Contract Report 607

Benthic Sediment Conditions and Remediation Alternatives for Horseshoe Lake, Alexander County

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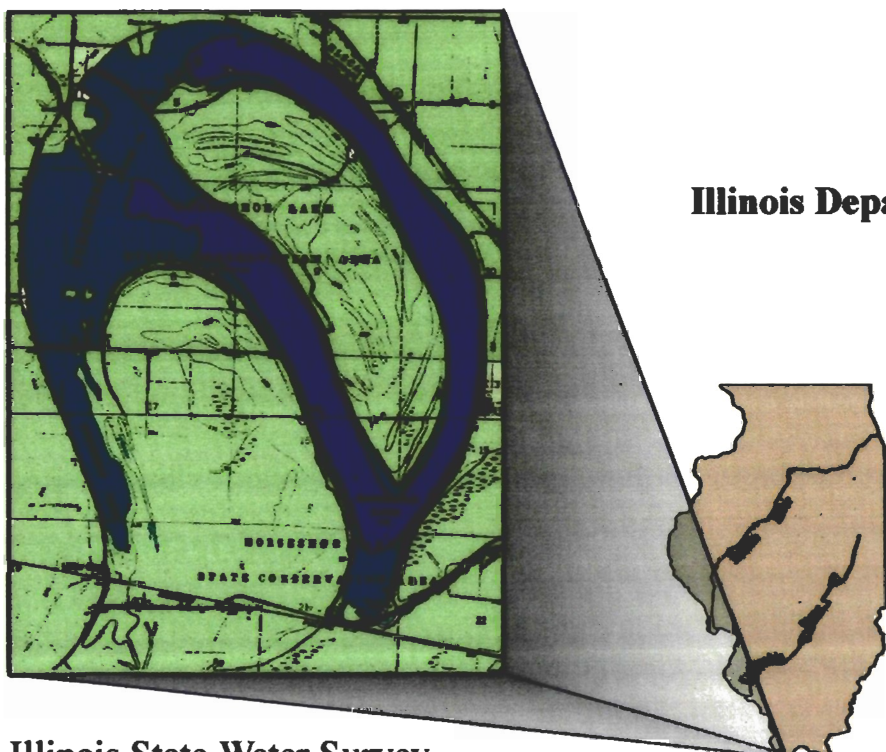

Prepared for the
Division of Fisheries
Illinois Department of Natural Resources
Springfield, Illinois

February, 1997

Illinois State Water Survey
Chemistry and Hydrology Divisions
Champaign, Illinois

ILLINOIS DEPARTMENT OF NATURAL RESOURCES

A Division of the Illinois Department of Natural Resources

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February 1997

Table of Contents

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By Thomas A. Butts and Krishan P. Singh

INTRODUCTION

Horseshoe Lake, a 2,007-acre lake created from a natural oxbow of the Mississippi River in extreme southern Illinois (figure 1), is part of a 9,560-acre state conservation area (exclusive of lake surface area). The 20.6-square-mile watershed is drained principally by Black Creek (9.96 square miles) and Pigeon Roost Creek (3.78 square miles). These streams are subject to flash flooding during heavy rains and are the primary sources of water and sediment to the lake. Generally, the Mississippi and Ohio Rivers flood the lake two out of three years, thereby creating a periodic, secondary source of water and sediment to the lake. The flooding event lasts an average of 30 days. The high floods occur predominantly during March and April; however, they may begin in early February and end in late June.

Horseshoe Lake existed as a shallow bottomland cypress swamp prior to its purchase by the state in 1927 (figure 2). The present conservation area was developed through a gradual acquisition of adjacent lands. The Illinois Department of Conservation (IDOC) constructed a stop-log dam/spillway in 1929, and it was washed into the lake by the Mississippi River backwater during a 1930 spring flood. A new and improved structure with two undersluices was built in 1931. A concrete spillway was added in 1939. The spillway crest was set at an elevation of 321.41 feet above mean sea level or ft-msl (figures 3 and 4). The lake was reportedly raised 4.5 feet above the pre-1929 level (figure 2), which significantly increased the potential sedimentation capacity of the lake because of the increased capacity/inflow ratio. The two undersluices have manually operated 4 foot x 5 foot gates. Fish screens (figure 4) were installed in front of the sluices during the spring of 1995, partially in anticipation of this study.

The lake watershed is bordered on the west along the Mississippi River by Dogtooth Bend and Len Small levees, completed in 1943, and the Fayville levee, completed in 1969. The area is bordered by bluffs on the north and east. Prior to Fayville levee, flooding was from the north. Historically, the Mississippi River has backed up into the lake from the south, thereby contributing some sediment to the lake. Future occurrences may be lessened due to implementation of drainage and levee construction projects in this area.

Background

Two major and one minor lake sediment surveys have been conducted over the past 45 years. O.M. Price of IDOC conducted an extensive survey during January and February 1951 (Lee et al., 1986), Don Garver of IDOC did an attenuated version of Price's survey during 1980 (Lee et al., 1986), while the Illinois State Water Survey (ISWS) conducted an extensive survey during 1984 (Bogner et al., 1985). The numbered transects shown on figure 1 were used during the 1984 ISWS survey. Nine transects are replicates of Price's 1951 survey. Some generalized conclusions paraphrased from Bogner et al. (1985) are:

- Lake areas near the mouths of Black and Pigeon Roost Creeks are rapidly filling with sediment.
- Some clay and fine silt particles appear to be flushed from or through the lake during floods, but at lesser flows these and coarser particles tend to settle in the middle and lower reaches of the lake.
- The rate of siltation in the shallower upper reaches of the lake is so rapid that this area will be converted to marshland in 30 to 50 years.
- The overall sedimentation rate is so great that the lake will lose 50 percent of its volume by 2022 and practically 100 percent by 2060.

A comprehensive water quality study of the lake was conducted by the ISWS during 1984 (Lee et al., 1986). The basic conclusion reached was that the lake is highly eutrophic. Nutrient levels are very high, and they result in prolific algal growths. These, in turn, produce wide swings in diurnal dissolved oxygen (DO) levels. Also, bottom sediments exert high sediment oxygen demand (SOD) rates. This creates significant DO stratification in the water column. Surface DO may be 150 to 200 percent saturation, whereas bottom values in only 3 or 4 feet of water are always less than saturation and may approach zero during warm weather conditions.

Comprehensive Study Necessary

Record flood flows persisted along the upper Mississippi River from July - September 1993, causing extensive breaching of levees upstream of Cairo. During July 1993, the Fayville levee broke, submerging Horseshoe Lake under as much as 10 feet of water for several weeks. Two ISWS engineers visited the area in early November 1993, and observed new sediment deposits as deep as 12 inches in farmland below the lake. This was a cause for concern. The engineers theorized that if similar deposits had occurred in the lake proper, an equivalent of 25 years of normal sediment accumulation would have occurred in 1993 alone. If this had indeed occurred, the present recreational usefulness and wildlife-refuge values of the lake would have been seriously threatened. The very existence of the lake, as an open water body, appeared bleak. Apparently, mitigatory plans needed to be developed and implemented within a two- to three-year period to prevent further deterioration of the lake and to start it back on a "road" to rehabilitation.

To this end, Singh and Butts in early 1994 submitted a comprehensive study plan entitled, *"A Proposal For the Preservation and Rejuvenation of Horseshoe Lake - Alexander County, Illinois,"* which outlined a unique and innovative long-term program that could possibly save the lake. The plan was based on a concept referred to as "sediment venting", a procedure designed to periodically remove sediments hydraulically over a number of years.

Succinctly, sediment venting, as applied to Horseshoe Lake, would consist of routing excess flows through the two bottom sluices instead of releasing flows solely over the spillway. The underflows would be conducive to sediment transport from the lake, which would lead to a gradual reduction in lake sedimentation over a period of 15 to 20 years. However, this shallow lake is not ideally suited for sediment venting. Significant portions are obstructed with cypress groves; two causeways (figure 1) bisect the lake; and the hydraulic capacity of the stream below the dam, Lake Creek (figure 1), is very limited. Lake Creek has a relatively flat gradient; it is full of brush and log jams, and is obstructed by a gravel road overpass about a mile below the lake outfall (figures 1 and 5), with pipe culverts sitting about 3 feet above the creek bed. Because of the limiting natural hydraulic conditions, the assumption was made that the benthic sediments would have to be physically disturbed during periods of flood flushing through the undersluices to achieve continuous sediment transport through the gates.

The principal objectives of the comprehensive study plan were:

1. To quantify changes in sedimentation in Horseshoe Lake resulting from the 1993 Fayville levee break.

2. To evaluate sediment quality throughout the lake.

3. To determine, through field studies, the hydraulic capacity of Lake Creek and the Cache River below Lake Creek.

4. To develop a 20-year hydrologic database and regime relating precipitation to Mississippi River water levels.

5. To develop a practical method of operating the undersluices in concert with spillway overflow to effect sediment venting without adversely affecting downstream woodland, prairie, and aquatic habitat.

These objectives were to be completed over a two-year period.

Proposed Study

Because of the hydraulic/hydrologic limitations and drawbacks related to sediment venting from shallow lakes, it was decided to conduct a small-scale preliminary study before embarking on a comprehensive two-year project. The preliminary study plan was originally designed to evaluate only the feasibility of venting sediments through the undersluices. As a precursor to this feasibility study, the hydraulic capacity of Lake Creek was to be increased by replacing the metal culverts (with inverts about 3 feet above the creek bed) shown on figure 5 with properly sized box culvert. Four field trips were to be made between June and September 1994, to operate the undersluices and to monitor discharge sediment concentration.

Each field trip was to be a 3-day visit. A 4- to 6-hour afternoon run would be made ,the first day, an 8- to 10-hour run the second day. The trips would culminate on the third day with a 4- to 6-hour morning run. If flow volumes were adequate, limited discharges would be maintained during the night. Water samples would be collected upstream and downstream of the dam and at the gravel-road culvert. The samples would be analyzed in the laboratory for total suspended sediment and volatile suspended sediment concentrations. Staff gages were to be installed immediately above and below the dam and above the gravel-road culvert on Lake Creek.

This plan, albeit limited in scope, was intended to provide basic information for determining:

- Best combinations of flow releases over the spillway and through the undersluices to maximize sediment transport downstream without causing physical and biological damage
- Sediment venting efficiencies for various undersluice gate openings
- Time required to deplete sediments amenable to venting in the area immediately upstream of the dam

- Practical methods for moving upstream sediments toward the dam to provide a continuous supply of sediments at the dam during venting operations

The field work was scheduled to be done between June and September of 1994. However, it was postponed until the summer of 1995 partly because dry conditions persisted during the spring and summer of 1994 and partly because corrugated metal culverts were not replaced with box culverts as agreed upon. In contrast to 1994, extremely wet conditions persisted during the first half of 1995. Early in 1995, significant flooding occurred in the area. Although the metal culverts had not yet been replaced, ideal overflow conditions developed early in July 1995, and field work initiated on July 12 was completed on November 1, 1995.

The data and information generated from the first three "three-day" trips indicated the possibility that significant sediment loads could not be vented during flow releases over the spillway or through the undersluices (or a combination of both) without efficient means of feeding the sediment to the area near the dam. A true test of the practicality of sediment venting could not be ascertained due to a lack of replenishment of ventable sediments in the immediate area above the dam. A fourth trip was used to verify this plausibility via sediment coring at numerous locations throughout the lake.

Acknowledgments

This study was partially funded by a research contract administered by Scott Stuewe, from the Illinois Department of Conservation (now Illinois Department of Natural Resources) - Division of Fisheries. The project was conducted jointly by the Office of River Water Quality and the Office of Surface Water Resources: Systems, Information, & GIS, both of the Illinois State Water Survey, under the general administration of Dr. John T. O'Connor, Chief. Thanks are extended to Water Survey personnel Dana Shackleford, Robert Larson, and Tori Spangler for their intensive efforts in the field and in the laboratory to make this study successful. Special thanks are extended to Horseshoe Lake site superintendent Russell Garrison and his staff for providing equipment and assistance when unforeseen problems developed during field activities. Norma Lee Rhines typed the final manuscript, which Eva Kingston edited.

METHODS AND PROCEDURES

Sediment Venting

Field data and suspended sediment samples were collected for three sediment venting scenarios. These scenarios are summarized as follows:

	Flow release		Sediment disturbance		
Scenario	Spillway	Sluices	None	Raking	Hydraulic
1	X	X	X		
2	X			X	
3		X			X

The natural flow over the spillway during the period of scenario 1 was high. Consequently, the sluice gates were completely opened to permit as much flow as possible to pass through the sluices. However, doing so did not prevent a significant portion of the flow from passing over the spillway. The plan was to collect suspended sediment samples from the downstream side of the Lake Creek Road bridge and below the metal culverts at hourly intervals over a span of six hours. The gate release time was quickly reduced to one hour when undesirable and potentially dangerous hydraulic conditions began to develop downstream. The culverts could not handle the flow, creating overbank water levels between the gravel road and the dam. The road embankment covering the culverts became water-logged in several areas. Moreover, most of the flow from both gates was being directed toward the west abutment of the Lake Creek Road bridge, creating a situation with potential for undermining.

The natural flow over the spillway during the beginning of scenario 2 was significantly greater than that observed during scenario 1. Consequently, the situation was viewed with trepidation. The decision was made not to open any sluice gate since undesirable and potentially dangerous conditions developed for lesser flows observed during the first field trip. Sampling was therefore done under ambient spillway conditions in concert with sediment "raking". Raking was accomplished by dragging two 15-foot lengths of log-chains behind a boat powered by a 40 horsepower outboard motor (figure 6). Nine sediment samples were collected over about a 4-hour period.

For scenario 3, the lake level was below the spillway (figure 4), and the west sluice gate was opened 35 percent while the east sluice gate was left closed. Nine sediment samples were collected over about a 4-hour period while sediments were hydraulically disturbed using a water jet. The water jet was created by mounting a 53 gallons per minute (gpm), gas-operated water pump on a small boat that towed it. The normal 1 1/2-inch discharge line from the pump was reduced to 1/2 inch. This created a high pressure discharge that was kept submerged into the bottom sediments as the boat transversed the area immediately above the dam.

During the three scenarios water samples were collected in a 1-gallon, wide-mouth, plastic bottle attached to a long dipping pole. Collections were made at water mid-depth from the centerline of the downstream side of the Lake Creek Road bridge. The samples were poured into a 5-gallon bucket and vigorously mixed as portions were transferred to 250 milliliters (mL) plastic bottles. The samples were cooled in the field and in the laboratory until suspended sediment analyses were made.

Discharge measurements were made at the upstream side of the bridge using a Price current meter attached to a bridge-board. Cross-sectional velocities and depths were determined at 11 verticals. Current-meter readings were taken at water depths of 0.2, 0.6, and 0.8 h, where h is the water depth along the vertical.

Sediment Coring

A cursory examination of the results achieved for the three scenarios indicated that a fourth sediment-venting field run would probably not produce any additional useful information. Consequently, the decision was made to conduct an attenuated sediment survey of the entire lake. Core samples were taken at locations established by Bogner et al. (1985) as shown on figure 1. Core samples were taken using a 2-inch Wildco hand core sampler fitted with either a 30-inch-long tube (figure 7) or a 48-inch-long tube (figure 8). Clear plastic tube liners were split down the center with a band saw, taped into full cylinder form (figures 7 and 8), and inserted into the core sampler tubes. The tubes were fitted with a plastic "nose piece". When loose, watery sediments were encountered, "egg-shell" retainers were used. A 5-foot hand extension was used to force the coring tube in the bottom sediments. Core samples, in the split liners, were removed from the tubes and capped as shown in figure 7 for transport back to the laboratory.

Cross-sectional distances were determined using a Leitz Model 8026-15 split-image rangefinder. Images were sighted on the closest bank at the coring stations and on both the right and left banks at a point approximately in the centerline of the transect to determine total transect distances. All coring stations were referenced to the left bank looking downstream (LBLDS) for the data tabulations and presentations.

A 2-inch diameter aluminum sounding pole, graduated in tenths of feet and fitted with a sliding, 8-inch diameter shoe, was used to determine water depths (figures 9 and 10). Water depths were measured by lowering the pole until a slight upward resistance was felt on the shoe, which was loosely engaged at the bottom of the pole. The shoe is sensitive to slight resistance's such as those which are encountered in soft, flocculent sediments. The pole is designed to measure sediment "depths" by disengaging the shoe using pressure and manually pushing the pole into the sediments to a point of "refusal". The sounding pole/shoe device combination has been successfully used in many lakes and reservoirs to accurately determine sediment deposition depths, but it does not appear to be applicable to the unique conditions in Horseshoe Lake. During this study, such depths were recorded, but not reported since the points of refusal did not match up well with the "hard compact, gray clay" depths observed in the split-core tubes.

Laboratory Analyses

Standard methods (APHA, 1992) procedures were used to determine the suspended solid concentrations in the samples collected during the three venting runs. Aliquots of either 50 or

100 mL were dried at 105°C to determine total suspended solids; the dried samples were then heated to 550°C in a muffle furnace to determine volatile suspended solids.

The sediment core samples were placed in cool storage in an upright position upon return to the laboratory. Sediment unit weights or densities were determined for 33 one-inch thick slices cut from 13 cores. Slices from the top, middle, and bottom were taken from seven of the cores while only top and bottom slices were extracted from the other six cores. Wet and dry weights and volatile solids content were determined. Dry weights were determined by completely drying the 1-inch deep, 2-inch diameter samples at 105°C in an oven. The volatile contents of the samples were determined according to standard methods (APHA, 1992) by heating the samples to 550°C in a muffle furnace to vaporize the organic matter.

The split-liners were opened, the sediment cores were cataloged and described, and the core slices were removed and analyzed within six days of collection. The split-liners enabled the cores to be examined in a relatively undisturbed state. The standard procedure of removing cores from whole or nonsplit tubes using a plunger type core remover or splitting frozen cores usually causes physical changes in the sediments that can alter the interpretation of *in situ* conditions.

The cores were subjectively described in terms of consistency (pasty, compact, watery, dry, etc.), detritus content (fibrous, wood chips, leafy etc.), color (tan, gray, tan-gray, etc.), and dominant particle size or sizes (silt, clay, etc.). The tubes were opened while they were in a prone position, a rule was laid in line with the core, and a dissecting knife was used to probe the core makeup and to select the one-inch slices. Visually discernible changes in consistency, detritus content, color, and particle size were noted and recorded by depth (inches). Particular note was made when the "native soil" core depth was reached. Usually it could be described as hard gray clay. A color photograph was taken of each core.

RESULTS

The results of this relatively small study are presented on the basis of the two substudies performed, i.e., sediment venting and coring. The results are informative, interesting, and could provide significant input in formulating management and restoration plans for the lake.

Sediment Venting

Table 1 provides the hydraulic/hydrologic conditions that were set or encountered during the three sediment venting runs. Note that the flow rates of 370, 83, and 215 cubic feet per second (cfs) were recorded for runs 1, 2, and 3, respectively. The relatively low flow recorded during run 2 was due to the fact that flow was not released through either of the two undersluices. The flow over the spillway at the time of run 2 was greater than during run 1 and was causing flooding in Lake Creek above the road culverts. Consequently, since sluice underflow, in conjunction with a much lesser spillway overflow, had created severe flooding and hazardous downstream hydraulic conditions during run 1, the decision was made to conduct run 2 under ambient conditions. In retrospect, the overflow rate was not as great as it visually appeared to be, thereby reducing the effectiveness of this venting run relative to the other two runs. However, a significant conclusion can be reached from this encounter; i.e., relatively low but persistent discharges in the range of 83 cfs will cause flooding between the roadway culverts and the lake, unless the pipe culvert is replaced by a box with invert about 3 feet lower than that for the existing pipe culvert.

The lake level during run 3 was significantly lower than during run 2 (figure 4), and no downstream flooding was evident. Consequently, one undersluice gate was opened approximately 1.5 feet vertically, releasing 215 cfs from the lake, a surprisingly large discharge for such a small gate opening. During run 1, 3.59 and 4.28 foot gate openings produced a discharge of only 370 cfs. Since Lake Creek was free-flowing during run 3 (versus flood condition and hence higher tailwater elevation during run 1), the undersluice release capacities were greater per foot of opening.

Table 2 presents the results of the suspended sediment samples collected immediately below the flow release structure for all three runs. Figure 11 presents plots of the percent increase in total suspended sediment (TSS) over time. Table 3 presents the results of sample collections made in Lake Creek at various points below the dam.

Sediment Coring

Figure 1 shows the sediment core locations. An effort was made to collect a significant number of samples at or near the same spots cored during the 1984 ISWS sediment survey (Bogner et al., 1985). Sixteen locations common to the 1984 study were cored while two cores (6 and 16) were taken near 1984 locations. The remaining eight cores were taken at sites totally remote from any of the 1984 locations.

Appendix A presents photographs of the cores in open split-liners. Table 4 provides the coordinates of the coring sites and segmental qualitative descriptions. The asterisks indicate the core segments from which a one-inch slice was removed for wet and dry density and for percent solids (or moisture) and volatile solids analyses. Table 5 presents the results of these analyses with the sample being referenced to the distance from the top of the core to the centerline of the 1-inch slice.

DISCUSSION

The study, by necessity, was subdivided into two separate work tasks: sediment flushing or venting and sediment coring. The need to explore, delineate, and define sediment conditions throughout the lake became evident when three sediment venting exercises in an area immediately above the dam did not produce encouraging results, party because the pipe culvert was not replaced with a box culvert.

Sediment Venting

The results presented in table 1 and figure 11 indicate that the potential for removing lake sediments by hydraulically flushing them downstream through undersluices can be realized only if the mechanisms are provided to feed sediments from upstream areas of the lake to the lake area near the dam. The flushing efficiencies of underflow releases, however, are probably better than the results indicate since the hydraulic capacity of the receiving creek has been reduced by the improperly installed downstream pipe culverts which restrict flow. In any event, even if Lake Creek were cleared of debris, ventable sediment was delivered to areas near the sluices, and the pipe culverts were replaced with a bridge or large box culvert, and sediment venting, with or without the aid of sediment agitation and movement toward the dam, so that this may not be a suitable means of removing the accumulated lake sediment over a period of years.

Direct comparison of the efficiencies of each of the three trial runs cannot be made for a number of reasons. These include factors related to periodic hydraulic/hydrologic differences, unequal run lengths, flow release differences, and the staging element. The highest flow release occurred during run 1 (table 1), but the accompanying increase in suspended solids was lower after 60 minutes than that for the lower flow-release conditions of runs 2 and 3 (figure 11). This could have been due to a lower head loss at the dam, i.e., 1.25 feet for run 1 versus approximately 3 feet for runs 2 and 3 (table 1) or because the bottom sediments were not artificially disturbed during run 1, or a combination of both.

Run 2 produced the highest sustained increase in suspended solids with mechanical disturbance (table 2, figure 11). This occurred in the absence of any underflow release and for an overflow rate that was only 22 and 39 percent of runs 1 and 3, respectively. Run 3, conducted during a relatively high head differential while releasing a large underflow containing suspended solids produced by hydraulic disturbance, resulted in a high "first-flush" suspended solids concentration. As time progressed, the solids concentrations dropped dramatically (table 2, figure 11). Possibly, the reason that this dropoff pattern developed is a lack of flushable sediments due to either continuous natural flushing, which may have occurred between runs 2 and 3, or due to the removal of most of these sediments during runs 1 and 2, or a combination of both.

The lack of potential for removing benthic sediments via underflow/overflow venting can be illustrated using the data presented in table 2 in combination with a rational formula developed as follows.

•The net fixed solids in the discharge during venting equals:

$$TNS_F = TSS - VSS \qquad (1)$$

where:

TNS_F = Total net fixed suspended solids in the discharge during venting (mg/L)
TSS = Total suspended solids in the lake discharge during venting (mg/L)
VSS = Total volatile suspended solids in the lake during venting (mg/L)

•Venting can be credited with removing a certain fraction of the measured VSS, but TNSp must be reduced by the fixed suspended solids naturally occurring in the lake due to the nonvolatile fixed solids contained in plankton and/or algae cells and fixed colloidal material in the water, therefore:

$$TNS_F = TSS - VSS + VSS_v - FSS_a \quad (2)$$

where:

VSS_v = Volatile suspended solids due to venting (mg/L)

FSS_a = Fixed suspended solids due to plankton and/or algae and colloidal material (mg/L)

•The sediment load resulting from venting is given by:

$$L = 5.39Q(TSS - VSS + VSS_v - FSS_a) \quad \textbf{(3)}$$

where:

L = Net suspended sediment load in the discharge due to venting in pounds per day (lbs/day)

Q = Discharge in cubic feet per second (cfs)

5.39 = Unit conversion factor

Using run 2 as an example where,

Q = 83 cfs

TSS = 151 mg/L (average of four maximum values given in table 2 or on figure 11)

VSS = 24 mg/L (average of the four VSS values corresponding to the respective maximum TSS values)

VSS_v = 11 mg/L (difference in the average disturbed VSS and the background VSS, i.e., 24 -13 mg/L)

FSS_a = 42 mg/L (difference in background TSS and VSS values in table 2, i.e., 55-13 mg/L) and inserting these values into equation 3 results in L = 42,948 lb/day. The dry volume of the benthic sediments can be estimated by averaging the 13 top dry sediment density values presented in table 5. This average is 24.2 lb/ft^3; consequently, approximately 1,775 ft^3/day of sediment would be removed under these conditions. At this rate, 14.9 ac-ft of sediment would be removed in one year. Increasing hydraulic conveyance of Lake Creek, using mechanisms to deliver more sediments for venting, and increasing flow releases could increase sediment evacuation to about 40 ac-ft per year. Average sediment inflow to the lake is about 80 ac-ft per year. If the pipe culverts, with present inverts about 3 feet above the creekbed, were lowered or a bridge culvert provided, the hydraulic conveyance of the creek will be greatly increased.

Sediment Coring

The success of venting is contingent upon the applicability of the concept to the physical setting at hand and/or to the availability of sediments susceptible to venting. The raw data, generated during the three runs, indicated that venting, even when the sediments were being disturbed, is probably not an efficient means of removing benthic sediments in shallow lakes, if indeed, ventable sediments exist in the shallow lake. Sediment deposition in the lake was not as great as assumed. During the disturbance venting runs 2 and 3, relatively stable hard bottoms were quickly encountered in an area 100 feet upstream of the dam. The possibility that minimal deposition had occurred in this area of the lake may account for the shape of the run-3 removal curve shown on figure 11. With this in mind, the decision was made to perform a cursory sediment depth survey over the entire lake bottom to ascertain the actual degree of deposition.

Sediment cores and deposition profiles are compared to those given by Bogner et al. (1985) and Lee et al. (1986). Table 6 provides dry-density and water to dry-solids ratio comparisons. The results for each core location, as referenced by the location of the 1995 core numbers, are presented in descending order by the mean sea level (msl) elevation of the core slice used in performing the laboratory analyses. The ratios of the water content to the dry solids appear to run somewhat higher for the 1984 samples. This may be due to differences in field core sampling and laboratory sample preservation methods used during each study. The 1984 samples were collected in a solid tube corer without a liner and extruded using a plunger. The 1984 laboratory samples were isolated from the cores in the field, placed in air-tight plastic bags, and cooled until analyzed. In contrast, the 1995 core samples were collected in removable split liners, which were capped, and placed in cool storage until the tubes were opened in the laboratory for extracting slices for analysis. The water to dry solid ratios given by Lee et al. (1986) in their Appendix 1 are in error and should be reduced by unity (private communication with Bogner, 1996). The corrected values were used in the 1984 water to dry-solid data tabulation in table 6.

Few of the core slices were taken at elevations that are common to both studies, and this limits direct comparison of the densities between the two studies. However, some comparisons can be made, such as at location 21 at elevations 317.00 (1984) and 316.94 ft-msl (1995) where the densities were 13.6 and 17.0 lb/ft^3, respectively. Appendix B provides cross-sectional comparisons between the 1984 and 1995 sediment surveys, and table 6 presents quantitative, physical comparisons. Except for transect 3 and possibly transect 4, the 1995-study sediment surface elevations were equal to or lower than those recorded during the 1984 study. The finite transect profiles were not presented in either the Bogner et al. (1985) or Lee et al. (1986) reports. Archived field notes were obtained for developing and publishing the 1984 profiles presented in Appendix B. The change in sediment deposition since 1984 for each transect investigated is summarized as follows:

- net deposition at transect 4,
- net deposition balanced by scouring at transect 3,
- no significant change in deposition at transects 5,8, 11, 12, and 14, and
- scouring at transects 7, 9, 10, 13.

Only one of the 11 transects visited exhibited a loss of water depth due to sedimentation, while four showed an increase in water depth due to scouring. Five of the remaining six transect water depths remained essentially unchanged since 1984. For the sixth (transect 3), the average cross-sectional depth remained virtually unchanged due to a balancing of deposition with scouring. At transect 4, located only a short distance above the dam/spillway, most of the shallower area along the cross section lost about a foot of water due to sedimentation. However, in the deeper area along the east bank (left bank looking downstream) where much of the flow appears to pass through this part of the lake, the bottom sediment level has remained essentially unchanged since 1984. This information clearly indicates that the lake has not lost water volume during the past 11 years. In reality, the average water depth probably has increased somewhat during this period. For example, the 1984 cross-sectional area and average depth at transect 10 were 5,269 ft^2 and 3.75 ft, respectively, as compared to the 1995 respective values of 5,725 ft^2 and 4.07 ft.

The black-shaded area of the representative cores shown on the profiles indicate heavy compacted "native" soil as subjectively described in table 4 and quantitatively described in table 5. The number accompanying the schematic core indicates the core segmental depth. See the legend sheet prefacing Appendix B for presentation details. The average dry density of the top 1-inch slices (excluding the results from core 18 collected near Black Creek delta) is 21.44 lb/ft^3 compared to 60.33 lb/ft^3 for the bottom 1-inch slices. The average bottom density is 2.81 times the average density of the top slices. The depth of soft sediments does not exceed 24 inches at any location. The deepest deposits appear in transects 7, 9, and 10.

The 5-foot contour interval lines presented on the 1:62500-scale U.S. Geological Survey (USGS) topographical map used in the development of figure 2 were used, in conjunction with the 1995 coring results, to develop estimates of lake depths prior to and immediately after the completion of the dam in 1931. These results are presented in terms of maximum and minimum cross-sectional depths in table 7. Also presented for comparison are similar water depths for the 1984 and 1995 sediment surveys. The mean sea level (msl) water surface elevation of the much smaller pre-dam lake (figure 2) appeared to fall somewhat below the 320 foot contour line. The dashed lines shown on transects 5 and 7-12 extend to this elevation (Appendix B). These cross sections fall with the bounds of the pre-dam lake. The pre-dam, completely dry-bed areas of the existing lake are represented by transects 3, 4, 13, and 14 and by point-core profile numbers 10, 11, and 18 (Appendix B).

Since the contour interval on the topographical map is 5 feet, the maximum depth in any portion of the expanded lake could *never* have been as great as 5 feet. In fact, the data in table 7, under the 1932-year column, show that the *maximum* water depth *at any location* within the newly expanded lake probably did not exceed 6.5 feet. Between 1932 and 1984, the average of the maximum water depths was reduced by 1.1 feet or 0.25 inches per year (in/yr) while between 1984 and 1995 the average water depth was reduced by 0.2 feet or 0.22 in/yr. Note from table 7, that the average of the minimum depths (the minimum depth is defined in the table) for 1984 is significantly lower by 1.5 feet (0.35 in/yr) than that estimated for 1932; however, the average of the depths *increased* by 0.4 feet (0.44 in/yr) from 1984 to 1995. Over the past 11 years, the deepest parts of the lake appear to be filling in at a rate slightly less than that which occurred the previous 52 years, whereas some scouring appears to be occurring in the shallower areas, a significant reversal of that which occurred between 1932 and 1984. The sedimentation rates computed using this methodology differ significantly with the rate of 0.5 in/yr stated by Bogner et al. (1985) to be occurring throughout the lake. The difference may be due to the 1993 flood: instead of depositing sediments, it may have scoured and flushed some existing deposits from the lake.

Casual statements that the lake is rapidly filling with sediment and that the 1993 flood deposited a foot of silt in the lake are not correct. To wit, circumstantial and scientific evidence generated by this study indicates the 1993 flood probably produced a net benefit by scouring and flushing existing benthic sediments from the lake. This is subjectively supported by a quote from Bogner et al. (1984):

> "Local residents have suggested that prior to 1969 the velocity and flow of the floodwater passing through the Black Creek delta area were great enough to flush this portion of the lake, thereby counteracting normal deltaic sedimentation processes. Residents suggest that the aggradation of the Black Creek delta was not a problem until after the Fayville Levee was completed."

The promotion of dredging as a means of initiating rehabilitation of the lake is questionable. Note from table 7 that the lake depth was never greater than 6.5 feet, when referenced to the spillway crest elevation of 321.41 ft-msl, at any location after the building of the dam in 1931. Furthermore, the average depth only ranged between 4.3 and 5.0 feet. If local areas are dredged to deeper depths, a significant depth of "native soil" would be removed in such areas.

Presently, major problems with the lake are related more to water and sediment quality than to sediment quantity. The lake is highly eutrophic due to nutrient inputs from agricultural runoff, goose feces, possible seepage from septic tanks, and the release of nutrients from the anaerobic sediments. Tremendous algal blooms persist in the lake from June - October. Lee et al. (1986) reported cell counts in excess of 44,000 per milliliters. The algal activity is most pronounced during warm, dry weather conditions when little or no flushing occurs. Consequently, the cells die and fall to the bottom, adding large amounts of decomposing organic material to the already heavily polluted benthic sediments. Due to the loss of periodic flow-through flooding because of levee construction and improvements, accelerated algal fallout and bottom degradation will continue.

In addition, overall poor water and sediment quality results reported by Lee et al. (1986) should be reviewed and taken seriously. The extreme vertical variation in DO reported in the shallow lake during the summer, in itself, clearly indicates extreme eutrophication and an "unhealthy" aquatic environment. Noteworthy, relative to this is the reporting by Lee et al. (1986) that:

> "Even though the lake remained well mixed as evidenced by the temperature data, significant gradient in the dissolved oxygen concentrations existed between the surface and deeper waters during the summer months (June to August). During this period, the surface waters exhibited supersaturated conditions due to profuse algal growths in the lake. At the same time, the near bottom waters were practically anoxic [i.e., DO ~ 0]. This is because the oxygen

demands exerted by the organically rich bottom sediments at the elevated summer temperatures were much higher than the rates at which oxygen was replenished from the atmosphere."

Low DO and extensive algal blooms are a persistent, annual phenomenon in the lake, and selective dredging to create local deep areas will not correct these problems. In fact, doing so will probably exacerbate water quality problems in general. Spot checks were made of the DO levels in the vicinity of transects 4 and 5 and at a point 50 feet above the dam during venting run 3 on August 22, 1995. The DO ranged from less than 1 mg/L to supersaturated highs in excess of 12 mg/L in only about 3 feet of water at transect 4 and 4.5 feet of water at transect 5. Close to the dam, where sediment scouring occurs and vertical mixing within the water column is evident, the DO ranged from a low of 5 mg/L near the bottom to a high of only 8 mg/L near the surface. During high flows, deeply dredged areas would become sediment traps, while during low flows, they would accumulate dead algal cells and goose feces. This could create sediment oxygen demand rates (SOD) comparable to those measured in the Fox Chain of Lakes, the highest recorded in a lentic environment in the state (Butts and Evans, 1978). During July - September, the DO in the bottom 4 or 5 feet of deeply dredged areas would probably be much less than that needed to support game fish.

A rehabilitation plan needs to be devised which would include ways of reducing and removing sediment contaminants along with removing and/or reducing sediment deposits. Only surficial, soft benthic sediments should be removed; "native soil" should not be disturbed. Alternate means to standard hydraulic dredging approaches should be considered and evaluated such as the innovative EDDY pump, vortex method presented in appendix C. Continuous water quality monitoring should be done *in situ* during any dredging operation. Automatic monitors and dataloggers, such as the Hydrolab DataSonde 3 or the YSI 6000, should be installed to provide continuous hourly records of DO, temperature, pH, conductivity, oxidation/reduction potential, and turbidity at selected locations in and around the dredged areas and at several other locations within the lake.

Nutrient loads to the lake must be controlled or significantly reduced if the lake's sport fishery is to be restored. "Vacuuming" loose sediments using the EDDY pump could be done in concert with implementing a nutrient inventory and reduction program. Components to be considered in an overall management program may include:

1. <u>Minimizing the use of all gas-operated outboards on the lake.</u> This would help prevent the recycling of nutrients trapped in the enriched, anaerobic bottom sediments.

2. <u>Developing and establishing an upland watershed erosion and nonpoint pollution control program.</u> The annual nitrogen, phosphorus, and biochemical oxygen demand (BOD) loads contributed by the Black Creek and Pigeon Roost Creek watersheds should be accurately monitored and measured.

3. <u>Conducting a study to determine the annual nutrient and BOD contribution by wintering geese.</u> Unit goose nutrient and BOD contributions need to be estimated from a sidebar study, and the result extended to ascertain seasonal population loadings. This will help in developing an overall annual budget of nutrients and BOD in the lake.

4. <u>Conducting an inventory and cataloging all domestic sources of nutrients and BOD to the lake.</u> Septic drainage systems, privies, and direct domestic sewage outlets that border the lake should be identified and quantified.

5. <u>Considering connection of the upper end of the lake to the Mississippi River with a river water diversion channel so that flushing of the lake can continue to make up for the loss of natural flushing due to levee construction.</u> The flushing frequency and water volume should be controlled by gates or by other regulatory structures. A controlled flushing system would not change the lake from a lentic to a lotic environment. It would only simulate and perpetuate the natural flushing

cycle that has been helping purge the lake of sediments and nutrients for thousands of years. A flushing and water control system has been operated at Lake Odessa along the Mississippi in Iowa for about 50 years. The extent of flushing may be moderate to lessen impacts on sport fishery management.

6. <u>Purchasing one or more EDDY sediment "vacuuming" pumps to periodically remove loose sediment accumulations from the lake.</u> These pumps and attendant equipment are easily operated and can be readily moved for temporary use at other locations throughout the state. Pump sizes range from 4 inches to 14 inches or greater. At the very least, a demonstration project using a small EDDY pump should be initiated.

Items 2 - 4 are the primary components of a nutrient inventory and balance study which should be undertaken. If the lake is allowed to gravitate into a solely lentic environment without focusing on nutrient control, its value as a sports fishery will continue to deteriorate. Several other factors often used to manage lake environments, such as the application of algicides, the use of chemicals to stabilize bottom sediments, and water level drawdown to promote sediment dryout and compaction, may not be feasible for Horseshoe Lake.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A study was designed to develop data and information to determine the feasibility of hydraulically venting benthic sediments from Horseshoe Lake through the two sluices in the dam. Sediment venting was tried under hydraulic/hydrologic conditions and results evaluated. On July 12, 1995, the two sluice gates were opened completely, releasing 370 cfs downstream. Only natural venting was tried (i.e., without artificial disturbance of the sediments). At this relatively high flow release, overbank water conditions quickly developed downstream. This flooding was caused by an undersized and poorly aligned two-pipe road culvert about two miles downstream and a trash-laden natural downstream channel. The run lasted only an hour.

A second run was made on July 27, 1995, in which the bottom sediments were physically disturbed immediately upstream of the dam by dragging log chains behind a power boat. The sluice gates were not opened and only a natural flow of 83 cfs over the spillway was used to carry the suspended solids downstream. The run lasted approximately two hours.

The third run was done on August 22, 1995, with one gate opened 1.5 feet at a flow release of 215 cfs. The bottom sediments were disturbed hydraulically using a high pressure pump with the discharge nozzle thrust into the sediments from a slow moving power boat. The run lasted approximately two hours.

The results of these three runs were not encouraging. Only moderate increases in suspended solids above ambient levels were observed during any of the three runs. These results could have been caused by: (1) sediment venting, in itself not effective, (2) a lack of a significant amount of ventable sediments in the lake immediately above the dam in very shallow lakes, (3) lack of transport of ventable sediment toward the dam, or (4) a combination of 1, 2 and 3.

After the completion of the third run and the examination of old USGS topographical maps developed prior to the installation of the dam in 1931, circumstantial evidence became available that indicated sediment deposition in the lake appears not to have occurred to the extent presumed by conventional wisdom . To test this idea, a plan was developed to perform a short, intensive sediment survey of the entire lake. Water depths and sediment core samples were taken at 11 of the 13 transects established during a 1984 study designed to quantify sediment deposition in the lake. Twenty-six core samples were taken, including one at the mouth of Black Creek and two immediately above the dam.

The cores were obtained using split liners inserted into a proprietary coring device. The sediments were dissected and subjectively described by exposing the entire length of the core in a relatively undisturbed state by removing half of the split liner. Thirty-three 1-inch slices were removed from selected cores to determine percent moisture, percent volatile solids, and wet and dry densities. The 1995 water and sediment depths were plotted on 1984 cross-sectional profiles developed from archived data. Also, historical water and mean sea level referenced elevations and depths were developed using the 1984 and 1995 sediment data in conjunction with dry-land contour elevations obtained from USGS topographical maps issued prior to the construction of the controlling dam during 1931.

The conclusions and attendant recommendations developed as a result of this study are:

1. <u>Sediment venting via undersluice releases is questionable for the shallow Horseshoe Lake.</u> Alternative methods should be evaluated for removing and/or stabilizing benthic sediments. Lowering pipe culverts to avoid backwaters below the dam and physically moving sediments toward the undersluices can improve the sediment venting efficiency.

2. <u>The perception that the 1993 flood reduced the lake water depth by a foot or more is incorrect.</u> On the contrary, the flood appears to have scoured sediments from the lake. This is supported by the fact that sediment and water depth data collected during this study indicate that, over the past 11 years, sedimentation in the *deepest* areas of the lake has occurred at a rate of 0.25 in/yr essentially equal to the rate of 0.22 in/yr, which was calculated for the period 1931 - 1984. In the

shallow areas of the lake, significant scouring has occurred at the rate of 0.44 in/yr. The 1984 study estimated the average sedimentation rate throughout the lake to be 0.5 in/yr. Clearly, the lake has gained water volume since 1984. Any lake dredging plans for lake rehabilitation may take these facts into account. There is some sedimentation around the trees in the water because of reduced water velocities.

3. <u>The deterioration of the lake's sport fishery is related to water quality problems caused more by sediment quality than by sediment quantity or deposition.</u> The lake is highly eutrophic and is constantly being subjected to nutrient and organic inputs from a number of sources. A nutrient and waste loading balance or budget should be developed for the lake system.

4. <u>Preventing periodic floods from passing through the lake will be detrimental.</u> The completion of Mississippi River levees upstream of the lake will prevent natural scouring of sediments and the flushing of some of the nutrients that constantly become entrapped in the benthic sediments. This inherent problem may be mitigated by connecting the upper end of the lake with the Mississippi via a controlled release canal or channel, and/or by vacuum dredging soft, surficial sediments using an EDDY pump. Occasional flooding has maintained a unique system for this lake.

5. <u>Deep dredging in selective areas of the lake will probably result in little enhancement of the lake fishery.</u> It may result in "native soil" disturbance and will only create deeper areas with deeper anoxic zones. An experimental area may be dug or dredged, preferably in the lower reaches of the lake, and continuously monitored for water quality and periodically monitored for changes in sediment quantity and quality over a two-year period. Such a pilot study will be useful for assessing favorable/unfavorable impacts of deep dredging.

6. <u>Alternative methods of sediment removal should be investigated and evaluated.</u> The most promising method applicable to Horseshoe Lake is a method of sediment vacuuming using an EDDY pump. A pilot study may be developed and instituted over a two-year period to evaluate its practicality and economy. This pump holds great promise for the shallow to medium depth lakes in Illinois.

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TABLES

Table 1. Hydraulic/Hydrologic Conditions

Run number	1995 date	Elapsed time (hr)	Gate opening (ft) East	Gate opening (ft) West	Flow (cfs)	Elevation (ft- msl) Lake	Elevation (ft- msl) Lake Creek Road bridge	Lake Creek culvert staff gage (ft)
1	7/12	0	0	0	41	321.82	318.03	0.35
		0.42	3.59	4.28	370	321.79	320.42	-
		1.00	"	"	"	321.77	320.52	-
		1.12	0	0	41	-	-	1.80
2	7/27	0	0	0	83	322.22	319.46	1.18
		5.57	"	"	"	322.22	319.29	-
		7.18	"	"	"	322.22	319.26	1.06
3	8/22	0	0	0	36	321.51	317.84	0.25
		1.00	"	1.49	215	321.49	318.18	-
		1.67	"	"	"	321.47	318.34	-
		4.22	"	"	"	321.49	318.44	-
		4.67	"	"	"	321.49	318.46	0.43

Table 2. Vented, Disturbed Suspended Solids Values for Runs 1 (7/12/95), 2 (7/27/95), and 3 (8/22/95)

Elapsed time (minutes)	Total suspended solids concentrations (mg/L) 1	2	3	Volatile suspended solids Concentrations (mg/L) 1	2	3	% Volatile 1	2	3
0	49	55	59*	14	13	17*	29	24	29*
20			190			30			16
50			126			24			19
60	62	94		22	20		35	21	
75		118			12			10	
80			95			21			22
90		162			20			12	
110			74			14			19
115		136			26			19	
140			86			20			23
150		164			24			15	
170**			106			24			23
180***		143			25			17	
200			92			28			30
210		84			20			24	
230		76	82		16	20		21	24

* Represents stagnant water values in Lake Creek and not Horseshoe Lake background
** Ceased sediment disturbance during run 3 after sampling
*** Ceased sediment disturbance during run 2 after sampling

Table 3. Vented Suspended Solids Values for Run 1 (7/12/95) at Four Locations along Lake Creek

Station location	Total suspended solids concentration (mg/L) for elapsed time in minutes 0	60*	120	Volatile suspended solids for elapsed time in minutes Conc. (mg/L) 0	60	120	% Volatile 0	60	120
Lake Cr. Rd. Bridge, Left	48	55	30	18	20	10	38	36	33
Lake Cr. Rd. Bridge, Right	60	64	60	10	26	18	17	41	30
Upstream Lake Cr. Culvert	66	49	62	16	14	22	24	29	35
Downstream Lake Cr. Culvert	44	84	84	12	20	22	27	24	26

* Closed sluice gates after sampling

Table 4. Horseshoe Lake Sediment Core Descriptions
October 31 - November 1, 1995

Core no.	Location: Transect number	Location: Distance LBLDS (ft)	Core segment depth (in)	Description of core segments
1	3	250	0.00	-
			3.50	pasty, gray-tan silt clay
			12.00	semi-compacted, tan-gray silt clay
			14.00	transition layer of gray silt clay
			16.50	compact, hard gray clay
2	3	600	0.00	-
			7.50*	pasty, gray-tan silt clay
			11.25	transition layer of tan-gray silt clay
			13.25*	compact, hard gray clay
3	13	2370	0.00	-
			6.50	pasty, tan silt clay
			9.25	compact, hard gray clay
4	13	2310	0.00	-
			0.75	crumbly, tan silt clay
			4.00	pasty, tan-gray silt clay
			5.00	transition layer of tan-gray silt clay
			9.00	compact, hard gray clay
5	13	800	0.00	-
			8.50*	pasty, gray-tan silt clay
			9.50	transition layer of tan-gray silt clay
			12.50*	compact, hard gray clay
6	14	1200	0.00	-
			7.00*	semi-compacted, tan-gray silt clay
			8.00	wood chips, semi-compacted tan-gray silt clay
			9.00	transition layer of tan-gray silt clay
			16.75*	compact, hard gray clay
7	14	1500	0.00	-
			8.00	semi-compacted, tan-gray and redish silt clay
			9.00	wood chips, transition layer of tan-gray silt clay
			11.00	compact, hard gray clay
			13.00	very compacted, hard, dry gray clay
8	4	300	0.00	-
			2.50	slightly watery, tan-gray silt clay
			5.00	full of wood chips, pasty, tan-gray silt clay
			6.00	transition layer of semi-compacted silt clay
			8.00	compacted, hard gray clay
9	4	450	0.00	-
			5.00*	semi-compacted, tan-gray silt clay
			6.50	compacted, gray-tan silt clay
			8.50*	compacted, hard gray clay
10	50' above dam	-	0.00	-
			7.00	semi-compacted, tan-gray silt clay
			7.50	transition layer of semi-compacted silt clay
			9.25	compacted, hard gray clay
11	75' above dam	-	0.00	-
			6.50*	semi-compacted, tan-gray silt clay
			7.50	transition layer of compacted tan-gray silt clay
			12.00*	compacted, hard gray clay
12 13 14 15	Core tubes pre-numbered 12 - 15 were not used			

Table 4. Continued.

Core no.	Location: Transect number	Location: Distance LBLDS (ft)	Core segment depth (in)	Description of core segments
16	12	1800	0.00	-
			9.00	semi-compact, tan-gray silt clay
			11.00	compact, tan-gray silt clay
			16.00	wood chips/detritus,
			20.00	compact, hard gray clay
				compact gray-tan silt clay
17	12	900	0.00	-
			9.00*	pasty, tan-gray silt clay
			15.00*	compact, tan-gray silt clay
			23.25*	compact, gray clay
18	75'	-		-
	below		5.00*	pasty, tan silt clay
	Black Cr.,		13.00*	woody/fibrous detritus, pasty, tan silt clay
			16.00	pasty, tan silt clay
			18.00	compact, gray clay
			22.00*	compacted, hard gray clay
19	11	1288	0.00	-
			9.00*	watery, tan-gray silt clay
			11.00*	compact, gray-tan silt clay
			18.00	pulverized detritus, dry, compact, gray silt clay
			21.00*	compacted, hard gray clay
20	11	700	0.00	-
			7.00	watery, tan-gray silt
			8.50	woody detritus, compact tan-gray silt
			10.00	pulverized detritus, pasty, tan silt clay
			13.00	pulverized detritus, compact tan silt clay
			17.00	transition layer of pulverized detritus, compact tan-gray silt
			20.50	compacted, hard gray clay
21	10	1056	0.00	-
			6.50*	watery, tan silt clay
			9.00*	woody/pulverized detritus, watery, tan silt clay
			21.50	woody/pulverized detritus, compact, tan silt clay
			22.50*	finely pulverized detritus, compacted, hard gray clay
22	10	400	0.00	-
			5.00	watery, tan silt clay
			10.00	fibrous detritus, semi-compact tan-gray silt clay
			17.50	fibrous/woody detritus, crumbly tan-gray silt clay
			19.50	compacted, hard gray clay
23	5	1253	0.00	-
			3.00*	pasty, tan-gray silt clay
			7.00	finely pulverized detritus, crumbly, tan-gray silt clay
			12.50	fibrous detritus, dry, crumbly, tan-gray silt clay
			16.50*	compacted, hard gray clay
24	5	500	0.00	-
			8.00	pasty, tan-gray silt clay
			18.00	leafy/fibrous detritus, crumbly, tan silt clay
			20.00	compacted, hard gray clay
25	7	340	0.00	-
			7.50*	leafy fibrous detritus, spongy, tan-gray silt clay
			20.50*	fibrous detritus, peaty, crumbly, tan-gray silt clay
			21.00*	transition layer of gray silt clay

Table 4. Concluded.

Core no.	Location: Transect number	Location: Distance LBLDS (ft)	Core segment depth (in)	Description of core segments
26	7	792	0.00	-
			6.00	fibrous detritus, watery, tan silt clay
			9.00	fibrous detritus, crumbly, tan-gray silt clay
			15.00	leafy fibrous detritus, peaty, crumbly, tan-gray silt clay
27	9	340	0.00	-
			4.00*	watery, tan-gray silt clay
			10.00*	leafy fibrous detritus, crumbly, tan-gray silt clay
			20.00*	leafy fibrous detritus, peaty, dry, crumbly, tan-gray silt clay
			21.00	compacted, hard gray clay
28	9	697	0.00	-
			8.00	watery, tan silt clay
			9.50	woody fibrous detritus, pasty, tan-gray silt clay
			15.00	fibrous detritus, peaty, crumbly tan silt
			18.00	woody detritus, compact tan-gray clay silt
			21.00	woody detritus, transition layer of gray silt
29	8	460	0.00	-
			5.50*	watery, tan silt clay
			8.00	detritus, semi-compacted, tan-gray silt clay
			18.00*	much pulverized, fibrous detritus, peaty, crumbly, tan-gray silt
			19.00	leafy detritus, transitional layer of gray clay
			20.50*	compacted, hard gray clay
30	8	1194	0.00	-
			11.00	watery, tan-gray silt clay
			19.50	fibrous detritus, peaty, crumbly, tan silt

* Slice taken for solids composition and density analyses

Table 5. Physical Characteristics of Horseshoe Lake Sediment Core Segments

Core no.	Depth (in) to center of 1-inch segment	Percent solids: Total	Percent solids: Volatile	Density lb/ft³: Wet	Density lb/ft³: Dry	Density g/cm³: Wet	Density g/cm³: Dry
2	1.50	49.2	6.0	64.0	28.3	1.03	0.45
2	11.75	68.6	5.2	119.2	81.8	1.91	1.31
5	1.50	39.1	8.9	80.4	31.7	1.29	0.51
5	10.88	63.0	5.8	119.8	83.6	1.92	1.34
6	1.50	46.2	7.2	60.5	28.9	0.97	0.46
6	15.25	75.3	2.7	120.9	91.6	1.94	1.47
9	0.50	43.1	8.2	73.0	29.8	1.17	0.48
9	7.00	56.4	6.5	97.1	55.9	1.55	0.90
11	0.50	48.0	6.0	68.9	34.3	1.10	0.55
11	10.50	65.6	4.3	105.6	68.2	1.69	1.09
17	3.50	30.6	14.4	55.5	15.9	0.89	0.25
17	13.00	43.6	15.9	88.0	39.7	1.41	0.64
17	20.75	53.5	17.2	107.6	57.3	1.72	0.92
18	0.50	63.3	3.8	93.5	56.8	1.50	0.91
18	10.50	61.6	4.3	92.1	56.1	1.48	0.90
18	18.50	58.8	8.5	100.3	60.4	1.61	0.97
19	0.50	32.1	12.4	58.8	18.0	0.94	0.29
19	9.50	29.7	19.7	68.8	20.0.	1.10	0.32
19	20.50	48.9	26.6	107.7	48.0	1.73	0.77
21	0.50	27.3	13.4	61.4	17.0	0.98	0.27
21	9.00	29.3	27.1	66.8	18.8	1.07	0.30
21	21.00	45.3	12.3	76.4	38.2	1.22	0.61
23	0.50	28.7	13.1	58.4	17.9	0.94	0.29
23	15.00	54.8	13.6	100.1	56.8	1.60	0.91
25	0.50	21.5	24.0	50.6	10.1	0.81	0.16
25	14.50	31.1	28.6	74.8	25.1	1.20	0.40
25	20.50	49.7	32.5	98.0	43.9	1.57	0.70
27	0.50	23.5	20.6	56.9	12.9	0.91	0.21
27	13.25	21.2	40.8	72.4	15.2	1.16	0.24
27	20.00	29.5	25.5	107.6	50.4	1.72	0.81
29	2.00	21.4	21.8	60.5	12.5	0.97	0.20
29	9.50	25.1	32.6	77.0	16.2	1.23	0.26
29	19.00	43.0	27.1	95.7	48.2	1.53	0.77

Table 6. Comparison of 1984 and 1995 Sediment Core Slice Moisture and Density

Location by 1995 core no.	*Lake bed elevation (ft-msl)*		*Elevation at centerline of core slice (ft-msl)*	*Lake bed depth (in)*	*Sample year*	*Dry density (lb/ft³)*		*Water to dry solids ratio by weight*	
	1984	*1995*				*1984*	*1995*	*1984*	*1995*
2	318.98	319.85	319.73	1.50	1995		28.3		1.26
			318.87	11.75	1995		81.8		0.45
			318.63	4.20	1984	66.3		0.48	
			318.13	10.20	1984	76.6		0.38	
6	319.61	319.84	319.84	1.50	1995		28.9		1.09
			319.16	5.40	1984	26.3		1.64	
			318.57	15.25	1995		91.6		0.32
			318.06	18.60	1984	64.5		0.52	
9	318.81	319.82	319.78	0.50	1995		29.8		1.45
			319.24	7.00	1995		55.9		0.74
			319.66	10.20	1984	61.0		0.59	
17	317.38	317.52	317.52	3.50	1995		15.9		2.49
			316.44	13.00	1995		39.7		1.22
			316.23	13.80	1984	17.1		2.96	
			315.79	20.75	1995		57.3		0.88
			315.43	23.40	1984	27.0		1.70	
19	317.21	317.80	317.14	0.50	1995		18.0		2.27
			316.66	6.60	1984	17.5		2.94	
			316.38	9.50	1995		20.0		2.44
			315.66	18.60	1984	27.3		1.67	
			315.48	20.50	1995		48.0		1.24
21	317.45	316.98	317.00	5.40	1984	13.6		3.46	
			316.94	8.50	1995		17.0		2.61
			316.23	9.00	1995		18.8		2.55
			315.80	19.80	1984	24.4		2.00	
			315.23	21.00	1995		38.2		1.00
23	317.16	316.78	316.74	0.50	1995		17.9		2.26
			316.33	5.40	1984	14.2		3.45	
			315.91	15.00	1984	29.0		1.52	
			315.53	15.00	1995		56.8		0.76
25	317.29	317.38	317.34	0.50	1995		10.1		4.01
			316.64	7.80	1984	9.8		4.51	
			316.17	14.50	1995		25.1		1.98
			315.67	20.50	1995		43.9		1.23
			315.14	25.80	1984	19.6		2.38	
27	317.16	316.98	316.94	0.50	1995		12.9		3.41
			316.91	3.00	1984	8.1		5.77	
			315.88	13.25	1995		15.2		3.76
			315.41	21.00	1984	12.4		4.16	
			315.31	20.00	1995		50.4		1.13
29	316.61	316.68	316.51	2.00	1995		12.5		3.84
			316.23	4.20	1984	6.5		6.18	
			315.89	9.50	1995		16.2		3.75
			315.10	19.00	1995		48.2		0.99
			314.86	21.00	1984	25.2		2.00	

Table 7. Comparison of Historical Lake Water Depths at 1984 Sediment Survey Transects

Transect number	Historical water depths (ft) referenced to 321.41 ft-msl: Maximum depth along transect 1930	1932	1984	1995	Minimum* depth along transect 1930	1932	1984	1995
3	0.0	2.8	2.6	1.9	0.0	2.2	0.5	1.6
4	0.0	3.4	3.8	2.9	0.0	1.9	1.7	2.1
5	4.3	5.8	4.7	4.8	4.0	5.5	3.8	3.9
7	5.0	6.5	4.1	4.3	4.5	6.0	3.0	4.0
8	5.0	6.5	4.8	4.8	4.8	6.3	4.4	4.7
9	5.0	6.5	4.3	4.7	4.5	6.0	4.2	4.0
10	4.7	6.2	4.9	4.8	4.5	6.0	3.0	4.4
11	4.3	5.8	4.6	4.5	4.2	5.7	4.1	4.1
12	3.8	5.3	4.3	4.3	3.3	4.8	3.0	3.5
13	0.0	3.0	2.9	2.0	0.0	1.9	1.7	0.8
14	0.0	2.9**	1.9	2.0	0.0	1.5	1.8	1.6
Average	4.6	5.0	3.9	3.7	4.3	4.3	2.8	3.2

* Subjective location 200-300 ft out from shallowest side
** In old streambed of Black Creek

FIGURES

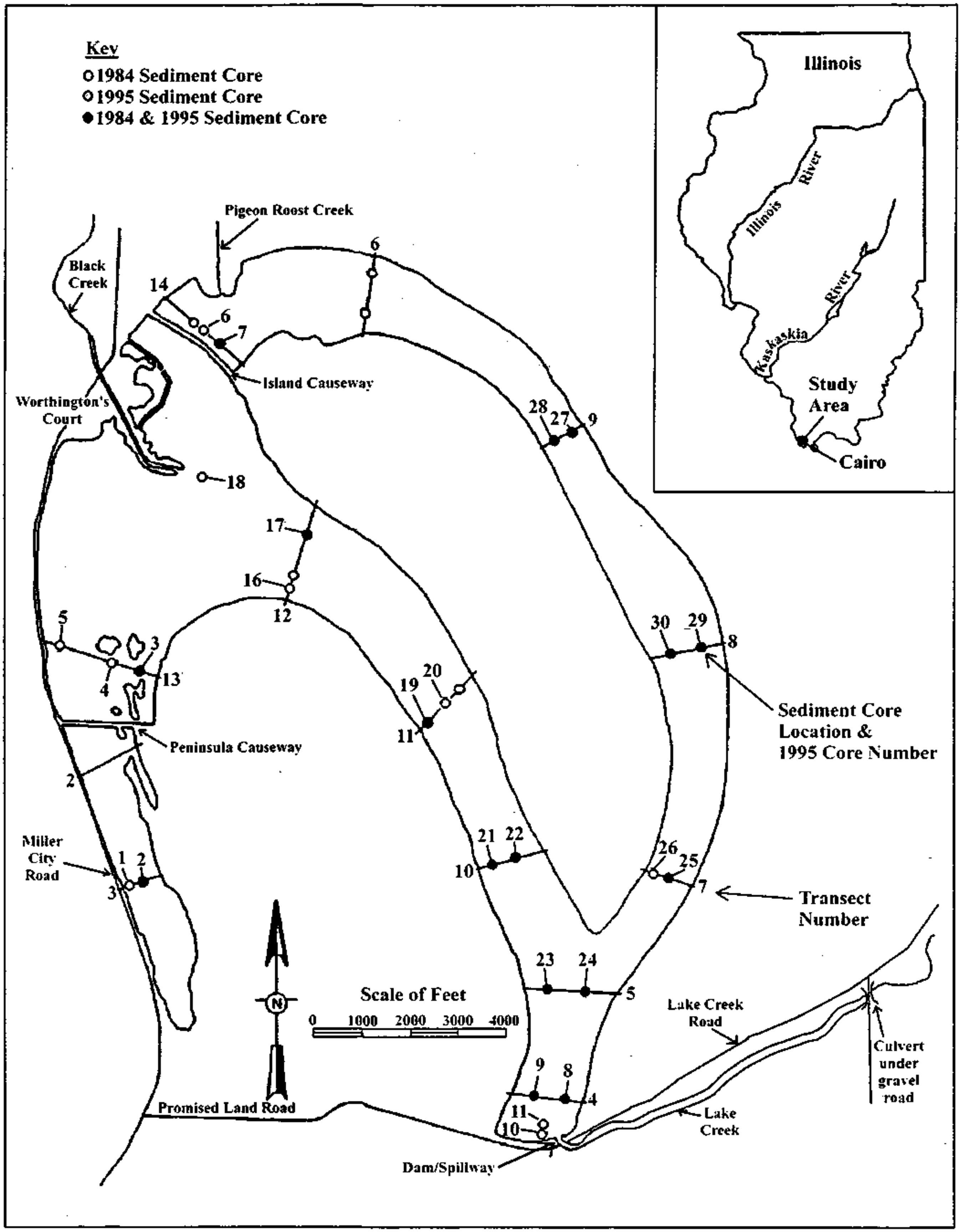


Figure 1. Horseshoe Lake location and plan view of sediment sampling transects established by Bogner et al. (1985)

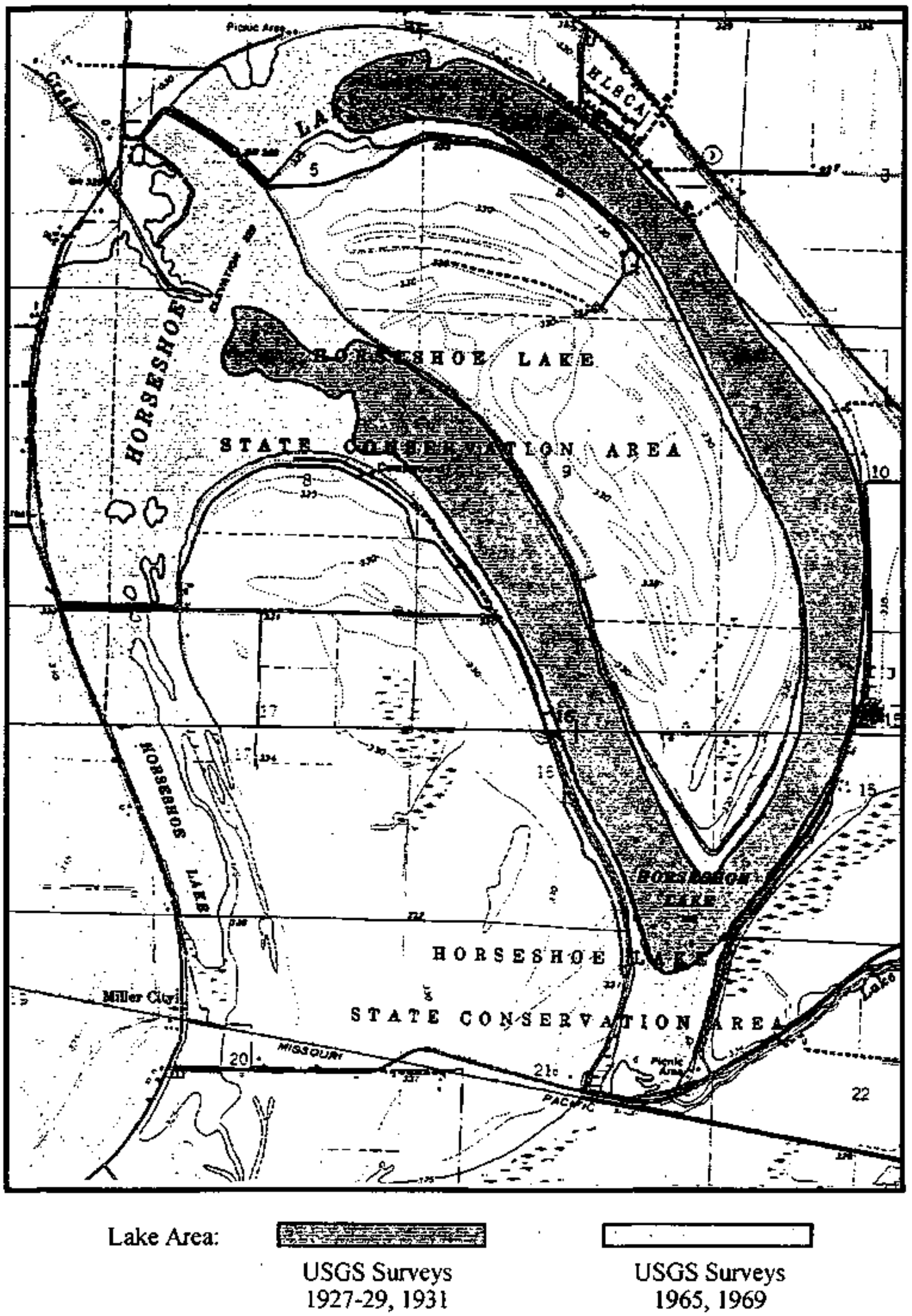


Figure 2. Comparison of Horseshoe Lake areas from USGS topographical maps

Figure 3. Panoramic view of upstream side of dam

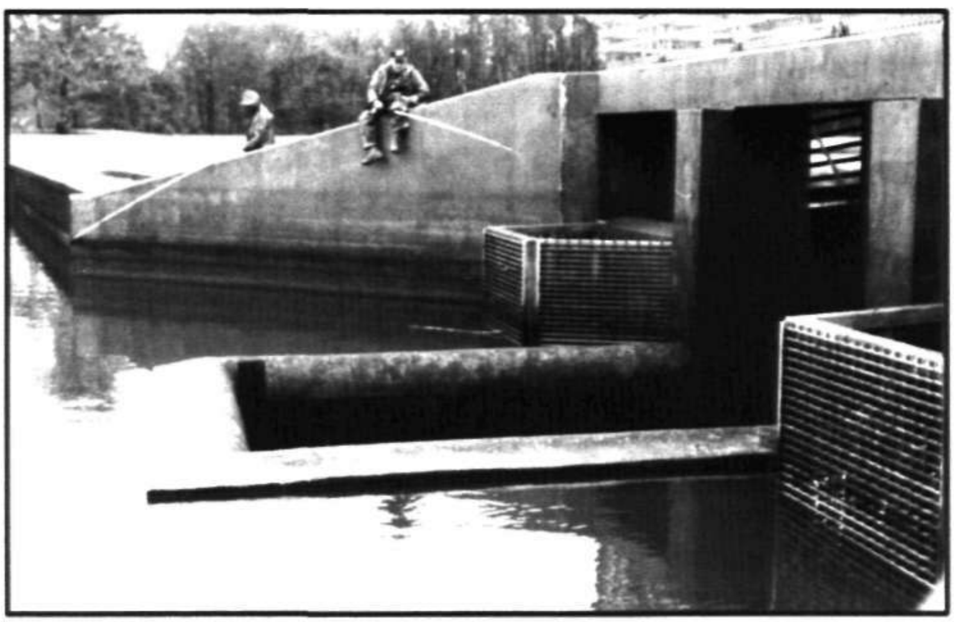


Figure 4. Upstream view of dam highlighting spillway and fish screens above sluice gates

Figure 5. Lake Creek gravel road overpass fitted with two corrugated metal culverts

Figure 6. Sediment raking above the dam using log-chains pulled behind a power boat

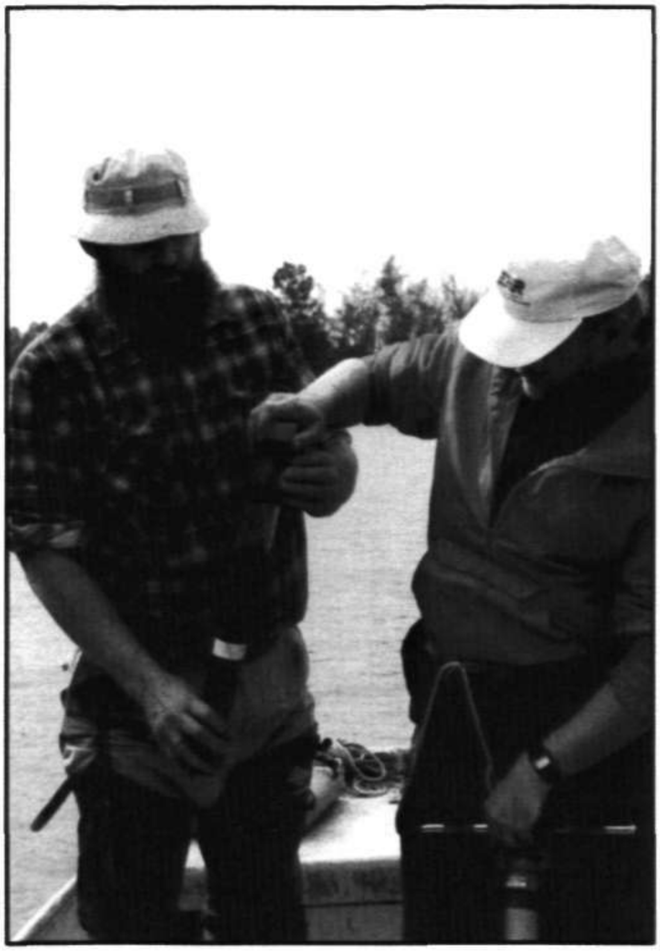


Figure 7. Sediment core taken with a 30-inch Wildco tube and liner

Figure 8. Sediment core taken with a 48-inch Wildco tube and liner

Figure 9. Sounding pole fitted with sliding shoe

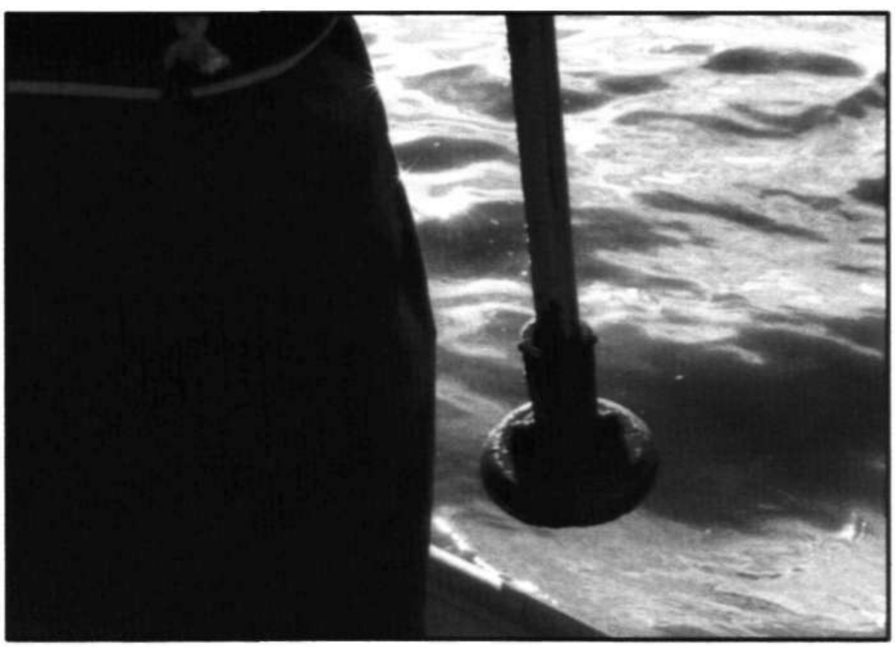


Figure 10. Detailed view of sliding shoe

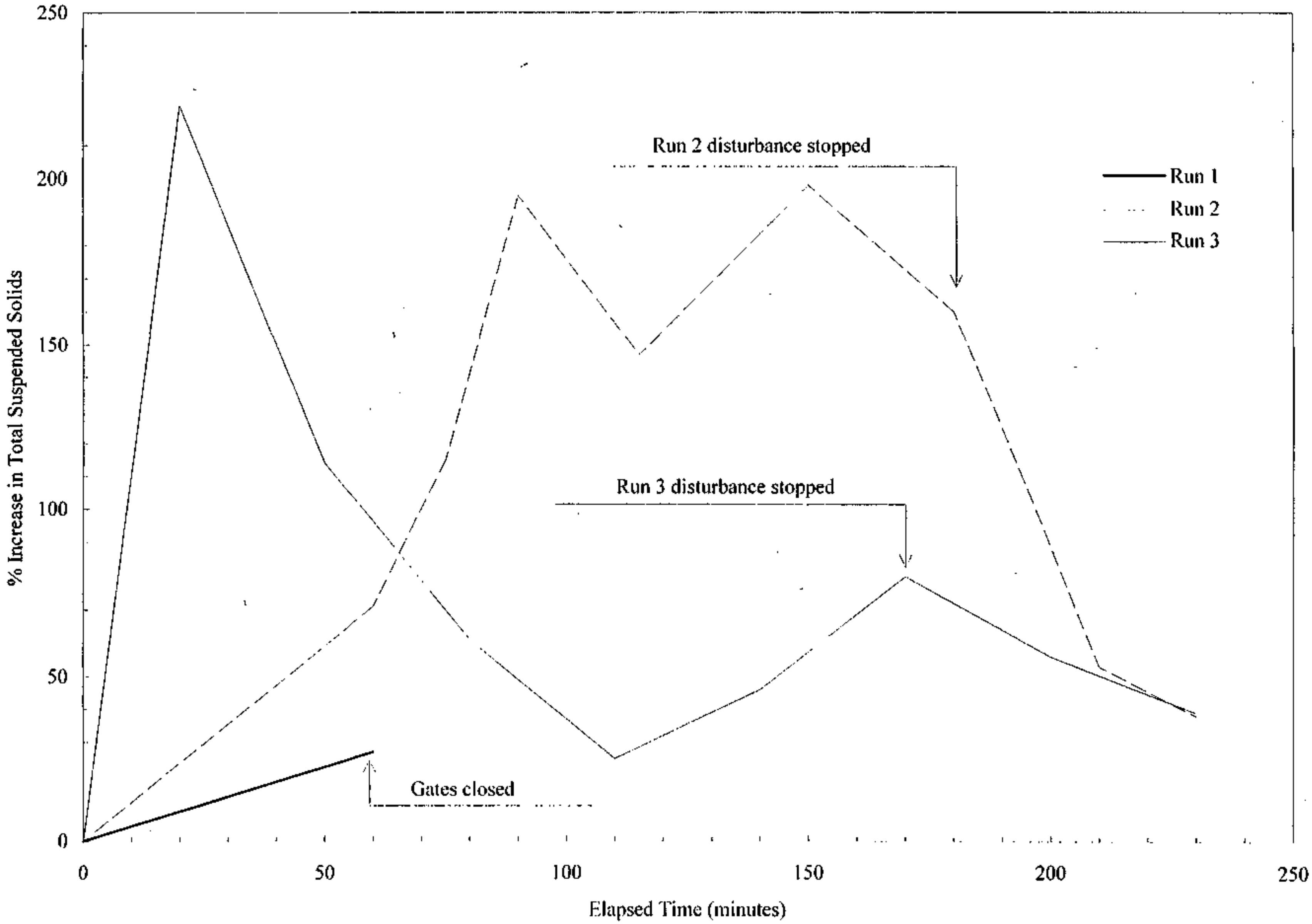
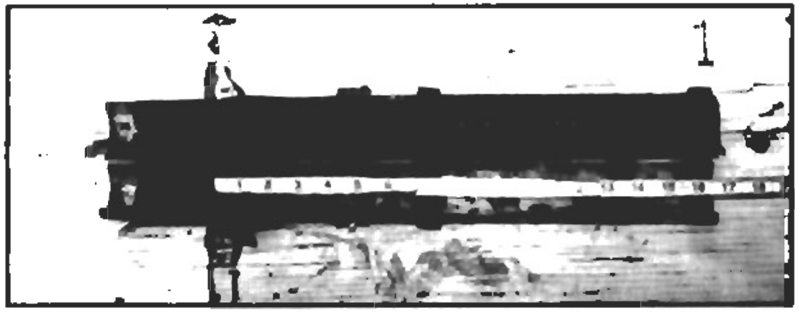
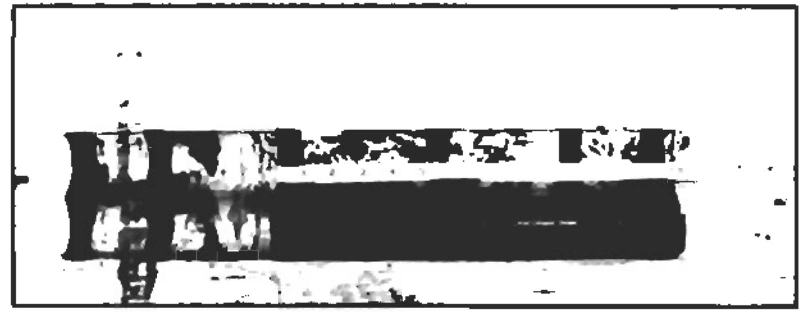


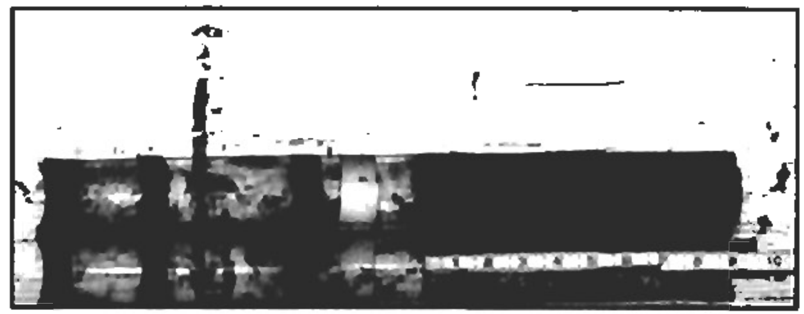
Figure 11. Percent increase in total suspended solids through and/or over the flow release structure

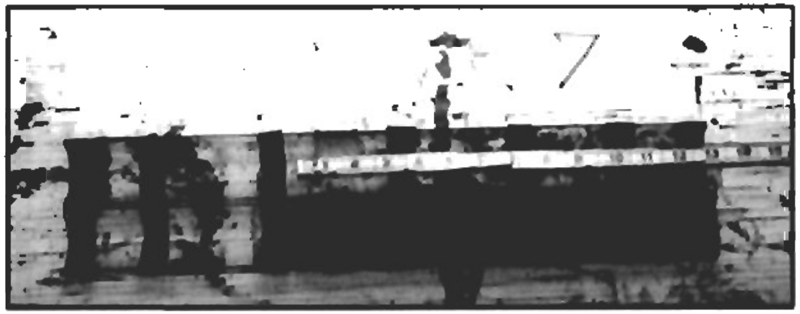
APPENDIX A

Photographs of Sediment Corings 1-30
(12-15 not used)





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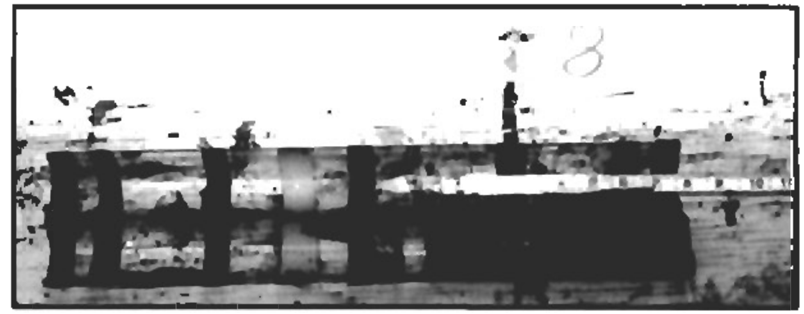
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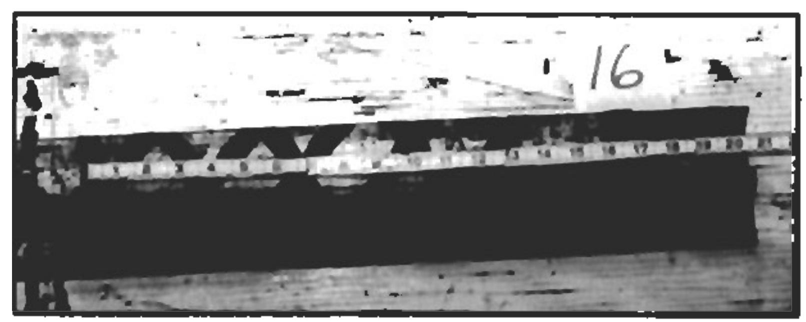
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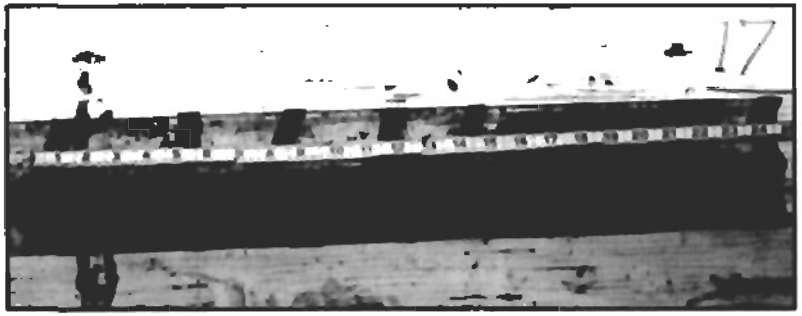
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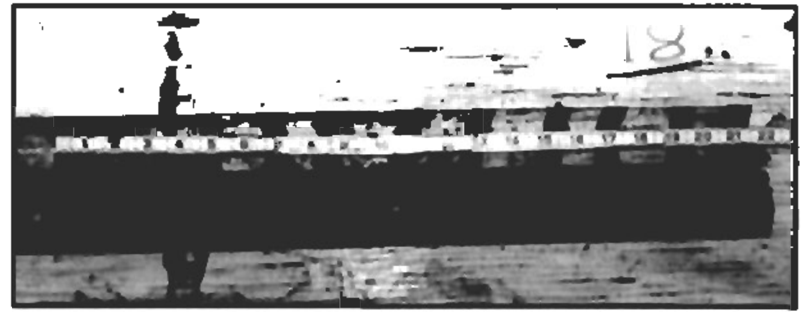
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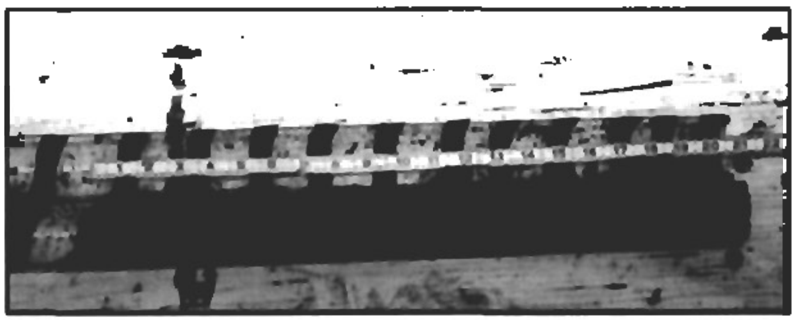
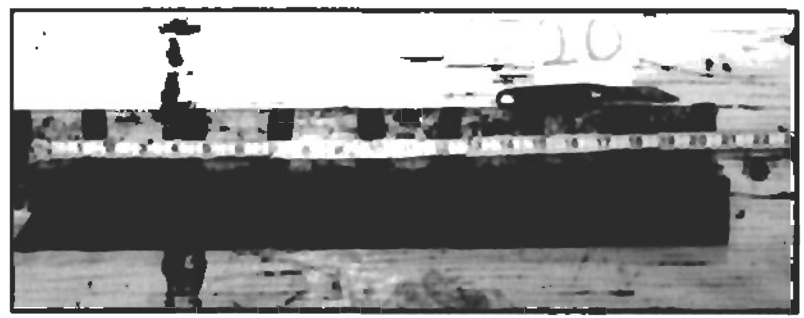
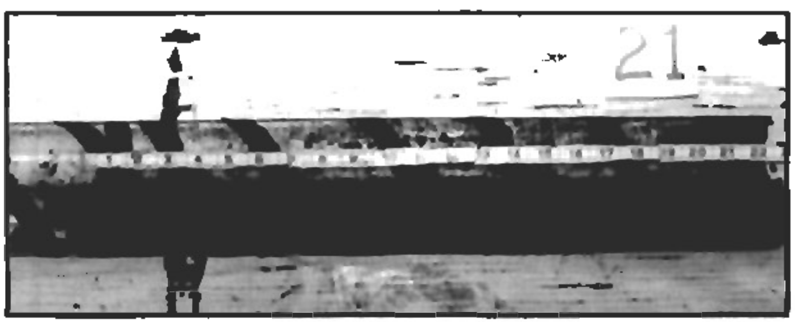
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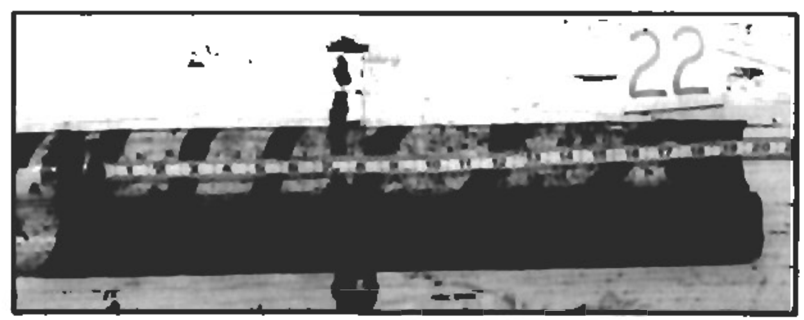
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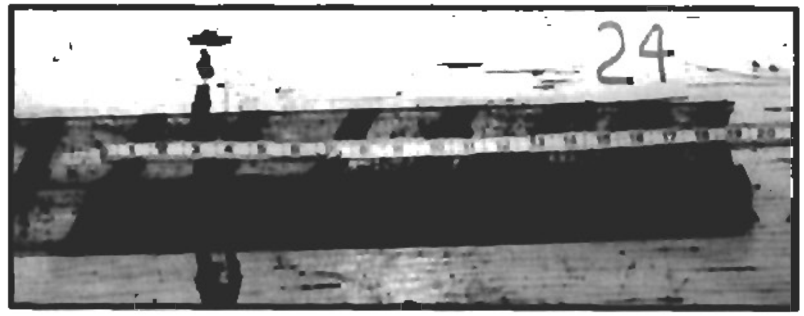
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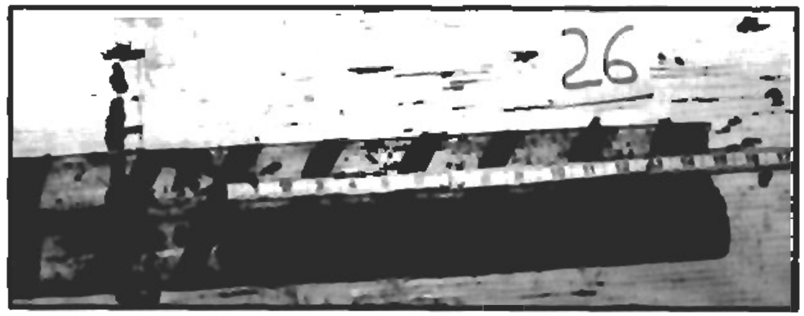
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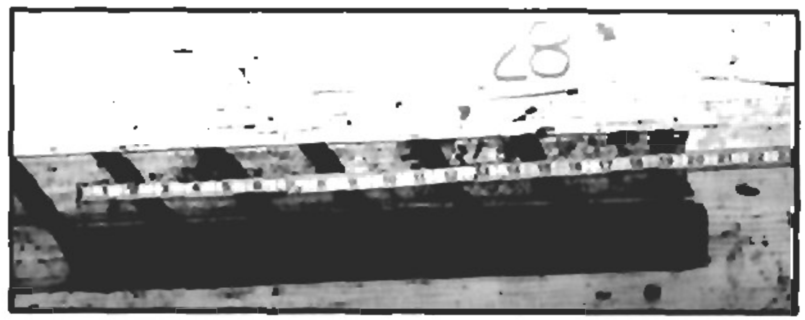
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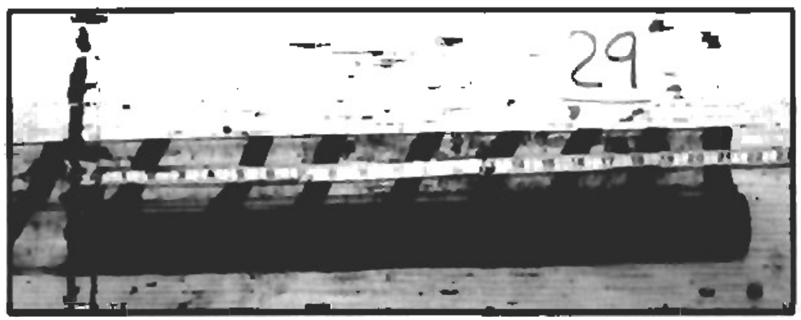
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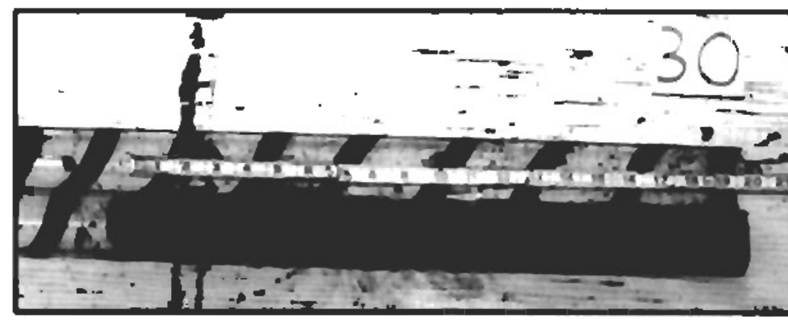
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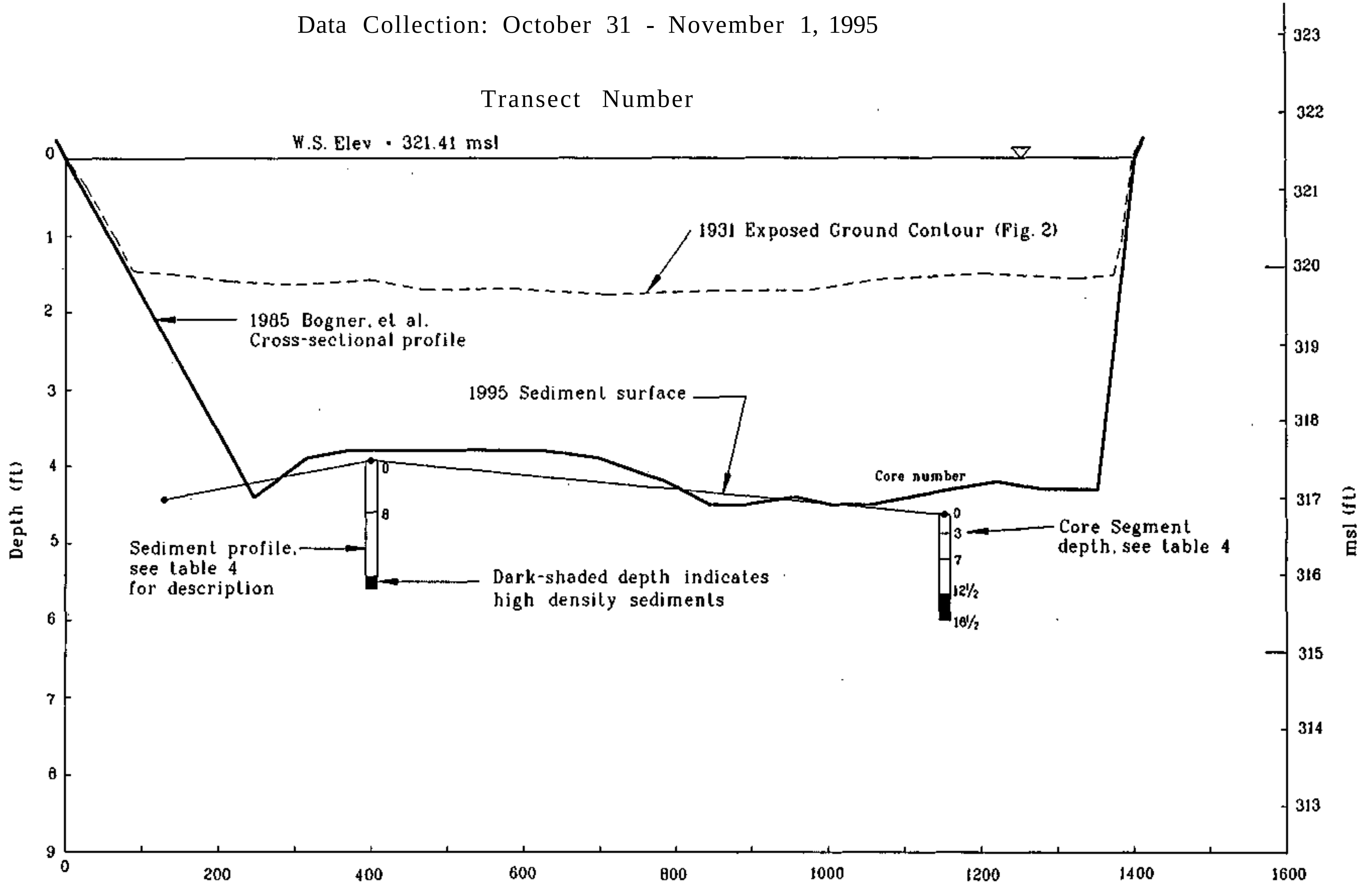
APPENDIX B

1995 Sediment Core Survey (October 31 - November 1)
with 1985 (Bogner et al.) Cross-sectional Profiles

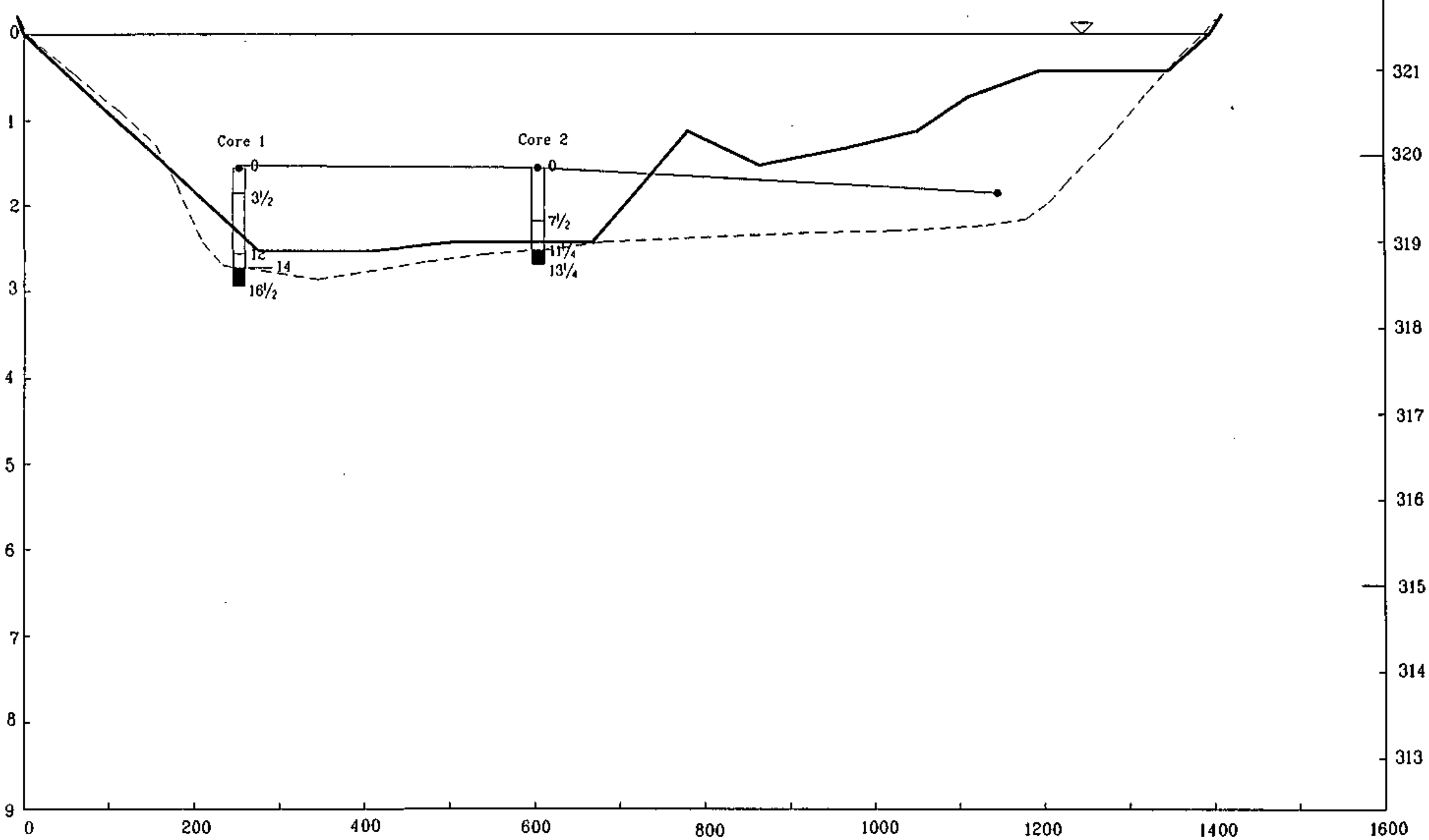
Data Collection: October 31 - November 1, 1995

Transect Number



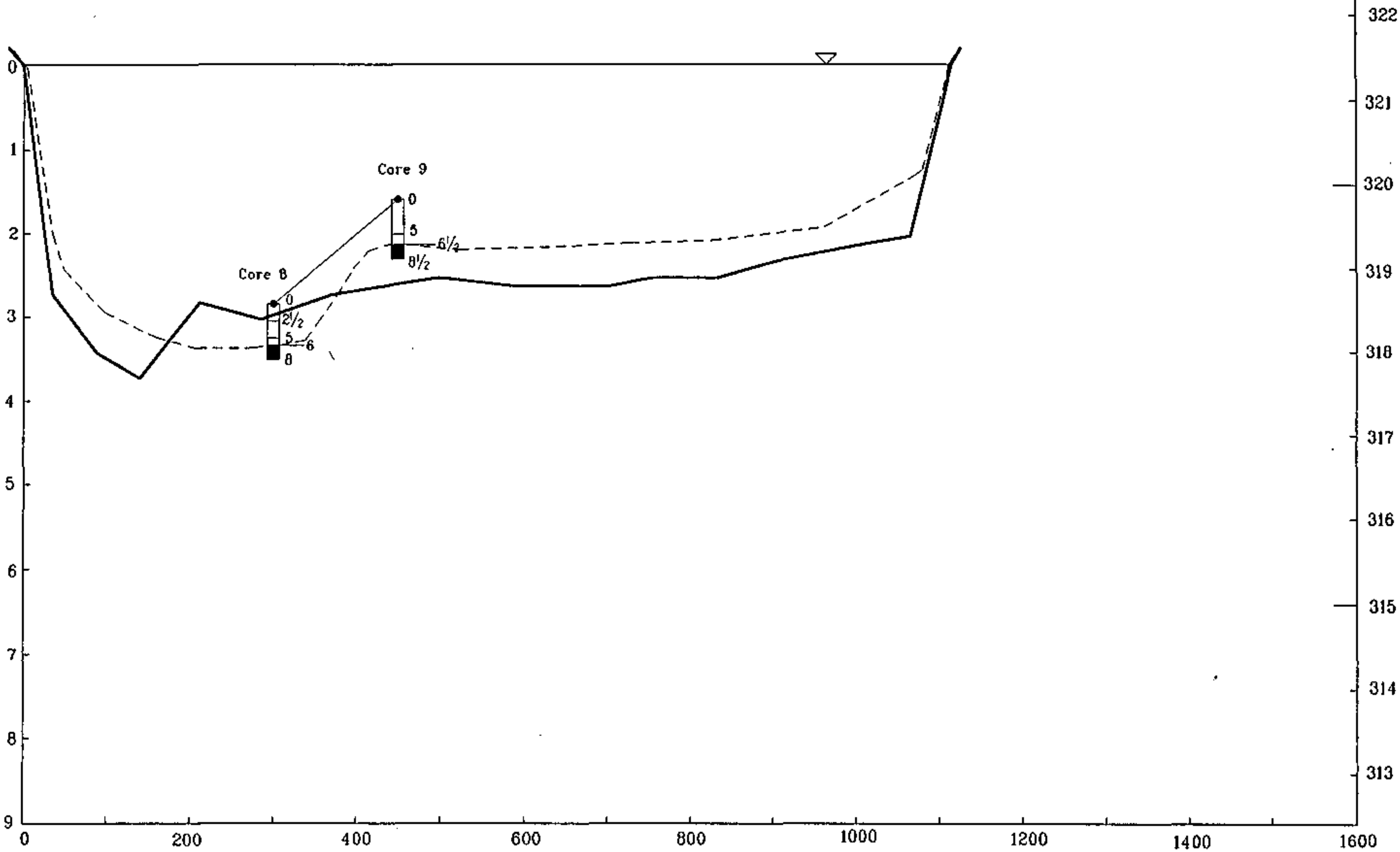
Distance from Left Bank Looking Downstream (ft)

Transect #3



Core 1
0
3½
12
14
16½
Core 2
0
7½
11¼
13¼
0
1
2
3
4
5
6
7
8
9
200
400
600
800
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #4



Core 9
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5
6½
8½
Core 8
0
2½
5
6
8
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200
1400
1600
322
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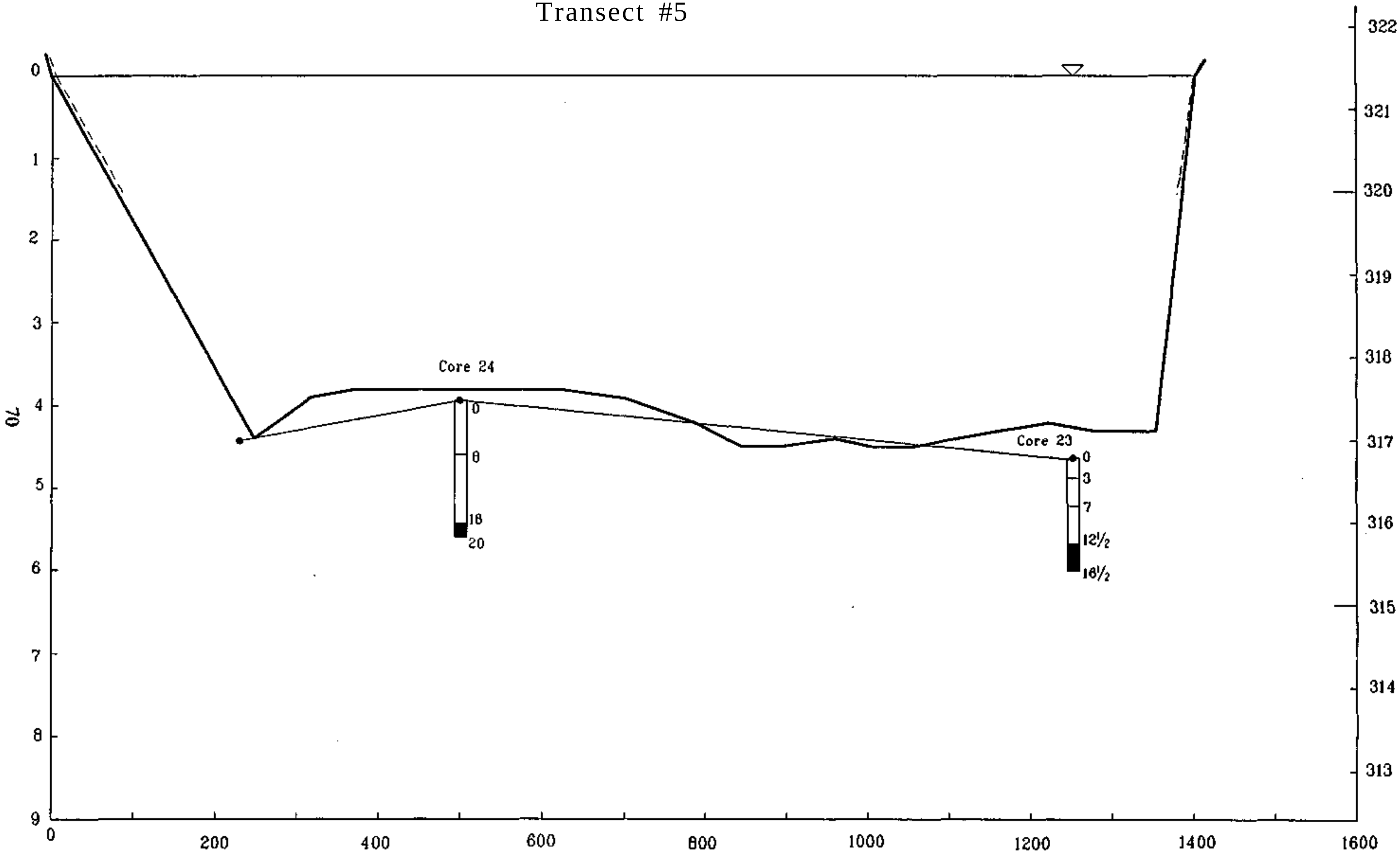
320
319
318
317
316
315
314
313

Transect #5



Core 24
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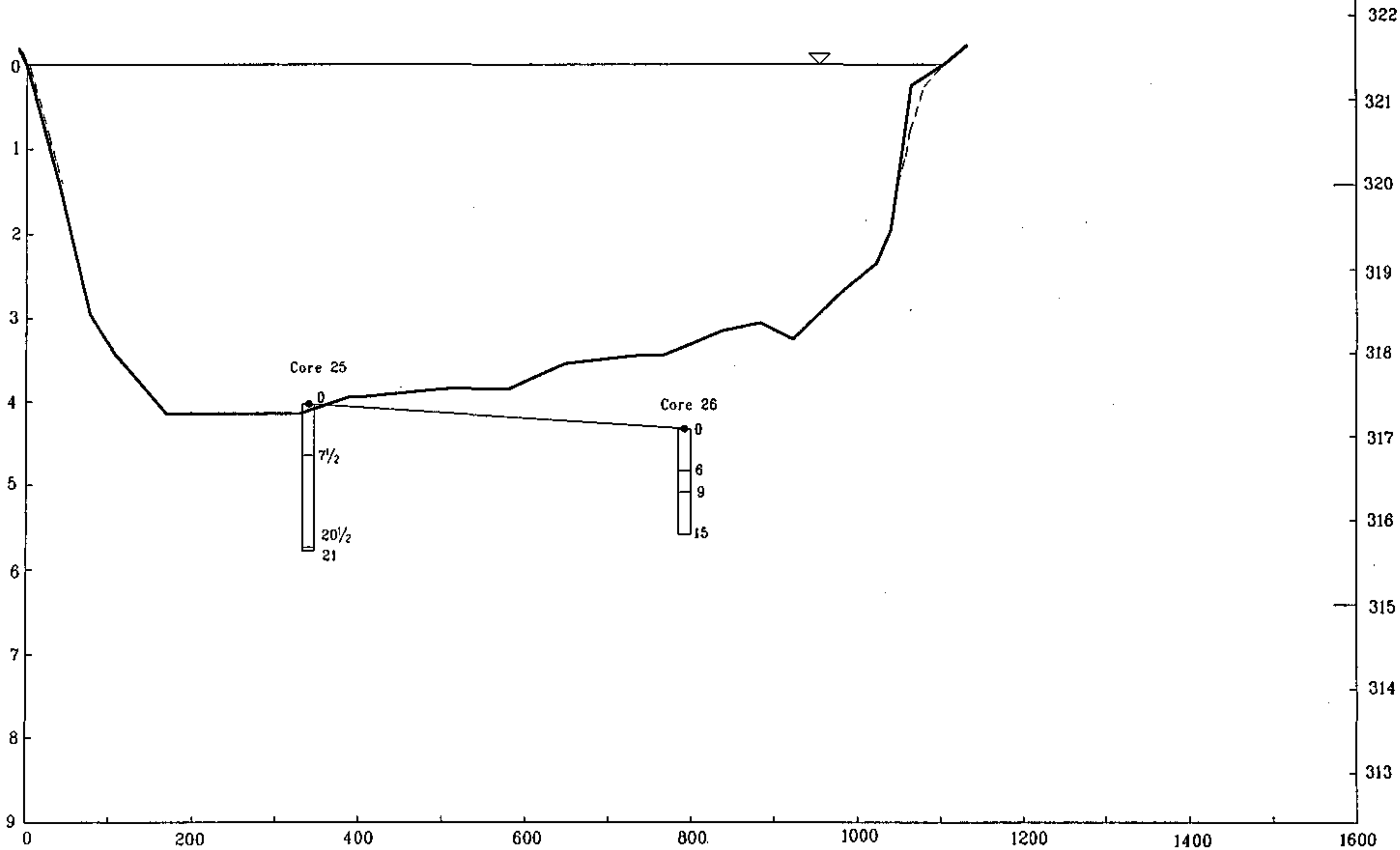
8
18
20
Core 23
0
3
7
12½
16½
0
1
2
3
4
5
6
7
8
9
70
0
200
400
600
800
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #7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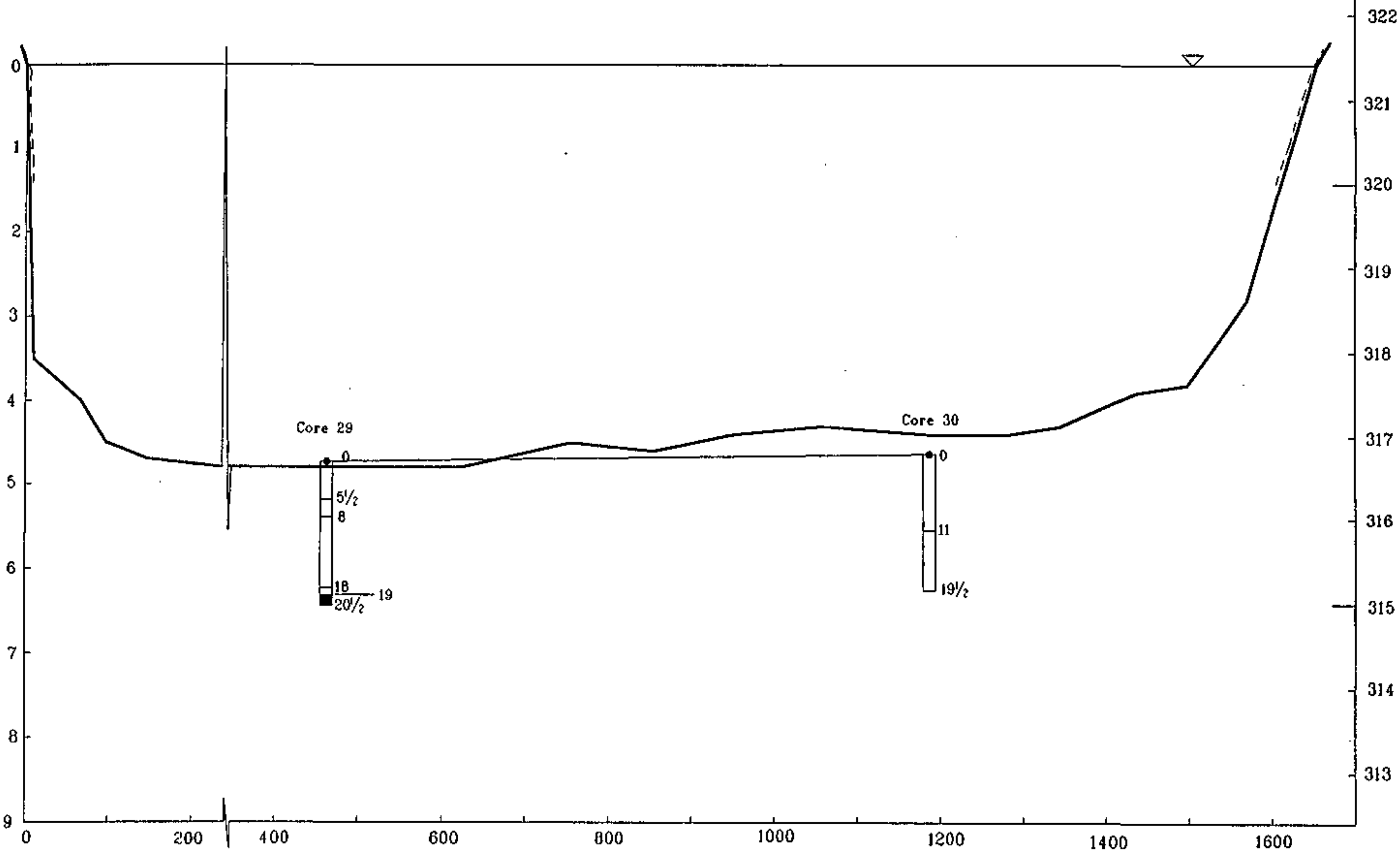
7 1/2
20 1/2
21
Core 26
0
6
9
15
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #8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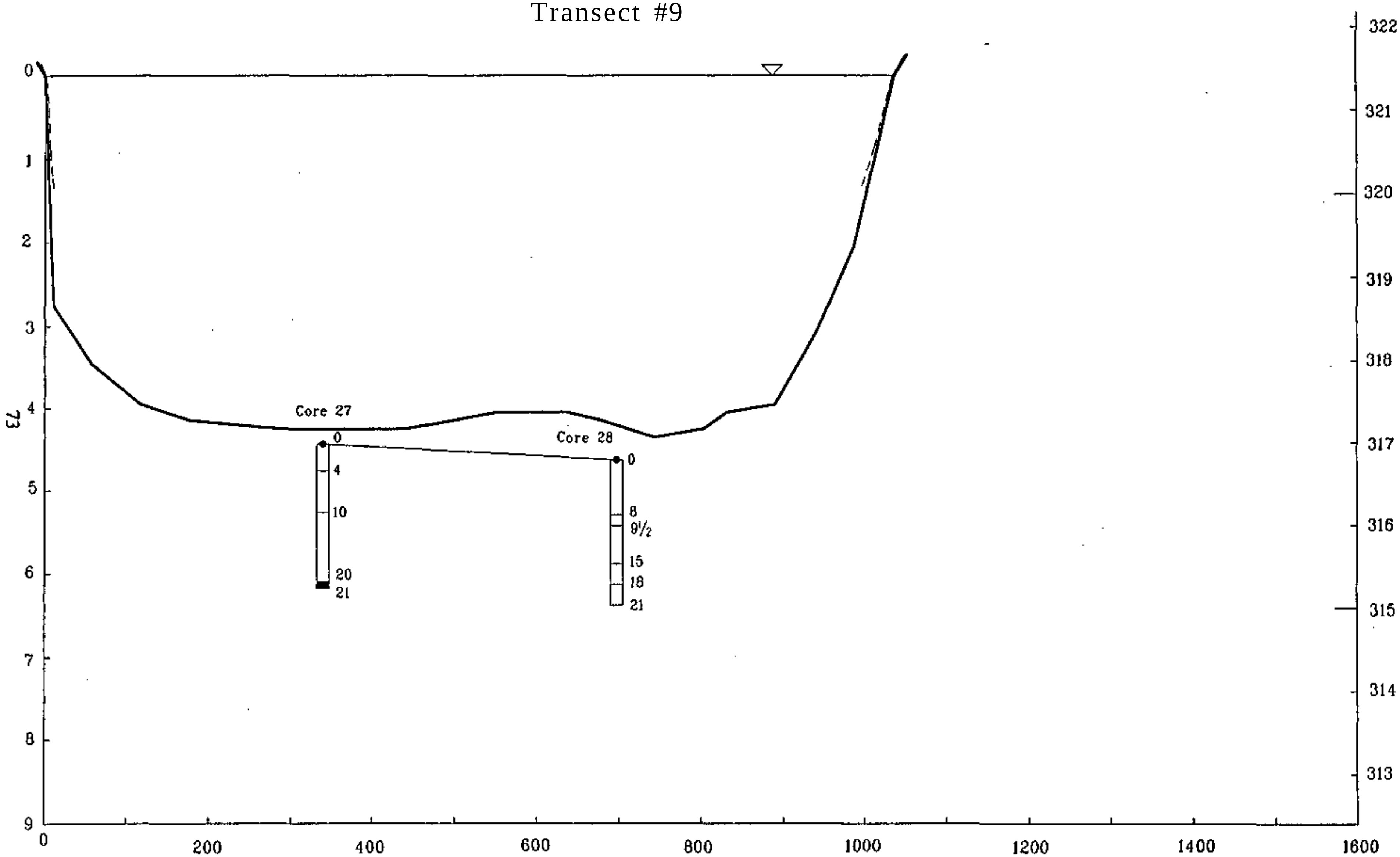
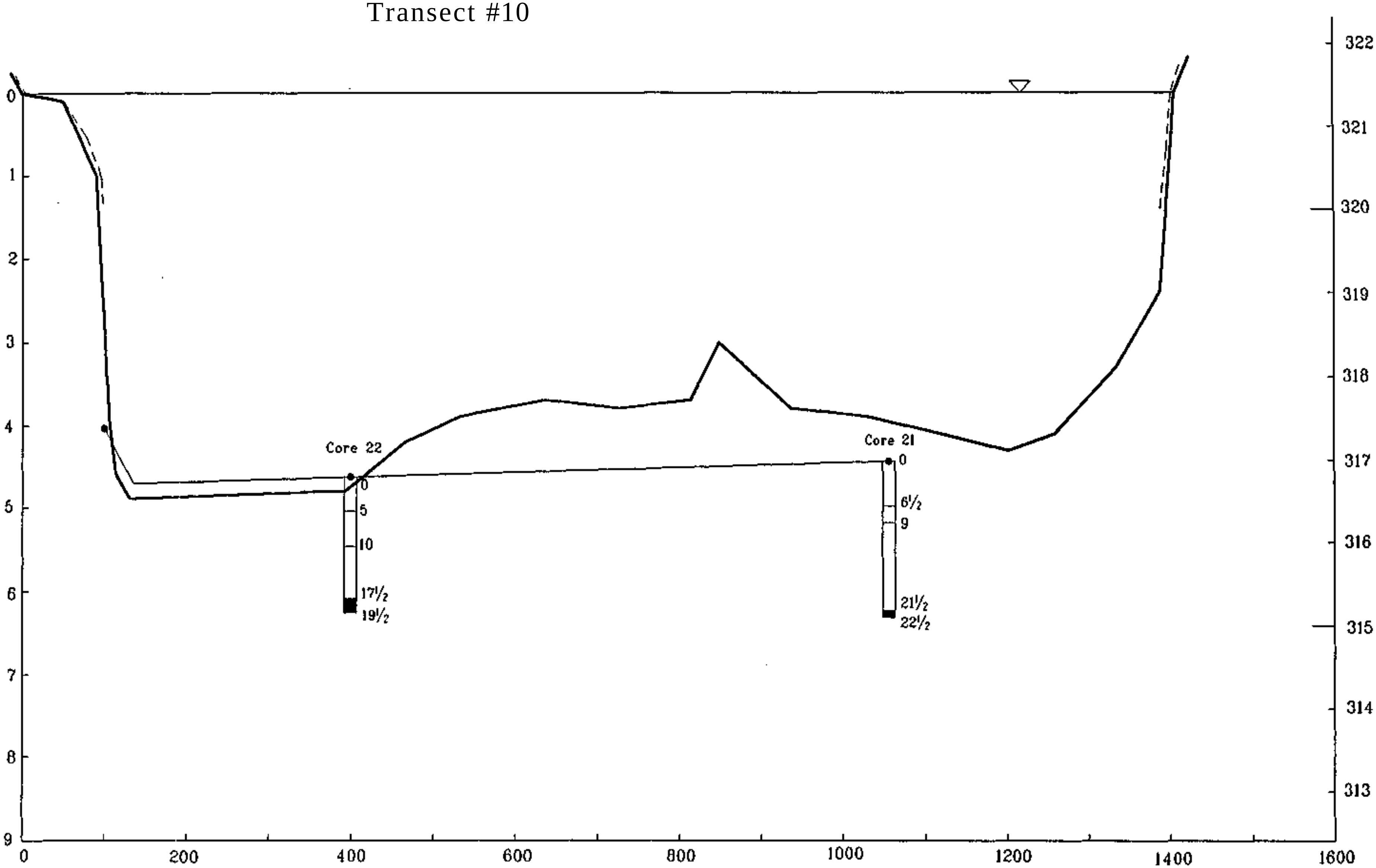
5½
8
18
19
20½
Core 30
0
11
19½
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #9



Core 27
0
4
10
20
21
Core 28
0
8
9½
15
18
21
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #10



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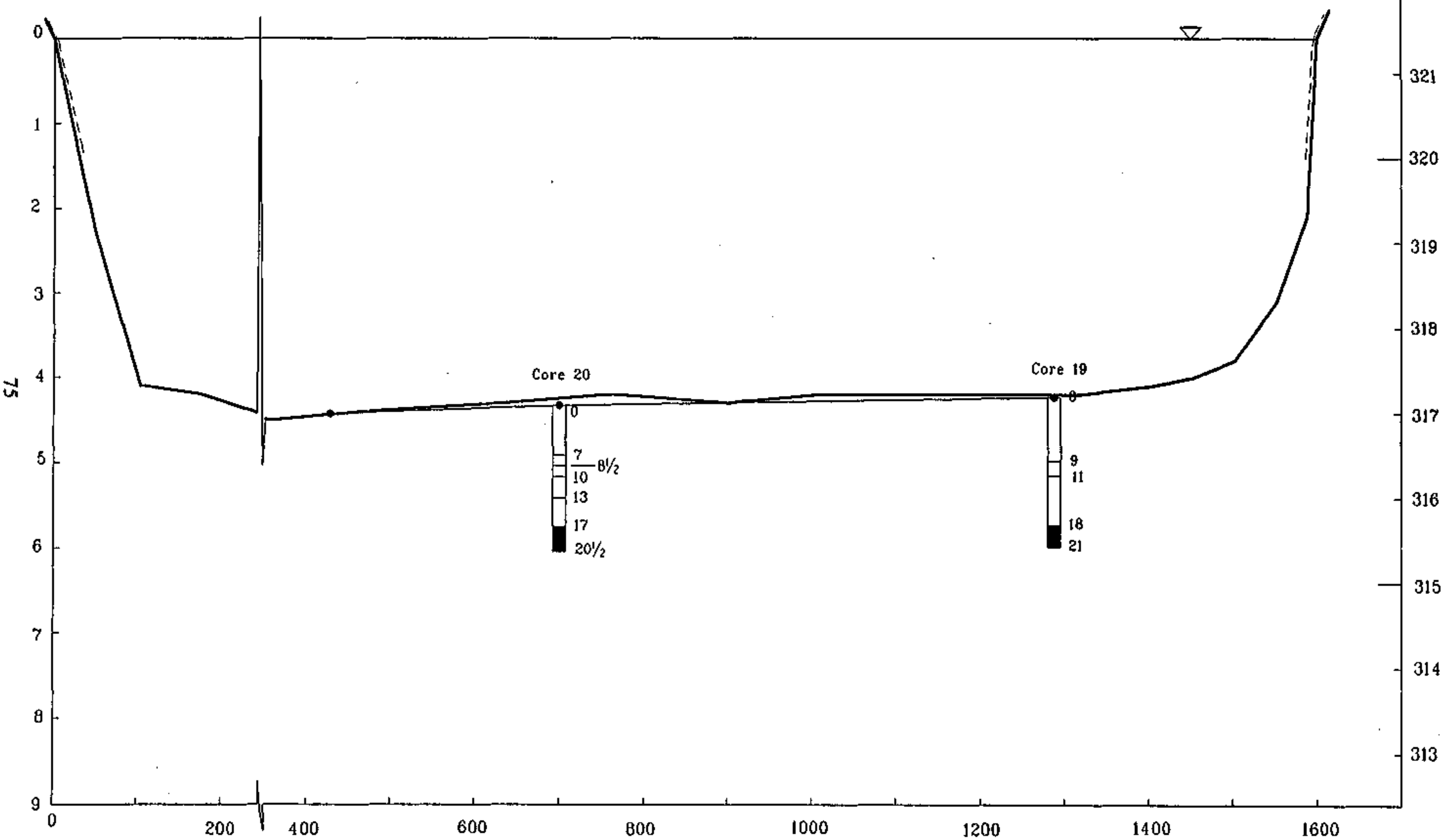
5
10
17½
19½
Core 21
0
6½
9
21½
22½
322
321
320
319
318
317
316
315
314
313
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200
1400
1600

Transect #11



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Core 19
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7
8½
10
13
17
20½
9
11
18
21
0
1
2
3
4
5
6
7
8
9
0
200
400
600
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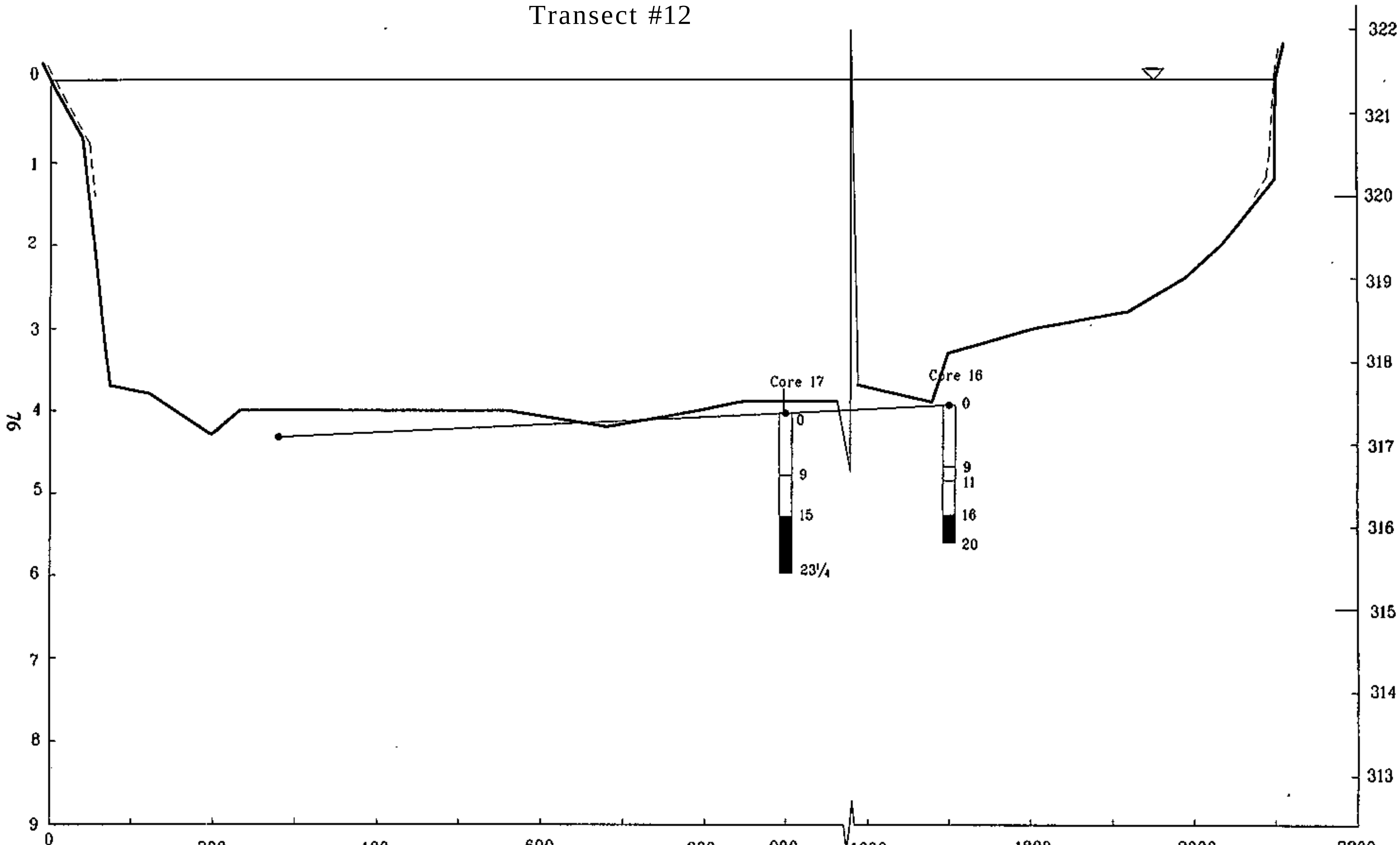
1000
1200
1400
1600
322
321
320
319
318
317
316
315
314
313

Transect #12



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Core 16
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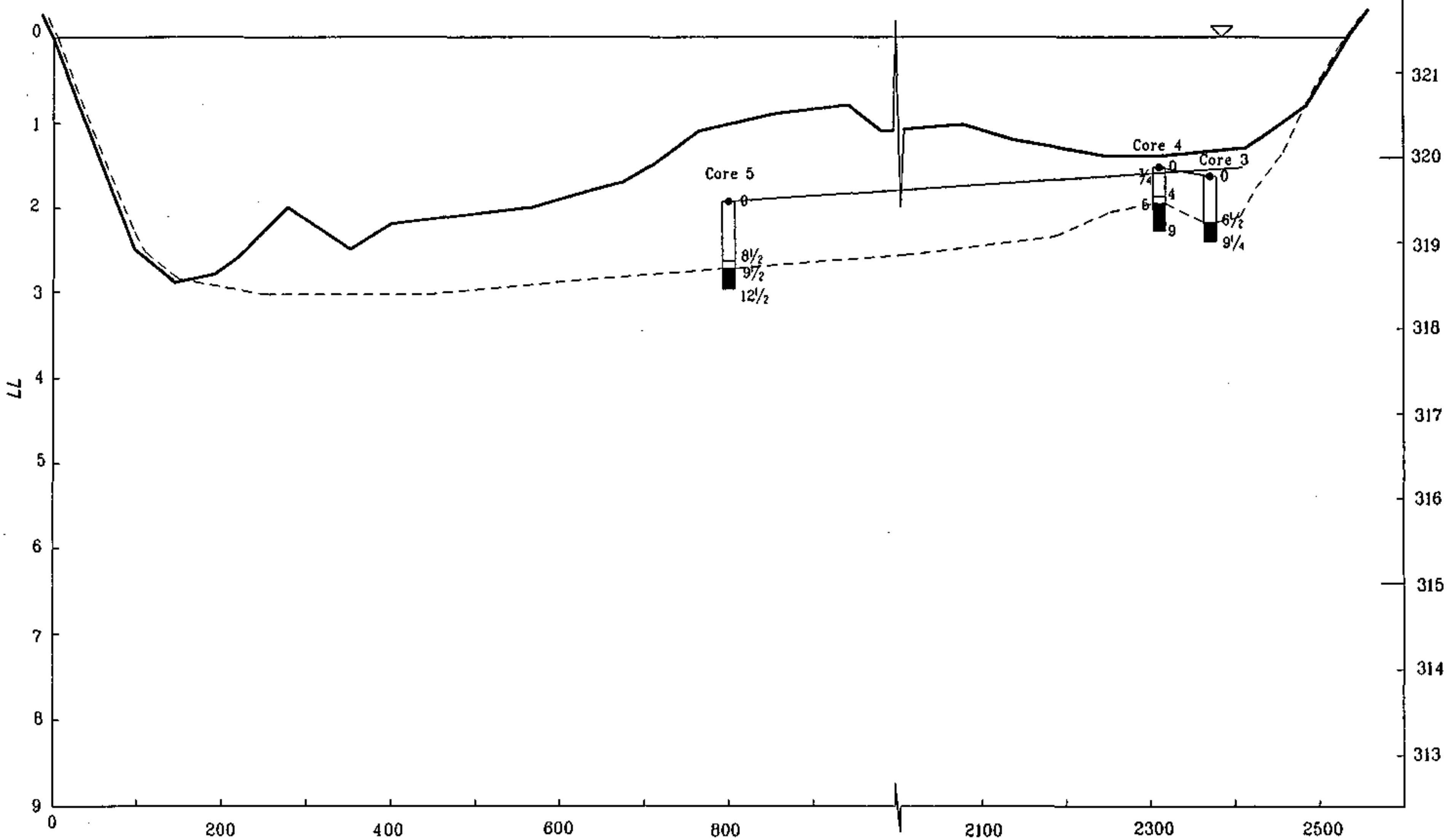
9
15
23¼
0
9
11
16
20
0
1
2
3
4
5
6
7
8
9
322
321
320
319
318
317
316
315
314
313
0
200
400
600
800
900
1600
1800
2000
2200

Transect #13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Core 4
Core 3
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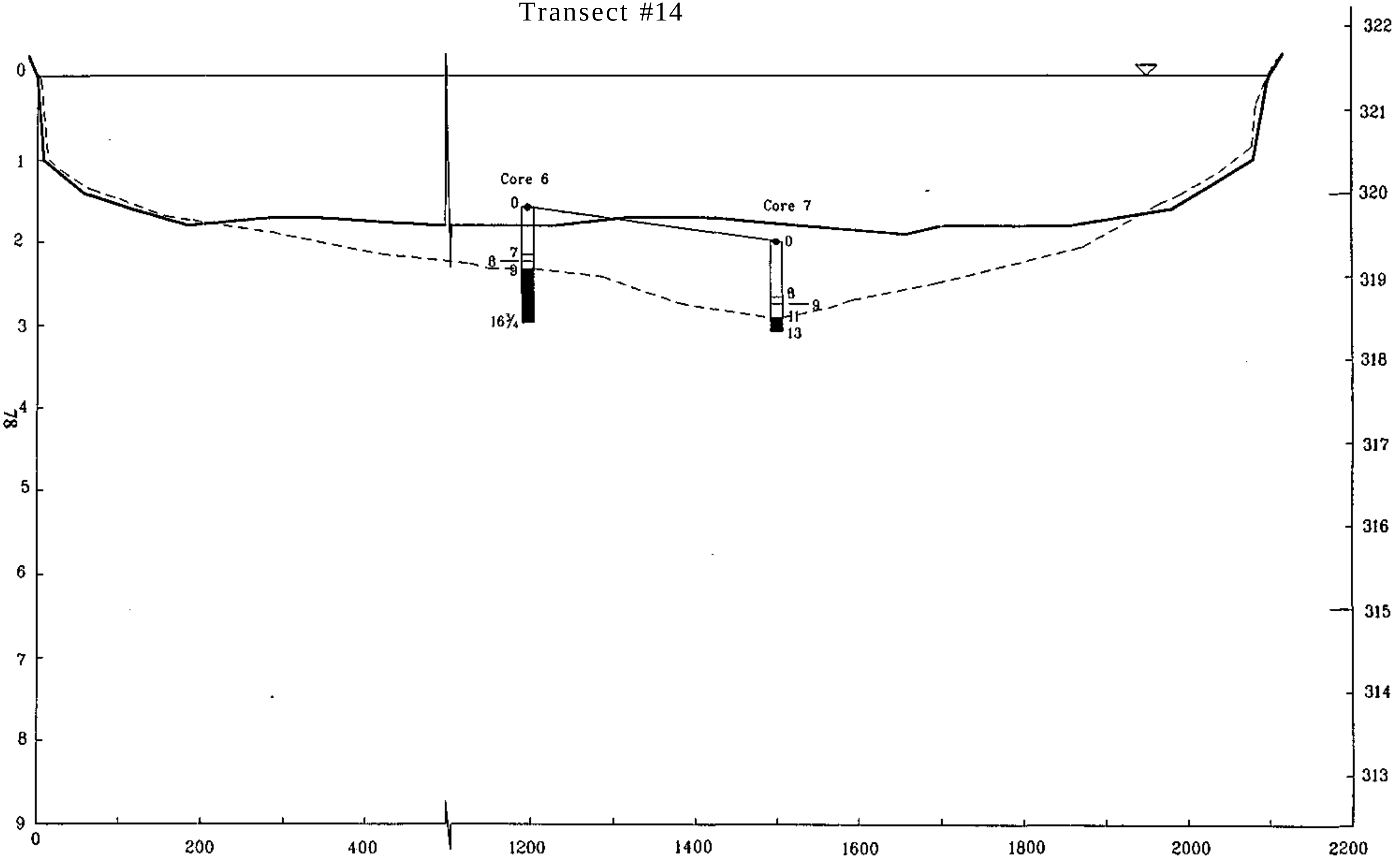
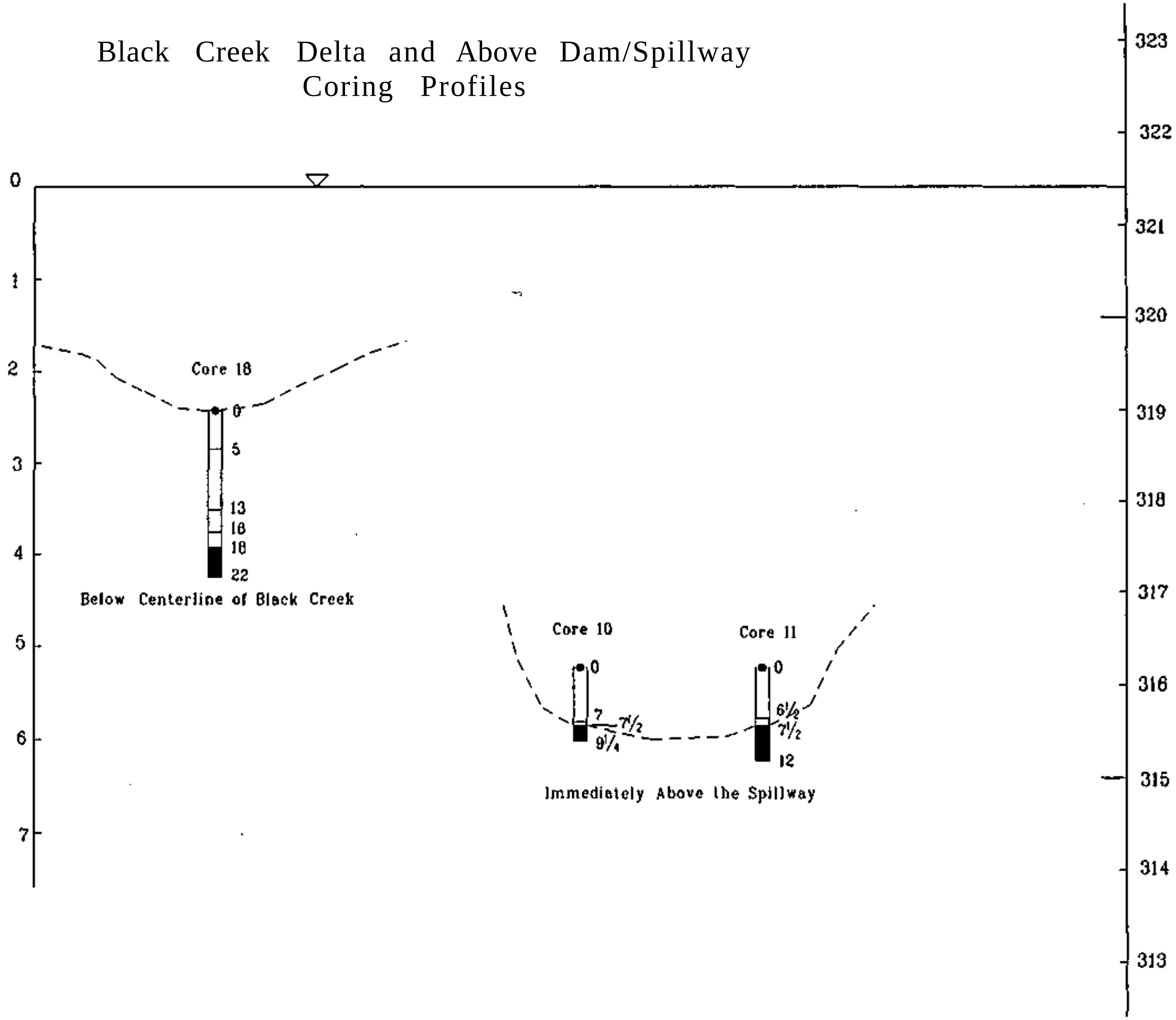
8½
9½
12½
¼
4
6
9
6½
9¼
0
1
2
3
4
5
6
7
8
9
322
321
320
319
318
317
316
315
314
313
0
200
400
600
800
2100
2300
2500

Transect #14



78

Black Creek Delta and Above Dam/Spillway
Coring Profiles



APPENDIX C

General Information on the EDDY Pump Method of "Vacuum Dredging"

Pacific Gas and Electric Company

PG&E Research Reporter

Inside:

Lineworker EMF exposures p. 2

Gas pipelines in earthquakes p. 3

Vol. 8, No. 4 A Quarterly Publication of the R&D Department Fall 1994

New Pump Application Cuts Cost of Dredging Reservoirs

PG&E's R&D and Hydro Generation departments have joined to demonstrate an innovative, cost-saving method for removing sediment at PG&E's Cresta and Rock Creek reservoirs. The dredging method, which uses a device called an EDDY pump, could provide a one-time savings of 510 million compared with conventional dredging techniques. If the demonstration is successful, Hydro could use the EDDY pump as pan of a comprehensive sediment management plan for the reservoirs.

"Sedimentation, which is the result of natural upstream erosion. has displaced about 50 percent of the original storage capacities of these two reservoirs and is threatening reliable operation of the dams and powerhouses," says Larry Harrison, Hydro Generation project manager.

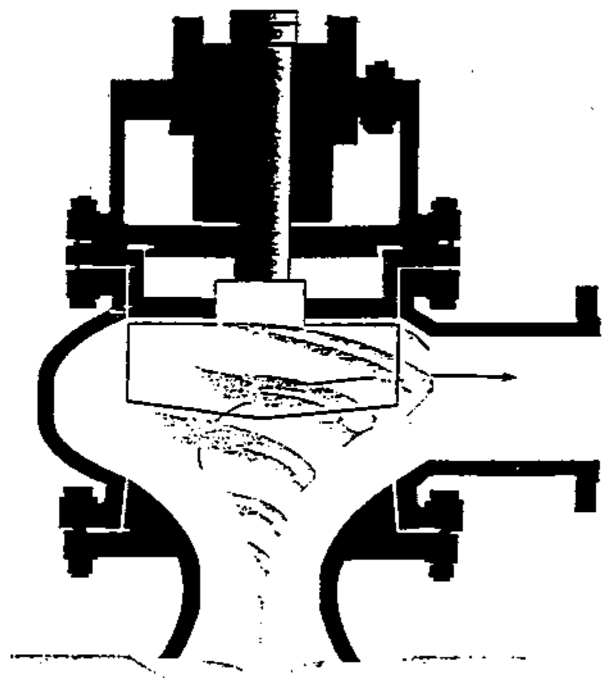
Since the mid-1980s, PG&E has experienced operational problems at the two facilities. Existing sediment deposits already partially obstruct key intake and outlet structures, and rurther buildup will threaten power generation. Also. because of the high levels of deposits, sediments readily pass into the power runnel and through the powerhouse. The abrasiveness of the sediment has accelerated wear and tear on turbines, increasing O&M costs by approximately 5100,000 annually.

To remedy the situation, Hydro Generation plans to. install additional low-level outlets at the base of each dam. These outlets will be opened during periods of high flows, when most sedimentation occurs, so waterborne sediment can pass through the dam instead of settling in the reservoir.

Prior to that installation, however, the sediment now blocking existing dam outlets must be removed. For this application, Hydro Generation invited the R&D Department to co-sponsor a demonstration of a novel dredging plan using the EDDY pump.

The EDDY pump, which was developed and patented by Dr. Harry Weinrib of PBMK Consultants & Engineers, operates on a physical principle similar to that of tornadoes or waterspouts (see figure). It creates an "eddy current," or concentrated

(*Continued on page* 4)



The EDDY pump *creates a vortex, or concentrated swirling column of fluid, that forces sediment up along the sides of the pump chamber and out a floating discharge hose running upstream of the dam out of harm's way.*

We're moving...

On December 28, the offices of the R&D Department will be relocated to 2303 Camino Ramon, Suite 200, San Ramon, CA *94583.* Our *telephone numbers will remain the same.*

Dredging
(Continued from page 1)

swirling column of fluid that forces the sediment up into a floating discharge hose that runs upstream of the dam, where the material is redeposited out of harm's way.

According to Harrison, the EDDY pump offers advantages over conventional techniques. It is cleaner, faster and less costly than clamshell dredging, which generally involves lowering a clamshell bucket into a stream to dig up sediment, placing the sediment on a barge, and draining it for cransport to a land site. Because the new technology stirs up the streambed to a lesser extent, it also has fewer adverse environmental impacts on water quality and aquatic habitat.

Compared to centrifugal pumps, the EDDY pump is less costly and cleaner because it moves less water, transporting a dense slurry the consistency of cake batter, and is more productive because its efficiency is not degraded by abrasive wear or clogging.

The EDDY pump will be a key enabling technology for resolving sediment problems in a low-cost way. Since all PG&E reservoirs are affected by sediment to some degree, the pump will be put to a great many uses.

At Cresta reservoir, a portion of the sediment now blocking the dam outlets—about 10,000 cubic yards—is being dredged. The resulting slurry (up to 60 percent solids by weight) is being moved about 1000 to 2000 feet upstream of the dam. Over the years, during periods of high flow, this redeposited sediment will be flushed out of the reservoir through the new dam outlets.

A research monitoring plan has been developed to validate the expected benefits of the technology and ensure that the pump meets strict requirements for water quality. Features such as turbidity and re-suspension of solids and oil into the water will be monitored. If the demonstration confirms the feasibility of the EDDY pump dredging strategy, Hydro may use the pump to remove an additional 125,000 cubic yards of sediment at the dams.

"The EDDY pump will be a key enabling technology for resolving sediment problems in a low-cost way," says Felmir Singson, R&D project manager. "Since all our reservoirs are affected by sediment to some degree, I foresee a great many uses for this technology. It's new technology such as EDDY pumps that will help Hydro Generation stay on the leading edge as a competitive provider of electricity."

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The *PG&E Research Reporter* is published quarterly by Pacific Gas and Eiectric Company's Research and Development (R&D) Department. under Garth Hall. department manager. Dick Davin is editor; Contributing editors include Jonas Weisel and Kathy McMorrow.
Subscriptions are free and can be obtained by writing to the R&D Report Center. R&D Department. PG&E. 2203 . Carr.ino Ramon, Suite 200. San Ramon. CA 94583.

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Region V Review of George Lake Clean Lakes Diagnostic-Feasibility Study

PUBLIC ACCESS

Calumet College owns the lake bottom, the lake water and a portion of the land adjacent to the lake. Calumet College President Dennis Rittenmeyer has stated publicly, and allegedly, in writing, that the college will continue their current policy of providing public access to the lake, and the lake waters, should the college retain ownership of the lake. President Rittenmeyer has also publicly stated that Calumet College will continue to hold title to land adjacent to the lake's east shoreline, and that the College would permit public access to the water's edge, should the lake be sold (George Lake is currently available for sale, and a prospective buyer has purchased an option to buy the lake).

Should Calumet College sell the lake and provide public access to the lake from their property on the eastern shore, there is no legal leverage to require the new owner, who will have obtained title to the lake water and lake bottom, to provide the public access to the waters of the lake. This would then counter both the spirit and the letter of the Clean Lakes Program Regulations requirements for public access, at 40CFR part 35.1605-3.

HEALTH OF THE FISHERY

1.) During the September 17, 1996 public hearing for the George Lake Diagnostic-Feasibility Study, Dennis Wesolowski pointed out that the U.S. Fish and Wildlife Service Biological Report of Fish Residue (July 1995) revealed elevated levels of polynuclear aromatic hydrocarbons (PAHs) in the bile of bullheads; however, the Diagnostic-Feasibility Study did not investigate concentrations of PAHs in the lake sediment, a likely source of the fish bile contaminant The potential role of sediment PAHS as an ongoing hazard to fish health in the lake should be clarified.
Without this data, it is difficult to project the future health of the bullhead fishery, or the impact of any dredging on the fishery, or on water quality.

(The study contractor did request supplemental funding for this task after initiating work on the project, and then discovering the need for PAH sediment data. However, we were not able to obtain additional funding for the project)

2.) The Indiana Department of Environmental Management recently revised their criteria for fish consumption advisories. As a consequence, your agency issued the following advisory for Northern Pike obtained from George Lake, based on concentrations of polychlorinated hydrocarbons (PCBs):

For individual fish greater than 18 inches in length, adults should eat no more than one meal each week, and women of childbearing age and children under 15 years old should eat no more than one meal each month.

LAKE USE GOALS

Public sentiment expressed at the project public meeting, the public hearing and George-Wolf Committee meetings preponderantly supported not developing/improving George Lake as a fishing lake, because the much better fishery at Wolf Lake is so near. Rather, those addressing the issue supported maintaining its current shallow lake status, which supports non-consumptive uses such as bird watching, observing nature, and lake aesthetic appreciation.

GROUNDWATER IMPACTS ON WATER QUALITY

Although it is our view that the project contractors fulfilled their responsibilities regarding ground water, we believe that the impact of ground water contamination from surrounding sites requires additional study.

SURFACE RUNOFF IMPACTS ON WATER QUALITY

Again, although the contractors fulfilled the work program requirements regarding the impacts of surface water runoff, this part of the study should also be expanded in the near future to analyze contaminants from specific land uses/sites, and their impacts on lake quality. Commentators from the public expressed frustration with the limited coverage of this aspect of the George Lake study.

This concludes our review.

ILLINOIS
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