INVESTIGATION OF SEDIMENT & VEGETATION PROBLEMS LITTLE FALLS RESERVOIR - LITTLE FALLS, MINNESOTA

MINNESOTA DEPARTMENT OF NATURAL RESOURCES & MINNESOTA DEPARTMENT OF TRANSPORTATION

March 1993

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Division of Waters

Pursuant to 1992 Laws-Chap 513
Art. 2, Sec. 5, Subd. 13

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This report is intended to fulfill the requirements of the 1992 Minnesota Legislature concerning resolution of the aquatic plant and sedimentation problems in the Little Falls reservoir. It acknowledges agreement between the Minnesota Department of Natural Resources (MNDNR) and the Minnesota Department of Transportation (MNDOT) on the nature of the problems in the reservoir and outlines alternatives for addressing the problems.

I. LEGISLATIVE MANDATE

Chapter 513, Article 2, Subdivision 13, of Laws of Minnesota for 1992, directs that:

> "*The commissioners of transportation and natural resources shall confer and make every reasonable effort to obtain a permanent resolution of the problem of excessive sedimentation and vegetation in the Mississippi river resulting from the construction of a bridge over the river on marked trunk highway No. 10 near the city of Little Falls.*
>
> *If the commissioners of transportation and natural resources are unable to reach a mutually agreeable resolution by February 1, 1993, the commissioner of natural resources shall file with the commissioner of transportation, the chair of the house committee on appropriations, and the senate committee on finance, a notification that specifies the project or projects that in the judgement of the commissioner of natural resources must be undertaken to achieve a permanent resolution of the excessive sedimentation and vegetation. The notification must contain an estimate of the total cost of the project or projects.*"

II. PUBLIC INFORMATION MEETING

On October 5, 1992 a public meeting was held at the Little Falls Courthouse to enlist concerns, comments, and ideas from residents in the *Riverwood* area concerning the problems in the reservoir. The following concerns and comments were expressed at the meeting:

- reduced water depths in many portions of the reservoir;
- siltation (muck) in areas that formerly had a sand bottom;
- stagnant water conditions;
- increased aquatic vegetation;
- odors from decaying vegetation;
- lowered property values;
- need for wing dike to increase flow through small east bridge;
- need for culverts to restore flow through old middle channel;
- expanded wild rice beds have improved wildlife habitat; and
- caution about projects to redirect sediment within the reservoir.

III. BACKGROUND

RESERVOIR CREATION

Attempts to establish a dam in the Mississippi River at the current site, which consisted of a series of natural rapids and a 20 foot waterfall, are recorded as early as 1850. The first permanent structure was built in 1886 and maintained a pool elevation of 1103 feet. Construction of the dam, essentially as it exists today, was completed in 1920. A reservoir elevation of 1107 plus or minus one-half foot is maintained except during extreme flow events. The record peak flow of 36,951 cfs (cubic feet per second) occurred on April 15, 1965. The low flow of record is 271 cfs, which occurred on August 29, 1976.

SIGNIFICANT FLOOD EVENTS

On July 21-22, 1972, 10-12 inches of rainfall fell over much of the Little Elk River and other local Mississippi River tributaries. This event resulted in very high flows, flooding, and significant erosion along these stream courses. There is speculation that this caused large amounts of sediment to enter the Mississippi River and deposit in the Little Falls reservoir. No hard data was found on how much sediment might have entered the Mississippi River or what percentage settled out in the Little Falls reservoir as a result of this storm.

HIGHWAY 10 BRIDGE/EMBANKMENT CONSTRUCTION

Bridge planning and design considerations are documented in the microfiche MNDNR Division of Waters (DOW) permit file (71-1341), however, little construction detail is included. A route location public hearing was held on April 29, 1967. MNDOT's preliminary site location preference was a more northerly site because of hydraulic advantages. Local officials strongly favored a location closer to the city and the more southerly site was finally selected. The original design for the southerly site included only a bridge opening over the main river channel. This was later modified to include a culvert near the east shore which was eventually enlarged to a small bridge at the request of MNDNR. Construction took place during 1974 and 1975. The existing structure consists of the embankment and two flow openings: the main bridge section approximately 1000 feet wide and the small bridge approximately 50 feet wide.

The plan for embankment construction originally called for dredging 1,150,000 cubic yards of fill from the bed of the reservoir immediately downstream of the embankment location. This proposed dredging caused concern over its potential negative effects on fish and wildlife and its potential to increase erosion along the east shoreline. The proposed dredging was not done, although allowed under MNDNR permit, and instead fill was acquired from an upland site as a convenience to the contractor.

Figure 1 depicts the bypass and reservoir and identifies location descriptions used throughout this report.

SITE DESCRIPTION

Little Falls Reservoir

Little Falls, Mn

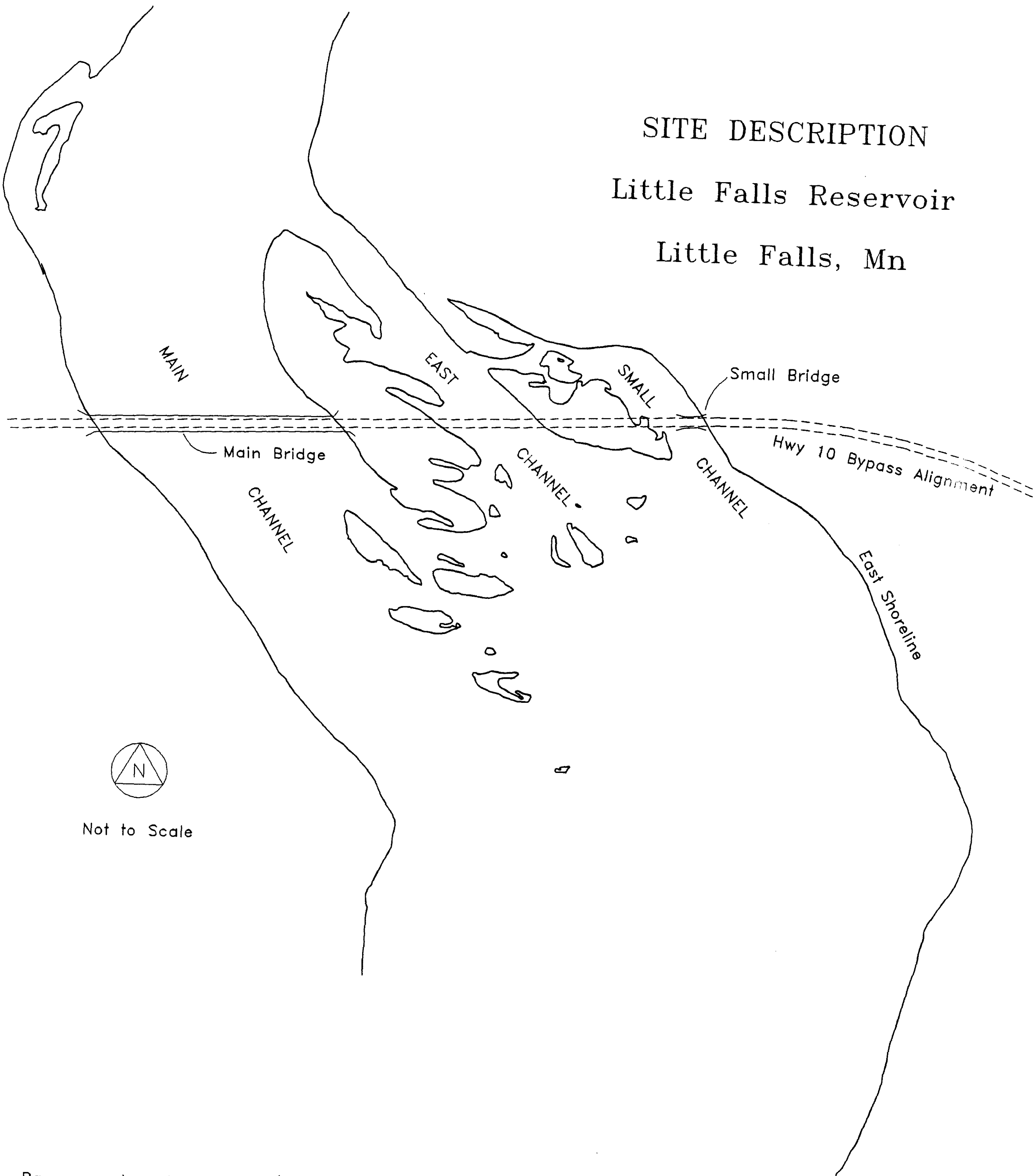

Figure 1

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PAST INVESTIGATIONS OF THE PROBLEM

The following past reports are available containing summaries, evaluations, and recommended actions related to the concerns expressed by *Riverwood* residents:

- 9/28/84 letter report by Russ Schultz, DNR Area Hydrologist, which summarized possible causes and recommended that Morrison County request MNDOT to perform a detailed study;
- 10/9/84 Morrison County Board resolution requesting that MNDOT conduct a study;
- 10/23/84 MNDOT recommendation that the County request the Corps of Engineers (COE) to evaluate the problems;
- 10/12/85 COE Letter Report summarizing possible causes; and
- 10/17/89 DNR Commissioner Alexander letter to State Representative Stephen Wenzel summarizing Fish and Wildlife investigation;
- March 1992 COE report found that the limited benefits provided by any combination of alternative actions could not justify a federal water project, but suggested that alternatives local interests could pursue might include:
    1) improve the channel leading to the small east bridge;
    2) remove sediment from small bridge opening, if needed;
    3) conduct a major dredging project along the east shoreline;
    4) control aquatic plants;
    5) make major bridge modifications;
    6) construct wing dam at upstream inlet of the east channel; and
    7) improve land management throughout the contributing watershed.

IV. PROBLEM ANALYSIS

A work plan was developed to acquire additional site specific data and a better understanding of the processes causing the sediment and vegetation problems. Dr. Gary Parker, a University of Minnesota professor at the St. Anthony Falls Hydraulic Laboratory and a recognized expert in river erosion and sedimentation processes, provided valuable assistance in formulating the work plan and interpreting the data collected. **Dr. Parker's observations are attached to this report in their entirety as an appendix.** Following are summaries of the data collection and analyses that were completed.

EFFECTS OF SEVERE RAINSTORMS

Erosion resulting from severe rainstorms is a known source of reservoir sedimentation and can shorten the useful life of any reservoir. In July, 1972 the Little Elk Creek and Fletcher Creek, which are tributaries that outlet into the Mississippi River a short distance upstream of the reservoir, experienced a flood which was estimated greater than a 500 year frequency. According to the Morrison County Flood Insurance Study, the storm of July 1972 delivered the greatest 24 hour rainfall in recorded Minnesota history.

The 9/28/84 letter report by Russ Schultz, DNR Area Hydrologist stated the following: "*Inspection of aerial photos prior to and after the 1972 flood reveal a significant change in sediment deposits in the bypass area. The little islands grew in size and new ones were created. I believe alot of the additional sediment came from other streams entering the Mississippi River. For example, the Fletcher Creek washout near Highway 371 during the 1972 flood contributed alot of the stream bed sidiment load, in addition to the Little Elk River. It is entirely possible that most of the sediment we see today may have been the result of the 1972 flood.*"

EFFECTS OF THE RESERVOIR

Bed and sediment load, sediment deposition, and sediment scour in a river are natural, dynamic (changing with time), and continuous. Reservoir construction severely upsets the balance of the natural riverine process of erosion and sedimentation. Creation of the reservoir pool results in velocities so low that sediment particles once carried downstream by natural river currents are allowed to settle out within the reservoir. In addition, the reduction of velocities during high flow events significantly reduces the river's scouring capability within the pool. More sedimentation than scour will occur until the flow area within the pool is restricted sufficiently to create velocities high enough to restore the balance between scour and deposition of sediment.

Increased vegetative growth in lakes and reservoirs is a problem encountered throughout the state and can result from a variety of natural and unnatural conditions. Deposition of silt and sediment results in decreased water depths and can result in aquatic vegetation growth in former open water areas. Other factors such as water clarity and increasing levels of nutrients which may or may not be associated with the silt and sediment also can affect the vegetative growth. In the Little Falls reservoir the additional vegetation has restricted public use of portions of the reservoir surface for activities such as water skiing. The decaying vegetation has caused odor and cleanup problems.

EFFECTS OF THE EMBANKMENT

The area of concern is downstream of the highway bridge embankment on the east side of the river (inside of a natural bend in the river). Sediment deposition tends to naturally occur on the inside and downstream of a river or stream bend. As flow moves around the bend, centrifugal force moves water to the outside of the bend causing a secondary current directed towards the inside of the bend approximately perpendicular to the main current. This secondary current directs sediment and bed load to the inside of the bend.

Construction of the highway embankment likely strengthened the secondary current by effectively increasing the sharpness of the natural bend. This would tend to increase the size of the sediment particles being brought into the problem area. The sand and larger sediments would deposit more immediately downstream of the closed off middle channel as the finer sediments (silts) are carried further towards the east shore.

Construction of the highway embankment changed the flow patterns and velocities in the river at and downstream of the embankment. Because these velocities are often very low, the changes may not be visually evident and would be difficult to ascertain even with sophisticated equipment. The best way to document the velocity differences would be through use of physical or mathematical simulation models.

The geometry of the existing bridge and embankment generally results in more flow in the main river channel and less flow in the area immediately downstream of the embankment. Some residents have observed that at times there is no apparent flow through the east bridge and at times floating material moves along the east shore in an upstream direction.

It is important to note that the bridge embankment has not affected the amount of sediment that enters the reservoir. Nor has it increased the amount of sediment which settles out in the reservoir. It has to some extent changed the pattern of sediment deposition within the reservoir. The growth of aquatic vegetation would likely have occurred with or without embankment construction because of the reduced depths resulting from ongoing sediment deposition.

AERIAL PHOTOGRAPHY - DNR

Reservoir shorelines and island outlines were digitized and plotted at the same scale from aerial photos taken in 1940, 1955, 1963, 1968, 1975, 1980, 1983, 1985, 1986, 1987, 1990, 1991, and 1992. The photographs from 1940, 1955, and 1968 show that increasing amounts of island growth had occurred before the highway embankment was built. Island areas were measured for each year of photography and were chronologically plotted to show change in area over time.

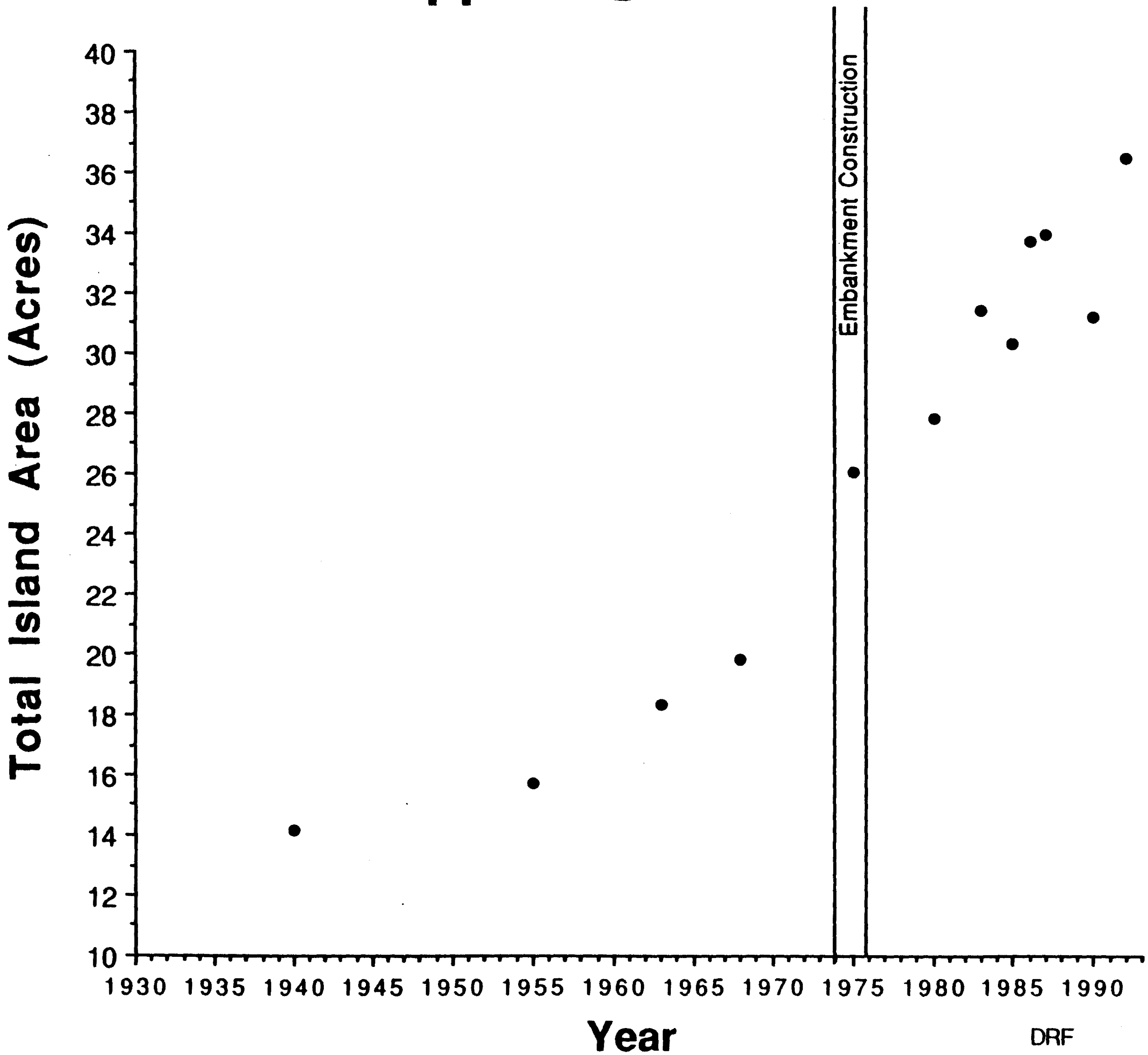
Figure 2 shows how island area has changed over time.

RESERVOIR DEPTH SOUNDINGS - MNDOT

Depth sounding data collected both before and after the embankment was built provide a more direct comparison of how sediment deposition rates have changed. Depth soundings and sediment cores were taken in January 1993 at the same locations where depth soundings had been taken in 1968/1973 and in 1985. The data show that in the area where the soundings were made the average sediment accumulation rate between 1985 and 1993 (0.029 feet/year) decreased compared to the rate for the period 1968/73 to 1985 (0.070 feet/year).

Figure 3 shows locations of individual test holes and Figures 4 and 5 show graphs comparing the change in bottom elevation for various sampling periods.

Island Area
Mississippi R. @ Little Falls



DRF
2/23/93

Figure 2

SOUNDING/BORING LOCATIONS

Little Falls Reservoir

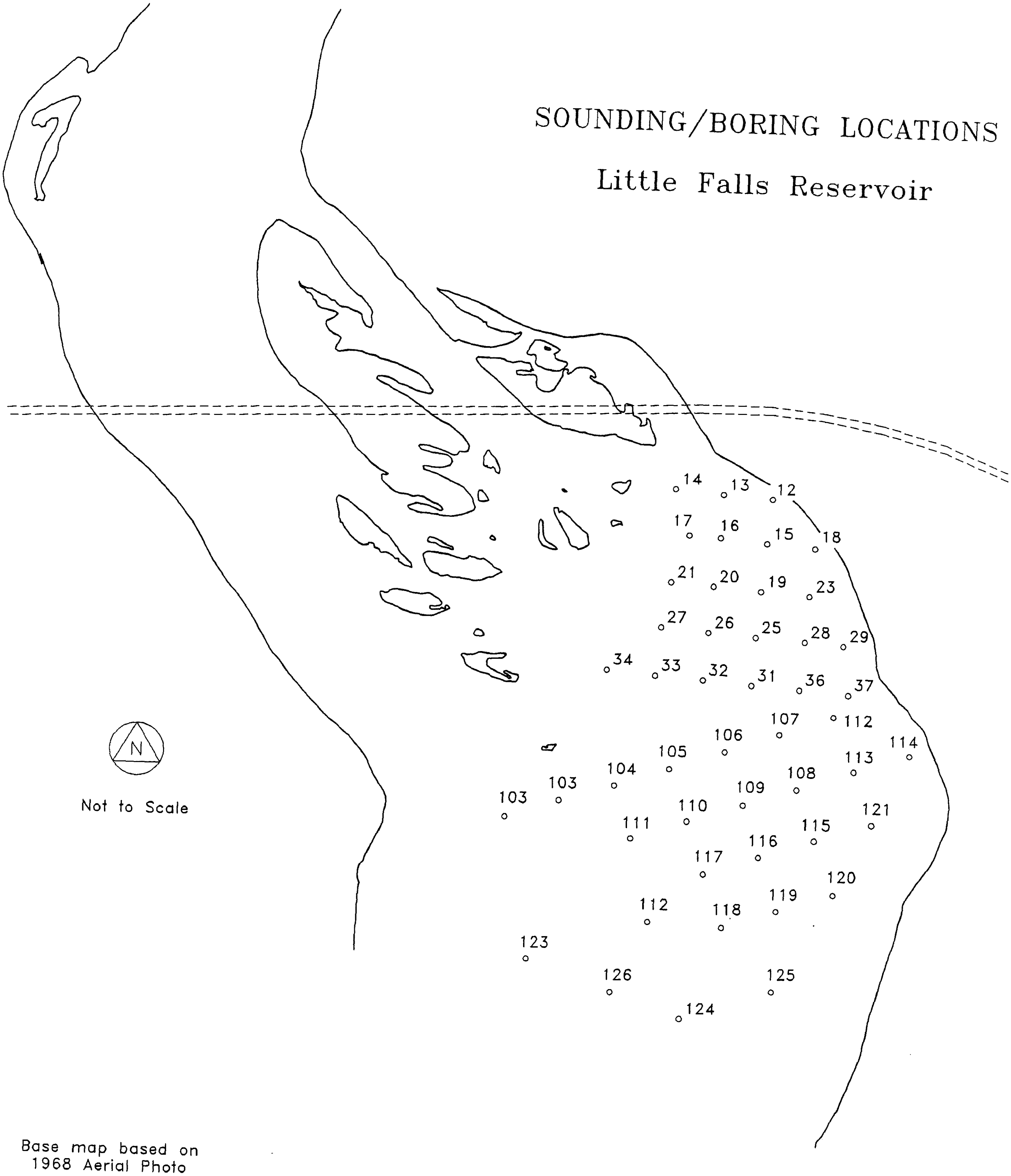


Figure 3

March 1993

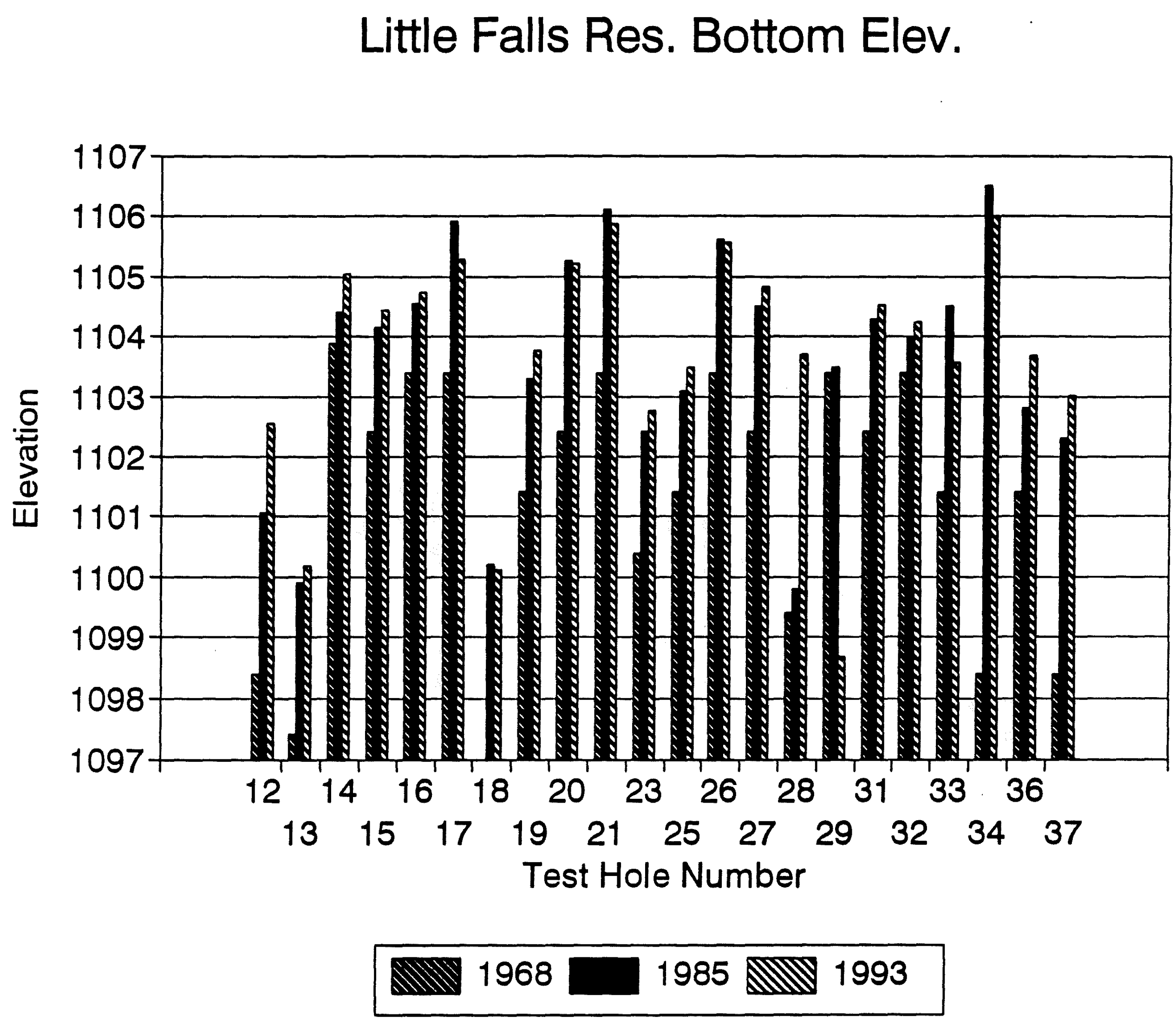

Little Falls Res. Bottom Elev.
1107
1106
1105
1104
1103
1102
1101
1100
1099
1098
1097
Elevation
12 14 16 18 20 23 26 28 31 33 36
13 15 17 19 21 25 27 29 32 34 37
Test Hole Number
1968
1985
1993

Figure 4

Little Falls Res. Bottom Elev.

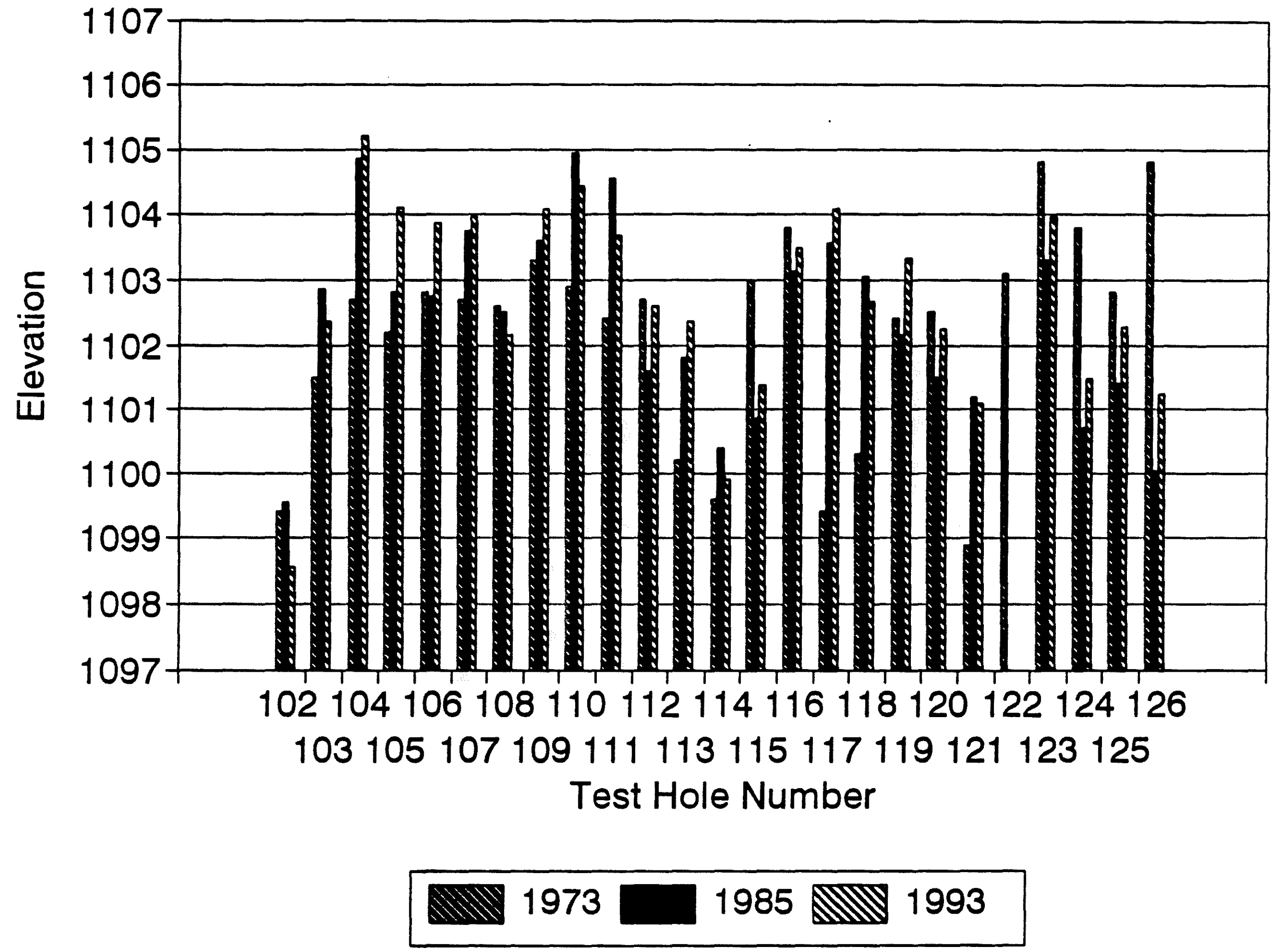


Figure 5

SEDIMENT SAMPLING OF RIVER BED - MNDOT

Sediment samples were collected at 8 locations and analyzed to determine if gross levels of contaminants were present in the bottom sediment. The results of the analyses indicated that one sample, T-33, had detectable levels of cadmium two times the upper end of the naturally occurring range of this element in soil. However, none of the other samples analyzed for metals detected cadmium. All of the other elements and parameters analyzed showed either no detection above the method detection limit, or detected levels that were well within the naturally occurring range in soil. The sample analyzed for the priority pollutant list of parameters (volatile organic compounds and pesticides) showed no detection of any parameter above method detection limits.

Prior to any final decision regarding dredging at this location, additional samples should be collected and analyzed for cadmium. In addition, samples should be analyzed for pesticides and acid base neutral compounds (PAH's - polycyclic aromatic hydrocarbons).

V. FINDINGS

Flow through the small highway bridge on the eastern edge of the reservoir apparently has been adequate to maintain a channel navigable by small craft. Although sedimentation has occurred in several areas, concerned residents have not been prevented access to the main river due to insufficient water depths. Certain portions of the reservoir, however, can no longer be used by large craft. The aquatic vegetation growth and sediment deposition in the island area downstream of the embankment would have occurred even if the embankment had not been built.

There is no practical way to stop sediment from entering and depositing in the Little Falls reservoir, however, the pattern of deposition may be changed through structural alterations. This would not permanently resolve the problems expressed by the residents and could possibly create new problems or make the existing ones worse, depending on how the alterations affected the deposition pattern.

The sediment deposition and aquatic plant growth problems are not unique to this site and construction of the bridge and embankment has only affected these problems - it has not created them. A permanent resolution of the problems through a one-time project or projects does not exist.

Dredging and removal of aquatic vegetation would address the problems, but only on a temporary basis. DNR Division of Fish and Wildlife staff have expressed concern over the environmental effects these actions could have. DNR would likely be able to support limited dredging or vegetation removal as needed to maintain access to the main reservoir by affected residents.

VI. POSSIBLE ALTERNATIVE ACTIONS

A) NO ACTION

- silt deposition could eventually close the small bridge channel

B) AQUATIC VEGETATION CONTROL (physical or chemical)

- temporary measure
- fish and wildlife concerns
- cost dependent on size of area desired to be treated
- disposal concerns

C) CLEAR, AND SNAG SMALL BRIDGE CHANNEL

- would maintain access to river for east shore residents
- may help minimize odor problems
- cost dependent on current and future channel conditions
- temporary measure
- fish and wildlife concerns

D) DREDGE DOWNSTREAM OF EMBANKMENT

- fish and wildlife concerns
- temporary measure
- costs range to over $2,000,000 depending on project scope

E) CONDUCT PHYSICAL MODEL STUDY

- to evaluate effects of structural changes to the bridge embankment
- to identify what improvements to small bridge and channel would be necessary to substantially increase flow along east shore during periods of low flow
- to evaluate effects of constructing wing dike at inlet of east channel
- cost range to $150,000 or more depending on scope of study

F) RESTORE FLOW THROUGH EAST CHANNEL

- best way to restore flow and velocities to pre-embankment conditions
- may not remove existing depositions
- may cause increased sand deposition along east shore, eventually causing access problems
- cost estimated from $500,000 to over $1,000,000
- fish and wildlife concerns
- would require physical model study to evaluate

G) CONSTRUCT WING DIKE AT INLET OF EAST CHANNEL

- may divert sediment/silt problems elsewhere
- could increase sediment delivery through small bridge and increase deposition over current rates
- unlikely to remove existing sediment through scour action
- cost estimated at $50,000 or more
- fisheries concerns
- would require physical model study to evaluate

The longevity of any structural alternative is uncertain. Before large amounts of funds are expended on this problem it would be well to consider the words of Dr. Parker in the final paragraph of his attached report:

> "...*the author would like to suggest that the natural process of deposition within the Little Falls Reservoir cannot be easily reversed or stopped. All that can be done is to rearrange the zones of maximum deposition. In terms of sedimentation along the east bank, all this does is slow an otherwise inevitable process.*"

VII. RECOMMENDATIONS

MAINTAIN THE SMALL BRIDGE CHANNEL

Flow in the small bridge channel, upstream to the main channel and approximately 3000 to 3500 feet downstream of the small bridge should be maintained. This may require some future clearing, snagging, and limited dredging to maintain existing channel geometry. Maintaining the flow along the east shore should minimize odor problems, tend to keep silt from depositing along the east shore, and help to ensure that access to the main river channel is maintained.

MONITOR THE SMALL BRIDGE CHANNEL CONDITIONS

Periodic measurement of water depths and channel geometry should be made to document future bed contour changes along the east shoreline. A baseline survey consisting of a profile and cross sections should be cooperatively completed by MNDOT and MNDNR to document existing conditions. The baseline survey should begin at the confluence of the main channel and the east channel, and extend downstreram along the east shoreline to a point approximately 3500 feet downstream of the highway embankment.

REQUIRE LOCAL SPONSORSHIP OF ANY PROJECT

Specific projects to be undertaken should be sponsored by local entities, however, the State may be interested in assisting with cost sharing funds. Because the highway embankment has had minimal impact on the problems, the residents and local entities should be responsible for the majority of funding for any alternative.

VIII. SUPPORTING DOCUMENTS NOT INCLUDED IN REPORT

9/28/84 Letter Report by DNR Area Hydrologist, Russ Schultz

10/9/84 Morrison County Board Resolution

10/23/84 MNDOT Response Letter

9/25/85 COE Report

March 1992 COE Report

Notes from 10/5/92 Public Information Meeting

Reservoir History by Minnesota Power Company

MNDNR Digitized Aerial Photo Overlays

MNDOT Sounding Data Summary Table, Graphs and Contour Maps

MNDOT Bed Sediment Sampling Report - Feb 22, 1993

ASCS Annual Aerial Photos (1980 - 1992)

NOTE: MNDNR and MNDOT Central, Regional and District office staffs contributed to various phases of the investigation. In addition, contacts were made with the following individuals:

Corps of Engineers - Ed McNally 220-0387
MN Power & Light - John Neimela (218) 723-2641 ext. 3329
St. Anthony Falls Hydraulic Laboratory (U of M) - Dr. Gary Parker

APPENDIX

SOME NOTES ON SEDIMENTATION IN THE MISSISSIPPI RIVER NEAR LITTLE FALLS, MINNESOTA

By Gary Parker
Professor
St. Anthony Falls Hydraulic Laboratory
Department of Civil and Mineral Engineering
University of Minnesota

January 28, 1993

INTRODUCTION

The present brief set of notes is devoted to a sedimentation problem at the upstream end of the reservoir created by Little Falls Dam on the Mississippi River. The author was first introduced to the problem by representatives of the Minnesota Department of Natural Resources (DNR) on September 30, 1992. After having obtained an overview of the issues, the author made several specific suggestions for analysis. Contact was subsequently maintained with the DNR via several telephone conversations. On January 26, 1993, some of the results of the analysis were presented to the author by several representatives from the DNR and the Minnesota Department of Transportation (DOT).

These notes are devoted to an interpretation of the analysis, with some suggestions for future work. The amount of time available for study was restricted. As a result, the conclusions offered here should be interpreted as preliminary.

BACKGROUND

Little Falls Dam was built on the Mississippi River toward the end of the previous century. An early map of the site (Exhibit R, Little Falls Hydro–Electric Project) indicates a wide zone of the river located some one to two miles upstream of the future dam site. This reach contained several large islands, dividing the Mississippi River into several subchannels. After dam construction, most of these islands were apparently submerged for most of the time. The dam supplies water to a run–of–the–river hydroelectric plant. The storage capacity of the dam is relatively small. It is drawn down from time to time, leaving much of the bed of the wide zone exposed.

A map of the site in 1985 (Mississippi River, Little Falls Dam to Belle Prairie Rapids, 2–21–85, Division of Fish and Wildlife, DNR) provides depth contours for the wide zone. As of 1985, a distinct deep channel appears with depths up to 7 ~ 8 ft. Both the width and the depth of the deep channel are comparable to river width and depth farther upstream, where the river is much narrower, In the wide zone, this channel is bounded on either side by sand and mud flats with depths ranging from 0 to 2 ft. The upstream end of the wide zone shows an area of siltation characteristic of the upstream end of a reservoir. At its downstream end, the wide zone is abruptly constricted into a narrow channel with depths ranging from 12 to 20 feet down to the dam itself.

In 1975, a bridge was placed across the deltaic zone at the upstream end of the wide zone. The main span of the bridge traverses the main channel of the Mississippi, which lies to the west here. On the east side, a branch channel with a width of perhaps one fifth of the main channel, here referred to as the "east channel," was filled in to form an embankment for the highway. An even smaller branch channel ("small channel") farther to the east, however, was left open with a short bridge span.

Since bridge construction, residents on the east bank of the wide zone just downstream of the bridge have observed a tendency for sediment deposition and vegetation growth. An area that was previously available to them for recreation is now too shallow for that purpose. One hypothesis concerning this sedimentation is that it was caused or accelerated by the closure of the east channel at the time the bridge was built.

ANALYSIS OF AERIAL PHOTOGRAPHY

The author was shown aerial photography from the following years: 1940, 1955, 1968, 1975, 1980, 1983, 1985, 1986, 1987, 1990, 1991, and 1992. In addition, overlays made by reducing the photographs to a common scale were presented to the author. These overlays cover the periods 1940–1955, 1955–1963, 1963–1968, 1968–1975, 1975–1980, 1908–1983, 1983–1985, 1985–1986, 1986–1987, 1987–1990, and 1990–1992. Finally, the author was given a diagram showing total island area in the wide zone near the bridge as a function of time, ranging from 1955 to 1990.

The material related to the period 1940–1975 is of particular interest, as it predates the closing of the east channel by embankment construction. In 1940, the river at the upstream end of the wide zone already appears as a region of active deltaic sedimentation. The areas of sedimentation range from barely–submerged sand bars at the dowstream end of the delta to a well–vegetated island on the west side of the east channel.

Both the aerial photographs and the overlays show a regular expansion of exposed island area in the deltaic zone over the period 1940–1955–1963–1968–1975. In the 1940 photograph, only a very small area of island is present immediately downstream of the future bridge site. By 1975, island area just downstream of the bridge site had increased by at least a factor of six. Although the embankment was in place in the 1975 photograph, it had evidently not been in place long enough to affect the sedimentation patterns apparent in the aerial photograph of that year.

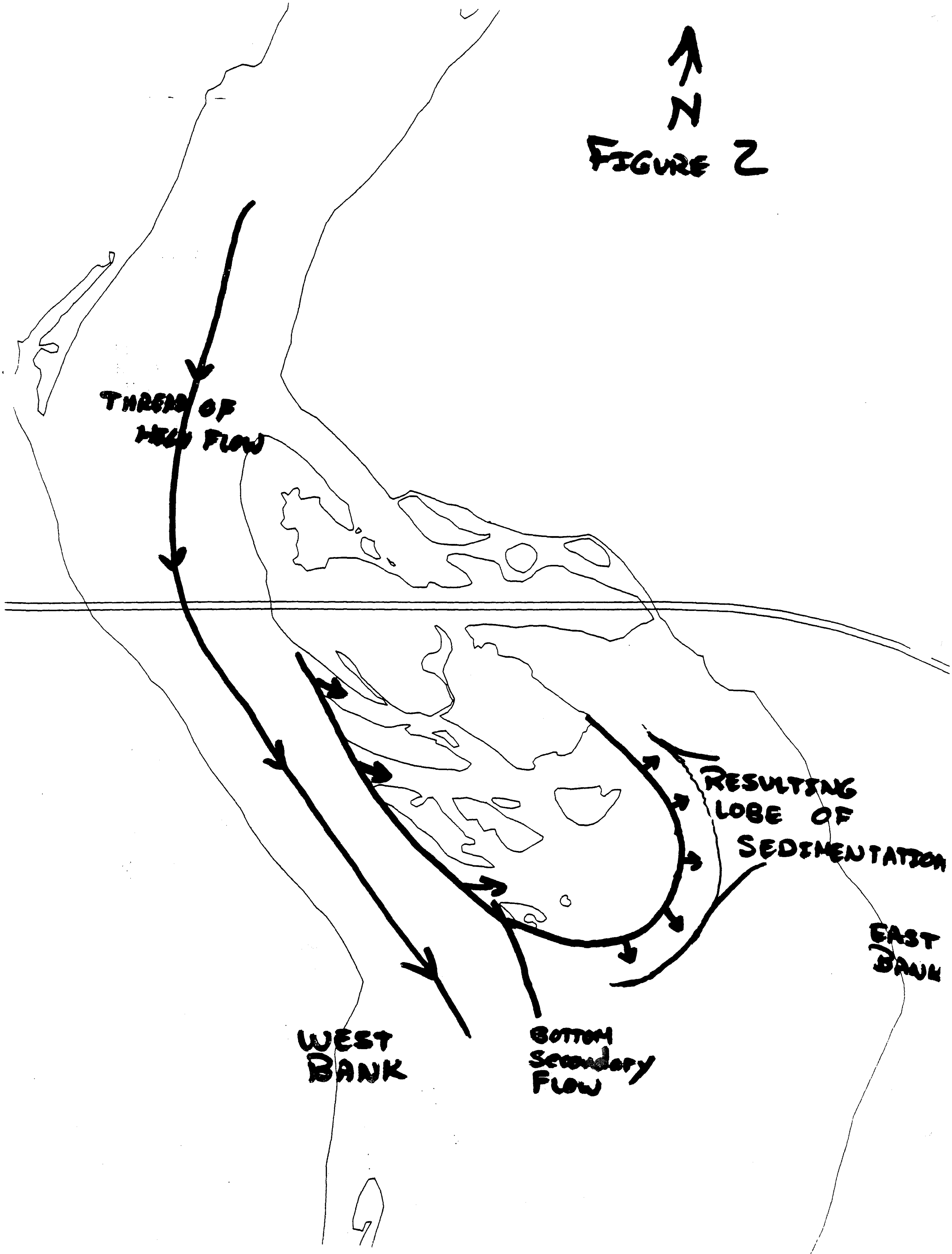
The implication is that the upstream, east side of the wide zone has been an active area of deltaic sedimentation since at least 1940. The region of maximum sediment deposition was located just downstream of the bridge, between the main channel and the east channel. Here sedimentation was progressing downstream at a rate on the order of 20 ft per year. Less sedimentation is apparent between the mouth of the east channel and the east bank of the upstream end of the reservoir itself. This notwithstanding, the photographs and ovrlays show clearly the existence of a branched delta at the mouth of the east channel that was progressing downstream at a slower rate than the lobe of deposition between the main and the east channel.

The construction of the embankment in 1975 arrested resulted in the closure of the east channel. This in turn halted the further downstream progression of deltaic deposits from the east channel. The implication is that closure has partially protected the east bank of the upstream end of the wide zone from further accumulation of river–borne sand. Subsequent aerial photographs and overlays bear this out. A comparison of the photographs from 1975 and 1990 show a general increase in island area between the main channel and the (now–closed) east channel, but practically no increase in island area betwwen the mouth of the east channel and the east bank of the wide zone.

A comparison of the overlays and photographs from 1975 and 1992 do not obviously suggest that the rate of delta formation has increased greatly over the period 1940 to 1975. In fact, the rate of progression of the main zone of deposition downstream at a rate of about 20 ft per year seems to have been continued.

The diagram presented to the author showing total island area as a function of time suggests that the rate of deposition in the deltaic zone has increased somewhat since 1975. Crudely extrapolating using the three pre–closure data points (1955, 1963, 1968), the indication is that 26 acres of island would have formed by 1990. The diagram indicates that 32 acres were actually formed by 1990. (Points for 1986 and 1987 on that graph may have been affected by drawdown, and thus may overestimate island area.)

It should be pointed out that the areas determined for different years are truly comparable only if every photograph were taken at the same reservoir stage. Low river stage exaggerates island area, and vice versa. In addition, time periods with few floods may also be times during which relatively little sediment enters the reservoir. A strict comparision would then involve normalization for varied reservoir stage and flood hydrology.


N
OF
FLOW
RESULTING
LOBE OF
SEDIMENTATION
EAST
BANK
WEST
BANK
BOTTOM
SECONDARY
FLOW
FIGURE 2

into islands. By closing the east channel, the growth rate of this lobe should be accelerated at the expense of sedimentation at the mouth of the east channel. The aerial photographs and overlays argue strongly for this effect.

In terms of sand deposition and island formation, then, the following conclusion can be reached with some degree of confidence. Downstream of the bridge, closure of the east channel has likely reduced the rate of sand deposition between the east channel and the east bank of the reservoir, and increased it between the main channel and the east channel. The net result is likely a lower rate of sand deposition along the east bank of the reservoir than would have resulted if the east channel had not been closed.

Information that further supports this picture is provided by bathymetric maps provided to the author. One map shows coutours for the years 1968 and 1973 (pre–closure). The other is for 1993. The maps show that the greatest increase in bed elevation downstream of the bridge occurred between the mouth of the (closed) east channel and the main channel, exactly where the bend would be expected to put sand. Excluding the thalweg of the main channel itself, the zone of deepest water in 1968–1973 and 1993 is immediately adjacent to the east bank of the reservoir. The same relatively deep channel along the east bank of the reservoir is apparent in the previously–quoted DNR map from 2–21–85. Although some sedimentation is evident even here, the rate would have been likely higher had the east channel not been cut off.

The eventual fate for the region downstream of the bridge and east of the main channel is complete siltation. This is the normal progression of events in a reservoir. It can be modified only by a) a reduction in sediment supply from upstream, or b) dredging in the reservoir. In the present configuration, however, the zone to silt last will likely be the east bank.

It might be argued that the small channel east of the east channel, which is presently open, maintains a flow sufficient to keep the east bank of the reservoir from silting up. In 1940 and 1955, however, this channel was not open, and in 1968 it was only barely open. The deep water adjacent to the east bank is nevertheless evident in the topographic map of 1968–1973, suggesting that the feature is a relict of pre–reservoir days that is not maintained by present fluvial processes.

In addition, when the reservoir is full, the small channel of today flows into a much wider reservoir, thus rapidly dissipating any extra capacity to scour sand. The only present–day process that might act to help maintain deep water along the east bank of the reservoir is reservoir drawdown. This is because drawdown, while very ineffective in removing sediment from the reservoir as a whole, does tend to encourage gullying at the head of existing deep spots as water is removed.

DEPOSITION OF SILT AND CLAY

The above analysis suggests that the closure of the east channel has, if anything, acted to reduce the deposition of sand near the east bank. The same, however, is not necessarily true of finer material. Finer material tends to be transported across the delta front and out into deeper and/or wider slack water, where it slowly settles out. Closure of the east channel may have modified the deposition patterns of this sediment. The process is schematized in Figure 3. The jet from the mouth of the delta may have helped keep a region along the east bank from relatively clear of fine material. Closure of the east bank would have created a zone of relatively slower-flowing water, in which the deposition of fines would have been promoted.

Recent sediment sampling in the reservoir does indeed suggest a progression from west to east from sand to fines. This is at least consistent with the above picture.

The author has no information other than anecdotal concerning the flow in the small channel that is presently open along the east bank. From its size, however, it may not provide enough flow to keep finer material in suspension.

POSSIBLE APPROACHES TO THE PROBLEM

It has been suggested that the closure of the east channel has been the cause of observed siltation along the east bank of the reservoir near the delta. The evidence suggests that the area along the east bank may have been subjected to a higher rate of samd deposition had the east channel not been closed. On the other hand, closure of the east channel may have elevated somewhat the deposition of fines downstream of the delta near the east bank. The eventual complete siltation of the region in question is a forgone conclusion, embankment or no embankment.

One proposal to help alleviate the deposition is the construction of a spur dike at the head of the small channel in order to bring more flow along the east bank of the reservoir. This is shown in Figure 4. As long as the silted zone is shallow covered by aquatic vegetation, however, even substantially increased flow is unlikely to result in removal of existing deposits. Indeed, if the flow brings more sediment, the vegetation may act to retard near-bottom flow and cause fine sediment to deposit anyway.

With this in mind, it makes little sense to augment the flow in the small channel without dredging out a substantial amount of sediment near the east bank of the upstream end of the reservoir. Once this is is done, an augmentation of flow may, but is not guaranteed to, slow down the rate of sedimentation. It will not halt the natural process by which a reservoir fills.

A spur dike may help to augment flow into the small channel, but a more effective approach might be to increase the bridge span across it. The

FIGURE 3.

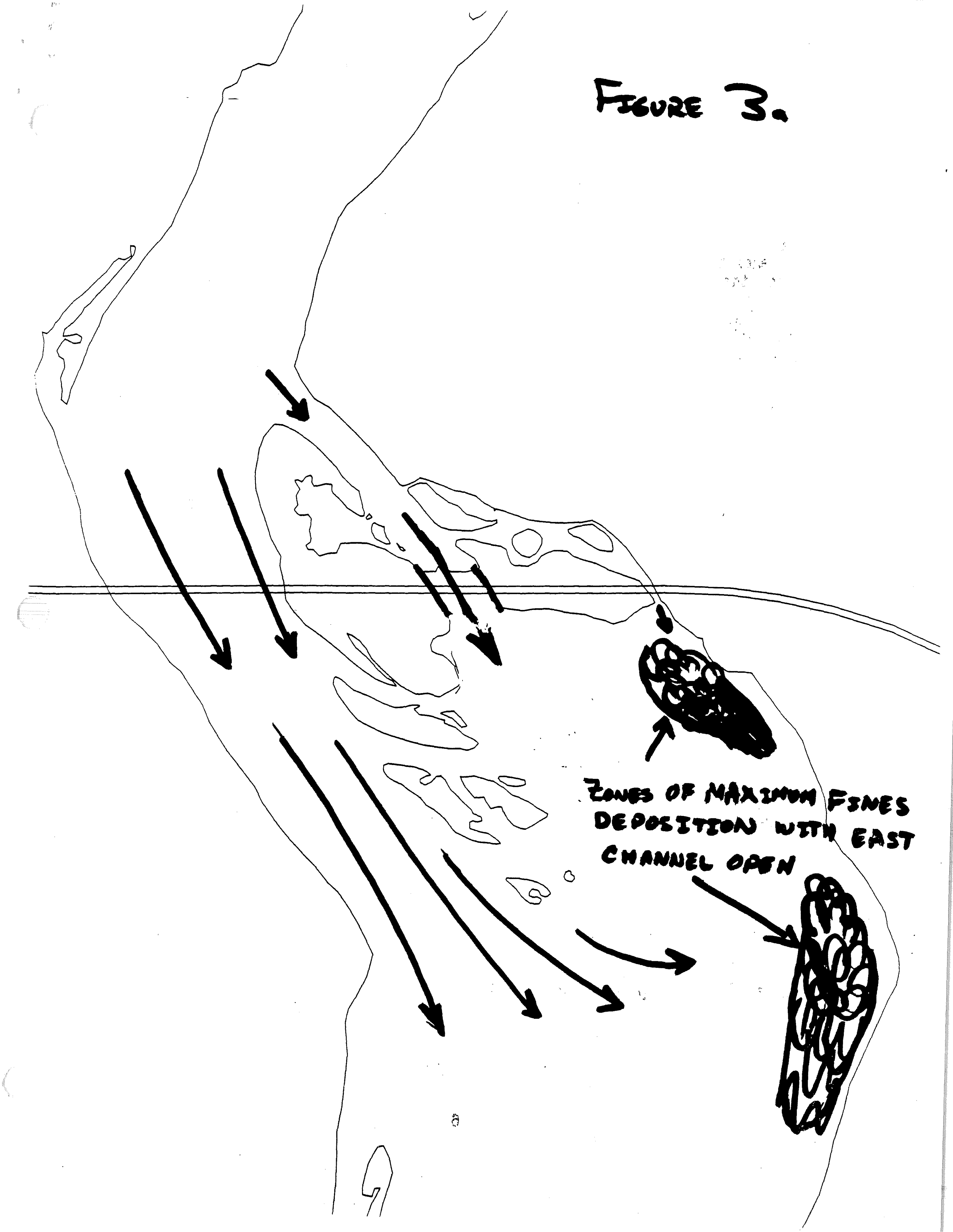
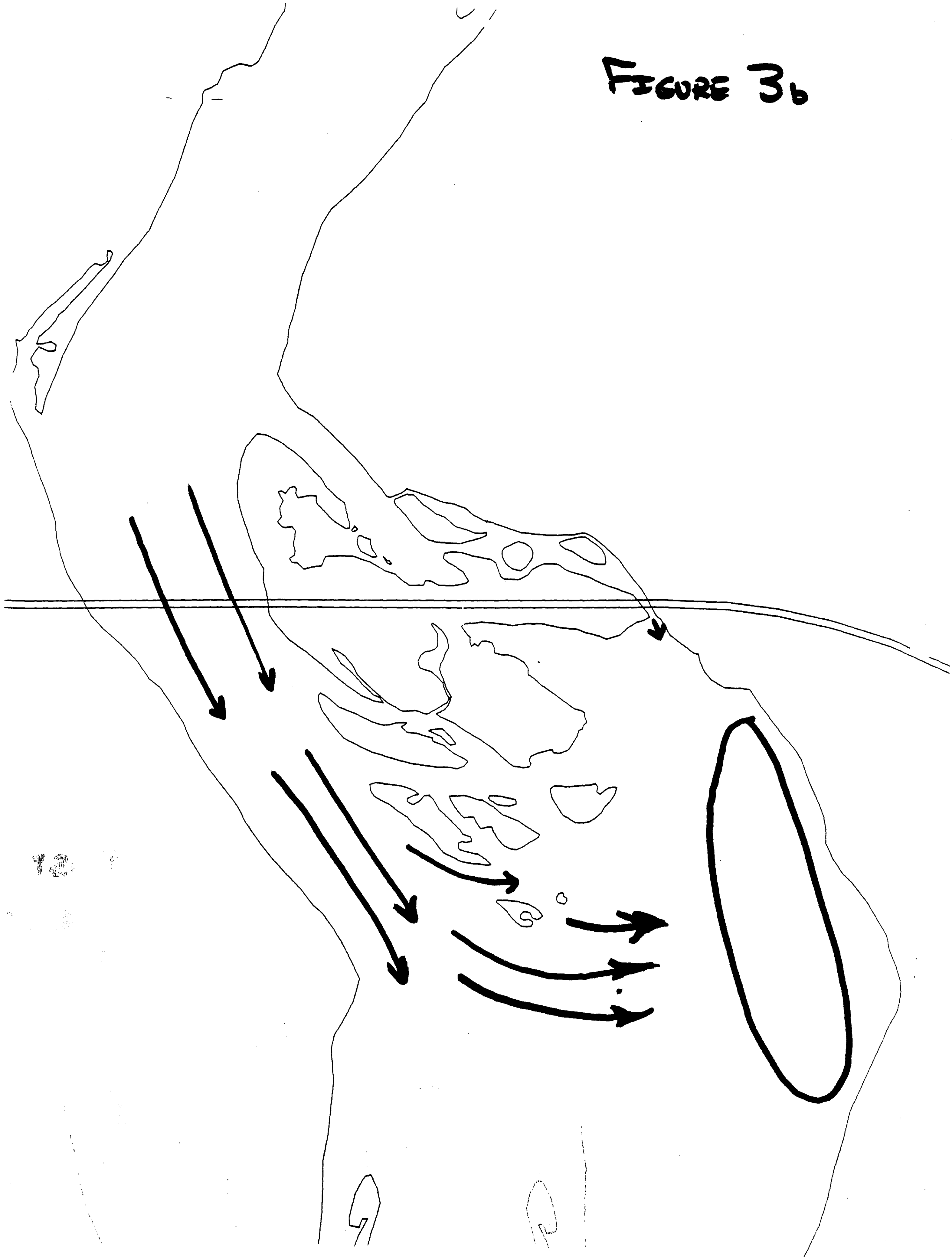


FIGURE 3b



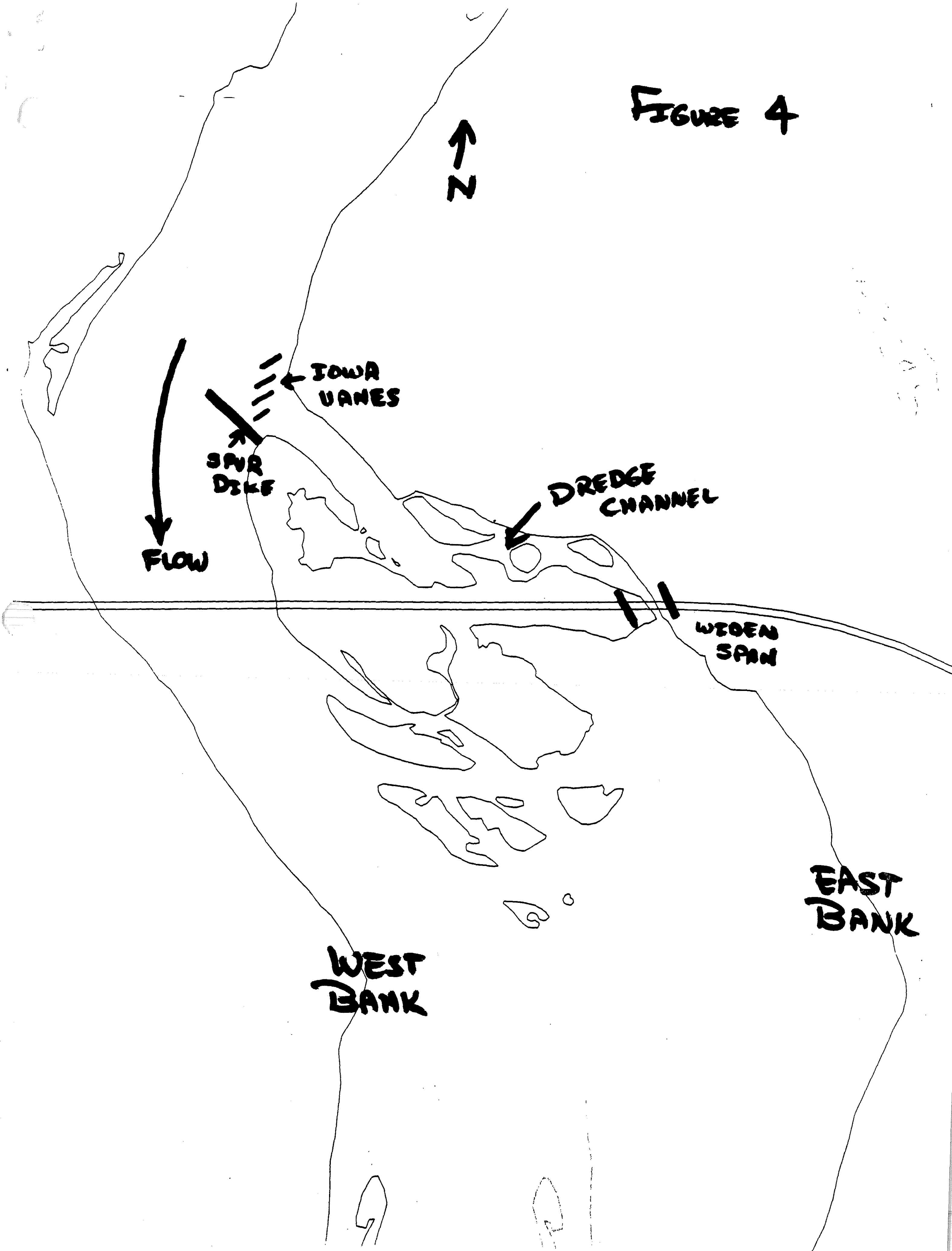


FIGURE 4
N
IOWA VANES
SPUR DIKE
FLOW
DREDGE CHANNEL
WIDEN SPAN
EAST BANK
WEST BANK

channel itself may need to be dredged. Dredging of the channel, however, invites more deposition within it. Therefore, the installation of some kind of control structure such as Iowa vanes at the head of the small channel may be necessary to reduce the supply of sand to it. This is shown in Figure 3.

Some insight concerning the efficacy of measures to increase flow to the small channel can be gained with a physical model study. The spur dike, a wider bridge span, and Iowa vanes can all be studied in a single movable–bed physical model. In addition, the sand deposition downstream of the bridge could be studied in such a model.

The pattern of circulation and deposition of fine material cannot be studied adequately in a movable–bed model. A fixed–bed model is recommended. Tracers such as plastic particles would be used in order to delineate the effect of increased flow from the small channel on patterns of fines deposition. Another possibility for studying the fate of fines is a two–dimensional numeral model of circulation in a shallow resevoir.

Having noted these possibilities, the author would like to suggest that the natural process of deposition within Little Falls Reservoir cannot be easily reversed or stopped. All that can be done is to rearrange the zones of maximum deposition. In terms of sedimentation along the east bank, all this does is slow an otherwise inevitable process.