

DEGRADATION AND AGGRADATION OF THE MISSOURI RIVER

Proceedings of a Workshop held in Omaha,
Nebraska, 23-25 January, 1978

Edited by
W. W. Sayre and J. F. Kennedy

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The Missouri River Degradation/Aggradation Workshop was made possible through the combined efforts of many individuals and agencies. In planning the Workshop, the Iowa Institute of Hydraulic Research was assisted in all phases by the Iowa Conservation Commission, and in particular by Messrs. Gerald F. Schnepf and Arnold Sohn. The Missouri River Basin Commission, through Alan S. Hersch provided many helpful contacts for resource persons and assisted in the mailings. The Corps of Engineers through the Omaha District and the Missouri River Division provided tremendous help by hosting the Workshop, presenting the key introductory session on the background and history of degradation and aggradation in the Missouri River, and providing Workshop participants with data and other background information. The contributions of Messrs. Alfred S. Harrison and Warren J. Mellema of the Missouri River Division, and of Howard Christian of the Omaha District were particularly valuable. They and other Corps personnel participated in the Workshop only as resource people, and were not a party to this report or its conclusions. Mr. Sulo W. Wiitala of the Iowa District, Water Resources Division, U.S. Geological Survey, also presented background data in the introductory session. Resource people who gave presentations describing various problems caused by degradation and aggradation in the Missouri River included John W. Robinson of the Missouri Department of Conservation, Gerald F. Schnepf of the Iowa Conservation Commission, Mark Looschen of the Iowa Department of Transportation, John Rexwinkel of the Iowa Public Service Company, Alfred S. Harrison of the Corps of Engineers, Robert L. Dunkeson of the Missouri Department of Natural Resources, Merwin D. Dougal of the Iowa Natural Resources Council, Walter Robohn of the U.S. Environmental Protection Agency, and Alan S. Hersch of the Missouri River Basin Commission. The chairmen of the four working subgroups, Dr. George R. Hallberg of the Iowa Geological Survey, Dr. Vito A. Vanoni of the California Institute of Technology, Dr. Carl F. Nordin of the U.S. Geological Survey, and Dr. Daryl B. Simons of Colorado State University, kept the participants to their tasks and made major contributions to the Workshop report. Ms. Marlene Janssen of the Iowa Institute of Hydraulic Research assisted ably in coordinating all aspects of the project from planning the Workshop through preparation of the report.

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EXECUTIVE SUMMARY

Degradation and aggradation of the Missouri River, which have given rise to a variety of problems of concern to riparian property owners, industrial and other water users, and fish and wildlife interests, were the subject of a three-day workshop held in Omaha, Nebraska, on 23-25 January 1978. Workshop participants included some of the nation's leading river-engineering specialists; representatives of state and federal agencies involved in water-resource management and fish and wildlife conservation in the Missouri River Basin; and representatives of some nongovernmental organizations. The objectives of the workshop were to examine, and delineate the investigations required to elucidate the following four facets of the degradation/aggradation problem: (1) background and history; (2) contributing factors; (3) likely future rate and extent; and (4) possible corrective measures.

Many factors, both man-made and natural, have contributed to the imbalances between the supply of sediment to and the sediment transport capacity of the Missouri River, which in turn have led to the degradation/aggradation being experienced along different River reaches. The Missouri River and its tributaries clearly constitute a complex, interconnected dynamic system which should be treated as a whole, and managed for the joint optimization of all the various river management objectives, with official recognition of the newer objectives of enhancement of fish and wildlife habitat, water-quality improvement, and provision of recreational opportunities, as well as of the traditional ones related to flood control, navigation, hydroelectric power generation, bank stability, and land reclamation. To achieve this end, a broader approach to the planning and decision-making process is needed for both technical and administrative matters relating to the management of the Missouri River system. This approach should include input from and active participation by all entities having responsibilities that relate to the River.

The recommended investigations are grouped into three phases. Phase I would consist primarily of assembling the relevant background information and data in a readily accessible and usable form, evaluating the applicability of the available analytical tools for prediction of river behavior,

and preparing detailed scopes of work for Phases II and III. Phase II would feature a combination of interpretive, analytical, and experimental studies, utilizing existing geomorphic data, mathematical and physical modeling of river processes, and the acquisition and analysis of new data relating to degradation and aggradation in the river system. Institutional history and models for a more comprehensive river-management program would also be examined and evaluated. Phase III would consist mainly of pilot studies along selected reaches of the Missouri River and its tributaries, to test and verify corrective measures designed in Phase II, and the formulation and development of comprehensive prognoses for future river behavior under alternative sets of inputs, corrective measures, and constraints.

It was concluded by the Workshop participants that the future success of Missouri River management would be enhanced by organization and operation of a coordinating effort, perhaps modeled after the GREAT programs on the Mississippi River, which would provide for active participation by all affected concerns in the decision-making process related to study, modification, and management of the River.

DEGRADATION AND AGGRADATION OF THE MISSOURI RIVER
Proceedings of a Workshop Held in Omaha, Nebraska
23-25 January 1978

I. INTRODUCTION

Since about 1960 there has been progressive degradation (lowering in elevation) of the channel bed and water surface along the reach of the Missouri River extending from Gavins Point Dam, near Yankton, South Dakota, to the mouth of the Platte River, about 25 miles south of Omaha, Nebraska. By the mid '70's the degradation ranged from about 8 ft just south of Gavins Point Dam, to about 6 ft at Sioux City, Iowa, to essentially zero at Omaha and southward to the Platte River. Simultaneously, along the river reach from the Platte-Missouri confluence to the mouth of the Missouri River at St. Louis, there have been lesser amounts of aggradation (raising in elevation) along some stretches and degradation in others. The degradation, and to a lesser extent the aggradation, have given rise to a variety of problems, including perils to the stability of various constructed works that are founded on the river bed; difficulties in diverting water from the river into fixed intake structures during lower stages; deterioration and destruction of fish and wildlife habitats and recreational resources; headcutting in tributary streams; and changes in property boundaries and ownership. Consequently, there has been steadily increasing concern among affected transportation interests, riparian property owners, water-using industries and municipalities along the river and its tributaries, fish- and wildlife-management organizations, and various state and federal agencies about the likely future rate and extent of the degradation and aggradation, and about what steps might be taken to stabilize the river profile.

The principal flow regulation and channel stabilization structures on the Missouri River, which were installed by the Army Corps of Engineers between 1930 and 1965, had as their main objectives flood control, bank stabilization, land reclamation, hydroelectric power generation, and development and maintenance of a navigation-channel. Recent years have witnessed a growth in demand for the adoption of additional river-management objectives, including enhancement or replacement of fish and wildlife habitat, water-quality

improvement, further development or restoration of recreational opportunities, and general management and enhancement of the river-affected aspects of the environment. Unfortunately, some of the newer objectives are adversely impacted by the flow regulation and channel stabilization measures which were installed to attain the original objectives. It is precisely this conflict which has led many state and federal agencies to express heightened concern for, and interest in, influencing plans for the future management of the Missouri River, including measures which might be adopted to control or accomodate the degradation/aggradation phenomenon. These concerns led the State of Iowa to make a special appropriation to the Iowa Conservation Commission (ICC) to enable it to seek answers and resolutions to questions and problems being raised by the degradation/aggradation. With the assistance of the Iowa Institute of Hydraulic Research (IIHR) of The University of Iowa and the Omaha District of the U.S. Army Corps of Engineers, the ICC staged a three-day workshop, on degradation and aggradation of the Missouri River, on 23-25 January 1978 at the offices of the Corps of Engineers Omaha District. Corps personnel participated in the Workshop only as resource people, and are not a party to this report or its conclusions. The workshop participants included some of the nation's leading river-engineering specialists; representatives of state and federal agencies involved in water-resource management and fish and wildlife conservation in the Missouri River Basin; and representatives of some nongovernmental organizations. The objectives of the workshop were to examine, and delineate the studies required to elucidate, the following four facets of the degradation/aggradation matter:

1. Background and history.
2. Contributing factors.
3. Likely future rate and extent.
4. Possible corrective measures.

To this end, the participants were organized into four subgroups, each of which prepared a report; the edited subgroup reports constitute Chapters II through V of these proceedings. Chapter VI presents a topical plan of study, developed from the subgroup reports, designed to establish definitively causes of the degradation/aggradation and kindred phenomena; and to lead to development of prognosis of its likely future course and a plan for possible corrective measures. It is believed that the investigations outlined

in Chapter VI, if financed and carried out, would resolve many of the concerns about the River, not only for Iowa-based groups but also for those in other Missouri River Basin states downstream from Gavins Point Dam.

Although the principal concern of Iowa is the river degradation along much of its western boundary, it is recognized that any solutions which might be adopted there likely would have impacts on neighboring states. The unimpounded reach of the River from Gavins Point Dam to St. Louis and its tributaries must be dealt with as an interconnected system, and not on a segmented basis. Indeed, it is believed that segmentation of effort, both functionally and geographically, has compounded the problems arising from river-management activities. The laws of river dynamics recognize neither geographical boundaries nor the division of responsibilities among agencies.

Throughout the course of the workshop one theme was so recurrent and dominant that it appears in order to record it here: Iowa, as well as the other affected states, desire a much more active role in the decision-making and planning processes related to management of the Missouri River. The broadened objectives of river management referred to above require inputs from groups and organizations which heretofore have not participated in planning for the management and future development of the River. It appears self-evident that the probability of achieving optimal joint use of this valuable resource would be significantly enhanced by a collective planning and decision-making process, for both technical and administrative aspects, that would include active participation by representatives from all entities having responsibilities that relate to the River. A successful effort would require extensive communication among the various groups and an attitude of receptiveness on the part of the Corps of Engineers, which likely will continue to carry primary responsibility for managing the River. The cooperative spirit demonstrated by the Corps in the course of this workshop, and the apparent success of the GREAT Programs on the Mississippi River (which might serve as models for future management of the Missouri River), suggest that these goals are attainable. In summary, Iowa, and presumably also the other affected states, no longer are satisfied with the traditional review role offered them by federal agencies. They actively are seeking a participatory role.

II. BACKGROUND AND HISTORY OF DEGRADATION AND AGGRADATION IN THE MISSOURI RIVER

Report of Subgroup 1

A. Introduction. The Missouri River as it now exists is the result of extensive, mandated regulation and stabilization works which were designed and constructed to meet the historic objectives of river management: bank stabilization, flood control, land reclamation, power generation, and formation and maintenance of a navigation-channel. Installation of these works was ordered by the Congress of the United States, starting in the 1930's. By any reasonable standards, the Corps has been very successful in achieving these historical goals. Many significant benefits have accrued to the installation and operation of the controls, and it is fair to say that they have resulted in major improvements over natural conditions for some uses. However, the river-control works also have caused other problems, which now must be addressed. The recent emphasis placed on recreation and environmental conservation as high priority objectives of river management needs to be reconciled with the traditional objectives, to develop a more comprehensive approach to river planning, management, and utilization.

The objectives of this review of the background history of degradation and aggradation on the Missouri River are:

1. To determine the natural changes in the Missouri River channel, flood plain, alluvial valley, and tributaries; and man's effects on these changes.
2. To use historical records to determine how the works of man have affected the behavior of the River, and as a guide to the prediction of future trends.

B. A Brief Summary of Missouri River History and Data. This brief review is not intended to be a complete detailed summary of the physical history of the Missouri River, or of the data available on it. It is presented only to outline the principal events, knowledge of which is essential to understanding of the present River situation and to prediction of likely future trends. The data are presented with little or no interpre-

tation, and are used only to illustrate trends and magnitudes of behavioral changes that have occurred in the River. Indeed, it was judged impractical to attempt any substantial amount of data analysis within the scope of this Workshop. However, it should be emphasized that a comprehensive data analysis and interpretation program is considered to be essential to a complete understanding of the present and likely future River behavior.

The following capsule summary is divided into time spans which characterize sequential stages in the development of the River.

1804-1890. Although some local, structural flow-control works were installed in the 1880's, the River was generally in its natural condition. Physical evidence and historical documents indicate (Dahl 1961) that:

1. The entire River adjacent to Iowa was undergoing natural degradation, resulting in entrenchment below what is commonly called the "high bank". In some areas the results of up to 15 ft of degradation still can be observed in the field.
2. There is considerable evidence indicating that the River channel evolved from a more clearly defined meandering pattern to one with many bifurcated and braided reaches. It is not completely clear what impact the flood-of-record in 1881 had on the geomorphic history. Here it should be noted that major floods generally tend to straighten rivers and shorten the channel length for some period following the flood. The time required for a river to recover from a major flood and reestablish a channel configuration characteristic of normal flows depends on many parameters.
3. During this time a significant reduction in channel length occurred due to natural causes along the reach from Ponca to the mouth of the Platte River. This reach seemed to exhibit greater sinuosity and to experience more cutoffs than lower reaches.
4. The characteristic width of the meander belt along the Iowa boundary was approximately 4 miles.

1890-1930. Additional, small, local, structural controls were installed, but the river remained in essentially its natural condition.

River channel continued to bifurcate and braid along the Iowa-boundary reach. Detailed Corps mapping and monitoring began in 1923.

1930-1941. A period of major channel realignment. Closure of Fort Peck Dam initiated period of River flow control. There was a general rise in stage relative to discharge, followed by the beginning of a decline in stage relative to discharge in the reach upstream from Omaha. Stage-discharge changes might have occurred in response to changes in channel configuration, low flows accompanying the drought of the 1930's, or other causes. During the period 1890-1941 the river length from its mouth to Yankton decreased by about 56.9 miles; of this, 29.5 miles, or 52 percent, occurred between Omaha and Yankton, a reach which constituted only 25 percent of the total 1890 length from the mouth to Yankton. Several braided reaches were channelized into a single sinuous channel, finally resulting in the 1941 design channel.

1941-1953. During WW II practically no construction or maintenance work was carried out on the River. The closure of Fort Randall Dam in 1953 had a major effect on the sediment discharge of the River. The decline in stage relative to discharge upstream from Omaha, referred to above, continued for a time and then ceased toward the end of this period. The 1952 flood (highest of modern record; estimated 1881 flood is considerably higher) severely disturbed control works in the Omaha-Sioux City reach. Many training works were breached, and new channels were established along several reaches. Following the 1952 flood, a radical drop in the stage-discharge relation was observed at Sioux City, and a somewhat smaller drop occurred at Omaha.

1953-1967. During the 13-year period beginning in 1954, many major control works were constructed along the River; literally thousands of structures were installed or modified. Five major dams were completed and closed during this period: Fort Randall in 1953, Garrison in 1955, Gavins Point in 1955; Oahe in 1962, and Big Bend in 1964. During this time the channel length between Sioux City and Omaha was artificially reduced by 11.7 miles. The channel

shortenings between Omaha and Sioux City, and between Omaha and Yankton accounted for 42 percent and 53 percent, respectively, of the total artificial decrease in channel length between Yankton and the mouth. These changes established a rather uniform channel width, which was reduced by 200 ft to 400 ft below that of the previous (1941) channel. Mean discharges for the 1955-65 period averaged about 20,000 cfs at Yankton; 22,000 at Sioux City; and 23,000 at Omaha. In 1965-67 these were increased by about 20 to 25 percent. Following closure of the dams, the yearly maximum discharges during the period 1954-67 averaged 37,000 cfs at Yankton; 46,000 at Sioux City; and 68,000 cfs at Omaha.

Tributaries produced significant flow events at Sioux City and Omaha in 1960 and 1962, respectively. During the 1953-67 period the stage-discharge relations for the river indicate: (1) a general decline of the Gavins Point Dam tail water; (2) at Sioux City, a low in 1953 followed by a general rise to 1958, then a period of stability until 1963 after which the stage again began to decline; (3) a slight rise at Omaha, following a low in 1953; (4) a "rotation" of the rating curve at Nebraska City, with a decline in stage of 20,000 cfs, little change at 40,000 cfs, and a general rise at 100,000 cfs; (5) a sharp rise at St. Joseph in 1952, followed by a stable relationship except at high discharges (greater than 100,000 cfs), for which there was a rise; (6) a general decline at Kansas City, perhaps as a result of localized effects, for discharges below about 100,000 cfs; (7) stable stage-discharge relations at downstream stations for low to moderate discharges, but a rise (possibly due to local obstructions produced by levees constructed on the flood plain) during overbank flows.

The water-surface slope increased in the Sioux City area from 1952 to 1962, and then stabilized. Between Ponca and Omaha the slope increased from 1952 to 1957, after which it stabilized. At Sioux City the river velocity (for a given stage) increased by 62 to 70 percent between 1954 and 1969, and then leveled off. During the 1953-67 period the average river-surface width around Sioux City

was reduced by some 30 percent; along this reach between 1952 and 1961 there was a general rise in the bed elevation, and reduction in channel cross-sectional area. After 1961 the cross-sectional area again increased, and the cross-sectional shape evolved from the triangular shape that typifies alluvial channel bends toward a more rectangular shape.

Following the closure of Fort Randall and Gavins Point Dams in 1953 and 1955, respectively, the sediment discharge of the river was drastically reduced. At Yankton the average suspended sediment discharge decreased from an average 138,000,000 tons per year (pre-1953) to 1,900,000 tons per year after 1955. During a period of several years following 1955, the suspended load discharges at Sioux City and Omaha averaged about 10,000,000 tons per year and 29,000,000 tons per year, respectively. A comparison of pre- and post-1952 data for Omaha shows that the fractions of sand, silt, and clay in the suspended load changed from 20 percent sand, 80 percent silt and clay before 1952, to 52 percent sand, 48 percent silt and clay after 1952. The D_{50} bed-material particle size at Yankton increased until about 1957, and then decreased slowly from 1957 to 1967. At Sioux City the D_{50} bed-material size averaged 0.27 mm from 1955 to 1961, and then increased to 0.30 mm from 1961 to 1967. At Omaha, decreases in bed-material D_{50} were observed, to a 1955-67 average value of about 0.22 mm.

1967-Present. During this period engineering activities on the River consisted primarily of maintenance of previously installed control structures. The mean discharge for the 1968-74 period was 31,700 cfs at Yankton, 33,600 cfs at Sioux City, and 35,500 cfs at Omaha; an increase of 52 to 60 percent over that for 1955-65. The maximum discharges for the 1969-74 period increased 30 to 50 percent above the 1963-68 values at Yankton and Sioux City, but increased only about 5 percent at Omaha. During the period that the discharges increased, stage-discharge rating curves began to decline sharply at Gavins Point and Sioux City. At other sites the trends in the stage-discharge curves (outlined above for the 1953-67 period) continued.

trends in channel cross-sectional shape and velocity near Sioux City also continued as described above. The suspended sediment discharge underwent no significant changes at Yankton or Omaha, but increased by some 50 percent, over the 1955-66 values, at Sioux City. The D_{50} bed-material particle size at Sioux City increased 17 percent over the 1955-62 values, and about 6 percent over the 1962-66 values, leveling off at about 0.32 mm. At Omaha there was a slight (7 percent) increase in D_{50} over the 1955-66 values, to an average of 0.26 mm.

The river-bed and water-surface degradation which began in the early 1960's in the Sioux City reach continued well into the 1970's. The data are inconclusive as to whether the degradation presently (1978) is continuing, or whether the channel has stabilized.

Size distributions of suspended load are summarized in the following table.

MISSOURI RIVER SUSPENDED SEDIMENT DATA

<u>Location</u>	<u>Period</u>	<u>Size Gradation</u>		
		<u>Sand%</u>	<u>Silt%</u>	<u>Clay%</u>
Yankton	1953-69	55%	19%	26%
Sioux City	1955-69	68%	22%	9.7%
Omaha	1939-52	20%	40%	40%
	1953-69	52%	35%	13%
Nebraska City	1957-70	51%	35%	14%

Figures II-1 through II-11, supplied by the Missouri River Division of the Corps, summarize changes in various properties of the River that have occurred in recent years.

C. Salient Questions Related to Physical History of the River.

The foregoing historical summary and questions raised by various participants in the course of the Workshop highlighted several questions which bear directly on the river-morphology history, and which best can be resolved through

studies based on available data. Before summarizing study needs and suggested approaches, in section D, below, these questions will be summarized.

1. *Behavior related to tributary streams.* The behavior of the lower reaches of streams that are tributary to a larger river are heavily influenced by the stage-discharge relation of the receiving stream. Degradation of the principal tributaries to the Missouri River along the Iowa-border reach, and presumably in others as well, is a serious problem. This degradation appears to be related in some measure to channelization of the tributaries. However, the relative contributions of channelization and of the Missouri River degradation are unclear presently, and need to be evaluated before rational plans can be developed for tributary stabilization.
2. *Peculiarities of the Ponca to Plattsmouth reach.* It is along this stretch of the River that the present degradation and related problems are most acute. Historically it has exhibited several anomalies including:
 - a. *A much broader alluvial plain.* This may relate to the prevalence of Cretaceous sandstone and shales instead of the Paleozoic bedrock that is found farther downstream.
 - b. *Consistent and continual larger than normal reductions in channel length.* Prior to 1890, and especially during the period 1804-75, the channel was more sinuous and unstable along this reach than along others, and extensive natural shortening (estimated to be 20 to 30 miles) occurred. Between 1890 and 1960 the average rate of shortening per unit length of this reach was about three times that for the reach extending from Plattsmouth to St. Louis.
 - c. *Effluence.* U.S.G.S. data indicate a significant water loss, at least at low flows, along this reach. The only apparent explanation is seepage of water from the river to the ground-water system. The Missouri River is known to lose water to aquifers underlying its valley.
 - d. *Control function.* The abrupt change in the local character of the terrain together with the water and sediment

inflows from the Platte River appear to form something of a "control point" for the River, which forestalls the downstream migration of channel degradation.

The individual and combined effects of these several anomalies confront geomorphologists and river engineers with several nettling questions which bear importantly on the future planning of the river.

D. Resource Losses. A historic summary would be incomplete if it did not cite the River resource losses that have occurred. The traditional objectives for the Missouri River led to installation of major engineering structures and adoption of operational programs which themselves have had numerous detrimental effects. Among these are:

1. Loss of recreation opportunities along the river, due to channelization and the attendant increases in velocity and loss of backwater areas.
2. Loss of diversity of fish and wildlife habitat, and attendant reduction in the quantity and quality of wildlife resources.
3. Loss of public lands.

It is feared that losses of these types will continue and expand to the tributaries if a comprehensive and participatory management strategy for the Missouri River is not adopted.

E. Study Needs and Possible Approaches. One of the principal assignments given each Subgroup was to develop a list of studies needed to elucidate the recent and historical river behavior and to serve as a basis for future improved river management in the context of the broadened objectives. It is realized that some of the recommended studies listed below may be underway already, under the aegis of the Corps or another agency, and/or may overlap with those proposed by other Subgroups. Indeed, some of the studies may have been conducted already, either in whole or part. The study subjects presented below are integrated in Chapter VI with those proposed by other Subgroups.

It is to be understood that a critical review and summarization of the relevant background literature and data would be an integral part of each of the studies proposed below.

The studies recommended by Subgroup 1 are as follows:

1. Produce a geomorphic map of the Missouri River alluvial plain from extant maps and aerial photos. (It was pointed out by the Corps when these proceedings were in the review stage that the Corps has done this for the river reach below Gavins Point Dam. Needless to say, before undertaking any new mapping effort the availability, coverage, detail, and reliability of existing maps should be determined.)
2. Examine historical maps of the Missouri River channel, for the periods both before and after the installation of man-made works, to establish the magnitudes, rates, and causal factors of historic channel variations.
 - a. The geomorphic map cited in Item 1, above, will show pre-historic variations in channel position. These data should be analyzed morphometrically.
 - b. From the maps the magnitudes and rates of river responses to natural and man-made regime modifications should be established.
 - c. Seek to establish historical variations in the configurations of ox-bow lakes, and relate the observed changes to natural and/or man-caused phenomena, especially those occurring in the River.
3. In examining the data obtained from the geomorphical maps, the impacts of natural and man-produced changes of the river which affected or could have affected land ownership and fish and wildlife habitat should be addressed.
4. Undertake a thoroughgoing analysis of hydrologic (including sediment) data, correlated with the river morphology established from the studies listed in items 1 and 2, above. The hydrologic investigation should include climatologic data and reviews of past climatic changes over the period included in the study. It is recognized that the Corps already has done extensive analysis of this type. However, they have not been provided with the necessary resources to undertake an extensive

analysis of the type recommended here. Nevertheless, the several fragmentary studies the Corps has conducted, which invariably are of very high quality, would contribute significantly to this investigation.

5. Prepare a complete, concise history of constructed works on the Missouri River, and correlate the effects of the constructed works with the results of the studies given in items 1, 2, and 3, above, to provide further insight to the causative factors responsible for the rates and magnitudes of observed channel changes.
6. Investigate the benefits which would accrue to retention of the Yankton to Ponca State Park reach of the River as a control area to provide benchmark river data for future comparison with corresponding data from other reaches. In this regard, it is recommended that a moratorium be imposed on further construction along this reach until the results of the investigation proposed here, and new management directions, are developed. The investigation of the desirability of retaining this reach of the river as a control area could also lead to a provisional plan of study which would be undertaken along the reach; the plan of study should outline the biological, geomorphological, and hydrological data that should be collected along the control reach, the analysis of the data, and the use which could be made of them.
7. Detailed studies of pilot projects should be undertaken to examine the effects of various mitigation efforts. The following studies are recommended:
 - a. An increase in the channel width of a reach of the river.
 - b. Reopening of some selected secondary channels, to decrease velocities and possibly inhibit degradation, and concurrently improve biological habitat.
 - c. Continuation of the Corps study of the effects of dike notching on habitat.

The results of pilot studies should, of course, be interpreted in the light of the historical data and trends which would be forthcoming from the preceding study items.

8. An institutional history of the agencies affecting and affected by the Missouri River should be prepared. It is recognized that this study would not contribute to an understanding of the physical aspects of river change, but is judged to be necessary before comprehensive, multi-objective management programs can be formulated and initiated.

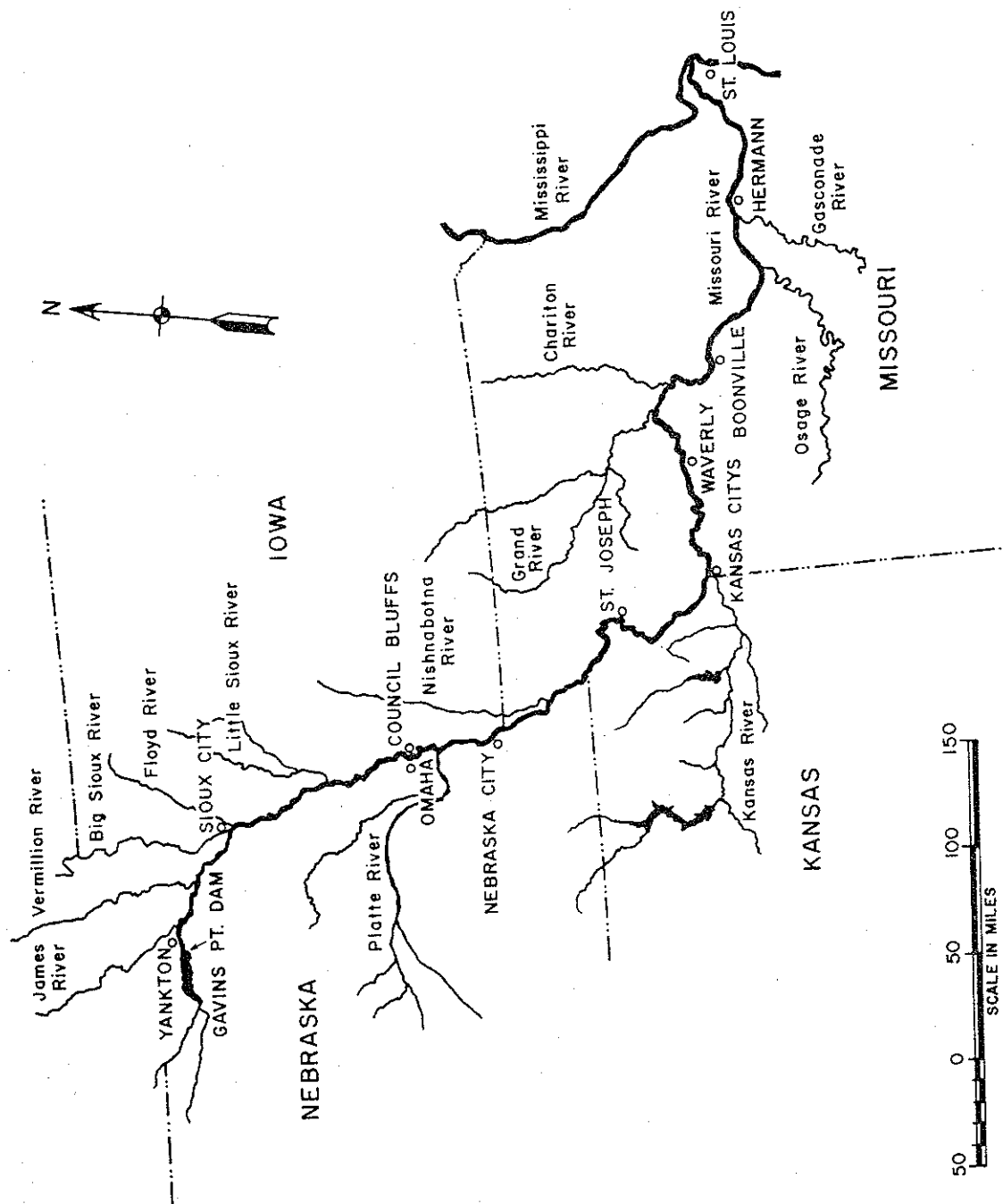


Figure II-1. Missouri River study reach.

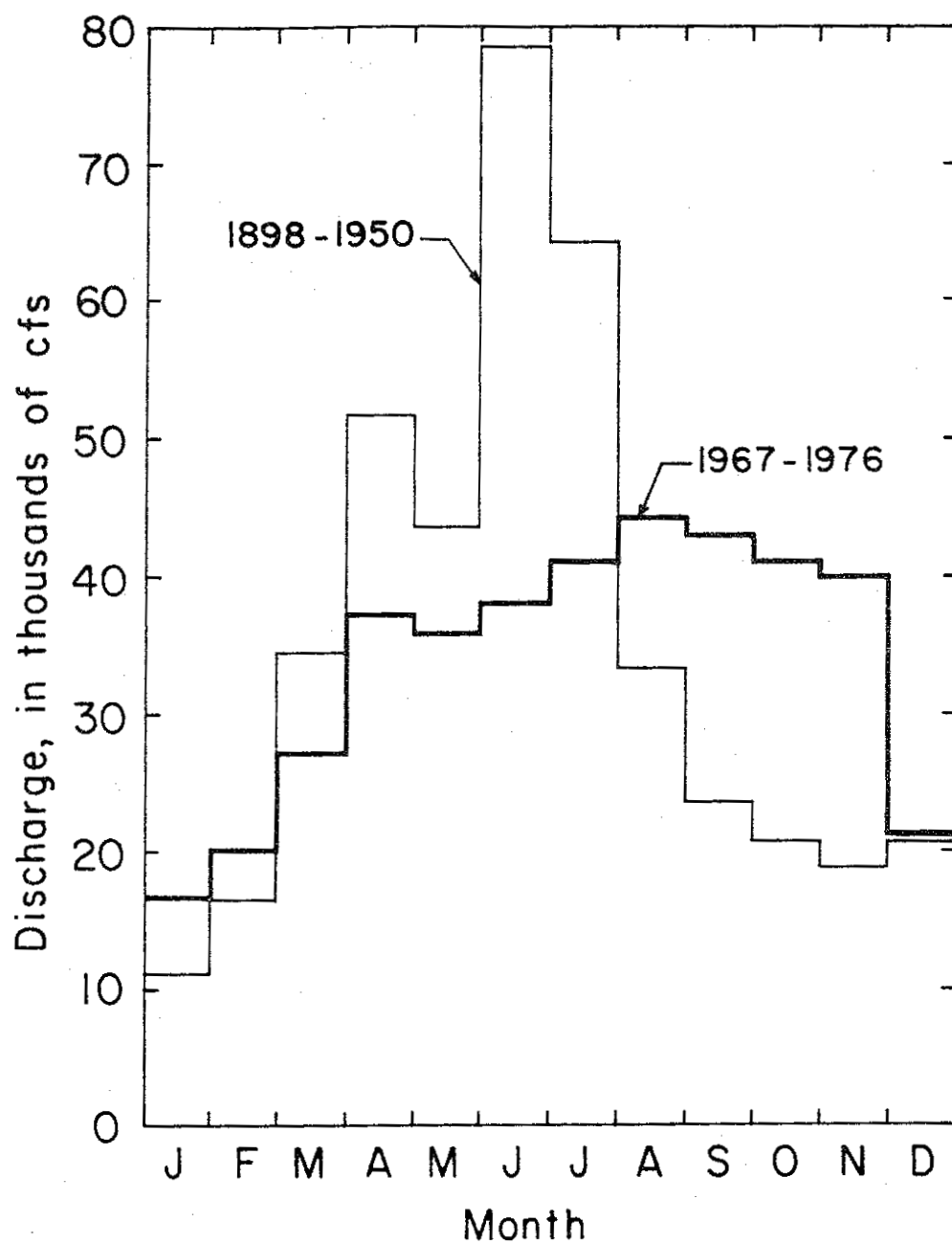


Figure II-2. Comparison of mean monthly discharges at Sioux City, Iowa before and after advent of flow regulation.

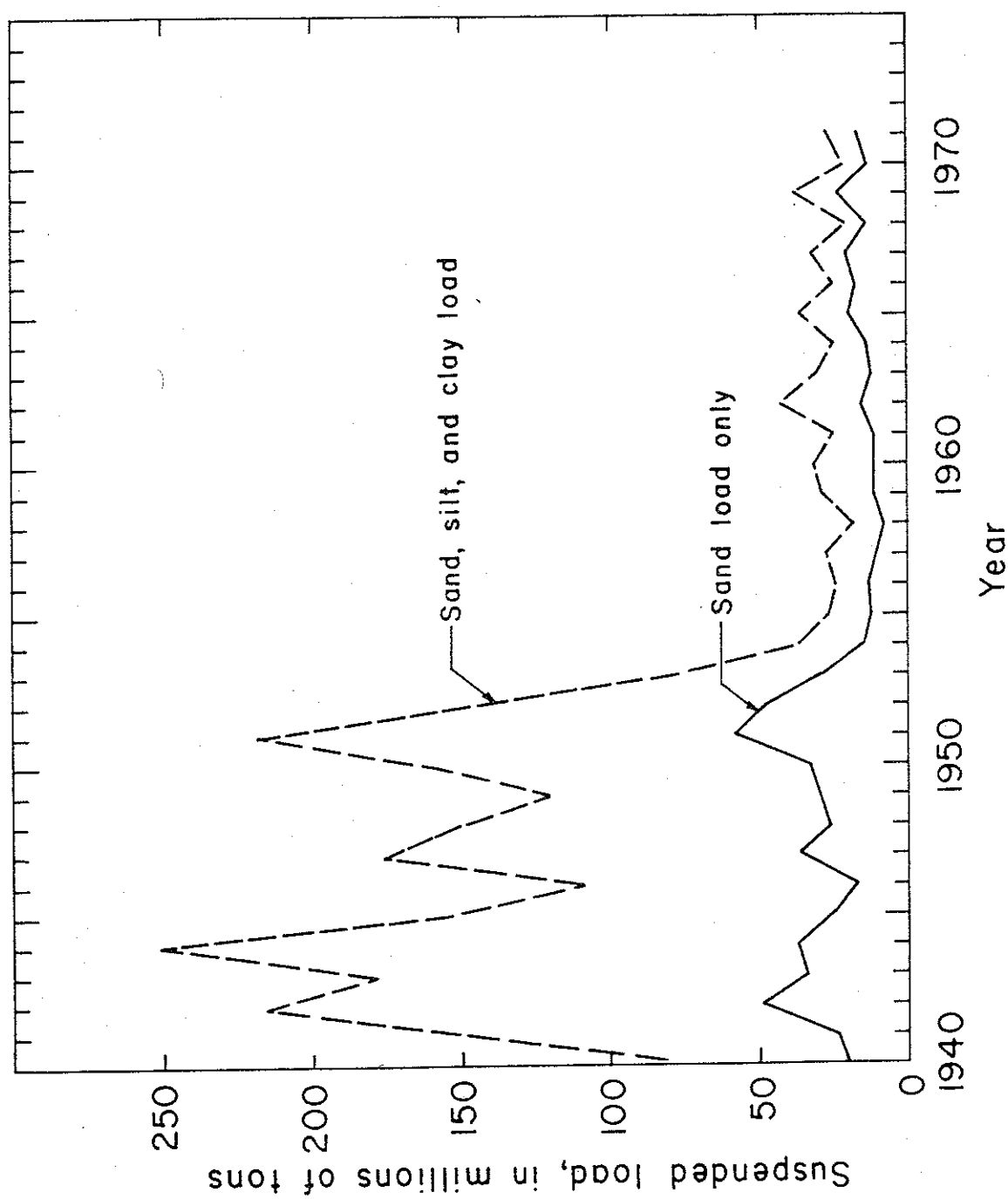


Figure II-3. Comparison of annual average daily suspended sediment load at Omaha, Nebraska before and after dam closures.

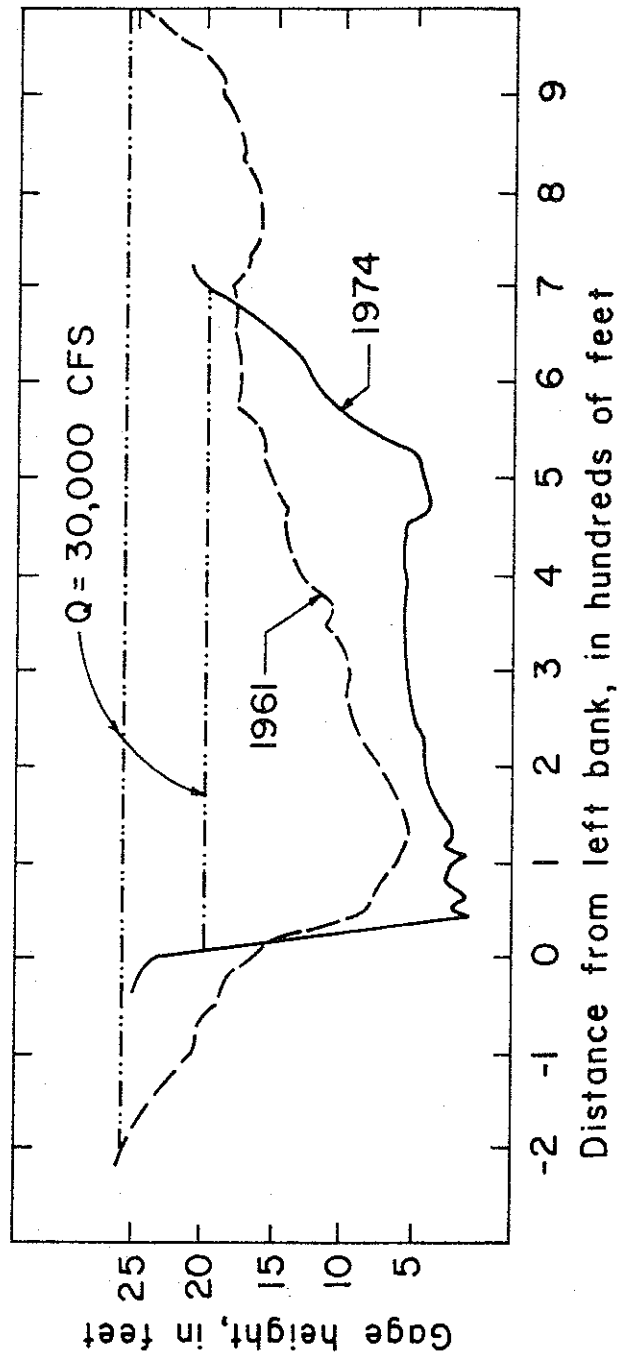


Figure II-4. Comparison of typical channel cross sections near Sioux City, Iowa before and after completion of channel stabilization works.

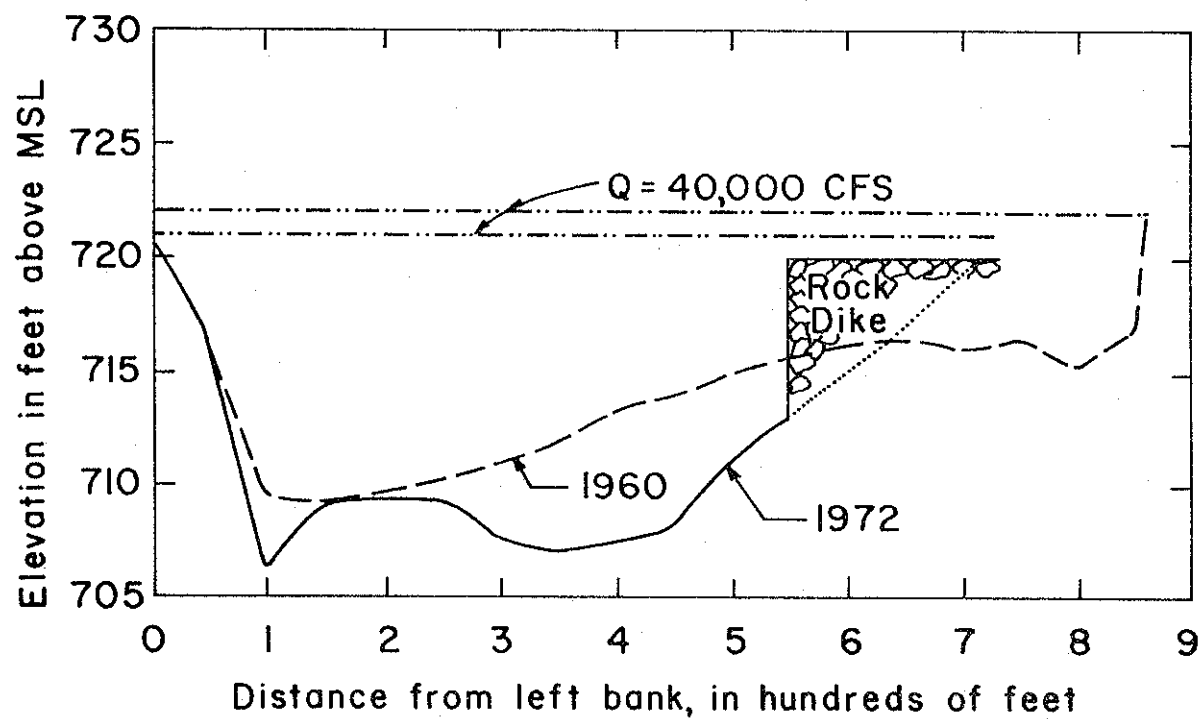


Figure II-5. Comparison of typical channel cross sections near Kansas City, Missouri before and after completion of channel stabilization works.

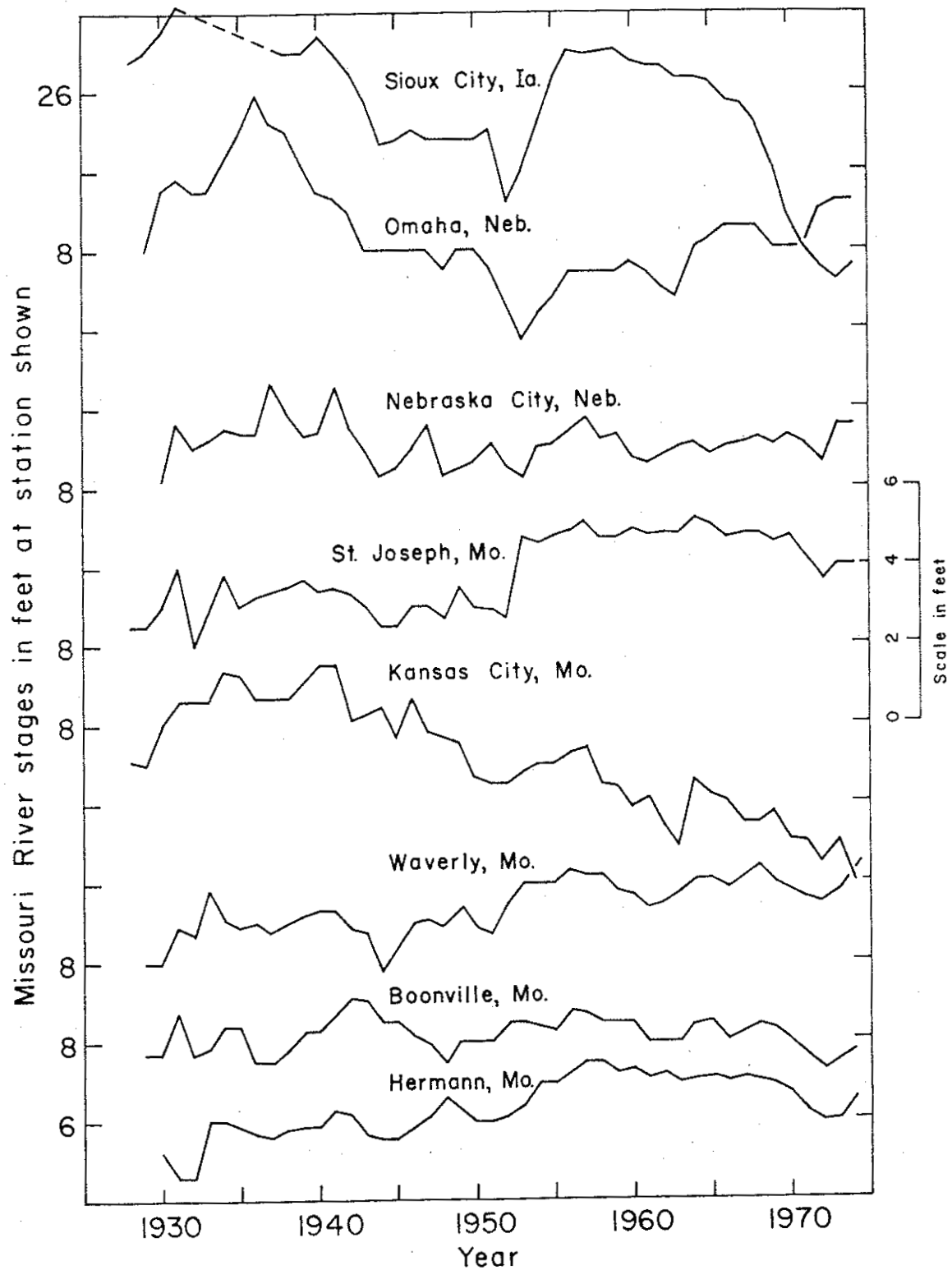


Figure II-6. Stage trends at selected Missouri River gaging stations for 40,000 cfs.

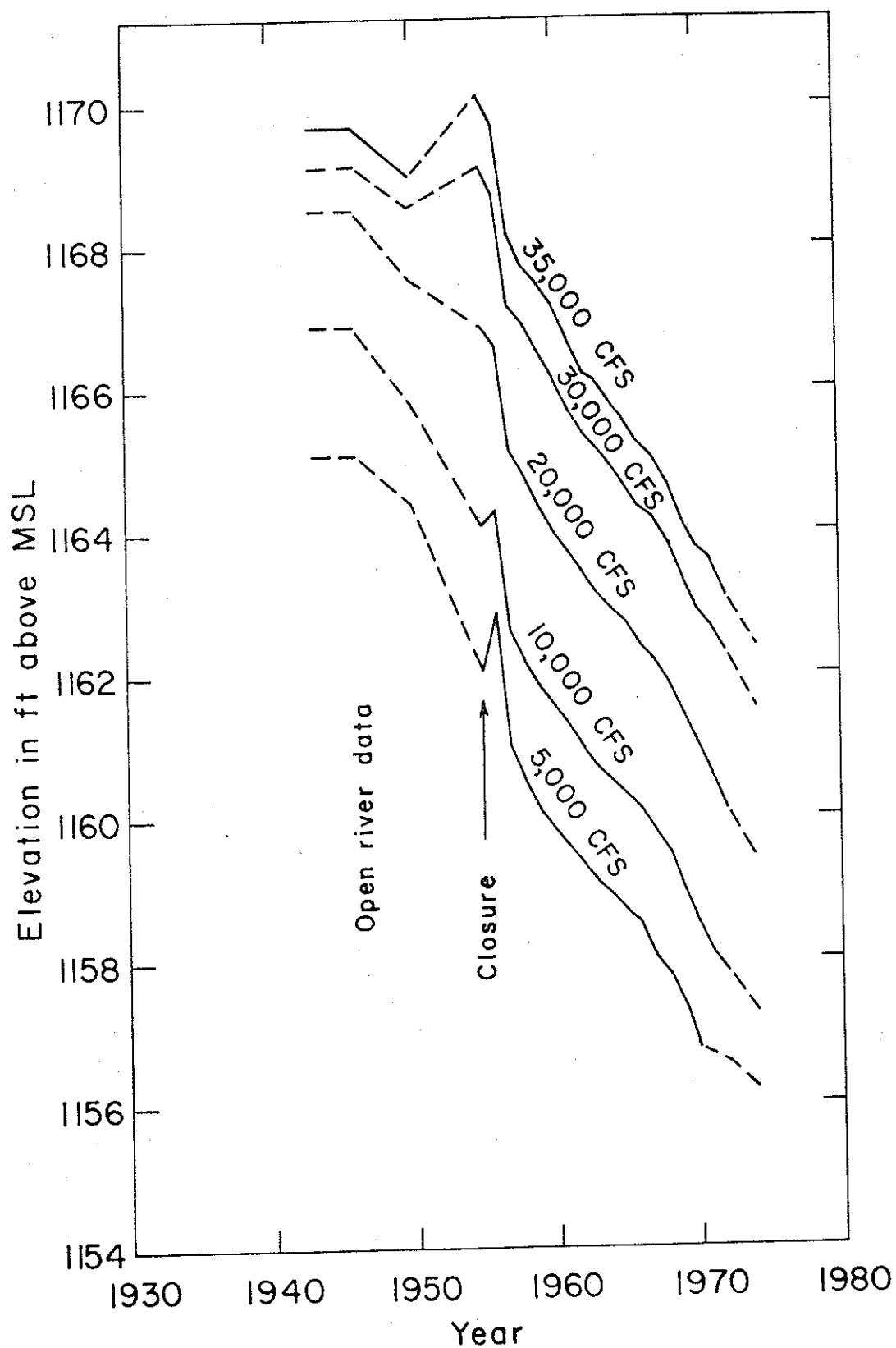


Figure II-7. Tailwater trends at Gavins Point Dam.

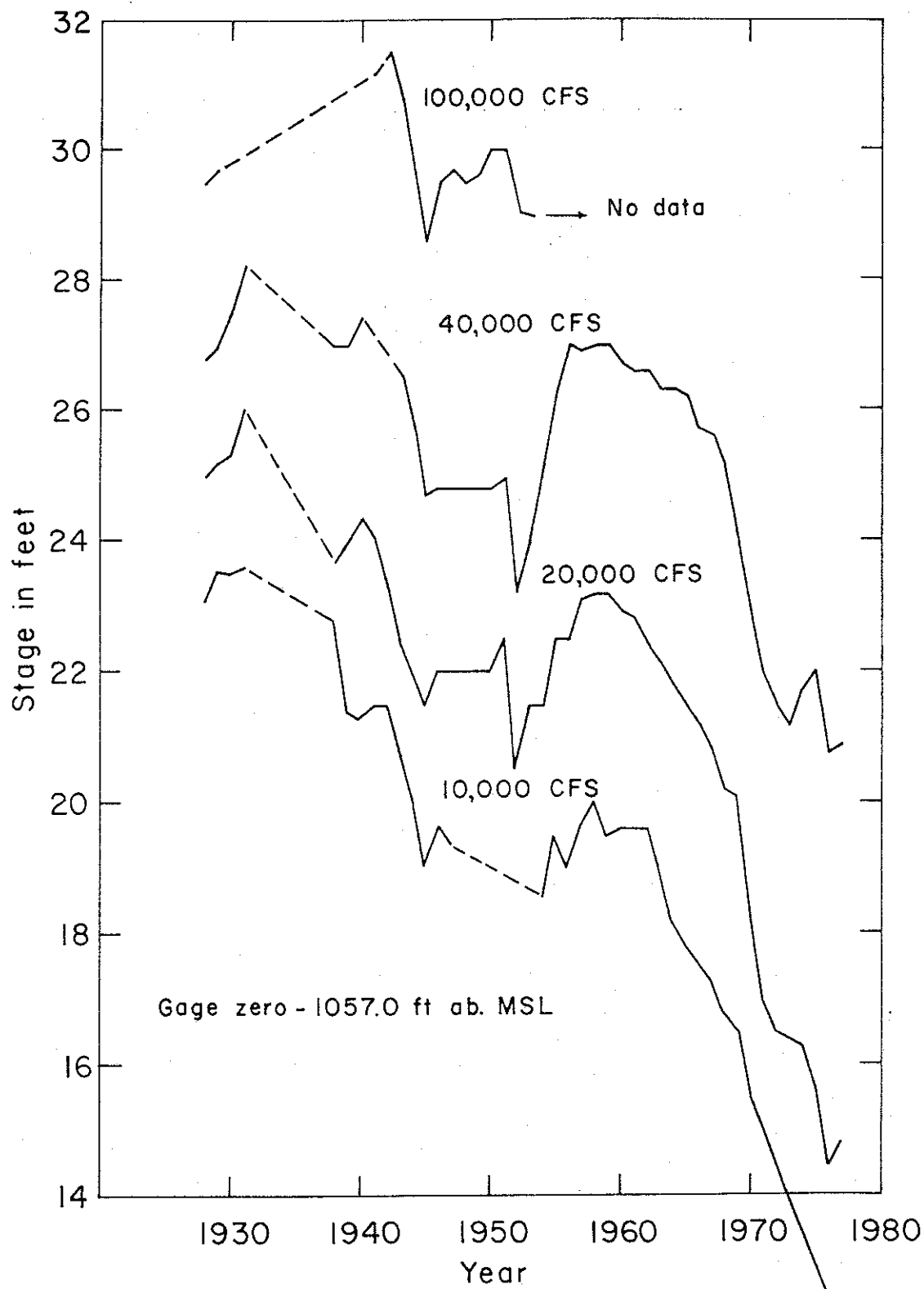


Figure II-8. Stage trends at Sioux City, Iowa.

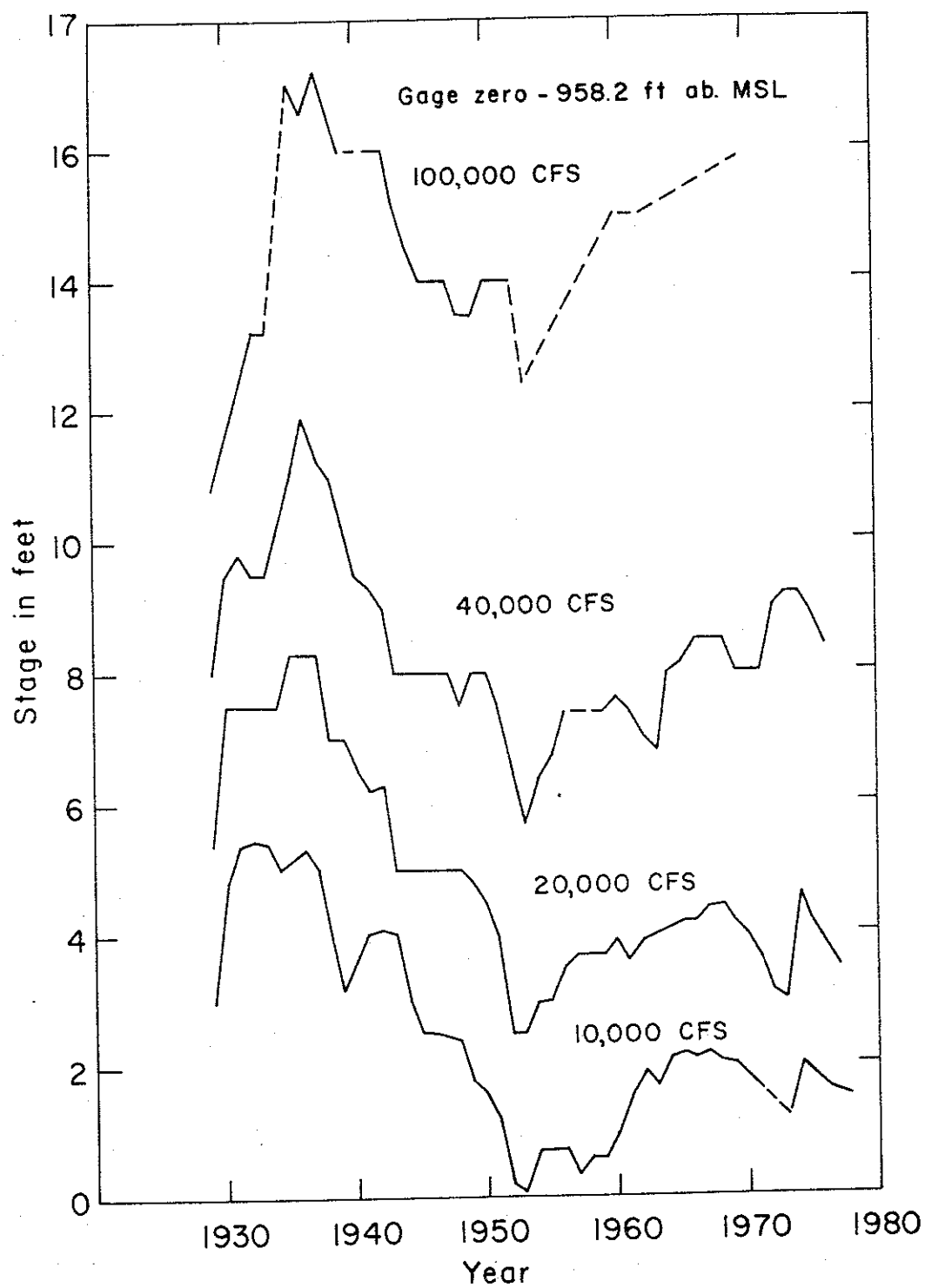


Figure II-9. Stage trends at Omaha, Nebraska.

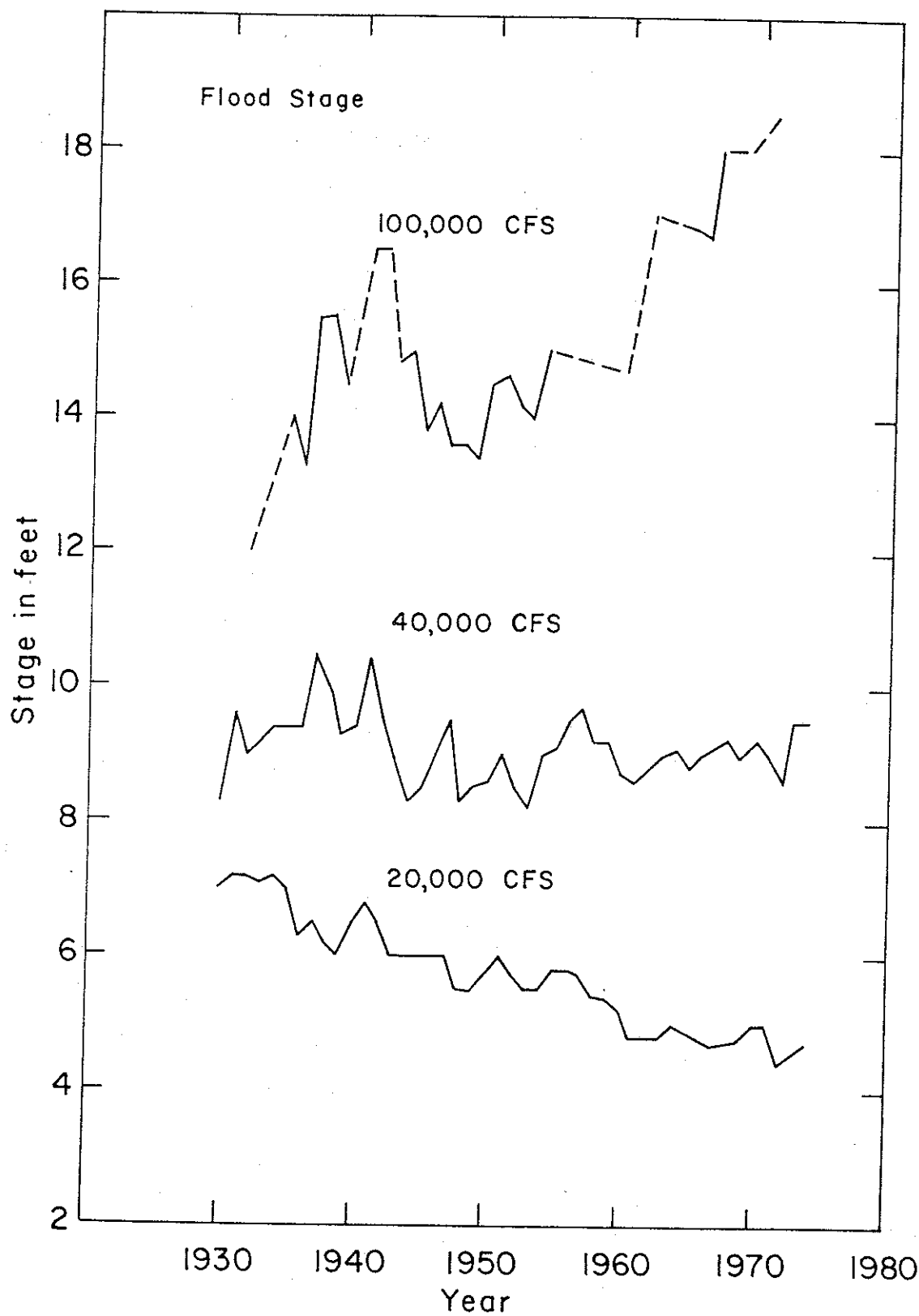


Figure II-10. Stage trends at Nebraska City, Nebraska.

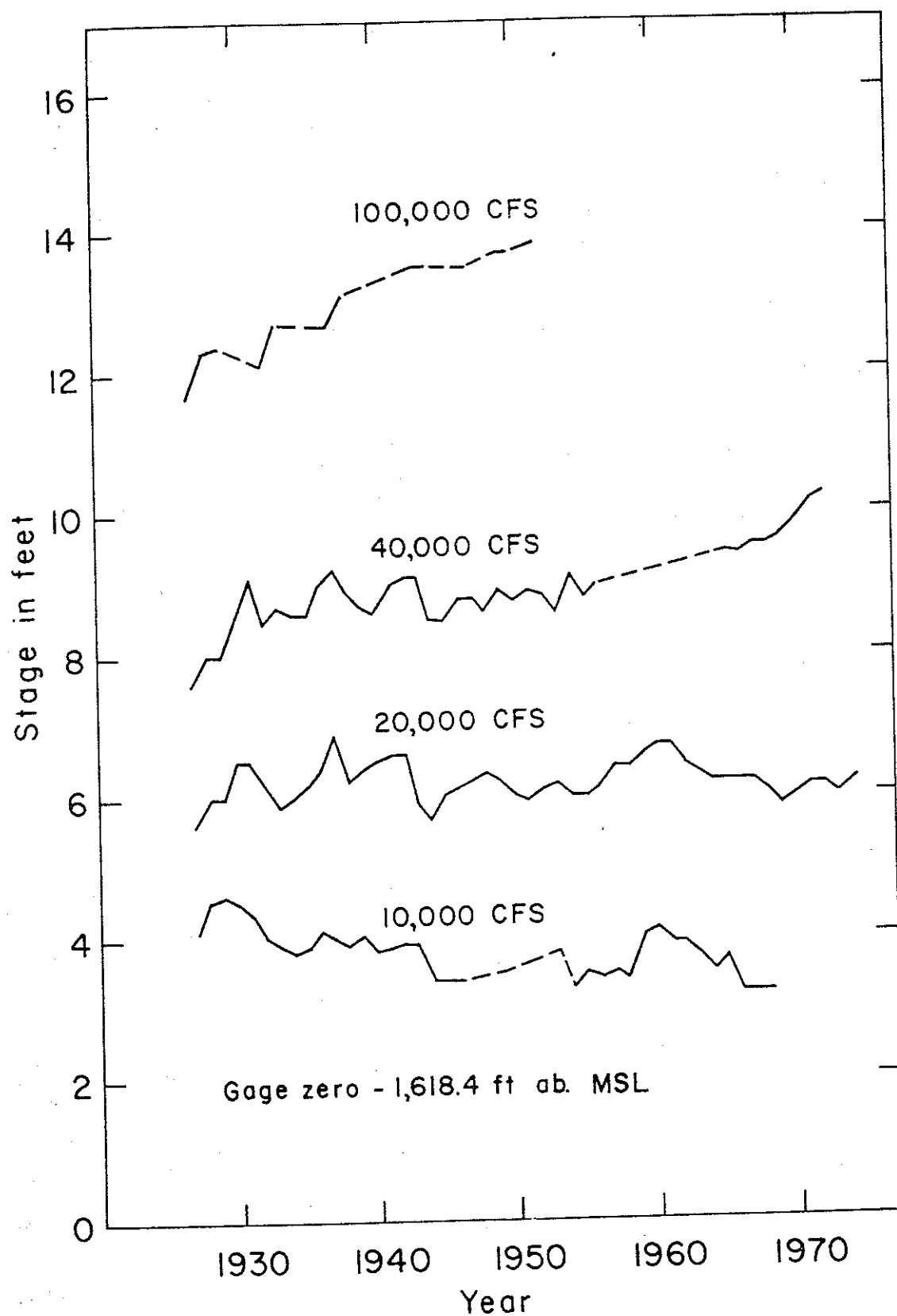


Figure II-11. Stage trends at Bismarck, North Dakota.

III. HISTORICAL AND CURRENT FACTORS CONTRIBUTING TO DEGRADATION/AGGRADATION IN THE MISSOURI RIVER

Report of Subgroup 2

A. Introduction. Degradation or aggradation occurs in a reach of an alluvial stream when the rate at which sediment is transported into the reach differs from that at which it is carried out of the reach. When the sediment discharge into the upstream end of the reach exceeds that from the downstream end, aggradation occurs; and when the sediment-outflow rate exceeds the inflow discharge, degradation results. These sediment-transport imbalances can occur when a change occurs in the rate at which sediment enters a reach, or when the sediment-transport capacity of a reach is altered. Because the sediment discharge depends strongly on the fluid velocity, an imbalance in the rates of sediment input to and output from a reach will appear if there is a change in the characteristic flow velocity in the reach. The stage for aggradation or degradation also can be set if the discharge of sediment into a reach is changed without the occurrence of concomitant changes in the sediment-transport capacity of the reach. Agents which can affect the rate at which sediment is supplied to a river reach, and those which influence the sediment-transport capacity of rivers are enumerated in Sections B and C, below.

B. Factors Affecting Supply of Sediment to Rivers. Any of the following items can have a major impact on the rate at which sediment enters a reach of a river, or on the mean concentration of transported sediment in the reach.

1. *Dams.* The reservoir formed behind a dam acts as a sediment trap. Therefore, the water released from the dam is practically sediment-free. Generally the flow seeks to satisfy its sediment-transport capacity by eroding material from the channel bed and banks in the river reach downstream from the dam.
2. *Land-use practices.* The sediment transported by an alluvial stream originates from the surrounding upstream or adjacent watershed. It is well established that changes in watershed treatment can have significant effects on the rate at which sediment reaches a stream channel, the character of the sedi-

ment, and the temporal distribution of sediment supply to the river during and after a storm. For example, clearing land of natural vegetation and then row-cropping it will radically increase the sediment yield. Only sediment in the bed-material size range can be expected to significantly affect aggradation and degradation. Finer material, which is transported as washload, usually is transported through practically any river reach.

3. *Tributaries.* Most sediment is carried to rivers by its tributaries. Therefore, factors which influence the sediment-transport rate to and along tributaries are the same ones which affect the sedimentary regime of the main channel.
4. *Aeolian transport.* Wind-transported sedimentary material from riparian lands can be transported to and deposited in rivers, thereby increasing the sediment concentration and discharge. The rate of aeolian transport is heavily influenced by land-use practices.
5. *Bank erosion.* Friable, easily eroded banks can contribute major quantities of sediment to a stream. The amount depends on many factors, including the kind and size of bank material, degree of channel sinuosity, slopes of the channel and of the surrounding water shed, bank vegetation, frequency of flooding, etc. Periodic channel surveys can provide the data necessary to estimate rates of bank erosion and its contribution to the sedimentary load of a stream.
6. *Solid wastes.* Domestic and industrial operations, as well as storm run-off from urban regions may contribute to the sediment load of a stream.
7. *Flood plain accretion.* The overbank flows which occur during flood transport major quantities of sediment to overbank areas, where much of it is deposited. The sediment discharge of the main channel is thereby reduced.
8. *Dredging and dredge-spoil disposal.* The process of dredging can cause a temporary increase in turbulence and a corresponding rise in the suspended-sediment discharge of a stream

in the vicinity of the dredge. Dredged material that is dumped in overbank areas can be returned to the river by storm runoff and/or overbank flows. When dredged material is returned directly to the river from a dredge, it can produce major local imbalances between the local sediment transport rate and the streams transport capacity. This practice often is detrimental to aquatic life.

The presence of dams is considered to be the most important of the foregoing factors. The sediment yields of tributaries and bank erosion are judged to be next in order of importance. The remainder have tertiary impact on the rate of sediment supply to a stream.

C. Factors Affecting the Sediment-Transport Capacity of Rivers.

In general, anything which affects the distributions of local depth and/or velocity in a river also will affect the local sediment-transport capacity per unit width, of a stream and therefore also the total transport capacity. Some of the principal agents which disturb sediment-transport capacity are:

1. *Training structures.* These generally are used to adjust the width and/or length of reaches of river channels, and to stabilize river banks. Length alterations invariably affect the channel slope, and thereby also the flow velocity and sediment-transport capacity of the flow. Width reductions increase the velocity and sediment-transport capacity, while width increases have just the opposite effects. Revetments and rock jetties used to train the rivers increase the hydraulic roughness of the banks, increase the intensity of flow turbulence, increase bed roughness, and consequently tend to reduce the velocity and unit sediment discharge in the near-bank regions.
2. *Flow regulation.* Dams on rivers are generally operated to regulate the release flows, in such a way that discharge and velocity variations at downstream locations are much smaller than they were naturally. The reductions in the maximum velocities also reduce the sediment discharge of the stream, and usually also the total (i.e., annual) sediment-transport capacity of the stream.
3. *Runoff cycles.* Regardless of whether the flow in a river is

regulated or not, the flow rates will fluctuate from season to season and year to year, depending on the patterns of rainfall and runoff for the watershed. These fluctuations will also cause variations in the rate at which sediment is delivered to the stream, and may promote alternate aggradation and degradation.

4. *Change in slope.* The two principal factors producing changes in channel slope are river shortening (generally by cut-offs of meanders), and aggradation/degradation. The increase in slope due to shortening by cut-offs and straightening increases the velocity and sediment-transport capacity of the river, which leads to a reach of degradation which generally propagates upstream as a head cut. Downstream from the steepened reach, aggradation generally is produced. The steepened portion ultimately will smooth out as the river tends to re-establish a uniform continuous slope. Degradation tends to reduce slope, velocity, and therefore also sediment-discharge capacity.
5. *Bed armoring.* Armoring of a sediment bed occurs when degradation selectively removes finer bed material, leaving behind the coarser particles which cannot be transported by the flow. Sampling of bed materials and bed-channel borings usually provide insight into this phenomenon.
6. *Change in roughness.* As a stream degrades and the bed sediment coarsens, the bed forms usually change in size and array, and their hydraulic roughness is thereby altered. This in turn produces changes in velocity which are accompanied by sediment-transport capacity alterations. When a stream bed is fully armored, the bed forms usually are obliterated, the bed is flat, and the roughness is at or near the irreducible minimum for that bed material.
7. *Artificial temperature rises.* Any increase in the water temperature resulting from the artificial addition of heat (e.g., from a once-through cooled power plant) can affect the river in two ways. First, the sediment-discharge capacity for suspended material is reduced, due to the larger fall velocity of the parti-

cles, which tends to induce aggradation. Second, the bed configuration and associated bed hydraulic roughness can be altered, leading to variations in the velocity and associated changes in the sediment-transport capacity.

8. *Diversions.* Diversion of water from a river may reduce the river discharge and produce an imbalance between the sediment supplied to the reach and its sediment-transport capacity. The extent of this effect will depend on how much water is diverted and the size and location of water and sediment return flows to the river.
9. *Boat traffic.* Power boats and barge tows increase the turbulence in the river, which increases the sediment-transport capacity of this stream and induces an immediate tendency for the bed to degrade and then subsequently aggrade. Waves created by boats also can erode stream banks and cause sediment-transport imbalances which promote aggradation.
10. *Ice.* Shorefast ice may attach to the banks and damage revetments, thereby promoting bank erosion and increasing the available sediment supply during the next high discharge. Ice jams may cause surges in the river discharge and consequently also in the sediment discharge. Ice problems tend to produce short-term perturbations; the attendant long-term, cumulative effects are believed to be minor.

Among the foregoing factors which tend to alter the sediment-transport capacity of a stream, training structures and flow regulation are judged to be of primary and equal importance. The former tends to accelerate or decelerate degradation, according as the channel is widened or narrowed. The latter tends to reduce degradation. Flow regulation is expected to be of greater importance in the upper reaches of a river than in the lower ones. Armoring of the bed may limit degradation in reaches downstream from dams. All other factors listed above are not necessarily unimportant, but are believed to have only minor impact on river degradation/aggradation.

D. Study Needs and Possible Approaches.* Subgroup 2 concluded that the following studies are necessary to arrive at an understanding of the

* The two introductory paragraphs of Section II-E apply also to the recommendations set forth here.

various factors contributing to the Missouri River degradation and aggradation.

1. *Analysis of existing data.* The physical (and ideally also the biological) data on the Missouri River that have been obtained by the Corps, USGS, and other agencies, state as well as federal, should be collected, placed in a uniform and readily usable format, coordinated, and analyzed. There is an abundance of data available from many sources that need to be examined and analyzed with the objective of understanding the degradation-aggradation process and the environmental impacts it has produced. Some objectives of this analysis would be:
 - a. Explain the temporal and streamwise variations in the rating curves, discussed in Chapter II. Some rating curves reveal a steadily increasing stage for a given discharge with the passage of time, whereas others remain constant, and still others show diminishing stage trends. The causative physical factors for these changes need to be elucidated.
 - b. Quantify the bed-elevation fluctuations which occurred under natural conditions. There are many sources of data that could be used to reconstruct river section profiles, thalweg profiles, and other stream-geometry parameters for the past century. Examples of data sources are those available on old highway and railroad river-bridge crossings. The degradation being experienced today could be merely a continuation of a long-term natural trend.
2. *Collection of additional field data.* The data available from the main stem and its principal tributaries on velocities, cross-sections, bed profiles, sediment-transport rates, bed-sediment composition, overbank-sediment composition, etc., while extensive, still are judged to be decidedly inadequate. The number of sampling stations along the river and the frequency of monitoring needed for the proposed data-collection effort would vary from reach to reach. Both the spatial and temporal fre-

quencies of measurements should be greater near confluences, during high discharges, and at times and locations of rapid degradation. It is believed that the objective of this recommendation can be achieved most practically by identifying, say, three to five study reaches along the Iowa border, and mounting intensive data-collection efforts along these reaches.

3. *Physical and/or mathematical modelling.* It is recommended that the effects of alterations in channel width and/or length and slope on the hydraulic and sediment-transport characteristics of the stream be investigated by both physical and numerical models. The existing river width was established because sediment deposition in the channel was reduced as the width was narrowed by increments to its present value. The increments during this process were quite large, and it well could be that the optimum width was overshot. It is recommended that the effects of river-width changes be investigated for selected critical reaches of the river using both laboratory models and numerical models. Another recommended mathematical modeling study would involve the effects of changing existing patterns of water releases from Gavins Point Dam. Depending on the outcome of these studies, one or more pilot field tests might be indicated.
4. *Bed borings.* Additional data on the vertical distributions of bed-sediment composition are needed to reveal armoring patterns, and for the light they might shed on historical aggradation/degradation. These data would be invaluable in reaching conclusions concerning the elevation (if any) at which the bed might become armored and degradation arrested.
5. *Development of bed-load transport relationships.* The relationship of the bed-sediment discharge to river-flow variables, including river discharge and/or velocity, needs to be understood and formulated, in order to evaluate the existing and future data, and to apply computer-modeling techniques to the river. Empirical relationships based on actual sediment-discharge measurements in the Missouri River are preferable to

information derived from existing theoretical or empirical relations. The necessary field data could be forthcoming from the study recommended in Item 2, above.

6. *Develop methods for preserving, restoring, and enhancing fish and wildlife habitats and/or recreation areas.* Examples of these are dike notching, pumping of water into sloughs and ox-bow lakes, etc. The dikes installed by the Corps have performed very efficiently, in a certain sense, and the areas immediately downstream from them now are practically glutted with sediment and tend to be regions of very little water movement. Notching of the dikes restores some flow through the wake areas of the dikes, and can be expected to remove some of the sediment from these regions. Additionally, dike notching diminishes the turbulence intensity of the flow around the ends of the dikes, and tends to reduce the sizes of the scour holes produced by the dikes. The investigation of dike notching should be continued, and expanded to include the effects of small dredged channels in the dike-wake areas. Anything that can be done to promote sediment transport out of and water transport through the dike fields would act to ameliorate the degradation problem. The results obtained from pilot studies of dike modification along selected study reaches should shed considerable light on the roles of the dike fields in promoting aggradation/degradation.

All of the investigations set forth above are considered to be of high-level importance. However, because all items cannot be funded or conducted at once, it is recommended that analysis of existing data be undertaken first, since the results of this investigation could be invaluable in providing guidance for future monitoring work. The final determination of a selection of a recommended sequence for conducting the remaining investigation should await completion of the data analysis.

7. *Investigate the rate at which perturbations to the sedimentary regime of a stream propagate upstream and downstream, and the attendant attenuation.* It would be invaluable to have esti-

mates of the rates at which the channel changes precipitated by curtailment of the sediment supply to the Missouri River, by closure of the dams, is moving downstream. This would aid significantly in ascertaining if the degradation presently being experienced along the Iowa border is principally the result of the dam closure. If the timing of the onset and the extent of the degradation that has been experienced are what would have been expected just from interrupting the delivery of sediment to the tail water of Gavins Point Dam, it would be reasonable to conclude that the degradation is resulting principally from the dam closure. It is believed that this aspect of the investigation should proceed analytically, with laboratory and field verification.

IV. FUTURE RATE AND EXTENT OF MISSOURI RIVER DEGRADATION/AGGRADATION

Report of Subgroup 3

A. Introduction. An accurate prediction of the future rate and ultimate extent of the degradation and aggradation that can be expected along different reaches of the Missouri River between Gavins Point Dam and the river mouth for different schemes of River development and utilization would be invaluable in the planning and evaluation of remedial measures, and in developing strategies for accommodating degradation/aggradation which cannot be controlled, either because of physical or administrative limitations. Indeed, one of the principal uncertainties confronting those planning future utilization of one or another aspects of the River's resources is the uncertainty surrounding the future course of degradation/aggradation which can be expected along the River and its tributaries, and its implications for the whole interconnected system, including also the alluvial aquifers, ox-bow lakes, and backwater areas. The report of this Subgroup treats four topics: (1) trend analysis (i.e., extrapolation of existing data); (2) mathematical modelling; (3) data analysis; and (4) problem identification and delineation of related research needs.

B. Extrapolation of Existing Data. During the quarter-century since the closure of Gavin's Point Dam, an extensive body of data has been accumulated on the flow and certain other characteristics of the River. It now would be useful to re-evaluate the original estimates, made at the time the dams were being designed and constructed, of the degradation and other channel responses of the River. The analysis of the accumulated data should include the following:

1. *Stage-trend analysis.*

- a. Stage-trend analysis has been carried out for most main-stem gaging stations, as well as for some gaging stations on the principal tributaries. The effort to analyze and understand the trends in the stage-discharge relations should be continued. Needless to say, the data-acquisition programs needed to supply the input information should be continued, and indeed even be broadened.

- b. Stage-discharge trends can be produced by changes in channel cross section, alterations in the character of the bed material, changes in the bed-configuration character of the stream, and other factors in addition to aggradation or degradation. The analysis of the stage-discharge trends should be sufficiently complete to identify the causative factors and their respective contributions to the shifts. Accordingly, the analysis should include changes in channel geometry, bed elevation, channel cross section, depth, velocity, river temperature, sediment discharge, etc.
 - c. In the cases of ungaged tributaries, or tributaries in which the gaging stations are remote from the tributary mouth, the following analyses are recommended:
 - i. Evaluate existing cross-section data, thalweg profiles, topographic maps, aerial photographs, etc, for the tributary reach that can be affected by main-stem degradation. In the case of gaged tributaries, this data collection should extend upstream to the gaging station.
 - ii. Establish survey cross-sections which would be tied to existing aerial photographs.
 - iii. Obtain additional aerial photography if needed to complete the coverage.
 - iv. Interpret the collected data to arrive at the stage-discharge trend for the reach and to establish the patterns of behavior of the channels.
 - d. These activities should provide a basis for evaluating the extents and rates of future changes (and past changes if the aerial photographs and topographical data are sufficiently detailed). The information obtained also would be required as input to the modeling efforts discussed below.
2. *Sediment trends.*
- a. Evaluate trends in the discharge and the size of transported sedimentary materials:
 - i. Temporal trends at selected stations.

- ii. During fixed, selected time intervals, along selected study reaches.
- b. Collect data on and evaluate the changes in bed material size since closure of Gavins Point Dam, and for as many earlier years as data permit.
- 3. *Bank erosion rates and trends.*
 - a. From existing detailed topographic maps and aerial photographs, compile data on bank-erosion rates and trends for the uncontrolled river reach above Sioux City.
 - b. Repeat this procedure for any uncontrolled reaches (between controlled ones) downstream from Sioux City.
 - c. Establish degree of correlation between rate of channel change and sediment-transport rate at Sioux City and other nearby gaging stations.
- 4. *Update degradation and profile computations.*
 - a. Review the methods and data utilized in the original degradation estimates, made in connection with the closure of Gavins Point Dam. Prepare a new degradation prediction, based on improved understanding of river mechanics that has been developed in the intervening years since the closure of Gavins Point Dam, utilizing presently available data. The newer prediction also could take advantage of the degradation and data that have been accumulated since closure of Gavins Point Dam. The degradation calculation should continue downstream to the mouth of the Platte River.
 - b. One of the principal objectives of this phase of the investigation would be to make a determination of whether the Platte River mouth will continue to act as a "control point", downstream from which no significant degradation can be expected.
 - c. In the course of this data analysis, the relative contributions to the river-bed material at Omaha (and other stations) from degradation and from bank erosion in the uncontrolled reach above Sioux City should be examined.

5. *Rates.* The original Corps estimate was that approximately 15 ft of degradation would occur in the Gavins Point Dam tailwater. To date, approximately 8 ft have occurred. Degradation at downstream locations decreases almost linearly to zero at the Platte River confluence. It would be very useful to know if this linear distribution of degradation can be expected to continue. It is believed that this point can be resolved by examining the data expected and analyzed under Item 3, above.

C. Mathematical Modeling. The improved understanding of river mechanics and the new dimension of data-handling capabilities made available by the modern high speed computer have combined to make it practical to develop computer-based numerical models of many aspects of river behavior which heretofore could not be calculated. It is recommended that steps be taken to develop numerical models of certain aspects of the Missouri River, as follows:

1. *One-dimensional flow--sediment-transport model.*
 - a. A computer-based, one-dimensional model of the water and sediment-transport characteristics of the River between Gavins Point Dam and the mouth, including effects of tributaries on the main stem and including reaches of tributaries extending some distance upstream from their mouths, should be developed.
 - i. The Sioux City Metro Plan Study presently being conducted by the Omaha District of the Corps will include, as presently scoped, application of HEC VI to the 140-mile long reach between Gavins Point and Blair. This calculation should be extended to the River's mouth.
 - ii. Consideration also should be given to application of other computer-based models for the routing of water and sediment flows along rivers. These models include the one- and two-dimensional models developed at Colorado State University; HEC VI as modified by Ted Yang (of North Central Division of the Corps); and the European models, including those available at Delft Hydraulics

Laboratory, the Danish Hydraulic Institute, and SOGREAH.

- iii. In any sediment-routing model, the sediment-transport relation utilized will be critical to the success of the calculation. Accordingly, attention should be directed toward using existing data to establish sediment discharge predictors for different reaches of the river.
- iv. A major objective of the mathematical modeling effort should be to modify existing computer-based river models as needed to make them reliable predictors for the Missouri River. The goal should be to obtain a model which would have sufficiently broad capabilities and adequate flexibility, and would be validated to the extent that it can be used to guide design and decision making related to remedial measures and/or alternative plans of development for the Missouri River.

2. *Two-dimensional ground-water/surface-water models.*

- a. Operational models currently exist. The most appropriate model should be interfaced with the flow model, described in Item 1, above, to obtain a comprehensive model describing water movement in the Missouri River valley.
- b. Ground-water models are heavily dependent on data on the aquifer properties and geology. Available data should be obtained as needed to provide an adequate base for development and application of the comprehensive ground-water/surface-water model.

D. Data Needs. Several data needs have been outlined in the preceding items. There is, however, need for a comprehensive data collection and analysis effort. The resulting data bank could provide the information needed for projection of further trends.

- 1. *Inventory and evaluation.* The existing data on the surface-water flow, sediment-transport characteristics, and ground-water movement of the Missouri River Basin should be inven-

toried and evaluated to determine the adequacy of the existing data for the studies which will be required to resolve the aggradation/degradation problem and for future river planning. The results of this inventory would be invaluable in planning future data-collection efforts. The data inventory and evaluation should take the following items into consideration:

- a. Frequency of sampling, length of record, and spatial coverage.
 - b. Continuity of historical records.
 - c. Data requirements for application of a one-dimensional computer-based model of water and sediment movement in the river to investigate the aggradation/degradation problem.
 - d. The data requirements for planning of possible remedial measures, or for estimating the future rate and extent of degradation/aggradation, and for developing strategies to cope with unavoidable degradation/aggradation.
 - e. Data required by ground-water models.
2. *Additional river-bed sampling.* The following additional data and data-collection programs are judged to be essential to future rational analysis and planning related to the river.
- a. Bed core samples spaced along the main stem of the River stream and along reaches extending up the principal tributaries from the mouths to points where the tributaries exhibit a significant hydraulic control or geologic discontinuity.
 - b. Bed core sampling should be more intense in the vicinity of Gavins Point, near the Platte River mouth, and along the intervening reach where degradation has been especially severe.
 - c. The following question should be considered before collecting and analyzing the bed-material samples:
 - i. Are there any unknown deposits of gravel, or other geologic controls, which might upset current or pre-

vious estimates of river-bed degradation? If such controls are discovered, their extent should be delineated and effects projected.

- ii. Will the Platte River confluence continue to act as a control on the river degradation?
- iii. Are there any contaminants adsorbed on the sediments which might be exposed and released by degradation?

E. Problem Identification and Research Needs. In addition to the problems and research activities described in Sections B, C, and D, certain other problems need to be addressed through conduct of studies, as follows:

1. *Future flow release patterns.* In Chapter III the effects of flow-release schedules on sediment transport were mentioned. It appears reasonable to expect that the water discharges from the dams could be scheduled in such a way as to minimize degradation/aggradation, subject to the constraints imposed by Flood control and navigation requirements. This matter should be considered as part of the computer-modeling effort described above.
2. *Water quality.* The computer-based model of the ground-water surface-water system in the Missouri River Valley could be expanded with minimal effort to include certain water-quality parameters, including temperatures, dissolved oxygen, and concentration and transport of surface contaminants. After a computer-based model is developed to describe the movement of water and sediment in the stream, it should be expanded to incorporate the principal water-quality parameters for both the surface water and ground water.
3. *Fish and wildlife habitats.* An effort should be made to quantify fish and wildlife habitats and to include their descriptive parameters in the comprehensive model. The quality and extent of these habitats is so closely linked to the physical characteristics of the main stem of the river and its tributaries and to the quality of the water that it appears likely that the habitat parameters could be included as an adjunct to

the comprehensive flow model.

4. *Future land and water use.* Do the states, counties, and local groups have sufficiently comprehensive descriptions of and plans for the present and future uses of the river so that their concerns can be incorporated into future planning? It appears doubtful that many do. Accordingly, a forum and a two-way information channel should be provided by means of which affected groups can participate in the management of and planning for the river. This would require conduct of a survey in order to establish precisely what groups do utilize the river in such a way that their activities are being affected by aggradation/degradation and other aspects of the Rivers behavior, and what effects different degrees of degradation/aggradation would have on these.
5. *Communication.* Improved communication and coordination is urged to insure that all valid interests will be represented, and to minimize duplication of effort. This function could be served by an effort modeled after the GREAT Programs on the Mississippi River.
6. *Local concerns.* Specific consideration should be given to the following questions which are primarily of local concern:
 - a. Local ground water development and pumping, and possible impacts of withdrawal on degradation/aggradation.
 - b. Effects of land drainage on river flows and on aggradation/degradation.
 - c. Headcutting, and its effects on the tributaries.
 - d. Fish and wildlife habitat, fisheries and wetlands.
 - e. Flood plain regulation and management.
 - f. Recreational uses.

Problems of these types tend to be highly site-specific, and to vary in character and severity from reach to reach along the river. A coordinating body, such as suggested in Item 5, above, would appear to be invaluable as a clearing house for

information on these types of problems; in providing an agency to which affected groups and individuals could come to seek help; and in promoting integrated management of the River.

F. Concluding Remarks. In summary, it was the judgement of Subgroup 3 that projections of the future rates and extents of degradation and aggradation on the Missouri River will have to be based primarily on examination and extrapolation of existing data on recent and historic trends in the river-channel behavior; and upon mathematical modeling which utilizes the improved understanding of river hydraulics which the profession has achieved in recent years and the capabilities of modern computing techniques. A carefully planned and adroitly executed plan of study integrating these two approaches should establish definitively the causes of the observed aggradation/degradation on the Missouri River; yield reliable estimates of its future course; and answer many related, important questions.

V. CONSIDERATION OF CORRECTIVE MEASURES

Report of Subgroup 4

A. Introduction. At present, development and management of the Missouri River is guided by the following concurrent, and sometimes competing, objectives:

1. Navigation.
2. Bank-erosion control.
3. Land reclamation.
4. Flood control.
5. Power generation.
6. Recreation.
7. Environmental management.

The first five objectives were dominant during the planning and design stages of the channel stabilization and navigation project. The relatively recent emergence of recreation and environmental management as major objectives is part of an evolutionary process whereby changing needs give rise to new objectives and shifting priorities. Benefits resulting from river modification and management programs undertaken on behalf of a given set of objectives, usually exact a price in the form of adverse impacts on other purposes served by the river. The major benefits which have accrued from the Corps' activities on the Missouri River include:

1. Effective flood control.
2. Enhanced navigation.
3. Hydroelectric power generation at upstream storage dams.
4. Stabilization of channel to minimize its lateral movement.
5. Increased area and value of farm land.
6. Increased tax revenue.
7. Reduced costs in the construction and maintenance of Highway I-29 and others.
8. Increased opportunities for water sports (boating, water skiing, etc.) on the mainstem reservoirs.

Great benefits to industry have resulted from reduced flooding, availability of hydroelectric power, attenuation of stage fluctuations, and the general economic health of the Basin. Adverse impacts which have resulted from the activities that led to the foregoing benefits include:

1. Loss of water area along the main stem (excluding reservoir areas).
2. Loss of wildlife habitat.
3. Loss of fish habitat.
4. Local lowering of ground-water table.
5. Degradation, which may endanger the stability and functioning of intake structures; expose pipeline crossings; undermine bridge piers; etc.
6. Increased potential for water-fowl epidemics.
7. Diminished water quality.
8. Loss of backwater areas and sloughs.
9. Lowering and size reduction of ox-bow lakes.
10. Loss of sovereign lands.
11. Making water sports more hazardous due to increased flow velocities.

It is against this background that Subgroup 4 undertook its deliberation of possible corrective measures for the degradation/aggradation phenomenon along the Missouri River from Gavins Point Dam to its mouth, and along the principal tributaries to the Missouri River. In considering the river, the Subgroup divided the River channel system into three categories, as follows:

1. Missouri River upstream of Omaha (Platte River mouth).
2. Missouri River downstream of Omaha (Platte River mouth).
3. Tributary channels.

In general, degradation is a serious problem upstream from Omaha on the main stem of the River and on some tributaries. Aggradation, as generally defined, is not a serious problem upstream from Omaha, except perhaps very locally. Downstream of Omaha degradation is presenting no serious problem at this time. As is discussed in the preceding chapters, it is by no means clear presently why degradation has been confined to the river reach north of Omaha. Perhaps sediment supplied to the Missouri River by the Platte River inhibits or prevents degradation downstream from the confluence. Over the river reach from the Platte River to the Missouri River mouth aggradation is not a serious problem, although river stages have increased along some reaches. As pointed out in Chapter II, this could be a consequence of flood-plain development and occupancy, construction of agricultural levees, and/or reduced width of the

over-bank channels.

B. Specific Impacts of Degradation. Subgroup 4 undertook to examine the impacts of degradation on each of the objectives listed in Section V-A above. These were examined in consideration of the river system as it has been and is being developed. The results of this exercise were as follows:

Objective	Impacts of Degradation
Navigation	No serious impact unless degradation increases to the extent that it undermines revetment and river-training works, and endangers or requires extensive modification of bank revetment and loading facilities.
Land utilization and reclamation	Agricultural land adjacent to the river is generally increased in quantity and quality by drainage that accompanies degradation.
Water supply	<ol style="list-style-type: none"> 1. The cost of utilizing ground water may be increased by the greater pumping heads and the necessity to replace shallow wells with deeper ones. However, there should be no adverse impact on the total available ground-water supply. 2. Degradation just below Gavins Point Dam increases the head on the turbines, and thereby increases hydropower by production. Note, however, that if the degradation were to exceed about 15 ft, problems could result from inadequate suction head on the turbines. 3. Existing water intakes for municipal and industrial uses may not function properly (or at all) at lower river stages. 4. Reduced sediment concentrations in the river water resulting principally from dam closure should have a positive effect on water quality. However, if degradation proceeds to the point that some detrimental substances are exposed to the riverflow, water quality may suffer.

Recreation

Continuing degradation adversely affects access to the river. Channel contraction, which apparently contributes to degradation, increases the flow velocities and consequently tends to increase the hazard to boating and other water sports.

Fish and Wildlife

1. Degradation of the river channel and channel contraction have adversely affected fish and wildlife habitat. Much vegetation has been removed from channel banks. The bed of the river consists of moving sand waves and bars without quiet areas. This tends to convert the river main channel to a submerged biological semi-desert.
2. Effects on commercial fishing have not been quantified, but fishing has been adversely affected. This impact requires further study to establish how important it is.
3. Channelization of River and stabilization of banks have reduced significantly the areas of backwaters and sloughs, and thereby have had an adverse effect on fish and wildlife.

C. Identification of Possible Corrective Measures. In order to define possible corrective measures to degradation/aggradation, some concept of the rates and ultimate extents of the processes is essential (see Chapter IV). For example, if degradation were to progress to the point that it undermined and caused failure of existing bank-protection works, the consequences would be very severe, and very expensive, extensive preventative measures would become necessary. On the other hand, if the river bed has stabilized and degradation has ceased at approximately its current level, no major problems are foreseen, except perhaps for wildlife habitats. In the absence of guidelines for the projected rate and ultimate extent of channel scouring, Subgroup 4 started by considering the following corrective measures for control of degradation/aggradation:

1. *Possible control measures for degradation.*
 - a. Removal of increments of bank-protection works, to widen the channel, reduce the velocity, and thereby diminish the

sediment-transport rate of the stream.

- b. Installation of channel bed-control structures or sills, to stabilize the slope of the river and fix its elevation at control points.
 - c. Introduce coarse sedimentary material into the river, to armor the bed.
 - d. Construction of locks and dams.
 - e. Modification of the outflow schedules from the dams.
 - f. Diversion of sediment-laden flow around the dams.
 - g. Construction of side channels.
 - h. Construction and operation of tributary controls (to stabilize the tributary profiles).
2. *Possible control measures for aggradation.* As noted above, aggradation of the bed of the Missouri River is presenting no major problem, except perhaps very locally, upstream from Omaha. However, local deposition in the dike fields, in low and wet lands, and in lakes adjacent to the River is posing problems that should be controlled. Possible remedial or corrective measures include:
- a. Notching of dikes.
 - b. Dredging at strategical locations.
 - c. Utilization of tributary controls.
 - d. Modification of reservoir-release schedules.
 - e. Opening of old ox-bow lakes.
3. *Corrective measures for tributary streams.* Degradation/Aggradation problems along tributaries must be considered in two groups.
- a. Those affected by degradation/aggradation in the Missouri River. Tributary degradation which is being produced by degradation of the Missouri River channel best can be arrested by control structures placed in the tributaries just upstream from their mouths, to stop degradation and arrest headcutting. Note that tributary degradation poses many serious problems, including increased sediment supply

to downstream reaches of the tributary and to the receiving river; local lowering of ground-water tables; changes in the local drainage pattern and shifts in the tributary channel; and erosion of land and destruction of improvements close to the channels. Each tributary stream should be analyzed separately to determine what remedial measure(s) should be adopted to control its degradation (or aggradation). Tributary channel control may also require installation of bank-protection works.

- b. Tributary reaches unaffected by Missouri River degradation/aggradation. Degradation and aggradation occurring along tributary reaches sufficiently far from the Missouri River that they are unaffected by the bed and water-surface elevations in the Missouri River require individual examination and treatment. In general, remedial measures which are effective in controlling main-stem degradation/aggradation also can be expected to prove effective when applied to tributaries.

D. Modification of Long Range Objectives. In order to incorporate broader objectives into present and long range river development planning and management, it is believed that new legislation should be sought which would include more specific authorization to consider the maximum utilization of the water resources of the Basin. In particular, authorization is needed to consider impacts of river development on fish, wildlife, water quality, recreation, bridge and pipeline crossings, etc. Enactment of the necessary legislation, provision of the funding necessary to carry out the related studies and designs and to construct the necessary works, and adopt the required programs which would enable the Corps and other responsible agencies to make optimal use of this multi-faceted resource would require the joint efforts of the Missouri River Basin states, as well as many other concerns. The GREAT projects on the Mississippi River comes immediately to mind as possible models.

E. Major Constraints to More Comprehensive River-Basin Development. Many imposed constraints presently inhibit adequate consideration of

objectives which should figure prominently in the continuing development of the River. One of these is the limited scope of the legislative acts that authorize river development; this is discussed in the preceeding section. In addition, there are both benefits obtained from and constraints imposed by serving specific interests. For example, furthering the objectives of navigation, energy production, and land reclamation generally has been achieved by methods that have had, and continue to have, serious adverse impacts on fish and wildlife habitats, recreational use of the Missouri River, and the general river environment. Conversely, some programs undertaken in the pursuit of one aim have had decidedly beneficial effects on other activities. An example of this has been the development and protection of riparian agricultural lands resulting from stabilization and improvement of the river channel for navigation purposes. The point is that optimum utilization of a multifaceted water resources, like the Missouri River, requires tradeoffs. A very broad view should be taken when considering river development, in order to make certain that all relevant issues have been identified and considered prior to adoption of final objectives and delineation of scopes of work.

F. Recommendations for Analysis of Degradation/Aggradation

Impacts and Study of Possible Corrective Measures. Throughout the preceding sections of this Chapter, some themes were recurrent: First, it is not reasonable to undertake to recommend specific corrective measures when the scope and ramifications of the degradation/aggradation problem are not fully documented or even understood, and no prognosis has been made for future rate and extent. Second, the ever broadening objectives of river management will require more extensive participation from affected agencies in the planning and decision-making procedures, and modified legislative framework under which the Corps will pursue its objectives.

The recommendations framed by Subgroup 4 are as follows:

1. *Data bank.* A very extensive data base, of generally high quality, on the Missouri River already exists in Corps' files and in the records of other state and federal agencies. However, these data are not available in a form in which they can be used readily. Accordingly a major recommendation of Subgroup 4 is the development of a common data storage and retrieval system for joint

use by the Missouri River Basin states and others. The data base should include information on the hydrologic (water and sediment) characteristics of the river; climatic data; water-quality parameters; biological data; and water use. Establishment of such a data base would significantly improve the efficiency with which degradation/aggradation and related problems can be analyzed.

2. *Mathematical models* should be investigated, and the best available one for simultaneously routing the water and sediment discharges through the Missouri River should be adopted and then adapted as necessary for application to the Missouri River system from Gavins Point Dam to the River mouth. This model could be designed so that both the surface and ground water flows could be jointly considered, and eventually broadened to include water-quality parameters as well. Furthermore, the model should be capable of routing sediments by size fraction, so that it could be used to investigate degradation, aggradation, and channel-bed armoring along the river. In due course, the model should be extended to include water-quality parameters, economic data, and data related to conservation and wildlife interests. It is believed that a computer model of this type would prove to be an extremely powerful tool. For example, if it were available now it likely could resolve the question that was addressed by Subgroup 3, concerning the future rate and extent of degradation/aggradation in the Missouri River. The model should be treated as a dynamic tool, and subjected to continuing refinement, development, and updating for continuing use by the Corps, the Missouri River Basin Commission, the Missouri River riparian states, and other agencies. It is believed that the available methodologies now are at hand to commence development of such a model, and recommended that consideration be given to initiating this task as soon as possible.
3. *Studies of possible corrective measures.* In Section V-C, many possible remedial and corrective measures for the degradation/aggradation were listed. The following were judged to

hold the most promise, and it is recommended that early attention be given to laboratory, field, and/or computer models, of them, as appropriate.

- a. Scheduling of reservoir releases to minimize degradation and aggradation of the main channel, subject to constraints imposed by other uses.
- b. Widening of the channel and/or increasing its sinuosity, to reduce degradation upstream from Omaha.
- c. Installation of low sills across the river, to stabilize the thalweg at the desired profile. Here it should be kept in mind that the sills would have to be spaced quite closely together, in order to be effective.
- d. Investigation of means of improving fish and wildlife habitats, including development of side channels which would serve as nursery areas and attractive habitat for wildlife; development of off-channel lakes and wet lands; restoration of ox-bow lakes by pumping or other means; dike notching; etc. In summary, early attention should be given to measures which will restore and/or improve the habitats essential to a healthy, balanced and vigorous wildlife population.
- e. Means should be investigated to bypass sediment around the Gavins Point Dam, or to route it through the reservoir to the outlet works. No specific measures for accomplishing this were arrived at by this Subgroup; but this approach is judged to be a worthy one for future brainstorming.

The different studies listed above would require different approaches. Some of them clearly would make use of analytical techniques, and be pursued using high speed computers. Others would entail laboratory model studies which would be followed by pilot field studies. In the studies of possible corrective measures, requirements for established objectives and uses (e.g., preservation of the 9-foot navigation channel, and continuation of the flood-control operating rules for the upstream storage reservoirs) should be included as design constraints.

VI. SUMMARIES OF CONCLUSIONS AND RECOMMENDATIONS

A. Summary of Conclusions. The principal conclusions resulting from the Workshop, and the background for them, may be summarized as follows:

1. It is well known that characteristics of the Missouri River along practically its whole length have been radically altered by the extensive flow-regulation and channel stabilization structures installed since about 1930 and operated so as to further one or another of the traditional objectives of river management.
2. It is less well known that the Missouri River was, in its natural state prior to 1930, and continues to be even after installation of the many regulation and stabilization measures, a constantly changing, dynamic system which responds in complex ways to both natural and man-induced changes in its inputs (water and sediment discharges) and boundaries.
3. The flow-regulation and channel-stabilization programs of the Corps of Engineers have been remarkably successful in achieving their original objectives: development and maintenance of a navigation channel; flood control; bank-erosion control; land reclamation; and hydroelectric power generation at the large storage dams.
4. Adoption of newer river-management objectives which have evolved in recent years could impose significant changes on river operation, which may not be compatible with, and in many instances might directly conflict with, the established river-training practices that were designed to serve the traditional river-management objectives enumerated above. The newer objectives are related mainly to environmental management, and include promotion of habitats for fish and wildlife; water-quality enhancement; and provision of increased opportunities for recreational use of the river. The flow-regulation and channel-stabilization operations carried out by the Corps clearly have furthered some aspects of the newer objectives (e.g., by eliminating major floods); however it is equally apparent that they have impacted unfavorably upon others.

5. Since about 1960 there has been progressive degradation (lowering of elevation) of the channel bed and water surface along the Missouri River reach extending downstream from Gavins Point Dam, near Yankton, South Dakota, to about the confluence of the Platte and Missouri Rivers, some 25 miles south of Omaha, Nebraska. The total depths of degradation have been about 8 ft just downstream from Gavins Point Dam; roughly 6 ft in the vicinity of Sioux City, Iowa; and practically zero from Omaha to the mouth of the Platte River. During the same period, along the river reach from the Platte-Missouri confluence downstream to the mouth of the Missouri River there has been comparatively minor aggradation along some reaches and slight degradation in others. The impacts of the degradation along the upper reach of the river are many and varied, and practically all of them are unfavorable. They include lowering of the water-surface elevation in and reduction of the areas of backwater areas and ox-bow lakes; problems in withdrawing river water through fixed intake structures; endangering the foundations of structures supported on the river beds; and shifts in property boundaries.
6. There are many contributing factors, both man-made and natural, to the degradation that has occurred between Gavins Point Dam and Omaha. In summary, the degradation is the result of the sediment-transport capacity of the river along the degrading reach exceeding the supply of sediment to the river from the main-stem reservoirs (which act as large sediment traps) and the tributary streams. The aggradation and degradation along the short river reaches downstream from Omaha are believed to originate from localized causes; i.e., local imbalances between sediment supply, due to local geological factors, flood-plain development, isolated changes in channel sediment-transport characteristics caused by flood-control dikes, etc. One of the most nettling problems, and one on which the Workshop participants could not reach unanimous accord, concerns how much of the degradation/aggradation is due to river regulation

and training works and how much is a result of natural processes and changes in the watershed (e.g., long-term climatic variations; effects of agriculture on watershed sediment yields; stochastic variations due to the nature of flow in erodible bed channels).

7. Reliable, quantitative estimates of the future rate and extent of long-term degradation and aggradation would be invaluable to river-management planning. The development of measures to control the degradation/aggradation along any reach of the river must consider the whole river system and take cognizance of the impacts of the measures on upstream and downstream reaches, and on all of the river-management objectives - both the traditional and newer ones.
8. The present levels of understanding of river mechanics and of the environmental and economic impacts of measures which might be adopted to control degradation/aggradation are not adequate to permit reliable, comprehensive planning of the type outlined in item 7, above. Consequently, optimum future management of the Missouri River, including control of degradation and aggradation, can be expected only if a coordinated, comprehensive, integrated plan of research, development, and management is undertaken. It appears that achievement of the required integration of efforts and of objectives will require a coordinating mechanism, perhaps modeled after the GREAT programs on the Mississippi River, which would provide for inputs to the decision-making process from all affected concerns.

B. Summary of Recommended Investigations. The following list of recommended investigations was extracted from the four Subgroup reports presented in Chapters II through V. Several of the investigations were recommended by two or more of the Subgroups. It is recognized that some of the studies included in the following list may already be in progress or planned for under the aegis of the Corps or another agency. It also is recognized that the study plan likely is deficient in some respects, especially those relating to legal and economic aspects.

The recommended investigations are grouped in chronological phases, each of which should follow upon completion of the preceeding one. The

Subgroups did not undertake to develop a detailed scope of work for, nor to identify the organization(s) which should support and/or carry out the studies.

1. Phase I studies. Phase I would consist primarily of assembling the relevant background information and data in a readily accessible and usable form, evaluating the applicability of the available analytical tools for prediction of river behavior, and preparing detailed scopes of work for the studies of Phases II and III. Specific studies recommended for Phase I are as follows:

- a. *Preparation of data bank.* The available data on the Missouri River should be collected, translated into standardized formats, and placed in computer storage. The format should be such that interested users could gain access to one or another blocks of data with minimal difficulty. Maintenance of the data banks should be a continuing effort, with new data placed in the banks as they become available. The data bank should include hydrologic data, sediment-transport data, channel characteristics, climatological data, water-quality parameters, and physical data on constructed works. Consideration also should be given to inclusion in the data bank of biological information.
- b. *Geomorphic map.* Preparation of a geomorphic map of the Missouri River alluvial plain from existing maps and air-photos would yield a tool that could prove invaluable in reconstructing the physical history of the river. This history would be a very useful guide in prognostication and interpretation of future river-behavior trends.
- c. *Mathematical models.* Available mathematical models for routing water and sediment flows along river channels should be evaluated critically, and a decision made concerning whether any of them is sufficiently versatile and reliable for application to the Missouri River, or whether there is a need to develop a new mathematical model which takes into account the peculiarities of the Missouri River. The model

adopted or developed should have the potential to be interfaced with a computer-based ground-water model of the River's valley. Because mathematical modeling of rivers still is in its infancy, a considerable amount of circumspection and judgement must be used in the selection of a mathematical model. It is suggested that this effort might proceed under the direction and with the counsel of a board of outside consultants many of whom are recognized authorities on river mechanics and/or computer modeling.

- d. *Development of plans of study.* Much of the success of any complex investigation depends on careful forethought and planning. Accordingly it is recommended that Phase I include an effort to develop plans of study for:
 - i. An investigation of the Yankton-to-Ponca reach, which should be retained in an unstabilized state to serve as a benchmark, or reference reach for comparison with other river reaches.
 - ii. Demonstration projects along selected reaches of stabilized river, to test methods for simultaneously retarding degradation and enhancing biological productivity/habitat (e.g., by increasing width, re-establishing secondary channels, dike notching, re-vegetation, increasing river sinuosity, etc.). Study plans for the demonstration should include the following phases: computer and/or laboratory investigation; selection of river reaches for pilot studies; and field pilot studies. In these and subsequent studies of possible corrective measures, requirements for established objectives and uses (e.g., preservation of the 9-foot navigation channel, and continuation of flood-control operating rules) should be included as design constraints. Non-technical (economic, legal, recreational, etc.) aspects of the river modification should figure prominently in the study plans.
 - iii. An expanded, comprehensive data-collection effort along the full length of the river below Gavins Point, with emphasis on rapidly degrading reaches.
 - iv. Pilot projects to promote recovery of oxbow lakes.
2. Phase II studies: The studies included in Phase II would be

continuations of, and would build upon those of Phase I. The specific recommendations are as follows:

- a. *Geomorphic interpretation.* Conduct a comparative study of the maps, including the geomorphic map, included in Phase I, for the period before installation of the flow-regulation and channel-stabilization works, and for subsequent periods. This investigation should aid in determining how much of the river-channel change is "natural", and how much is a consequence of man-made works.
- b. *Mathematical modeling.* Apply the mathematical model forthcoming from Phase I to the Missouri River. High priority questions to be addressed to the model include:
 - i. The effect on the downstream degradation/aggradation of curtailment of the sediment supply to the river by the main-stem reservoirs.
 - ii. Effects of flow-release schedules on degradation/aggradation, and the potential for reducing degradation/aggradation by modification of flow-release schedules, subject to the constraints imposed by flood-control requirements.
 - iii. Effects of Missouri River stages on ground-water table, and thereby on ox-bow lake levels.
 - iv. Effects of artificial channel shortening on the channel behavior, with particular emphasis on aggradation/degradation.
 - v. The time-scale of Missouri River channel adjustments. The question of particular interest here is the rate at which channel changes resulting from curtailment of the sediment supply at Gavins Point Dam propagate downstream.
- c. *Control reach studies.* Continued investigation and use of the Yankton-to-Ponca control reach, to obtain bench-mark data on unstabilized river reaches.
- d. *Channel widening study.* Conduct of mathematical and/or laboratory studies of effect of channel widening on degradation/aggradation. These studies should be concentrated in selected reaches where degradation has been particularly severe.

- e. *Channel sinuosity study.* Conduct of mathematical and/or laboratory studies to explore effects of changes in channel sinuosity (i.e., length and slope) on degradation/aggradation. The particular question to be addressed here is whether permitting the river to recover more of its natural sinuosity would relieve the degradation problem.
 - f. *Bed-material sampling.* Conduct of an extensive bed-core sampling program, to obtain data on river sediments to determine the potential for self-limiting of the degradation by bed armoring.
 - g. *Institutional history.* Compile an institutional history of the river to facilitate implementation of a comprehensive multi-objective management program in which all affected concerns would have a voice.
 - h. *Analysis of existing data.* Analyze the hydrologic and sediment-transport data included in the data bank and compare changes in the stage-discharge rating curves and channel characteristics which have occurred in the stabilized reaches and along reaches without training works and/or major flow-regulation effects (if such reaches exist); changes occurring before and after flow regulation; and changes that have occurred along various River reaches. Interpretation should be guided by results of mathematical modeling and geomorphic interpretation. The objective would be to obtain another prediction of the future rate and extent of bed-aggradation.
 - i. *Data collection.* Initiate and continue intensified data-collection effort on flow and sediment-transport characteristics of the River.
3. Phase III studies. These would be in many respects the culmination of the investigation.
- a. *River pilot studies.* Conduct pilot studies of the effects of channel modifications, including channel widening, increased channel sinuosity, dike notching, backwater channels, etc.

- b. *Ox-bow lake pilot studies.* Conduct of pilot studies of measures to assist recovery of ox-bow lakes.
- c. *Prognosis for aggradation/degradation.* On the basis of historical, mathematical, and laboratory investigations, reach conclusions concerning future rate and extent of degradation/aggradation, and select measures for controlling it or accomodating its unavoidable consequences. Possible remedial measures are listed in Chapter V. Against the background of the information collected in Phases I and II, make a judgement concerning the practicality and likelihood of success of each of these and other possible measures.

APPENDICES

1. Agenda of Workshop
2. List of Participants

APPENDIX A

MISSOURI RIVER DEGRADATION/AGGRADATION WORKSHOP
January 23-25, 1978, Omaha, Nebraska

Sponsored by: Iowa Conservation Commission (ICC)

Organized by: Institute of Hydraulic Research,
The University of Iowa (IIHR)

Location: Office of the Omaha District,
Corps of Engineers
6014 U.S.P.O. & Courthouse

A G E N D A

Monday, January 23

Morning Session (Room 2404)

- 8:30-9:00 Welcome by Col. Ray, District Engineer. Review of background and objectives of workshop by Gerald F. Schnepf (ICC) and John F. Kennedy (IIHR).
- 9:00-10:15 Background and history of Missouri River Degradation/Aggradation, presented by Alfred S. Harrison, Missouri River Division, and Howard Christian, Omaha District, Corps of Engineers.
- 10:15-10:30 Coffee break.
- 10:30-11:45 Continue presentation of background and history. Question and answer period.

Afternoon Session (Room 2404)

- 1:30-5:00 Brief presentations describing problems caused by river degradation and/or aggradation. Chaired by W.W. Sayre (IIHR).
1. Slide presentation. Jack Robinson, Missouri Department of Conservation.
 2. Concerns related to conservation. Gerald F. Schnepf, Iowa Conservation Commission.
 3. Scour at bridges and other river structures. Mark Looschen, Iowa Department of Transportation.
 4. Problems at riverside electrical power stations. John Rexwinkel, Iowa Public Service Company.
 5. Channel maintenance for flood control and navigation. Alfred S. Harrison, Corps of Engineers, Missouri River Division.

6. Problems relating to aggradation in Missouri. Robert L. Dunkeson, Missouri Department of Natural Resources.
7. Concerns related to water resources management. Merwin D. Dougal, Iowa Natural Resources Council.
8. Environmental impacts of river degradation and aggradation. Walter Robohn, Environmental Protection Agency, Region VII.
9. Concerns of the Missouri River Basin Commission. Alan S. Hersch MRBC.

3:15-3:30 Coffee break

Open discussion, chaired by W.W. Sayre (IIHR).

Evening Session (for working participants, at Imperial 400 Motel, 2211 Douglas, at 8:00 p.m.)

1. Summary by J.F. Kennedy (IIHR) of day's proceedings and how they relate to workshop objectives. Charge to working participants.
2. General discussion and brainstorming.
3. Assignments to and organization of working subgroups.

<u>Subgroup</u>	<u>Chairman</u>
a. Background and history	G.R. Hallberg (IGS)
b. Causative mechanisms	V.A. Vanoni (Caltech)
c. Future rate and extent	C.F. Nordin (USGS)
d. Corrective measures	D.B. Simons (CSU)

Tuesday, January 24

Morning Session (Room 2404)

8:30-10:15 Panel discussion on subgroup topics a,b,c,d, above, participated in by subgroup chairmen, and moderated by J.F. Kennedy (IIHR).

10:15-10:30 Coffee break.

10:30-11:45 Open discussion, chaired by J.F. Kennedy

Afternoon Session

1:30-5:00 Working subgroups meet separately to develop recommendations for plans of study to identify causes and investigate possible corrective measures.

Subgroup a	Room 7403
Subgroup b	Room 6018B
Subgroup c	Room 5402
Subgroup d	Room 4410

Room 2404 available for observers not joining working subgroups who wish to conduct ad hoc meetings.

Evening Session (for working participants at Imperial 400 Motel, 2211 Douglas, at 8:00 p.m.)

1. Oral progress reports from subgroup chairmen to total working group.
2. Feedback from total working group to individual subgroups.
3. Regroup into subgroups and work on reports.

Wednesday, January 25 (Morning)

8:00-10:00 Subgroups complete report drafts.

Subgroup a	Room 7403
Subgroup b	Room 6018B
Subgroup c	Room 5406
Subgroup d	Room 4410

Room 2404 available for ad hoc meetings.

10:00-10:15 Coffee break.

10:15-12:00 (Working participants and observers gather in Room 2404)

1. Oral presentations of reports and recommendations by subgroup chairmen. Chaired by W.W. Sayre (IIHR).
2. Final discussion and summarization by J.F. Kennedy (IIHR).

APPENDIX B

LIST OF PARTICIPANTS

SUBGROUP 1: BACKGROUND AND HISTORY OF DEGRADATION AND AGGRADATION IN
THE MISSOURI RIVER

Chairman: Dr. George R. Hallberg Iowa Geological Survey	R.A. Lohnes Iowa State University
D.A. Becker Missouri River Basin Commission	J. Mayhew Iowa Conservation Commission
D.R. Coster U.S. Fish & Wildlife Service	G.E. Schnepf Iowa Conservation Commission
R. Downing Iowa Conservation Commission	Resource Person from Corps of Engineers:
J.C. Kirk South Dakota Department of Game, Fish & Parks	H.E. Christian Omaha District

SUBGROUP 2: HISTORICAL AND CURRENT FACTORS CONTRIBUTING TO DEGRADATION/
AGGRADATION IN THE MISSOURI RIVER

Chairman: Dr. Vito A. Vanoni California Institute of Technology	S.W. Wiitala U.S. Geological Survey
M.K. Bansal Nebraska Natural Resource Commission	C.T. Yang Corps of Engineers, North Central Division
T.L. Berkley Iowa Conservation Commission	Resource Persons from Corps of Engineers:
J.D. Riessen Iowa Natural Resources Council	T.J. Bogler Omaha District
G. Sturm Sioux Land Interstate Metropolitan Planning Council	R.F. McAllister Omaha District

SUBGROUP 3: FUTURE RATE AND EXTENT OF MISSOURI RIVER DEGRADATION/
AGGRADATION

Chairman: Dr. Carl F. Nordin
U.S. Geological Survey

T.H. Yorke
U.S. Fish & Wildlife Service

A. Baldwin
U.S. Fish & Wildlife Service

Resource Persons from Corps of Engineers

W.J. Mellema
Missouri River Division

J.R. Boudreaux
U.S. Fish & Wildlife Service

W. Dorrough
Omaha District

D.E. Brazelton
Iowa Conservation Commission

D. McDonald
Omaha District

A.S. Hersch
Missouri River Basin Commission

M.F. Looschen
Iowa Department of Transportation

M.A. Tesar
Omaha Public Power District

S.W. Wiitala
U.S. Geological Survey

SUBGROUP 4: CONSIDERATION OF CORRECTIVE MEASURES

Chairman: Dr. Daryl B. Simons
Engineering Research Center
Colorado State University

J. Hall
Iowa Department of Transportation

M.C. Ackelson
Iowa Conservation Commission

J.A. Henderson
Kansas Water Resources Board

W.C. Brabham
Iowa Conservation Commission

J.H. Johnson
U.S. Fish & Wildlife Service

B.L. Burnham
U.S. Environmental Protection Agency

J. Kennedy
Iowa Department of Transportation

M.D. Dougal
Iowa Natural Resources Commission

K. McCartney
South Dakota Dept. of Natural Resources
Development

R. L. Dunkeson
Missouri Department of Natural
Resources

W.F. Robohn
U.S. Environmental Protection Agency

J.W. Robinson
Missouri Department of Conservation

A.J. Sohn
Iowa Conservation Commission

N.P. Stucks
Nebraska Game & Parks

D.E. Sutherland
U.S. Fish & Wildlife Service

Resource Persons from Corps of Engineers:

K. Murnan
Omaha District

A.S. Harrison
Missouri River Division

GENERAL WORKSHOP PARTICIPANTS

G.G. Bachman
Omaha Public Power District

B. Stebbings
U.S. Fish & Wildlife Service

D. Bonneau
Iowa Conservation Commission

C. Stevens
Nebraska Department of Water
Resources

T.C. Bruegger
Monona County Conservation Board

J. Stokes
Iowa Conservation Commission

N. Heiser
Iowa Conservation Commission

D. Whiteley
Nebraska Game and Parks

J. Rexwinkel
Iowa Public Service Company

D. Williamson
Nebraska Natural Resources Commission

Resource Person from Corps of
Engineers:

J.M. Horne, Omaha District

WORKSHOP CO-CHAIRMEN:

John F. Kennedy
Iowa Institute of Hydraulic Research

William W. Sayre
Iowa Institute of Hydraulic Research