FINAL REPORT

Jordan River Corridor Preservation Study

CITY OF

SARATOGA SPRINGS

Prepared for

City of Saratoga Springs

Prepared by

JE Fuller/Hydrology & Geomorphology, Inc.

and

CH2MHILL

March 2007

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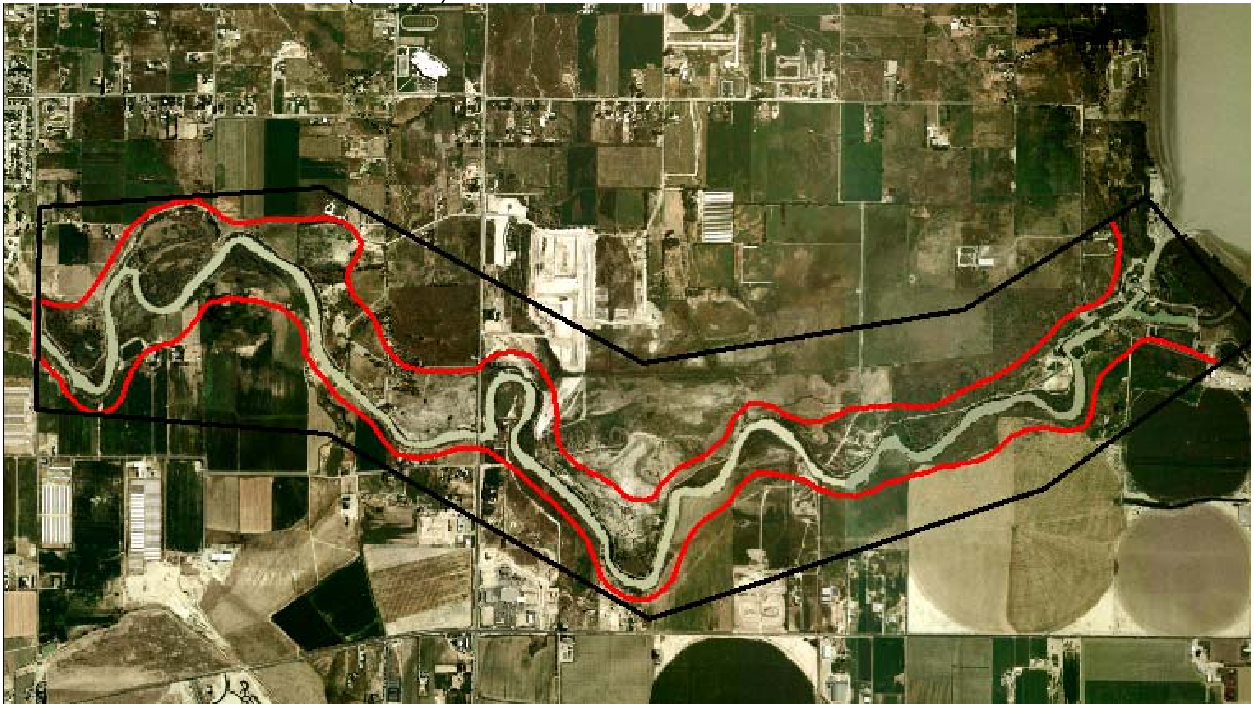
Executive Summary

Riverine erosion causes over $450 million in damages each year with the most severe erosion occurring in the Arid West (FEMA, 1999). Unlike flood inundation hazards, where damaged structures may be repaired or replaced, riverine erosion not only completely destroys structures in its path, but also removes the land on which the building stood, eliminating any chance of reconstruction. Therefore, erosion management is a key element for floodplain management.

An erosion hazard zone was defined for the Jordan River from Utah Lake to 9600 North in the City of Saratoga Springs. The erosion hazard zone (see Figure E-1) was delineated based on state-of-the-art geomorphic mapping, field investigations, historical evidence of river movement, sediment transport analyses and principles of river mechanics. The geomorphic mapping indicates that the Jordan River lies within a several mile wide geologic floodplain in which the river has migrated over the past several thousand years. Field investigation documented an abundance of recently eroded cutbanks, as well as evidence of recent long-term degradation (scour), probably caused by dredging of the river. Comparison of historical aerial photographs and maps dating to 1856 reveals low to moderate rates of channel movement over the past 150 years. Sediment transport studies concluded that bed and bank materials are erodible, even at the low velocities experienced in the study reach. River behavior models predict continued meander migration and local bank failures that will continue to impact properties adjacent to the river.

FIGURE E-1
Jordan River Erosion Hazard Zone (Red Line).



Alternatives for management of the riverine erosion hazard zone are proposed for consideration by City planners and floodplain managers. The management alternatives include monitoring and inspecting future river behavior, best management practices for maintenance of existing facilities, development guidelines for lands within the erosion hazard zone, and design guidelines for new road crossings or bank stabilization.

Contents

Tables

Figures

Appendices

1.0 Introduction

The Jordan River is a unique river system with unusual hydrologic characteristics created by its geomorphic setting. The Jordan River connects two major static water bodies, the fresh water Utah Lake and the Great Salt Lake. While the river retains much of its historical natural river form and function, its natural hydrology has been substantially altered by operation of the river as a de facto irrigation and flood control facility. During the prolonged floods of the 1980's, reaches of the Jordan River in Salt Lake County experienced extensive lateral erosion, widening and scour. In Utah County, the Jordan River experienced somewhat less lateral erosion, but greater flood inundation during the 1980's floods.

1.1 Study Objective

The primary objective of the Jordan River Corridor Preservation Study was to delineate an erosion hazard zone for the Jordan River in the City of Saratoga Springs. The findings of the study will also be used to develop river management alternatives to be implemented by the City.

1.2 Study Limits

The Jordan River Corridor Preservation Study extends approximately 5.5 miles from Utah Lake to the 9600 North Bridge, and is located within the incorporation limits of the City of Saratoga Springs, Utah. The study reach is located in Utah County, within portions of Sections 12, 13, 14, 23, 24, and 25 of Township 5 South, Range 1 West (Figure 1-1). The study reach also abuts portions of the City of Levi, Utah and unincorporated Utah County.

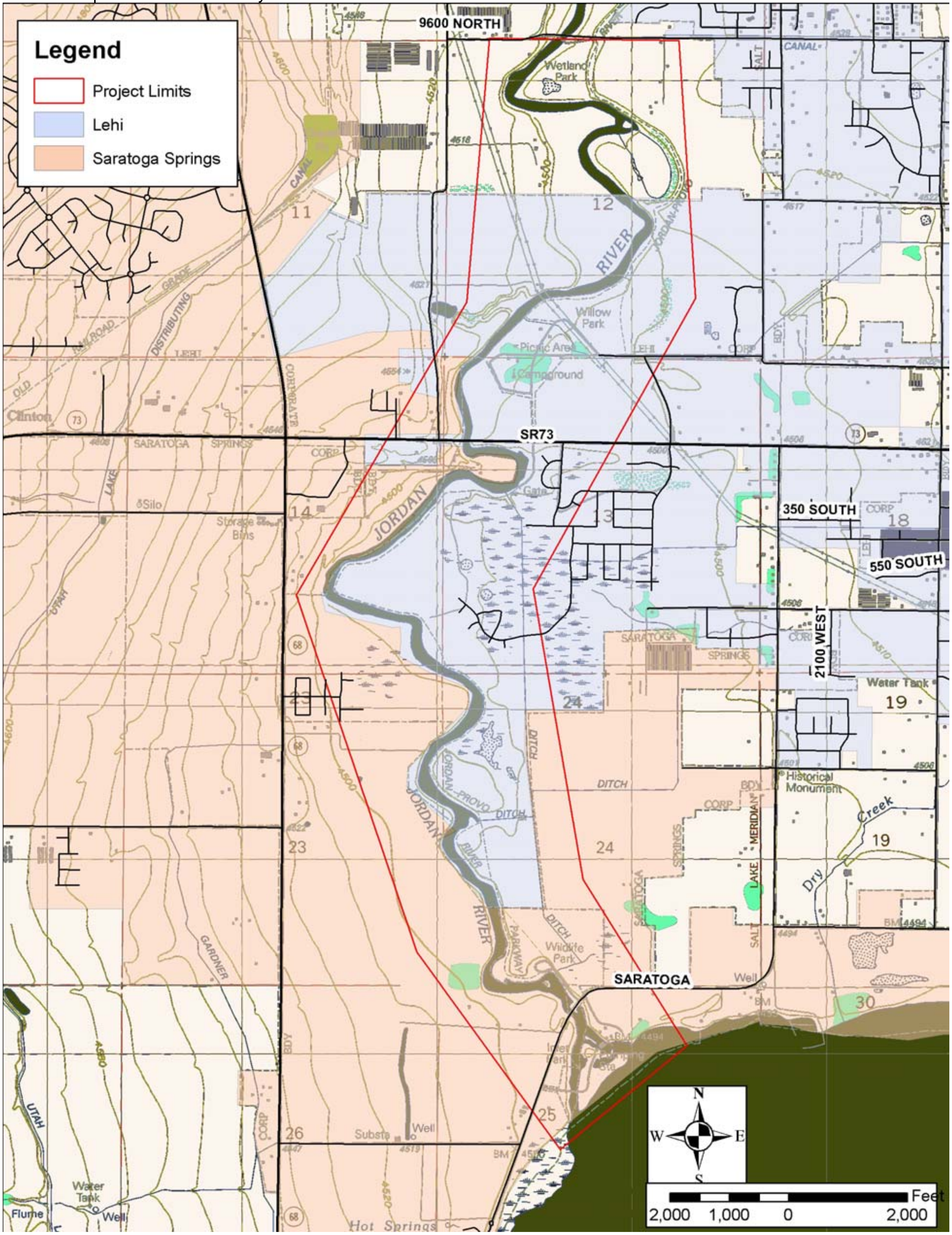
1.3 Reach Definition

For the purposes of the erosion hazard analyses, the Jordan River study area was divided into the following reaches based on site-specific characteristics, hydrology, geomorphology and geography:

- Reach 1 – Utah Lake to Saratoga Road
- Reach 2 – Saratoga Road to Main Street (State Route 73)
- Reach 3 – Main Street to 9600 North

Field observations and hydraulic models indicate that there are only minor differences within the study reach. Therefore, the three reaches were defined primarily by geographic characteristics, with the three existing roadway bridges serving as reach dividers.

FIGURE 1-1
Location Map of Jordan River Study Reach



1.4 Report Organization

This report is organized as follows:

- Chapter 1: Introduction. Contains information about the study objectives, study limits and project participants.
- Chapter 2: Data Collection. Describes the sources of data used for the erosion hazard assessment such as mapping, hydrology, hydraulics, geology, and geographic information.
- Chapter 3: Field Investigation. Summarizes the results of the field-based analysis tasks, including sediment data and bank stability, and also shows examples of field observations of the river.
- Chapter 4: Geomorphic Analysis. Presents the results of the geomorphic analyses used to assess river stability, such as stream classification, landform mapping, and empirical (mathematical) techniques.
- Chapter 5: Bed Elevation Analysis. Summarizes the results of the assessment of potential for vertical changes in channel condition that might impact the lateral or long-term stability of the river.
- Chapter 6: Sediment Transport Analysis. Summarizes the sediment continuity analysis used to support the lateral stability assessment.
- Chapter 7: Lateral Migration Analysis. Presents the evaluation of historical changes in channel geometry, location, pattern, as well as an assessment of the vulnerability of the channel banks to erosion. The recommended erosion hazard zone is defined in Chapter 7.
- Chapter 8: River Management Guidelines. Describes alternatives for managing the Jordan River in the City of Saratoga Springs are provided in Chapter 8. Management alternatives include erosion protection, inspection and monitoring, and implementation of development guidelines.

2.0 Data Collection

2.1 Data Collection

The sources and types of data used in the Jordan River Corridor Preservation Study are described in this chapter. The following types of data were collected to support the study:

- Hydrology
- Hydraulics
- Aerial Photography
- Historical Maps
- Topography
- Soils & Geologic Maps
- Geographic Information

The spatial data sets collected for the study were imported into a geographic information system (GIS) created for the project.

2.2 Hydrology

Hydrologic data were obtained from the most recent Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for the Jordan River, from U.S. Geological Survey (UGS) streamflow records, and from previous technical reports. A summary of base-level hydrologic data for the Jordan River is provided in the following paragraphs.

The Jordan River is the only natural outlet for Utah Lake, which has a drainage area of about 2,950 square miles. Since 1902, flow from Utah Lake into the Jordan River has been regulated by a gated outlet structure and pumping plant. Releases into the Jordan River from Utah Lake are governed by a legal settlement known as the “Compromise Agreement” which, among other things, dictates the following:

- The Utah Lake gate outlet is opened when lake storage exceeds elevation 4,489.045 ft. (the “compromise elevation”) with the release rate determined by the Jordan River or Utah Lake outlet capacity. More specific flood control alternatives are also included in the Compromise Agreement.
- Minimum flows determined by the water rights of downstream users are released or pumped into the Jordan River when the lake elevation falls below elevation 4,489.045 ft.

Historically, floods have occurred on the Jordan River when Utah Lake exceeded elevation 4,491.1 ft. Because of the combination of lake storage and the operational effects of the Compromise Agreement, the following flood characteristics apply to the Jordan River:

- When Utah Lake is below the compromise elevation, floods are rare and annual peak flow rates are relatively constant in the study reach.
- When floods do occur, they tend to be of very long duration as a result of the long drain time caused by the large storage volume of the lake.

- Periods of flooding are directly correlated to decadal scale wet/dry climatic fluctuations.

Flood discharge data for the study reach were derived from the FEMA Flood Insurance Study, as shown in Table 2-1. Due to the relatively short reach length and lack of significant tributary inflow, there is no change in the 100-year discharge within the study area. No information on more frequent flood magnitudes was available for this study.

TABLE 2-1
Jordan River Flood Discharge Data (cfs)

Concentration Point	100-Year	500-Year
Reach 1	2570	3190
Reach 2	2570	3190
Reach 3	2570	3190

Seasonal average flow rates and flow duration data from the UGS Gage Jordan at Narrows 10167000 are shown in Tables 2-2 and 2-3. The flow data in Table 2-2 indicate that peak flows typically occur in late spring and early summary due in part to snow melt. High flows also occur as a result of increased irrigation and water supply demands delivered through the river. UGS records indicate that near-zero flow rates can occur throughout the year, except in July and August due to pumping requirements and downstream water demand.

TABLE 2-2
Jordan River Flow Seasonality Data (cfs)

Month	Average Flow Rate	Minimum/Maximum Flow Rate
January	188	1 / 1700
February	234	1 / 1610
March	268	0 / 1610
April	326	0 / 1920
May	603	0 / 2680
June	700	8 / 3030
July	760	112 / 2660
August	696	94 / 1880
September	550	2 / 1530
October	249	3 / 1360
November	158	4 / 1380
December	170	2 / 1500

UGS flow duration data (Table 2-3) indicate that base flow is about two to three orders of magnitude less than the annual peak high flows. Such a wide range in discharge is common on mountain rivers in the western USA and is often associated with vulnerability to lateral erosion.

TABLE 2-3
Jordan River Flow Duration Data (cfs)

Location	5% Flow	10% Flow	50% Flow	90% Flow
UGS Gage 10167000	1150	795	382	9

2.3 Hydraulics

Hydraulic data used in the Jordan River Corridor Preservation Study were obtained from a HEC-RAS model developed by converting the HEC-2 model for the most recent FEMA floodplain delineation (Baker, 1998; Figure 2-1). The HEC-2 model was converted to HEC-RAS version 3.1.3 format using the HEC-RAS import subroutine. Minor adjustments to the HEC-2 model input file were made to account for differences in input requirements, particularly at bridge sections. The HEC-RAS model output compared favorably with the FEMA HEC-2 model results. HEC-RAS data used in the Jordan River Corridor Preservation Study included cross section geometry, longitudinal minimum elevation profiles, hydraulic output such as flow depth, velocity, and width (Table 2-4). The hydraulic data were also used in empirical geomorphology equations, sediment transport routing, and scour equation computations, as described in Chapters 4, 5 and 6 of this report.

TABLE 2-4
HEC-RAS 100-Year Hydraulic Data

River Station #	Velocity Channel (ft/s)	Top Width (ft)	Froude # Channel	Hydraulic Depth Channel (ft)	Max Channel Depth (ft)	Q Channel (cfs)	Top Width Channel (ft)	E.G. Slope (ft/ft)
26	2.1	113	0.11	11.6	15.2	2565	108	0.00008
28	2.0	113	0.11	11.7	15.6	2565	108	0.00007
29	1.7	135	0.09	11.6	16.1	2569	128	0.00005
30	0.7	1080	0.05	6.7	17.7	2252	469	0.00002
31	0.9	1378	0.05	8.3	14.1	1729	241	0.00002
32	1.1	871	0.05	14.3	17.6	2091	130	0.00002
33	1.3	1127	0.07	9.8	14.3	2029	165	0.00003
35	1.4	1510	0.07	12.4	17.0	2473	141	0.00003
36	1.6	2411	0.08	11.7	15.9	2332	125	0.00005
37	1.8	144	0.10	11.6	14.9	2564	120	0.00006
38	2.4	80	0.11	13.6	14.8	2570	80	0.00010
40	1.1	291	0.05	12.4	19.7	2407	184	0.00002
41	1.8	1428	0.09	12.2	17.0	2077	97	0.00005
42	1.2	1901	0.06	11.3	16.6	1740	134	0.00002
43	1.2	2082	0.06	10.6	13.5	2172	173	0.00003

TABLE 2-4
HEC-RAS 100-Year Hydraulic Data

River Station #	Velocity Channel (ft/s)	Top Width (ft)	Froude # Channel	Hydraulic Depth Channel (ft)	Max Channel Depth (ft)	Q Channel (cfs)	Top Width Channel (ft)	E.G. Slope (ft/ft)
44	1.2	2605	0.06	11.4	15.0	2184	156	0.00003
46	1.1	3511	0.06	10.6	16.2	2018	167	0.00003
47	1.0	2272	0.06	9.1	13.1	2178	249	0.00002
48	0.9	2823	0.06	8.5	12.4	2008	253	0.00002
49	1.1	3690	0.06	11.7	14.9	1647	128	0.00002
50	1.4	3369	0.07	11.0	15.8	2057	136	0.00003
51	1.3	3979	0.07	10.4	12.6	1970	147	0.00003
52	1.0	3184	0.06	8.6	14.5	2197	269	0.00002
53	1.0	3637	0.06	8.6	11.7	1951	238	0.00002
54	1.2	1466	0.07	9.5	12.2	2058	184	0.00003
55	2.7	102	0.15	10.4	14.7	2563	92	0.00014
56	2.7	99	0.15	10.4	14.7	2555	92	0.00014
58	2.7	102	0.14	10.5	14.3	2553	92	0.00014
59	1.8	489	0.10	9.6	11.5	2296	136	0.00007
60	1.4	228	0.07	11.3	15.0	2556	165	0.00003

FIGURE 2-1
FEMA Floodplain Map for the Jordan River Near the Study Reach. The Blue Zone A and A4 is the 100-Year Regulatory Floodplain.

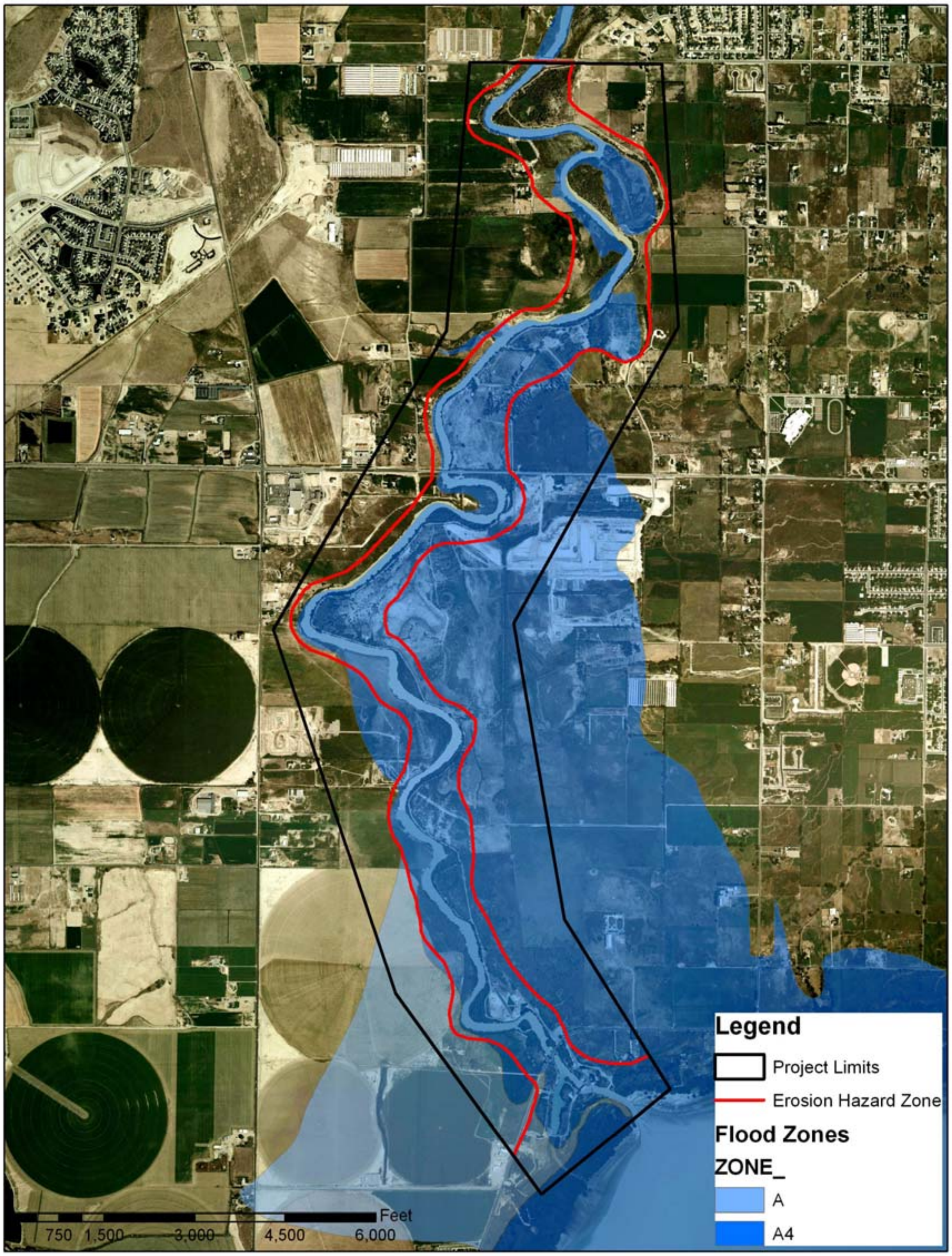


FIGURE 2-2
100-Year Velocity Profile for the Jordan River Study Reach

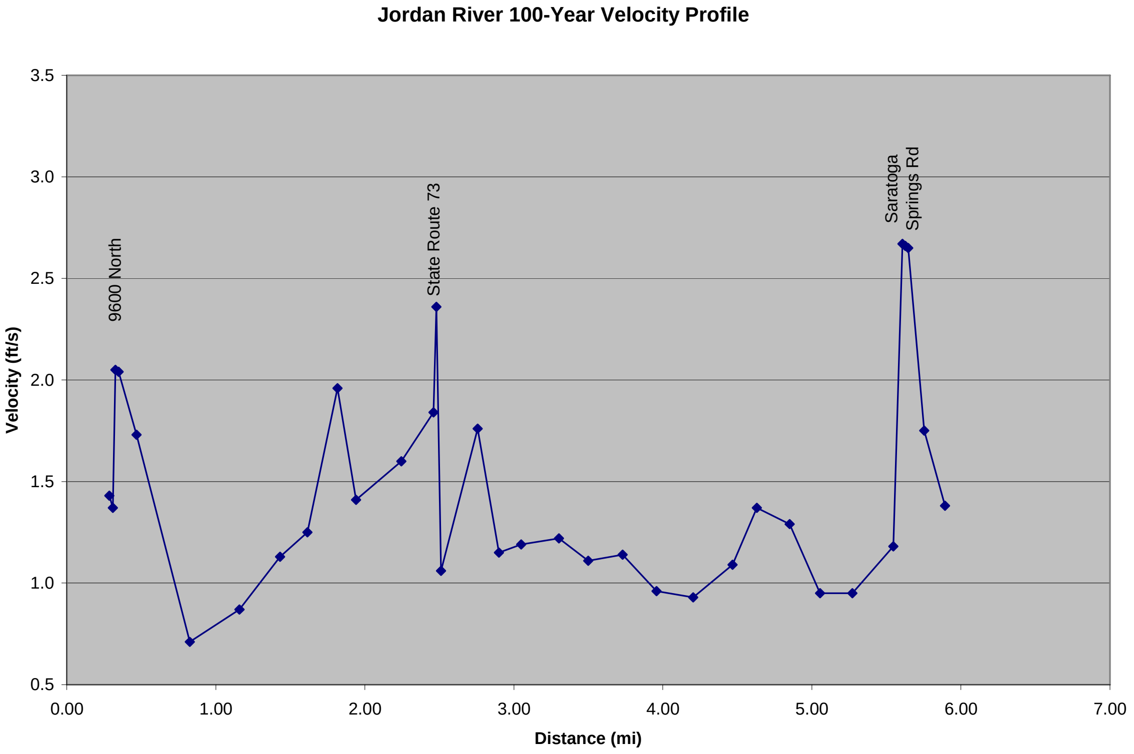
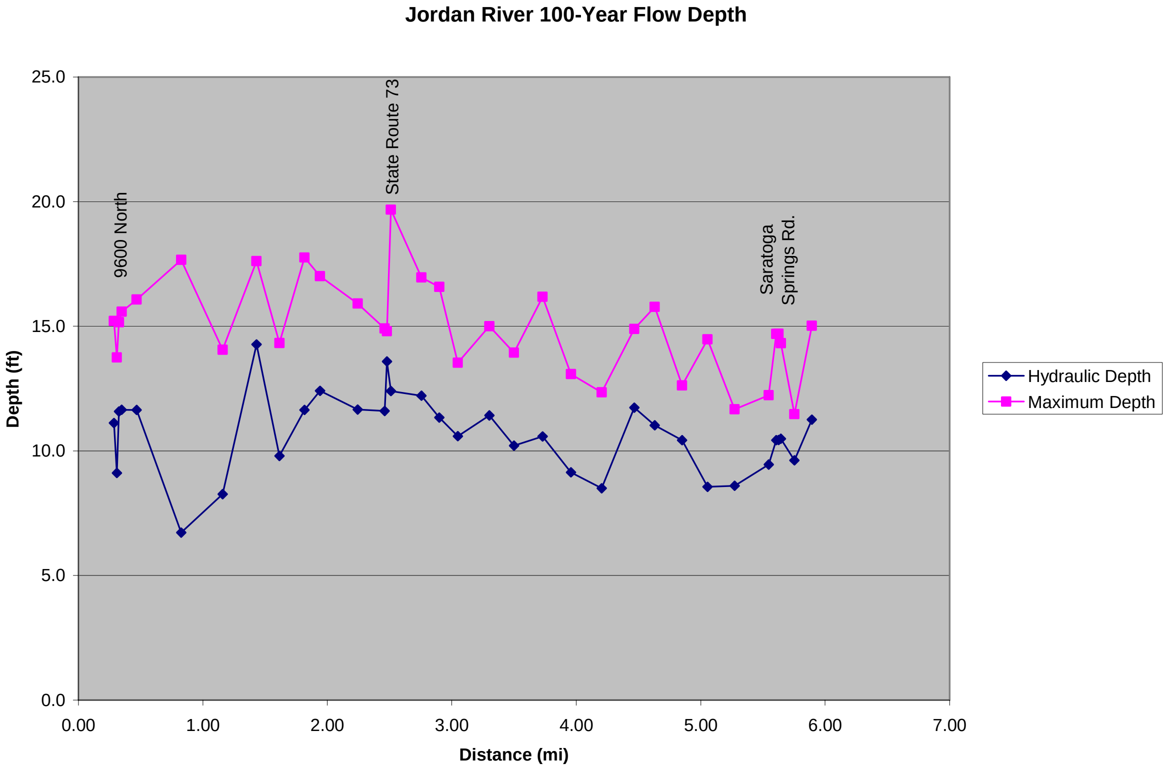


FIGURE 2-3
100-Year Depth Profile for the Jordan River Study Reach



As shown in Figure 2-2 (velocity), Figure 2-3 (depth) and Table 2-4, the study reach is a relatively low energy stream, even at 100-year flow rates. 100-year average channel velocities are predicted to be below three feet per second, and computed Froude numbers are well below critical. The HEC-RAS data also indicate that most of the 100-year discharge is currently conveyed in the main channel (Q channel), even though the total 100-year top width far exceeds the channel top width at most cross sections. This indicates that floodplain conveyance is largely ineffective.

2.3.1 Aerial Photography

Historical and recent aerial photography of the study reach were collected to document channel movement. Aerial photographic coverage for the study reach dating to 1946 (Table 2-5) was obtained and used to track channel change.

TABLE 2-5
Aerial Photography

Year	Source	Scale	Description
2004	http://agrc.utah.gov/agrc_sgid/naip.html	1 meter resolution	Color – Orthorectified
1995	http://agrc.utah.gov/agrc_sgid/digorthquadintro.html	1 meter resolution	Black and White – Orthorectified
1993	http://agrc.utah.gov/agrc_sgid/digorthquadintro.html	1 meter resolution	Black and White – Orthorectified
1988	UGS	1:63,000	False Color - Scanned Image
1985	UGS	1:32,333	False Color - Scanned Image
1980	Utah County Mapping Dept.	1:6,000	Blue Prints - Scanned Image
1975	Utah County Mapping Dept.	1:12,000	Blue Prints - Scanned Image
1966	Utah County Mapping Dept.	-	Black and White - Scanned Image
1958	Utah County Mapping Dept.	-	Black and White - Scanned Image
1946	Utah County Mapping Dept.	-	Black and White - Scanned Image

The scanned aerial photographs were semi-rectified in ArcMap version 9.1 using key landmark positions such as bridges, houses, road intersections, and other non-dynamic geographic features common to each photograph. The UGS topographic quadrangle maps were used as the base map for the GIS semi-rectification process.

2.3.2 Historical Maps

Historical maps showing the Jordan River were collected to extend the record of channel position into the 19th century. Cadastral maps made by the General Land Office (GLO), the predecessor to the U.S. Bureau of Land Management, were the oldest available mapping of the

Jordan River study reach. Cadastral mapping from 1856, 1884, and 1893 were used to document channel position relative to existing and other historical records of channel position. The GLO maps were scanned and semi-rectified using the Section-Township-Range grid. Digital raster graphic (drg) files of the UGS topographic quadrangle maps were obtained directly from the UGS. Note that the cadastral mapping is most accurate along Section, Township, and Range lines. Except where meander lines were established, the bank lines drawn between Section lines tend to be sketches of variable accuracy interpolated by the original surveyors. Use of the GLO cadastral maps extended the historical record of channel movement to nearly 150 years.

2.3.3 Topographic Data

Topographic data were collected to document changes in channel characteristics and identify trends of channel change. Historical topographic information was available from 7.5-minute, 1:24,000, 20 or 40-foot contour interval UGS topographic quadrangle maps- Saratoga Springs (1994) and Jordan Narrows (1999). Historical 1923 1-foot topographic mapping was also available from a proposed channelization plan1 for the Jordan River (USRS, 1923).

2.3.4 Soil & Geologic Data

UGS geologic mapping was available from the following two maps that span the region surrounding the study reach:

- Geologic Map of Jordan Narrows Quadrangle (Biek, 2005)
- Geologic Map of Saratoga Springs Quadrangle (Biek, 2004).

Figure 2-4 is a compilation of the two UGS geologic maps for the Jordan River study area. The UGS maps were obtained digitally and were semi-rectified using ArcMap Version 9.1 GIS tools. Detailed soils mapping by the Natural Resource Conservation Service (NRCS) available for the study area was also collected and is shown in Figure 2-5. Digital shape files for the NRCS soils mapping were obtained directly from the NRCS website and imported into the project GIS. Approximate topographic data were obtained for index cross section locations by field surveys made by the project team, as described in Chapter 7.

2.3.5 Geographic Data

Geographic data were obtained from the Utah County Online[2] and the Utah Automated Geographic Reference Center (AGRC)[3] websites. Geographic data collected included street names, public facilities, bridges, storm drains, city limits, infrastructure coverages, hazard zones and land ownership. As shown in Figure 2-6, most of the lands along the river corridor are privately owned.

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[1] There is no record or indication that the proposed USRS channelization plan was ever completed.

[2] http://ims2.co.utah.ut.us/website/download1/data1.cfm

[3] http://agrc.utah.gov/agrc_sgid/sgidintro.html

FIGURE 2-4
Surficial Geology Map for the Jordan River Study Reach (Descriptions of Maps provided in Table 4-3)

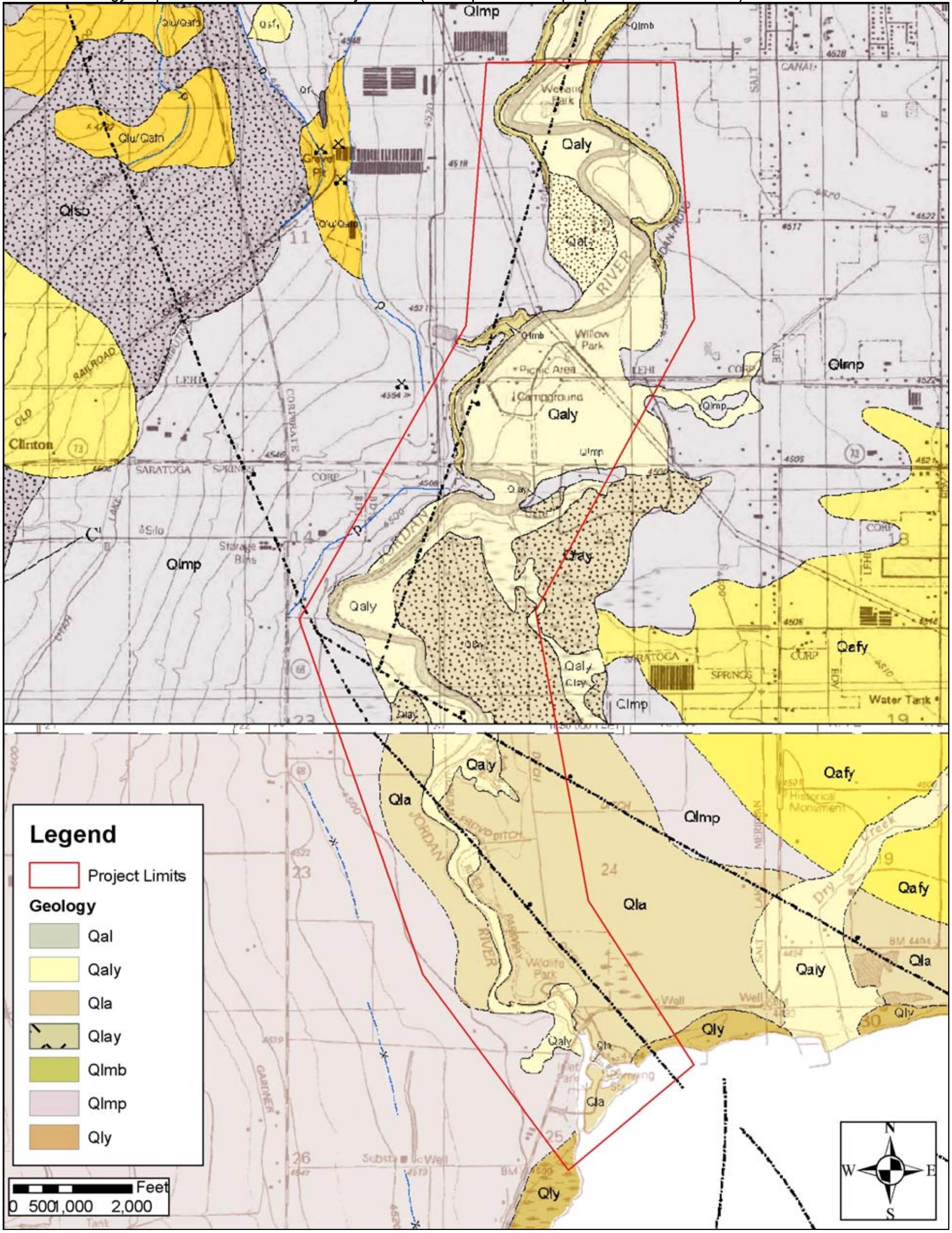


FIGURE 2-5
NRCS Soils Map for the Jordan River Study Reach (Soil Unit Descriptions are Provided in Table 4-2)

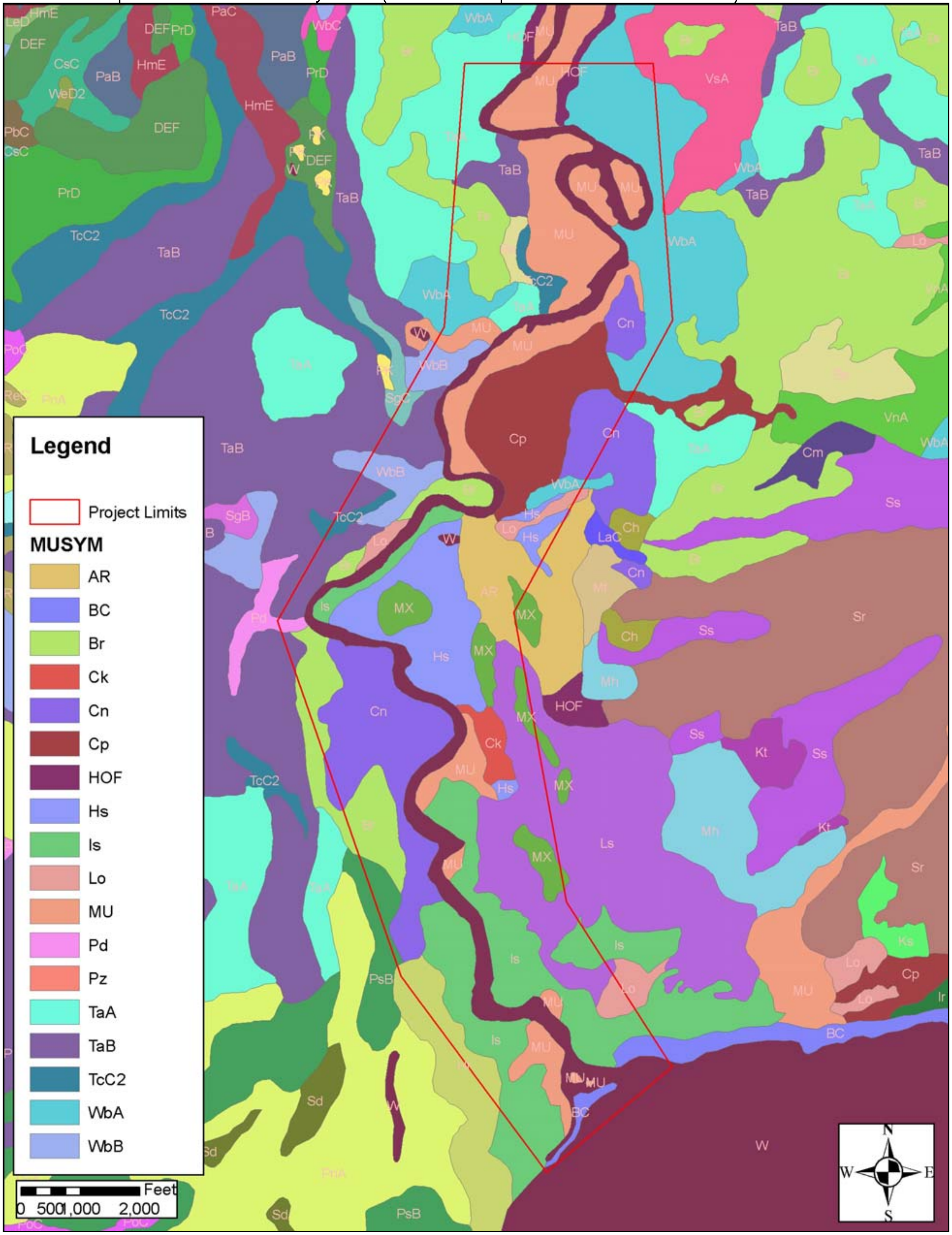
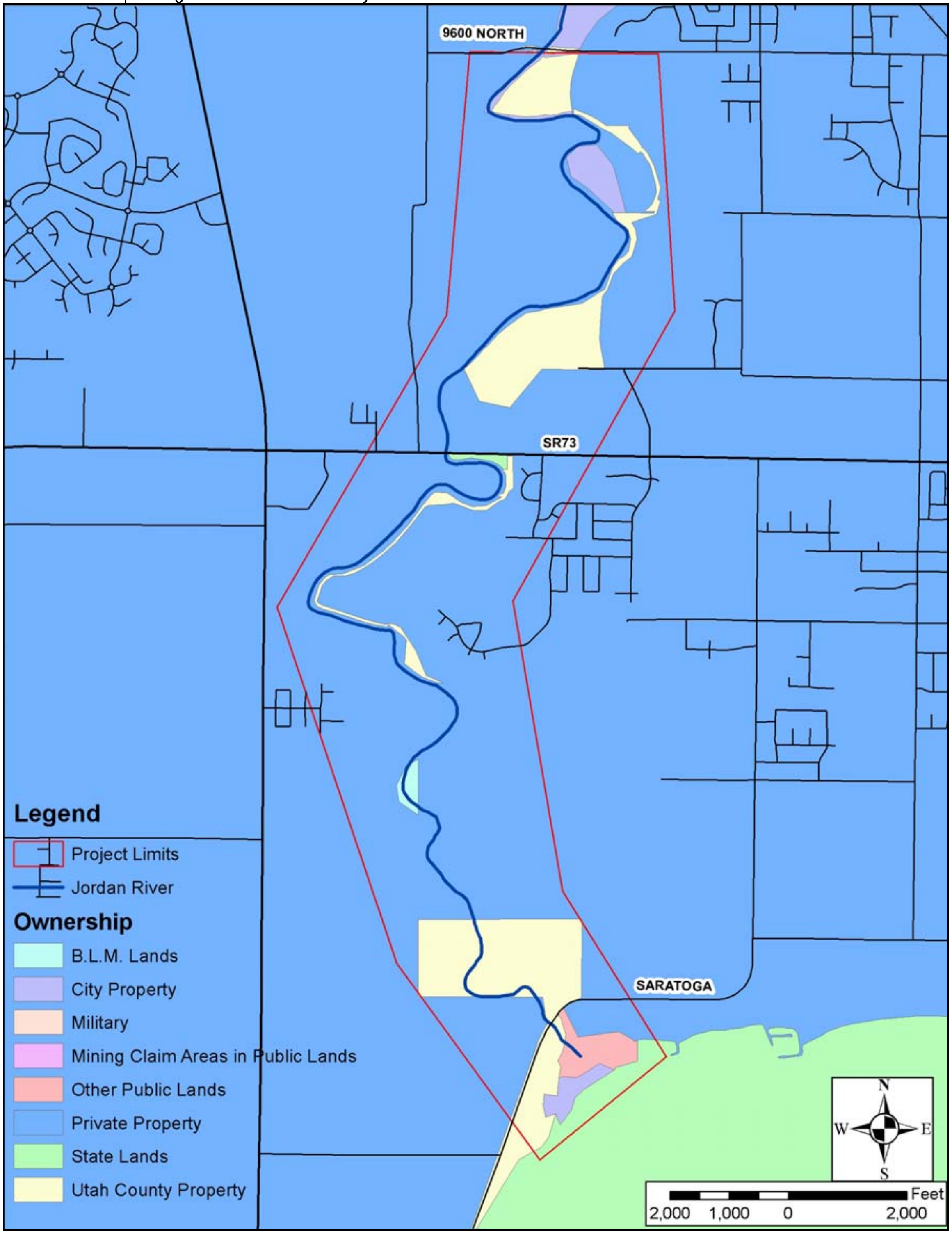


FIGURE 2-6
Land Ownership Along the Jordan River Study Reach



3.0 Field Investigation

Field visits to the study reach were made on June 27 and 28, 2006 and on August 4 and 5, 2006 to observe site conditions and collect field data. The objectives of the field investigation were to collect data for use in the stability analyses, collect sediment data for the stream bed and banks, and to document existing conditions in the study reach.

3.1 Field Observations

River Description. During both field visits the Jordan River was flowing bank-to-bank. The river consisted of a single well-defined alluvial channel with a mild slope, meandering channel pattern, and a wide floodplain which narrowed in the downstream direction. The channel banks were very well vegetated, except where bank failures have left bare cutbanks. Historically, the main channel was connected to a wide floodplain, much of which was rich wetlands. Channel slopes and velocities were extremely low, with no riffles, runs or rapids in the study reach.

FIGURE 3-1
Typical Channel Section Within Study Reach with Dense Bank Vegetation and Low Velocity Flow

FIGURE 3-2
Example of Healthy Floodplain Reach Near Upstream End of Study Reach

FIGURE 3-3
Typical Section Near Downstream End of Study Reach at 9600 North

FIGURE 3-4
Typical Channel Section Near Utah Lake Outlet to Study Reach

Bank Vegetation. In general, bank vegetation within the study reach consists of a mixture of shallow rooting and deep rooting woody vegetation, brush and ground cover. However, given the prevalence of cutbanks, the presence, type or density of bank vegetation does not appear to prevent bank failures. The number of bank failures in well-vegetated reaches suggests that the dominant bank failure mechanism is not excess shear from flow velocities, but instead is related to degradation, some other bank toe process, or from seepage forces within the bank. The bank vegetation consists of a variety of native riparian species, but also includes a high percentage of invasive species such as Russian Olive and Tamarix.

FIGURE 3-5
Dense Brushy Bank Vegetation Near Upstream End of Study Reach at Utah Lake

FIGURE 3-6
Mixed Brushy and Woody Vegetation with Toe Scour at the Waterline

FIGURE 3-7
New Bank Vegetation Colonizing Toe of Recently Eroded Cutbank

FIGURE 3-8
Dense, Well-Vegetated Bank Upstream of the Old 9600 North Bridge

Cutbanks. Vertical or near-vertical cutbanks were observed throughout the study reach, as documented later in this chapter. In many locations, cutbanks were observed on both banks, rather than just on the outside of channel bends as would occur on most meandering rivers. The double cutbanks indicate a disequilibrium condition or river response to an artificially imposed channel or hydrologic condition.

FIGURE 3-9
Tall Vertical Cutbank on Outside of Bend Downstream of Willow Park

FIGURE 3-10
Recent Erosion Exposing Edge of Asphalt Bike Path Surface

FIGURE 3-11
Erosive Cutbanks Exposing Roots of Woody Bank Vegetation

FIGURE 3-12
Tall Cutbank with Hanging Fence Post Indicative of Recent Bank Failure

FIGURE 3-13
Long Low Cutbank Adjacent to Low Floodplain Surface

FIGURE 3-14
Undercutbank with Accelerated Erosion at Toe of Vertical Bank Slope

Bank Soil Profiles. Channel banks in the study are composed of sandy clay loam soils. Little variability in bank sediment composition was observed within the study reach. The bank soils have enough silt/clay content to stand at vertical slopes, develop a blocky soil texture, and retain soil moisture, but do not have enough clay content to be resistant to lateral erosion from loss of basal support. The bank materials contain very little sediment coarser than medium sands although some lenses with gravel were observed in a few places.

FIGURE 3-15
Cutbank Showing Bank Soil Characteristics Such as Fine Stratification, Preferred Rooting Zones, Piping, and Fine-Grained Texture

FIGURE 3-16
Tall Cutbank Illustrating Capacity of Bank Soils to Maintain Vertical Slopes and Common Blocky Soil Texture Due to Fine-Grained Content

Terraces. Several sets of terraces[4] were observed along the study reach. A low floodplain terrace is present along most of the study reach, but is most obvious in subreaches near Utah Lake. In many places, the direct hydrologic connection between the main channel and floodplain to the east of the river has been disrupted by the raised bike path. Hydraulically connected floodplain terraces were observed on the west side of the main channel in many places. Terraces above the (historical) floodplain were also observed along the study reach. The highest terrace, which stands at 15 to 20 feet above the main channel, is a Pleistocene aged surface that represents lake levels during the most recent glacial period. This Pleistocene-aged terrace bounds the modern geologic floodplain of the Jordan River.

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[4] The geologic definition of terrace is used in this report, which includes the floodplain as a terrace.

FIGURE 3-17
Channel Section Showing Connection to Floodplain Terrace (River Left) With a Bounding Higher Terrace

FIGURE 3-18
Wide Wetland Floodplain Terrace Indicative of Pre-Development Floodplain Widths in the Study Reach

FIGURE 3-19
The High Pleistocene Terrace and An Intermediate Terrace Visible on River Left Upstream of the SR73 Bridge

FIGURE 3-20
Two Intermediate Terrace Elevations Visible As Varying Cutbank Heights

Meander Cutoffs. Formation of cutoff channels between sharp meander bends is a process that is common to most meandering streams. Evidence of only one recent meander cutoff was observed during the field investigations. This cutoff meander is located on the east side of the existing channel about 0.6 miles upstream of the 9600 North Bridge. The meander cutoff is slightly perched above the active channel, but still has several connected open water areas. It is possible that the meander was cut off by human intervention rather than by natural processes. The meander immediately upstream of the SR73 Bridge is the only other candidate for future cutoff in the study reach, since the other bends are not yet sufficiently sinuous.

FIGURE 3-21
Former Inlet to the Meander Cutoff (Oxbow) Near 9600 North

FIGURE 3-22
Former Outlet to the Meander Cutoff Near 9600 North

FIGURE 3-23
Aerial Photograph of the Meander Cutoff South of the 9600 North Bridge

FIGURE 3-24
Potential Future Meander Cutoff Upstream of The SR73 Bridge (Red arrow indicates possible future cut off path)

Tributary Confluences. No significant tributaries join the main channel of the Jordan River within the study limits (Figure 3-25). Historical flow paths of tributaries in the vicinity of the study reach have been altered by agricultural development, canal diversions and urbanization. Several minor watersheds drain to the Jordan River study reach and enter the main channel via storm drains that outfall into the main channel. Several of these storm drains are perched well above the normal water surface and have sizable scour holes at the storm drain outlet. Typically, perched confluences are indicative of long-term scour on the main stem stream, although given the level of alteration of the study area, this interpretation is somewhat tenuous without corroborating evidence.

FIGURE 3-25
UGS Topographic Map Showing (Lack of) Tributaries Near Study Reach

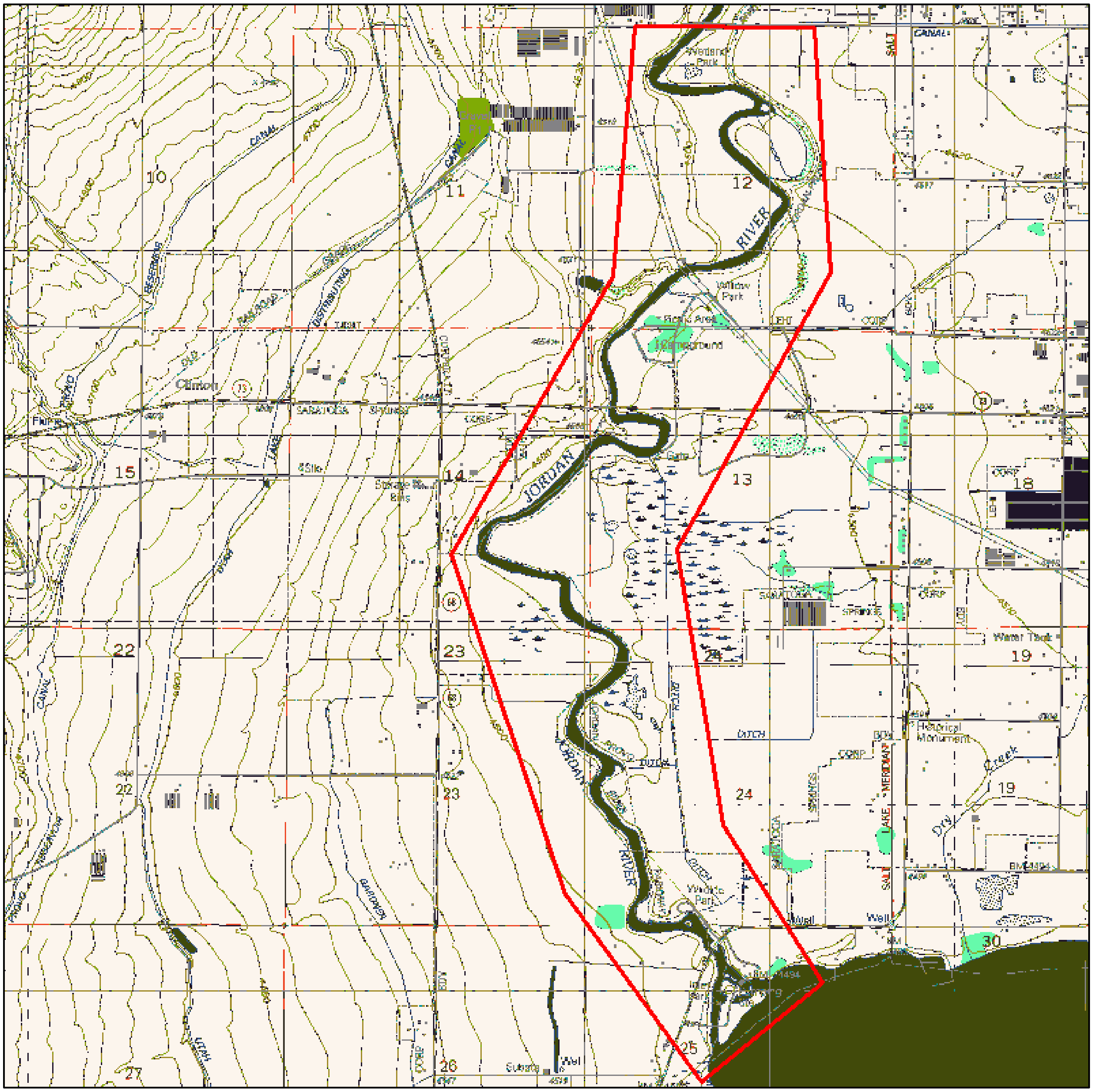

FIGURE 3-26
Storm Drain Inlet Perched Above Active Channel With Minimal Scour

FIGURE 3-27
Tributary Confluence Through Culvert Under Bike Path

Structures. A number of manmade structures were observed along the study reach. Structures in the study reach included bridges (road, pedestrian), utilities, water control structures (gate inlet, pump house), storm drain outfalls, a raised, paved bike/pedestrian pathway, and some wooden structure remnants of unknown purpose. The bridge and water control structures appear to have some impact on the river morphology by controlling the channel width and preventing natural bank migration, although no significant negative impacts were observed at any structure.

FIGURE 3-28
Gated Outlet Structure at Utah Lake

FIGURE 3-29
Utah Lake Pumping Station

FIGURE 3-30
Overhead Utility Lines and Sewer Line at the Saratoga Springs Road Bridge Crossing

FIGURE 3-31
High Tension Power Lines and Power Pole Adjacent to Eroding Cutbanks

Human Impacts. In addition to structures placed in or near the Jordan River, humans have had a variety of other impacts on the morphology of the study reach. Significant impacts include placement of fill in the floodplain or channel for development, dumping trash over stream banks, allowing cattle to over-graze stream banks and floodplains, and leaving abandoned structure remnants in the channel. The net result of these human activities in the floodplain is either to increase the risk of lateral erosion or increase the economic consequences of natural erosion by placing assets in harm's way.

FIGURE 3-32
Recent Development Along the Margin of the Historical Floodplain

FIGURE 3-33
Fill Placed in the Floodplain for Expansion of Developed Areas

FIGURE 3-34
Fill Placed Across Wetlands and Floodplain Storage Areas for Access to New Development

FIGURE 3-35
Trash Dumped Over the Bank of the Main Channel in the Study Reach

FIGURE 3-36
Tires and Dumped Material Integrated Into the Main Channel Bank Profile

FIGURE 3-37
Cattle Grazing on the Main Channel Bank Line

FIGURE 3-38
Overgrazed Area Devoid of Vegetation with Barrel of Unknown Source and Substance at Waterline

FIGURE 3-39
Corroding Abandoned Bridge Abutment (Note damage to concrete and metal elements)

Grade Control. No man-made permanent grade control was observed in the Jordan River study reach downstream of the Utah Lake outlet structures. The pump station and gated outlet at Utah Lake provide grade control that prevents channel change in the study reach from lowering the outlet level of the lake. Lowering the lake outlet elevation would have significant consequences for the hydrology and morphology of the study reach, as well as for water levels in Utah Lake. Because of the outlet structures, the lake is unlikely to be affected by bed elevation or slope changes in the study reach. The change from a very flat slope near the Utah Lake outlet to a steeper slope at the Jordan Narrows suggests some level of geologic grade control between 9600 North and the Jordan Narrows, but no physical evidence of bedrock control was observed in the channel bed, on boring logs, in soils reports or on geologic mapping of the study area. Implications of the observed slope change are discussed in more detail in Chapter 5.

Other River Features. Several other noteworthy features observed in the study reach include pipes with extensive calcic build-up discharging what appeared to be spring flow into the river and several wooden structures of unknown purpose. These features do not appear to impact river morphology or lateral erosion potential.

FIGURE 3-40
Water Flowing From Pipe with Apparent Calcium Carbonate Build Up

FIGURE 3-41
Pipe Discharging Spring Water to Main Channel of Jordan River

FIGURE 3-42
Unusual Wooden Structures Built in Main Channel

FIGURE 3-43
Failure of Tributary Culvert Crossing Due to Apparent Loss of Foundation

3.2 Sediment Sampling

Sediment data obtained were from sieve and hydrometer analyses performed for previous studies[5] (CH2M HILL, 1985) at 24 bed material boring sites and three bank material borings sites located between the Saratoga Springs Road Bridge and the 9600 North Bridge. The sediment samples were taken prior to the most recent dredging of the river. Field observations made for this study suggest that the current channel bed materials have a similar size distribution to those reported in the boring logs. Despite dredging and levee construction, there is no evidence that the consistency of the bank materials have changed. The sediment size distribution data for each boring site is provided in Appendix A. Tables 3-1 and 3-2 give the mean, minimum, and maximum D-15, D-50, and D-85 for the bed and bank samples. Field photographs showing typical bank sediments observed in the study reach were provided with the discussion above.

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[5] New sediment samples were not obtained by field measurements or sieve analysis (alone) due to the small size of the bed and bank sediments, as well as the availability of previous sample results.

TABLE 3-1
Summary of Bed Material Diameter Distributions

	D-15 (mm)	D-50 (mm)	D-85 (mm)
Mean	0.06	0.28	0.78
Minimum	0.001	0.003	0.02
Maximum	0.55	1.5	4

TABLE 3-2
Summary of Bank Material Diameter Distributions

	D-15 (mm)	D-50 (mm)	D-85 (mm)
Mean	0.001	0.005	2.04
Minimum	0.001	0.003	0.04
Maximum	0.001	0.006	6

Table 3-3 shows the approximate D-15, D-50, and D-85 for the samples closest to the surface at each boring sites. Figure 3-44 shows a typical sediment distribution curve for two of the boring site locations.

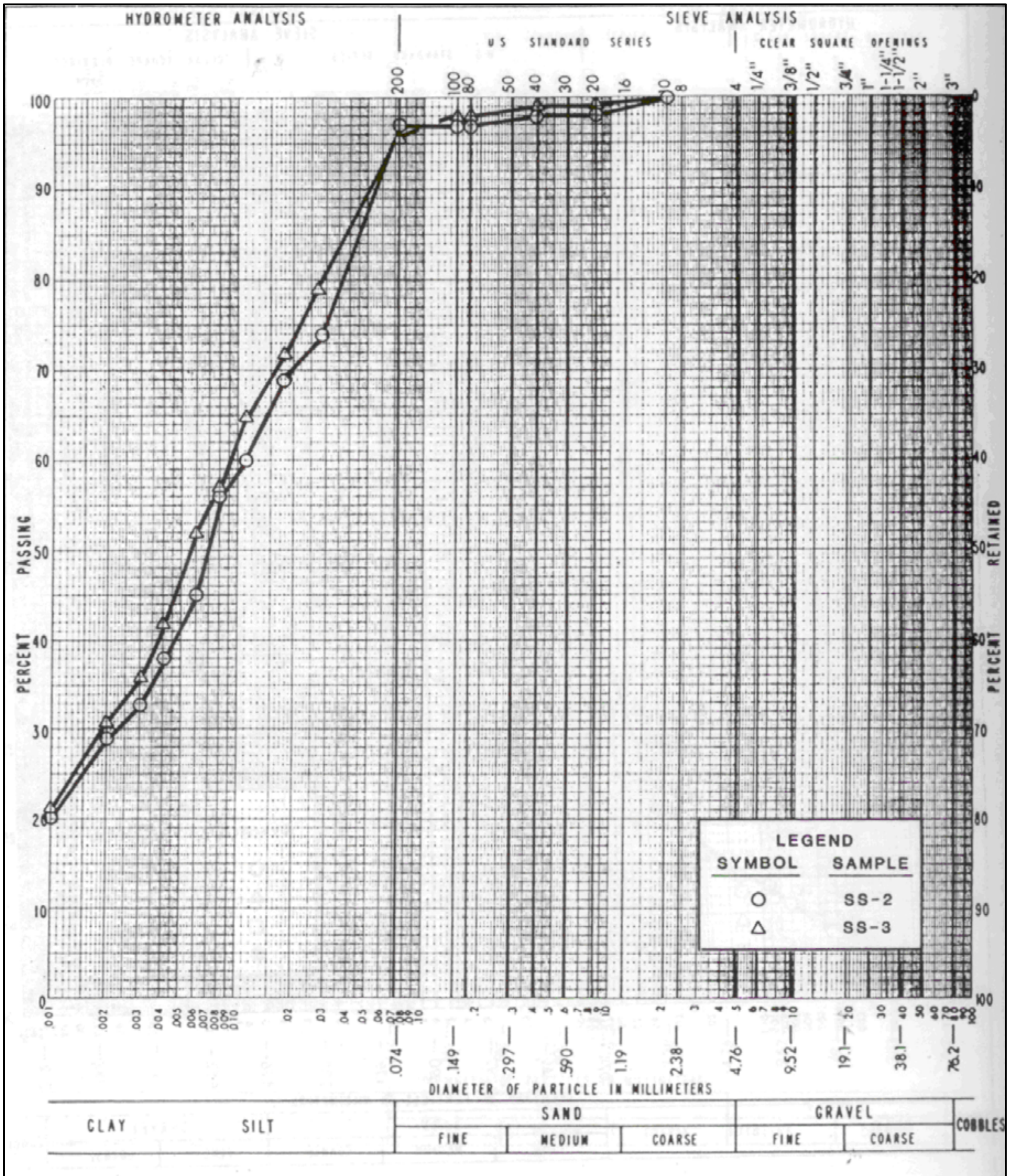
TABLE 3-3
Channel Bed and Bank Material Diameter Distribution (CH2M HILL, 1985)

Boring Site	Sample	Channel Bed or Bank	Approximate D-15 (mm)	Approximate D-50 (mm)	Approximate D-85 (mm)
B-23	SS-2	Bed	0.001	0.007	0.045
B-24	SS-1	Bed	0.001	1.5	0.05
B-25	SS-2	Bed	0.55	1.5	4
B-26	SS-1	Bed	0.07	0.2	0.5
B-27	SS-1	Bed	0.15	0.3	1.8
B-28	SS-1	Bed	0.07	0.13	0.25
B-29	SS-1	Bed	0.07	0.07	0.3
B-30	SS-2	Bed	0.001	0.005	0.035
B-31	SS-2	Bed	0.07	0.55	1.5
B-32	SS-1	Bed	0.15	0.45	2.5
B-33	SS-1	Bed	0.001	0.0035	0.015
B-34	SS-1	Bed	0.001	0.035	0.15
B-35	SS-1	Bed	0.07	0.15	0.8
B-36	SS-1	Bed	0.001	0.075	0.18
B-37	SS-1	Bed	0.002	0.095	0.9
B-38	SS-2	Bed	0.001	0.0025	0.015
B-39	SS-1	Bed	0.001	0.0055	0.04
B-40	SS-1	Bed	0.001	0.015	0.065
B-41	SS-1	Bed	0.003	0.13	0.9
B-42	SS-1	Bed	0.07	0.18	0.8
B-43	SS-1	Bed	0.07	0.1	0.18

TABLE 3-3
Channel Bed and Bank Material Diameter Distribution (CH2M HILL, 1985)

Boring Site	Sample	Channel Bed or Bank	Approximate D-15 (mm)	Approximate D-50 (mm)	Approximate D-85 (mm)
B-44	SS-2	Bed	0.001	0.005	0.045
B-45	SS-1	Bed	0.07	0.09	0.15
B-46	SS-1	Bed	0.07	1.1	3.5
B-D-15	SS-2	Bank	0.001	0.003	0.04
B-D-19	SS-1	Bank	0.001	0.0055	0.07
B-D-23	SS-1	Bank	0.001	0.0055	6

FIGURE 3-44
Example Sediment Distribution for Jordan River Study Reach (See Appendix for complete list of sediment sampling data)



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422.

FIGURE 32
PARTICLE – SIZE ANALYSES
BORING B–23

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

B18331.D1

3.3 Bank Stability Assessment

Recently eroded vertical cutbanks were observed throughout the Jordan River study reach. The presence of cutbanks is not uncommon in meandering alluvial rivers. However, on stable healthy stream systems, cutbanks are typically observed primarily on the outside of bends with depositional point bars on the inside of bends and sloped, vegetated banks elsewhere. In the study reach, cutbanks were commonly observed extending over long distances on opposite banks, on the inside and outside of bends, as well as on straight reaches. A field assessment of existing condition bank stability was performed by mapping the extent of cutbanks and by documenting cutbank characteristics.

The cutbanks in the study reach had the following characteristics:

- Extent. Cutbanks were observed in many locations where cutbanks would not be expected based on the channel pattern, such as on the inside of channel bends and in straight reaches.
- Variable Height. Cutbank heights up to approximately 20 feet were observed where the main channel intersected the oldest and highest riverine terraces. Very low cutbanks less than one foot in height were also observed at the margins of some low floodplains.
- Bank Material. The bank material exposed in cutbanks was sandy clay loam with minor amounts of coarse materials in thin lenses at a few locations. The fine-grained content of the bank materials supports semi-stable vertical slopes up to at least 20 feet high.
- Basal Control. In most locations, collapsed bank materials are readily transported due to the limited cohesiveness and fine sediment size of the bank material, leaving no basal control of the toe of slope. In a few locations, the collapsed bank material has accumulated at the toe of the slope and has begun to be colonized by thin bank vegetation comprised mainly of fast-growing species such as Tamarix or other annual species.
- Vegetation. Obviously, no vegetation is present on the most recent vertical cutbanks. The presence of vegetation does not appear to prevent bank failures, suggesting that the point of attack is below the rooting layer, which points to the cause of bank failure being related to vertical changes in bed elevation (degradation), rather than lateral erosion processes like meander migration.
- Lateral Erosion Distance. Despite the extent of bank failures, in no place the cutbanks appear to be caused by extensive widening or rapid lateral channel migration. The river has not widened or moved significantly[6] as a result of the bank failures.

The bank stability field assessment consisted primarily of mapping the locations and extents of cutbanks, as shown in Figure 3-45 and Table 3-4. The field observations were compared to locations of cutbanks interpreted from 1984 aerial photographs and pre-dredging plan topographic mapping (Table 3-4). The pre-dredging topographic mapping comparison was used to determine if the extent of cutbanks increased after the dredging.

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[6] Erosion rates are insignificant relative to other rivers in the Arid West, where erosion rates of several hundred to several thousand feet in a single flood are common.

FIGURE 3-45
Field Mapping of Cutbanks (Red Lines) Observed During August 2006 Field Investigations

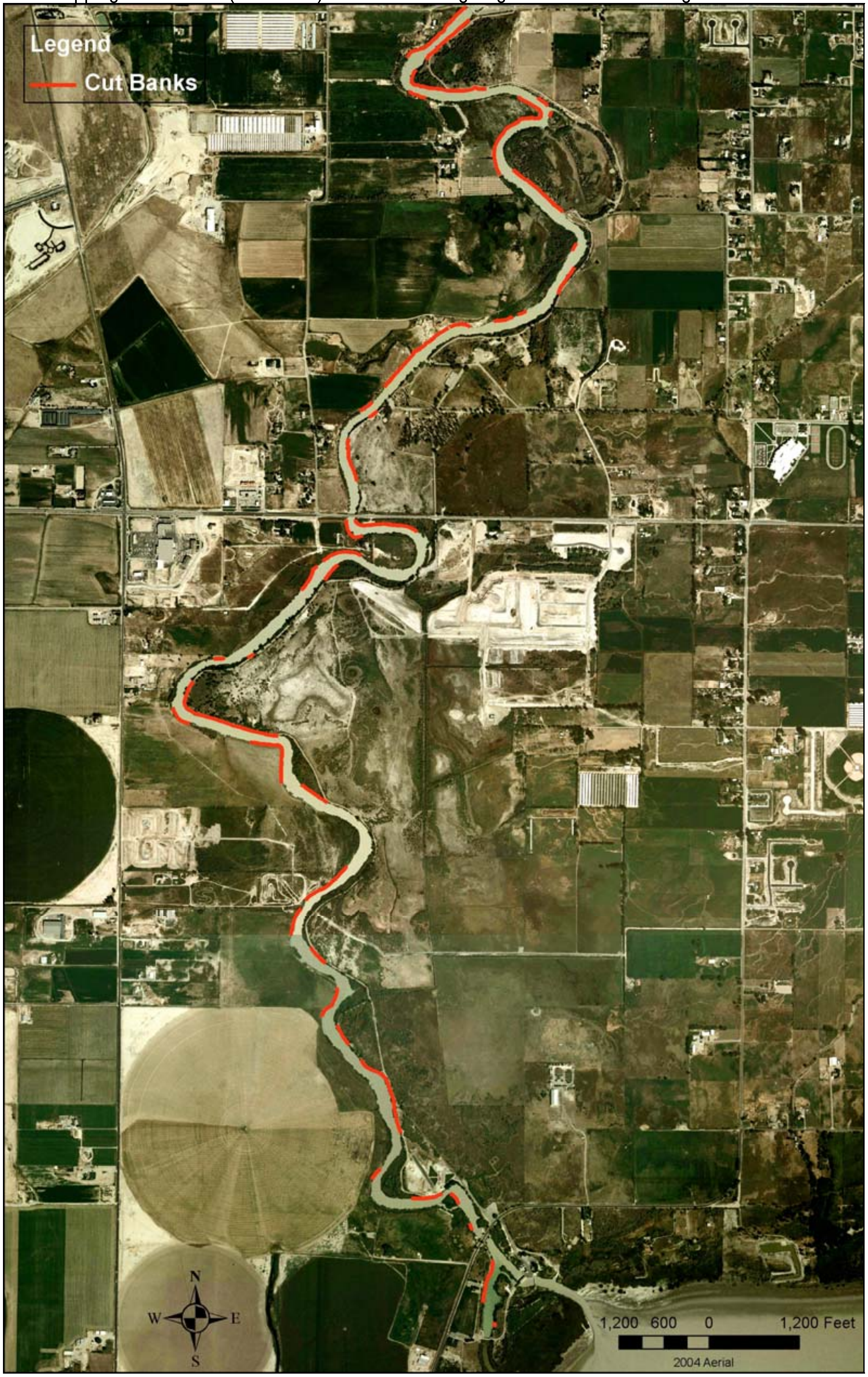


TABLE 3-4
Comparison of 2006 Cutbank Observations and 1984 Interpreted Cutbank Locations

1984 Station	1984		2006		1984 Station	1984		2006		1984 Station	1984		2006	
	Left	Right	Left	Right		Left	Right	Left	Right		Left	Right	Left	Right
22454	X	X	X	X	32446	X				41108	X	X	X	
23315			X	X	32703		X			41277			X	
24075		X	X	X	32912		X		X	41603			X	
24262				X	33137	X	X		X	41854				X
24525		X		X	33375		X		X	42011		X		X
24712		X		X	33583	X	X			42386		X		
24915		X		X	33860					42592		X		
25133					33939	X	X	X	X	42803				
25336					34075	X		X	X	42993		X		
25539	X		X		34337		X		X	43234	X			
25763			X	X	34415		X		X	43361				
25985	X	X	X		34559		X		X	43761	X		X	
26195					34982		X		X	43723	X		X	
26472	X				35285	X	X			43867	X		X	
26678	X				35500					44180				
26897					36003					44576		X	X	
27128				X	36157		X			44783				
27335		X		X	36358	X	X	X		44938		X		X
27711	X	X		X	36585			X		45675	X	X	X	
27979		X		X	36756		X		X	45950			X	
28046		X		X	37080	X		X		46182				
28329					37158	X	X	X		46294				X
28679					37402	X	X			46492				X
28964	X			X	37614	X				46771		X		
29197	X	X		X	37831	X	X			46999				X
29301					37986		X			47291		X		X
29570		X			38190		X			47586	X			X
29788	X	X	X		38440	X	X			47763		X		X
30077	X		X		38766	X	X	X		47973		X		X
30226					38980		X			48231		X		
30438					39123					48534		X	X	

TABLE 3-4
Comparison of 2006 Cutbank Observations and 1984 Interpreted Cutbank Locations

1984 Station	1984		2006		1984 Station	1984		2006		1984 Station	1984		2006	
	Left	Right	Left	Right		Left	Right	Left	Right		Left	Right	Left	Right
30672	X	X	X		39420		X		X	48874				
30801	X	X	X		39529				X	48980		X		
31028	X	X	X		39851	X		X	X	49318				
31233	X		X		40082		X		X	49550		X		X
31490	X		X		40291		X		X	49891		X		
31694	X		X		40456	X	X		X	50117			X	
31887	X		X		40678	X	X	X	X	50239				
32234	X		X		40954	X	X	X	X	50426				

Of the 118 cross sections identified in Table 3-4, about 44 percent had cutbanks in 1984 and about 34 percent had cutbanks in 2006, a slight decrease. Although there were more cutbanks identified from the 1984 data, the majority of the 1984 cutbanks were less than three feet tall and many of those may have been hidden below the water line or by dense overhanging bank vegetation during the 2006 field survey. Another explanation for an apparent decrease in cutbanks from 1984 to 2006 was that the post-1984 dredging project graded the channel banks to a more stable 3:1 or 3.5:1 slope.

TABLE 3-5
Comparison Summary for Cutbank Observations 1984-2006

	1984 Left Cutbank	2006 Left Cutbank	1984 Right Cutbank	2006 Right Cutbank
Total number of cross sections surveyed in 1984	118	118	118	118
Total number of cross sections with cutbanks	43	37	61	44
Additional Cutbanks identified in 2006 mapping	n/a	10	n/a	12
Additional Cutbanks identified in 1984 cross sections	16	n/a	29	n/a

The field assessment of bank stability indicated the presence of numerous (up to 37 percent) unstable cutbanks, many of which probably formed since the river was dredged in the 1980's. The extent and location of the cutbanks cannot be fully explained by normal, equilibrium stream process, pointing to a disequilibrium condition to which the study reach is adjusting.

3.3.1 Natural & Man-Made Erosion Barriers

Erosion barriers are natural or man-made features that prevent lateral erosion. Erosion barriers on rivers might include constructed bank protection, natural bedrock, or resistant soil layers. Engineered erosion protection is provided at the abutments of each of the three bridges in the study reach (Saratoga Springs Road, State Route 73, and 9600 North) and at the Utah Lake gated outlet structure. There are also isolated areas where individual landowners appear to have dumped rock, soil, or construction rubble on the banks apparently in efforts to mitigate or prevent bank erosion. The engineered bank protection observed at the bridges and at the Utah Lake outlet appears to be effectively controlling lateral erosion. The less formal attempts at bank protection by local landowners do not appear to be effective.

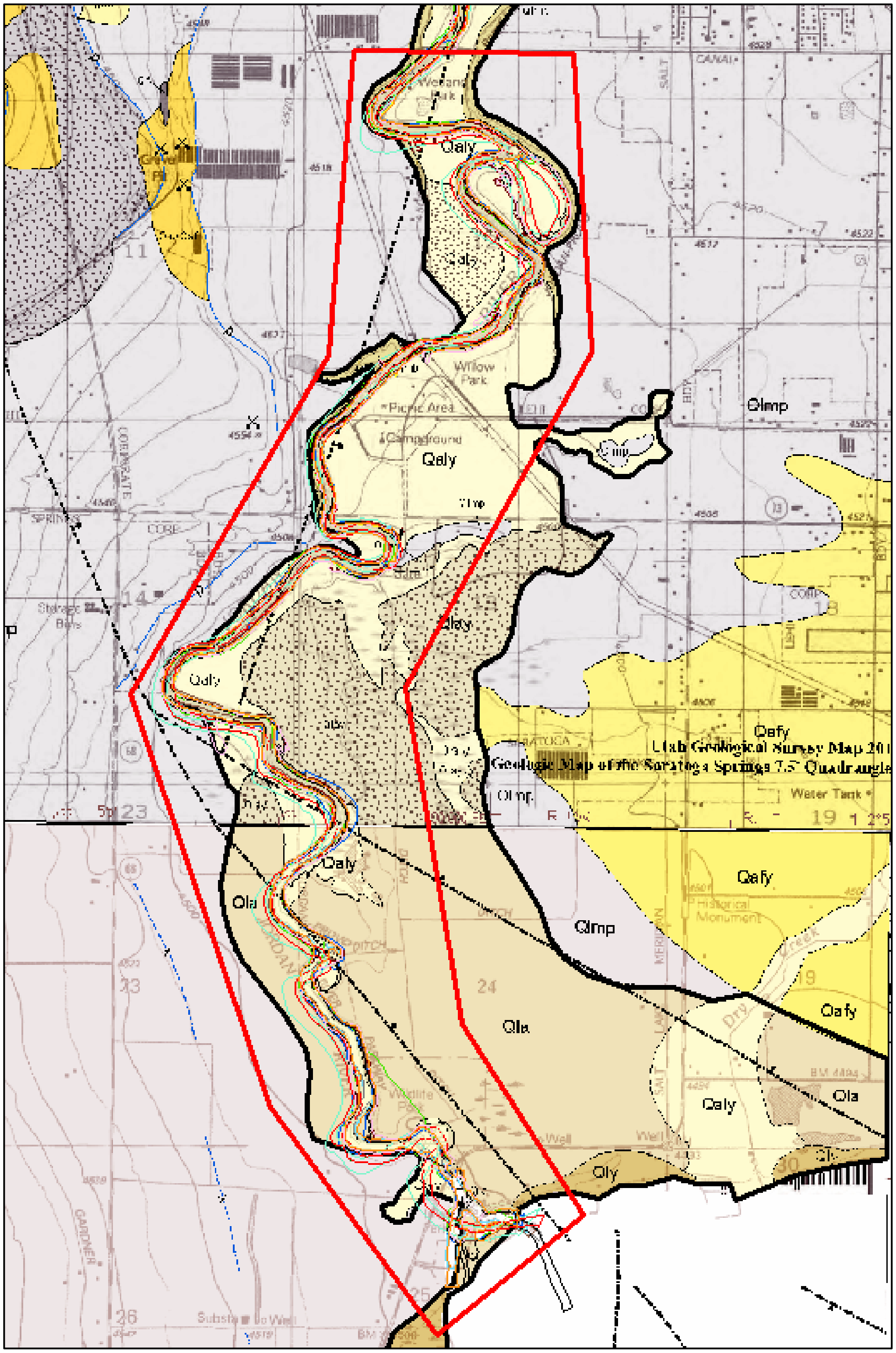
Priority is often in protecting public facilities or large developments that exist within the pre-historic natural floodplain of the river. Depending on the community's river management plans, political pressure will probably often mandate that such structures be replaced or protected if damaged, and the river returned to its pre-damage alignment. Thus, these features may be considered practical erosion barriers even though the structures themselves may not be safe from erosion hazards unless permanent erosion barriers are designed and constructed.

No bedrock crops out in the banks along the study reach. The observed natural soils do not effectively resist erosion. Therefore, there are no natural erosion barriers to lateral erosion. However, the older high terraces appear to be composed of slightly more resistant soil materials than the lower terraces and floodplain surfaces, and thus provide a slight barrier to lateral erosion, as shown in Figure 3-46. The older surfaces appear to be more resistant to lateral erosion due to increased clay content (a product of soil processes, chemical weathering of soils, and their depositional environment), increased carbonate content, and increased induration. The older terraces are also higher than the lower terraces, so that a greater volume of sediment is removed for each unit width of lateral erosion (increased sediment supply during erosion). Therefore, the lower, less indurated terraces and the floodplain will tend to be preferentially eroded.

3.4 Summary

The field investigation did not identify any reaches of significant instability, although the extent of vertical cutbanks suggests some level of adjustment to a disequilibrium condition. Field evidence such as elevation of minor tributaries relative to the main channel, prevalence and extent of cutbanks on both banks, and the undercutting of bank slopes suggest that the reach has experienced a degree of long-term degradation. No existing significant structures appear to be at risk of imminent failure due to lateral erosion, although several side drainage culverts and a few utility power poles may warrant monitoring and/or mitigation. Local bank failures are likely to continue to result in loss of bank vegetation or damage to the asphalt bike trail.

FIGURE 3-46
Plots of Channel Position Showing Minimal Erosion of Older Geomorphic Surfaces (Qlmp) Compared to Younger Geomorphic Surfaces (Qla & Qaly)



4.0 Geomorphic Analyses

The geomorphic analyses performed for Jordan River Corridor Preservation Study included the following:

- Stream Classification
- Geomorphic Landform Mapping
- Empirical Geomorphology

The objective of the geomorphic analyses was to identify trends in river behavior from which predictions about lateral stability could be made.

4.1 Stream Classification

The Rosgen Classification System (Rosgen, 1996) is based on measurable channel characteristics observed on streams located primarily in the western mountain region of the United States, although the classification system is now used in most of North America. The Rosgen (1996) Classification System was applied to the study area because it has many adherents among State and Federal agencies in the western United States. The field survey techniques used for the study reach incorporated procedures recommended by Rosgen (1996) for obtaining channel sections, pool and riffle spacing, bankfull elevations, entrenchment ratio, slope, meander geometry, bank characteristics, and bed sediment distribution. A summary of the Rosgen classification system data are listed in Table 4-1.

TABLE 4-1
Rosgen Classification Data

Jordan River		**Utah Lake to 9600 North Bridge**
Entrenchment ratio	> 2.2	Entrenchment ratio – Flood-prone width/bankfull width
Width/Depth Ratio	> 12	Width/Depth ratio – Bankfull flow width / mean depth
Sinuosity	> 1.2	Sinuosity – measured on 2004 aerial photographs
Channel Slope	< 0.001	Channel slope – reach average of HEC-RAS So values
Channel Materials (d_{50})	0.28 mm	Channel materials – average from sieve analysis (fine sand)
Rosgen Classification	C5c	

The stream classification data presented above indicate that the Jordan River within the study reach is a C5c stream. Application of the Rosgen Classification System to this reach of the Jordan River is somewhat problematic because of the level of human impacts that have been imposed on the river. However, the C5c category generally meets the Rosgen criteria, despite differences in some categories. The following description of a Rosgen C5c stream is excerpted from *Applied River Morphology* (Rosgen, 1995):

> *The C5 stream type is a slightly entrenched, meandering, sand-dominated, riffle/pool channel with a well developed flood plain. The C5 stream type occurs in broad valleys and plains areas*

> *with a history of riverine, lacustrine, glacial (outwash and glacio-fluvial), and eolian deposition. The C5 stream type can be found in very low relief basins typical of the interior lowlands, great plains, coastal plains, and in river deltas. Glacial outwash areas can also develop C5 stream types. The C5 stream channels are found in Valley Types IV, V, VI, VIII, IX, X, and XI. It is obvious that the C5 stream type is widely distributed thought a wide range of physiographic provinces. Generally, C5 stream channels have gentle gradients of less than 2%. Gradients less than 0.001 are denoted as C5c to indicate the slope condition of many C5 stream types. The C5 stream channel displays a higher width/depth ratio than the C4 and C3 stream types due to the depositional characteristic of the stream bed and the active lateral migration tendencies. The riffle/pool sequence for the C5 stream type averages 5-7 bankfull channel widths in length. Bed forms of ripples, dunes, and anti-dunes are prevalent. The streambanks are generally composed of sandy material, with stream beds exhibiting little differences in pavement and sub-pavement material composition. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation. Sediment supply is high to very high, unless stream banks are in a very low erodibility condition. The C5 stream type, characterized by the presence of point bars and other depositional features, is very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed.*

The primary differences between the Jordan River study reach and Rosgen's C5c category archetype, as described above, include the following:

- Pool/riffle sequence. No riffles were observed during field visits. Historical dredging and alternation of natural flow rates probably impact the natural pool riffle sequence, if one ever existed.
- Sediment supply. Because the Jordan River study reach source is Utah Lake, it has a low sediment supply rather than the high sediment supply found on many C5 streams.
- Active lateral migration. Historical data suggest that relatively limited lateral movement has occurred on the Jordan River study reach compared to other Arid West C5 streams.
- Point bars and deposition features. Point bars were lacking in the study reach, probably due to the low sediment supply and manipulated hydrologic regime.

4.2 Geomorphic Landform Mapping

Geomorphic landform mapping consisted of field verification of surficial mapping performed by the UGS (Biek, 2004; 2005) and consideration of detailed soils mapping prepared by the NRCS. Figure 2-4 and Figure 2-5 show UGS and NRCS mapping, respectively, in the area near the study reach. Descriptions of the geologic units mapped in the vicinity of the Jordan River study reach are provided in Table 4-3. Descriptions of the NRCS soils units near the study reach are provided in Table 4-2. The geologic and soils map unit descriptions were interpreted to identify units vulnerable to riverine erosion as shown in Figures 4-1 and 4-2.

The NRCS soil descriptions reflect the genesis of the soils rather than their current geomorphic or topographic position. Many units are shown as having a lacustrine origin because they were deposited during past geologic periods which experienced much higher lake levels. Therefore, the NRCS mapped some of the upland terrace units similarly to soil units which are clearly within the modern floodplain of the Jordan River.

TABLE 4-2
NRCS Soil Unit Descriptions

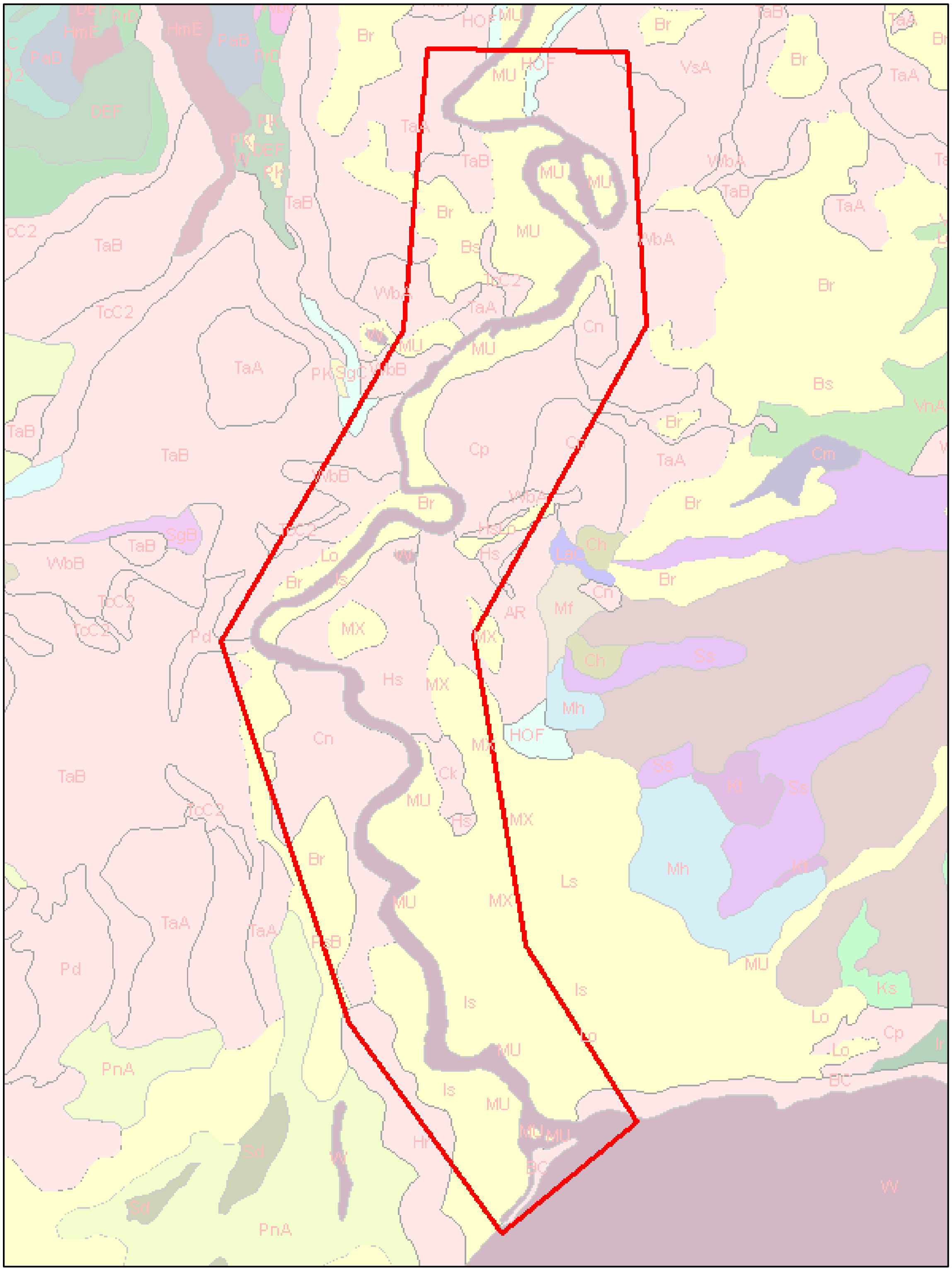
Code	Name	Description
AR	Arave silt loam	The Arave series consists of very deep, somewhat poorly drained soils that formed in lacustrine deposits derived from sedimentary rocks. Arave soils are on lake plains and low lake terraces. Slopes are 0 to 1 percent.
BC	Beaches	Undifferentiated beach sediments along lake shores.
BR	Bramwell silty clay loam	The Bramwell series consists of very deep somewhat poorly drained soils on floodplains and low terraces. They formed in mixed alluvium. Permeability is slow.
BS	Bramwell silty clay loam,	See above. BS is drained.
Ck	Chipman silty clay loam	The Chipman series consists of very deep poorly drained soils formed in lacustrine sediments from shale and limestone. Chipman soils are low lake terraces and floodplains. Slopes are 0 to 2 percent.
Cn	Chipman silty clay loam	See above. Cn is moderately saline.
Cp	Chipman-Mcbeth complex	The Chipman series consists of very deep poorly drained soils formed in lacustrine sediments from shale and limestone. Chipman soils are low lake terraces and floodplains. Slopes are 0 to 2 %. The McBeth series consists of very deep poorly drained soils that formed in stratified alluvium derived from limestone, sandstone and quartzite. McBeth soils are on flood plains and alluvial fans and have slopes of 0 to 1 %.
HOF	Hillfield-Sterling complex	Hillfield series consists of very deep, well drained soils that formed in lake sediments from gneiss, granite, limestone and sandstone. Slopes range from 4 to 60 %. The Sterling series consists of very deep, well drained or somewhat excessively drained soils that formed in alluvium, colluvium, and lacustrine deposits derived mainly from limestone and other sedimentary rocks. Sterling soils are on alluvial fans, fan remnants, stream terraces, lake terraces, and hills. Slopes are 0 to 70 %.
HR	Holdaway silt loam	The Holdaway series consists of moderately deep, poorly drained soils that formed in mixed lake sediments on low lake terraces. Slope ranges from 0-3%.
Hs	Holdaway silt loam	See above. Hs is strongly saline-alkali.
Is	Ironton loam	The Ironton series consists of very deep, somewhat poorly drained soils that formed in alluvium and lacustrine deposits derived from mixed rocks. Ironton soils are on low lake terraces and flood plains. Slopes are 0 to 6 percent. Moderately saline-alkali
Lo	Logan silty clay loam	The Logan series consists of very deep, poorly drained, slowly permeable soils. These soils formed in alluvium and lake sediments from many kinds of rocks, but dominantly from quartzite, sandstone, and limestone gneiss on flood plains, low smooth undulating lake terraces, and stream terraces. Slopes range from 0-3%.
LS	Logan silty clay loam	See above. LS is a heavy variant.
MU	Mixed alluvial land	Unclassified soils of riverine origin.
MX	Mixed alluvial land	Unclassified soils of riverine origin. Saline.
Pd	Payson silty clay loam	The Payson series consists of somewhat poorly drained or moderately well drained soils that formed in alluvium and lacustrine deposits derived mainly from quartzite,

TABLE 4-2
NRCS Soil Unit Descriptions

Code	Name	Description
		shale, and limestone. Payson soils are on low lake terraces. Slopes are 0 to 3 %.
PsB	Pleasant Vale silty clay loam	The Pleasant Vale series consists of deep, well drained soils that formed in alluvium. The soils are on alluvial fans and floodplains. 1 to 3 percent slopes.
Pz		No information available.
SgC	Sterling gravelly fine sandy loam	The Sterling series consists of very deep, well drained or somewhat excessively drained soils that formed in alluvium, colluvium, and lacustrine deposits derived mainly from limestone and other sedimentary rocks. Sterling soils are on alluvial fans, fan remnants, stream terraces, lake terraces, and hills. 3 to 6 percent slopes.
TaA	Taylorsville silty clay loam	The Taylorsville series consists of very deep, well drained, slowly permeable soils that were formed in calcareous, mixed lacustrine sediments derived mainly from limestone and shale. These soils are on nearly level to moderately steep, intermediate, and low lake terraces. Slopes are 0 to 1 percent slopes.
TaB	Taylorsville silty clay loam	See above. TaB is on 1 to 3 percent slopes.
TcC2	Taylorsville silty clay loam	See above. TcC2 is on 3 to 6 percent slopes, eroded.
VsA	Vineyard fine sandy loam	The Vineyard series consists of very deep, somewhat poorly drained soils that were formed in mixed lacustrine sediments from mainly from sedimentary rocks. These soils are on nearly level and gently sloping lake terraces with slopes of 0 to 2 %.
WbA	Welby silt loam	The Welby series consists of very deep well drained soils that were formed in lacustrine sediments derived from a mixture of limestone, sandstone, and shale. These soils are on nearly level to strongly sloping lake terraces. Slopes are 0 to 1 percent.
WbB	Welby silt loam	See above. WbB is on 1 to 3 percent slopes.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available at: http://soils.usda.gov/technical/classification/osd/index.html.

FIGURE 4-1
Interpreted NRCS Soils Unit Map Showing Riverine, Lacustrine and Upland Soils Units. Yellow Units Indicate Floodplain Soils. Pink Indicate Lacustrine Deposits.

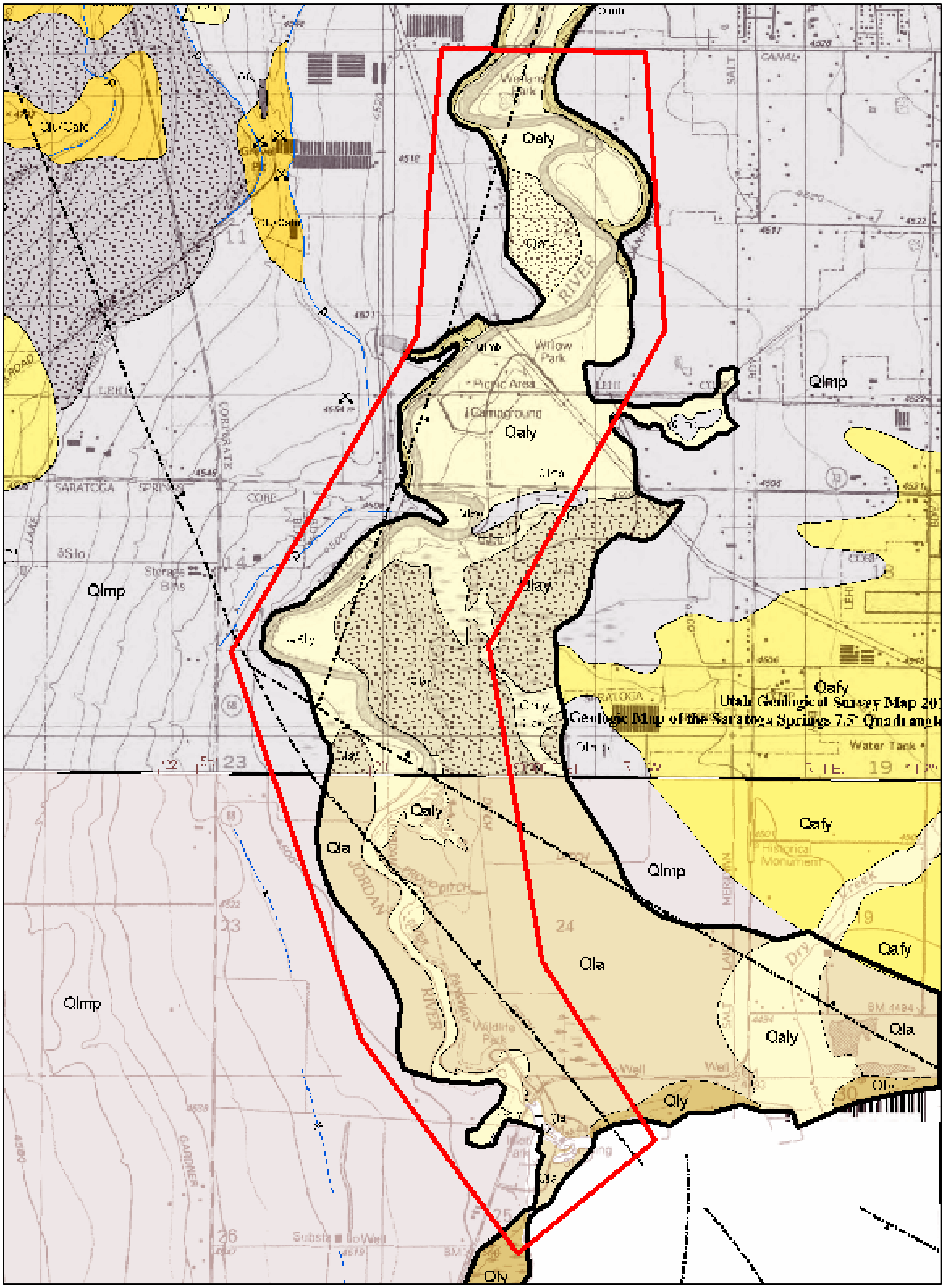


The UGS geologic mapping more clearly depicts the existing geomorphic setting along the study reach because geologic map units reflect not only the genesis of the soil material but also the topographic setting and landform function. The UGS mapping reveals that a wide natural geologic floodplain exists along the Jordan River. Areas within the geologic floodplain were subject to flood and erosion hazards in the recent past and are therefore somewhat more likely to experience such hazards in the future. The geologic floodplain establishes the outer limits for riverine erosion processes, except at points where the active channel abuts the older geologic surfaces. In these places, some trimming of the older geologic surfaces by riverine erosion should be expected.

TABLE 4-3
UGS Geologic Map Unit Descriptions

Code	Name	Description
Qaly	Young alluvial deposits	(Holocene to Upper Pleistocene) − Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in river channels and flood plains; incised by active stream channels, and locally include small alluvial-fan and colluvial deposits; equivalent to modern stream deposits (Qal1) and older, post-Bonneville stream deposits that are undifferentiated because units are complexly overlapping; probably less than 20 feet (6 m) thick.
Qat_2	Stream-terrace deposits	(Holocene to Upper Pleistocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel that forms level to gently sloping terraces incised by modern streams; subscript denotes height above modern stream channels; level 2 deposits are 10 to 30 feet (3-9 m); may include older lacustrine and alluvial sediment below a veneer of terrace deposits along the Jordan River north of Jordan Narrows; older (higher level) terraces may include loess veneer; generally 0 to 20 feet (0-6 m) thick.
Qla	Lacustrine and alluvial deposits	(Holocene to upper Pleistocene) - Moderately to well-sorted, fine-grained sand, silt, and clay adjacent to the Jordan River; grades into silt and clay deposits of the Bonneville Lake cycle; includes network of anastomosing alluvial deposits and lacustrine silt and clay deposits at the sinks east of Fairfield, which grades upstream to young alluvial deposits, and sandy deposits that grade into young alluvial deposits northwest of Lake Mountain; thickness unknown.
Qlay	Lacustrine and alluvial deposits	(Holocene to Upper Pleistocene) − Younger (Qlay) deposits consist of moderately to well-sorted, fine-grained sand, silt, and clay adjacent to the Jordan River that postdate the Bonneville lake cycle; exposed thickness up to about 90 feet (30 m).
Qlmb	Lacustrine silt and clay deposits	(Upper Pleistocene) − Calcareous silt (marl) with minor clay and fine-grained sand; typically laminated but weathers to appear thick bedded; locally concealed by loess veneer; Qlmb deposited below Bonneville shoreline and Qlmp deposited below the Provo shoreline; Qlmb is inferred to be exposed in cutbanks along the Jordan River south of Jordan Narrows (see, for example, Machette, 1992); grades upslope into lacustrine sand and silt; exposed thickness less than about 40 feet (12 m).
Qlmp	Lacustrine silt and clay deposits	(Upper Pleistocene) − Calcareous silt (marl) with minor clay and fine-grained sand; typically laminated but weathers to appear thick bedded; locally concealed by loess veneer; Qlmp deposited below the Provo shoreline; grades upslope into lacustrine sand and silt; exposed thickness less than about 40 feet (12 m).
Qly	Younger lacustrine and marsh deposits	(Holocene) - Silt, clay, and minor fine-grained sand deposited along the margin of Utah Lake; locally organic rich; probably 0 to 10 feet (0-3 m) thick.

FIGURE 4-2
Interpreted Geologic Map Units Showing the Modern Geologic Floodplain Outlined in Black



4.3 Empirical Geomorphology

Regime equations and hydraulic geometry analyses relate measurable stream characteristics, such as sediment size, mean annual discharge or bankfull discharge, to equilibrium channel geometry characteristics such as stream width, channel depth, flow velocity or channel slope. Regime theory originated from studies of non-scouring and non-silting stable alluvial canals (cf. Kennedy, 1895), and has been extended to a wide variety of stream types (cf., Ackers & Charlton, 1971; Blench, 1951). Regime equations are typically based on discharge, sediment characteristics, and channel geometry. Hydraulic geometry analyses are theoretically similar to regime theory, but are based on empirical data gathered from natural streams or flumes and are typically based solely on discharge. Hydraulic geometry expresses the variation of channel characteristics with increasing discharge at a single section or along the length of a stream. The U.S. Geological Survey (cf., Leopold & Maddock, 1953) published the most widely used hydraulic geometry data.

Regime equation and hydraulic geometry analyses were applied to the Jordan River study reach to evaluate the following stream characteristics:

- Channel Pattern
- Channel Geometry
- Hydraulic Geometry

Potential lateral instability on the Jordan River was evaluated by comparing predicted stream characteristics from one or more of these methodologies to observed characteristics in the study reach. These analyses assume that over the long-term, alluvial rivers will tend to modify their bed and banks or adjust their slope or channel pattern to better match the expected characteristics. In addition, even though regime equations and hydraulic geometry relationships are empirically derived using data sets from very specific stream types (e.g., sand-bed rivers, canals, etc.), the data typically still have a large amount of scatter. This scatter limits the accuracy of the application to new rivers. To increase the accuracy of the results, the equations selected for this study were based on data sets from streams which were the most similar to the study area characteristics. It is noted that every stream is unique, and therefore the results obtained by applying these equations must be interpreted cautiously. In general, the results are best interpreted as order-of-magnitude estimates of the direction of expected change, rather than precise predictions of the magnitude of future channel adjustments.

Channel Pattern Relationships. A channel pattern is a description of the planform of a river. Common channel patterns include meandering, braided, straight, distributary, and various intermediate and transitional forms of the latter categories. Regional studies have found that channel pattern is strongly correlated to stream slope and discharge. Numerous researchers have used empirical data, flume studies, and theoretical relationships to establish a threshold slope that separates braided and meandering stream patterns. The following slope-discharge relationships were selected for evaluation of the channel pattern in the study reach:

- Lane Equation
- Ackers & Charlton Equation

Lane Equations. Lane (1952) published empirical formulas to define the threshold slope for channel pattern, based on data from alluvial sand bed rivers. Lane’s equations leave an intermediate zone between the lines defined by the two slope equations where either pattern occurs. The Lane equations for channel pattern are:

$S_o > 0.010\ Q_m^{-0.25}$ (Braided channels)
$S_o < 0.001\ Q_m^{-0.25}$ (Meandering channels)

Where S_o = channel slope (ft./ft.), and
Q_m = mean annual discharge (cfs)

The mean annual discharge for the Jordan River was estimated from UGS mean daily discharge gauge records at the Jordan Narrows station (Q_m = 408 cfs).

Ackers & Charlton Equations. The Ackers and Charlton (1971) equations are based on data obtained from flume studies. The results generally agree with the results of the Lane equations (MacBroom, 1981).

$S_o > 0.0015\ Q_m^{-0.12}$ (Straight channels)
$S_o < 0.0021\ Q_m^{-0.12}$ (Meandering channels)

Where S_o = channel slope (ft./ft.), and
Q_m = mean annual discharge (cfs)

The data sources were the same as for the Lane equation.

Results. Application of the channel pattern equations to the study area are shown in Table 4-4. The measured bed slope for each reach is also shown. Computation using the energy slope allows one to assess how the channel pattern might adjust to a discharge higher than the mean annual flood. A full pattern adjustment to higher discharges is not expected during any single flood, but a tendency in a particular direction is of interest to the stability assessment.

TABLE 4-4
Channel Pattern Relationships: Threshold Slope for Braided Channels

Reach	**Methodology - Channel Pattern**		**Observed Pattern**	**Observed Slope**
	Lane	Ackers & Charlton		
100-Year				
1	M100	M100	Meander	0.00009
2	M100	M100	Meander	0.00004
3	M100	M100	Meander	0.00005
Bankfull				
1	M100	M100	Meander	0.00009
2	M100	M100	Meander	0.00004
3	M100	M100	Meander	0.00005

The subscript number after the pattern code (S, I, B, M, H) indicates the percent of sections predicted for the given pattern, e.g. B87 = 87% braided.

Field observations suggest that the Jordan River study reach is a meandering stream. As shown in Table 4-4, the channel pattern equations predict that the study reach is well within the meandering regime regardless of the discharge. The pre-development mean annual discharge of the Jordan River may have been less than the mean annual discharge recorded at the UGS gauging station. For the study reach, a lower mean annual discharge would tend to indicate a stronger meandering trend. Therefore, no pattern adjustment is expected.

Channel Geometry Relationships. Equations for stable channel geometry have been developed from descriptions of streams that have been stable for long periods of time. These equations relate bankfull channel width, depth, and velocity to a specific discharge rate, such as the average annual flow or the dominant discharge. Several stable geometry equations were applied to the study reach to assess the expected direction of future channel change.

Ackers & Charlton Equation. The Ackers and Charlton (1971) equations were based on data from flume studies which used sand bed materials.

$$W = K_{ac}\, Q^{0.42}$$

Where W = surface channel width (ft.)
Q = discharge (cfs)

K_{ac} is a coefficient varying from 3.6 for straight channels to 7.2 for meandering channels

Lacey Equation. The Lacey equation (1929) was developed to describe the geometry of silt-laden canals in India. However, Bray reported (1979) that in gravel rivers in Canada, the Lacey equation was as accurate for predicting velocity as the Manning's equation.

$$V = 0.8Q^{0.167}$$

Where V = mean channel velocity (ft./sec.)
Q = discharge (cfs)

Schumm Equation. Schumm (1961) preferred to examine the width/depth ratio of semi-arid streams, rather than either parameter separately. Schumm's equation is based on the percentage of fine-grained material in the channel banks.

$$F = 255\, M^{-1.08}$$

Where F = width/depth ratio
M = percentage of silt/clay in the bed.

The percentage of silt and clay in the bed material and banks was extracted from the sediment sampling data reported in Chapter 3 of this report.

Moody & Odem Equations. Moody and Odem (1999) completed an investigation of bankfull channel geometry relationships on a variety of stream types in the arid west using Rosgen channel classification methods. Channel geometry relationships were defined for a number of regions in the Southwest. Note that use of the Moody & Odem equations is hampered by inclusion of a drainage area factor in their equation. The drainage area of the study reach includes Utah Lake, which may affect the accuracy of the predicted trend.

$$Q_{bf} = 52.334\, DA^{0.5766}$$
$$A = 11.428\, DA^{0.5291}$$

$TW = 12.301\ DA^{0.3756}$
$d = 0.9455\ DA^{0.1506}$

Where Q_{bf} = Bankfull discharge (cfs)
DA = Watershed drainage area (mi^2)
A = Section flow area at bankfull discharge (ft.)
TW = Flow width at bankfull discharge (ft.)
d = Average flow depth at bankfull discharge (ft.)

Results. The results of applying the channel geometry equations to the Jordan River study reach are shown in Table 4-5. The 100-year FIS discharge was substituted for the discharge variable used in the original channel geometry equations to examine the trend of potential adjustments in channel geometry at peak flow rates like those that occurred in the floods of the 1980's. The predicted values of width, depth, slope and velocity from the channel geometry equations were compared to the measured values obtained from field data, topographic mapping and HEC-RAS models. The differences were interpreted as follows:

- Width. The regime equations indicate that the existing channel is over-widened and that a narrower channel may be expected to form. Narrowing would probably take the form of deposition of point bars, which are currently lacking from the river.
- Depth. Where predicted channel depth is less than the HEC-RAS modeled channel depth, the regime equations may be interpreted to predict deposition to reach the equilibrium state. For the study reach, the regime equations indicate that the existing channel is deeper than average and that deposition should be expected, a response not unexpected given the history of deepening the river by dredging.
- Slope. Where the predicted slope is less than the existing slope, the channel is expected to decrease its slope (scour) to achieve a more stable form. For the study reach, the regime equations predict long-term scour and erosion. This result was expected, given that the river was steepened when the river was dredged.
- Velocity. Where the predicted velocity is greater than the HEC-RAS modeled velocity, floods will tend to be less erosive than predicted by the channel geometry equations. For the study reach, higher velocities than those predicted by HEC-RAS modeling would be expected if the river were in regime.

Note that the stable geometry equations described above reflect the dimensions of channels which have been stable over long periods of time. Given the wide disparity between the observed and predicted channel geometry, as well as the unique hydrology of the Jordan River downstream of Utah Lake, these regime-based predictions should be viewed as less reliable than predictions based on observed (i.e., historical) channel changes. In general, the empirical geomorphology equations indicate a low potential for future lateral erosion.

TABLE 4-5
Observed and Expected Channel Characteristics

Equation	Channel Width (ft)		Flow Depth (ft)		Channel Slope (ft/ft)		Channel Velocity (ft/s)	
	Q100	Bankfull	Q100	Bankfull	Q100	Bankfull	Q100	Bankfull
Reach 1								
Ackers & Charlton/Lacey	96	56	-	-	-	-	3.0	2.4
Schumm	104	85	-	-	8.3E-05	1.1E-04	-	-
Moody & Odem	159	159	5.3	5.3	-	-	-	-
Average	120	100	5.3	5.3	8.3E-05	1.1E-04	3.0	2.4
HEC-RAS Data	121	111	10.5	5.0	9.3E-05	1.2E-04	2.1	1.4
Expected Behavior	No Change	Narrow	Fill	No Change	Scour	No Change	No Erosion	No Erosion
Reach 2								
Ackers & Charlton/Lacey	90	56	-	-	-	-	2.9	2.4
Schumm	134	103	-	-	4.0E-05	6.5E-05	-	-
Moody & Odem	159	159	5.3	5.3	-	-	-	-
Average	128	106	5.3	5.3	4.0E-05	6.5E-05	2.9	2.4
HEC-RAS Data	165	144	10.6	4.9	4.4E-05	7.1E-05	1.4	1.1
Expected Behavior	Narrow	Narrow	Fill	Scour	Slight Scour	Slight Scour	No Erosion	No Erosion
Reach 3								
Ackers & Charlton/Lacey	94	56	-	-	-	-	2.9	2.4
Schumm	122	88	-	-	4.5E-05	5.4E-05	-	-
Moody & Odem	159	159	5.3	5.3	-	-	-	-
Average	125	101	5.3	5.3	4.5E-05	5.4E-05	2.9	2.4
HEC-RAS Data	160	117	11.1	5.8	5.1E-05	5.8E-05	1.6	1.1
Expected Behavior	Narrow	Narrow	Fill	Fill	Slight Scour	Slight Scour	No Erosion	No Erosion

Allowable Velocity. Allowable velocity criteria have long been used in channel design to estimate the velocity at which channel bed and bank sediments will begin to erode. A variety of allowable velocity data have been published by the US Army Corps of Engineers (1970, 1990, 1995) and the USDA Soil Conservation Service (1977), as well as by many other agencies.

Methodology. The following allowable velocity approaches were applied to the study reach:

- Fortier & Scobey Table
- BUREC/Mavis & Laushey Equation
- Neill Equation
- USACOE Permissible Velocity Tables

Fortier & Scobey Table. Fortier and Scobey (1926) published one of the first tables of permissible velocity in 1926. Their data, based on records of seasoned stable canals, was later republished by a number of federal agencies and other organizations including the Federal Highway Administration (FHWA), American Society of Civil Engineers (ASCE), and Chow (MacBroom, 1981). The Fortier and Scobey data (Table 4-6) distinguish erosion hazards for clear water, silt-laden water, and water transporting sand and gravel (bedload). Their data presumably do not account for the stabilizing effect of bank vegetation.

TABLE 4-6
Fortier & Scobey Table of Permissible Canal Velocities (ft/s)

Bank Material	Clear Water	Silt-Laden	Sand/Gravel Bedload
Sandy Loam	1.75	2.50	2.00
Firm Loam	2.50	3.50	2.25
Fine Gravel	2.50	5.00	3.75
Stiff Clay	3.75	5.00	3.00
Coarse Gravel	4.00	5.50	6.50
Cobbles	5.00	5.50	6.50

BUREC/Mavis & Laushey Equation. The BUREC (1974) recommends that permissible velocity be estimated using a modification of the Mavis and Laushey equation (Jurnikis, 1971), which was developed by bridge engineers in Great Britain (MacBroom, 1981). The BUREC equation is a function of grain size, and is most applicable to erosion of non-cohesive bed material.

$Vb = 0.64\ D(4/9)$ for $D < 6.0$ mm
$Vb = 0.5\ D^{1/2}$ for $D > 6.0$ mm

Where Vb = competent velocity (ft/sec)
D = particle diameter (mm)

Neill Equation. Neill (1975) developed equations that are a function of flow depth and grain size for permissible velocities on gravel and cobble bed streams, with a separate equation for cohesive soils. While the Jordan River clearly is not a gravel bed stream, the Neill data were applied to illustrate the affect of soil cohesiveness on bank stability. The Neill equations are formulated as follows:

$Vb = 3.15\ d(1/3)\ D(2/3)$ (non-cohesive soils)
$Vb = 7.5\ d(1/6)\ \tau c^{1/2}$ (for cohesive soils)

Where Vb = competent velocity (ft/sec)
d = flow depth (ft)
D = grain size (ft)
τc = critical shear stress (lb/ft2)

US Corps of Engineers Permissible Velocity. The Corps of Engineers (1970; 1995) has established suggested maximum velocities for design of non-scouring flood control channels of various bank materials, as shown in Table 4-7.

TABLE 4-7
Suggested Maximum Permissible Mean Channel Velocities (USACOE, 1995)

Channel Material	Mean Velocity (ft/sec)
Fine Sand (0.075 – 0.45 mm)	2.0
Coarse Sand (2 – 5 mm)	4.0
Fine Gravel (5 - 20 mm)	6.0
Grass-Lined Banks (< 5% Slope, Sandy Silt, Bermuda Grass)	8.0
Poor Rock (Sedimentary)	10.0
Good Rock (Igneous or Metamorphic)	20.0

The Corps of Engineers (1990) has also developed criteria relating flow depth and velocity to the beginning of movement of granular bed materials and erosion of cohesive bank materials, as summarized in Table 4-8.

TABLE 4-8
Corps of Engineers Erosive Velocity Data

Grain Size (mm)	Flow Depth (ft)	Velocity (ft/sec)	Cohesiveness	Flow Depth (ft)	Velocity (ft/sec)
1	5	2.5	Very Soft	5	2.0
(sand)	10	4.0		10	2.5
10	5	4.5	Average	5	3.5
(gravel)	10	5.5		10	4.0
100	5	9.5	Very Stiff	5	5.5
(cobbles)	10	10.5		10	6.0

Results. In general, the alluvial banks of the Jordan River are composed of sandy clay loam with good vegetative cover, even where the channel cuts into Pleistocene- or Tertiary-aged terraces. The bank soils are moderately cohesive. 100-year channel velocities derived from the HEC-RAS model indicate average channel velocities of 1 to 3 feet per second.

The reach-averaged velocities estimated from the HEC-RAS models for the flood profiles were compared to the allowable velocities determined by the methodologies described above, as shown in Table 4-9. Erosion (E) is expected where the allowable velocities are exceeded by the predicted HEC-RAS reach-averaged velocities. Where the allowable velocities are not exceeded, the channel is expected to be stable (S). The number listed after S or E in Table 4-9 indicates the percent of the cross sections within the reach which exhibit the S or E trend.

Table 4-9 shows reach-averaged velocities for the channel at 100-year and bankfull conditions. The reach-averaged data show mixed results. Neill and USACOE data indicate that predicted velocities are non-erosive, especially where the bank materials are cohesive. For non-cohesive soils, the bed and banks would be considered erodible. Field evidence and soil descriptions indicate that the bank materials are marginally cohesive. Therefore, it is concluded that the allowable velocity charts predict that the banks are marginally erosive during peak flows.

TABLE 4-9
Allowable Velocity Results

Reach	**Fortier-Scobey**	**BUREC**	**Neill: Non-cohesive**		**Neill: Cohesive**		**USACOE**
			Erosive	**Velocity**	**Erosive**	**Velocity**	
100-Year							
3	E75	E100	E100	0.3	S100	2.6	S100
2	S78	E100	E100	0.3	S100	1.7	S100
1	E64	E100	E100	0.3	S100	2.0	S100
Bankfull							
3	E75	E100	E100	0.2	S100	1.7	S100
2	S83	E100	E100	0.2	S100	1.4	S100
1	S79	E100	E100	0.2	S100	1.3	S100

Notes:

E = allowable velocity exceeded; erosion expected
S = allowable velocity not exceeded; erosion not expected
E100 = 100 % of sections in reach have indicated erosive trend, E87 = 87 % of sections in reach

4.4 Summary

The geomorphic analysis indicates that although the Jordan River study reach has a stream pattern that is characteristic of significant lateral movement, and the river lies within a broad geologic floodplain, the empirical methodologies used predict greater stability and only minor expected adjustments in channel geometry and planform. Allowable velocity analyses indicate that continued bank erosion is possible.

5.0 Bed Elevation Analysis

Changes in stream bed elevation are strongly correlated to lateral instability. A bed elevation analysis consisting of the following elements was conducted for the Jordan River study reach:

- Base Level Evaluation
- Historical Topographic Data Evaluation
- Longitudinal Profile Analysis
- History of Dredging Analysis
- Equilibrium Slope Analysis
- Scour Estimates
- Armoring Analysis

5.1 Base Level

Base level is defined as the lowest elevation to which a stream can erode. Ultimate base level world-wide is the water surface elevation of the ocean, while in northern Utah, the regional base level is defined by the Great Salt Lake. Local base level on a river is dictated by local geologic control such as bedrock or by the elevation of the stream into which a study reach flows. The UGS geologic maps indicate that no bedrock crops out along the Jordan River until the Jordan Narrows, which is located several miles downstream of the study reach. No geologic or manmade base level controls were identified near the downstream end of the study reach during the field investigation or from any published source that might define a permanent base level control. The boring logs obtained for previous dredging plans did not indicate that any shallow bedrock or non-erodible layers underlies the study reach.

Prior to dredging the river in the 1984, a topographic rise in the profile of the Jordan River between 9600 North and Turner Dam provided the temporary local based level control (and limited the hydraulic capacity of the river) within the study reach (Figure 5-1). However, dredging removed this topographic rise, effectively lowering the local base level by about seven feet. Base level lowering typically results in long-term degradation upstream as the stream bed erodes to achieve a stable slope at the new lower base elevation.

5.2 Comparison of Historical Topographic Data

The following three topographic data sets were obtained for comparison of historical bed elevation changes:

- 1985: A pre-dredging topographic profile was obtained from CH2M HILL ((1985). The exact date of the topographic profile was not reported.

- 1985: The post-dredging design (not as-built) profile was obtained from the dredging contract documents (CH2M HILL, 1985).

- 1998: Profile and cross section data of uncertain date, presumably 1998, were obtained from the most recent FIS HEC-2 model (Baker, 1998).

The 1-foot contour interval topographic map dated 1923 obtained during the data collection effort did not include bed elevations or any data below the Jordan River water surface elevation, and thus could not be used for the bed elevation analyses. The contour intervals on the UGS topographic quadrangle maps of the study area were too large to be useful for a longitudinal profile comparison since no contours crossed the river within the study limits. Some approximate bed elevation data were obtained during the field investigation at specific cross sections as described below.

The historical topographic data were used to perform the following analyses:

- Longitudinal Profile Comparison
- Cross Section Comparison

Longitudinal Profile Comparison. A longitudinal profile is a plot of the channel elevation versus distance along the stream bed. Plots of the 1984 pre-dredging profile, the proposed dredging design profile, and the circa 1998 post-dredging profile are shown in Figure 5-1. Five-station moving average trend lines are plotted in Figure 5-1 for the 1984 pre-dredging and the 1998 post-dredging profiles to reduce the scatter in the data. The following conclusions regarding recent historical bed elevation change in the study reach can be made from the data shown in Figure 5-1:

- Channel Excavation. The invert elevation of the study reach was manually lowered by dredging by an average of about three feet. The prominent topographic rise in the profile located downstream of the study reach was removed by dredging of up to seven feet below the channel bed.

- Long-Term Degradation. Since the dredging occurred there has been net bed lowering of almost two feet within the study reach. The 1998 profile indicates that there is a sag in the profile with adverse slope between 9600 North and State Route 73.

- 9600 North. The depth of degradation increases upstream of the 9600 North Bridge. There is a low point in the minimum bed elevation upstream of 9600 North. These facts suggest that some sort of more resistant soil or bed material layer in the vicinity of 9600 North that provides a degree of grade control.

- Dredging. The profile data indicate that the minimum bed elevations have not increased above the dredging design elevations, which suggests that further dredging may not be needed.

- Irregular Profiles. The zig-zag trend of the 1984 and 1998 profiles indicate development of deeper pools and shallower “riffles” that are normal for this stream type.

Cross Section Comparison. Post-dredging cross section data were available from 1988, 1998, and from approximate field survey data collected during the field reconnaissance. The data sets for six cross sections spaced throughout the study reach are shown in Figures 5-3 to 5-8. The locations of the repeat cross sections are shown on Figure 5-2. The cross section numbers correspond to the numbering used for the revised FIS (Utah County, 1989). Note that the left bank and right banks were identified looking upstream to be consistent with the other two sources.[7] All other sections of this report refer to left bank and right bank looking downstream.

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[7] Everywhere else in this report, river left and right are identified looking downstream, following normal river conventions.

FIGURE 5-1
Pre and Post Dredging Longitudinal Profile Comparison

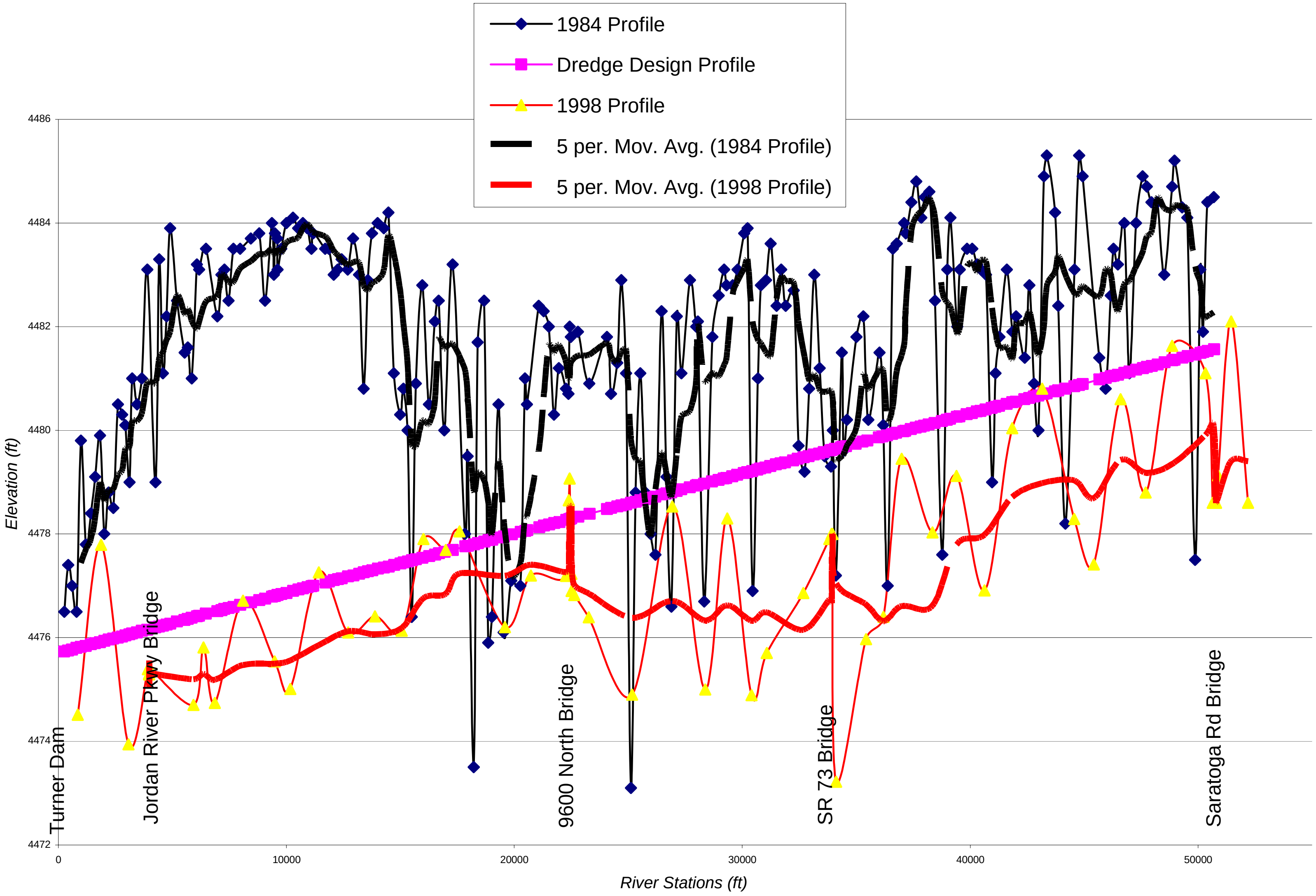


FIGURE 5-2
Location of Repeat Survey Cross Sections, 1988-2006

FIGURE 5-3

Cross Section #10 Profiles, 1988-2006, Downstream of Saratoga Springs Road Net degradation

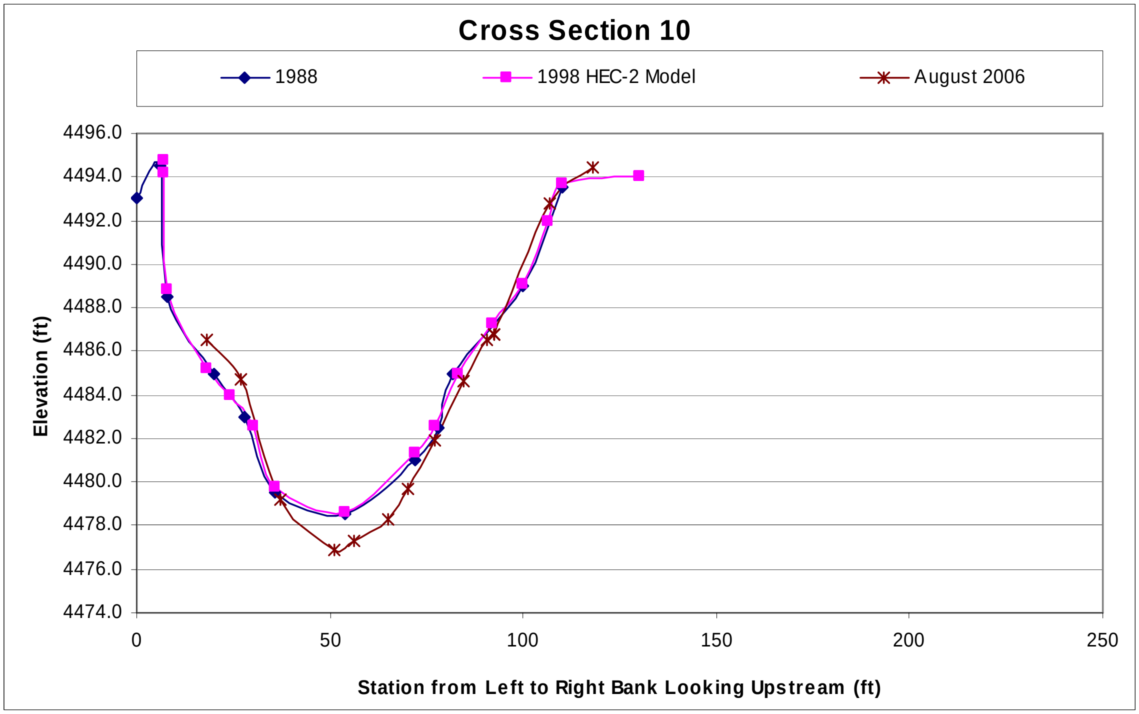


FIGURE 5-4

Cross Section #9 Profiles, 1988-2006 Between Saratoga Springs Road and SR 73 Slight Net Degradation and Widening

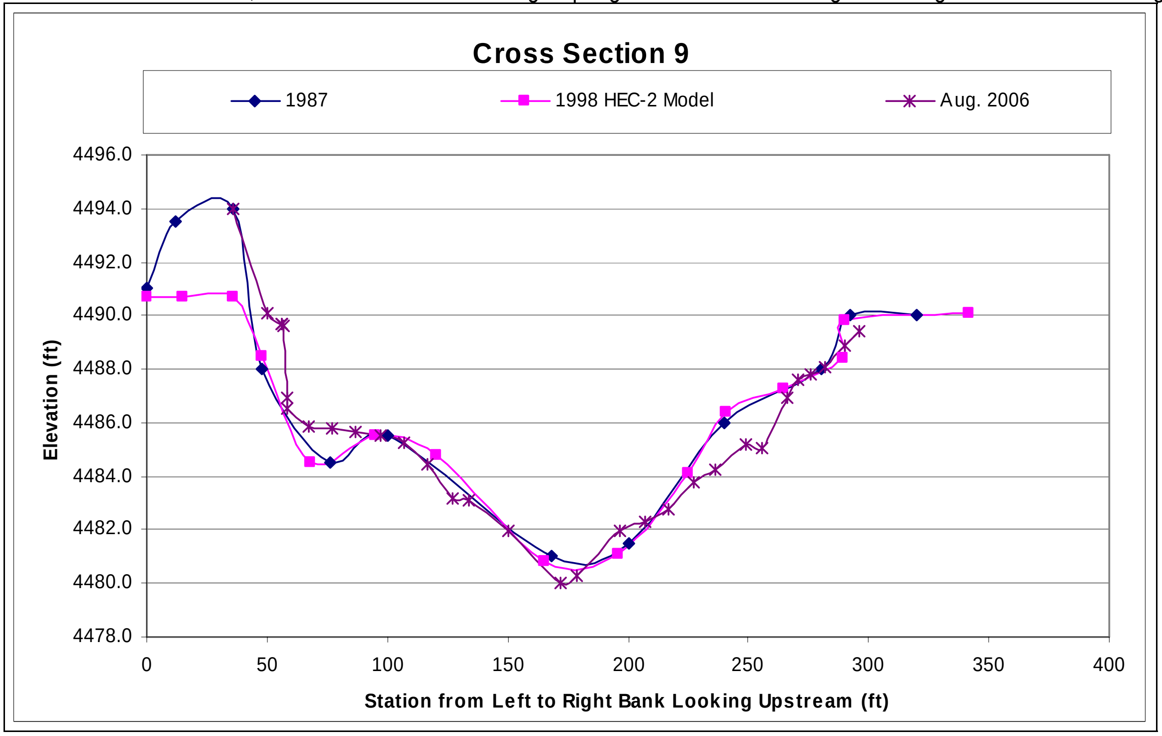


FIGURE 5-5
Cross Section #8 Profiles, 1988-2006 Downstream of SR 73 Degradation

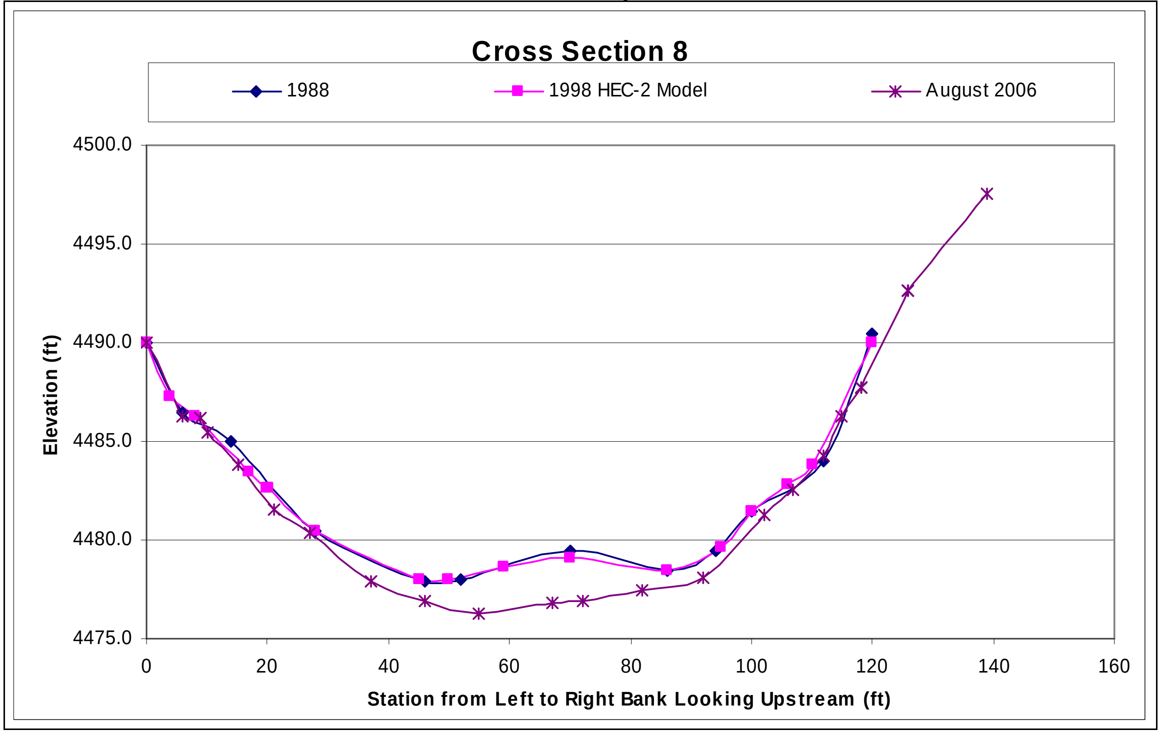


FIGURE 5-6
Cross Section #7 Profiles, 1988-2006 Near Willow Park Aggradation and Widening

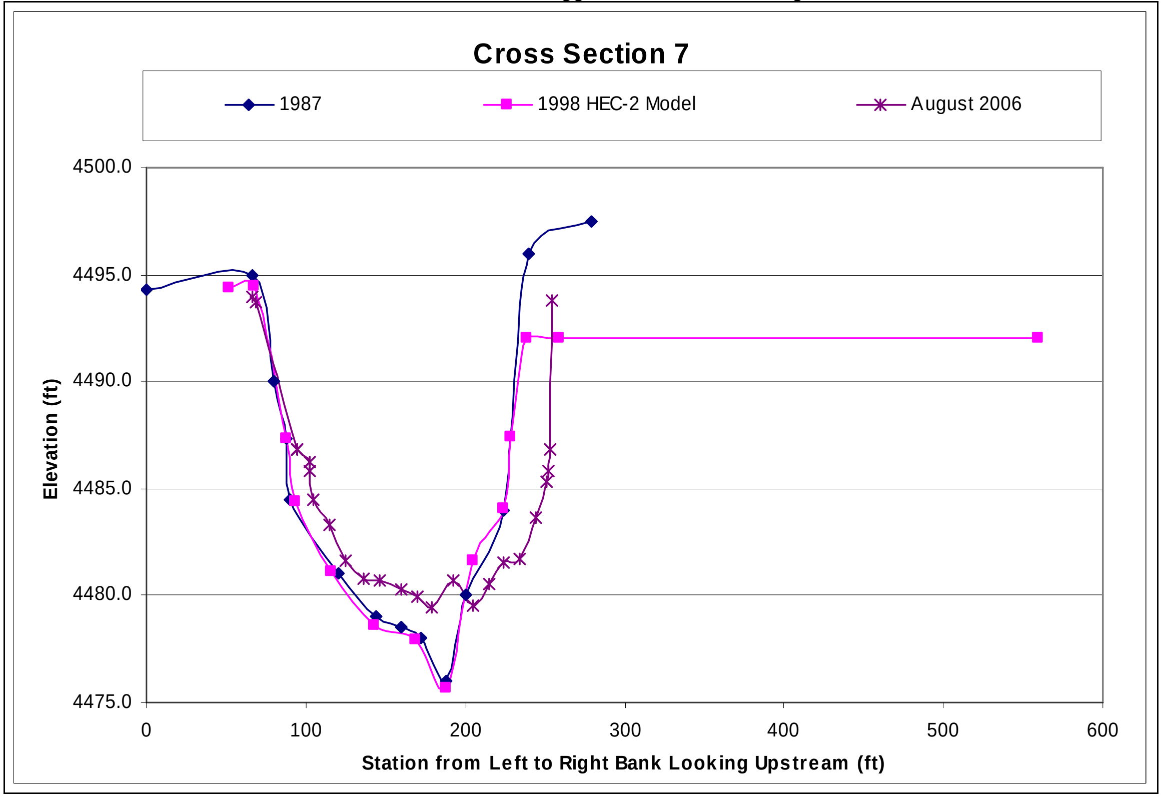
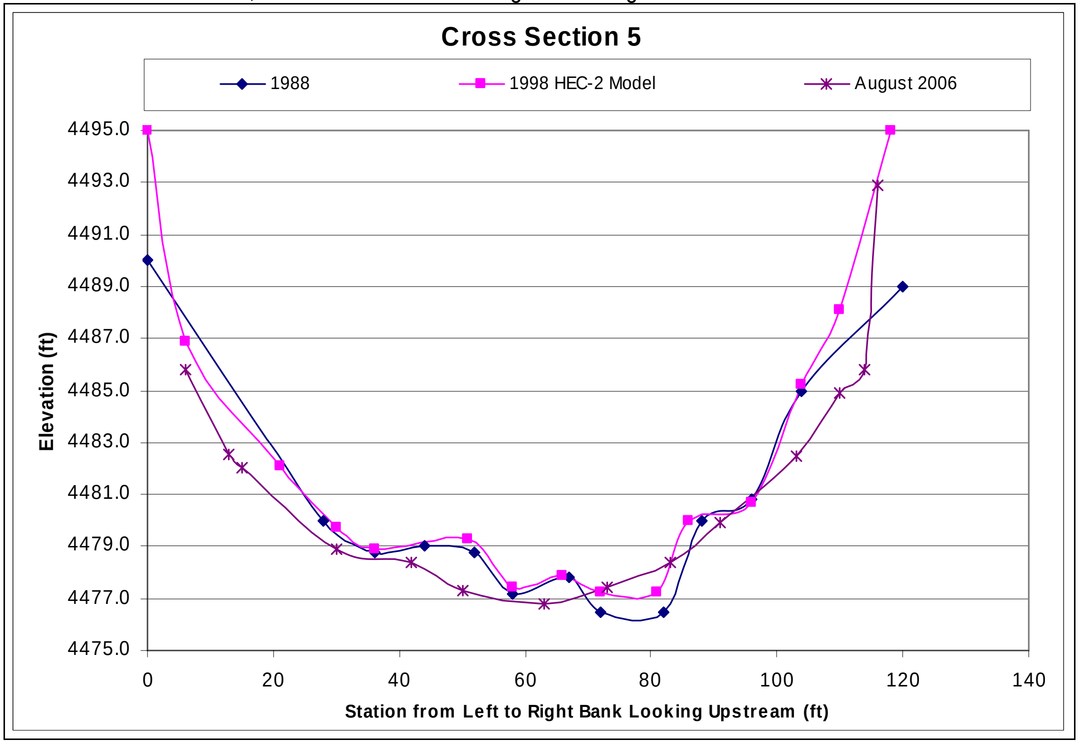


FIGURE 5-7
Cross Section #6 Profiles, 1988-2006 Upstream 9600 North Widening & Slight Aggradation

FIGURE 5-8
Cross Section #5 Profiles, 1988-2006 9600 North Slight Widening



For the Jordan River Flood Zone Revisions Report, Cross Sections 10, 8, and 5 were surveyed in December 1988. These three cross sections are located at the downstream end of the Saratoga Road, SR 73, and Old 9600 North Bridges, respectively. The remaining three cross sections were surveyed in January of 1987 (Utah County, 1989). All six cross sections were included in the 1998 hydraulic model (Baker, 1998). During the field reconnaissance for this project, the six cross sections were surveyed using approximate methods.

The following observations were made from the cross section comparison:

- 1988-1998: The 1987/88 cross sections were nearly identical to the 1998 cross sections, suggesting the possibility that the 1987/88 data were also used in the 1998 hydraulic model. The source of the 1998 model cross sections was not available from which to investigate this possibility.
- 1998-2006: There were significant differences between the 2006 data and the 1987/88 data. The differences varied by cross section.
    - Degradation: Degradation occurred at cross sections 10, 9, and 8 in Reach 2
    - Aggradation: Slight aggradation occurred at cross sections 7, 6, and 5 in Reach 3. The aggradation in Reach 3 could be a response to filling the adverse slope shown in longitudinal profile in Figure 5-1.
    - Widening. Widening of the main channel occurred at cross sections 9, 7, 6 and 5. The observed widening is directly correlated with aggradation at these sections, and is inversely correlated to section with degradation, leading to the hypothesis that the material eroded from the banks was deposited in the bed rather than transported out of the reach.

None of the changes observed at the repeat cross section represent alarming amounts of channel change, although in conjunction with the historical profile comparison, may indicate a progressive trend of long-term degradation in the study reach.

5.3 Longitudinal Profile

The shape of the longitudinal profile can also be used to interpret river behavior. A typical longitudinal profile on an alluvial river flattens parabolically in the downstream direction. Differences from the expected parabolic trend may indicate the presence of geologic control, on-going slope adjustments such as long-term aggradation or degradation, or other specific riverine processes. Slope irregularities, such as stair-stepped reaches, over-steepened or flat reaches, and head cuts also indicate stream processes and adjustments.

The 1998 longitudinal profile shown in Figure 5-1 indicates the following with regard to the Jordan River morphology:

- Profile Shape. Overall, the stream profile appears to flatten in the downstream direction as expected.
- Pool/Riffle Sequence. The zigzag appearance of the profile is probably the result of alternating series of deeper pools and shallower runs (no riffles occur in the study reach).

- Adverse Slope. An area of adverse slope upstream of 9600 North is unlikely to persist over the long-term. Either the low area will fill by deposition or the high point will be eroded and a new local base level will occur, leading to continued upstream degradation and/or slope flattening.

5.4 Dredging

Following major flooding in the mid-1980's, during which the Cities of Saratoga Springs and Lehi experienced significant flooding, a dredging project was funded to decrease the flood potential along the river from Utah Lake to the Jordan River Narrows. Pre- and post-dredging profiles are shown in the longitudinal profile in Figure 5-1. The dredging project lowered the bed elevation by up to seven feet. The dredging design called for a bottom width from the 9600 North Bridge alignment to the SR 73 Bridge of 75 feet with excavated side slopes of 3:1 up to the then existing channel banks. From the SR 73 bridge to the Saratoga Springs Road Bridge the channel was dredged about two feet deeper with a 70-foot bottom width and 3.5:1 side slopes. (CH2M HILL, 1985). The volume of dredged material was estimated at about 850,000 cubic yards, as indicated in the Phase 1 Design Report:

> *The final dredging plan calls for a trapezoidal excavation with a 75-foot bottom width and a constant slope between the base of Turner Dam and Utah Lake… The total quantity of excavation will be approximately 850,000 cubic yards. Of that quantity, approximately 25, 000 cubic yards are expected to be rock; the rest will be silt, sands, and gravels.*

The meaning of the estimated 25,000 cubic yards of "rock" is unclear since the sediment samples reported in the contract documents compiled in 1985 (CH2M HILL, 1985) show no evidence of excavation in bedrock. Given field observations made for this study and the sediment data reported by CH2M HILL, "rock" probably means sediment sizes larger than gravel, i.e., cobbles and boulders.

River Response to Dredging. The historical data summarized above indicate that there were two key responses to dredging of the study reach - decreased channel bed elevations (by direct excavation and by degradation in response to lower local base level) and decreased channel slope i.e., degradation due to increased flow velocities and channel capacity. Average bed elevation differences are summarized in Table 5-1. The channel bed dropped significantly below the pre-dredging profile designated in the design plans by 1998. The maximum drop between 1985 and 1998 of 6.5 feet occurred upstream of the SR 73 Bridge. The average bed elevation change between 1985 and 1998 was 1.9 feet between the 9600 North Bridge and the Saratoga Road Bridge.

TABLE 5-1
Average Channel Bed Elevation

Profile Data Set	Average Bed Elevation: Saratoga Rd. to 9600 N (ft)	Average Bed Elevation: 9600 N to Turner Dam (ft)	Average Bed Elevation: Saratoga Rd. to Turner Dam (ft)
1984	4481.96	4481.30	4481.66
Dredge Design	4479.93	4476.95	4478.57

TABLE 5-1
Average Channel Bed Elevation

Profile Data Set	Average Bed Elevation: Saratoga Rd. to 9600 N (ft)	Average Bed Elevation: 9600 N to Turner Dam (ft)	Average Bed Elevation: Saratoga Rd. to Turner Dam (ft)
1998	4478.03	4476.03	4477.32
Difference between 1984 and dredge design	-2.0	-4.4	-3.1
Difference between dredge design and 1998 profile	-1.9	-0.9	-1.3

The post-dredging slope of the Jordan River also changed. The slope of the reach between Saratoga Road and 9600 North decreased 69% compared to the dredging design profile slope. The overall slope has decreased because the channel bed between Saratoga Road and 9600 North has dropped more significantly than has the reach below 9600 North. Table 5-2 gives the values for the slopes and quantifies the changes that have taken place in response to the dredging.

TABLE 5-2
Channel Slope Comparisons

Profile Data Set	Saratoga Rd. to 9600 N (ft/ft)	9600 N to Turner Dam (ft/ft)	Saratoga Rd. to Turner Dam (ft/ft)
1984	0.000134	0.000190	0.000159
Dredge Design	0.000157	0.000115	0.000156
1998	0..000049	0.000126	0.000082
% Change from 1984 to dredge design	17	-39	-2
% Change from dredge design to 1998 profile	-69	10	-47

5.5 Equilibrium Slope

Equilibrium slope[8] is defined as the slope which causes the channel's sediment transport capacity to equal the incoming sediment supply. If the slope is too steep, channel velocities will be high and net erosion will occur. If the slope is too flat, channel velocities will be low and net

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[8] Equilibrium slope is also referred to as stable slope or limiting slope.

deposition will occur. Channel slope adjustments can occur by degradation or aggradation, or by meandering or straightening of a river reach. The equilibrium slope is the slope that the undisturbed, natural channel will tend towards over the long term. Equilibrium slope equations provide a useful order-of-magnitude assessment of the likelihood of vertical channel adjustments.

Methodology. Reach-averaged data required for application of equilibrium slope equations to the study area were derived from the HEC-RAS modeling, the FIS hydrology and UGS mean daily discharge data and topographic data from the FIS HEC-2 model. Most equilibrium slope equations are based on the mean annual flood, the “channel-forming,” or “bankfull” discharge. On many perennial alluvial streams, particularly in humid climates, the mean annual flood and the channel-forming and bankfull discharges are nearly equivalent. The following equilibrium slope equations were applied to the study reach:

- Schoklitsch Equation
- Meyer-Peter Muller Equation
- Shield’s Diagram Method

The latter three equations listed above are zero bed sediment discharge (clear water) equations, and represent minimum slopes that would occur if sediment supply were disrupted. The BUREC equations apply to the Jordan River study reach since the sediment supply from Utah Lake is close to zero.

Schoklitsch Equation. The Schoklitsch (Shulits, 1935) equation is based on the concept of zero bedload transport.

$$S_L = K_s\ (D\ W_{bf}/Q)^{3/4}$$

Where S_L = Stable slope (ft/ft)
K_s = 0.00174
W_{bf} = Bankfull width (ft)
D = Mean bed sediment diameter (mm)
Q = Dominant discharge (cfs)

Meyer-Peter, Muller Equation. The Meyer-Peter, Muller (1948) equation is based on the incipient motion theory, or the point of initiation of sediment transport, for zero sediment inflow.

$$S_L = K_{mpm}\ (Q/Q_{bf})\ (n_s/D_{90}^{1/6})^{3/2}\ D\ /\ d$$

Where S_L = Stable slope (ft/ft)
K_{mpm} = 0.19
Q/Q_{bf} = Ratio of total flow to flow over the channel
Q_{bf} = Dominant discharge (cfs)
n_s = Manning’s n for the stream bed
D_{90} = Bed sediment diameter for which 90 percent is smaller (mm)
D = Mean sediment diameter (mm)
d = Channel depth (ft)

Shields Diagram Method. The Shields diagram (1936) for determining the boundary condition for no sediment transport can be used to define an equation for stable slope.

$R_* = U_* D / \upsilon$
$U_* = (S_L R g)^{1/2}$
$T_* = \tau_c / ((\gamma_s - \gamma_w) D)$

Where S_L = Stable slope (ft/ft)
R_* = Boundary Reynold's number
U_* = Shear velocity = $(S_L R g)^{\wedge 0.5}$
D = Mean sediment diameter (mm)
υ = Kinematic viscosity of water (ft^2/sec)
R = Hydraulic radius for wide channels (ft)
g = Gravitational constant = 32.2 ft/sec^2
T_* = Dimensionless shear stress
τ_c = Critical shear stress (lb/ft^2)
γ_s, γ_w = Specific weight of sediment (lb/ft^3) and water (lb/ft^3)

Results. The results of the equilibrium slope computations are shown in Table 5-3. The Schoklitsch, Meyer-Peter Muller, and Shield's Diagram results represent minimum slopes for the specific condition of clear-water discharges. For both sets of equations, long-term degradation (or aggradation) can be predicted by comparing the equilibrium slope and existing channel slopes for a given reach. If the predicted equilibrium slope is less than the existing channel slope, long-term degradation should be expected. Conversely, if the predicted equilibrium slope is greater than the existing channel slope, long-term aggradation should be expected.

TABLE 5-3
Equilibrium Slope Analysis

	Methodology - Stable Slope (ft/ft)					
Reach	**Scoklitsch**	**MPM**	**Shield**	**Average (ft/ft)**	**Measured Slope (ft/ft)**	**Predicted Trend**
100-Year						
1	0.00007	0.00003	0.00001	0.00003	0.00009	Degradation
2	0.00010	0.00003	0.00001	0.00005	0.00004	No Change
3	0.00009	0.00003	0.00001	0.00004	0.00005	No Change
Bankfull						
1	0.00017	0.00006	0.00001	0.00008	0.00009	No Change
2	0.00020	0.00006	0.00002	0.00009	0.00004	Aggradation
3	0.00017	0.00005	0.00001	0.00008	0.00005	Aggradation

MPM = Meyer-Peter, Muller

Summary. The equilibrium slope equations that assume no sediment inflow (Schoklitsch, MPM, and Shield) predict channel slopes that are close to or steeper than the existing slope, which indicates the assumption of zero sediment inflow is probably valid, and indicates that any historical degradation is not the result of decreased sediment supply.

5.6 Scour Estimates

Scour is defined as any lowering of the channel bed elevation that occurs as a result of flowing water. Scour can be caused by changes in the sediment transport capacity of a channel during the passage of a flood wave (general scour), by the formation of bed forms (dune, anti-dune, thalweg scour), by velocity currents around channel bends (bend scour), by local flow obstructions (local scour), or by progressive slope adjustments to watershed and watercourse changes (long-term scour). Scour is directly proportional to flow velocity and flow duration, and inversely proportional to sediment size, sediment supply, and flow depth. Scour during the 100-year flood and a bankfull flow event (a.k.a. single-event scour or short-term scour) is discussed in the following paragraphs. Long-term scour, or progressive bed elevation change over long time periods, was evaluated using a variety of approaches and is discussed throughout this chapter. The objective of the scour analysis was to compute reach-averaged scour estimates for use in predicting future channel change and order of magnitude relative differences in channel behavior between adjacent reaches. The scour analysis is not intended to generate design-level scour estimates at any point within the study reach. Site-specific scour analyses should be performed in support of any design.

Methodology. General scour for the study reach was estimated using procedures outlined in the City of Tucson's *Standards Manual for Drainage Design and Floodplain Management - Chapter VI - Erosion and Sedimentation* (1989; hereafter, "the COT Manual"). Depth of scour in a stream is given in the COT Manual:

$$Z_t = 1.3\ (Z_{gs} + \tfrac{1}{2}\ Z_a + Z_{ls} + Z_{bs} + Z_{lft})$$

where:

Z_t = Design scour depth, excluding long-term degradation or aggradation (ft)
Z_{gs} = General scour depth (ft)
Z_a = Anti-dune trough depth (ft)
Z_{ls} = Local scour depth (ft)
Z_{bs} = Bend scour depth (ft)
Z_{lft} = Low-flow thalweg depth (ft)
1.3 = Safety factor to account for non-uniform flow distribution

General scour, Z_{gs}, is the component of scour that represents the mobile portion of the bed-material of the channel bottom. General scour was estimated using the following equation:

$$Z_{gs} = Y_{max}\ [(0.0685\ V_m^{0.8})/(Y_h^{0.4}\ S_e^{0.3})-1]$$

where:

Z_{gs} = General scour depth (ft)
V_m = Average velocity of flow at design discharge (ft/sec)
Y_{max} = Maximum depth of flow at design discharge (ft)
Y_h = Hydraulic depth of flow at design discharge, (ft)
S_e = Energy slope (ft/ft)

Where Z_{gs} was determined to be negative, the general scour component was assumed to be zero.

Anti-dune trough depth, Za, is the component of scour caused by movement of dune shaped bed forms along the bottom of the channel. The anti-dune trough depth was estimated using the following equation:

$$Z_a = 0.0137\ V^2_m$$

where:

V_m = Average velocity of flow at design discharge (ft/sec)

The anti-dune trough depth is limited to a maximum of ½ the flow depth. Given the low velocities predicted by the HEC-RAS model, anti-dunes are not expected to form a significant component of the total scour in the study reach.

Low-flow thalweg scour, Z_{lft}, occurs if a small channel forms to convey minor flows within the main channel of an over-widened stream. Typically, a low-flow thalweg forms on large streams with a high width to depth ratio and with mobile bed sediments, conditions which do not apply to the Jordan River study reach.

Bend scour, Z_{bs}, occurs on the outside of bends in a stream channel, and is caused by spiral transverse currents. Bend scour was estimated using the following equation:

$$Z_{bs} = 0.0685\ Y_{max}\ V_m^{0.8}\ Y_h^{-0.4}\ S_e^{-0.3}\ \{2.1\ [\sin^2(\alpha/2)/\cos\alpha]^{0.2} - 1\}$$

where:

Z_{bs} = Bend-scour component of total scour depth (ft), and
= 0 when $r_c/T > 10.0$, or $\alpha < 17.8^o$
= computed value when $0.5 < r_c/T < 10.0$, or $17.8^o < \alpha < 60^o$
= computed value when $\alpha = 60^o$ when $r_c/T < 0.5$, or $\alpha > 60^o$
Y_{max} = Maximum depth of flow immediately upstream of the bend (ft)
V_m = Average velocity of flow immediately upstream of the bend (ft/sec)
Y_h = Hydraulic depth of flow immediately upstream of the bend (ft)
S_e = Energy slope immediately upstream of the bend (ft/ft)
α = Angle formed by the projection of the channel centerline from the point of curvature to a point which meets a line tangent to the outer bank of the channel (degrees)
r_c = radius of curvature along centerline of channel (ft)
T = channel topwidth (ft)

The reach-averaged bend angle was computed from the arccosine of the reciprocal of the sinuosity. Because of this a bend scour is overestimated for straight section and may be underestimated at the tightest channel bends.

Local scour, Z_{ls}, occurs where there is an abrupt change in the direction of flow caused by obstructions such as bridge piers, abutments, or other structures. Local scour will occur at the three bridges in the study reach, as well as at future bridge crossings currently planned. However, since local scour at these structures occurs only at the bridge section, the local scour component was not included in the estimate of total scour for the reach.

Long-term scour, or aggradation and degradation, is best evaluated from historical evidence and field data. Historical evidence of long-term changes in channel bed elevation was discussed above in the longitudinal profile and cross section comparison analyses. Depending on the time scale considered, long-term scour can be the largest component of scour. For example, if sufficient time is allowed for the channel to achieve its equilibrium slope or to become armored, the long-term scour component could more than double the scour estimate.

Results. Scour estimates for the study reach obtained from the City of Tucson scour equations are summarized in Table 5-4. In general, the largest component of scour other than long-term scour is the bend scour. Given that the bend scour is limited to the outside of channel bends, the scour estimates listed in the first columns of Tables 5-4 are conservative when applied to the entire reach. General scour was calculated as a negative value, which the COT Manual dictates should be interpreted as a zero depth of scour. Local scour was estimated as zero for the study, since reach-averaged values for a local condition could not be justified. Thalweg scour was also estimated as zero because a low flow thalweg was not observed in the study reaches.

TABLE 5-4
Scour Estimates

Reach	Total Zt	General Zgs	Antidune Za	Bend Angle	Bend Zbs	Local Zls	Thalweg Zlft
Q100							
1	8.8	-2.8	0.6	48.2	6.5	0.0	0.0
2	8.1	-4.0	0.3	48.2	6.1	0.0	0.0
3	9.1	-4.0	0.4	48.2	6.8	0.0	0.0
Bankfull							
1	4.5	-2.1	0.3	48.2	3.3	0.0	0.0
2	4.5	-2.5	0.2	48.2	3.4	0.0	0.0
3	4.9	-2.8	0.2	48.2	3.6	0.0	0.0

Note: Long-term and local scour not included in estimate of total scour.

The scour estimates indicate that significant lowering of the channel bed can occur at bends. The bed scour has the potential to reduce bank stability and create local bank failures.

5.7 Armoring

When the channel sediment transport capacity exceeds the upstream sediment supply, the balance of the sediment load may be eroded from the channel bed, causing the channel to degrade. Because fine sediments can be transported at more frequent lower discharges and velocities than coarse sediments, which may require large floods to be moved, fine sediment tends to be preferentially removed from the channel bed. Selective removal of fine sediments causes channel bed material to become progressively coarser over time, as long as the upstream sediment supply is limited. If this process continues over a long period, it ultimately creates a surficial layer of coarse channel sediments, called an armor layer, that the stream is incapable of transporting (Yang, 1996).

Methodology. The BUREC (Pemberton and Lara, 1984) recommends the following methodologies for estimating the minimum sediment size and depth of scour required to form an armor layer for a given flow rate:

- Meyer-Peter, Muller Bedload Transport Function
- Competent Bottom Velocity
- Shields Diagram
- Yang Incipient Motion

Each of these methodologies was applied to the study reach.

Meyer-Peter, Muller Bedload Transport Function. The Meyer-Peter, Muller (1948) bedload sediment transport function for the beginning of transport of individual grain sizes can be used to estimate the non-transportable sediment size.

$$D_c = d\ S\ /\ (K_{mpm}\ (n/D_{90}^{(1/6)})^{3/2})$$

Where D_c = Non-transportable sediment diameter (mm)
d = Average flow depth (ft)
S = Energy slope (ft/ft)
K_{mpm} = 0.19
n = Manning's n for the stream bed
D_{90} = Particle size for which 90% of the bed material is finer (mm)

Competent Bottom Velocity. This methodology is based on the work of Mavis and Lushey (1948), who developed an equation for the beginning of sediment movement on a stream bed.

$$D_c = 1.88\ V_m^2$$

Where D_c = Armor size (mm)
V_m = Average channel velocity (ft/s)

Shields Diagram. The Shields (1936) diagram is a standard method used to define the initiation of motion for various channel bed sediment sizes. The method uses an iterative process to compute dimensionless shear stress (T*) and the armor diagram from the Shields diagram.

$$T_* = \tau_c\ /\ ((\gamma_s - \gamma_w)\ D_c)$$

Where T_* = Dimensionless shear stress
D_c = Armor size (mm)
τ_c = Critical shear stress (lb/ft^2)
γ_s = Specific weight of water = 62.4 lb/ft^3
γ_w = Specific weight of sediment = 165 lb/ft^3

Note that for gravel sediment sizes and turbulence levels typical in natural streams $T_* = 0.05$ for sediment sizes greater than 1 mm and Boundary Reynold's Number (R_*) > 500.

Yang Incipient Motion. Yang (1973) developed a relationship between dimensionless critical velocity (V_{cr}/w, where w = fall velocity, ft/s) and shear velocity Reynold's number R* at incipient motion. Under natural stream conditions for sediment sizes greater than 2 mm, Yang's equation can be written as follows:

$$D_c = 0.00659\ V_{cr}^2 \qquad \text{(For D > 2 mm)}$$

Where D_c = Armor size (ft)
V_{cr} = Critical average velocity at incipient motion (ft/s)

Depth to Armor Equation. Once the size of material (D_c) that will form an armor layer is estimated from one or more of the equations listed above, the depth of scour required to form a stable armor layer can be estimated from the sediment distribution of the channel bed material. The equation for the depth to armor is the following:

$$Y_d = y_a\,(1/\Delta p - 1)$$

Where Y_d = Depth from original streambed to the bottom of the armor layer (ft)
y_a = Thickness of the armor layer (ft)
Δp = Decimal percentage of the bed material larger than the armor size

Results. The armoring analysis results are summarized in Table 5-5. As can be seen from the data in Table 5-5, the bed materials are not large enough to form an armor layer in the upper reaches, but some limitation on scour is possible in reach 3 near the 9600 North Bridge.

TABLE 5-5
Armoring Analysis Results

Reach	Methodology - Critical Armor Diameter (mm)				Average Critical Diam. (mm)	Field D50 (mm)	Armor Layer Likely?	Depth to Armor (ft)
	MPM	CBV	Yang	Shield				
100-Year								
1	1.0	8.9	9.5	3.3	6	0.3	No	-
2	0.5	4.2	4.5	1.6	3	0.3	No	-
3	0.6	5.2	5.6	2.0	3	0.3	Possible	0.5
Bankfull								
1	0.6	3.9	4.1	1.8	3	0.3	No	-
2	0.3	2.3	2.5	1.1	2	0.3	No	-
3	0.3	2.3	2.4	1.0	2	0.3	Yes	0.2

MPM = Meyer-Peter, Muller
CBV = Competent Bottom Velocity
Yang = Yang's incipient motion
Shield = Shield Method

5.8 Summary

The bed elevation analysis indicates that the Jordan River study reach has experienced net degradation in the past twenty years, primarily in response to dredging of the river for flood control purposes. The profile data indicate that further degradation may be expected over the long-term, although some short-term aggradation may continue in the sag area upstream of 9600 North. A slight potential for armoring may exist in Reach 3, which may explain the lower rates of degradation observed in that reach. The total depth of long-term degradation is likely to be equivalent to the depth of the local base level lowering caused by the dredging, which was a maximum of about seven feet.

6.0 Sediment Transport Analysis

The sediment transport analysis was conducted to predict the long-term stream profile response, by considering the following:

- Sediment Supply
- Sediment Continuity

The sediment transport analysis was conducted using reach-averaged hydraulic parameters for the 100-year and bankfull flow conditions.

6.1 Sediment Supply

Utah Lake captures and stores the vast majority of the sediment supply derived from the Jordan River watershed. It is unlikely that any sediment other than the dissolved load and a portion of the wash load is conveyed from the lake to the Jordan River. Furthermore, agricultural and urban development of the tributary areas downstream of Utah Lake as well as the wetland buffer areas prevent most of any natural sediment supply from reaching the main channel in the study reach. Therefore, the majority of the sediment supply in the study reach is derived from erosion of the channel bed and banks. Given the low flow velocities, low channel slopes, and dense bank vegetative cover will limit the available supply and transport of material eroded from the channel margins.

6.2 Sediment Continuity Analysis

A sediment continuity analysis was conducted using the Zeller-Fullerton Equation (ADWR, 1985), which is a combination of the Meyer-Peter, Muller bedload transport function with Einstein's integration of the suspended bed-material discharge relationship. The Zeller-Fullerton Equation is a total bed-material discharge equation developed for sand-bed channels, and is formulated as follows:

$$Q_s = 0.0064\, n^{1.77}\, V^{4.32}\, G^{0.45}\, Y_h^{-0.30}\, D_{50}^{-0.61}$$

Where:
Q_s = sediment discharge rate (cfs)
n = Manning's roughness coefficient, channel
V = mean channel velocity (ft/s)
G = gradation coefficient
Y_h = hydraulic depth, channel (ft)
D_{50} = median bed sediment size (mm)

The change in sediment transport capacity between adjacent reaches was estimated by subtracting the sediment inflow rate from the sediment outflow rate (i.e., continuity) to determine if a net sediment deficit or net sediment surplus was likely. A sediment deficit (i.e., more sediment leaving a reach than entering a reach) translates to potential scour and degradation. A sediment surplus (i.e., more sediment entering a reach than leaving a reach) translates to potential deposition and aggradation. Sediment continuity was estimated using the continuity equation:

$$\text{Sediment}_{\text{(in)}} - \text{Sediment}_{\text{(out)}} = \text{Change in Sediment Storage}$$

The volume of the change in sediment storage at each cross section was then applied over the distance between the cross sections using the average channel width (i.e., channel area) to estimate the vertical change in bed elevation equivalent to the sediment flux volume. The procedure described above is similar to the HEC-6 modeling algorithm, except that only the peak discharges, rather the entire hydrograph, were evaluated for this analysis. The vertical bed elevation changes reported are not intended to depict actual changes in bed elevation. Instead, they are intended to illustrate the expected direction of channel change (scour or deposition) so that trends in expected channel behavior can be identified.

Results. Sediment continuity principles dictate that if less sediment is supplied to a reach than can be transported out of the reach, erosion will occur and the stream will degrade, widen, or meander. Conversely, if more sediment is supplied than can be transported, the excess will be deposited and the stream will aggrade and become braided or anastomosing. Sediment supply from a watershed can be disturbed by construction of bank protection, paving of natural surfaces, or conversion of natural landscapes to irrigated turf. The time it takes for a channel to respond to such disturbances depends on the frequency of runoff, the magnitude and duration of floods, and the degree of disturbance. The sediment continuity analysis results are shown in Table 6-1.

TABLE 6-1
Sediment Continuity Analysis Results

Reach	**Sediment Transport Rate**		**Bed Elevation Change (ft/day)**
	CFS	**Tons/Day**	
100-Year			
1	0.095	422	-
2	0.031	138	+0.0023
3	0.034	153	-0.0001
Downstream 9600 N	0.037	163	-0.0004
Bankfull			
1	0.018	80	-
2	0.008	35	0.0004
3	0.006	27	0.0001
Downstream 9600 N	0.009	39	-0.0001

The following conclusions can be drawn from the sediment continuity analysis results:

- Transport Rate. Very low concentrations of sediment are transported by the Jordan River, even during peak flow rates. This finding is consistent with field observations and velocity measurements.
- Sediment Continuity. Relative differences in transport rate appear significant when only magnitude is considered, but are trivial when applied over the reach length. The sediment surplus or deficits would result in minute fractions of a foot of elevation change, even if peak flow rates persist for an entire year.
- Net Aggradation. At bankfull flow, net aggradation is predicted for most of the study reach. The river changes to a deficit condition with net degradation downstream of 9600 North.

6.3 Summary

The sediment transport analysis indicates that the Jordan River study reach is a supply limited stream due to its position as an outlet from a large lake, flat slope and disrupted tributary network. Sediment transport capacity appears to decrease in the downstream direction within the study reach and increases downstream of 9600 North.

7.0 Lateral Migration Analysis

A primary objective of the Jordan River Corridor Preservation Study is to identify a lateral erosion hazard zone. The potential for future lateral erosion along the study reach was assessed by considering the results of the analyses summarized in Chapters 3, 4, 5, and 6, and by considering the following types of evidence of historical lateral movement:

- Channel Width Change
- Channel Pattern Change
- Channel Responses to Flooding
- Channel Cross Section Change

Measurements of historical channel movement examined within an appropriate geomorphic context are the most reliable tool for predicting future channel movement and defining lateral erosion hazards. This chapter describes the types of historical measurements available for the study reach and documents how these data were used to define the recommended erosion hazard zone for the study reach.

7.1 Historical Channel Position Data

Historic channel position information can be quantified to determine the magnitude and frequency of past river movement. This historical information can then be extrapolated to predict future channel change. To identify historical lateral migration trends for the study reach, historical mapping and aerial photography were obtained dating back to 1856. For each year of map or aerial coverage, bank lines were digitized in the project GIS. Bank lines were defined on the aerial photographs as the point where the bank slope met the water surface. For the 1985 flood photo coverage, the bank lines were defined as the top of the banks visible within the flood waters. The 1985 area of inundation was also delineated to determine channel behavior when the banks are overtopped. The 1975 and 1980 aerials were available only as blue-line drawings, which were of lower quality than the photography for other years of coverage. For the 1975 and 1980 coverage, the bank lines were drawn by hand on the blue-lines, which were then scanned and semi-rectified. The 1985 and 1988 false color aerials depict flood and post-flood river conditions. Side-by-side plots of the aerials for the study reach shown at an identical scale for each year of coverage are provided in Figure 7-1.

Once channel bank lines were digitized for each year of coverage, changes in channel position, channel width, and channel pattern could be measured and quantified. Figure 7-2 is a plot showing the digitized bank positions for every year of coverage. There are several potential sources of error in the methodology used to identify and compare channel positions. First, some of the traditional map-scale-accuracy issues are overcome by working in a digital GIS environment where the mapper can zoom in to relatively small scales. The scale issue then becomes a photograph resolution issue as the aerials tend become blurrier and more pixilated at smaller scales. The scale issue does affect the delineation in that the width of the digitized bank line, when presented as a report exhibit, has a finite width. At the scale used in Figures 7-2, the line has a width of about 30 feet. Therefore, the delineations shown in Figure 7-2 are accurate to about ±30 feet. Second, bank vegetation obscured the bank location in some places. Therefore, the bank line delineations may be no more accurate than the width of the swath of bank vegetation, which varied from about 10 to 30 feet. Third, the rectification process is not able to move all differences in the source material orientation, skew and shape. This inaccuracy is apparent where the bank lines are displayed nearly parallel but slightly offset from the other years of coverage. This source of potential measurement error can be addressed by careful interpretation of the delineations and understanding of the nature of river movement. Finally, the bank line delineation used the water-ground contact as a proxy for the bank location since the top of bank cannot be identified without topographic mapping. Therefore, differences in water surface elevation alone would result in slightly different “bank” positions even without lateral migration of the channel. Based on these potential sources of error, we assume that the bank line delineations are accurate to about ±50 feet.

FIGURE 7-1

Side by Side Comparisons of the Jordan River, 1856-2004

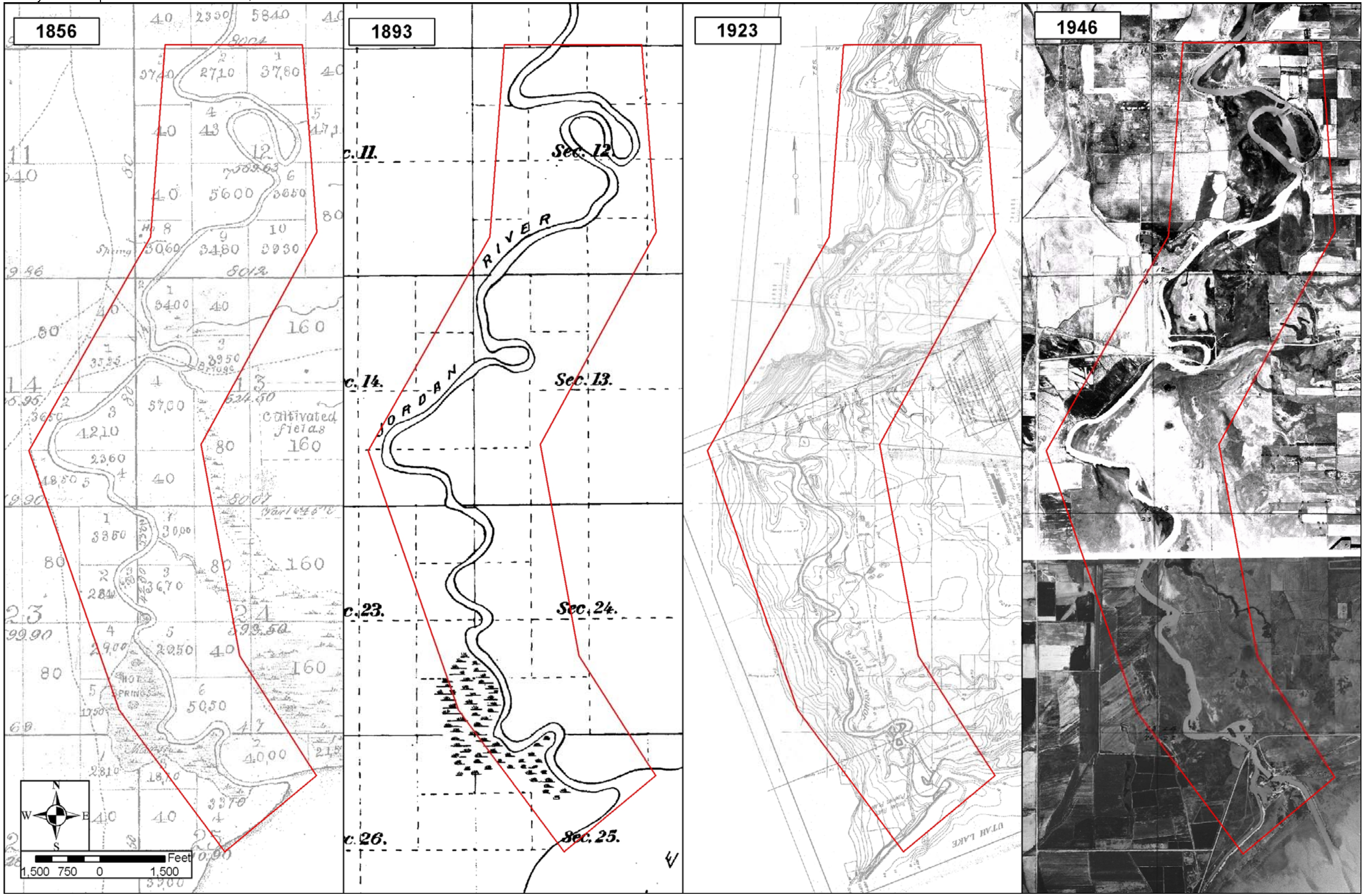


FIGURE 7-1 (CONTINUED)
Side by Side Comparisons of the Jordan River, 1856-2004

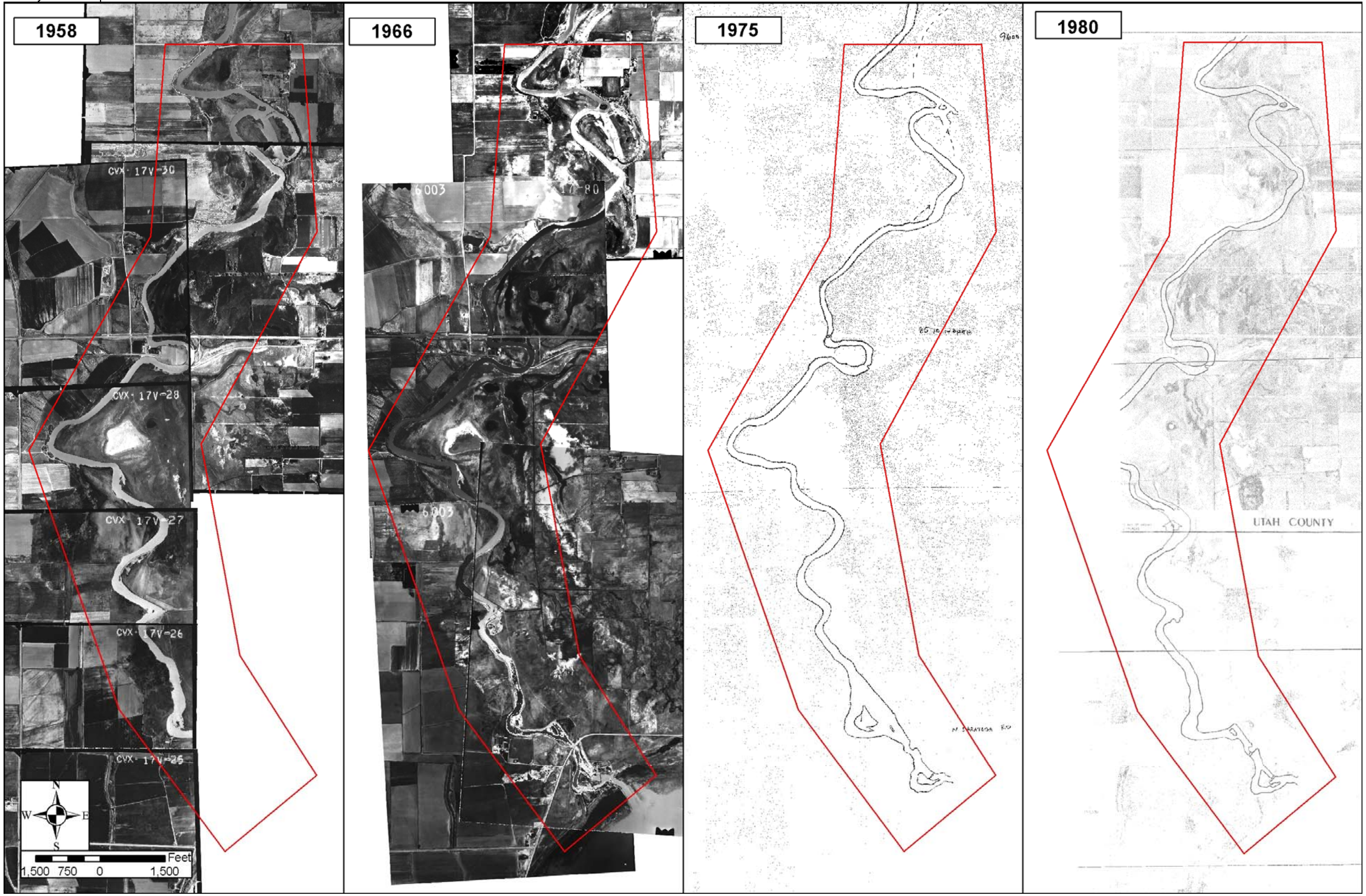


FIGURE 7-2
Bank Line Locations for All Years of Map-Photographic Coverage, 1856-2004, for the Study Reach

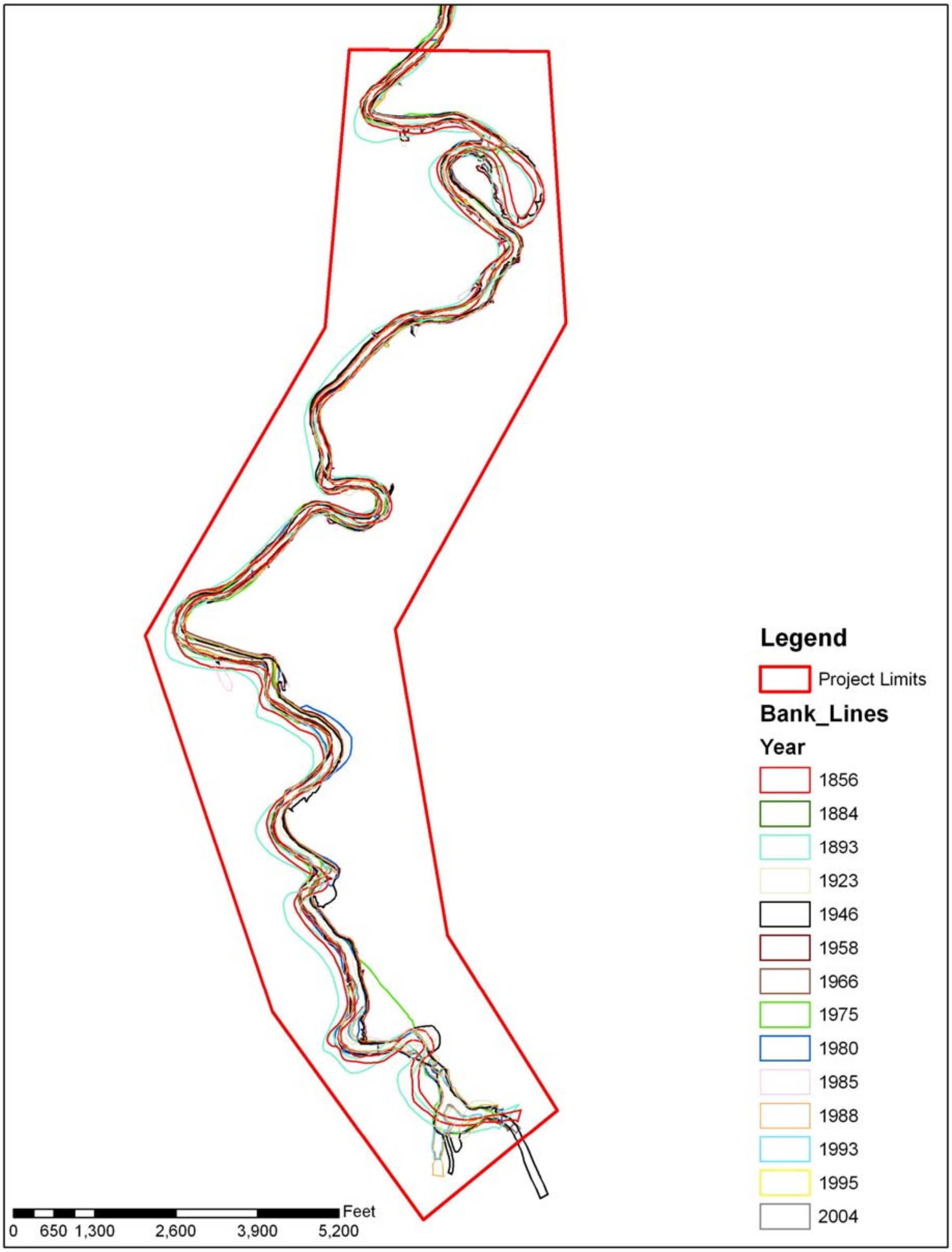
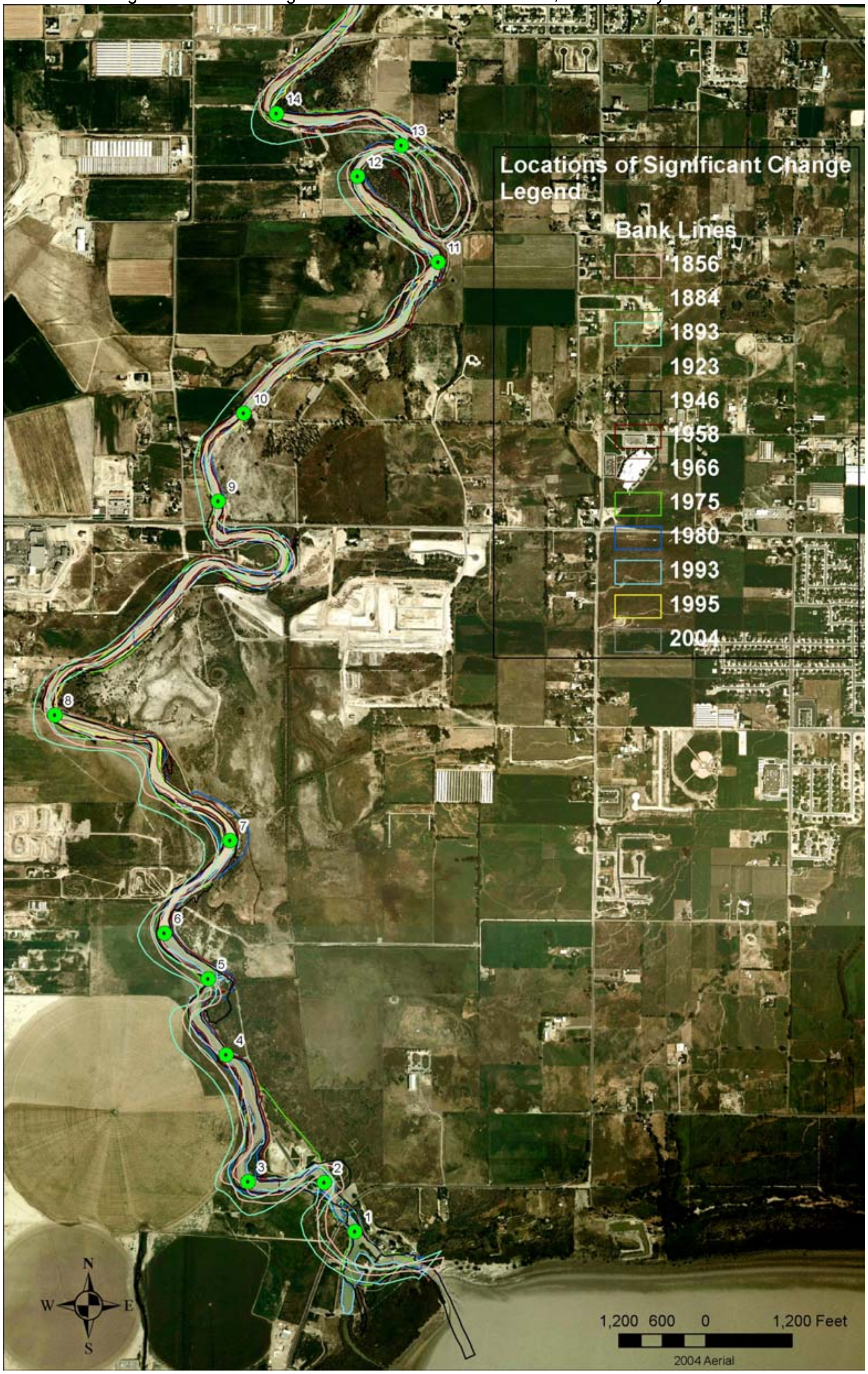


FIGURE 7-3
Locations of Significant Lateral Migration Between 1856 and 2004, Indicated by Green Markers



7.2 Channel Position Change

A plot of bank line position for each year of coverage is shown in Figure 7-2. Overall, there is a surprising degree of consistency in channel location, given that the bank materials are marginally erosive, that there has been recent long-term degradation, the stream classification and pattern, and that the record includes a period of prolonged high magnitude flooding. Except at the meander just upstream of 9600 North, the study reach did not exhibit any significant meander migration, widening or lateral erosion. Given that 150 years of record were available, the lack of channel change is surprising, especially given the scale of channel change observed on the lower Jordan River in Salt Lake County. In most places, the measured change in the delineated bank position can be attributed to map rectification or is within the assumed accuracy of measurement. Even after the major flooding in the 1980's, the channel remained essentially unchanged.

Table 7-1 shows points of the largest measured differences in channel position during the period of record. The measurements reported in Table 7-1 do not account for potential rectification errors. As shown in Table 7-1, neglecting man-made channel change, rectification and map accuracy issues, and the meander cutoff at 9600 North, the historical record indicates that the greatest channel movement was measured at channel bends. Interestingly, both meander cutoffs were reoccupied by the floods in the 1980's.

TABLE 7-1
Largest Measured Changes in Lateral Channel Position for Total Period of Record

Site ID	Time Period of Largest Movement	Largest Measured Channel Movement (ft)	Notes
14	1893-1980	380	Point on meander bend
13	1856-2004	1530	Measurement reflects meander cutoff
12	1893-1988	240	Point on meander bend
11	1893-1958	250	Point on meander bend
10	1893-1923	200	GLO data not on section line, map accuracy issue
9	1856-1893	200	GLO data not on section line, map accuracy issue
8	1893-1966	360	May be rectification issue, not lateral movement
7	1893-1923	350	Points are on meander bends
6	1893-1923	330	Point on meander bend
5	1893-1923	400	Point on meander bend
4	1893-2004	320	Flood erosion circa 1946
3	1893-1975	1200	Measurement reflects meander cutoff
2	1923-1946	490	Measurement reflects human activity - channelization
1	1893-1923	650	Measurement reflects human activity - channelization

NOTE: See Figure 7-3 for Site ID locations (measurement points).

Maximum changes in channel bank line position were also measured between sequential years of historical aerial photograph and map coverage, as shown in Table 7-2. In most years, the maximum movement was less than the assumed measurement accuracy. The higher movement values indicated for the earliest years of coverage can be attributed to poor map accuracy between Township Section lines.

TABLE 7-2
Channel Change Between Years of Aerial Coverage

Site ID	1856 - 1893	1893 - 1923	1923 - 1946	1946 - 1958	1958 - 1966	1966 - 1975	1975 - 1980	1980 - 1985	1985 - 1988	1988 - 1993	1993 - 2004
14	270	285	65	20	20	65	80	40	30	30	25
13	30	150	130	90	1280	290	280	1300	1360	30	170
12	130	180	80	15	15	10	60	40	40	20	15
11	100	210	20	25	10	70	45	30	30	30	15
10	180	200	60	25	30	35	30	40	20	20	25
9	200	180	25	25	10	20	40	30	30	20	10
8	240	-	-	10	75	95	-	-	20	20	10
7	160	350	75	10	25	55	40	150	10	20	15
6	200	330	70	25	35	25	30	30	10	40	10
5	175	400	195	40	150	153	300	30	100	100	60
4	175	305	70	30	15	35	10	24	70	20	10
3	145	360	70	40	30	825	860	150	220	50	30
2	185	350	490	-	-	20	90	100	90	20	40
1	110	650	40	-	-	30	25	25	40	60	20

7.3 Channel Width Change

As shown by the bank line plots in Figure 7-2, only minimal changes in channel width occurred during the 150 year period of record. Where channel movement is implied by the bank line position plots, the channel width is unchanged. That is, if the channel moved, it did not move by widening, but rather by shifting its position. Therefore, the historical data indicate that the width of the Jordan River study reach channel has been stable and apparently is adequate to convey a range of flows.

7.3.1 Channel Pattern Change

No change of channel pattern was observed during the 150 year period of record, as indicated by the channel bank line plots in Figure 7-2. As indicated by the geomorphic analysis summarized in Chapter 3, the Jordan River plots strongly within the meander pattern zone. No future change in channel pattern is anticipated.

7.3.2 Changes in Response to Flood

The Jordan River floods in the 1980's were unprecedented in magnitude and duration. Flood stages persisted for several years in response to water levels above the Compromise Elevation in Utah Lake. In the lower Jordan River in Salt Lake County, the prolonged flood stage caused massive lateral erosion and flood damages. In the Jordan River study reach in Utah County, the aerial photographs indicate that while prolonged flood stages occurred, the river essentially returned to its pre-flood configuration. Most of the modern geologic floodplain was inundated, but the main channel appeared to convey flooding effectively without significant changes in width, planform, sinuosity or location.

7.3.3 Cross Section Change

Historical change in channel cross section geometry was discussed in Chapter 5 using data from 1985 to the present. The data indicated minor widening and degradation at several cross sections upstream of State Route 73 and slight aggradation downstream of State Route 73. The observed cross section change can be attributed to dredging or a response to dredging in the 1980's. Overall, the degree of cross section change is minor.

7.3.4 Potential Lateral Erosion From Expected Vertical Change

The bed elevation analysis presented in Chapter 5 indicated a potential for continued long-term degradation in the study reach. The scale of expected degradation is not significant relative the scale of incision observed on other river systems in more arid parts of Utah. As the expected degradation occurs, the following impacts on lateral stability can be expected:

- Bank Failures. Undercutting and loss of basal support appears to be primary mechanism for bank failures in the study reach. Continued degradation will increase the potential for local bank failures. Bank failures have not significantly widened the river or led to increased rates of lateral erosion.

- Bank Vegetation. Undercutting from degradation may lead to increased loss of bank vegetation and riparian habitat.

In general, the scale of expected degradation is not likely to significantly impact lateral migration except at localized bank failure points.

7.3.5 Lateral Erosion Hazard Zone Delineation

Erosion hazard boundaries for the Jordan River study reach were identified based on the results of the geomorphic, historical and engineering analyses of lateral stability presented in this report. The following types of information were considered in defining the erosion hazard boundaries:

- Field Data
- Stream Classification
- Historical Channel Changes
- Geomorphic Mapping
- Longitudinal Profile Analysis
- Regime Equations
- Expected Channel Pattern
- Allowable Velocity

- Equilibrium Channel Slope
- Armoring Potential
- Sediment Continuity Modeling

The paragraphs below describe how those data were summarized into a single map element which was used to generate the erosion hazard zone map.

Field Data. Field data were described in Chapter 3. At each field section, and at significant points between sections, the relative bank stability was assessed, evidence of past erosion was documented, and the likelihood of future erosion was predicted. Field data were also used to identify reaches of historically recent scour and degradation, as well as to identify actively eroding areas outside the main channel. Based on the field observations, the right and left primary channel banks were classified as either stable or unstable. Field data indicated that local bank failures from undercutting or oversteepening of the banks were common, that bank vegetation did not prevent bank failures, and that the bank materials were not sufficiently cohesive to fully resist lateral erosion. A conservative stable bank slope of 4:1, based on field evidence, was used to define a minimum erosion setback from the toe of the projected future bank location.

Stream Classification. Stream classification data were described in Chapter 4. Based on the stream classification methodologies, expected channel processes identified included high rates of lateral migration by meandering. In general, field observations and historical evidence contradict the expected behavior based on the classification. In addition, the meander pattern was used to define a belt width for the river in which lateral movement may be expected.

Historical Channel Changes. Mapping of historical channel movement was described in Chapter 7 above. The maximum measured channel movement within the 150 year period of record was used as a guideline for delineating predicted erosion distances. Figure 7-2 shows the bank line positions for the 150 years (1856 to 2004) of historical aerial coverage. The historical bank line positions roughly define a corridor that was used as starting point for the hazard zone delineation. Neglecting meander cutoffs, maximum historical movement between years of coverage was typically much less than 150 feet, and averaged less than 50 feet.

Geomorphic Mapping. The geomorphic mapping was described in Chapter 4. The modern geologic floodplain represents the expected maximum extent of lateral erosion during large floods and over very long time periods. Geomorphic map data were useful for distinguishing areas of active and inactive channel movement, and for constraining the maximum and minimum rates of channel movement. Interpretation of the reach geomorphology was used to identify potential meander cutoff paths, pre-historical meander paths that could be re-occupied, and expected future channel movement trends. The older, higher geomorphic surfaces are somewhat more resistant than the younger surfaces in the modern geologic floodplain. Therefore, preferential erosion of the younger surfaces is expected.

Longitudinal Profile. The longitudinal profile analysis was presented in Chapter 5. Longitudinal profiles derived from recent and historical topographic maps were compared to identify reaches of historical degradation, and expected future degradation or aggradation. Potential aggradation reaches are expected to expand their floodplain over time. Degrading reaches are subject to local bank failures.

Regime Equations. Regime equations for expected channel geometry and channel pattern were described in Chapter 4. Regime relationships for channel width were applied to the study reach using the bankfull and 100-year peak discharges to estimate the expected direction and possible magnitude of channel adjustment to flood flows. Based on these equations, channel widening due to regime adjustment is not expected in the study reach.

Expected Channel Pattern. Channel pattern analysis was described in Chapter 4. Published data relating expected channel pattern (meandering) to channel slope, mean annual discharge, and/or the mean annual flood were used to predict the equilibrium channel pattern at each cross section in the study reach. The existing channel pattern was then compared to the predicted channel pattern and the anomalies were noted on the orthorectified aerial photographs. The expected and existing channel pattern in the study area is a meandering channel. Given the meandering channel pattern, the erosion hazard zone is wider along the outside of meander bends than on the inside of bends. However, the meander belt width was considered when defining the erosion zone between adjacent bends.

Allowable Velocity. Allowable velocity analyses were described in Chapter 4. Published values of non-erosive velocities were compared to existing channel velocities computed by HEC-RAS modeling. The analyses indicated that bank materials are marginally erodible at peak flow rates and that overbank flows have only limited velocities. Overbank areas within the geologic floodplain are subject primarily to flood inundation hazards, rather than avulsive or erosion hazards.

Equilibrium Slope. Equilibrium slope calculations were described in Chapter 5. The equilibrium channel slope was predicted based on channel hydraulics, bed sediment characteristics, empirical data, and discharge. Reaches expected to experience long-term degradation are more likely to experience lateral erosion due to undercutting. Aggrading reaches are more likely to experience avulsive channel changes. The equilibrium slope results predict only minor slope adjustments, with some potential aggradation in the flattened reach above 9600 North.

Armoring. The channel bed armoring analysis was presented in Chapter 5. Bed armoring was computed using the sediment distribution of the bed material, HEC-RAS hydraulic data, and flood discharge estimates. Armoring can prevent general and long-term scour, and limit undercutting of the banks. However, armoring of the bed could lead to preferential erosion of the banks for reaches with a sediment deficit relative to the transport capacity. The reach closest to 9600 North has a slight potential for armoring.

Sediment Continuity Modeling. Sediment continuity routing was performed using reach-averaged hydraulic data. The computed sediment deficit (scour) or surplus (deposition) was divided by the average bank height and the reach length to estimate the relative magnitude of bed elevation change. The low computed rates of sediment supply and sediment transport indicate that lateral erosion due to sediment transport will be minimal.

Appendix B includes a cursory summary of public records identifying properties included within the erosion hazard zone.

7.4 Summary

The recommended Jordan River erosion hazard zone, based on the information summarized previously, is shown in Figure 7-4. The erosion hazard zone represents the areas with some risk of future damage to structures. Erosion damage may be the result of lateral channel migration, channel widening, bank failures, floods, and normal flow conditions over a long planning period. Structures within the erosion hazard zone require either erosion protection or more detailed site-specific evaluation. While structures located outside the erosion hazard zone are considered reasonably safe from riverine erosion, they are not free of risk. Changing conditions and/or catastrophic events could alter the erosion hazard zone in the future. Definition of the erosion zone boundary was based to some degree on judgment and experience, particularly where the factors considered indicating conflicting trends. No one factor, of those listed in this Chapter, could be considered as the primary basis for defining the erosion zone boundary. All of the factors were considered together. Given the uncertainty in predicting future river behavior, as well as the potential for catastrophic damage due to riverine erosion, application of a safety factor is warranted when determining erosion hazard setbacks.

The erosion hazard zones reflects the data available at the time of the study, the accuracy of the FIS hydraulic modeling, as well as the historical record of channel change in the study reach. If reach conditions change significantly in the future due to floods, drought, land use, or human activities in or along the river, revision of the erosion hazard zone delineation may be warranted.

FIGURE 7-4
Recommended Erosion Hazard Zone for the Jordan River Study Reach

8.0 River Management Guidelines

The erosion hazard zone (EHZ) delineation is one element of an effective river management plan. Other elements include floodplain management, recreation and open space, wildlife habitat, water quality, and land use planning. A brief outline of general river management guidelines relating the erosion hazard zone delineation area is provided in this chapter.

Management of rivers is complex. Rivers do not adhere to political jurisdictions or respect property lines. Nature has a way of following its own rules. Even if the natural river system could be completely and perfectly understood (which it can’t), the future distribution of floods, droughts and sediment supply cannot be known with certainty. Furthermore, changes in the watershed, occurrences of wild fire, introduction or remediation of invasive plant species, changes in water supply agreements, changes in the regulatory environment, and other factors may have profound impacts on the behavior of a river system. Because the Jordan River is no longer a pristine natural river system due to water supply practices and development within its geologic floodplain, management of the river is even more complex.

The possible range of river management schemes reflects the broad spectrum of political, environmental, and economic philosophies of the agencies and people who care about the Jordan River. At one end of the spectrum, a possible management strategy would be to remove all non-natural influences on the river and return it to pre-development natural condition. At the opposite end of the spectrum would be constructing an engineered channel to control flooding and erosion, while maximizing the amount of developable land. Within that wide spectrum is an infinite number of possible approaches. Similarly, with respect to management of erosion hazards, the erosion hazard zone delineation could be implemented simply as a warning to future developers and land owners to account for riverine erosion is design of their facilities. Alternatively, the erosion hazard zone delineation could be managed as a no-build zone to remain as a “natural” corridor in perpetuity.

Selection of the most appropriate river management strategy should be done with stakeholder input, coordination with regulatory agencies and community groups, and ample opportunity for discussion in public forums. Some possible alternatives for consideration in this process are provided in this chapter.

8.1 General Recommendations

The following general recommendations are suggested for potential inclusion in a river management plan:

- Neighbor Communities. River management plans are most effective with all communities along the river corridor adopt the same plan. The City of Lehi and Utah County should be included in the planning effort. Input from both entities was solicited as part of this report.
- Agency Support. The Jordan River Natural Area Forum should be included in development of the management plan. Input from several state and federal agencies was included in this final report.

- Floodplain Revision. Where structural measures are proposed, the FEMA Flood Insurance Study maps should be revised to reflect existing conditions. Cursory review of the existing floodplain delineation maps indicates that new modeling tools may produce more reasonable depictions of the actual flood hazard.
- Monitoring & Inspection. The management plan should include regular inspection and monitoring of the river bank position and condition, and survey of index cross sections and bed elevations. The inspection results will serve as a baseline from which to measure change as well as the success of the adopted management plan.
- Access. The City should require maintenance and emergency access to top of the existing main banks so that erosion protection measures can be implemented if needed during or after erosive floods.
- Additional Studies. The following additional technical analyses would complement the existing stability study:
    - Hydrology – Frequency Data. Establish flow frequency data, particularly for more frequent floods.
    - Hydrologic Impacts. Assess the hydrologic impact of on-going and/or projected future encroachment of the geologic floodplain on downstream peak flow.
    - Floodplain Delineation. Two-dimensional modeling of overbank flow to better establish floodplain flow rates, depths and velocities.

8.1.1 Erosion Hazard Zone

The recommended erosion hazard zone for the study reach may be incorporated into a river management plan in the following ways:

- Erosion Hazard Zone Boundary. The erosion hazard zone delineation should be formally adopted as a regulatory tool by the City.
- Floodplain Ordinance. The floodplain ordinance should be amended to address management of activities within the erosion hazard zone.
- Erosion Hazard Zone Restrictions. The following management guidelines are recommended for development within the erosion hazard zone:
    - Construction of habitable structures, as defined by FEMA, within the EHZ is discouraged but not prohibited.
    - All development within the EHZ should be protected from erosion damage by measures designed by a registered professional engineer.
    - A list of allowed or preferred land uses in the EHZ, such as grazing, agriculture, parks, golf course, etc. should be adopted by the City.
- Erosion Hazard Zone Revisions. Guidelines for the types of analyses needed to amend or revised the EHZ should be adopted by the City.

8.1.2 Potential Urbanization & Development Impacts

The probable outcome of urbanization and continued development in the watershed and river corridor is increased storm water discharge, decreased sediment supply, damaged riparian vegetation, and continued floodplain encroachment. The net effect of these types of changes is to increase scour and erosion. Therefore, continued stress on the river environment should be expected in the future. The following specific development types are discussed:

- Bikeway Trail. The bikeway trail is located with the erosion hazard zone and is likely to experience periodic local damage due to lateral erosion and bank failures. Per County personnel, this bikeway is not an engineered facility designed for flood or erosion control, and will not be managed as such.

- Storm Water Outfalls. Minor scour problems were noted at most of the storm water outfalls that discharge to the Jordan River. Design of future outfalls should consider scour protection and maintenance needs.

- Bridge Crossings. Bridge crossings can impact the river by preventing effective flow on the floodplain, and can in turn be impacted by lateral movement and scour along the river. Specific design recommendations for river crossings are provided below.

- Utility Crossings. Utility crossing impact the river, or are impacted by it, where structural elements are placed too close the banks or not buried sufficiently below the long-term scour depth. Specific design recommendations for river crossings are provided below.

- Future Dredging. Dredging has significant impacts on river morphology and can adversely impact existing bridges, utility crossings, riverfront property, or riparian and aquatic habitat. Past dredging appears to have increased the long-term degradation hazard in the study reach. Opportunities for a more natural, sustainable dredged channel section should be considered as part of future dredging designs. A sustainable channel section would include a connection to the floodplain and a non-prismatic cross section.

- Encroachment. Encroachment into the floodplain increases flood peaks by reducing floodplain storage, increases flow velocities by narrowing the floodplain, and has the potential to induce erosion by deflecting flow and removing natural erosion barriers.

8.1.3 Bank Stabilization Measures

Development within the erosion hazard zone should be protected by engineered channel stabilization measures. Such measures could include hard structural features like concrete, rip rap, geotechnical materials, or gabions. The measures could also include bioengineering techniques that use natural materials and harness natural river processes. The following recommendations and design guidelines for bank stabilization measures are proposed:

- No Adverse Impact. Development within the erosion hazard zone should positively demonstrate no adverse impact on any adjacent property. Engineering analyses should be required to demonstrate no adverse impact on hydraulic, hydrologic and scour/erosion conditions on neighboring parcels.

- Replace Bank Vegetation. In general, bank and floodplain vegetation disturbed by construction should be replaced or enhanced with acceptable species.

- Bank Slope. Vertical or steep channel banks should be regraded to flatter, more stable slopes. In general, bank slopes of 2.5:1 or flatter are stable and support vegetative growth.
- Toe-Down. Structural measures should be adequately toed-down below the design scour depth, which should include consideration of the long-term scour depth. Alternatively, grade control can be provided to limit long-term scour.
- Overtopping. Bank stabilization measures that do not contain the 100-year flood should be design to withstand overtopping as well as flow on the lee side.
- Bioengineering. Toe protection may be required to assure proper function of bioengineered bank stabilization measures, given the potential for toe erosion-induced bank failures in the study reach.

8.1.4 River Crossing Design Guidelines

The following general design guidelines—as well as applicable federal, state, and local requirements—are recommended for future river crossings, such as bridges and utilities.

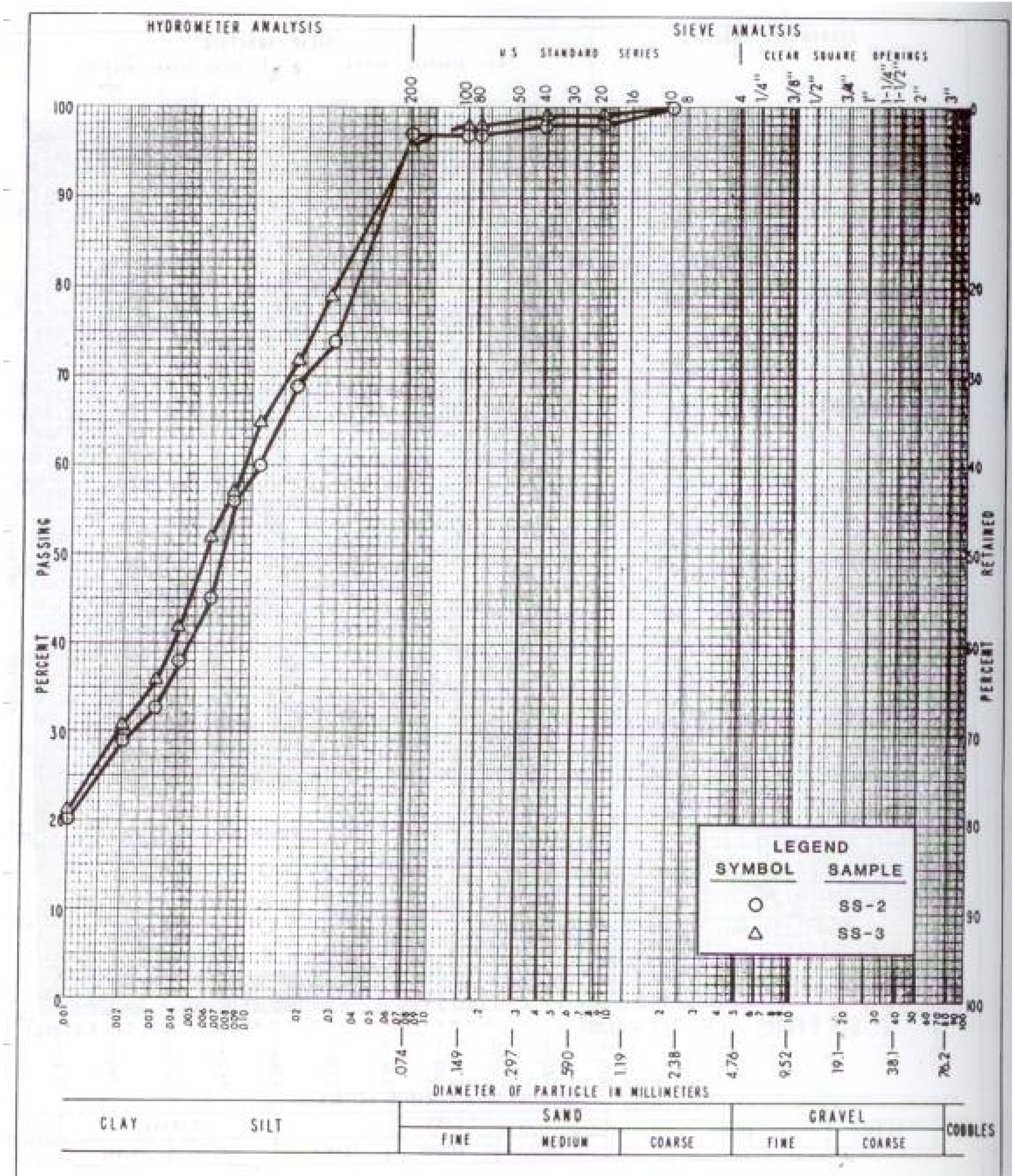
- Span. Bridges and overhead utilities should span the main channel wherever possible. It is not necessary to span the erosion hazard zone. However, structural elements such as road approaches or utility poles located within the erosion hazard zone should be protected from scour or plans for replacement and maintenance should be incorporated into the design.
- Acceptable Level of Impact. Designs that do not impact the 10-year depth, velocity, water surface, and channel section generally have minimal impact on the river or adjacent parcels, especially where any changes in the 100-year values change by less than 10%.
- Buried Crossings. Utilities and underground crossings should be buried below the 100-year scour depth, including long-term scour. The channel burial depth should be maintained across the entire erosion hazard zone, or structural erosion protection should be provided and the crossing designed to withstand hydraulic forces if exposed by lateral erosion.
- Alignment. Bridge crossings should be located on straight channel segments, rather than on bends, and should be oriented perpendicular to flow wherever possible

APPENDIX A

Sediment Size Distribution Plots

Sediment Size Distribution Plots for Each Boring Site

Boring Site B-23



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422.

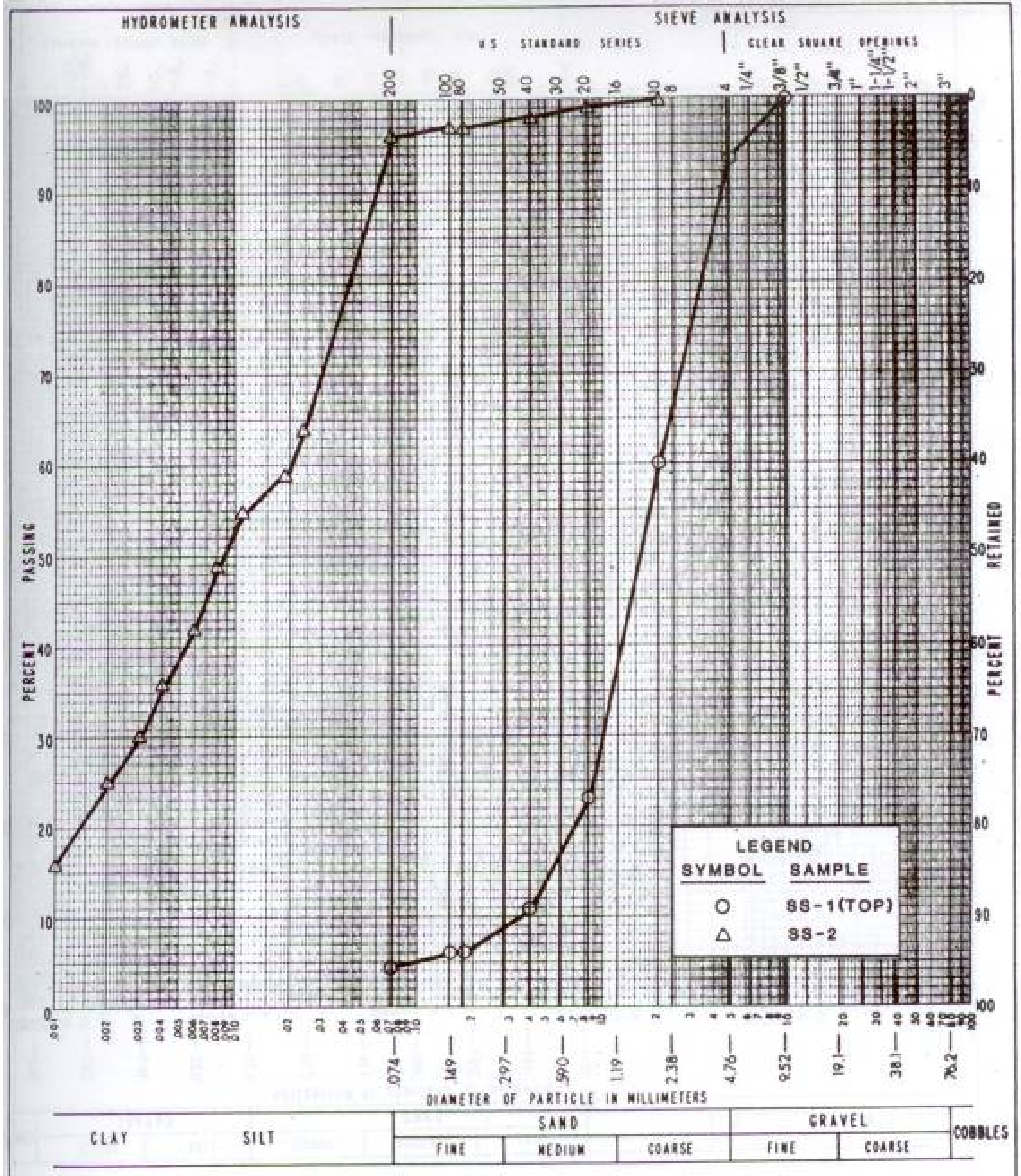
FIGURE 32
PARTICLE – SIZE ANALYSES
BORING B-23

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

B18331.D1

Boring Site B-24



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

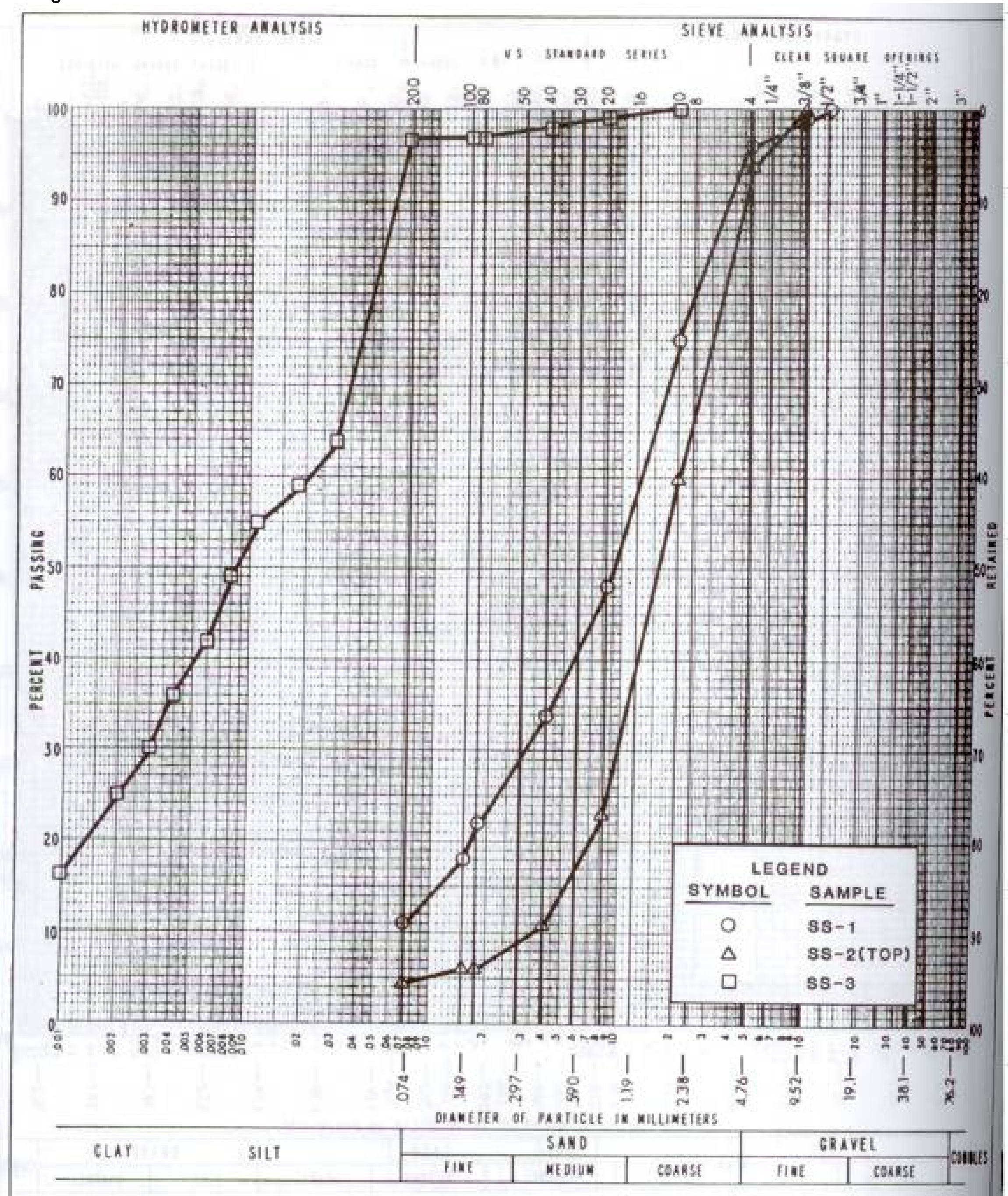
FIGURE 33
PARTICLE - SIZE ANALYSES
BORING B-24

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

B18331.D1

Boring Site B-25



NOTE:

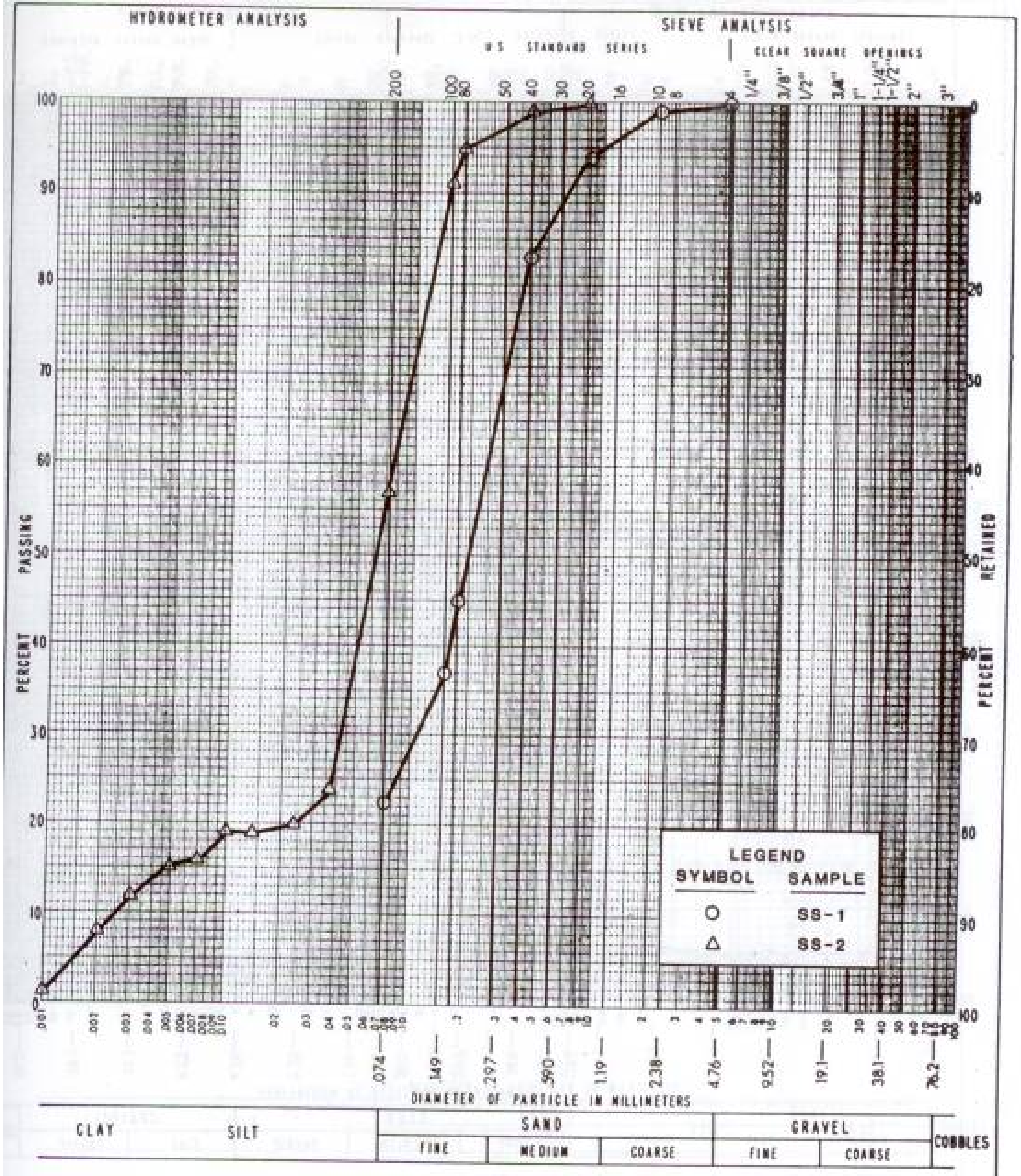
TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 34
PARTICLE – SIZE ANALYSES
BORING B-25

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

B18331.D1

Boring Site B-26



NOTE:

TESTS WERE PERFORMED IN
ACCORDANCE WITH ASTM D422
AND D1140.

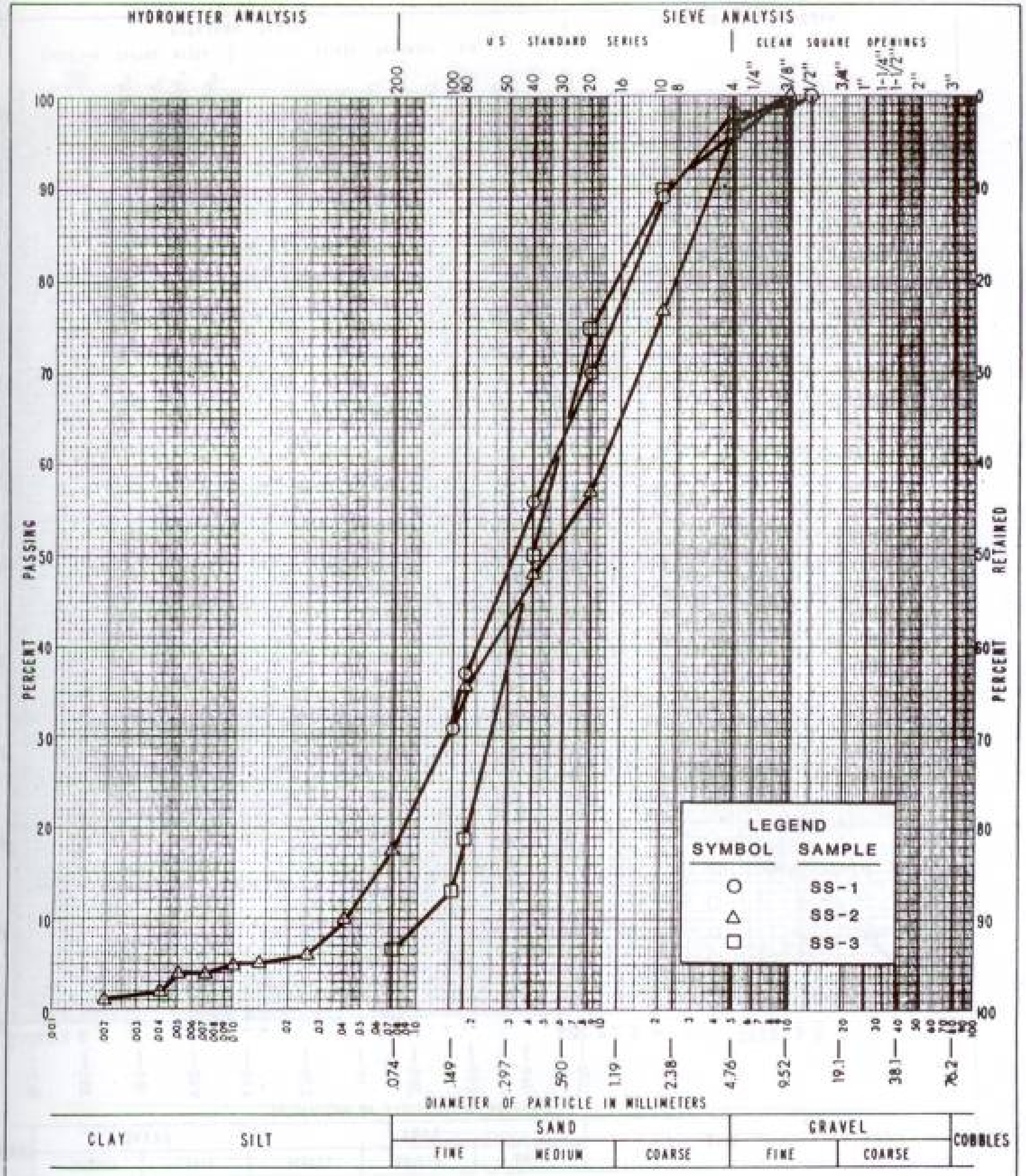
FIGURE 35
PARTICLE - SIZE ANALYSES
BORING B-26

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

18331.D1

Boring Site B-27



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

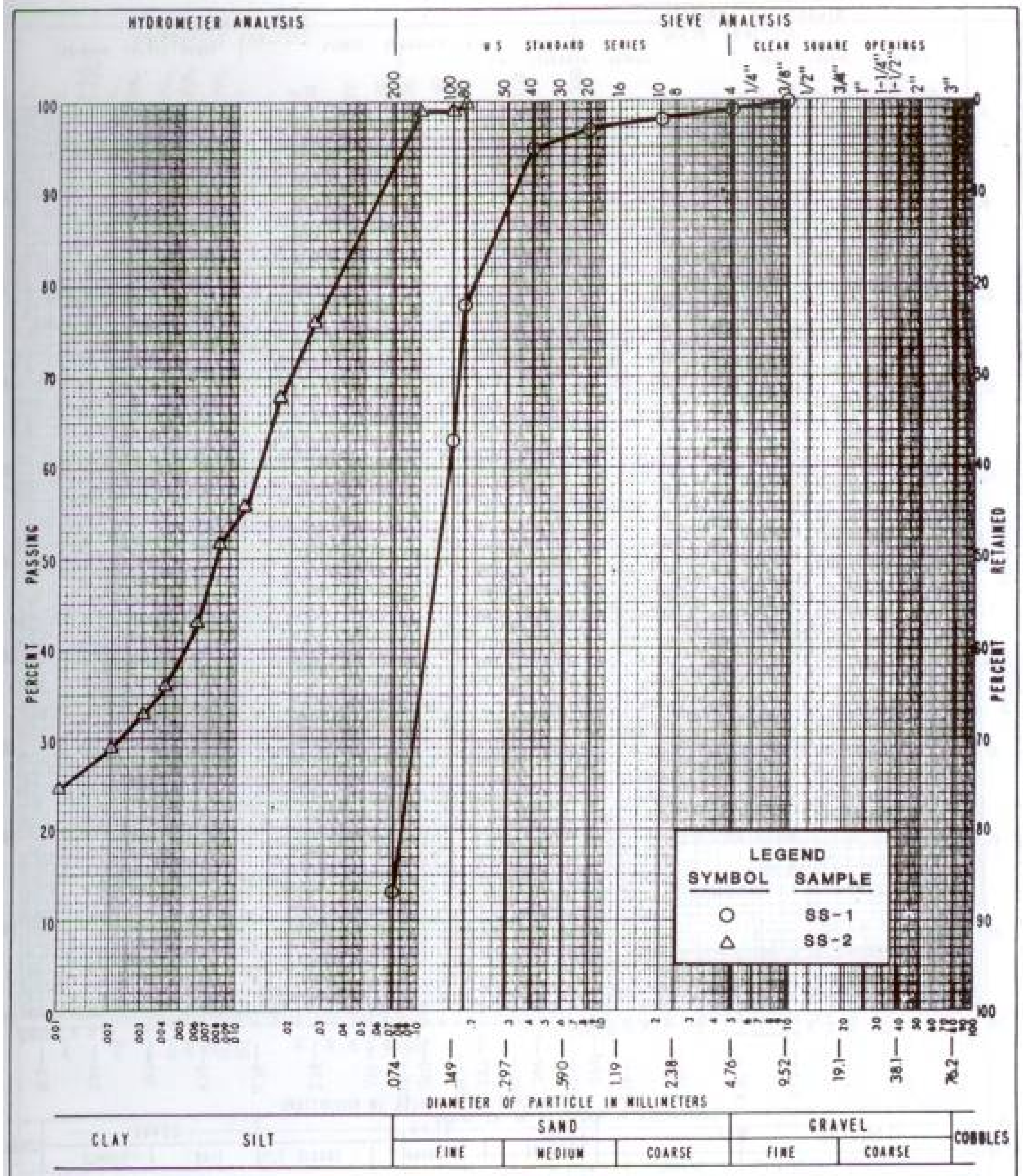
FIGURE 36
PARTICLE - SIZE ANALYSES
BORING B-27

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

B18331.D1

Boring Site B-28



NOTE:

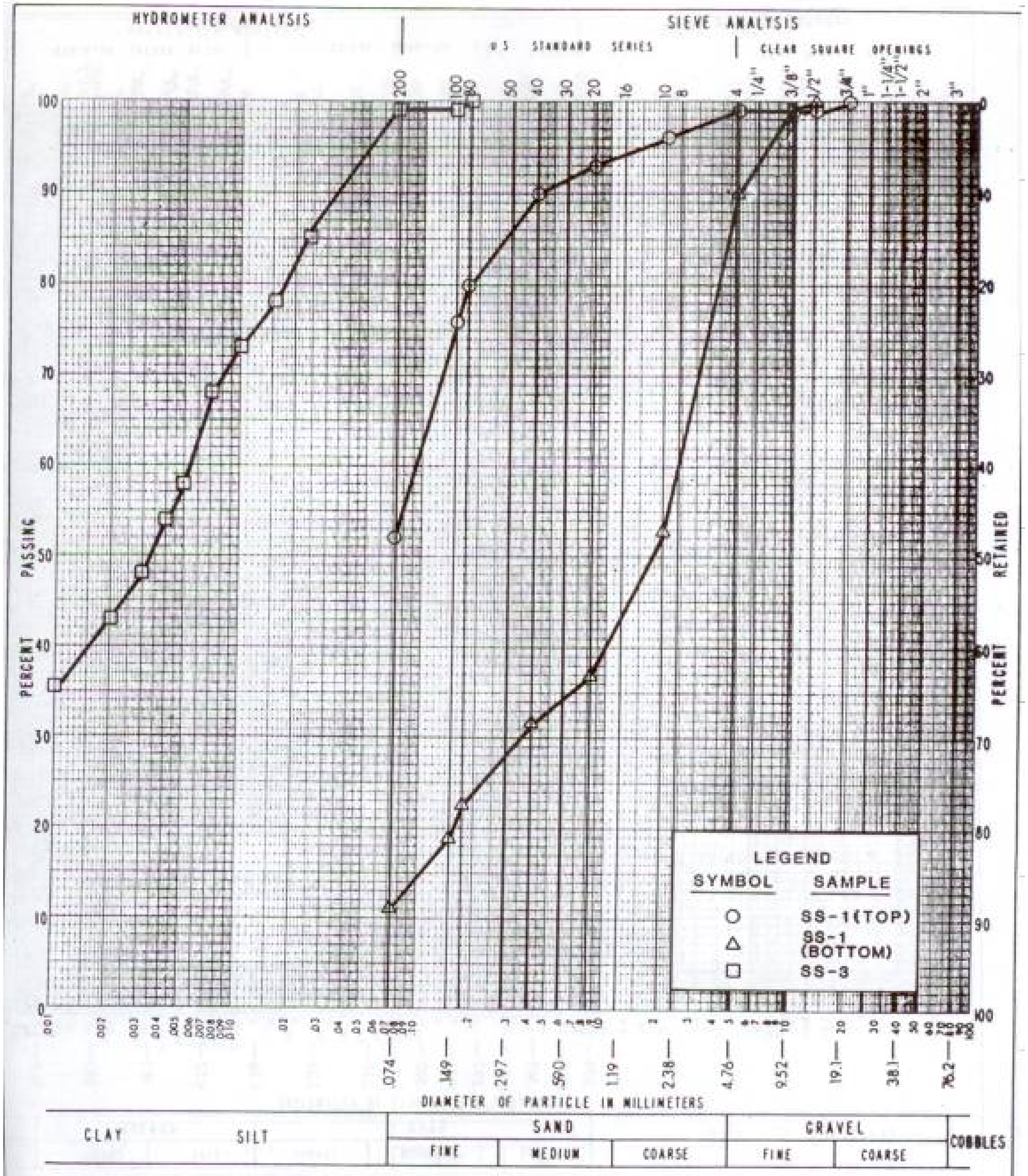
TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 37
PARTICLE - SIZE ANALYSES
BORING B-28

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

Boring Site B-29



NOTE:

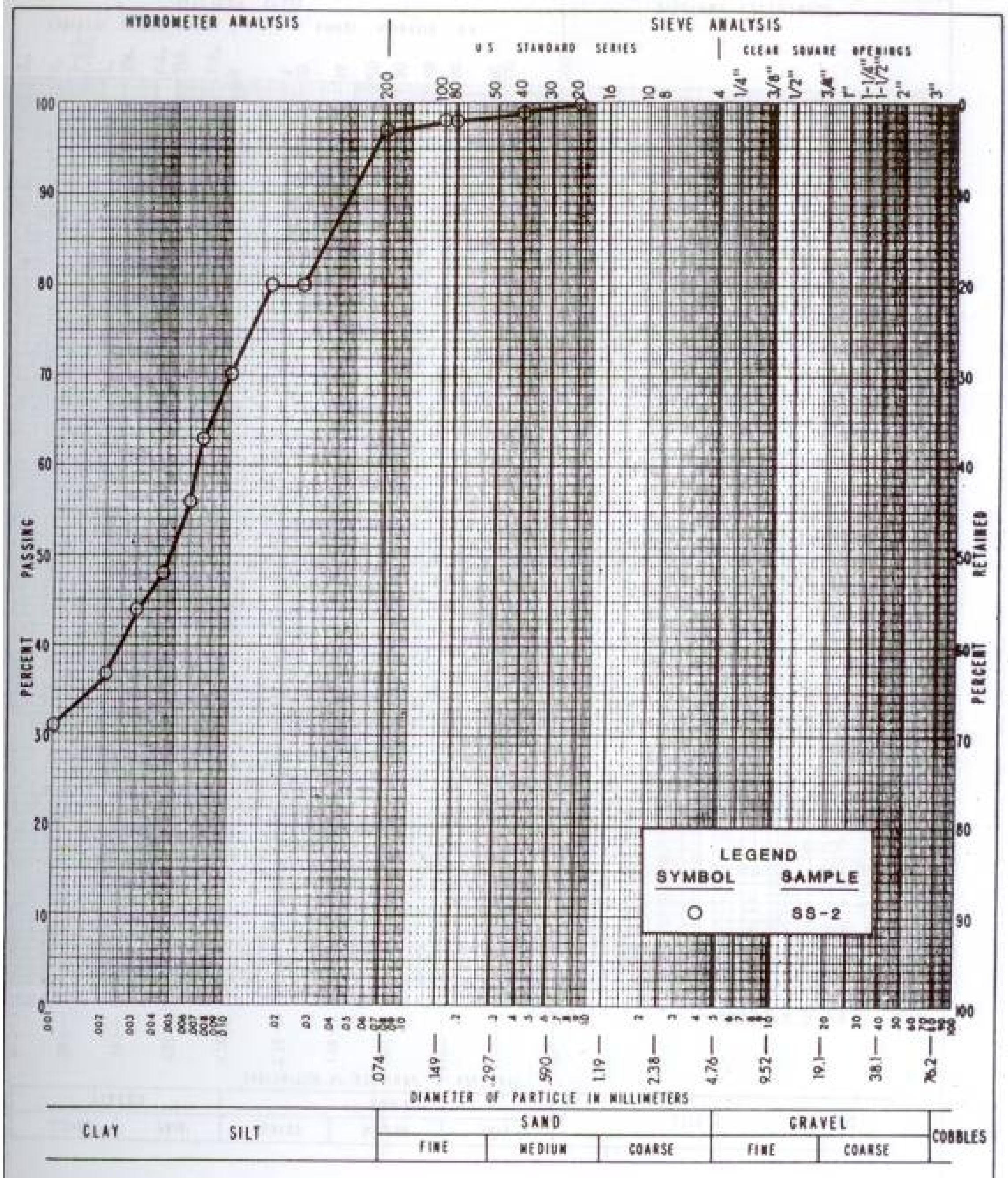
TESTS WERE PERFORMED IN
ACCORDANCE WITH ASTM D422
AND D1140.

FIGURE 38
PARTICLE - SIZE ANALYSES
BORING B-29

Geotechnical Investigation,Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

B18331.D1

Boring Site B-30



NOTE:

TEST WAS PERFORMED IN ACCORDANCE WITH ASTM D422

FIGURE 39

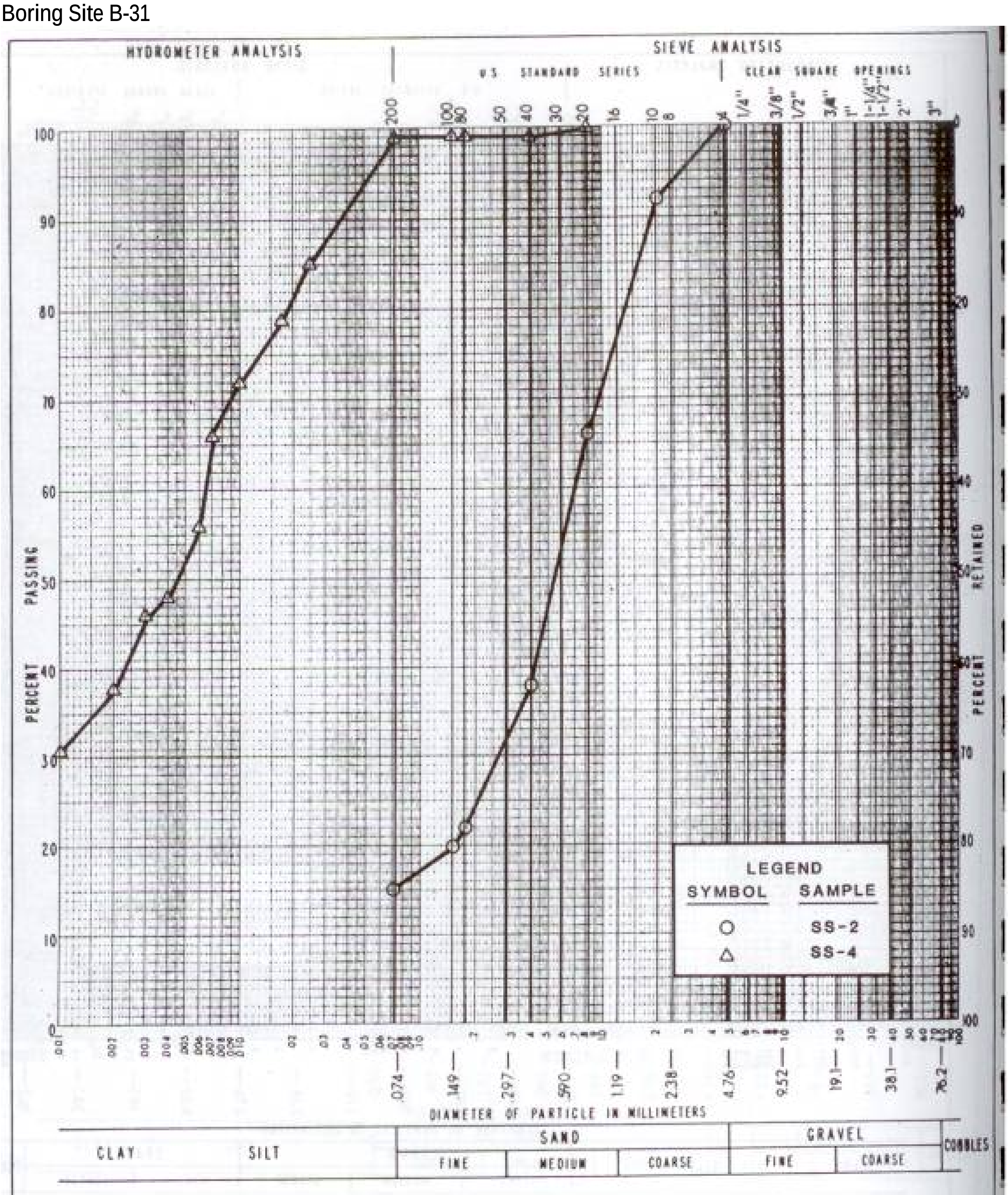
PARTICLE – SIZE ANALYSIS
BORING B-30

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

CH2M HILL

B18331.D1

Boring Site B-31



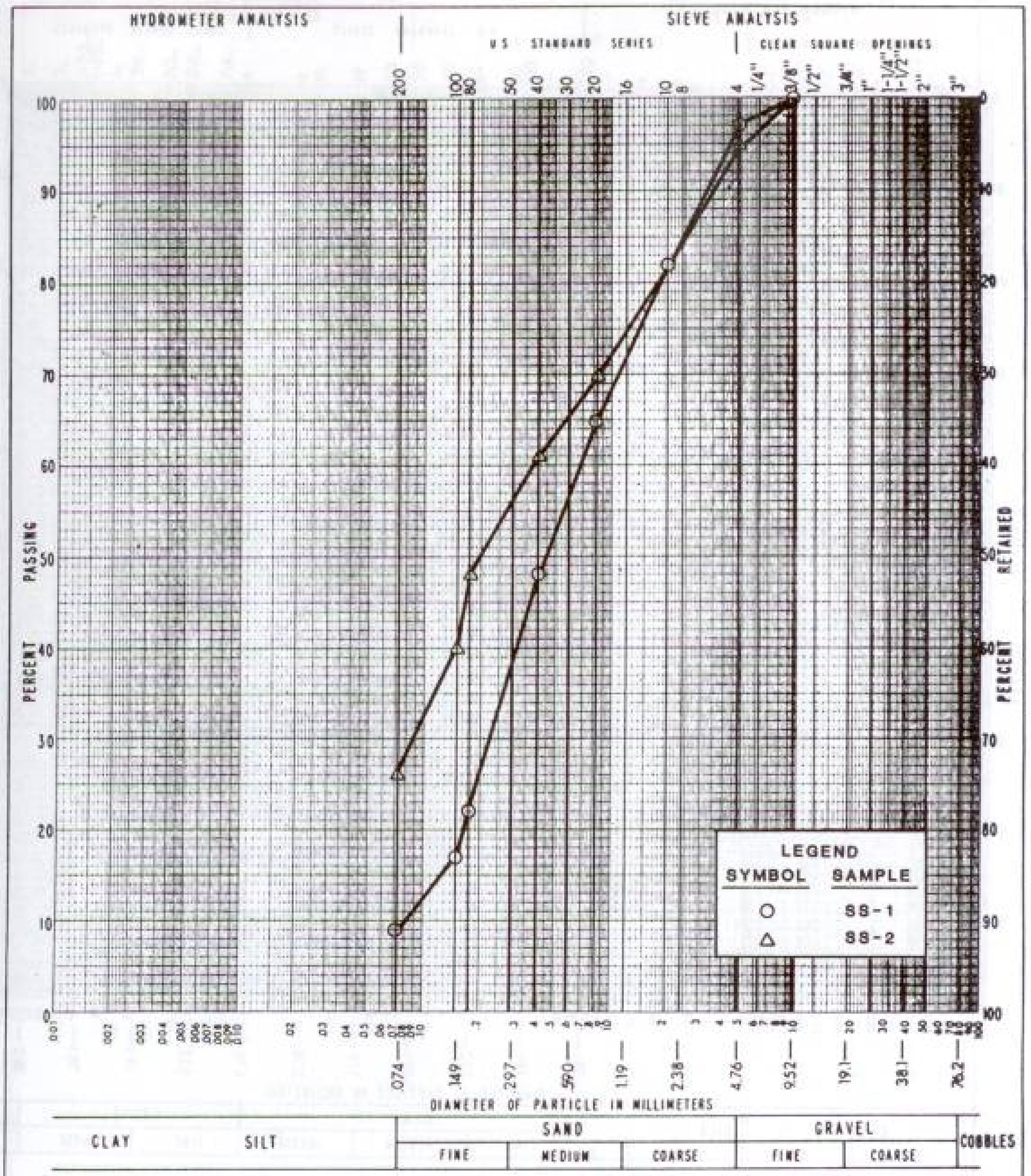
NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 40
PARTICLE - SIZE ANALYSES
BORING B-31

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-32



NOTE:

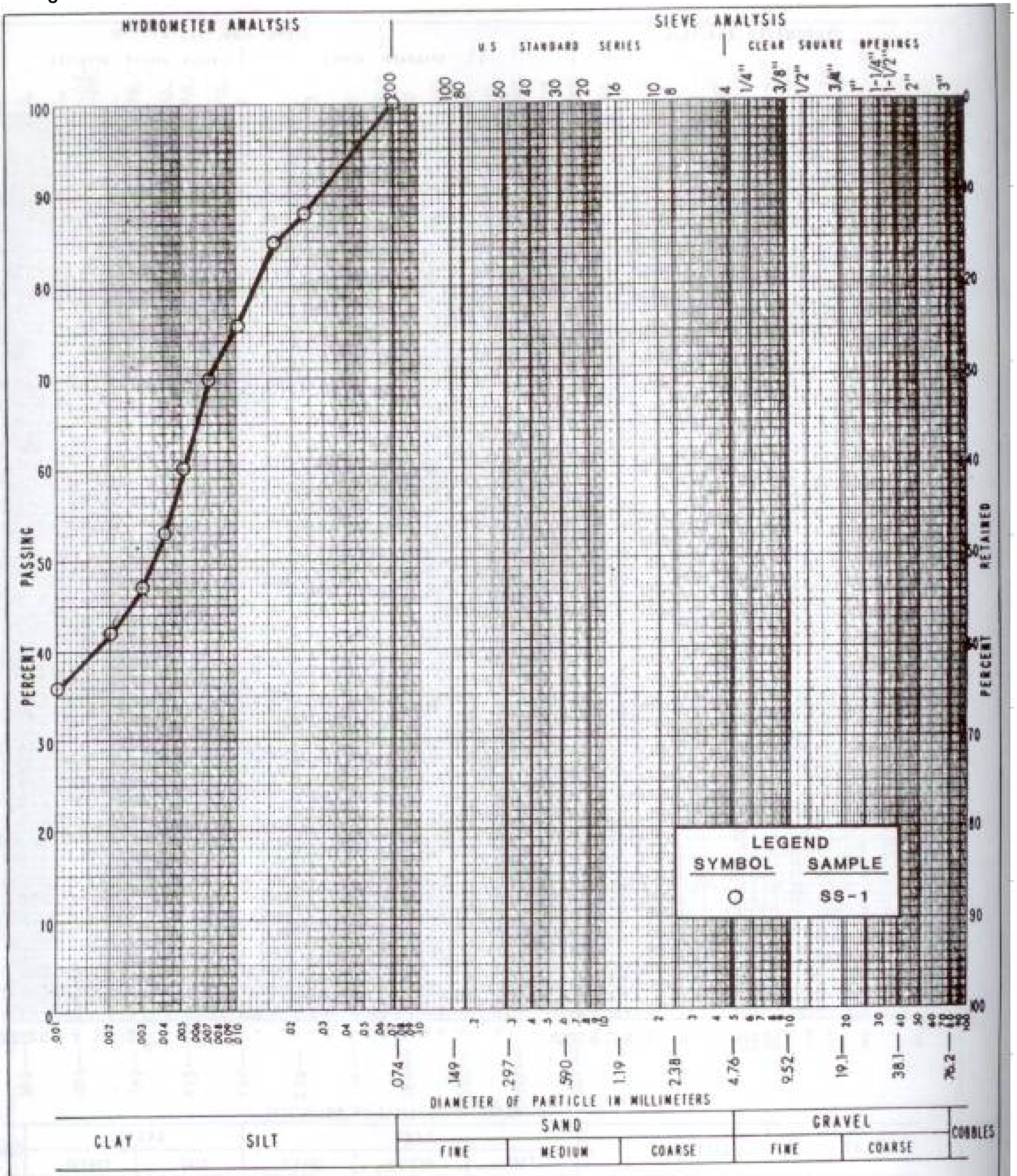
TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 41
PARTICLE - SIZE ANALYSES
BORING B-32

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

B18331.D1

Boring Site B-33



NOTE:

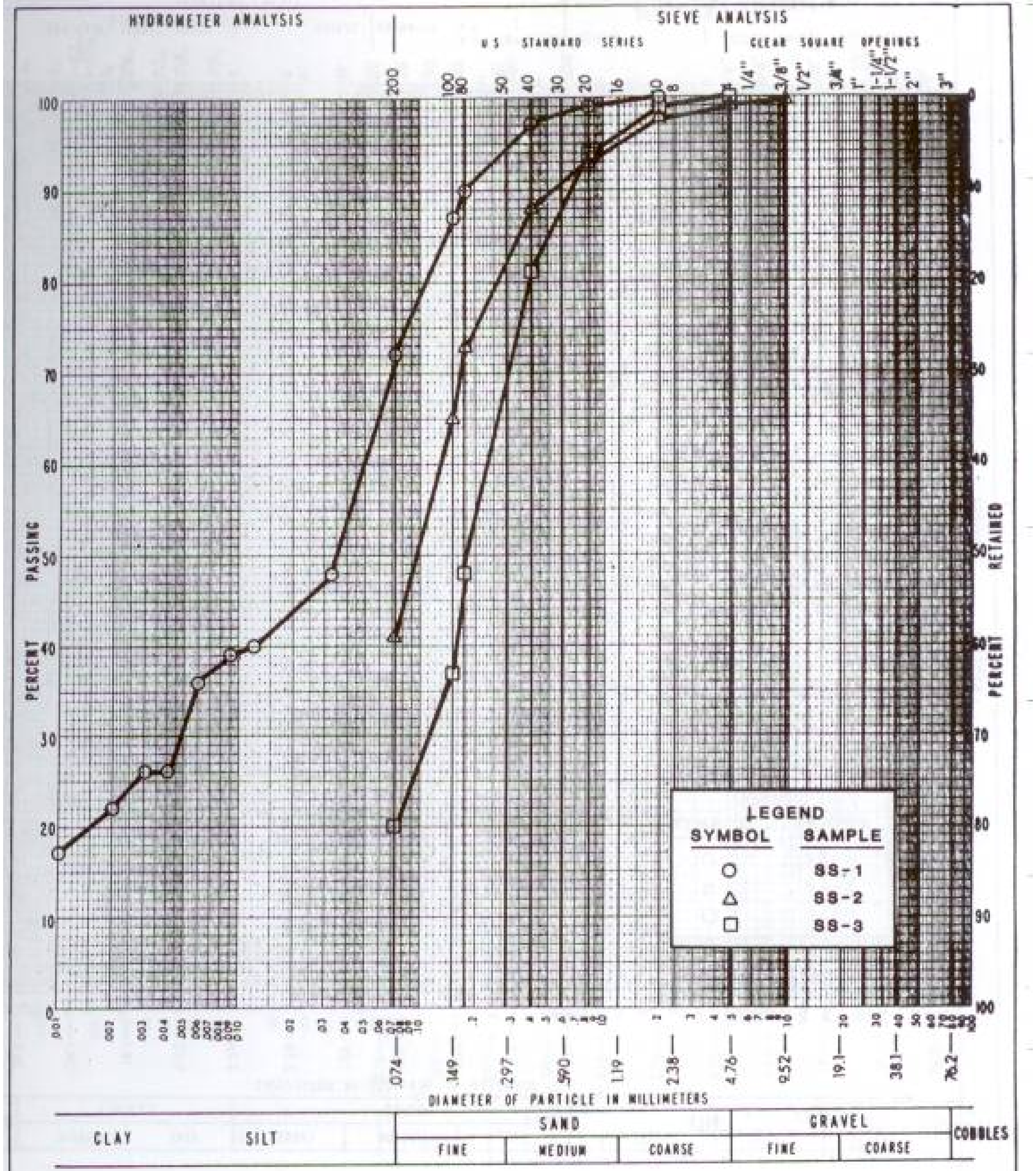
TEST WAS PERFORMED IN ACCORDANCE WITH ASTM D422

FIGURE 42
PARTICLE – SIZE ANALYSIS
BORING B-33

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

B18331.D1

Boring Site B-34



NOTE:

TESTS WERE PERFORMED IN
ACCORDANCE WITH ASTM D422
AND D1140.

FIGURE 43
PARTICLE – SIZE ANALYSES
BORING B-34

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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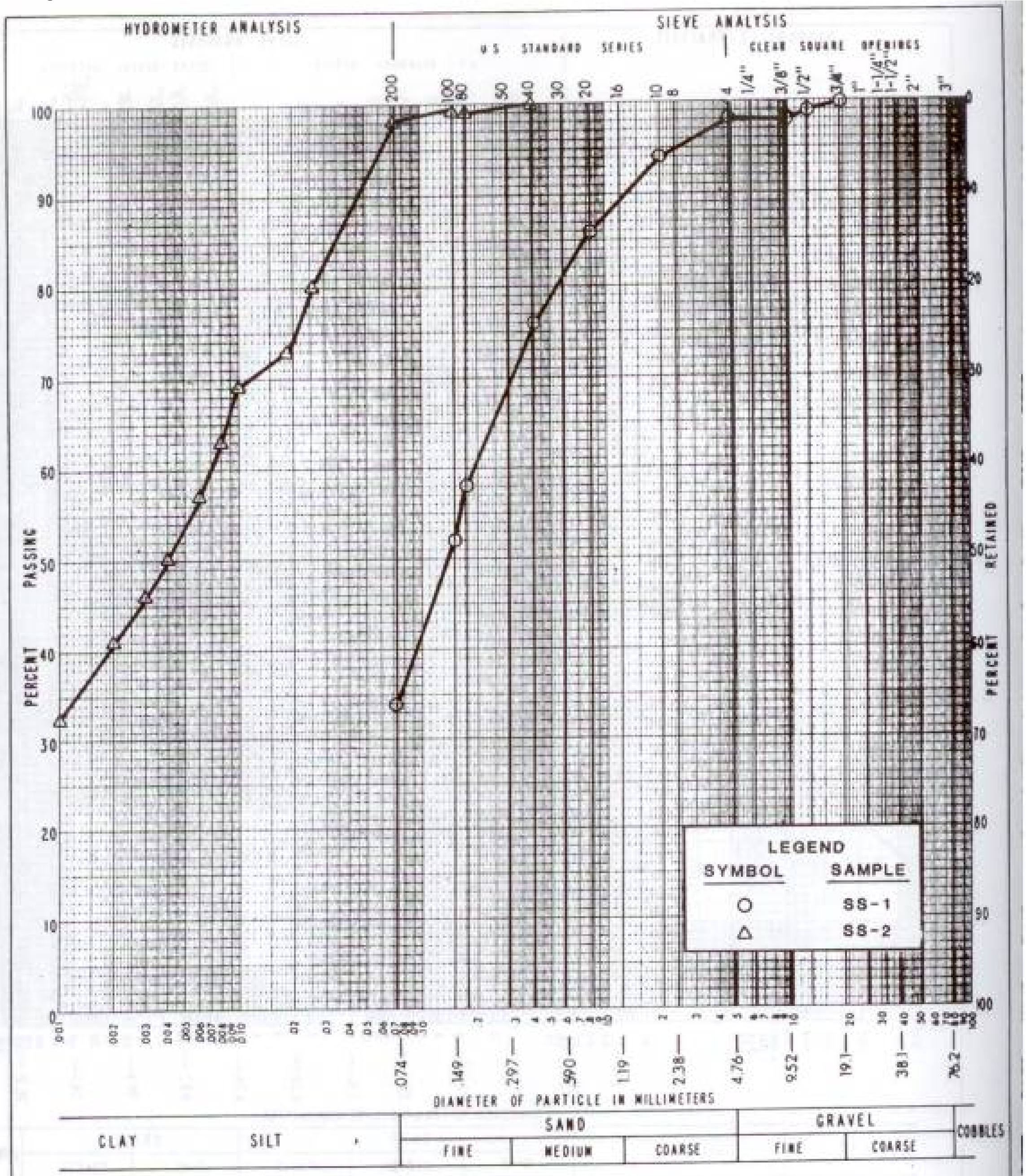
B18331.D1

Boring Site B-35



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 44

PARTICLE - SIZE ANALYSES
BORING B-35

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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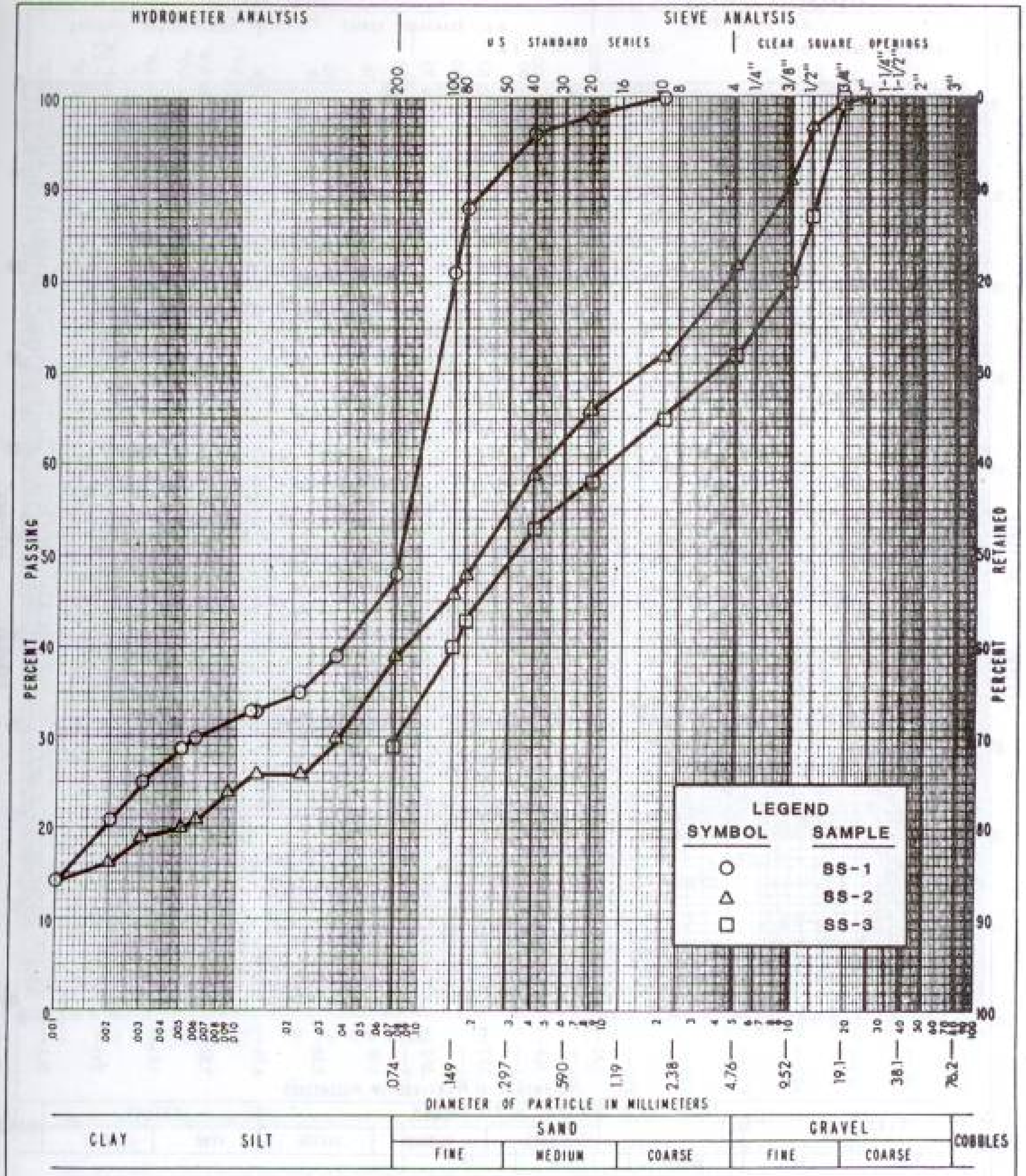
Boring Site B-36



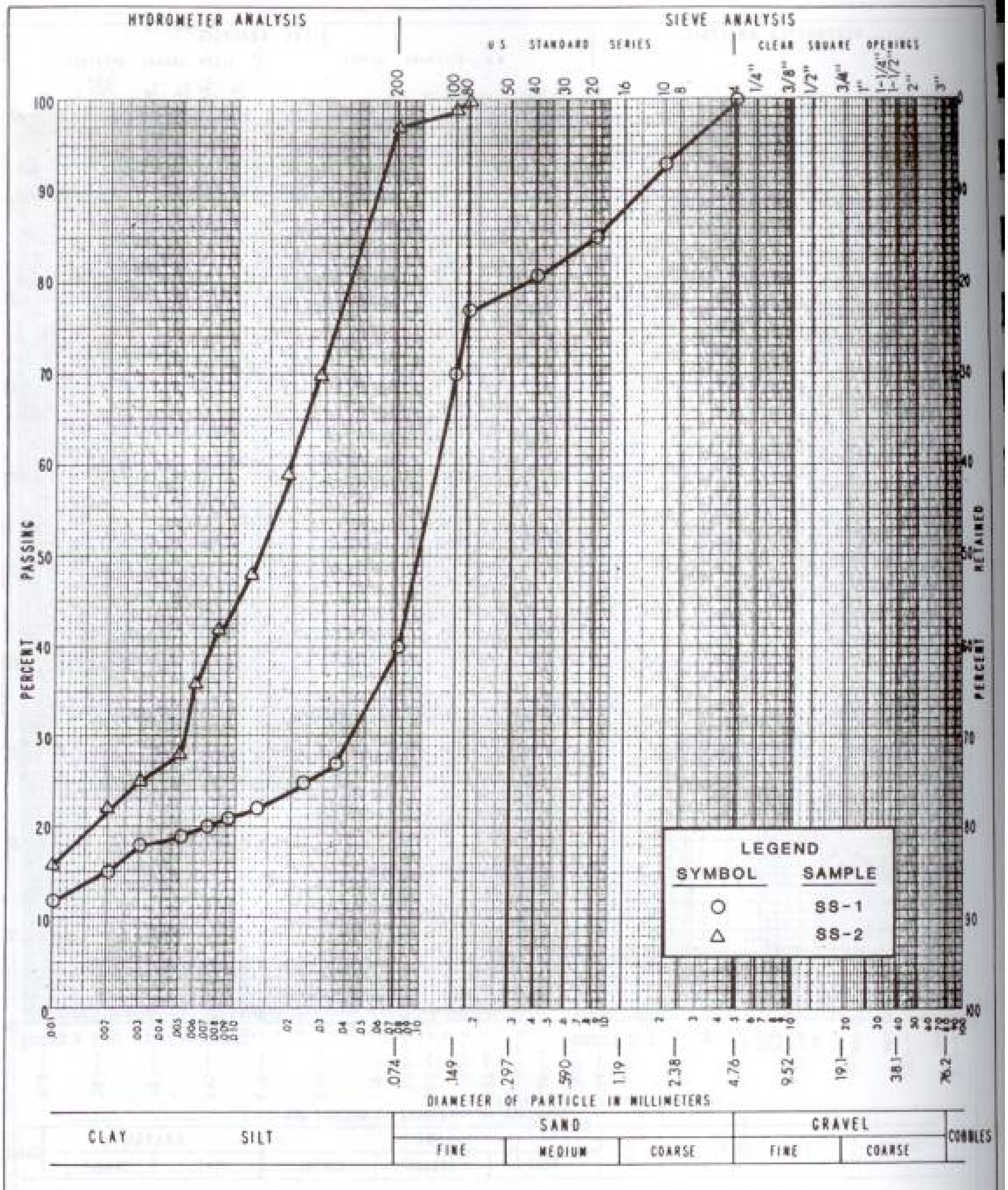
NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 45
PARTICLE - SIZE ANALYSES
BORING B- 36

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-37



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422.

FIGURE 46
PARTICLE - SIZE ANALYSES
BORING B- 37

Geotechnical Investigation,Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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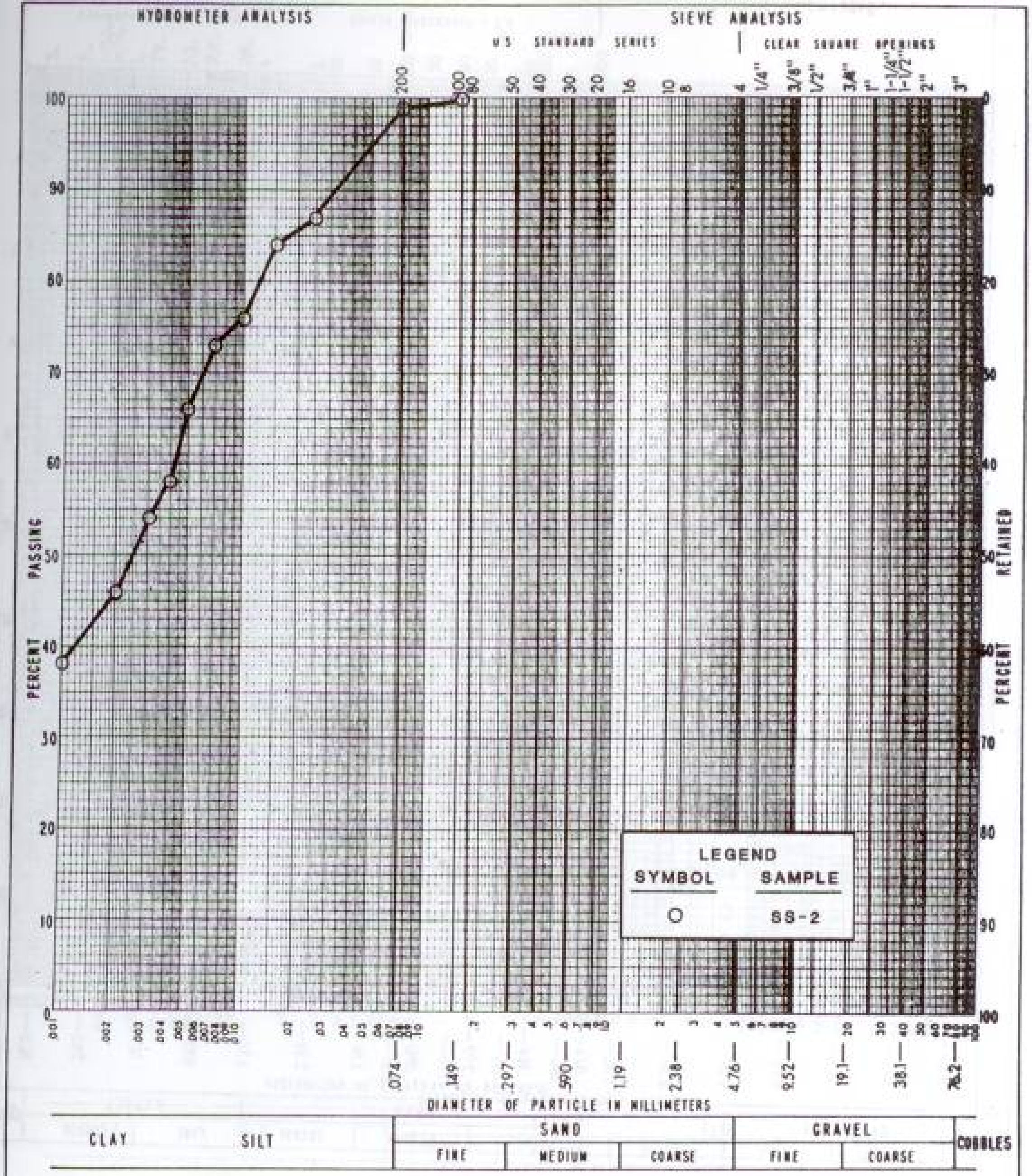
Boring Site B-38



NOTE:

TEST WAS PERFORMED IN
ACCORDANCE WITH ASTM D422

FIGURE 47
PARTICLE - SIZE ANALYSIS
BORING B- 38

Geotechnical Investigation,Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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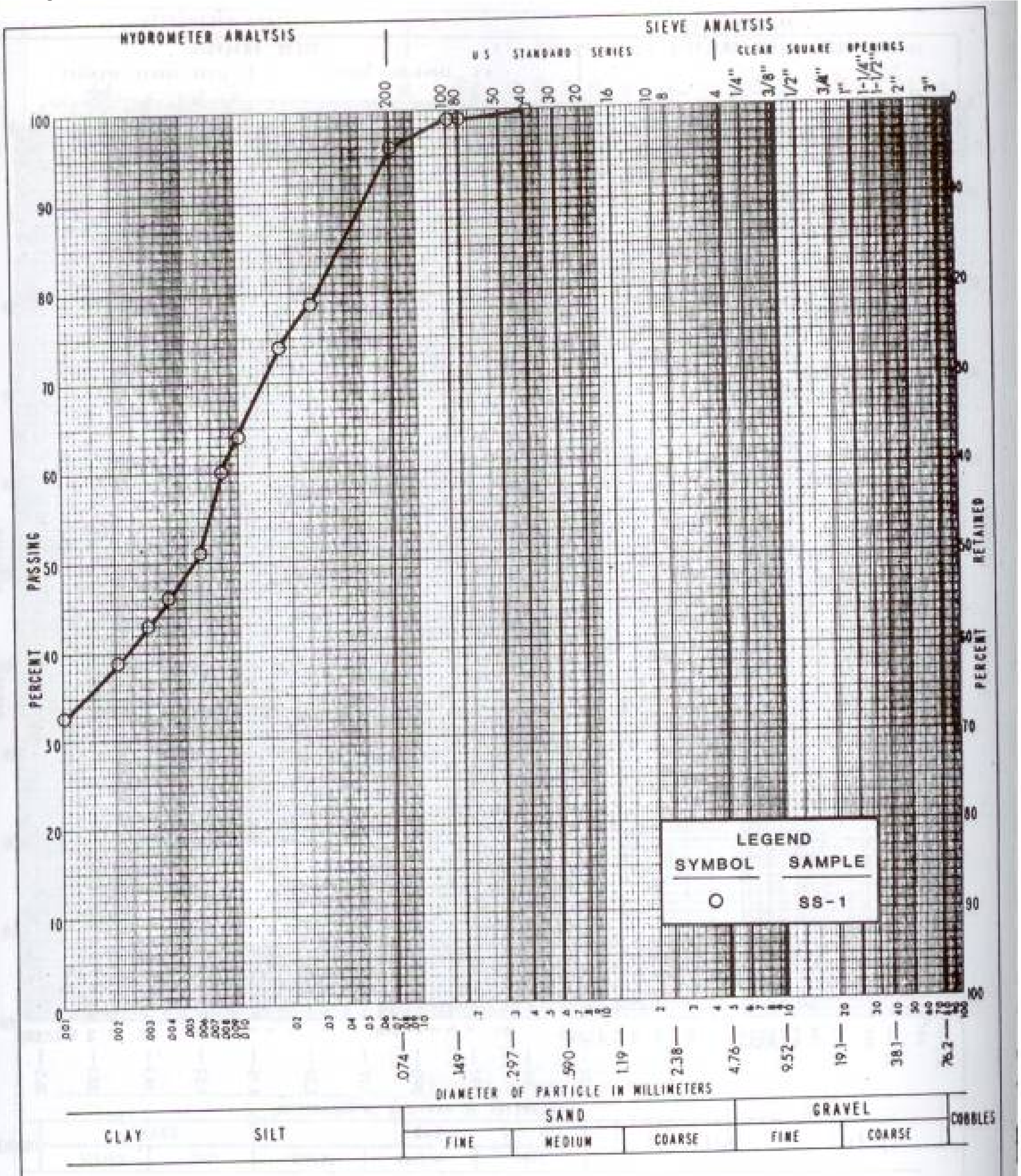
Boring Site B-39



NOTE:

TEST WAS PERFORMED IN ACCORDANCE WITH ASTM D422

FIGURE 48
PARTICLE - SIZE ANALYSIS
BORING B- 39

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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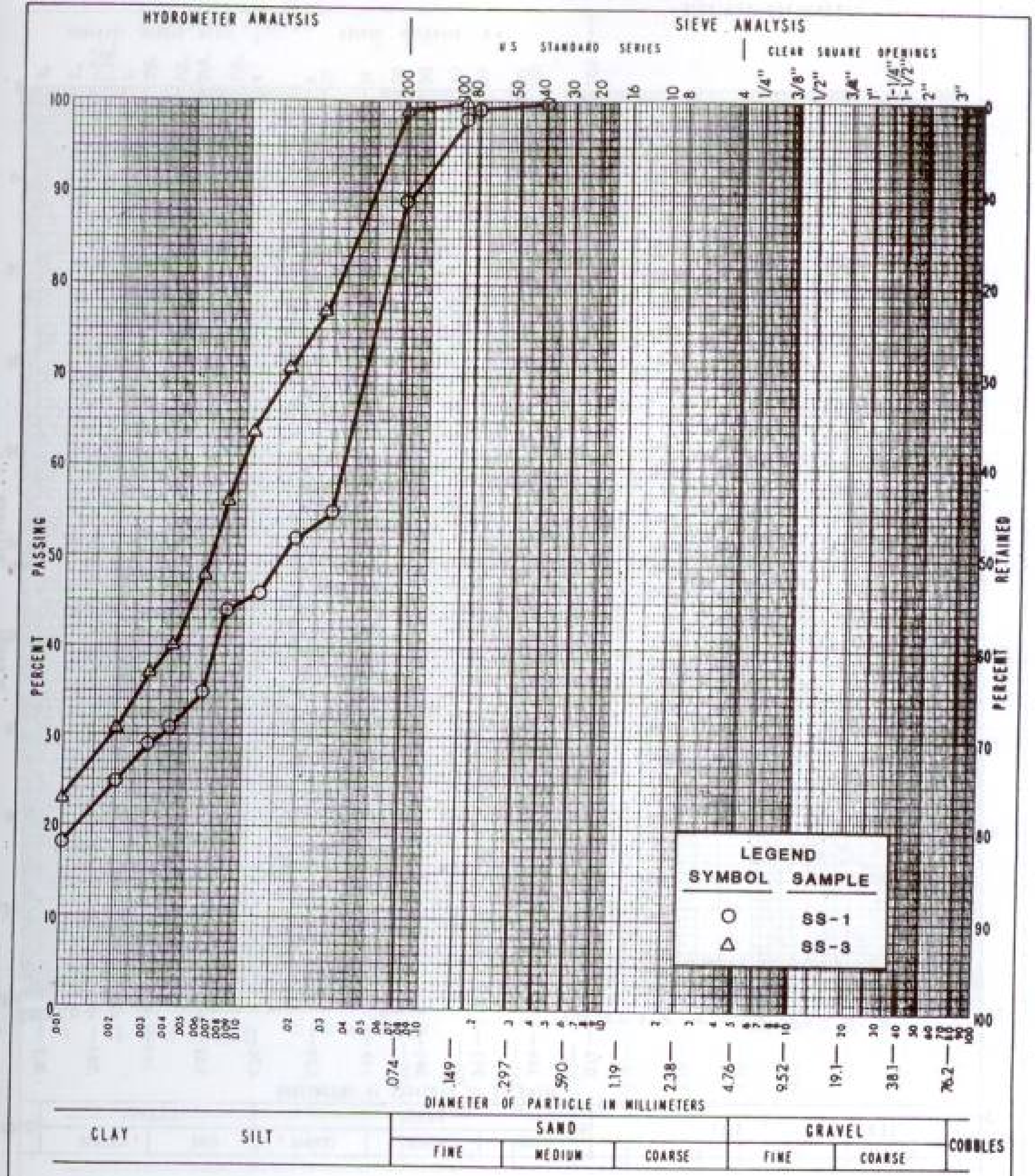
Boring Site B-40



NOTE:

TESTS WERE PERFORMED IN
ACCORDANCE WITH ASTM D422,

FIGURE 49
PARTICLE - SIZE ANALYSES
BORING B-40

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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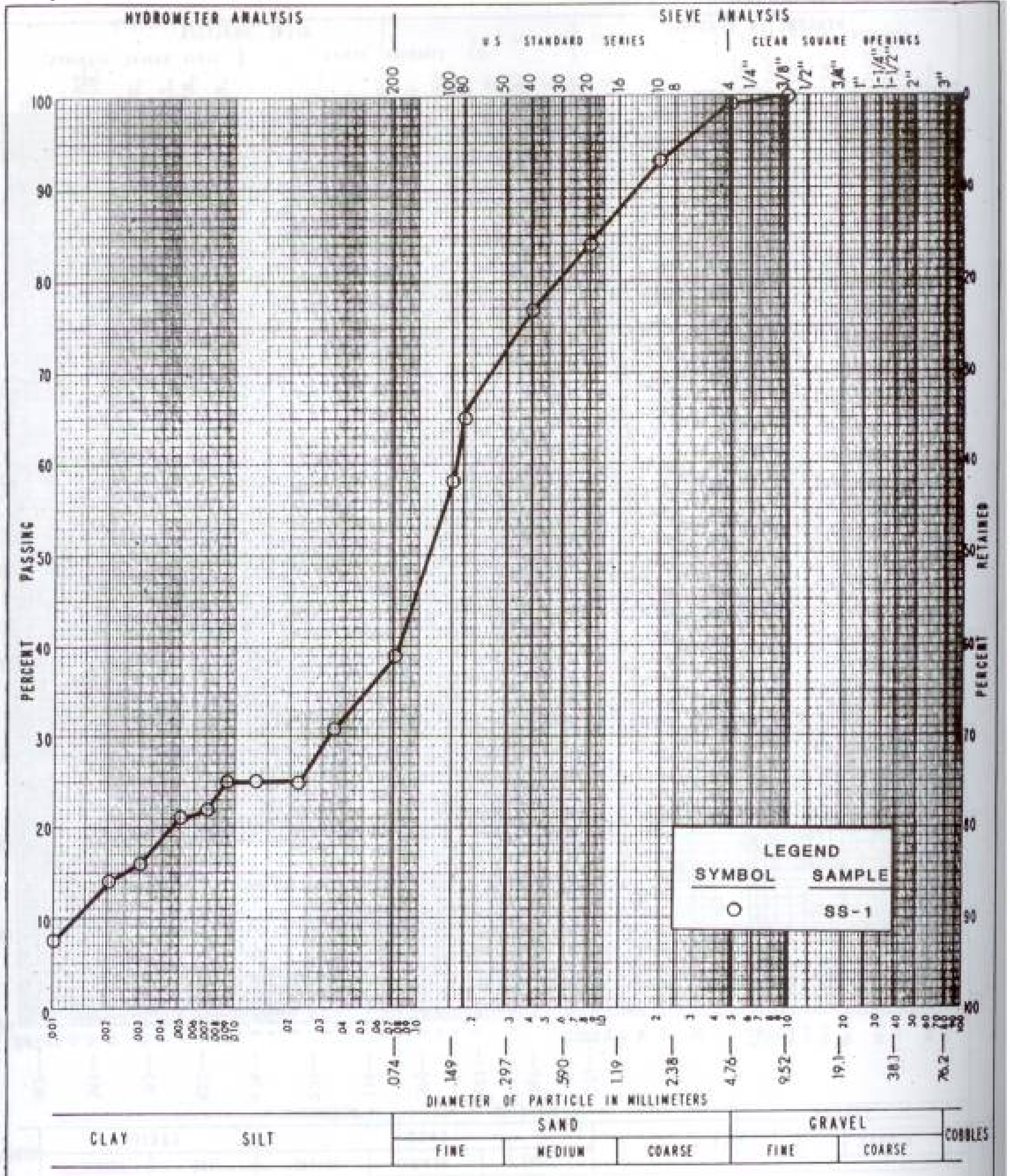
Boring Site B-41



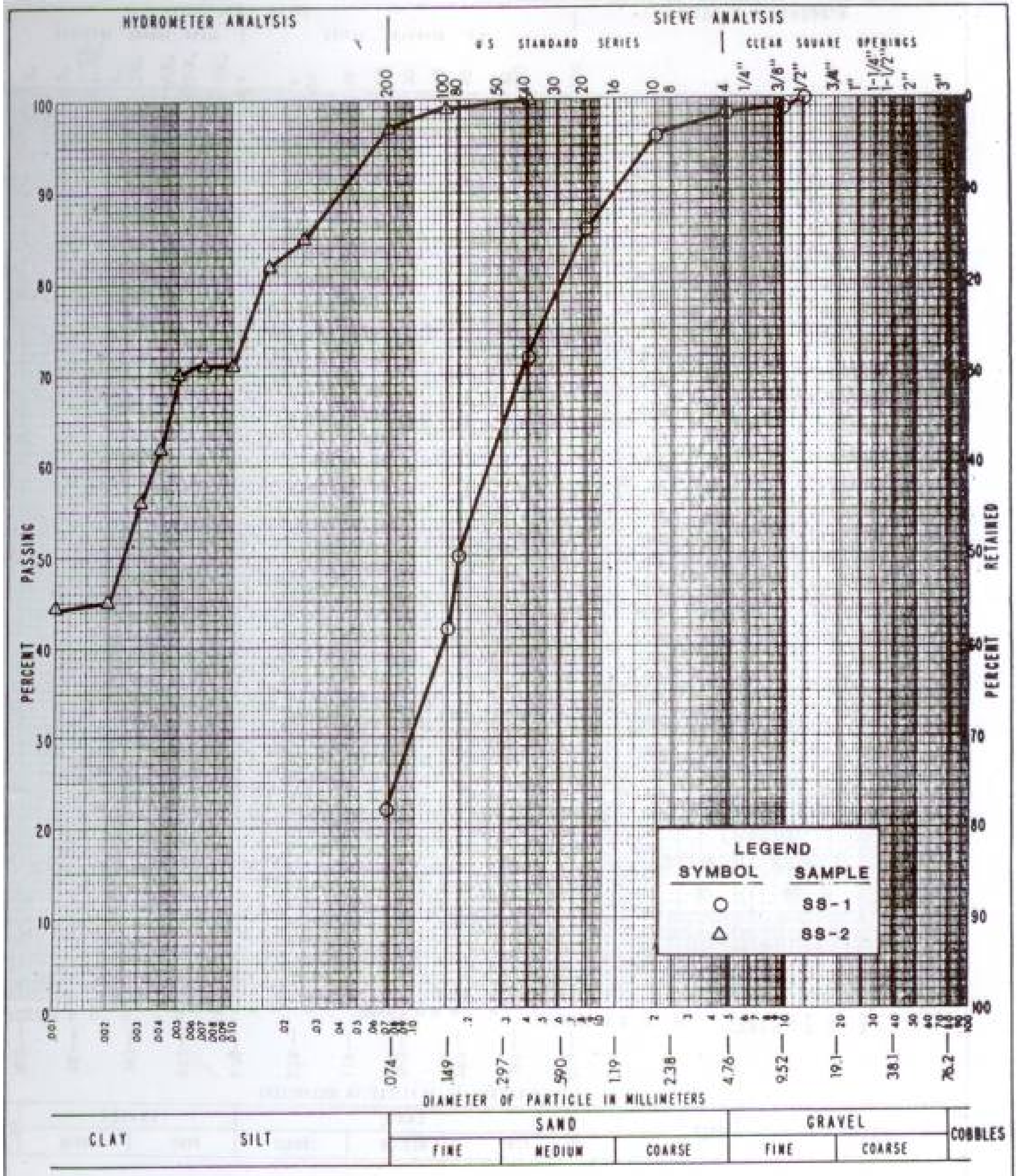
NOTE:

TEST WAS PERFORMED IN
ACCORDANCE WITH ASTM D422

FIGURE 50
PARTICLE – SIZE ANALYSIS
BORING B-41

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-42



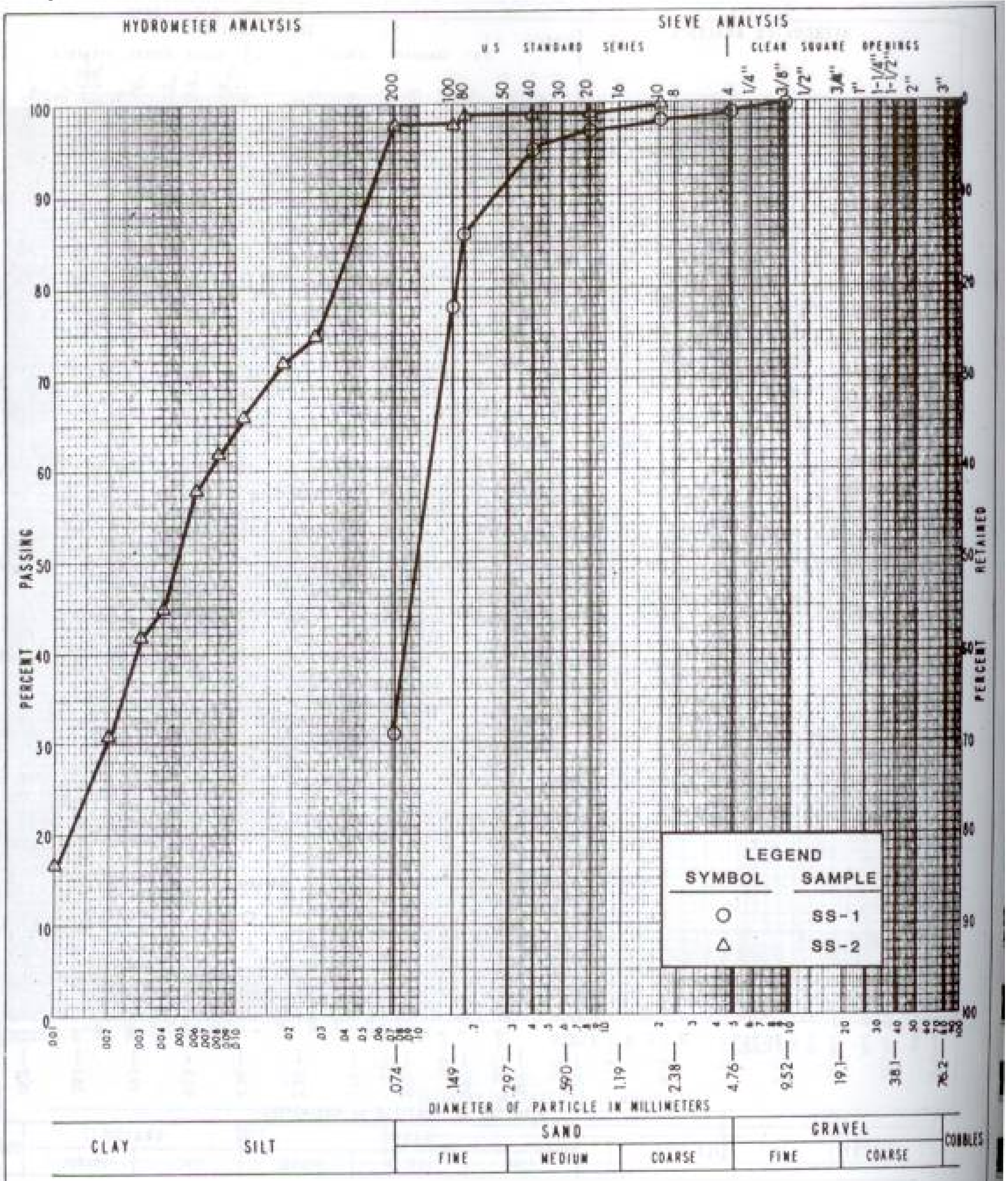
NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 51
PARTICLE - SIZE ANALYSES
BORING B-42

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-43



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 52
PARTICLE - SIZE ANALYSES
BORING B-43

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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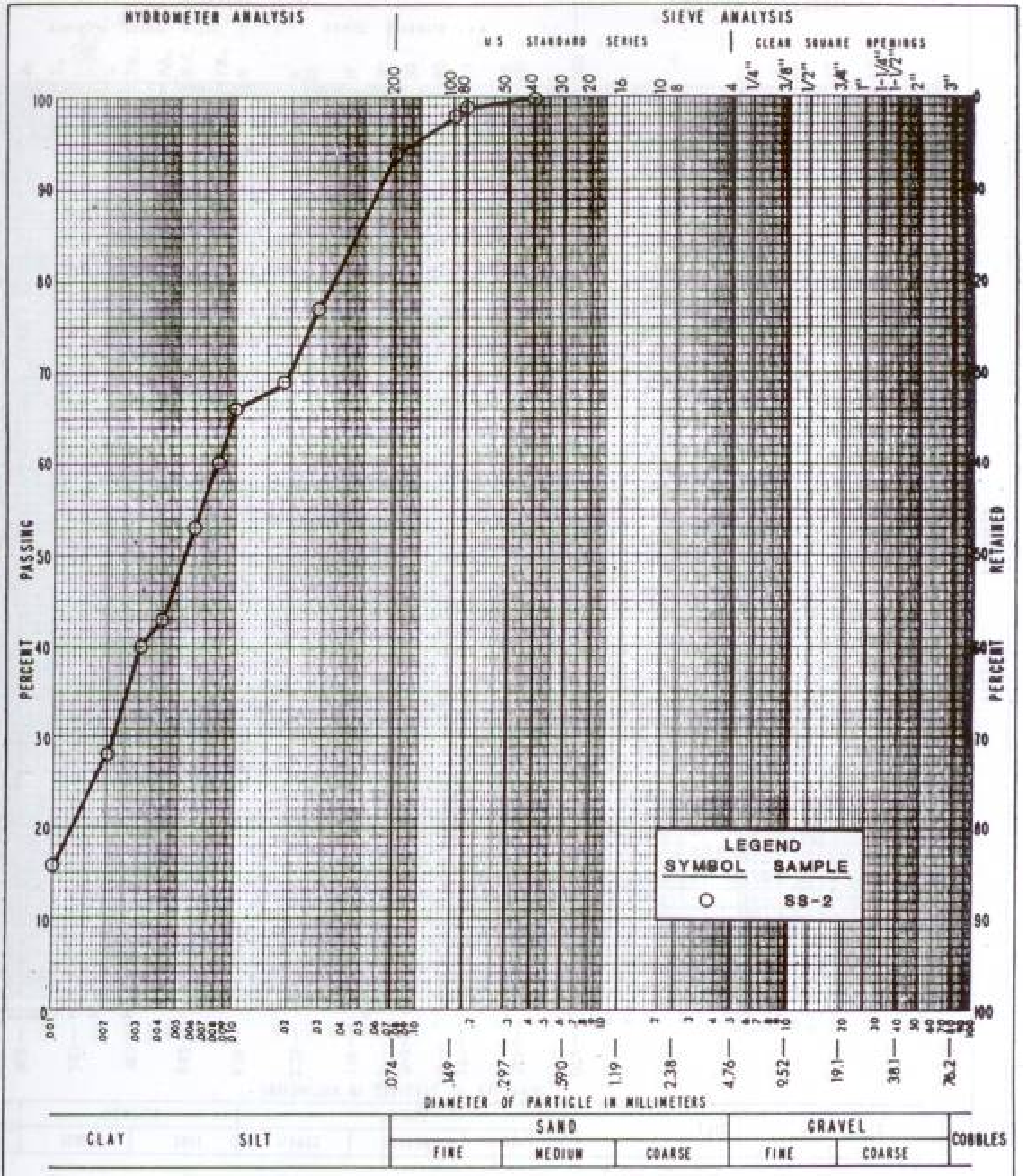
Boring Site B-44



NOTE:

TEST WAS PERFORMED IN ACCORDANCE WITH ASTM D422

FIGURE 53
PARTICLE – SIZE ANALYSIS
BORING B- 44

Geotechnical Investigation,Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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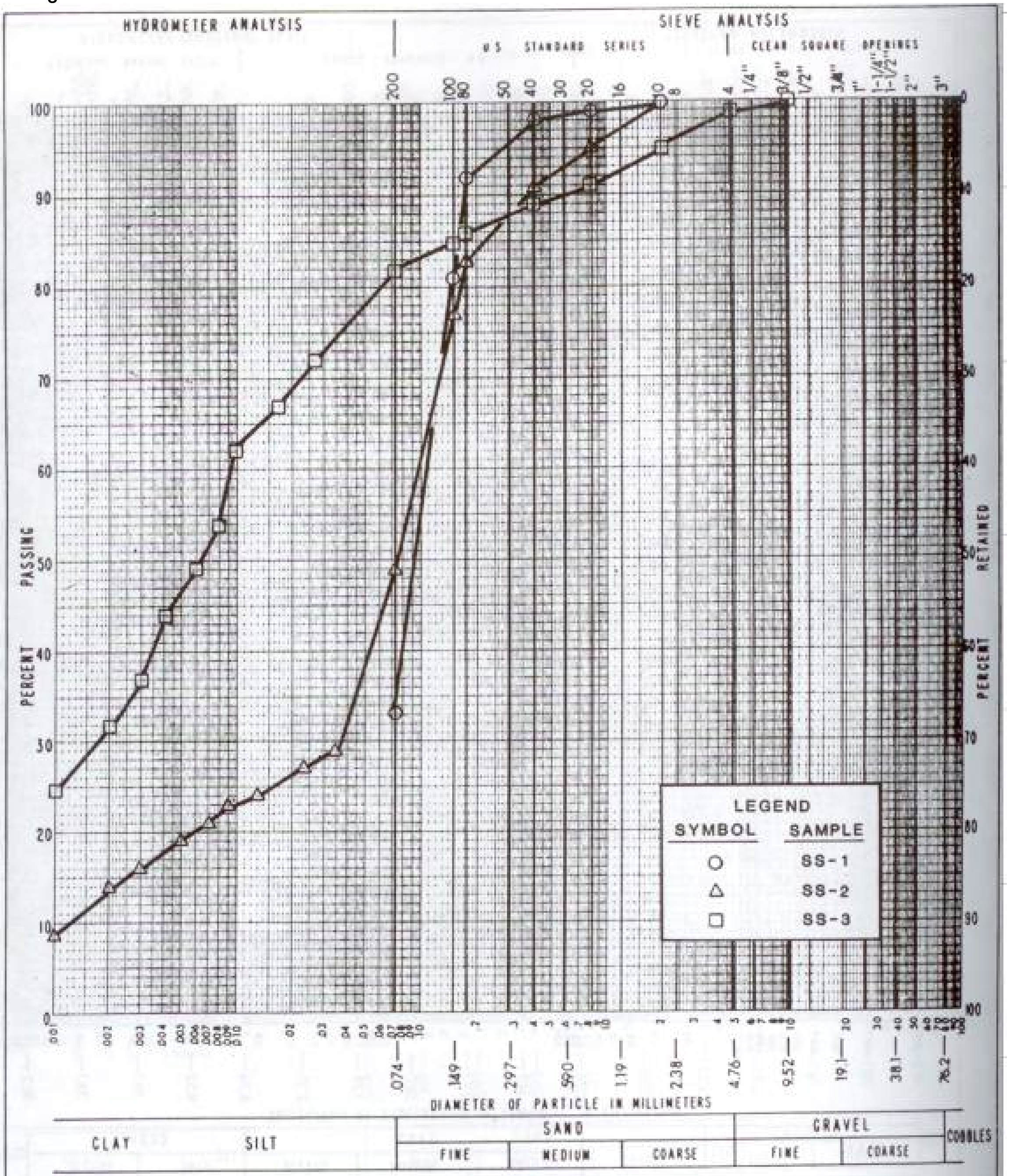
Boring Site B-45



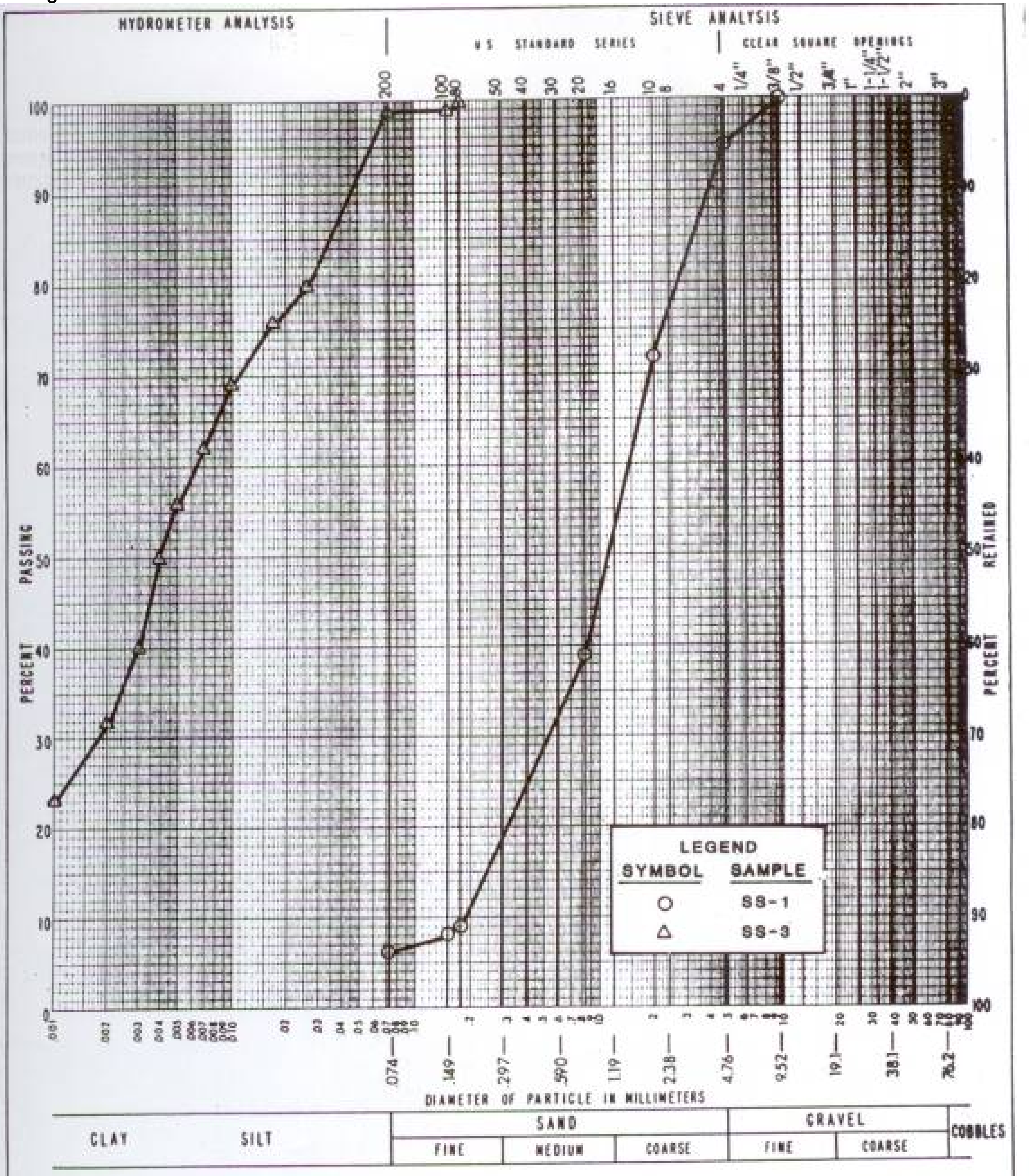
NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 54
PARTICLE - SIZE ANALYSES
BORING B- 45

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-46



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422 AND D1140.

FIGURE 55
PARTICLE - SIZE ANALYSES
BORING B-46

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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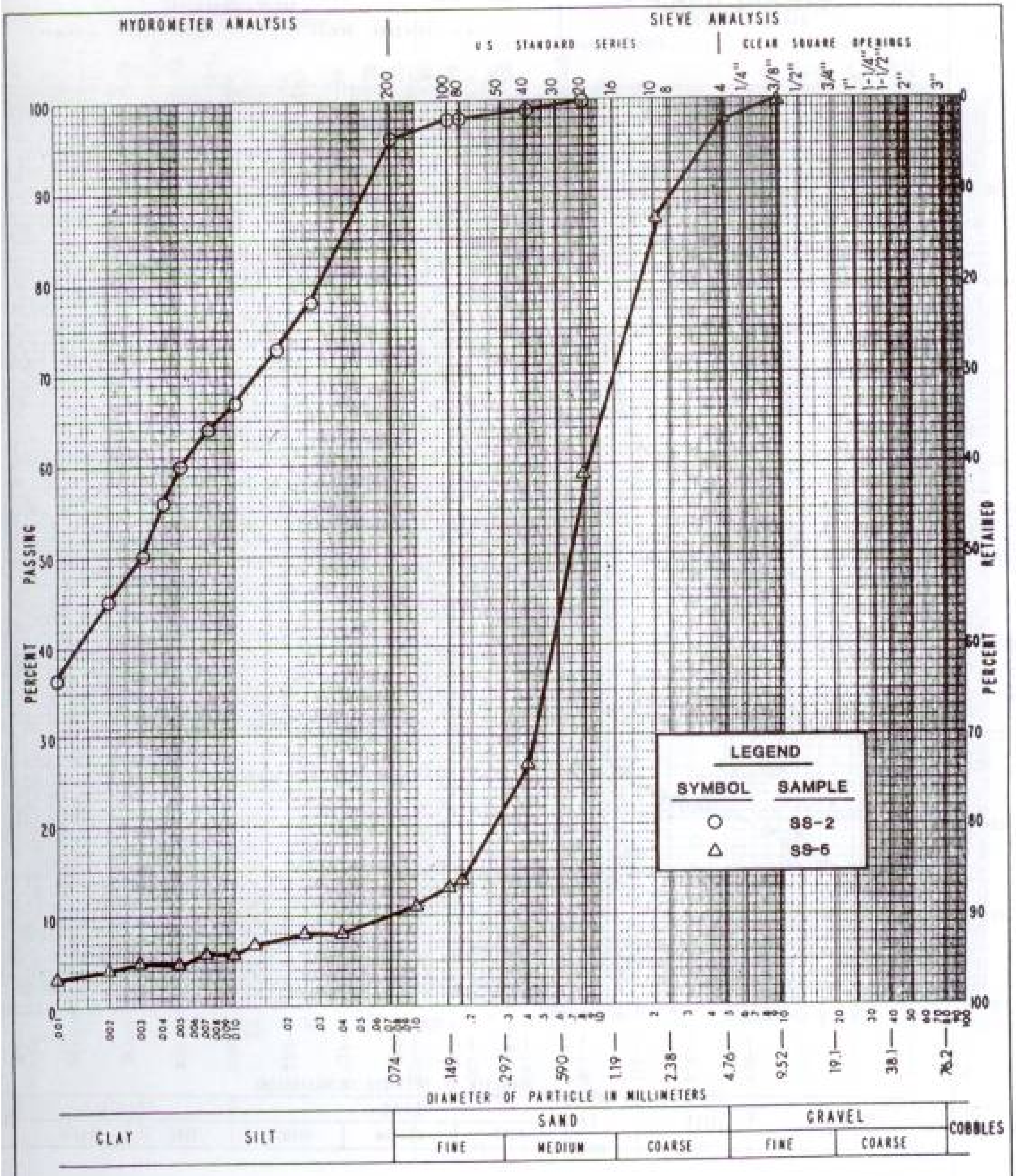
818331.D1

Boring Site B-D-15



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422.

FIGURE 7
PARTICLE – SIZE ANALYSES
BORING B-D-15

Geotechnical Investigation, Utah Lake Outlet
Utah Lake/Jordan River Flood Management Program

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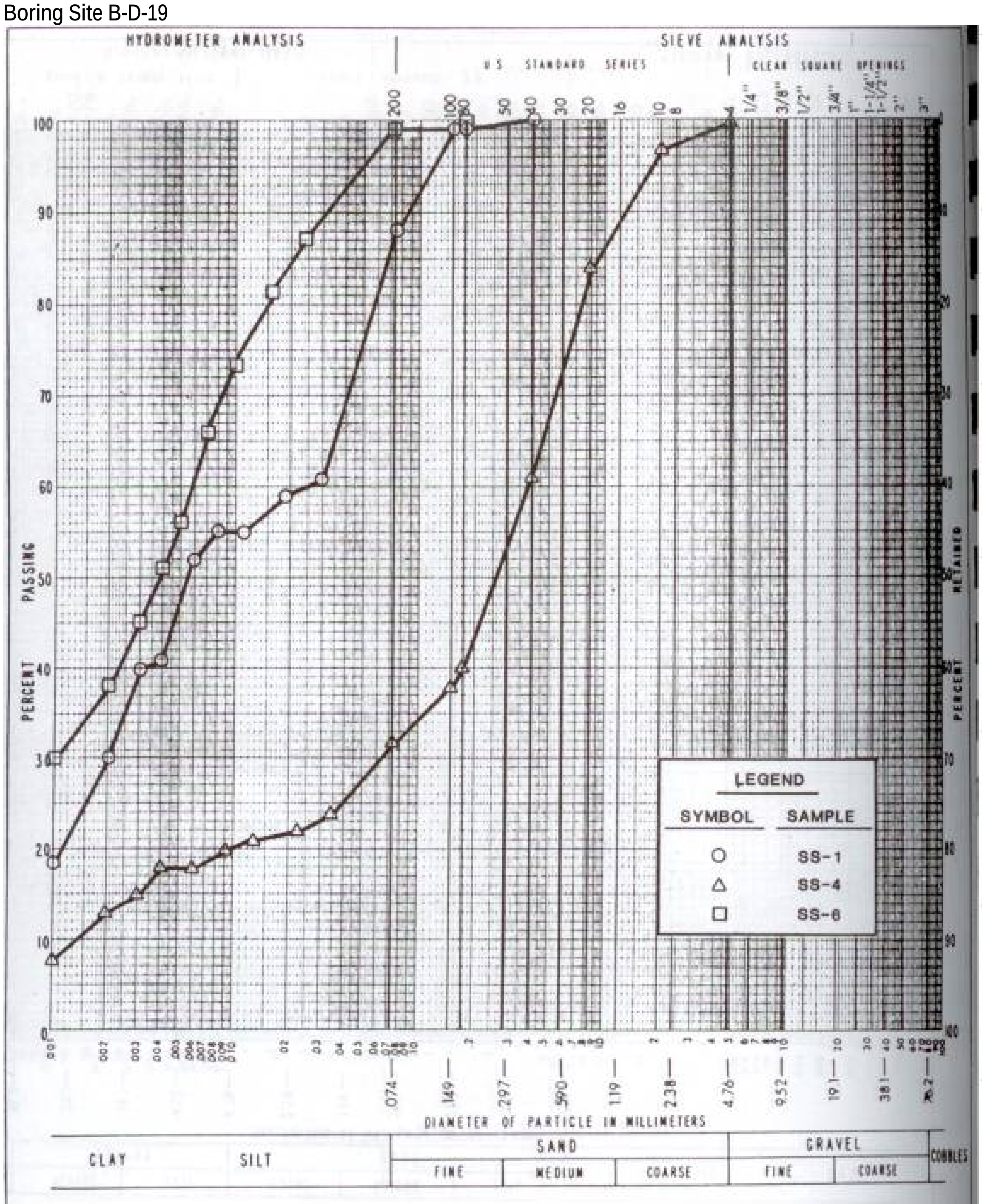
Boring Site B-D-19



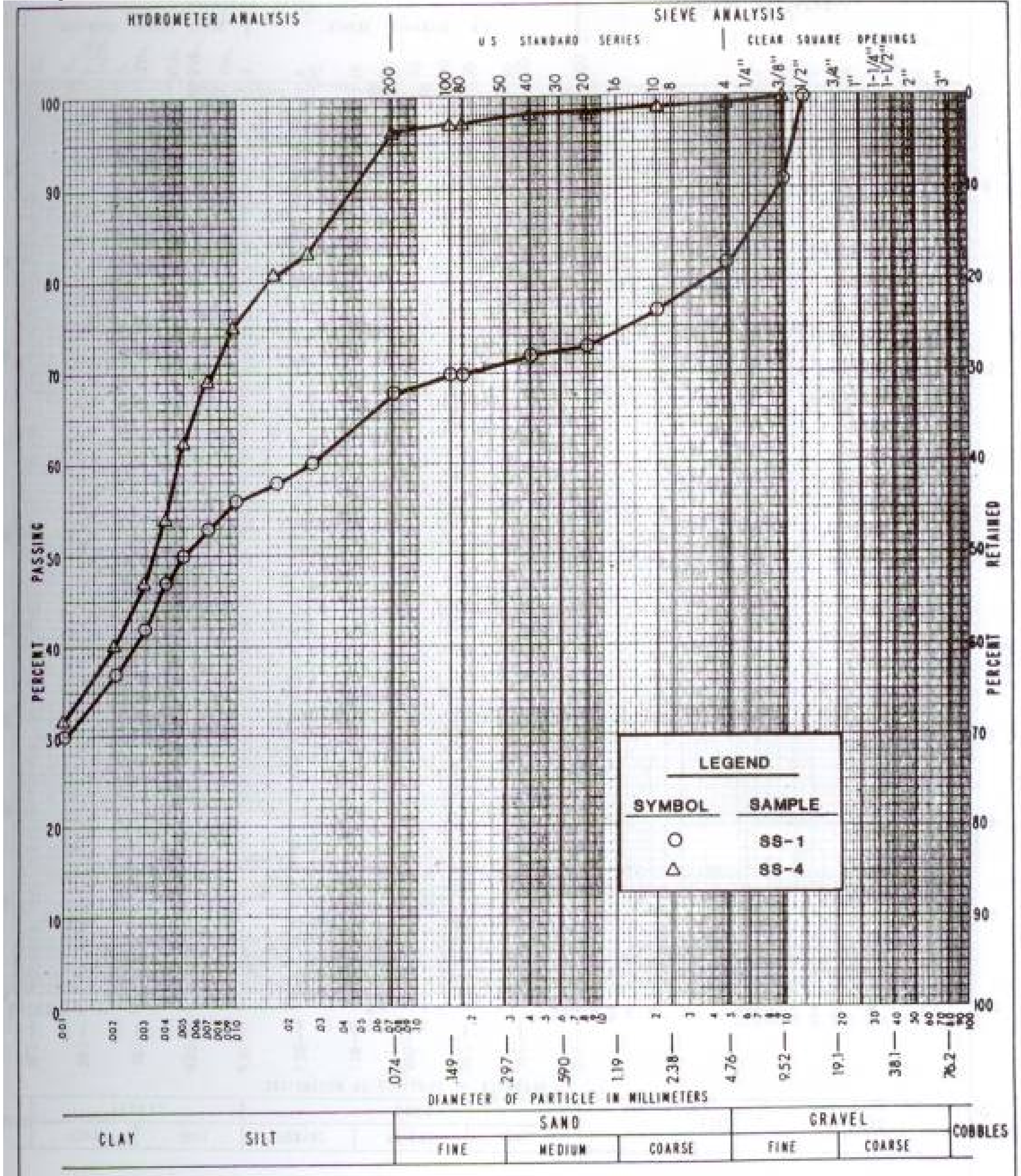
NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D422.

FIGURE 8
PARTICLE - SIZE ANALYSES
BORING B-D-19

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

Boring Site B-D-23



NOTE:

TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM D 422.

FIGURE 9
PARTICLE - SIZE ANALYSES
BORING B-D-23

Geotechnical Investigation, Jordan River Dredging
Utah Lake/Jordan River Flood Management Program

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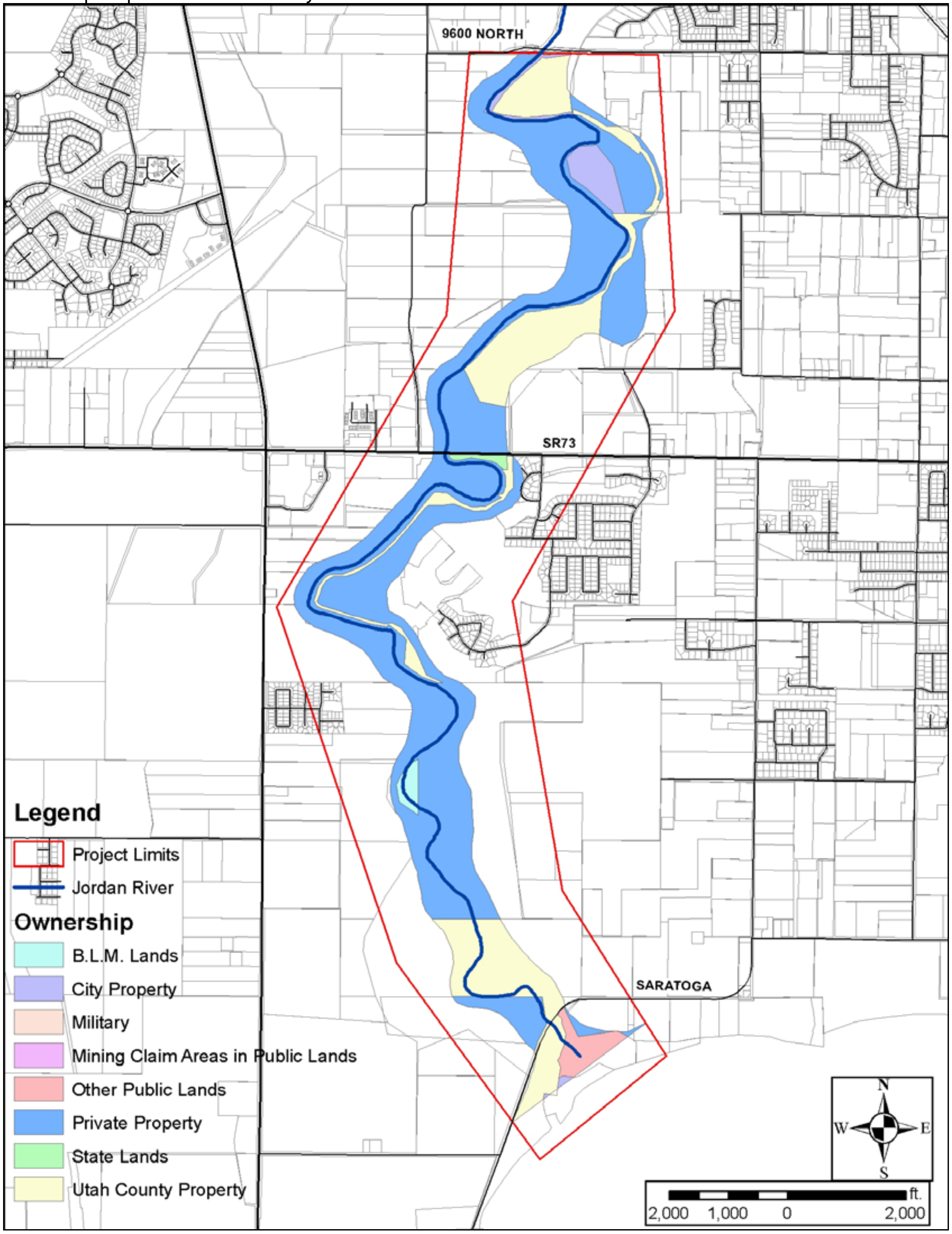
APPENDIX B

Affected Land Owner List (EHZ Properties)

Affected Land Owner List (EHZ Properties)

Figure B-1 shows the property ownerships affected by the recommended erosion hazard zone. The majority of lands affect are classified as private or as property controlled by Utah County. Isolated areas belong to city, state, and other public lands. Table A-1 lists the names of the owners as well as a brief description of the property as supplied in the Utah County parcel database.

FIGURE B-1
Ownership Map of Affected Areas by Erosion Hazard Zone



Using the Utah County parcel information there are 98 properties with some portion of the property within the erosion hazard zone (Table B-1). More information about these parcels can be found in the GIS shape file named EHZ_Ownership_utahco.

TABLE B-1.
Owners Affected by Erosion Hazard Zone

OWNER	PROPERTY TYPE
ALLRED, LILIAN D	MULTIPLE RES + AG
BROTHERS, GARNA L	VACANT
CAMPBELL, CLINE TEE	VACANT
CHIU, RICHARD H & PATRICIA JT	VACANT
CHIU, RICHARD H & PATRICIA M JT	VACANT
CORP OF PRES BISHOP CHURCH OF JESUS	NOT LISTED
CROOKSTON, ROBERT N & PHYLLIS TEE	VACANT
DAKOTA HOMES INC	VACANT
FRANC, JAMES & BONNIE JT	RESIDENTIAL-SINGLE > 1 ACRE
GULBRANDSEN INVESTMENTS LLC	VACANT
HARKER FAMILY LIMITED PARTNERSHIP	VACANT
HATCH INVESTMENTS	AGRICULTURAL
HEISELT, JAY D & VIKI M JT	VACANT
JESSOP, KARL W ET AL LF EST	RESIDENTIAL-SINGLE > 1 ACRE
JOHNSON, KRAIG	VACANT
JORDAN LANDING INVESTMENTS LC AN INT	VACANT
JORDAN RIVER FARM & RANCH LTD	VACANT
KUHN, K PAUL & JENNIFER E JT	VACANT
LEHI CITY	NOT LISTED
LIEBER MANAGEMENT CO	VACANT
MC LACHLAN, JOSH & SCOTT S JT	VACANT
MC LACHLAN, SCOTT C & JULIE A	VACANT
MC LACHLAN, SCOTT C & JULIE A JT	RESIDENTIAL-SINGLE > 1 ACRE
MERRILL, BARBARA FRANCES	VACANT
MERTENS, GENEVIEVE	VACANT
MILLER, GAE O	AGRICULTURAL
MITCHELL, VERN C & ARDYCE L E JT	VACANT
NOT LISTED	NOT LISTED
OLD TOWNE SQUARE LLC	MULTIPLE RES + AG
PETERSON, JEFFREY SCOTT	VACANT

OWNER	PROPERTY TYPE
POSEY, BOBBIE M & KERRY R TEE	VACANT
RIVER BEND LLC	VACANT
ROWLAN, STAN T ET AL AN INT	VACANT
SALT LAKE CITY	NOT LISTED
SOA INVESTMENTS LTD	AGRICULTURAL
STREET ON BOOK 58 PAGE 37	NOT LISTED
SUMSION, THOMAS CRAIG	VACANT
THOMPSON, HYRUM	VACANT
THOMPSON, LELAND	RESIDENTIAL-SINGLE > 1 ACRE
UTAH COUNTY	NOT LISTED
VALLEY VIEW STAKE CHURCH OF JESUS CH	NOT LISTED
WILLOW PARK LLC	RESIDENTIAL-SINGLE > 1 ACRE
WILLOW PARK RIVER LLC	VACANT

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