.

Although this is probably the more expensive routing, it has the advantage that it would supply the water to the users at their existing intakes and thus would minimize the

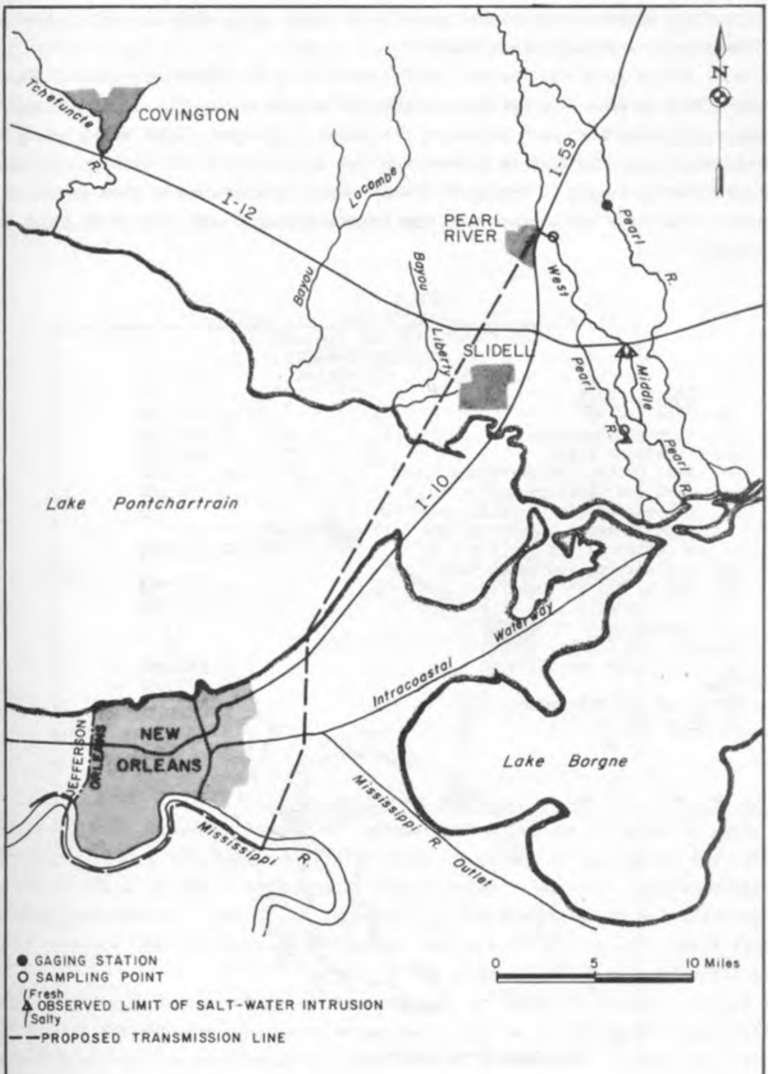


FIGURE 8. ALTERNATE A, SEGMENTS 1 AND 3

need of modifying existing facilities. These savings would more than justify the additional cost for this routing system. Also, since the Mississippi River levee rights of way would be used, there would be a minimal amount of disruption or dislocation in the communities. The existing fresh water storage facilities of each water works would be used to meet part of the fluctuations in demand, where adequate.

The total system to be constructed would consist of a 55 MGD water treatment plant, a 340 MGD well field of producing wells, injection wells with a capacity of 55 MGD, and a 340 MGD pumping station and river intake at Pearl River, Louisiana which would supply the raw water to the trunk pipelines to the metropolitan area. Additional pumping stations would be installed as needed in the trunk lines. The estimated cost of this system is shown in Table VII. The total annual cost would be $26,000,000 or a unit cost of $0.22 per 1000 gallons (1976 prices).

TABLE VII.
CAPITAL COST OF WATER DELIVERY, TREATMENT AND STORAGE SYSTEM, 1976 PRICES
(ALL FIGURES ROUNDED)
SEGMENT 1, NEW ORLEANS

Capital Cost	
(a) Pipeline	$141,000,000
(b) Pumping Equipment	10,000,000
(c) Treatment Plant	11,000,000
(d) Well Fields and Emergency Power	49,000,000
(e) Land and Right-of-Way	1,000,000
(f) Connections for existing pipeline, Appurtenances, buildings and contingencies @ 20% of (a + b + c + d + e)	42,000,000
(g) Engineering and Legal Fees 15% of (a) through (f)	38,000,000
TOTAL	$292,000,000
Annual Cost	
Interest and Capital Recovery (@ 7% for a 50 year life)	$ 20,000,000
Power	3,500,000
Operation and Maintenance (@ 1% of Capital Costs)	2,500,000
TOTAL	$ 26,000,000

Segment No. 2 - Middle River Parishes and Bayou Lafourche

As shown in Table VI, the water requirements for Segment 2 were estimated to be 15 MGD for public, 120 for industrial and 10 for thermo-electric plants, for a total of 145 MGD.

To the northeast, the nearest major surface water stream is the Amite River, which has an average daily flow of about 1675 MGD at its mouth. It is about fifteen miles east of the Mississippi River. The minimum flow on the lower river is about 230 MGD, which is slightly more than the average water requirements for this area.

The nearest substantial stream to the west would be in the Atchafalaya Basin. The East Atchafalaya Basin Protection Levee lies about twelve miles away from the Mississippi in the vicinity of Plaquemine. The distance to this levee increases gradually to about twenty-five miles in central St. James Parish. With the Mississippi River flow passing through the Atchafalaya Basin, a substantial discharge could be maintained in the Grand River and the Intracoastal Waterway which both pass along the inside of the East Atchafalaya Basin Protection Levee. The freshwater requirement for Segment 2 could be satisfied with a withdrawal from any location along this waterway.

Groundwater in Segment 2 is found in the Mio-Pliocene deposits and the Mississippi alluvium as discussed earler in the paper. To the east, beneath Lake Pontchartrain and in the parishes to the north and east, vast quantities of ground water of relatively good quality are available.

Fresh ground water along the Mississippi between Baton Rouge and New Orleans is found in relatively shallow sands which are thought to be hydraulically connected to the Mississippi

River. Salt water intrusion into the river channel would probably increase the salinities of these aquifers in a very short time, especially if they were pumped at the needed rates of withdrawals to meet the demand of Segment 2. Thus, it is believed that the deeper aquifers to the east constitute the only large source of fresh ground water which could be operated as a cyclic water storage reservoir, being used during drought periods and replenished during periods of adequate flow.

The fresh water stream just inside the East Atchafalaya Basin Protection Levee was chosen as the source of supply for all of Segment 2, primarily because of its proximity to Bayou Lafourche and Iberville and Ascension Parishes. While a combination of ground water and water from the Amite River would be another possibility as a source for Segment 2, it is believed, pending additional investigations, that this latter combination would better serve Segment 4.

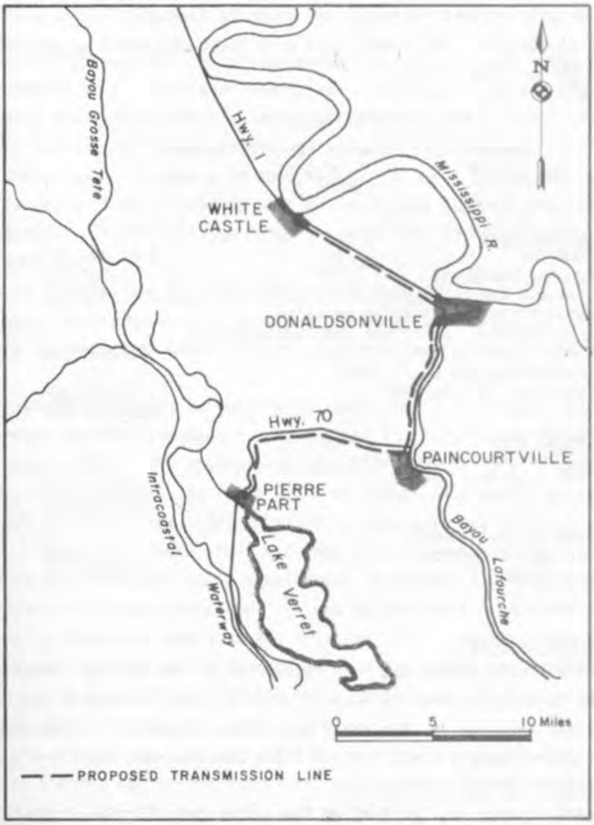


FIGURE 9. ALTERNATE A, SEGMENT 2

The fresh water supply system for Segment 2 includes a single 150.0 MGD pumping station (145 MGD requirement, rounded off) at the East Atchafala Basin Protection Levee near Pierre Part, with transmission lines from there generally following the roadways and railroad lines to Bayou Lafourche, to the Mississippi River at White Castle, all as shown in Figure 9. The untreated water is then delivered up and down stream from these points to the existing fresh water intakes of all users. Along the Mississippi the water transmission lines are placed in the right of way of the levees (which would be allowable if the Mississippi no longer reached flood stage downstream of ORCS). This would be done in order to minimize disruptions to communities and existing facilities. Lack of information as to the exact location of the sites of fresh water demand along the reach made the actual design of a functional distribution system impossible. Some existing intake structures were located, such as municipal water treatment plants and some steam electric generating plants. Representative average flows were assumed using these exact locations and demands, combined with estimated flows for the rest of the users to determine transmission line sizes.

Costs

The cost estimates for the fresh water delivery system for Segment 2 are summarized in Table VIII. Further details of cost estimates are given in Appendix C. The total capital cost would be about $144,000,000. The annual cost of $13,050,000 would be equivalent to a unit cost of about $0.24 per 1000 gallons.

TABLE VIII.
CAPITAL COST OF WATER DELIVERY SYSTEM,
(1976 PRICES)
SEGMENT 2

Capital Cost	
(a) Pipeline	$ 96,000,000
(b) Pumping Equipment	7,000,000
(c) Land and Right-of-Way	1,000,000
(d) Connections for Existing Pipeline, Appurtenances, Buildings and Contingencies @ 20% of (a + b + c)	21,000,000
(e) Engineering and Legal Fees 15% of (a) through (d)	19,000,000
TOTAL	$144,000,000
Annual Cost	
Interest and Capital Recovery (@ 7% for a 50 year life)	$ 10,400,000
Power	1,400,000
Operation and Maintenance (@ 1% of Capital Costs)	1,250,000
TOTAL	$ 13,050,000

Segment No. 3 - Below New Orleans

Below New Orleans all development has been restricted to the natural levees of the Mississippi which vary in width from a few hundred yards to about a mile in some locations. Using the data summarized in Table VI, the total water requirement for Segment 3 would be 10 MGD, consisting of approximately 5 MGD for municipal supplies and 5 MGD for industry. There are no thermoelectric plants in the area.

This demand would be spread over a strip of land about 65 miles long. A substantial portion of the West Bank requirement would be in the lower third of this reach, from Empire at mile 30 AHP down to Venice at mile 10 AHP. There are no communities on the east bank of the Mississippi below Pointe a la Hache at mile 50 AHP.

In Plaquemines Parish no significant quantities of fresh groundwater are available anywhere. The few shallow sands that do contain fresh water are connected hydraulically to the Mississippi River and thus would become saline should the river become a salt water estuary. There is no fresh surface water available in the area due to the low relief of the land and its proximity to the Gulf of Mexico. The nearest surface water stream that could provide an adequate amount of fresh water to Segment 3 is the Pearl River. As outlined in the discussion for Segment 1, the water requirement of Segment 3 would be met with water from the Pearl River - New Orleans transmission system. The water would be transported by pipeline from Algiers, down the west bank of the Mississippi to Venice, and delivered to the existing intakes of the water users.

The cost of furnishing the water to the point of offtake described above was included in the cost analysis for Segment 1. The additional costs for Segment 3 are for a transmission line down the west bank of the Mississippi levee to serve all customers, with river crossings to Dalcour and Pointe a la Hache on the east bank. With the Mississippi River water diverted, these river crossings could be made at reasonable cost.

From Algiers to Belle Chasse the line would carry the full 10 MGD. The Belle Chasse water plant serves about 40 percent of the total population. To meet the requirements for the remainder of the population and industries south of Belle Chasse, a line of 9 MGD capacity would suffice.

Costs

The total estimated cost for the transmission lines and pumping stations are $19,600,000 and $1,200,000 respectively. Estimated additional costs imposed on the New Orleans Metropolitan System are $10,500,000 plus an annual pumping cost of about $500,000, and are included here for the purpose of determining unit costs for Segment 3.

The total annual cost chargeable to this segment is about $3,200,000 or $0.89 per 1000 gallons. The reason for this relatively high cost per 1000 gallons, when compared to costs for the other segments, is the small quantity of water that is distributed over the long reach of this segment.

Segment No. 4 - St. Charles and St. John the Baptist Parishes

The total water requirements for Segment 4, as shown in Table VI, is 130 MGD. Of this amount, 10 MGD is for municipal users, 75 for industrial users, and 45 MGD for thermoelectric plants.

Possible fresh water sources to meet these requirements are those that are available for the middle river parishes--Segment 2. By highway the Atchafalaya Basin lies some 65 miles to the west of LaPlace, the approximate center of Segment 4. The nearest surface water east of the Mississippi is the Amite River at French Settlement, which is about 40 miles to the northwest of LaPlace. Ground water is generally available in large quantities north of a line through Baton Rouge and the center of Lake Pontchartrain.

Systems to satisfy the fresh water requirement of Segment 4 with groundwater and with water from the Amite River were evaluated. It was determined that neither would be sufficient to provide a permanent supply at the required rate. For this reason a combined system, similar to the system used at Pearl River for Segment 1, was selected as the most feasible. Water would be withdrawn from the Amite River near French Settlement, with a large dual-purpose well field being located nearby.

During periods of high flows on the Amite River, the full 130 MGD requirement could be withdrawn. During the dry periods on the river, the constant demand would be supplied from the combined production from the deep wells and Amite River, as long as the discharge of the river remained above some minimal rate of flow. When the discharge dropped to or below this minimum, the total demand would be satisfied by the wells. During the periods of sufficiently high discharge in the Amite River, water that would otherwise be wasted would be withdrawn from the river, treated, and injected into the aquifers to replenish them. Figure 10 shows the route of the distribution line.

The nearest gaging station on the Amite River for which stream-flows are published is at Denham Springs, some 25 miles upstream from French Settlement. While there are several tributaries to the river between these two locations, they are minor and the flows at French

Settlement are properly represented by the record of discharge at Denham Springs.

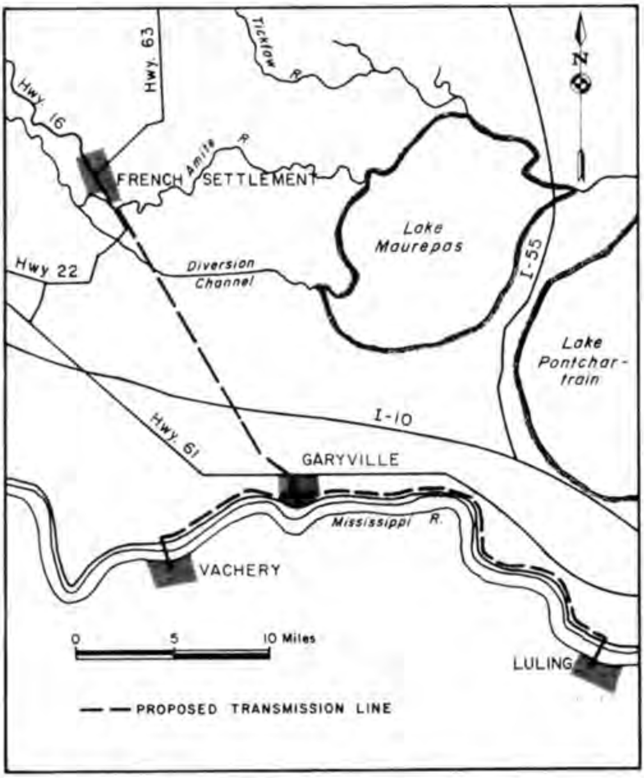


FIGURE 10. ALTERNATE A, SEGMENT 4

The minimum recorded daily flow at Denham Springs was 270 cfs. On the assumption that withdrawals at French Settlement for this project should not decrease the natural flow below 300 cfs, the average demand of 200 cfs (130 MGD), could be completely satisfied from the Amite River whenever the stream flow was more than 500 cfs.

A frequency analysis of streamflows between 1938 and 1970 (LMRCSCC, 1974) shows that the average flow for a 30 day period would be less than 300 cfs about once every 20 years. The average streamflow for a seven day period would be less than 300 cfs about once every eight years. Similar analyses show that on the average the discharge would not satisfy the 200 cfs demand and still leave 300 cfs as unregulated flow for 30 days about twice every three years.

To determine the size of the water treatment plant necessary to process the Amite River water for injection a mass curve analysis was made. The minimum withdrawal rate from the Amite River was determined which would provide enough water during the wet months to offset the steady demand on the aquifers during the dry months of the worst four-year period of record. The worst four-year period was determined to be the years 1966 through 1969. During these four years the monthly average stream flows in the dry months would have resulted in the greatest cumulative shortage: 14 billion gallons over a 13-month period. The aquifers in the area would be mined at this rate to make up the surface water shortage. To replenish the aquifers during the other 35 months of the four year period would require recharge at an average rate of about 15 Million gallons a day, about 25 cubic ft/sec.

For the system to be adequate, it would require a 15 MGD water treatment plant and injection well system, a 225 cfs pumping station (200 cfs demand and 25 cfs for well replenishment), and 50 production wells. A single 78-inch diameter transmission line would carry the 200 cfs to the Mississippi river bank at Garyville, 30 miles away. From that point a 10-inch line would run upstream to a point opposite Vacherie, and a 72-inch line would carry the water downstream as shown in Figure 10. River crossings would be located as needed to get water to users on the West Bank.

The production well system would consist of a series of 50 wells in the vicinity of French Settlement, each producing 1800 gpm. Although it is not possible to pinpoint exactly where the wells might be located, a general area where substantial fresh water aquifers occur was outlined (Cardwell and Rollo, 1960; Winner, 1963), and cost estimates are based on those assumed locations. Small changes in the location of the well field or in the alignment of the transmission lines would not alter the overall estimated costs significantly.

As in the other segments, the raw untreated water would be delivered to the customers at their existing water intakes. Water treatment and storage would be provided by the individual customers according to their needs.

Costs

The cost estimates for this segment are presented in Table IX. Additional details of the costs estimated are presented in Appendix C. The total annual cost of $11,800,000 for this portion of the project is equivalent to about $0.25 per 1000 gallons.

TABLE IX.
COST ESTIMATES OF WATER WITHDRAWALS, REPLENISHMENT, AND DELIVERY (1976 PRICES ALL FIGURES ROUNDED)
SEGMENT 4

	Capital Cost	
(a)	Pipeline	$ 58,000,000
(b)	Pumping Equipment	3,000,000
(c)	Treatment Plant	4,000,000
(d)	Well Fields, Emergency Power	32,000,000
(e)	Land & Right-of-Way	1,000,000
(f)	Connections to Existing Systems, Appurtenances, Contingencies @ 20% of (a + b + c + d + e)	20,000,000
(g)	Engineering & Legal Fees @ 15% of (a + b + c + d + e + f)	18,000,000
	TOTAL	$136,000,000
	Annual Costs	
	Interest & Capital Recovery (@ 7%, 50 year life)	$ 9,800,000
	Power	800,000
	Operation & Maintenance (@ 1% of Capital Costs)	1,200,000
		$ 11,800,000

Alternate Water Supply Plan B

Several other alternate water supplies were evaluated, independently, by other researchers. Some were eliminated as not being feasible. Alternate B finally selected consisted of a combination of portions of Alternate A, modifications of other portions of Alternate A, and completely different systems for other portions.

The system developed in Alternate A for segments 1 and 3 were used in Alternate Plan B as the most practicable solution. All other water requirements for the East Bank would be taken from Amite River deep well system as described in Segment 4 of Alternate A. All water for the West Bank users would come from the Atchafalaya Basin.

East Bank Requirements

Other than those parishes included in Segments 1 and 3 of Alternate A, water requirements on the East Bank in the study area are those in Ascension, Iberville, St. Charles, St. James, and St. John the Baptist Parishes. The total requirement for these parishes on the East Bank (some of the parishes are located on both banks) was estimated at about 140 MGD. This estimate was based on an investigation of industrial and municipal site locations on maps furnished by Illionois Central Gulf, Industrial Development Department, revised March, 1976 and Waste Discharge Data furnished in the State of Louisiana Water Quality Management Plan of the Lower Mississippi River Basin, revised March 1974, pp. 39-43, and therefore are considered quite reasonable.

This total requirement of 140 MGD (220 cfs) is slightly more than required at the Amite River deep well system detailed in Segment 4 of Alternate A. This would require four or five additional 1800 gpm deep wells above the 50 required in Alternate A. A similar study of the mass curves indicates that during this period requiring a recharge rate of about 18 MGD during the 35 wetter months of the four year period.

The system at the Amite River would consist of a water treatment plant (18-20 MGD) and an injection well system, a 245 cfs pumping station to supply the current demand plus water for aquifer replenishment and 54 production wells. Each well would be capable of producing at a rate of 1800 gpm, and be located in the vicinity of French Settlement.

The transmission line would follow Louisiana Highway 22 from French Settlement to Burnside, approximately 16 miles. At Burnside, part of the flow would be diverted upstream and the remainder downstream to supply all users in the five parishes included in this phase of the study. The transmission lines would follow the Old River Road so that the water would be supplied to all users at their present intake structures. Locations of the intakes of major users were estimated from maps and the flow passing downstream was reduced accordingly. This made possible a reduction in pipe sizes along the 29 mile stretch upstream and 55 mile stretch downstream. Since the intakes could not be precisely pinpointed, nor actual demands determined, the flows and pipe sizes determined are, at best, reasonable estimates.

Costs

The cost estimates for this phase are presented in Table X. Additional details of cost estimates are presented in Appendix C. The total annual costs of $13,300,000 for this phase of the study gives a unit rate of $0.26 per 1000 gallons.

TABLE X.
COST ESTIMATES OF WATER WITHDRAWALS, REPLENISHMENT, AND DELIVERY
(1976 PRICES, ALL FIGURES ROUNDED)
Alternate Plan B--East Bank

	<u>Capital Cost</u>	
(a)	Pipeline	$ 71,000,000
(b)	Pumping Equipment	5,000,000
(c)	Well Fields and Emergency Power	33,000,000
(d)	Land and Right-of-Way	1,000,000
(e)	Connections to Existing Systems, Appurtenances, Contingencies @ 20% of (a + b + c + d)	22,000,000
(f)	Engineering & Legal Fees @ 15% of (a + b + c + d + e)	20,000,000
	TOTAL	$152,000,000
	<u>Annual Costs</u>	
	Interest & Capital Recovery (@ 7%, 50 year life)	$10,600,000
	Power	1,400,000
	Operation and Maintenance (@ 1% of Capital Costs)	1,300,000
	TOTAL	$13,300,000

West Bank Requirements

Should the Atchafalaya capture the Mississippi River, it is only reasonable to look to the Atchafalaya River to meet the total demands of all users of fresh water on the West Bank of the Mississippi River. The problem is to find the most feasible method to get this water to the respective users. One possibility is to pump water from the Atchafalaya at Bayou Sorrell Lock into the Intracoastal Waterway. This would bring water to Plaquemine, Louisiana and close to Bayou Lafourche. However, the Intracoastal Waterway is not a reliable source of fresh water if it continues to serve as a navigable waterway for barge traffic.

Several alternates to this scheme were investigated, and it was decided to bring the water from the Atchafalaya Basin to the Mississippi River by two routes.

Plaquemines to White Castle:

To serve industrial and domestic users south of Plaquemines to White Castle would require 39 MGD. This water could be supplied to Plaquemines through the Intracoastal Waterway at relatively low cost. However, as discussed previously, this water source is probably unsatisfactory. A better method seems to be to pump water through a transmission line along Louisiana Highway 75 from the Bayou Sorrell Lock, a distance of 13 miles. The water would then be pumped through 9 miles of transmission line to White Castle, with the industries receiving water from the pipeline where it is nearest their property. After making two cost estimates it was determined it would be more economical to run the transmission lines down Louisiana Highway 1 to White Castle, which would require the industrial users to install pipe lines from Highway 1 to their present intake facilities along the River Road. To follow the River Road with the main transmission line would approximately double its length due to the bend in the river in this reach, with the consequent increase in total costs.

The cost estimate for this phase is predicated on a 39 MGD pumping station at the Bayou Sorrell Lock, 13 miles of transmission line along Louisiana Highway 75, and 9 miles of transmission line along Louisiana Highway 1, along with necessary booster stations in the transmission lines.

White Castle to Jefferson Parish, and Including Bayou Lafourche

To satisfy the remaining fresh water requirement of the West Bank, water would first be pumped into Bayou Lafourche from the Atchafalaya Basin. Water requirements in Assumption and Lafourche Parishes, 14 MGD, would be taken from the bayou at present intake structures. Users north of Donaldsonville in Ascension and Iberville Parishes would be served through 5 miles of transmission line along the river road. 5 MGD would be required for this area. The 16 MGD requirement south of Donaldsonville in Ascension, St. James and St. John the Baptist Parishes would be served through 46 miles of transmission line from Donaldsonville also along the river road.

The 62 MGD requirement for St. Charles Parish would be met by pumping through 19 miles of transmission line along U.S. Highway 90 from Bayou Lafourche to Boutte. At Boutte the flow would be diverted up and down the river to meet the requirements in those respective areas. All water, the 42 MGD going north as well as the 20 MGD going south, would be brought directly to present intake structures of users.

With the loss of the Mississippi River, Bayou Lafourche would no longer be a source of fresh water to its present users since the bayou is supplied with water from the Mississippi river through a pumping station at Donaldsonville. It will thus be necessary to pump all the water required into the bayou. Since the bayou is navigable below Thibodaux, is heavily used and is a definite economic asset to the area, additional water must be pumped into Bayou Lafourche to maintain this capability.

At present the pumping station at Donaldsonville has the capability of pumping 200 MGD of Mississippi River water into Bayou Lafourche. Any substitute system of water supply must satisfy this requirement after all consumptive withdrawals have been made. Since the total requirements placed on the bayou under this phase of the study is 97 MGD, the designed system is calculated to furnish 300 MGD to Bayou Lafourche.

This total system would include a 300 MGD capacity pumping station in the Atchafalaya Basin, a dual transmission line of 36 miles, generally along U.S. Highway 90 and Louisiana Highway 20 to Thibodaux, to pump the water into Bayou Lafourche at that point, preferably just north of the weir in Thibodaux. It is probable the bayou north to Donaldsonville may have to be deepened and channeled to handle the flow to that town.

In addition there is a need for two pumping stations at Donaldsonville, one to pump 5 MGD north and one to pump 16 MGD south. A 62 MGD pumping station in the vicinity of Raceland will be required to pump the water from Bayou Lafourche to Boutte. At Boutte two stations with capacities of 42 MGD and 20 MGD will be required to pump the water north and south, respectively. Of course the system would have to include all necessary transmission lines and booster stations.

Costs

The total cost estimates for the West Bank include these, and those listed for the area between Plaquemines and White Castle. Table XI gives the breakdown of costs for this phase. Additional details of the costs estimates are given in Appendix C. The total annual cost of $22,200,000 yields a unit cost of $0.45 per 1000 gallons.

TABLE XI.
ALTERNATE PLAN B--WEST BANK
TRANSMISSION COSTS

Capital Cost	
(a) Pipeline	$174,000,000
(b) Pumping Equipment	8,900,000
(c) Land and Right-of-Way	1,000,000
(d) Connections to Existing Systems, Appurtenances, Contingencies @ 20% of (a + b + c)	36,900,000
(e) Engineering and Legal Fees @ 15% of (a + b + c + d)	33,200,000
TOTAL	$254,000,000
Annual Costs	
Interest and Capital Recovery (@ 7% for a 50 year life)	$ 17,800,000
Power	2,200,000
Operation and Maintenance (@ 1% of Capital Costs)	2,200,000
TOTAL	$ 22,200,000

VIII

COST COMPARISONS AND SUMMARIES

One major difference in the water requirements between the two alternates makes a direct comparison of costs between the two impossible without a modification to one or the other:

In Alternate A water was furnished to the users along Bayou Lafourche through a system of pipe lines and the present freshwater flow in Bayou Lafourche was not maintained. Alternate B took into account the importance of the navigability of this bayou to the South Central portion of Louisiana and the costs shown in Table XI included an additional 200 MGD for this purpose.

Note: Bayou Lafourche flows in a generally southerly direction from Donaldsonville, on the Mississippi River to the Gulf of Mexico. Water in the bayou is furnished from the Mississippi River, through a pumping station in Donaldsonville. With the exception of rainfall and some runoff, this is the only source of water for the bayou. Loss of flow past Donaldsonville by virtue of the Atchafalaya capturing the Mississippi would eliminate this major source of fresh water. The pumping station at Donaldsonville is rated at 200 MGD.

TABLE XII.
COST SUMMARY FOR ALTERNATE A
(Rounded Numbers)

Segment No.	Total Capital Cost	Total Annual Cost	Flow (MGD)	Cost $/1000 gals.
1.	$292,000,000	$26,000,000	330	0.22
2.	144,000,000	13,000,000	147	0.24
3.	31,000,000	3,200,000	10	0.89
4.	136,000,000	11,800,000	130	0.25
	$603,000,000	$54,000,000	617	0.24

The summary of costs for Alternate A are given in Table XII. Table XIII gives the costs for Alternate B, including the additional costs for maintaining the freshwater discharge of Bayou Lafourche. In order that the costs between the two alternates may be compared, additional calculations were made for Alternate B to isolate the cost of furnishing the water to the users, using the same route, and neglecting those costs directly attributable to maintaining the flow in Bayou Lafourche. These costs are summarized in Table XIV.

TABLE XIII.
COST SUMMARY FOR ALTERNATE B
INCLUDING COSTS FOR BAYOU LAFOURCHE
(Rounded Numbers)

Segment	Total Capital Cost	Total Annual Cost	Flow (MGD)	Cost $/1000 gals.
1 and 3	$323,000,000	$29,200,000	340	0.23
East Bank	152,000,000	13,300,000	141	0.26
West Bank	254,000,000	22,200,000	340*	0.45**
	$729,000,000	$64,700,000	821*	0.28

NOTES: * Includes approximately 200 MGD flow for Bayou Lafourche in addition to approximately 140 MGD for Municipalities, commerce and industry.
** Based on the water sold to the industrial, commercial and municipal users.

From Tables XII and XIV the costs for furnishing approximately 620 MGD to the consumers along the river and Bayou Lafourche are essentially the same. When rounded off to $/1000 gallons the two alternates give virtually the same unit costs.

TABLE XIV.
COST SUMMARY FOR ALTERNATE B
EXCLUDING COSTS FOR BAYOU LAFOURCHE
(Rounded Numbers)

Segment	Total Capital Cost	Total Annual Cost	Flow (MGD)	Cost $/1000 gals.
1 and 3	$323,000,000	$29,200,000	342	0.23
East Bank	152,000,000	13,300,000	141	0.26
West Bank	128,000,000	11,500,000	136	0.23
	$603,000,000	$54,000,000	619	0.24

Table XIII shows that the cost for furnishing water to the West Bank users was $0.45/1000 gallons when the costs included furnishing the 200 MGD to maintain the navigability of Bayou Lafourche. This unit cost is about double the cost that it would be in the absence of bayou navigation. The total cost for Alternate B under this condition was $0.28/1000 gallons, or about 16 percent higher than if navigation were neglected. Both of these figures would seem to indicate that maintenance of Bayou Lafourche as a navigable body of fresh water is economically questionable. It might, however, be possible to maintain navigation at a smaller cost by using pumped seawater for this purpose.

Bayou Lafourche is a very important waterway artery in South Central Louisiana, as it is kept navigable from just below Thibodaux to the Gulf of Mexico. Along its banks are several industries that rely on boat and barge traffic to bring in raw materials and carry out finished products. Of prime importance is the shellfish industry, so vital to the economy of Lafourche Parish. Most of the boats that make up the Lafourche Parish shrimping fleet are docked on both banks of Bayou Lafourche north of Golden Meadow, as well as those boats used to harvest oysters. The loss of the bayou would be a severe blow to the economics of these two industries in Lafourche Parish. In addition, the bayou is presently used for recreational boating and fishing.

The analysis indicates that maintenance of fresh-water navigation in Bayou Lafourche (and the decreased salinity in the Lafourche outlet) would cost approximately $10,000,000 per year. Such an annual expenditure would result in a number of direct benefits, benefits that should be evaluated before a final judgment can be made. Such an evaluation is beyond the scope of this report.

IX

CONCLUSIONS

Should the Old River Control Structure fail, and the Mississippi River be captured by the Atchafalaya, the present Mississippi River as we know it would be lost as a source of water supply for the many users of its water along the reach south of East and West Baton Rouge Parishes. Navigation of ocean going vessels would be slightly affected, if at all, but barge traffic above Baton Rouge would stop. Additional sources of water supply would have to be found to serve the many domestic, industrial and thermoelectric users. Assuming that the industrial and thermoelectric users would reduce their demands by appropriate technology, the costs to all users would undoubtedly be much higher than they are at present.

However, the additional cost for the water is not the only consequence of a possible collapse of the structure. To reduce their requirements, which will be an absolute necessity, the industries would have to alter their present processes, and the industries and thermoelectric plants would have to install elaborate recycling units. These additional costs would have to be included in the overall cost analysis, and would certainly be a major component of their new, and increased, costs.

Another concern, and probably more critical than costs, is the time lag between the collapse of the Old River Control Structure and the construction of the pumping stations, well fields, and transmission lines required in either alternate. A project of either magnitude would take years to complete. The users have two options:

Option A would be to trust the integrity of the Old River Control Structure and hope that it never fails. If, and when it did fail the industrial and thermoelectric plants would soon have to shut down until construction of one or more of the systems outlined in the two alternates were completed. For a short while water for the domestic users might have to be hauled in by truck or other methods. Option B would require that work be initiated on a number of the systems outlined in the alternates so that they would be immediately available when the structure failed. Option A is to do nothing. Option B might be undertaken to improve the quality and reliability of present water supplies.

Considering Option A, it seems doubtful that water for domestic users in the quantities required could be supplied by any means other than large diameter transmission lines. Secondly, the loss of water to the many industrial users, for even a small period of time, would require them to shut down their operations, and would be a financial burden from which some could never recover. It could result in many of them moving to new locations. Such an exodus would be an economic disaster to the many parishes along the Mississippi River that depend upon these industries for their livelihood.

Option B remains. However, a combination of leadership and persuasion would be needed to motivate the various users to invest in the proposed construction on the assumption it will be needed in the future. Among the unanswered questions: how would the costs be prorated between domestic, industrial, and thermoelectric users? The benefit to one would certainly be of benefit to the other. Some sort of coordinating agency would have to be created to arbitrate the cost allocations. Lawsuits could develop which might delay any construction, and with protracted litigation it seems unlikely that timely action would be undertaken. Of course the New Orleans water supply is not presently of satisfactory quality and it may be that regardless of the ORCS existence a new source will be sought from the Pearl River. Such an action would alert the municipalities and industries of the area to the possibilities of alternate water sources as well as improve the quality of water in the New Orleans area and decrease its vulnerability.

There is, of course, another and parallel possibility--a vigorous effort should be made to preserve the Old River Control Structure. The Corps of Engineers is presently studying methods to reduce the stress on the structure and hope to have an auxilliary structure operating by 1985. But they make no guarantees as to the longevity of the system.

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APPENDIX A

PEARL RIVER FLOW AT BOGALUSA AND PEARL RIVER, LOUISIANA

During the 38 years of record, the minimum average daily flow in the Pearl River at Bogalusa, Louisiana was found to be 1020 cfs, occuring during several days in October, 1963. The minimum recorded average daily flow in the Pearl River at Pearl River, Louisiana during this period occurred in 1963 when it reached a low of 1580 cfs. The assumption that the flow in the West Pearl River at Pearl River, Louisiana is approximately 85 percent of the total Pearl River discharge during periods of low flow, would establish the minimum flow in the West Pearl as 1340 cfs.

If it is assumed that, as a result of withdrawals, the flow in the West Pearl should not be reduced below 110 percent of this minimum value, the limiting flow in the West Pearl would be 1.1 x 1340 cfs, or 1470 cfs. The demand of 340 MGD (330 and 10 MGD for Segments 1 and 3 respectively) could be completely satisfied whenever the discharge in the West Pearl was greater than 1470 + 530, or 2000 cfs.

The ratio between the total discharge at Bogalusa and the discharge in the West Pearl at Pearl River averages about 1.1. Thus, the corresponding discharge at Bogalusa which would limit fresh water withdrawals from the West Pearl would be 2000/1.1, or 1820 cfs.

APPENDIX B

WATER REQUIRED FROM STORAGE AT PEARL RIVER DURING THE DRIEST PERIOD OF RECORD

The daily streamflow records at Bogalusa for January through December, 1954 indicate that there was a period of 135 days during which the flow was less than 1820 cfs, the minimum which would allow the withdrawal of the full 530 cfs (340 MGD) at Pearl River, Louisaina. For each of these days the flow at Pearl River, Louisiana withdrawal point was determined as 1.1 times the flow at Bogalusa. It was then assumed that water could be withdrawn at a rate that would reduce the flow in the West Pearl River down to its minimum acceptable of 1470 cfs. When flows in the West Pearl were below 1470 cfs no water would be withdrawn. The 340 MGD would then have to be withdrawn from another source. This source would be a well field. Withdrawals from the well field would have to be replenished during periods of adequate flows in the Pearl River.

Over the entire period of record, an operational analysis shows that with a filter plant capacity of 55 MGD, the maximum withdrawals from storage would have amounted to 60 billion gallons. A larger filter plant capacity would reduce this maximum, a smaller filter plant capacity would increase the amount of ground-water withdrawal from storage. Detailed engineering and economic studies are needed to determine the optimum capacity of filter plant and the well field for injection purposes.

One such field and treatment facility was included in the costs analysis for Segment 1 of Alternates A and B.

APPENDIX C

ASSUMPTIONS USED IN COST ESTIMATES

The cost estimates used in this study were developed from a variety of sources. Published literature on costs were used whenever possible. Old data were updated using appropriate cost indexes published by Engineering News Record (ENR). Where no appropriate cost estimates for a particular item could be found, estimated costs were made based on data for similar items and conditions.

Capital cost estimates for pumping stations, transmission lines and booster stations were obtained from expressions developed by Singh, et. al (Singh, et. al, JAWWA, October, 1974). The costs presented by Singh, et. al were based on 1964 dollars and included all items involved in cost of materials, transportation and installation. The 1964 dollars were updated to 1976 dollars using the ENR Construction Cost Index for the United States. The multiplication factor was 2401/936 or 2.57.

The capital cost for construction of a water treatment plant using chemical coagulation, sedimentation, rapid sand filtration and chlorination was also obtained by a modified expression by Singh, et. al. adjusted to 1976 dollars. A water well producing 2.2 MGD (or an injection well of the same capacity) was assumed to cost $175,000. Pumping costs for pumping and booster stations, as well as for well fields were estimated to average $97 per year for each installed horsepower. This value was obtained by calculating the average cost of power per year for a large power service with a constant demand of 36,000 KW, using the graduated utility rates of a local power company. No attempt was made to account for rising power costs or for the effects of variation in power demands throughout the months of the years.

Finally, right-of-way costs were estimated as $5,000 per mile of transmission on public property. Right-of-way along the Mississippi River between the levee and River Road was assumed to be free of charge.

A computer program on a Wang computer unit was developed. The program was set to receive flow requirements and length of transmission lines. The computer then calculated the head requirements and subsequent pumping station costs for a various range of pipes believed to be economical. Included in the costs were annual pumping power costs. The construction costs were broken down for a 50-year life and added to the annual power costs. This resulted in annual cost for power, and transportation and pumping station (over the 50-year life), for each pipe diameter included in the range. The pipe diameter yielding the lowest annual costs was considered to be the optimum and those costs were used in the final estimates for each phase.

It should be pointed out that these costs at best are informed estimates. However, since the same data, assumptions and mathematical input to the same computer program were used, the relative costs are probably valid.

BULLETIN 12 Addendum B

A CHANGE IN THE COURSE OF THE LOWER MISSISSIPPI RIVER: DESCRIPTION AND ANALYSIS OF SOME ECONOMIC CONSEQUENCES

DAVID B. JOHNSON

College of Business Administration

NOTE:

AN UNUSUALLY LARGE NUMBER OF INDIVIDUALS EMPLOYED BY THE DIVISION OF RESEARCH WORKED ON VARIOUS PARTS OF THIS REPORT. RONALD GILBERT, TERRY ROBERTSON, AND JOHN METCALF DIRECTED AND PREPARED MATERIALS FOR PORTIONS OF THE REPORT. GRADUATE ASSISTANTS EDWARD KING, MARK MILLER AND ALTHEA GRUDEM DESERVE SPECIAL MENTION FOR THEIR WORK IN GATHERING AND ASSIMILATING THE DATA, AND VERY HELPFUL SECRETARIAL ASSISTANCE WAS GIVEN BY JANE MITCHEN, DORA LEBLANC, AND LAURA TOLAR.

SEPTEMBER 1980

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DESCRIPTORS: Water Policy, Louisiana, Atchafalaya Diversion, Economic Impacts, Floods, Disaster Planning

IDENTIFIERS: Old River Control Structure, Highway Disruption, Gas Pipeline Breaks, Low Sill Structure, New Orleans Water Supply

A B S T R A C T : The Mississippi River is attempting to take a short cut to the Gulf of Mexico via the Atchafalaya River at the Old River Control Structure. This study does not discuss the relative probabilities of failure of the Old River Control Structure (ORCS) but examines some of the economic consequences should the structure fail.

If the ORCS failed, the resulting scouring activity in the Atchafalaya River could undermine the supporting piers of the five bridges serving I-10, U.S. 90, U.S 190 and LA. 1, as well as three railroad bridges in the Basin. Total cost (1977 prices) of replacing the bridges: \$65 million; damage to approaches and roadways: \$9 million. If all four of these major highways were closed, the total additional operating cost <u>per day</u> would be \$1.6 million; the total additional value of time lost by the vehicle operators would be \$1.1 million <u>per day</u>. The additional costs for railroads utilizing alternative routes would be \$103 thousand per day.

Twelve percent of Louisiana's total land area and 140,000 people live in the immediate flood prone area. Some land within the area would become permanently uninhabitable whereas other areas would be flooded only during the Spring Floods. Total private property losses are estimated at \$262 million. Should natural gas pipelines be severed due to scour in the Atchafalaya Basin, the worst case scenario indicates that approximately 15 percent of the natural gas supplies in 28 eastern states would be disrupted.

REFERENCE: Johnson, David B., A CHANGE IN THE COURSE OF THE LOWER MISSISSIPPI RIVER: Description and Analysis of Some Economic Consequences. *Louisiana Water Resources Research Institute Bulletin 12 B*, Louisiana State University, Baton Rouge, September, 1980.

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I

INTRODUCTION

The Economic and Physical Attributes of the Mississippi River

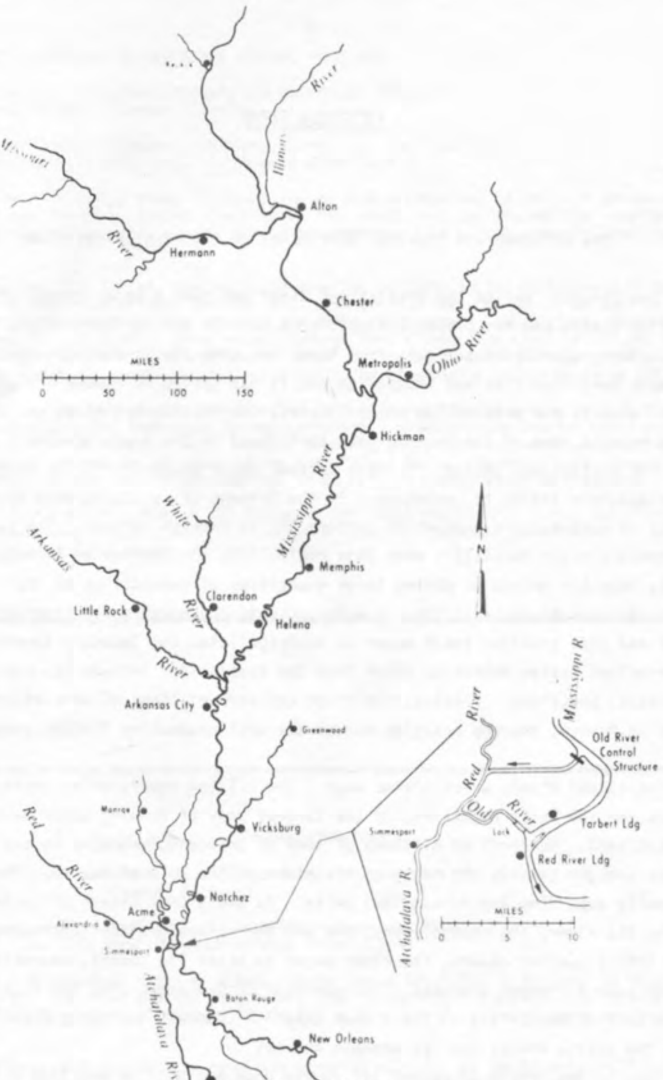
Since the colonial period the Mississippi River has been a major artery of transportation for the United States and has played a significant role in the agriculture and fishing industries. More recently, the Mississippi River has been the predominant source of fresh water for many municipalities and industries and it has served to remove their waste products.

In the colonial and ante-bellum United States, the Mississippi River was vital to agriculture because some of the most fertile soil found on the newly developed continent was located in the Mississippi valley. Farmers shipped their products via the river from Illinois and other midwestern states to Louisiana. In New Orleans the products were transported by clipper ship to northeastern population centers and to foreign markets. The paucity of overland transportation facilities made this route, long and tedious as it was, the only economically feasible method of moving large quantities of commodities to their markets.

The Mississippi River still plays a major role in the north-south transportation of commodities and also provides fresh water to municipalities and industry located along its course. Principal cities obtaining water from the Mississippi include St. Louis, Missouri; and New Orleans, Louisiana. Finally, the river delivers millions of tons of organic nutrients to the Gulf of Mexico, thereby creating one of the most productive fishing grounds in the world.

The Mississippi River, which drains over 1 1/4 million square miles located between the Appalachians and the Rocky Mountains, is the largest body of flowing water on the North American Continent. Hundreds of millions of tons of sediment, produced by the erosion process, are brought towards the mouth of the river on the Gulf of Mexico. These deposits are continually expanding the Mississippi delta. As additional layers of sediment are deposited by the river, the channel lengthens and the stream gradient approaches the horizontal. When this situation occurs, the river seeks to alter its course, searching for a shorter path with a steeper gradient. The geologic record shows that the Mississippi has reached the Gulf of Mexico via at least four separate channels including Bayous Teche and Lafourche, the Sabine River, and its present channel.

The river is now trying to change its course once again. The existing delta now extends to the edge of the continental shelf and the lower Mississippi River has a stream gradient that approaches the horizontal. In effect, there are strong physical forces acting upon the river which are causing it to seek a more direct access to the Gulf. These forces are focussed at a place about 45 miles northeast of Baton Rouge, Louisiana, where the Old River meets the Mississippi River. This location is the site of the Old River Control Structure (ORCS) which controls the distribution of the flow of the Mississippi between the lower Mississippi River and the Atchafalaya River. Below this point the Mississippi River flows approximately 300 miles in a southeasterly direction to the Gulf of Mexico. By way of comparison, the distance to the Gulf via the Old River and the Atchafalaya River is only about 150 miles and the Mississippi River has shown a tendency to use this shorter route to the Gulf of Mexico (see Figure 1.1).



MISSISSIPPI RIVER SYSTEM

FIGURE 1.1 The Mississippi River System and the Relationship Between the Mississippi River, the Atchafalaya River and the Old River Control Structure.

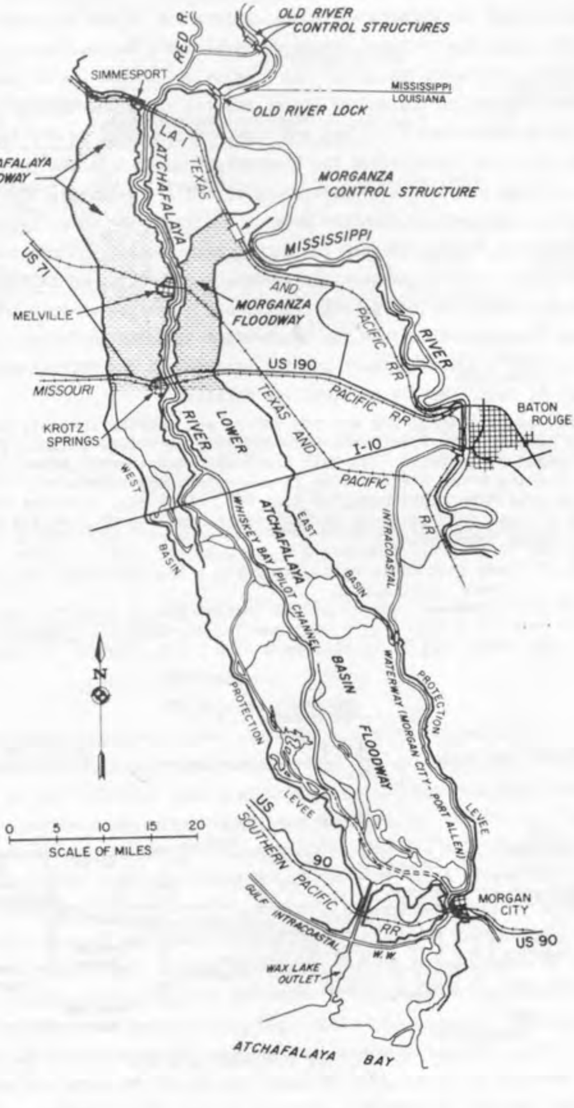


FIGURE 1.2 Map of the Atchafalaya Basin Showing the Highways and Railroads, the Intracoastal Waterway, and the Protection Levees. Note the Relative Postions of Morgan City and the Wax Lake Outlet.

The Old River Control Structure: Background and Significance

The origins of the Old River Control Structure date back to 1950 when Latimer and Schweizer conducted a survey for the Mississippi River Commission (MRC) and concluded that the Mississippi's flows were increasingly being diverted into the Atchafalaya River. It was then estimated that by 1965 the Atchafalaya would capture 43% of the discharge of the Mississippi. At this point the critical discharge level would be reached, and the Atchafalaya would enlarge and become the main channel of the Mississippi River. As a consequence of this study, the 83rd Congress of the United States enacted the Flood Control Act of 1954 (Public Law #780) which authorized a project and appropriated funds to develop a control structure where the Old River intersected the Mississippi River with the objective of maintaining the 1950 discharge ratio. This ratio would permit approximately 70-75 percent of the Mississippi's flows to continue down the present course of the river and allow the remainder of the discharge to flow through the Atchafalaya River. The control complex was to consist of a low-sill structure to maintain the discharge ratio, an overbank structure to accommodate discharges during periods of high water, and a navigation lock to permit the continuance of water transportation from the Mississippi to the Atchafalaya. Figure 1.2 shows the location of the proposed project and its relation to the Atchafalaya Basin.

Horne (1976, p. 4) described the construction details:

> Construction of the low-sill structure and the inflow and outflow channels was begun in September 1955 and completed in 1959. The 566-feet long structure (Fig. 1.3) has 11 bays, each with a clear width of 44 feet. Two weir crest elevations were chosen to provide diversion at high and low river stages. The three center bays have a weir crest elevation of -5 feet MSL; the remaining eight bays, 10 feet MSL. Each bay, equipped with a steel vertical-lift gate divided into sections to facilitate handling by a mobile gentry crane, can be opened and closed independently.

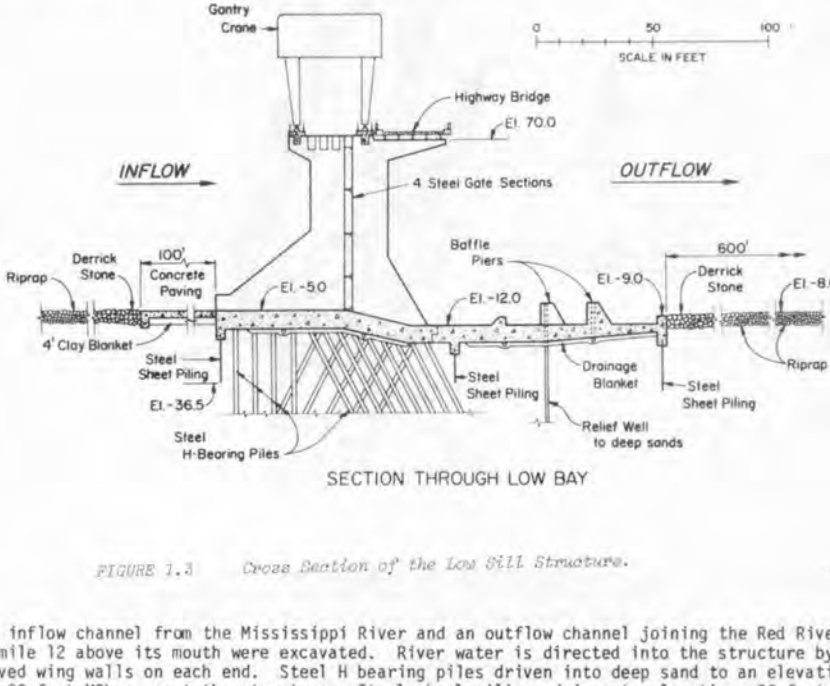


FIGURE 1.3 Cross Section of the Low Sill Structure.

The inflow channel from the Mississippi River and an outflow channel joining the Red River at mile 12 above its mouth were excavated. River water is directed into the structure by curved wing walls on each end. Steel H bearing piles driven into deep sand to an elevation of -90 feet MSL support the structure. Steel sheel piling, driven to elevation -36 feet MSL, was used as cut-off walls to minimize erosion and seepage under the structure.

No piles were used under the guide wells on the inflow channel because stability studies showed pile supports to be unnecessary.

The overbank structure, begun in 1956 and completed in 1959 consists of 73 gated bays, each with a clear width of 44 feet between piers (Fig. 1.4). The total length is 3,358 feet. The weir crest elevation in all bays is 52 feet MSL. Flow is controlled by hinged timber panels operated by a gentry crane.

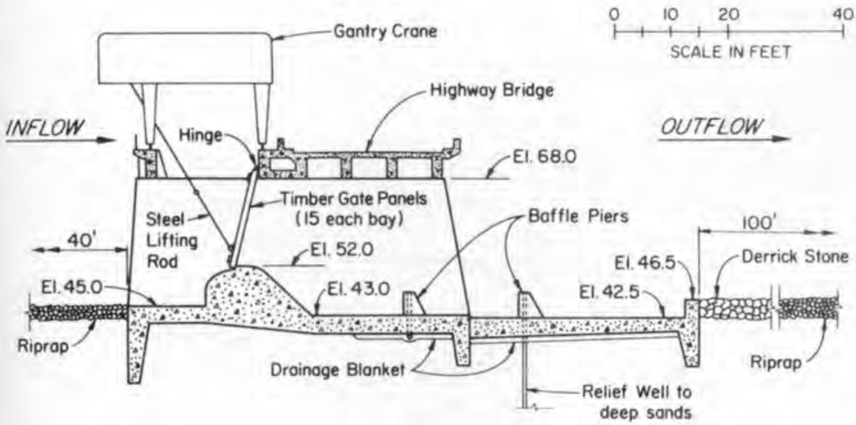


FIGURE 1.4 Cross Section of the Overbank Structure. This Structure Controls the Flow During Periods of Flood and Reduces the Flow Through the Low Sill Structure.

The earth dam to permanently close Old River was begun during the low-water period of 1962 and completed in October 1963. The dam, which prevents by-passing of the control complex, has a base length of 1,500 feet and a crest elevation of 68 feet above MSL.

The navigation lock adjacent to the channel of Old River, and connecting the Mississippi and Atchafalaya Rivers, is a concrete U-frame type with a usable chamber length of 1,185 feet, a clear width of 75 feet, and a sill elevation of 11 feet above MSL.

Scour Problems

Scour of the channel has undermined the structure since it was built. After only a few months of operation (1961), a scour hole to -40 feet MSL was observed; stone and riprap were placed in it but in the following year a scour hole to -90 feet MSL was observed and repaired. During 1964, the scour hole was observed to have deepened to -140 MSL and some caving occurred in the outflow channel. Since the pilings supporting the low sill structure only go to -90 feet MSL, there was cause for concern and 150,000 tons of stone riprap were placed into the scour hole.

The first major test of the ORCS came during the flood of 1973. Three separate factors were responsible for the flood: 1) the melting of the heavy snow cover in the midwest, 2) abnormally large amounts of rainfall in the lower Mississippi Valley, and 3) sustained southerly winds for about two weeks during May, 1973 which retarded the movement of flood waters downstream in the Basin and hindered normal drainage into the Gulf.

Shortly after the onset of the Spring flood of 1973, it was discovered that a large scour hole had been created in the bed of the inflow channel of the ORCS which not only undermined the left wing wall of the Low Sill Structure but exposed the supporting pilings of the Low Sill Structure down to -50 feet MSL. On April 14, 1973, the wall collapsed and it became apparent to the Corps that emergency actions were needed. The Overbank Structure and the Morganza floodway were opened for the first time to reduce the flow through the Low Sill Structure. Despite these measures the Corps of Engineers reported a maximum discharge of 500,000 cfs through the Low Sill Structure, as compared with the expected maximum of

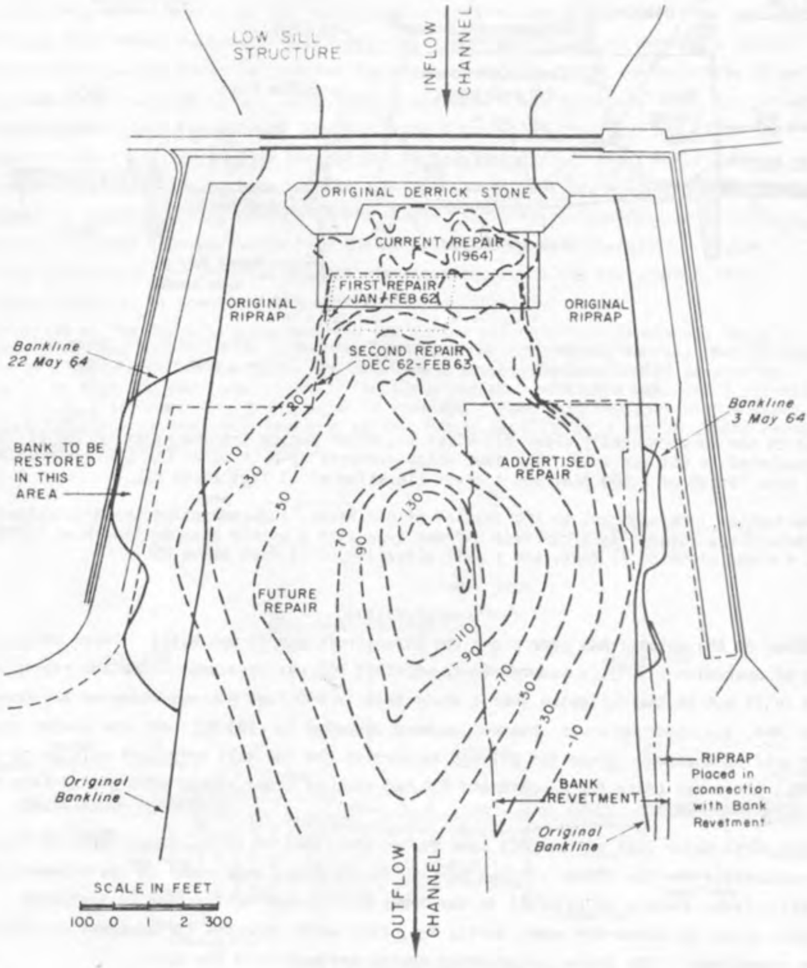


FIGURE 1.5 Scour Hole Just Downstream of the Low Sill Structure in 1963. In 1973 this Hole Was Undoubtedly Scoured Deeper Than Shown Here.

325,000 - 350,000 cfs. After the flood had subsided, the Corps surveyed the riverbed to determine the extent of the scour activity and found that in addition to the -50 MSL hole in the inflow channel there was a scourhole in the outflow channel at -130 ft.

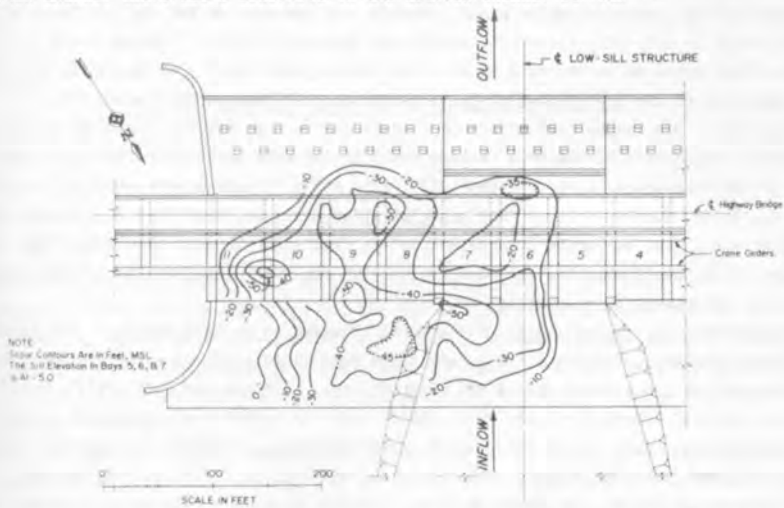


FIGURE 1.6 Scour Hole Upstream from and under the Low Sill Structure During the Flood of 1973. This Figure Should Be Studied in Conjunction with 1.5.

Since 1973, the Corps has rebuilt the wing wall and has continued to drop concrete and granite boulders into the scour holes. The approximate extent and location of the scour activity in the inflow and outflow channels is depicted in Figures 1.5 and 1.6 respectively.

Resource Allocation Effects

The conditions which have created the scouring activities are very likely to become more severe in the future. For any given set of flood conditions in the watershed, the water levels of the lower Mississippi River are higher. The Atchafalaya River is in the process of deeping and widening, with a resulting lowering of the water level in the upper reaches of the river for the same discharge. This means the water level differences between the two rivers at and near the ORCS are becoming greater. This increasing differential between the respective levels of the two rivers will increase discharge and velocity through the ORCS which, in turn, will increase scouring.

This paper does not discuss the probability of ORCS failure, nor the time frame in which failure is most likely to occur. Its purpose is to examine some of the economic consequences which would result from an ORCS failure if it occurred. Most of the cost estimates are very approximate and not all of the consequences are examined in detail.

Relatively little has been done to correct the underlying deficiencies of the ORCS. Many engineers believe that the structure has been weakened to such an extent that, were another flood similar to that of 1973 to occur, the ORCS could not successfully withstand it. Other engineers speculate it would take a flood at least 1.5 times as large as the Spring, 1973 flood to cause the structure to fail. If the structure does fail, the Atchafalaya would probably capture most of the Mississippi within three months: the discharge ratio might become 70% down the Atchafalaya and 30% down the present main-stem Mississippi. Once a complete failure of the ORCS occurred, it would be very expensive, if not technically impossible, to restore the previous discharge ratio.

The extent of the first year flooding in Louisiana could, as a minimum, reach from Bayou Teche in the west to Bayou Lafourche in the east. This area constitutes almost 11% of

Louisiana's total land area, and the entire Atchafalaya Basin would be subject to severe inundation each spring until new flood protection works could be built. The Basin would be essentially uninhabitable and serious disruptions of production in the oil and gas, agricultural, and fishing industries would occur. Morgan City and most of the smaller towns within the Basin would be initially severely flooded, and subsequent annual flooding would occur. One side-effect would be an increase in the short term oyster and shrimp mortality rate due to the pollution of the brackish water by large amounts of fresh water flowing into the Atchafalaya Bay. The longer term effect on oysters and shrimp, however, could be beneficial.

Another consequence of the ORCS failure would be the salt water intrusion in the present channel of the Mississippi River. Essentially, this would produce a salt water estuary in what is now fresh, flowing water. Many municipalities utilizing the river as a source of fresh water would have to locate alternate supplies from other sources should the ORCS fail. Industrial plants would have the choice of developing new water supplies, installing expensive desalination equipment, or relocating.

Several modes of transportation will also be affected by an ORCS failure. The three major federal highways, four rail lines, and seven major interstate pipeline systems crossing the basin would be jeopardized should the ORCS collapse. Vehicle and rail traffic would have to be rerouted around the Basin which would result in higher fuel, maintenance, and capital costs as a result of the increase in travel distance. Products transported via the rails and highways would be delayed temporarily in reaching their destinations because of need to by-pass the Basin. It should be noted that the interstate pipelines intersecting the Basin transport about 15% of the total natural gas consumed in 28 eastern and southern states each year. If all or most of the pipelines fail, many communities and industries in the north-east portion of the United States might be without supplies of natural gas for some period of time.

Another anticipated effect is that as the Atchafalaya continued to capture an ever larger portion of the Mississippi, the Mississippi River channel below the ORCS structure would fill with silt and barge navigation on the river would be imperiled. If this occurred there are three options which could be pursued. River traffic could be routed down the Atchafalaya River, then east on the intercoastal waterway to New Orleans; a lock and dam, accompanied by some dredging, could be built south of the ORCS to by-pass the shoal; or extensive and continual dredging operations could be conducted in the silted area south of the ORCS.

II

THE HIGHWAY AND RAIL TRANSPORTATION SECTORS

Introduction

The failure of the Old River Control Structure would have a significant impact on the transportation system serving Louisiana and the Nation. This impact would take the form of flooded highways, eroded banks, and, possibly, collapsed bridges and approaches. The purpose of this chapter is to examine some possible economic effects resulting from the destruction of key bridges and related approaches and roadways of the four major highways and four railroad lines in the Basin.

The major highway crossing the Basin is Interstate 10 which, for most of the country, is the southernmost interstate highway. It originates on the east coast in Jacksonville, Florida, and terminates in Santa Monica, California. The southernmost major highway in Louisiana is U.S. 90 which crosses the Basin at Morgan City and follows a route through New Orleans, Houma, Lafayette, and Lake Charles. Both I-10 and U.S. 90 serve as major east-west transportation routes. U.S. 190 which runs parallel to I-10 and about 15 miles north of it connects Covington, Baton Rouge, and Eunice and crosses the Atchafalaya Basin at Krotz Springs.

The northernmost rail line, owned by the Texas and Pacific Railroad crosses the Atchafalaya River at Simmesport. The two central railroad lines which cross the Basin at Melville and Krotz Springs are owned by the Texas and Pacific and Missouri Pacific railroads, respectively. The southernmost line is operated by the Southern Pacific Company and passes through Morgan City - Berwick area. If the ORCS were to fail, the bridges serving these highways and railroads would be subject to increased scour activity which might undermine the supporting piers and cause the bridges to collapse. Loss of these commercial arteries would virtually disrupt all rail and highway transportation across the basin. In Figure 1.2, a map of the four major highway and four rail line bridges transversing the basin is presented.

Estimate of Economic Costs Resulting From Highway Disruption

Highways and Bridges

Although the failure of the ORCS could result in flood and erosion damage to the highways and their roadbeds, the most significant impact would be the destruction of the bridges. In discussions with bridge design consultants at the Louisiana Department of Transportation and Development, it was apparent that the bridges were designed to operate safely during average and high water levels and that the bridge super-structure could withstand severe stresses. Even if the ORCS should fail and most of the waters of the Mississippi River were to flow under the affected bridges, it is very unlikely that the bridges would be destroyed as a direct result of the impact of water. The most probable cause of destruction would be the undermining of the supporting piers by scouring activity. During the 1973 flood a scour hole deeper than the depth of the centerline pier (-155 ft.) was observed approximately 600 downstream of the I-10 bridge over Whiskey Bay and, although that hole has been filled in by loose sediment it will scour very quickly in the next flood.

As shown in Table 2.1 the total costs of replacing the five bridges across the Atchafalaya are approximately $65 million in 1977 dollars. These estimates are made by adjusting the bridge construction costs in the year in which they were incurred by the Federal Highway Administration's construction cost index for 1977.

TABLE 2.1

PUBLIC EXPENDITURES ON HIGHWAY BRIDGES AND ESTIMATED REPLACEMENT COSTS

Highway	Location	Substructure Year	Substructure Cost	Superstructure Year	Superstructure Cost	1977 Dollar Cost[1] Sub-	1977 Dollar Cost[1] Super-	Estimated Replacement Costs
I-10	Atch. River	--	--	1972	$ 6,590,350	--	$ 9,693,346	$ 9,693,346[2]
I-10	Whiskey Bay	--	--	1972	13,340,047	--	19,621,065	19,621,065[2]
U.S. 190	Krotz Springs	1972	$3,265,244	1973	4,371,590	$ 4,802,649	5,772,955	10,575,604
La. 1	Simmesport	1967	2,861,938	1971	2,838,043	5,918,488	4,237,598	10,156,086
U.S. 90	Morgan City	1972	4,790,457	1975	7,847,902	7,045,992	7,709,958	14,755,950
Total			$10,917,639		$34,987,932	$17,767,129	$47,034,922	$64,802,051

1 Costs of structure in the year it was completed were inflated by the Federal Highway Administration Construction Cost Index.

2 Costs for that portion of the project directly over the Atchafalaya River and Whiskey Bay.

Source: Louisiana Department of Transportation and Development, Bridge Design Section.

The cost estimates for the bridges do not include the elevated approaches to the bridges. It is possible that a failure of the bridges would also cause partial failure of the approaches. Because I-10 and U.S. 90 are elevated on both sides of the bridges, there are no identifiable approaches. The costs of the bridge approaches for U.S. 190 and La. 1 are shown in Table 2.2. These replacement costs, which are estimated to be $5.9 million, are adjusted to reflect 1977 prices.

TABLE 2.2

REPLACEMENT COSTS FOR BRIDGE APPROACHES

Highway	Location	Approach Length (ft.)	Departure Length (ft.)	Total Length (ft.)	Replacement Cost
U.S. 190	Krotz Springs	970	915	1,885	$2,525,900
La. 1	Simmesport	1,171	1,311	2,482	3,325,880
Total					$5,851,780

Flood waters in the Basin could also erode and damage the roadways within the Basin but I-10, which is elevated throughout the Basin, is unlikely to suffer extensive roadway damage. The Louisiana Department of Transportation and Development's 1977 estimate of the costs of replacing, or extensively repairing, one mile of high-grade road surface is about $250,000. Total cost (1977) of replacing all roadways excluding I-10 which is elevated in the Basin, are estimated to be approximately $14 million as shown in Table 2.3. Not all of the roadways would suffer damages, however, so it assumed that only 20 percent would require extensive repairing at a cost of approximately $2.8 million.

TABLE 2.3

REPLACEMENT AND REPAIR COSTS OF MAJOR ROADWAYS IN THE ATCHAFALAYA BASIN (Excluding Bridges and Approaches)

Highway	No. of Miles	Total Cost at $250,000/mile	Estimated Damages at 20%
190	25	$ 6,250,000	$1,250,000
1	29	7,250,000	1,450,000
90	3	750,000	150,000
TOTAL		$14,250,000	$2,850,000

Table 2.4 presents total replacement costs estimates for the major highways in the Basin including roadways, approaches, and bridges. Total estimated replacement costs (1977 prices) are $74 million. This estimate does not include the damages to rural access roads, municipal streets or secondary highways. These losses are included in the estimate of the losses to the public sector in Chapter IV of this study.

TABLE 2.4

Total Replacement Costs:
Highways, Approaches, and Bridges

Highway	Roadways	Approaches	Bridges	Total
I-10	--	--	$29,314,411	$29,314,411
U.S. 190	$1,250,000	$2,525,900	10,575,604	14,351,504
LA 1	1,450,000	3,325,880	10,156,086	14,931,966
U.S. 90	150,000	--	14,755,950	14,905,950
TOTAL	$2,850,000	$5,851,780	$64,802,051	$73,503,831

a. Operating Costs: If one or more of the major highways crossing the Basin should be closed for any period of time, highway users would have to use alternative routes which would result in increased costs for fuel, tire wear, maintenance, and other "wear and tear" on automobiles and trucks. In addition, individuals and employers will suffer a significant loss for the value of additional time spent on alternative routes.

The vehicle counts listed in Table 2.5 were taken at the Atchafalaya crossings in 1977. These vehicle counts are listed by automobiles and trucks for each crossing.

U.S. 90, whose bridges are the least vulnerable of all four bridges, carried the most traffic each day in 1977. The I-10 bridge, the structure most likely to collapse, had the second highest traffic count per day. Although the other two bridges carried lesser amounts of traffic, these roadways play an important part in the Louisiana transportation network.

Cost per mile data for automobiles were obtained from the United States Department of Transportation. Only variable costs are included in the total figure inasmuch as fixed costs would not be affected by the increased usage of the vehicles. The variable costs included in the cost per mile data include: maintenance, tires, gasoline, and motor oil. A breakdown of these pertinent costs is presented in Table 2.6.

TABLE 2.5

Average Traffic Counts for Bridges Crossing the Atchafalaya Basin (vehicles/day, 1977)[1]

Bridge	Automobiles[2]	Trucks[3]	Total
US I-10	10,185	3,395	13,580
US 190	6,040	1,510	7,550
LA 1	3,348	372	3,720
US 90	14,339	3,811	18,150

[1] Louisiana Department of Transportation and Development, Traffic Planning Division
[2] Pickup and panel trucks, automobiles, all other vehicles
[3] 18-wheeler and medium trucks

TABLE 2.6

Variable Costs Per Mile for Automobiles (1977)

Type	Cost (cents)
Maintenance	2.9
Fuel	3.3
Tires and Oil	5.9
Total	12.2

SOURCE: United States Department of Transportation

The federal government has not conducted a survey of operating costs for trucks on a per mile basis so private sources were used for these estimates. In 1975, the Hertz Corporation produced a survey of operating expenses for both automobiles and trucks. The costs for automobiles were higher than those reported in the Federal publications so the relative ratios were utilized. Variable expenses for trucks were roughly twice as high as those for cars in 1975; and if the ratio of variable expenses for trucks to cars is the same in 1977 as in 1975, the estimated variable costs for trucks are almost 25 cents per mile.

The amount of variable costs imposed on individuals and business firms will be affected by the number and types of highway closed. Since U.S. I-10 and U.S. 190 bridges are the most vulnerable to failure, Case I assumes that these will fail. In the second, and worst, case it is assumed that all four bridges are undermined and transportation through the Basin is impossible.

If the two bridges in Case I were to fail, vehicular transportation would be able to cross the Basin via the Highway 1 bridge to the north and the Highway 90 bridge to the south. Travelers from Lafayette to Baton Rouge could be rerouted through Morgan City via U.S. 90, La. 20 from Morgan City to Thibodaux, and La. 1 from Thibodaux to Baton Rouge. As a result of the I-10 and U.S. 190 bridge failures there would be a 96 mile detour at a daily total cost of $119,266 for automobiles and $79,511 for trucks (Table 2.7). Similarly, travelers from Alexandria to Baton Rouge would use La. Highway 1 and U.S. 190 through Simmesport rather than La. 71 and U.S. 190 through Krotz Springs. The detour would total 6 nt a daily cost of $4,400 for automobiles and $2,200 for trucks should the ollapse. It is assumed in the calculations that all U.S. 190 traffic is exandria to Baton Rouge, which is a very conservative assumption. The costs per vehicle produced by the detours, and total cost, is shown in cost for a one year detour would be $45 million for automobiles and $30 s for a total of $75 million.

TABLE 2.7

COSTS OF DETOURS ASSUMING FAILURES OF
U.S. I-10 AND U.S. 190 BRIDGES

Variable Operating Costs for Automobiles

	No. Miles Detour	Cents Per[1] Mile	Cost Per Vehicle	No. Veh.[3] Per Day	Total Cost Per Day
	96	12.2	$ 11.71	10,185	$119,266
)0	6	12.2	.73	6,040	4,409
ly Cost for Automobiles					$123,675
st					$45,141,375

Variable Operating Costs for Trucks

	No. Miles Detour	Cents Per[2] Mile	Cost Per Vehicle	No. Veh. Per Day	Total Cost Per Day
	96	.244	$23.42	3,395	$79,511
	6	.244	1.46	1,510	2,205
ly Cost for Trucks					$81,716
st					$29,826,340

ly Costs for Automobiles and Trucks	$ 205,391
ual Costs for Automobiles and Trucks	$74,967,715

1. U.S. Department of Transportation
2. The Hertz Corporation, 1975, adjusted to 1977 prices
3. Louisiana Department of Transportation and Development

icts a situation in which all four bridges across the Basin have been under- instance all traffic will have to be rerouted north of the Basin through ippi. This route, of course, involves many more miles of detour than the

I-10 traffic would be detoured from Baton Rouge northward along U.S. 61 to ithwest to Alexandria along U.S. 54 and La. 28, and finally back to I-10 via 13. The total detour necessitates 221 additional travel miles. Vehicles . 190 should take the same route as above, but the detour for Highway 190 les less for a net 203 additional miles. Traffic utilizing La. 1 will also e to Natchez, but will be able to rejoin La. 1 at Alexandria for a total of

Finally, U.S. 90 runs parallel to I-10 to the west of the Basin. Most west bound traffic using this highway passes through New Orleans and would be forced to take U.S. 61 to Natchez and then the same southwesterly route to U.S. 90 as described above. This additional distance would require a detour of approximately 300 miles.

Total variable operating costs of automobiles and trucks assuming failure of all bridges are shown in Table 2.8. The daily costs for automobiles making the detour are $1 million and for trucks it is $550,000. The total costs of detouring for one year would be approximately $573 million.

TABLE 2.8

COSTS OF DETOURS ASSUMING FAILURE OF ALL BRIDGES CROSSING BASIN

Variable Operating Costs for Automobiles

Highway	No. Miles in Detour	Costs Per[1] Mile	Cost Per Vehicle	No. Veh.[3] Per Day	Total Cost Per Day
US I-10	221	12.2	$26.96	10,185	$ 274,588
US 190	203	12.2	24.76	6,040	149,550
LA 1	159	12.2	19.40	3,348	64,951
US 90	302	12.2	36.84	14,339	528,249
TOTAL Daily Cost					$ 1,017,338
Annual Cost					$371,328,370

Variable Operating Costs for Trucks

Highway	No. Miles in Detour	Costs Per[2] Mile	Cost Per Vehicle	No. Veh. Per Day	Total Cost Per Day
US I-10	221	.244	$53.92	3,395	$ 183,058
US 190	203	.244	49.53	1,510	74,790
LA 1	159	.244	38.79	372	14,430
US 90	302	.244	73.69	3,811	280,833
TOTAL Daily Cost					$ 553,111
Annual Cost					$201,885,515
TOTAL Daily Costs for Automobiles and Trucks					$ 1,570,449
TOTAL Costs of a one year detour for Automobiles and Trucks					$573,213,885

Sources: 1. U. S. Department of Transportation
2. The Hertz Corporation, 1975
3. Louisiana Department of Transportation and Development

b. Value of Time Loss: In addition to the operating costs which would be incurred by highway users, the failure of the bridges and the resulting detours would result in additional time utilized by the travelers. This additional time has a value both to those engaged in economic pursuits and to those who are traveling for leisure. The average wage rate of drivers of semi-trucks and medium trucks, obtained from the U.S. Department of Labor, was

TABLE 2.9

VALUE OF TIME LOSSES PER DAY ASSUMING FAILURES OF U.S. I-10 and U.S. 190 BRIDGES

Vehicle	Vehicles/ Day Crossing Basin	Ave. No. Occupants/ Vehicle	Ave. Wage Rate/ Occupants	No. of Miles Detoured	Hours Required to Detour	Total Time Value Loss
U.S. I-10						
Semi-truck	2,580	1.0	$9.90	96	2.13	$ 54,404
Medium truck	815	1.0	5.30	96	2.13	9,200
Automobiles and Other	10,185	1.5	2.65	96	2.13	86,234
Total	13,580					$149,838
U.S. 190/LA 2						
Semi-truck	981	1.0	$9.90	6	0.13	$ 1,262
Medium truck	529	1.0	5.30	6	0.13	364
Automobiles and Other	6,040	1.5	2.65	6	0.13	3,121
Total U.S. 190	7,550					$ 4,747
Total Cost Per Day						$154,585
Total Costs Assuming a one year detour						$56,423,525

(1) Department of Labor, 1977
(2) Data from Table 2.8
(3) Calculated at 45 mph.
(4) Cols. 1 x 2 x 3 x 5

TABLE 2.10

VALUE OF TIME LOSSES PER DAY ASSUMING FAILURES OF U.S. I-10, U.S. 190, LA 1, and U.S. 90 BRIDGES

Vehicle	Vehicles/ Day Crossing Basin	Ave. No. Occupants/ Vehicle	Ave. Wage Rate/ Occupant	No. of Miles Detoured	Hours Required to Detour	Total Time Value Loss
U.S. I-10						
Semi-truck	2,580	1.0	$9.90	221	4.91	$ 125,411
Medium truck	815	1.0	5.30	221	4.91	21,209
Automobiles and Other	10,185	1.5	2.65	221	4.91	198,783
Total	13,580					$ 345,403
U.S. 190/LA 2						
Semi-truck	981	1.0	$9.90	203	4.51	$ 43,801
Medium truck	529	1.0	5.30	203	4.51	12,645
Automobiles and Other	6,040	1.5	2.65	203	4.51	108,281
Total	7,550					$ 164,727
LA 1						
Semi-truck	149	1.0	$9.90	159	3.53	$ 5,207
Medium truck	223	1.0	5.30	159	3.53	4,172
Automobiles and Other	3,720					46,978
Total	3,720					$ 56,359
U.S. 90						
Semi-truck	1,996	1.0	$9.90	302	6.71	$ 132,592
Medium truck	1,815	1.0	5.30	302	6.71	64,657
Automobiles and Other	14,339	1.5	2.65	302	6.71	382,453
Total	18,150					$ 579,591
TOTAL DAILY COST FOR ALL HIGHWAYS						$ 1,146,078
TOTAL COSTS, ASSUMING A ONE YEAR DETOUR						$418,318,470

(1) Department of Labor, 1977
(2) Data from Table 2.8
(3) Calculated at 45 mph.
(4) Cols. 1 x 2 x 3 x 5

applied to the number of similarly classed vehicles crossing the Atchafalaya highways. These are good wage estimates but they are conservative because they do not include many fringe benefits.

Estimating the value of time of the occupants of automobiles is more complicated. If individuals were free to adjust their hours, the value of their leisure time, at the margin, would equal their wage rate, less an income tax adjustment. We utilized the minimum wage rate of $2.65 which, before income taxes, would be approximately equal to an hourly wage rate of $3.53.

The daily costs of lost time in Case I, in which only I-10 and U.S. 190 bridges were closed, would be $154,585 with an annual cost of $56 million (Table 2.9). The daily cost in Case II, in which all bridges were closed, would be $1.1 million with an annual cost of $418 million (Table 2.10).

Table 2.11 presents estimates of the total operating and time costs involved in the detours. In Case I, the total daily costs of the detours are $360 thousand and in Case II they are approximately $2.7 million. Generally the construction of major bridges would take two to three years, but because part of the bridges would remain intact and because of the emergency nature of the situation the bridges would be reconstructed in less time. If the time period from the moment of failure to the reopening of the bridge were one year, the total time and operating costs imposed by the detours would be $130 million in Case I and approximately $1 billion in Case II.

TABLE 2.11

TOTAL ESTIMATED COSTS OF BRIDGE FAILURES

Case 1: Assumes Failure of I-10 and U.S. 190 Bridges

	Daily	One Year
Additional operating costs	$205,391	$ 74,967,715
Value of time losses	154,585	56,423,525
	$359,976	$131,391,240

Case 2: Assumes Failure of All Bridges Across the Basin

	Daily	One Year
Additional operating costs	$1,570,449	$573,213,885
Value of time losses	1,146,078	418,318,470
	$2,716,527	$991,532,355

Losses to Rail Carriers

Currently there are four rail bridges spanning the Atchafalaya River, but the only two which remain in service are the Southern Pacific's bridge near Morgan City and the Missouri Pacific Railway crossing at Krotz Springs. Both lines were originally constructed in the early part of this century, and both are probably vulnerable should the ORCS fail.

If the Southern Pacific bridge at Morgan City collapsed as a result of ORCS failure, the six trains per day that cross the Basin on this line would have to be rerouted from New Orleans through Natchez and finally reconnect at the main line west of the Atchafalaya. The total detour mileage necessitated by the failure of the Southern Pacific bridge would be approximately 300 miles. The four daily trains passing through the Basin on the Missouri Pacific tracks would follow virtually the same route; but their line lies roughly 20 miles north of the Southern Pacific's. Therefore, the Missouri Pacific trains would have to detour approximately 280 miles.

Table 2.12 presents the operating losses per day for the rail industry caused by an ORCS failure. The figure for cost per mile of $35.25, was obtained from the Economics and Finance Department of the Association of American Railroads. The loss of the two bridges would cost Southern Pacific about $63,000 per day and Missouri Pacific just under $40,000 per day in additional expenses. The total cost per day would be almost $103,000. Again, if it is assumed that it would take one year to rebuild the two bridges, the total cost to these two railroads, alone, would be more than $37 million dollars.

TABLE 2.12

POTENTIAL COSTS TO THE
RAIL INDUSTRY DUE TO DETOURS

Line	Cost per mile per train	# Miles in Detour	Cost per Train	# Trains per day	Total Cost per day
So. Pac.	$ 35.25	300	10,575	6	$ 63,450
Mo. Pac.	35.25	280	90,870	4	39,480
TOTAL PER DAY					$ 102,930
ANNUAL COSTS					$37,539,450

Source: Division of Research and the Economics and Finance Department of the Association of American Railroads, 1977

In addition to the operating losses, the railroads would suffer the capital loss of replacing the bridges. We were unable to obtain any information on the costs of replacing the bridges, primarily because no similar major railroad bridges have been built recently. There is also some doubt about the financial ability of the railroads to replace these bridges. They might continue the detour routes indefinitely.

III

EFFECTS OF A LOSS OF THE OLD RIVER CONTROL STRUCTURE ON NATURAL GAS PIPELINES

Introduction

Seven major interstate gas pipeline systems cross the Atchafalaya Basin and would be vulnerable to damage by flood waters if the ORCS should fail. The seven systems include pipelines owned by the Columbia Gulf Transmission Compnay (CGT), the Florida Gas Transmission Company (FGTC), the Southern Natural Gas Transmission Company (SNG), the Texas-Eastern Transmission Company (TET), the Texas Gas Tramsmission Company (TGT), the Transcontinental Company, (TRANSCO), and the United Gas Transmission Company (UGT). Collectively the pipelines of these companies which cross the Basin carry about 15 percent of the natural gas consumption east of the Mississippi River. Although even a 15 percent decrease in natural gas availability which occured suddenly and without time to make adjustments for other energy sources would be a cause for concern, some states would have a much larger percentage of their natural gas curtailed.

The purpose of this chapter is to describe the situation and to analyze some alternative scenarios. The analysis is presented in three scenarios: The first scenario assumes the failure of only one or two lines crossing the Atchafalaya Basin. The second scenario is a situation in which five of the seven lines in the Basin are ruptured. In this instance there could be some curtailments of gas deliveries to most of the states served by natural gas lines crossing the Atchafalaya. Finally, the third scenario is the worst case situation: a failure of the ORCS which has ruptured all the lines in the Basin would most likely cause some curtailments of natural gas deliveries.

The Probability of Failure of Natural Gas Pipelines

A general overview of the major natural gas pipeline systems crossing the Atchafalaya River Basin is presented here. Variables such as the age of the system, the type of crossing (i.e., under river or aerial), subsoil characteristics at crossings, discharge of the river at the point of crossing, and the number of lines contained within each system have been evaluated and the various pipelines ranked in order of their probability of failure. The probabilities assigned are ordinal rankings of likelihood of failure because precise numerical values could not be assigned. For example, it is impossible to state that an ORCS failure would result in a seventy percent chance of a rupture in the United Gas pipeline. It is a matter of judgement to conclude that should the ORCS fail, United Gas pipeline would be more likely to fail than, say, the Transco line, but less likely than the Columbia Gulf line. The ordinal ranking of the likelihood of failure has been based upon detailed analyses of the five variables mentioned above. Although there are no generally accepted criteria which can be used to assess the probability of a pipeline failure, the pipeline companies generally agreed with the analysis.

The age of the system is one variable which must be considered in the ordinal ranking. Some pipelines constructed as early as 1942 have been inspected recently and have shown no evidence of deterioration while other lines constructed as recently as 1960 are already showing signs of wear.

The type of pipeline crossing the waterway, whether under river or aerial, plays a major role in the probability of line destruction. Subriver crossings are occasionally exposed on a river bed through the process of bottom scour or erosion. Major floods can increase the rate of erosion and uncover the buried lines, thus exposing them to swift currents and to impacts from large pieces of debris. It was precisely this situation which produced the rupture of one major and four minor pipelines during the 1973 flooding in the Atchafalaya Basin. Such pipeline ruptures are virtually impossible to correct during a period of flooding.

As a result of the 1973 experience, aerial crossings were constructed by two firms to eliminate the possibility of pipeline rupture due to underwater exposure. The aerial design is more capable of withstanding high water, high discharge velocities, and the movement of debris. The pilings or piers that support the aerial crossing are usually driven to an elevation of between -15 to -30 feet msl. This means that if a river overtopped its levees, the erosion process would have to be sustained for long periods in order for the structure to be undermined to the point of collapse. However, while this type of crossing is satisfactory for minor floods, it is not designed to survive a major disaster such as a failure of the ORCS. Under such conditions it is possible that the piers which support the pipeline could be undercut and washed away. The probability that the piers which support an aerial crossing would be undermined depends on several major factors: the depth to which the piers are driven, the distance from the river banks to the piers, and the expected duration of exposure should the river leave its banks. If the ORCS collapsed, the flooding and subsequent erosion would be significant since the reach of the river in which most aerial crossings have been made is degrading (cutting) and there is some probability that the aerial crossings of the Atchafalaya would also fail. An engineering firm involved in the design of these piers stated that it is conceivable that a major flood which is worse than the 1973 flood could undermine the supporting piers for the aerial crossings. In the final analysis, however, the aerial crossings are much less vulnerable than the existing sub-river crossings.

The third variable affecting the probability of failure of a river crossing is the velocity of the discharge at the crossing. The velocity of discharge varies at different locations along the river. In the area from Simmesport southward to the I-10 bridge, the guide levees direct the river into a relatively narrow channel which means that during high water the flow velocity is high and the bottom is more quickly scoured and degraded. Pipelines located in this area would, other things being equal, have a greater chance of being disrupted. In the area south of I-10 the absence of guide levees allows flood discharge to fan out through the entire Basin area, thus resulting in lower discharges and volume at any location. Erosion is less likely to be a serious problem in the area immediately south of I-10. As the water in the Atchafalaya River moves further south, however, the discharge of the river is once again directed into narrow channels. There are two potential trouble spots in the extreme southern portion of the Basin. The first is the Morgan City-Berwick area where seventy percent of the Atchafalaya's discharge (under normal low water circumstances) moves through a narrow channel into Atchafalaya Bay. The other potential trouble spot is the Wax Lake outlet. During times of normal water level, only about thirty percent of the river's discharge passes through Wax Lake. However, during flood stages, about fifty percent goes through the Wax Lake outlet into the Gulf. Both of these areas are subject to serious scour activity during flood stages.

Soil type and stratigraphic history also play an important role in the determination of the probability of pipeline failure. In the area between Simmesport and I-10, and also in the region near US 90 at the origin of the Wax Lake Channel, scour is prevalent not only because of high discharge velocity, but also as a result of the existence of numerous unconsolidated sandy-silty formations in the area. The coupling of these two conditions causes serious problems of scour on the river bottom. A survey in the Basin made after the 1973 flooding revealed that the channel bottom was at -125 msl. During the 1973 flooding, at least three pipelines were ruptured in this specific area.

Finally, the area bounded by US I-10 in the north and US 90 in the south is not subject to unusual erosion for the following reasons: 1) the subsoil in this area consists of numerous pleistocene clay formations which are consolidated and tough and 2) the river in this area loses its identity among the several lakes, bayous, and swamps contained within the Basin. As a result, the discharge in this area is neither concentrated nor strong enough to cause serious scour problems; instead, it is an area of sediment deposition.

Major Interstate Gas Pipelines Crossing the Basin

The ordinal rankings of failure probabilities are discussed below by grouping the pipelines into three ordinal categories: the pipelines of Transco and Florida Gas Transmission comprise the group considered least likely to fail. Pipelines operated by companies in the second group - Southern Natural Gas, Texas Eastern, and United Gas, have a greater chance of being ruptured in the aftermath of a failure of the ORCS. Pipelines operated by members of Texas Gas and Columbia Gulf are considered most likely to experience pipeline failure.

Category I.

a) Transco: This system consists of a total of four natural gas pipelines (two 18-inch and two 30-inch lines) originating in the offshore waters of Louisiana and Texas. It crosses the Basin just north of the town of Melville, Louisiana. The lines serve the states of Alabama, Delaware, District of Columbia, Georgia, Kentucky, Louisiana, Maryland, Mississippi, New Jersey, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Virginia, and West Virginia and terminate in New York City. The predominant sector served by Transco is the gas and electric utility industry, including Consolidated Edison of New York and Atlanta Gas and Light.

The two 30-inch lines, built in 1974, cross the river on a bridge. The piers of the crossing are not in the river and would not readily be subject to river scour. A senior official of Transco has indicated that the loss of the Low Sill Control Structure, with the increased possibility of bottom scour due to increased flow, would only affect the two 18-inch underwater crossings and not the two 30-inch lines. Because the river near Melville contains the reach which is eroding and scouring, there is an increased probability that the two 18-inch lines (built in 1966) would fail. Company officials have indicated, however, that the excess capacity generally available in the aerial crossings would enable near normal throughput to be maintained. The Transco system would most likely be able to function at or near normal levels should the ORCS fail.

b) The Florida Transmission System: The system owned by Florida Gas Transmission (FGTC) consists of one 24-inch aerial crossing of the Atchafalaya. This line was constructed in 1974 after the submerged river line was ruptured during the 1973 flooding. The FGTC system originates in south Texas and terminates in Miami, Florida. Virtually all gas transmitted by FGTC is delivered to Florida. The dominant industry group served by FGTC is the gas and electric utility industry in Florida.

The aerial crossing is located approximately one mile north of Krotz Springs, Louisiana and is in a reach of river where the bed is cutting. Since bed erosion plays no direct part in the rupture of an aerial crossing, there is a very small probability that a failure of the ORCS would cause a failure of FGTC's pipeline. There is, of course, the possibility that the banks could be undercut sufficiently to wash out the supporting piers; but the probability of a failure of this line is much less that that of the pipelines in Categories II and III.

Category II.

The second category consists of three underwater crossing systems between US 190 at Krotz Springs and US 90 directly north of the Wax Lake outlet. Continuing the ranking from the least to the most likely to fail, the systems in this group are: Southern Natural Gas, Texas Eastern Transmission System and United Gas Pipeline.

a) Southern Natural Gas: The pipeline system which Southern Natural Gas operates within and across the Basin consists of one 20-inch line crossing the central portion of the Basin and two parallel lines, one 20-inch and one 30-inch crossing in the south near the Franklin, Louisiana area. From its point of origin in southeastern Louisiana, the system continues through Louisiana, Mississippi, Alabama, Georgia, Florida, South Carolina, Tennessee, Pennsylvania, New Jersey, Rhode Island, Massachusetts, and Connecticut. This system delivers natural gas to industrial, utility, commercial, and residential customers along its route.

The system serves municipally-owned and investor-owned public utilities and a number of industrial customers such as petrochemicals, rubber, clay products, canneries, aero-space (Martin-Marietta), and rail yards. In addition, the Corps of Engineers and Naval Auxiliary air bases in Mississippi have direct connections with Southern. Because Southern's system traverses the Basin in the area between US 190 in the north and US 90 in the south, the system falls entirely in that portion of the Basin in which the river loses its identity among the various lakes, bayous, and swamps. Thus, a rupture caused by scour is not very likely to occur. Southern lost no lines during the flood of 1973, and it might not be adversely affected by a similar flood in the future.

b) The Texas Eastern Transmission System: This system originates in south-central Texas near the Mexican border and terminates on Manhattan Island. It provides natural gas to public utilities in the states of Alabama, Arkansas, Connecticut, District of Columbia, Illinois, Indiana, Kentucky, Louisiana, Maryland, Massachusetts, Mississippi, Missouri, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Tennessee, Texas, Virginia and West Virginia. Most of TET's system consists of several lateral lines which join together at St. Francisville, Louisiana and proceed to the northeastern part of the country. In addition, Texas Eastern also operates a northern line which cuts diagonally across Texas and Arkansas, and connects with the main system in southern Ohio. The portion of the system crossing the Atchafalaya, consists of one 36-inch line at St. Francisville. This crossing built in 1950 is in an area of potentially serious scour where the main channel levees contain the waters within the narrow confines of the present course of the river.

c) United Gas Pipeline: The United Gas Pipeline Company operates an intricate web of pipeline systems serving much of Louisiana and Mississippi as well as isolated areas in Texas, Alabama, and the Florida panhandle. One line which does not cross the Basin originates near Corpus Christi, Texas, enters Louisiana south of Shreveport, passes through Monroe, and terminates in Kosciusko, Mississippi.

The second line, which does go through the Basin, originates in southeastern Louisiana, crosses the Basin at Wax Lake, joins another lateral line to the northwest, and again goes through Monroe in route to Central Mississippi. The third line in the system originates south of New Orleans, crosses Lake Ponchartrain, cuts across southern Mississippi, Alabama, and terminates in the Florida panhandle.

An 18-inch line crosses the Wax Lake outlet which is very narrow and constrained by levees on both sides. During high water this small outlet discharges about fifty percent of all flood waters passing through the Basin. United's line at Wax Lake is an underwater crossing and, therefore, subject to exposure resulting from bottom scour. On the other hand, available subsoil data indicates that the line crosses the outlet in an area of Pleistocene clay which is somewhat resistant to erosion. This may be the reason that United was one of the few lines in the Wax Lake area to have escaped rupture in 1973. However, the tremendous volume of water projected to pass through the Atchafalaya Basin should the ORCS fail might be sufficient to cause a rupture.

United's customers are primarily public utilities and some industries are connected directly to the system. Specific customers listed in the FPC flow diagram include firms in the following industries: brick and tile, petrochemical, paper products, aluminum and chemical, cement manufacture, steel, canneries, packing, poultry, agriculture, and sugar refining.

Category III.

The third category consists of those pipelines which are located south of US 90, in the Wax Lake area (the area where failure is considered most likely to occur). The two systems located here are operated by Texas Gas Transmission Company and Columbia Gulf Transmission Company.

a) Texas Gas Transmission: TGT's main system originates at Eunice, Louisiana and terminates in Lebanon, Ohio. The system consists of three parallel lines: one 20-inch, one 26-inch, and one 36-inch serving the states of Louisiana, Arkansas, Mississippi, Tennessee, Kentucky, Indiana, and Ohio. The western line originates southwest of Eunice and does not cross the Basin. However, the eastern line, consisting of one 20-inch and one 26-inch line, does cross the Basin in the vicinity of the Wax Lake outlet. This would be the only part of the TGT system that would be affected by a failure of the ORCS.

This system, which serves only public utilities and gas distribution systems, crosses the Atchafalaya Basin in the Wax Lake area. In addition, the lines cross the Atchafalaya River main channel just south of Morgan City. Both of these crossings, which are in narrow leveed channels, would be vulnerable to sustained scour activity should the ORCS collapse. Taking into account the age, depth of cover, discharge and width of the river, this part of the T G T system is one of the most likely to fail should the ORCS collapse.

b) Columbia Gulf Transmission: Columbia Gulf's system west of Lafayette, Louisiana consists of three parallel lines: two 30-inch and one 36-inch, that traverse Louisiana, Mississippi, Tennessee, and Kentucky.

Delivery points, as listed on the FPC flow diagram, are located in Louisiana and Kentucky. In Louisiana, the delivered natural gas is used in the agricultural and refining sectors of the state's economy. In Kentucky, much of the natural gas delivered is interconnected with other gas transmission lines and transported out of the state into West Virginia, Virginia, Pennsylvania, and Maryland. The portion of the delivered gas retained in Kentucky is used in the public utilities and natural gas distribution sectors.

Three lateral lines cross the Atchafalaya Basin southwest of Morgan City, in the Wax Lake Outlet, of which one is aerial. During the 1973 flooding, the southernmost line was ruptured and had to be replaced, while the northern line remained intact. The outflow channel at Wax Lake is subject to scour so Columbia's system is classified as one of the systems more likely to fail if the ORCS were lost.

Summary.

The major systems within the Basin fall into three categories: 1) those that are least likely to fail because they operate aerial lines crossing the Basin, 2) those that might fail because their lines are underwater crossings between Simmesport and US 90, and 3) those that are most likely to fail because they are located in the troublesome area below US 90 and the Wax Lake Outlet. The categories and their respective systems are classified as follows:

I. Least Likely to Fail
   1) Transco
   2) Florida Gas

II. Intermediate Likelihood of Failure
   3) Southern
   4) Texas Eastern
   5) United
III. Most Likely to Fail
   6) Texas Gas
   7) Columbia Gulf

The Volume of Gas Crossing the Basin

Not all of the natural gas delivered by the seven major pipeline systems described above cross the Atchafalaya Basin. Some natural gas is imported into the system east of the Basin and some gas from west of the Basin is routed north of the Basin. After unsuccessfully trying to piece together data from numerous sources in order to determine the amount of natural gas which traveled across the Basin, the writer had to rely on estimates made by officials in the various pipeline companies. The quantity estimates of the natural gas passing through the Basin are 1979 data. Tables 3.1 through 3.7 present the quantities of natural gas passing through the Basin. The total quantity of natural gas traversing the Basin is shown in the total of column (1). Other data in that column show the allocation of this quantity of natural gas to the various market areas. The allocation formulae for Tables 3.1-3.9 were derived from FPC/FERC flow charts and other sources. These allocations relate to the entire system and are crude approximations. The relative distributions of natural gas in the various markets of each system were applied to the quantity of natural gas crossing the Basin. For example, in Table 3.1, a total of 438,000 mmcf delivered by Transcontinental crossed the Basin in 1979. Of that amount 24 percent, or 107,063 mmcf was delivered to New York. This amount was equal to 15.79 percent of the total natural gas consumption in New York. The latest state consumption data available are for 1977, whereas the quantities delivered are for 1979 but the consumption quantities have not changed very much in the two year interval. Tables 3.8 and 3.9 present summary data on the relative impact of natural gas disruption in each of the affected states. The data in Table 3.8 are based on the assumption that all of the pipelines crossing the Basin are disrupted. This is a worst case scenario which is highly unlikely to occur but which presents an extreme order of magnitude.

Approximately 15 percent of the natural gas in 28 eastern states would be disrupted if all of the pipelines should fail. The more seriously affected states and their percentage of natural gas shortfall are: New Jersey (46.7), South Carolina (42.1), Delaware (40.9), and Georgia (39.4).

Table 3.9 is constructed on the assumption that only the pipelines in Categories II and III fail. In this case, 10 percent of the natural gas in 28 eastern states could be disrupted. The states which would suffer the most significant losses would be Georgia (33.5), Alabama (27.7) South Carolina (26.7), Rhode Island (24.8), and Connecticut (23.0). Table 3.10 presents the relative impact on the various states if only the two pipelines in Category III should fail. It appears that Kentucky with a loss of 13 percent of its natural gas would suffer the most significant impact.

Tables 3.8, 3.9 and 3.10 present data on the relative quantities of natural gas which would be disrupted if the relevant pipelines in the Basin should fail. They do not provide any estimates of the economic costs of such failures. Tables 3.11, 3.12 and 3.13 provide data on estimated economic and social costs. An example might clarify the information presented in the tables.

In table 3.11, column (1) shows that Alabama could lose 226,701 mcf per day if all pipelines were ruptured. At a cost of 92.38¢ per mcf, the value of the natural gas in this daily shortage is $209,426. This is not the only effect which will be experienced in Alabama

TABLE 3.1

TRANSCONTINENTAL GAS PIPE LINE CORPORATION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	5,010	280,100	1.79
Delaware	7,983	19,546	40.84
Dist. of Col.	2,287	28,873	7.92
Georgia	20,261	340,630	5.95
Kentucky	628	236,043	.27
Louisiana	2,667	345,280	.77
Maryland	7,522	179,113	4.20
Mississippi	2,167	250,990	.86
New Jersey	87,743	277,103	31.66
New York	107,063	677,930	15.79
N. Carolina	71,612	137,609	52.04
Ohio	7,290	1,048,448	.70
Pennsylvania	72,202	763,322	9.46
S. Carolina	22,038	143,017	15.41
Virginia	20,582	148,330	13.88
W. Virginia	946	101,950	.93
Total	438,001	4,983,284	8.79

TABLE 3.2

FLORIDA GAS TRANSMISSION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	65	280,100	0.00
Florida	51,135	271,994	37.65
Louisiana	194	345,280	.001
Mississippi	71	250,990	.028
Total	51,465	1,148,364	4.48

TABLE 3.3

SOUTHERN NATURAL GAS COMPANY
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	65,140	280,100	.232
Connecticut	27	68,932	.00039
Florida	12,349	271,994	.0045
Georgia	107,887	340,630	.0317
Louisiana	1,911	345,280	.00055
Massachusetts	508	167,457	.003
Mississippi	13,020	250,990	.518
New Jersey	696	277,103	.0025
Pennsylvania	1,352	763,322	.00177
Rhode Island	13	18,927	.000816
S. Carolina	36,205	143,017	.25
Tennessee	5,442	270,115	.02
Total	244,550	3,197,867	.0763

TABLE 3.4

TEXAS EASTERN TRANSMISSION CORPORATION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	1,072	280,100	.38
Arkansas	995	253,792	.39
Connecticut	12,858	68,932	18.65
Dist. of Col.	579	28,873	2.01
Illinois	1,866	1,193,012	.16
Indiana	2,211	543,530	.41
Kentucky	4,219	236,043	1.79
Louisiana	1,508	345,280	.44
Maryland	3,980	179,113	2.22
Massachusetts	24,385	167,457	14.56
Mississippi	1,356	250,990	.54
Missouri	1,472	383,452	.38
New Jersey	33,451	277,103	12.07
New York	45,681	677,930	6.74
Ohio	59,006	1,048,448	5.63
Pennsylvania	64,377	763,322	8.43
Rhode Island	3,228	18,927	17.06
Tennessee	2,402	270,115	.89
Virginia	2,375	148,330	1.60
W. Virginia	3,092	101,950	3.03
Total	270,113	7,236,699	3.73

TABLE 3.5

UNITED GAS TRANSMISSION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	11,443	280,100	4.09
Arkansas	2,252	253,792	.89
Connecticut	1,853	68,932	2.69
Dist. of Col.	147	28,873	.51
Florida	6,428	271,994	2.36
Georgia	6,184	340,630	1.82
Illinois	6,730	1,193,012	.56
Indiana	4,297	543,530	.79
Kentucky	4,851	236,043	2.06
Louisiana	45,787	345,280	13.26
Maine	9	1,970	.46
Maryland	997	179,113	.56
Massachusetts	3,635	167,457	2.17
Mississippi	19,108	250,990	7.61
Missouri	24,382	383,452	6.90
New Hamshire	38	8,648	.44
New Jersey	4,507	277,103	1.63
New York	8,176	677,930	1.21
Ohio	12,800	1,048,448	1.22
Pennsylvania	10,543	763,322	1.38
Rhode Island	880	18,927	4.65
S. Carolina	1,964	143,017	1.37
Tennessee	4,168	270,115	1.54
Virginia	642	148,330	.43
W. Virginia	673	101,950	.66
Total	182,494	8,002,958	2.28

TABLE 3.6

TEXAS GAS TRANSMISSION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumpti Delivered
Alabama	16	280,100	.01
Arkansas	1,067	253,792	.42
Connecticut	1,116	68,932	1.62
Delaware	15	19,546	.08
Dist. of Col.	494	28,873	1.71
Georgia	30	340,630	.01
Illinois	2,042	1,193,012	.17
Indiana	21,299	543,530	3.92
Kentucky	28,553	236,043	12.10
Louisiana	3,222	345,280	.93
Maryland	3,317	179,113	1.85
Massachusetts	2,116	167,457	1.26
Michigan	3,143	839,266	.37
Mississippi	5,536	250,990	2.21
New Jersey	2,919	277,103	1.05
New York	12,145	677,930	1.79
North Carolina	108	137,609	.08
Ohio	2,819	1,048,448	.27
Pennsylvania	13,595	763,322	1.78
Rhode Island	576	18,927	3.04
Tennessee	19,703	270,115	7.29
Virginia	2,029	148,330	1.37
W. Virginia	1,889	101,950	1.85
Total	127,750	8,190,298	1.56

TABLE 3.7

COLUMBIA GULF TRANSMISSION
DISTRIBUTION OF NATURAL GAS CROSSING THE BASIN

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Dist. of Col.	1,253	28,873	4.340
Kentucky	3,176	236,043	1.346
Louisiana	696	345,280	.202
Maryland	8,411	179,113	4.696
Mississippi	579	250,990	.231
New York	2,237	677,930	.330
Ohio	24,520	1,048,448	2.339
Pennsylvania	11,219	763,322	1.470
Tennessee	379	270,115	.140
Virginia	5,157	148,330	3.477
W. Virginia	4,415	101,950	4.331
Total	62,042	4,050,394	1.51

TABLE 3.8

RELATIVE IMPACT IF ALL PIPELINES FAIL

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	82,746	280,100	29.5
Arkansas	4,314	253,792	1.7
Conneticut	15,854	68,932	23.0
Delaware	7,998	19,546	40.9
Dist. of Col.	4,760	28,873	16.5
Florida	69,912	271,994	25.7
Georgia	134,362	340,630	39.4
Illinois	10,638	1,193,012	0.9
Indiana	27,807	543,530	5.1
Kentucky	41,427	236,043	17.6
Louisiana	55,985	345,280	16.2
Maine	9	1,970	0.5
Maryland	24,227	179,113	13.5
Massachusetts	30,644	167,457	18.3
Michigan	3,143	839,266	0.4
Mississippi	41,837	250,990	16.7
Missouri	25,854	383,452	6.7
New Hampshire	38	8,648	0.4
New Jersey	129,316	277,103	46.7
New York	175,302	677,930	25.9
N. Carolina	71,720	137,609	52.1
Ohio	106,435	1,048,448	10.2
Pennsylvania	173,288	763,322	22.7
Rhode Island	4,697	18,927	24.8
S. Carolina	60,207	143,017	42.1
Tennessee	32,094	270,115	11.9
Virginia	30,785	148,330	20.8
W. Virginia	11,015	101,950	10.8
Total	1,376,414	8,999,379	15.3

TABLE 3.9

RELATIVE IMPACT IF PIPELINES IN CATEGORIES II AND III SHOULD FAIL

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption Delivered
Alabama	77,671	280,100	27.7
Arkansas	4,314	253,792	1.7
Connecticut	15,854	68,932	23.0
Delaware	15	19,546	0.1
Dist. of Col.	2,473	28,873	8.6
Florida	18,777	271,994	6.9
Georgia	114,101	340,630	33.5
Illinois	10,638	1,193,012	0.9
Indiana	27,807	543,530	5.1
Kentucky	40,799	236,043	17.3
Louisiana	53,124	345,280	15.4
Maine	9	1,970	0.5
Maryland	16,705	179,113	9.3
Massachusetts	30,644	167,457	18.3
Michigan	3,143	839,266	0.4
Mississippi	39,599	250,990	15.8
Missouri	25,854	383,452	6.7
New Hampshire	38	8,648	0.4
New Jersey	41,573	277,103	15.0
New York	68,239	677,930	10.1
N. Carolina	108	137,609	0.1
Ohio	99,145	1,048,448	9.5
Pennsylvania	101,086	763,322	13.2
Rhode Island	4,697	18,927	24.8
S. Carolina	38,169	143,017	26.7
Tennessee	32,094	270,115	11.9
Virginia	10,203	148,330	6.9
W. Virginia	10,069	101,950	9.9
	886,948	8,999,379	9.86

TABLE 3.10

RELATIVE IMPACT ASSUMING FAILURE OF PIPELINES IN CATEGORY III

State	(1) Natural Gas Delivered mmcf/yr	(2) State Consumption of Natural Gas mmcf/yr	(3) Percentage of State Consumption mmcf/yr
Alabama	16	280,100	.01
Arkansas	1,067	253,792	.42
Connecticut	1,116	68,932	1.62
Delware	15	19,546	.08
Dist. of Col.	1,747	28,873	6.05
Georgia	30	340,630	.01
Illinois	2,042	1,193,012	.17
Indiana	21,299	543,530	3.92
Kentucky	31,729	236,043	13.44
Louisiana	3,918	345,280	1.13
Maryland	11,728	179,113	6.55
Massachusetts	2,116	167,457	1.26
Michigan	3,143	839,266	.37
Mississippi	6,115	250,990	2.44
New Jersey	2,919	277,103	1.05
New York	14,382	677,930	2.12
North Carolina	108	137,609	.08
Ohio	27,339	1,048,448	2.61
Pennsylvania	24,814	763,322	3.25
Rhode Island	576	18,927	3.04
Tennessee	20,082	270,115	7.43
Virginia	7,186	148,330	4.84
W. Virginia	6,304	101,950	6.18
TOTAL	189,791	8,190,298	2.32

Table 3.11

ESTIMATES OF ECONOMIC COSTS
ASSUMING FAILURE OF ALL MAJOR PIPELINES

	Estimated Shortages mcf per day	1977 Value Per Day of Shortage	Estimated Reduction in Gross State Output Per Day	Estimated Reductions in State Income Per Day	Estimated Reductions in Employment
Alabama	226,701	$ 209,426	$ 418,852	$ 502,622	5,272
Arkansas	11,819	10,918	21,836	26,203	276
Conneticut	43,436	40,126	80,252	96,302	1,007
Delaware	21,912	20,242	40,484	48,581	511
Dist. of Col.	13,041	12,047	24,094	28,913	304
Florida	191,540	176,945	353,890	424,668	4,457
Georgia	368,115	340,065	680,130	816,156	8,563
Illinois	29,145	26,924	53,848	64,618	676
Indiana	76,184	70,379	140,758	168,910	1,773
Kentucky	113,499	104,850	209,700	251,640	2,643
Louisiana	153,384	141,696	283,392	340,070	3,567
Maine	25	23	46	55	1
Maryland	66,375	61,317	122,634	147,161	1,546
Massachusetts	83,956	77,559	155,118	186,142	1,953
Michigan	8,611	7,955	15,910	19,092	200
Mississippi	114,622	105,888	211,776	254,131	2,663
Missouri	70,833	65,436	130,872	157,046	1,649
New Hampshire	104	96	192	230	2
New Jersey	354,290	327,293	654,586	785,503	8,245
New York	480,279	443,682	887,364	1,064,837	11,171
N. Carolina	196,493	181,520	363,040	435,648	4,575
Ohio	291,603	269,383	538,766	646,519	6,783
Pennsylvania	474,762	438,585	877,170	1,052,604	11,047
Rhode Island	12,868	11,887	23,774	28,529	297
S. Carolina	164,951	152,382	304,764	365,717	3,836
Tennessee	87,929	81,229	162,458	194,950	2,042
Virginia	84,342	77,915	155,830	186,996	1,960
W. Virginia	30,178	27,878	55,756	66,907	704
Total	3,770,997	$3,483,646	$6,967,292	$8,360,750	87,723

Sources:
1. Table 3.8 column 1 multiplied by a 1000 and divided by 365 days
2. Column 1 times the price of natural gas which was calculated as the 1976 will lead price of 58.0¢/mcf adjusted by 23.9% inflation factor, plus 20.52¢/mcf which is the average cost of transporting one mcf. (58.0) (1.239) + 20.52 = 92.38¢/mcf.
3. Column 2 times the average of State gross output multiplier of 2.0
4. Column 2 times the average State income multiplier of 2.4
5. Employment data were calculated as follows: Average output per employer in the utility sector, was divided into a million dollars to determine the number of utility employees necessary to produce $1 million of output. This number of employees per million dollar of output was multiplied by the average state utilities employment multplier to obtain total primary and secondary employment reduction per million dollar of decrease in output. This total employment reduction multiplied by the reduction in output of the gas utility sector equals total estimated reduction in employment.

   Example:
   a) Average dollar output per employee in the utilities sector = $33,764.
   b) $1 million ÷ $33,764 = 30
   c) 30 employees multiplied by the average utilities employment multiplier of 2.3 equals 69 employees
   d) Alabama's decrease in natural gas value of $209,426 per day equals a reduction of $76.4 million per year. The reduction of 69 employees per million dollars of annual output multiplied by 76.4 will yield an annual reduction in employment of 5272.

Table 3.12

RELATIVE IMPACT IF PIPELINES IN CATEGORIES II AND III SHOULD FAIL

	Estimated Shortages mcf per day	1977 Value Per Day of Shortage	Estimated Reduction in Gross State Output Per Day	Estimated Reduction in State Income Per Day	Estimated Reduction in Employment
Alabama	212,797	$ 196,582	$ 393,164	$ 471,797	4,954
Arkansas	11,819	10,918	21,836	26,203	276
Connecticut	43,436	40,126	80,252	96,302	1,007
Delaware	41	38	76	91	1
Dist. of Col.	6,775	6,259	12,518	15,022	159
Florida	51,444	47,524	95,048	114,058	1,194
Georgia	312,605	288,784	577,568	693,082	7,273
Illinois	29,145	26,924	53,848	64,618	676
Indiana	76,184	70,379	140,758	168,910	1,773
Kentucky	111,778	103,261	206,522	247,826	2,601
Louisiana	145,545	134,454	268,908	322,690	3,381
Maine	25	23	46	55	1
Maryland	45,767	42,280	84,560	101,472	1,063
Massachusetts	83,956	77,559	155,118	186,142	1,953
Michigan	8,611	7,955	15,910	19,092	200
Mississippi	108,490	100,223	200,446	240,535	2,525
Missouri	70,833	65,436	130,872	157,046	1,649
New Hampshire	104	96	192	230	3
New Jersey	113,899	105,220	210,440	252,528	2,650
New York	186,956	172,710	345,420	414,504	4,347
N. Carolina	296	273	546	655	7
Ohio	271,630	250,932	501,864	602,237	6,320
Pennsylvania	276,948	255,845	511,690	614,028	6,445
Rhode Island	12,868	11,887	23,774	28,529	297
S. Carolina	104,573	96,605	193,210	231,852	2,436
Tennessee	87,929	81,229	162,458	194,950	2,042
Virginia	27,953	25,823	51,646	61,975	649
W. Virginia	27,586	25,484	50,968	61,162	642
Total	2,429,993	$ 2,244,829	$ 4,489,658	$ 5,387,591	56,524

TABLE 3.13

ESTIMATES OF ECONOMIC COSTS
ASSUMING FAILURE OF PIPELINES IN CATEGORY III

	Estimated Shortages mcf per day	1977 Value Per Day of Shortage	Estimated Reduction in Gross State Output Per Day	Estimated Reductions in State Income Per Day	Estimated Reductions in Employment
Alabama	44	$ 41	$ 82	$ 98	1
Arkansas	2,923	2,700	5,400	6,480	68
Connecticut	3,058	2,825	5,650	6,780	69
Delaware	41	38	76	91	1
Dist. of Col.	4,786	4,421	8,842	10,610	110
Georgia	82	76	152	182	2
Illinois	5,595	5,169	10,338	12,406	131
Indiana	58,353	53,906	107,812	129,374	1,359
Kentucky	86,929	80,305	160,610	192,732	2,022
Louisiana	10,734	9,916	19,832	23,798	248
Maryland	32,132	29,684	59,368	71,242	745
Massachusetts	5,797	5,355	10,710	12,852	138
Michigan	8,611	7,955	15,910	19,092	200
Mississippi	16,753	15,476	30,952	37,142	386
New Jersey	7,997	7,388	14,776	17,731	186
New York	39,403	36,400	72,800	87,360	918
North Carolina	296	273	546	655	7
Ohio	74,901	69,194	138,388	166,066	1,746
Pennsylvania	67,984	62,804	125,608	150,730	1,580
Rhode Island	1,578	1,458	2,916	3,499	37
Tennessee	55,019	50,827	101,654	121,985	1,283
Virginia	19,688	18,188	36,376	43,651	455
W. Virginia	17,271	15,955	31,910	38,292	400
Total	519,975	$ 480,354	$ 960,708	$ 1,152,848	12,092

TABLE 3.14

PERCENTAGE OF ELECTRICITY
GENERATED BY NATURAL GAS, 1978

STATE	ELEC. GENERATED BY NATURAL GAS, MEGAWATT HOURS	TOTAL ELECTRIC POWER GENERATED, MEGAWATT HOURS	GAS GENERATED ELECTRICITY AS % OF TOTAL GENERATION
Alabama	671,979	69,268,379	0.97
Arkansas	486,000	17,669,319	2.75
Conneticut	0	25,820,043	0.00
Delaware	154,164	7,047,603	2.19
Dist. of Col.	0	1,780,295	0.00
Florida	14,304,153	92,023,566	15.54
Georgia	462,401	52,525,337	0.88
Illinois	1,908,319	106,830,507	1.79
Indiana	298,047	62,196,223	0.48
Kentucky	105,468	55,615,853	0.19
Louisiana	36,935,279	51,504,383	71.71
Maine	0	8,207,727	0.00
Maryland	45,578	35,132,853	0.13
Massachusetts	122,390	36,262,800	0.34
Michigan	1,974,623	74,534,338	2.65
Mississippi	3,508,886	19,009,395	18.45
Missouri	2,130,108	45,873,468	4.64
New Hampshire	0	4,811,560	0.00
New Jersey	73,070	30,363,579	0.24
New York	100,438	113,121,167	0.09
N. Carolina	168	63,332,705	0.00
Ohio	164,566	109,217,425	0.15
Pennsylvania	31,941	122,579,577	0.03
Rhode Island	0	559,249	0.00
S. Carolina	454,215	42,348,208	1.07
Tennessee	0	58,939,242	0.00
Virginia	82,692	41,211,628	0.20
W. Virginia	1,304	61,981,781	0.00
TOTAL	64,015,789	1,409,768,210	4.54

Source: Edison Electric Institute

because utilities and industry will have to decrease their damand for other goods and so forth. After these secondary and tertiary effects have worked themselves through the state economy the total reduction in state output per day will be $419 thousand. The estimated reduction in state income will be $503 thousand. Total employment will be reduced by 5272. If the pipelines remain ruptured for 180 days, the reduction in gross state output and personal income for Alabama would be $75 million and $90 million dollars respectively. Total employment would be reduced by 5272. Total reductions in gross state output per day for all of the states is $7 million, state income is reduced by $8 million and total employment will decrease by 88 thousand.

If the pipelines in Categories II and III should fail (Table 3.12) gross output would be reduced by $4 million, income by $5 million and employment reduced by 57 thousand. If only the pipelines in Category III should fail (Table 3.13), output would be reduced by $1 million dollars, and income would be reduced by $1 million. Twelve thousand individuals would become unemployed. As explained in footnotes to Table 3.11, input-output analyses were utilized in deriving these estimates. While this is the most appropriate method available for making these estimates in view of our constraints in time, they are subject to numerous analytical and data limitations. The results should be interpreted with caution.

Southeastern Louisiana and part of Southern Mississippi might be two regions most severely affected by a disruption of natural gas deliveries. Data pertaining solely to the substate regions could not be disaggregated from state data for this study. The petrochemical firms located along the Mississippi River between New Orleans and Baton Rouge, rely heavily upon natural gas as feedstock and boiler fuel. Based on a cursory analysis, it is possible that the disruption of one or two major natural gas pipelines could have a significant effect on this area.

An original concern that severe shortages of electricity could occur in several eastern states as a result of the potential disruption in natural gas deliveries appears to be unwarranted. After obtaining data on the use of natural gas in the affected states it appears that those states likely to suffer the most significant decreases in natural gas generate only a small proportion of their electricity by natural gas (Table 3.14). The only state in which the disruption of natural gas could have a very noticeable effect is Louisiana, particularly southeastern Louisiana. Sufficient alternative sources exist through the interconnect system to provide electricity for Louisiana alone, but providing electricity for all of the affected area might prove more difficult. The interconnect system should be able to replace the generation lost by the disruption of natural gas deliveries if the disruption occurs during the Spring. However, if the pipelines cannot be repaired, or substitute routing put into place, by July and August, which are the peak periods of electricity consumption in the southern and southeastern portions of the country, there could be a shortage of generating capacity.

Another concern related to electricity was that the high voltage electric lines which cross the Basin could be undermined by the action of flood waters. Gulf States Utilities, which services southern Louisiana and southeastern Texas, has two 138 KV lines and one 500 KV line crossing the Basin. The lines cross the Basin south of Krotz Springs, Louisiana where scouring within the channel is most likely to occur. The towers, however are located outside the channel but they would be subject to scouring in the event of a major flood or failure of the ORCS. (GSU engineers have stated that they do not believe the ORCS structure is in danger of failure.) The 500 KV line is looped through Arkansas and Mississippi so that a break in the line in the Basin would not result in an interruption of service. If another break would occur, however, there could be an interruption in service.

GSU officials have stated that it would cost between $500,000 and $1 million to replace one transmission line tower.

Substitute Routing and Pipeline Replacement Costs

The various economic and social costs that would result from a disruption depend not only upon the failure of the Old River Control Structure and/or the channeling of excess flood waters down the Basin, and the probability of one or more pipelines being severed, but also upon the availability of feasible rerouting possibilities and the time interval involved in making the necessary interconnections and replacing or repairing the severed pipeline.

Based on the information we have obtained, the pipeline companies have made no plans nor identified a set of specific options which would be available should one or more pipelines fail. If a particular pipeline fails during a flood period, repairs or replacement could take as long as six months to a year. During this time, the pipeline company could reroute the gas if it could find a pipeline with available excess capacity which crossed, or was located near, its pipeline on the west side of the Basin and which crossed, or was located near its pipeline on the east side of the Basin. Generally pipelines do have interconnections with some other pipelines but few, if any, pipelines have interconnections with the same pipelines on both sides of the Basin. Interconnections can be constructed but - especially if compressors are involved - the purchase of a compressor and the necessary construction could take 6 months to a year.

Prospective companies and some of their customers do hold reserves of natural gas but such reserves are at a seasonal low during the months of March and April, which is when an ORCS failure or an extensive flood are likely to occur.

IV

FLOOD DAMAGE EXPECTED

Introduction

Although one inevitable consequence of a failure of the Old River Control Structure would be the flooding of lands in and adjacent to the Basin, there is no general agreement among engineers about the extent of the area which would be flooded. The Louisiana Department of Public Works suggests that the failure of the ORCS would inundate most of southeastern Louisiana -- from the Bayou Teche ridge in the west to the Mississippi River in the east. This area would include the heavily populated areas near New Orleans which are situated along the west bank of the Mississippi River, including the towns of Gretna, Harvey, and Marrero.

Based on the extent of the inundation caused by the 1927 flood, the U.S. Corps of Engineers estimates that flooding might occur in the entire Atchafalaya Basin, as well as in areas extending westward to the Bayou Teche ridge and eastward to the Bayou Lafourche ridge. The Atchafalaya project guide levees could be expected to be overtopped, or to fail from other causes, south of I-10. During the 1973 and 1975 floods the levees around Ramah and Henderson were approaching failure and the levee system was found to be honeycombed with armadillo holes. Approximately 12 percent of Louisiana's total land area -- or approximately three million acres with a population of approximately 140 thousand -- is in the flood prone area. Principal towns which would be affected include Morgan City, Berwick, Patterson, Melville, Krotz Springs, and portions of Franklin, Houma, and Thibodaux.

Moderate to serious flood damage was sustained in Morgan City during the 1973 flood and much emergency work was required to protect the city from more serious losses. If the ORCS had failed in 1973, 70 percent of the discharge of the Mississippi River -- or 1.5 million cfs -- might have been diverted down the Atchafalaya Basin. In addition, approximately 50,000 cfs from the Red River would also have been discharged into the Atchafalaya. Given these flows, it can be stated with a fairly high degree of certainty, that the channel would enlarge and deepen, the existing levees would be washed away in parts, and the Morgan City/Berwick area would be very seriously flooded. Even after the first flood receded, Morgan City, as well as the entire Basin, would be under constant threat of serious flooding annually which would tend to make the Basin uninhabitable.

Our study includes four distinct sectors of economic activity within and outside the Basin area: estimates of private property losses within and outside of the Basin, public sector losses and expenditures, and some impacts on the fishing inductry.

Private Property Losses

Introduction

One of the consequences of extensive flooding in the Atchafalaya Basin would be the damage to private homes, commercial establishments and other private property. A number of problems were encountered in estimating the value of these property losses. One immediate problem confronting the research team was that property value estimates were available only on a parish-wide basis, whereas only portions of some parishes would be flooded. In order to adjust for this problem, the assessed value of real property in each parish was divided by the 1976 estimated population within the parish. This estimate of per capita value was then multiplied by the population in each voting ward in order to obtain the property loss in each ward. The property values* in those voting wards in the projected flood plain were aggregated to obtain the estimates of the value of property which has a probability of being flooded.

Losses Within the Basin.

Table 4.1 presents the estimates of the total real estate values of those parishes that would be affected by flooding and Table 4.2 shows the estimated growth in parish population between 1970 and 1976. Both of these tables were employed in calculating the losses within and outside the Basin. Since entire parishes do not lie within the Basin, the voting wards which are expected to be flooded are shown in Table 4.3. Even some of the voting wards do not lie entirely in the Basin, so an estimate was made of the percentage of population within each ward that would be affected. Because current 1976 ward population data do not exist it was assumed that the population in each ward changed proportionately to the change in parish population between 1970 and 1976 (Table 4.2).

TABLE 4.1

ESTIMATED 1976 PRIVATE PROPERTY VALUES (BY PARISH)

PARISH	TOTAL 1976 REAL ESTATE ASSESSMENT	ASSESS RATIO %	VALUE OF REAL ESTATE	EXEMPTED PROPERTY	ESTIMATED ACTUAL VALUE OF REAL ESTATE
ASSUMPTION	$ 10,289,790	10.12	$ 101,677,766	$ 17,374,818	$ 119,052,584
AVOYELLES	21,880,390	9.73	224,875,539	3,338,909	228,214,448
IBERIA	39,377,320	17.21	228,804,881	7,124,106	235,928,987
IBERVILLE	14,490,986	7.38	196,354,823	N/A	196,354,823
LAFOURCHE	34,115,964	9.96	342,529,759	9,511,413	352,041,172
POINTE COUPEE	14,606,741	9.11	160,337,442	40,790,876	201,128,318
ST. LANDRY	64,869,080	13.76	471,432,267	32,222,334	503,654,601
ST. MARTIN	7,129,140	7.98	89,337,594	20,703,092	110,040,686
ST. MARY	58,258,650	16.72	348,436,901	110,485,782	458,922,683
TERREBONNE	36,956,480	7.01	527,196,576	20,243,265	547,439,841
TOTAL	$301,974,541		$2,690,983,548	$261,794,595	$2,952,778,143

Source: Division of Business and Economic Research, Louisiana State University.

Table 4.4 utilizes data presented in Tables 4.1, 4.2 and 4.3 to produce an estimated value of lost private property for those areas of each parish located within the Basin.

The estimates of property losses within the Basin are based on the assumption that the portions of Avoyelles, Iberville, Point Coupee, St. Landry, St. Martin and St. Mary which are located within the Basin would most probably be subject to permanent inundation, thus making these areas virtually uninhabitable. As shown in Table 4.4, the Basin contains approximately 60,000 residents and private real wealth of nearly $380 million. Although, the buildings and other construction situated on the land would lose virtually all value,

* The assessed values were taken from the Eighteenth Biennial Report (1976-1977) published by the Louisiana Tax Commission. The assessed valuations were revised upward on the basis of the parish assessment ratios made by Dr. Terry Robertson, Division of Research at LSU. Estimates of the value of tax exempt property was obtained and added to the totals for each parish.

TABLE 4.2

PERCENT CHANGE IN PARISH

POPULATIONS FROM 1970 to 1976

PARISH	1970 CENSUS	1976 ESTIMATES	PERCENT CHANGE IN POPULATION 1970 - 1976
ASSUMPTION	19,654	20,499	+4.2
AVOYELLES	37,751	38,516	+2.0
IBERIA	57,397	62,747	+9.3
IBERVILLE	30,746	30,835	+0.3
LAFOURCHE	68,941	74,783	+8.5
POINTE COUPEE	22,002	22,100	+0.4
ST. LANDRY	80,346	81,970	+1.9
ST. MARTIN	32,453	34,994	+7.8
ST. MARY	60,752	61,590	+1.3
TERREBONNE	76,049	85,784	+12.8

Source: Division of Business Research, Louisiana Tech University and U.S. Census Bureau.

the land itself would most probably retain some value for grazing cattle and hunting and fishing and some buildings could be inhabited on a periodic basis. A conservative estimate of the property value loss would approximate 60%. Thus applying 60% to $380 million yields as an estimated loss of $228 million.

TABLE 4.4

1976 ESTIMATES OF PRIVATE
PROPERTY LOSSES WITHIN THE BASIN

PARISH	ESTIMATED PROPERTY VALUE	1976 POP. ESTIMATE	PER CAPITA PROPERTY VALUE	ESTIMATED POPULATION AFFECTED	ESTIMATED VALUE OF PROPERTY	ESTIMATED LOSS AT 60% OF VALUE
AVOYELLES	$ 228,214,448	38,156	$5,925	2,931	$ 17,366,175	$ 10,419,708
IBERVILLE	196,354,823	30,835	6,368	87	544,009	326,405
POINTE COUPEE	201,128,318	22,100	9,101	2,934	26,702,334	16,021,400
ST. LANDRY	503,054,601	81,970	6,137	4,026	24,707,562	14,824,537
ST. MARTIN	110,040,686	34,994	3,145	10,725	33,730,125	20,238,275
ST. MARY	458,922,683	61,590	7,451	37,005	275,724,255	165,434,553
TOTALS	$1,697,715,559	269,645		57,708	$ 378,774,460	$ 227,264,878

Source: Division of Research, Louisiana State University.

St. Mary Parish, which contains 65 percent of the affected population and 73 percent of the private sector wealth of the ten parishes, would be most seriously damaged. 37,000 people would be affected and at least $165 million in private property would be lost. If St. Mary Parish were inundated, the effectiveness of the oil industry both onshore and offshore could be impaired due to the large number of oil industry employees and equipment centered in the Morgan City area. The Avondale, Brown and Root, and J. Ray McDermott companies each have huge offshore platform construction facilities in the immediate area and many of the support facilities are located within the Basin. It is doubtful that these firms would be able to resume immediate operations in this area and these construction and

TABLE 4.3

ESTIMATED 1976 POPULATION
WITHIN THE BASIN, BY PARISH

PARISH	WARDS AFFECTED	1970 WARD POP.	ESTIMATED PERCENT OF POPULATION AFFECTED	1970 POP. AFFECTED	PERCENT CHANGE	1976 POPULATION AFFECTED
AVOYELLES	#7	2812	100%	2812		
	#8	2497	2.5	62		
TOTAL				2874	+2.0	2931
IBERVILLE	#8	3480	2.5	87		
TOTAL				87	+0.3	87
POINTE COUPEE	#1	1289	100	1289		
	#2	1633	100	1633		
TOTAL				2922	+0.4	2934
ST. LANDRY	#3	5483	0.3	16		
	#4	10,367	37.8	3919		
TOTAL				3951	+1.9	4026
ST. MARTIN	#1	9728	100	9728		
	#4	8856	2.5	221		
TOTAL				9949	+7.8	10,725
ST. MARY	#4	18,870	100	18,870		
	#5	7,736	100	7,736		
	#6	7,213	100	7,213		
	#8	2,711	100	2,711		
TOTAL				36,530	+1.3	37,005
TOTAL AFFECTED POPULATION IN BASIN						57,708

Source: Division of Business and Economic Research, Louisiana State University.

support services could be disrupted for a considerable period of time. We have made no estimates of the losses resulting from delays on disrupted operations in the oil industry.

St. Martin Parish would also sustain serious damage. While there are no large towns in this parish, there are rural communities interspersed throughout the Basin with an affected population of about 11,000 people. Additionally, the greatest amount of oil and natural gas production in the Basin is concentrated in St. Martin Parish. Many of these areas are heavily endowed with fossil fuels but are located in swampy areas which makes current access difficult and expensive. However, should the ORCS fail, access to these fields would be made more difficult, which might disrupt exploration, production, and maintenance of facilities in the parish.

Outside the Basin.

Approximately 81,000 people live in the affected area outside of the Basin and the private reality value is approximately $480 million. Although the affected areas outside the Basin would suffer an initial flooding, the waters would eventually recede and the population could move back into their homes and places of employment. During the 1973 flood many areas remained underwater for two months. A further problem is that, until the Corps of Engineers upgrade the present flood protection systems along the Atchafalaya River, the area outside the Basin would suffer periodic flooding but to a lesser extent than would be experienced within the Basin. Until the levee projects are completed, some areas outside of the Basin would not be suitable for permanent residence or, in many instances, for permanent employment.

Utilizing the same methodology employed in the previous section, Tables 4.5 and 4.6 show that the total value of real property in the area outside the Basin which could be affected by flooding is $480 million. During the 1973 flood, the areas between Bayous Teche and Lafourche sustained capital losses of approximately $24 million. Excluding the heavily populated areas of Thibodaux, Houma, New Iberia and Franklin, which were not seriously flooded in 1973, the capital value of real property in the area that was flooded is approximately $330 million. Thus, flood damages in 1973 amounted to 7.2 percent of the value of real property in the area. Applying this percentage to the entire potentially affected area outside the Basin yields a conservative estimate of future losses. This estimate is a conservative one because it does not include repetitive losses from periodic floods subsequent to the first one. Until the appropriate levees are constructed, there will be periodic floods outside the Basin. Table 4.7 presents an estimate of these losses. Total property losses outside the Basin would approximate $34 million.

Terrebonne Parish, which is the fastest growing parish in this area, would sustain the greatest losses. Approximately 28,000 people in eight voting wards (about one-third of the parish's population) could be forced to take refuge on higher ground should the ORCS fail. Private property losses would be approximately $813 million. The western portion of Houma would probably sustain serious flooding, but the eastern part of that city is built on the Bayou Lafourche alluvial ridge and is on higher ground. Therefore, the probability of flooding in this area is somewhat reduced. Other parishes which would probably sustain heavy initial flooding are Assumption, Iberville, and Lafourche.

As shown in Tables 4.8 and 4.9 the total flood losses inside and outside Basin are estimated to be $262 million affecting 139 thousand people. The most significantly impacted parish is St. Mary with total potential losses of $168 million.

TABLE 4.5

ESTIMATED AFFECTED
POPULATION BY PARISH OUTSIDE
THE BASIN
1976

PARISH	WARDS AFFECTED	1970 WARD POP.	ESTIMATED PERCENT POP. AFFECTED	1970 POP. AFFECTED	PERCENT CHANGE	1976 POPULATION AFFECTED
	#5	3758	1.000	3758		
	#6	3135	1.000	3135		
	#7	2232	1.000	2232		
	#8	3035	1.000	3035		
	#9	3236	1.000	3236		
ASSUMPTION				15,396	+4.2	16,043
	#1	1073	0.667	716		
	#2	3165	0.210	665		
	#4	3388	0.290	983		
IBERIA				2364	+9.3	2,584
	#1	5454	1.850	4636		
	#2	8280	1.200	1656		
	#7	2203	0.950	2093		
	#8	3480	1.000	3480		
	#9	2530	1.000	2530		
IBERVILLE				14,395	+0.3	14,438
	#5	1821	0.550	1002		
	#6	4323	1.000	4323		
	#7	3063	0.350	1072		
	#11	3033	0.750	2275		
LAFOURCHE				8672	+8.5	9,409
	#4	3530	0.400	1412		
	#10	1683	0.050	84		
POINTE COUPEE				1496	+0.4	1,502

TABLE 4.5 (Continued)

PARISH		WARDS AFFECTED	1970 WARD POP.	ESTIMATED PERCENT POP. AFFECTED	1970 POP. AFFECTED	PERCENT CHANGE	1976 POPULATION AFFECTED
		#3	5,483	0.025	137		
		#4	10,367	0.050	518		
ST. LANDRY	Total				653	+1.9	665
		#1	9,728	0.050	486		
		#3	4,772	0.250	1,193		
		#4	1,578	0.200	316		
		#5	3,945	0.500	1,973		
ST. MARTIN	Total				3,968	+7.8	4,278
		#2	957	1.000	957		
		#4	2,711	0.500	1,356		
		#7	1,555	1.000	1,555		
ST. MARY	Total				3,868	+1.3	3,984
		#2	1,344	0.900	1,210		
		#4	4,739	1.000	4,739		
		#5	2,053	1.000	2,053		
		#6	3,139	1.000	3.139		
		#7	6,573	1.000	6,573		
		#8	2,390	1.000	2,390		
		#9	1,934	1.000	1,934		
		#10	2,998	1.000	2,998		
TERREBONNE	1				25,036	+12.8	28,254

Source: Division of Research, Louisiana State University

TABLE 4.6

ESTIMATES OF AFFECTED PRIVATE PROPERTY VALUES OUTSIDE THE BASIN*

PARISH	ESTIMATED PROPERTY VALUE	1976 POP. ESTIMATE	PER CAPITA PROPERTY VALUE	ESTIMATED POP. AFFECTED	ESTIMATED VALUE OF AFFECTED REAL PROPERTY OUTSIDE BASIN
ASSUMPTION	$ 119,052,584	20,499	$ 5807	16,043	$ 93,161,701
IBERIA	235,928,987	62,747	3760	2,584	9,715,840
IBERVILLE	196,354,823	30,835	6368	14,438	91,941,184
LAFOURCHE	352,041,172	74,783	4708	9,409	44,297,572
POINTE COUPEE	201,128,318	22,100	9101	1,502	13,669,702
ST. LANDRY	503,654,601	81,970	6144	665	4,085,760
ST. MARTIN	110,040,686	34,994	3144	4,278	13,450,032
ST. MARY	458,922,683	61,590	7451	3,984	29,684,784
TERREBONNE	547,439,841	85,784	6381	28,254	180,317,028
TOTAL	$2,724,563,695			81,157	$ 480,323,603

TABLE 4.7

ESTIMATED PRIVATE PROPERTY LOSSES OUTSIDE THE BASIN*

PARISH	ESTIMATED PRIVATE PROPERTY (7% OF VALUE)
Assumption	$ 6,708,482
Iberia	698,852
Iberville	6,619,683
Lafourche	3,067,070
Pointe Coupee	948,200
St. Landry	249,193
St. Martin	968,574
St. Mary	2,137,377
Terrebonne	12,982,028
TOTAL	$ 34,379,459

* Source: Division of Research, Louisiana State University

TABLE 4.8

TOTAL POPULATION AFFECTED
INSIDE AND OUTSIDE THE BASIN

PARISH	POPULATION AFFECTED
ASSUMPTION	16,043
AVOYELLES	2,931
IBERIA	2,584
IBERVILLE	14,525
LAFOURCHE	9,409
POINTE COUPEE	4,436
ST. LANDRY	4,691
ST. MARTIN	15,003
ST. MARY	40,989
TERREBONNE	28,254
TOTAL	138,865

TABLE 4.9

TOTAL PRIVATE PROPERTY LOSSES
INSIDE AND OUTSIDE THE BASIN
1977 Prices

PARISH	PRIVATE PROPERTY LOSSES
ASSUMPTION	$ 6,708,482
AVOYELLES	10,419,705
IBERIA	698,852
IBERVILLE	6,946,083
LAFOURCHE	3,067,070
POINTE COUPEE	16,969,600
ST. LANDRY	15,073,730
ST. MARTIN	21,206,649
ST. MARY	167,571,930
TERREBONNE	12,982,028
TOTAL	$ 261,644,129

Public Sector Losses and Expenditures

During the flooding of 1973 losses and expenditures were incurred by local, state, and federal governments. According to the 1973 Post Flood Report of the Corps of Engineers, principal categories of expenditures for flood-related activities in the Atchafalaya and Mississippi-Atchafalaya Basins included strengthening of levees and floodwalls, raising of the Atchafalaya Basin guide levees, sand bagging, plugging cluverts, emergency pumping operations, and patrolling. Additionally, governmental units expended funds to repair damaged roads and highways, to provide flood relief to refugees, and to issue emergency food stamps in the affected areas.

The most extensive governmental losses and expenditures in 1973 occurred in the Atchafalaya Basin where the inundation was the most severe and extensive. Total damages sustained in this area were almost $37 million and government damages and expenditures were $11.5 million, or about 31 percent of the total. Losses in the Mississippi-Atchafalaya Basin to the east were only about $2 million, or 12 percent of the total.

If the ORCS fails, the Atchafalaya Basin will essentially be an area where little can be done to mitigate the effects of the flooding. In other words, much of the land will be perennially or permanently inundated. The estimated loss of public sector capital is conservatively estimated to be $60 million. Thus, the major additional explicit expenditures in this area would be funds used to evacuate the population as quickly as possible and to repair levees around Morgan City and other inhabited areas in the Basin. No estimates have been made of these costs. Other losses to the federal government would include the capital loss involved in the ORCS itself as well as the navigational locks in the area. A conservative estimate, in 1977 dollars, of the value of the entire complex would be approximately $200 million.

The areas in the greatest need of emergency governmental services would be outside the Basin itself. Here, the land would be submerged for a period of a few months, and as the waters receded, flood control systems would have to be rebuilt, roads and highways repaired, and displaced persons sheltered and fed. In short, these areas would require the same services that the Atchafalaya Basin needed after the 1973 flood. A very conservative estimate of $11 million would be spent by governmental units in addition to the more than $200 million replacement cost of the ORCS, if such reconstruction is possible. This amount excludes government expenditures on levees, additional dredging, or federal disaster relief and makes an allowance for inflation.

TABLE 4.10

ESTIMATED GOVERNMENTAL DAMAGES
AND EXPENDITURES

ORCS COMPLEX	$ 200,000,000
GOVERNMENTAL LOSSES OUTSIDE THE BASIN	11,000,000
CONSERVATIVE ESTIMATE OF CAPITAL LOSSES IN THE BASIN	60,000,000
TOTAL	$ 271,000,000

Fishing Industry Losses

The oil and gas industries and commercial fishing are the two major sources of income to residents of the lower Atchafalaya Basin. The effect of the failure of the ORCS on the oil and gas industries was discussed very briefly above. The purpose of this section is to discuss the impact of the failure on the fishing industry.

Apart from flooding the homes of some fisherman, disrupting their vehicular transportation, and damaging structures in the Basin, the ORCS failure will have relatively little impact on fishing except for oyster dredging and shrimp trawling, which are the most economically important portions of the fishing industry in this area. The total value of fish and shellfish landings in Louisiana in 1977 was $139 million of which 63% were shrimp landings and 7.5% were oyster landings. Approximately $69 million in landing value was reported for the central Louisiana area which includes the coastal and bay areas extending from Bayou Lafourche to Bayou Teche. Forty-six million dollars of shrimp landings and $4 million of oysters landings were reported for the central district. The total value of shrimp and oyster landings in the central district constitute 36% of total state landings. These figures are based on the National Marine and Fishery Service publication "Current Fisheries Statistics #7520: Louisiana Landings, Annual Summary, 1977.

The oyster mortality rate is affected by both water salinity and temperature; as salinity and water temperature decrease the oyster mortality rate increases. If the ORCS should fail, the greatly increased flow of water in the Atchafalaya Basin would significantly decrease the salinity and temperature of the waters and, thus, destroy the oyster beds in portions of the Atchafalaya Basin and areas adjacent to it.

During the flood of 1973, the Morganza and Atchafalaya flood control structures were opened during the third week of April. During the months of May and June oyster harvesting in the central district surged far above the levels of the same months in previous years. This increase was due to the efforts of the oystermen to salvage as many oysters as possible in anticipation of high oyster mortality rates in the area. By the end of June, however, the stations around the Atchafalaya Bay were reporting close to one hundred percent mortality and during September only a few thousand pounds of oysters were harvested.

Because the flood waters receded and the salinity level returned to its previous level, the 1974 oyster populations and harvests were higher than in previous years. The reason for the apparent growth in population and harvest is that the previous year's flooding deposited an increased amount of nutrients in the affected areas and eliminated many of the oyster's natural enemies. In the event of a failure of the ORCS, however, the salinity level, while fluctuating during periods of high and low water, would be permanently higher in that immediate vicinity and many of the current oyster beds around the Atchafalaya Bay would be permanently destroyed. However, the estuarine area would expand and the oyster beds would, in a couple of years, be thriving in new areas. The additional sediment and nutrients which would be discharged in the lower Basin would have a very beneficial impact on oyster yields in future years.

The major difficulty with the relocation of the oyster beds is that those individuals who had leases on the beds which were destroyed would suffer economic losses. Some oystermen would gain but those who had their leased oyster beds destroyed would seek compensation for some or all of these losses.

The marshy wetlands which constitute Louisiana's coast line are one of the world's largest shrimp nurseries. The major reasons for the existence of these nurseries are the estuarine areas of southern Louisiana and the Mississippi and Atchafalaya Rivers which deliver nutrients, sediments, and fresh water without which the shrimp could not survive.

Shrimp require an average water temperature of 68 degrees or warmer and a salinity level of the range of 10 - 20 parts per thousand during the months of their maturation period (March, April and May) in the estuaries before they begin their movement to the offshore waters. During periods of floods, such as that which occurred in 1973, the water discharge rate of the rivers increase, and the water temperature decreases as does the salinity of the waters in the estuaries. The result is a high mortality rate among the juvenile shrimp. If the ORCS structure should fail in the months of March through May, the young shrimp located in the estuaries fed by the Atchafalaya River would have a very high mortality rate and the harvest of shrimp during that spring would most likely be decreased as compared with normal years. If the structure should fail, and the waters of the Mississippi are diverted down the Atchafalaya, the fresh water discharge into the estuaries would be permanently increased and at least the northern portions of these estuaries would become permanently unsuitable for shrimp nursuries.

Although, there would be a short run (1-2 years) decrease in the number of shrimp harvested and some shrimp nursery grounds would be permanently destroyed, the long run consequences of this diversion are likely to be positive because the additional nutrients and sediments deposited by the Atchafalaya would help abet the settling of the marshland area and would actually increase the area in which nurseries could be established. One of the problems associated with the Mississippi levee system is that the sediments are channeled down the Mississippi where most of them are deposited in very deep waters located adjacent to the Mississippi outlet. Because the Atchafalaya River is not leveed and the waters distributed over a wide area, the sediments would be deposited in shallow waters where shrimp nurseries and oyster beds could be established.

A positive benefit of the ORCS failure might be a significant increase in the production of both shrimp and oysters, but it must be recognized that this increase would occur in different areas and certain shrimpers and oystermen would be damaged.