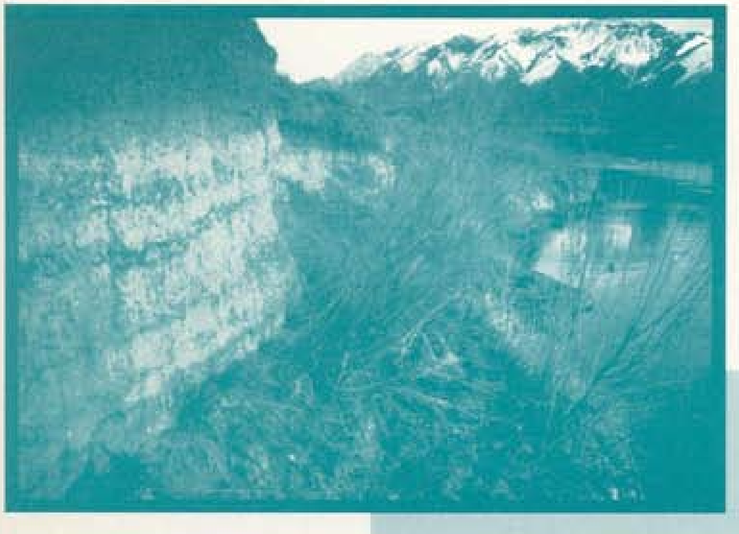
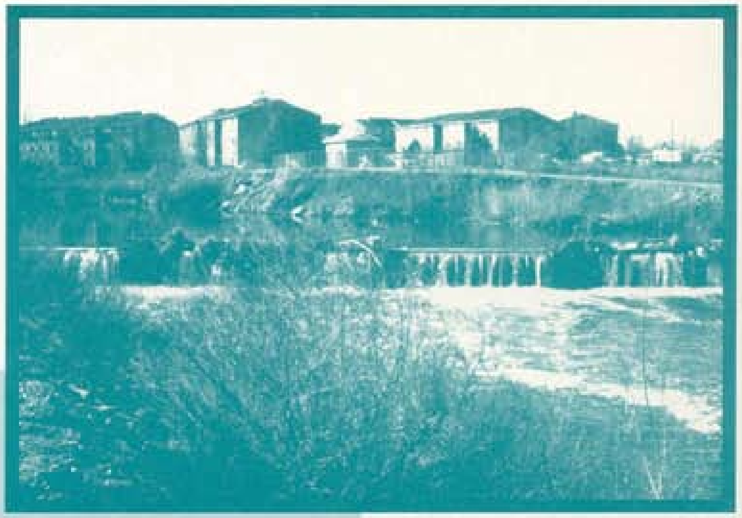
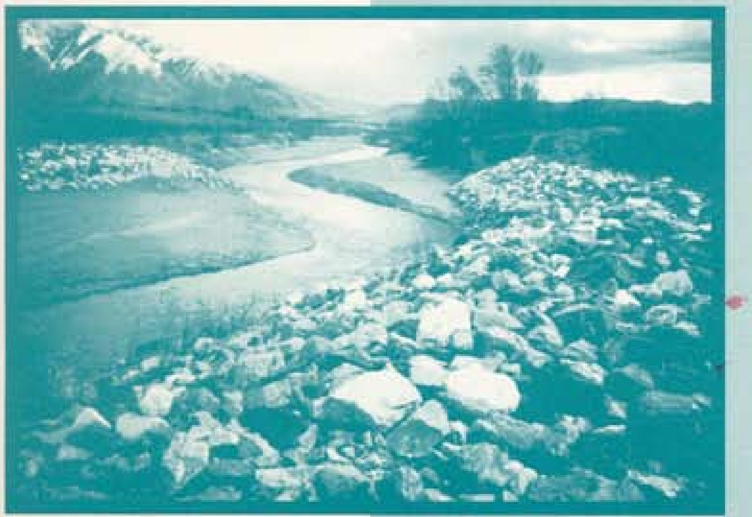
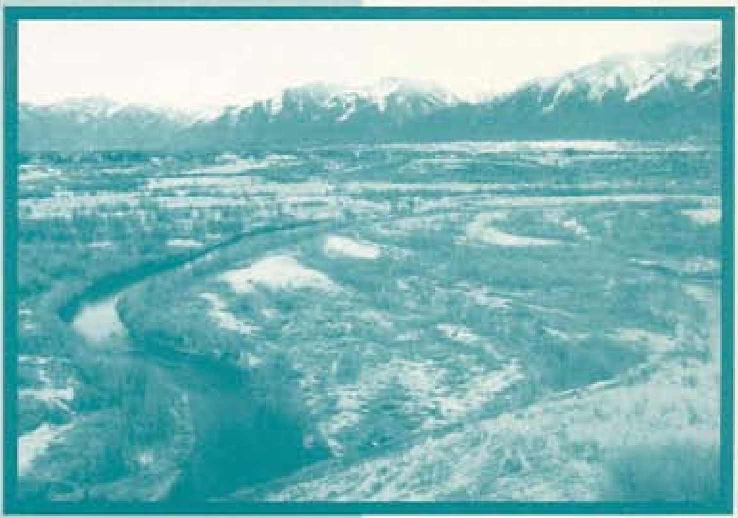
JORDAN RIVER STABILITY STUDY

DEC. 1992









Submitted to
SALT LAKE COUNTY

Submitted by
CH2M HILL

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Executive Summary

This report summarizes the results of analyses performed to evaluate the stability of the Jordan River from the Surplus Canal diversion to the Utah/Salt Lake County line. The primary purpose of this study was to develop a stability management plan that could be used by Salt Lake County and the ten incorporated cities that border the Jordan River to manage and protect the river, as well as development along the river. The channel instability problems experienced during the floods of the 1980s, in conjunction with current and projected development along the Jordan River flood plain, accentuate the need for this study.

Detailed historical, empirical, and geomorphic analyses were conducted to assess the existing river stability and to identify existing and potential future stability problems. The detailed stability analyses indicated that long-term degradation and bank erosion are likely to occur throughout the study reach of the Jordan River until a more stable slope and channel pattern is established. A stable slope will be provided for through increased meandering and strategic placement of grade control structures. A stable channel pattern will develop naturally by increased meander development. A meander corridor that will contain expected channel changes was proposed based on the detailed analyses.

The river stability management plan was developed to prioritize recommended river management alternatives that will control stability problems. The plan stresses the importance of utilizing nonstructural management techniques, such as zoning restrictions and control of land use, within a defined channel meander/bend migration corridor. Structural elements of the plan are intended to be used to enhance natural, on-going fluvial processes that are reestablishing a more natural channel pattern as well as protect existing development from erosion hazards. This stability management plan may be used as one element of an overall river parkway management plan for the Jordan River.

The major findings and recommendations of the report are summarized below:

- The Jordan River is more like a managed irrigation facility than a natural river that floods in response to rainfall and snowmelt. River management impacts from the Utah Lake Compromise Agreement, irrigation releases and diversions, and riverine development give the Jordan River unique hydrologic and geomorphic characteristics.
- The channel stabilization work performed in the 1950s between 2100 South and 14600 South contributed to many of the existing river stability problems. The channel slope increase induced by this channel straightening resulted in increased flow velocities and caused higher sediment transport rates. These factors acted to destabilize the channel bed and cause accelerated bank and bed erosion.

- The future equilibrium characteristics of the Jordan River include increased meander amplitude, decreased meander wavelength and radius of curvature, slightly flatter channel slopes, bank slopes of 3:1 or flatter, increased riparian vegetation, and an increased channel width/depth ratio.

- Much of the channel instability witnessed during the 1983-1987 floods was probably the result of the river trying to reestablish its prechannelization slope, width, and meander pattern. Efforts to prevent the river from returning to an equilibrium form will require increasing levels of structural improvements such as riprap bank protection, grade control structures, and scour protection.

Prioritized recommended management alternatives for the study reach are summarized below and shown in Figure 16, (all figures are included in Attachment 1).

Reaches 1 to 9: Entire Study Area

- Restrict development within the meander corridor.

- Allow bank erosion to occur within the meander corridor until prechannelization sinuosity is reestablished.

- Revegetate and regrade channel banks after stable channel pattern is established.

- Establish a bridge inspection and monitoring program.

- Establish a channel monitoring program using monumented cross sections.

- Survey, or prepare legal descriptions of meander corridor limits for use in zoning and community development plans.

- Acquire key parcels within the meander corridor.

- Regulate construction of future bridge and utility crossings to ensure adequate design for scour, flood conveyance, and conformance with goals of the river corridor.

Reach 1: Turner Dam to Joint Diversion

- Monitor bank stability near railroad grades and canals.

Priority for structural solutions: No structural measures recommended.

Reach 2: Joint Diversion to 14600 South

- Monitor bank erosion near canals.

Priority for structural solutions: No structural measures recommended.

Reach 3: 14600 South to 12600 South

- Construct riprap bank protection to protect sewer line in overbank area upstream of 12600 South. An alternative improvement would be to relocate the sewer line.

- Construct riprap bank protection to stabilize bridge approach section at 12600 South.

Priority for structural solutions: HIGH (sewer line protection)
LOW (bridge approach)

Reach 4: 12600 South to 10600 South

- Construct grade control at 10600 South to prevent headcut migration.

Priority for structural solutions: LOW (grade control)

Reach 5: 10600 South to North Jordan Diversion

- No special considerations.

Priority for structural solutions: No structural measures recommended.

Reach 6: North Jordan Diversion to 6400 South

- Construct grade control at 7800 South, 9000 South.
- Construct riprap bank protection on east bank, Stations 462 to 475.
- Stabilize Sharon Steel tailings embankment.

Priority for structural solutions: MODERATE (grade control)
LOW (bank protection)
LOW (tailings embankment)

Reach 7: 6400 South to Brighton Diversion

- Construct grade control at 5400 South, 4800 South, and I-215.
- Construct riprap bank protection on west bank, Stations 373 to 385.
- Monitor bank erosion, Stations 320 to 330.
- Monitor sediment deposition at monumented cross sections.

- Dredge deposition near mouth of Little Cottonwood Creek to surveyed 1990 flow line, as needed.

Priority for structural solutions:
HIGH (grade control at 5400 South)
HIGH (dredge near Little Cottonwood Creek confluence)
MODERATE (bank protection, Stations 373 to 385)
LOW (grade control and 4800 South, I-215)
LOW (bank protection, Stations 320 to 330)

Reach 8: Brighton Diversion to Mill Creek

- Construct grade control at 3900 South and 3300 South.
- Construct riprap bank protection on east bank, Stations 120 to 127.
- Construct riprap bank protection on west bank, Stations 95 to 100.
- Monitor bank erosion, Stations 140 to 157. If required, extend riprap bank protection on west bank, Stations 140 to 157.
- Monitor sediment deposition at monumented cross sections.
- Dredge deposition near mouth of Big Cottonwood Creek to surveyed 1990 flow line, as needed.

Priority for structural solutions:
MODERATE (dredge bear Big Cottonwood Creek confluence)
MODERATE (grade control)
MODERATE (bank protection, Stations 140 and 157)
LOW (bank protection, Stations 95 to 100 and Stations 120 to 127)

Reach 9: Mill Creek Confluence to 2100 South

- Dredge sediment deposition in accordance with U.S. Army Corps of Engineers (COE) maintenance agreement.

Priority for structural solutions: MODERATE (dredge channel to COE standards)

Glossary

Alluvial Fan. A fan-shaped deposit of sediment located where a stream issues from a narrow valley of high slope onto a plane or broad valley of low slope.

Amplitude. A characteristic of a river meander. See Figure 9A.

Angle of Repose. The maximum slope or angle at which a cohesionless material such as soil or loose rock remains stable. When this slope or angle is exceeded, mass movement by slipping and water erosion may be expected.

Contraction Scour. A form of scour frequently occurring in rivers at bridge crossings where stream width rapidly contracts causing an increase in stream velocity and/or turbulence.

Dynamic Equilibrium. A natural state of regular, expected channel change with time where stream characteristics naturally adjust to the physical conditions of the environment.

Emphemeral Stream. A stream or reach of stream that does not flow during parts of the year.

Escarpment. A cliff or steep slope separating two comparatively level or more gentle sloping surfaces. Escarpments are formed by erosion or faulting.

Facies. A grouping of sediments, rocks, or soils with a common or related origin.

Fluvial. Of or pertaining to rivers and stream flow.

Froude Number. A number describing the ratio of inertial to gravitational forces in flowing water. A Froude number greater than one indicates supercritical flow.

Geomorphic. Of or pertaining to the figure of the earth or the form of its surface; resembling the earth.

Geomorphology. A branch of physiography and geology that deals with the form of the earth, landforms or the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.

Headcutting. Channel degradation associated with abrupt changes in the bed elevation (headcut) that migrate in an upstream direction.

Holocene. Recent; that period of geologic history (an epoch) since the last ice age in North America (the past 10,000 years); also the series of strata deposited during that epoch.

Oxbow. The abandoned bow-shaped or horseshoe-shaped reach of a former meander loop that remains after a stream cuts a new, shorter channel across the narrow neck between closely approaching bends of a meander.

Perennial Stream. A stream or reach of a stream that flows continuously for all or most of the year.

Pier Scour. Scour resulting from the acceleration of flow around a pier and the whirling or circular motion of the water around the pier.

Planform. The form or pattern contour of an object as viewed from above; map view.

Pleistocene. The earlier of the two geologic epochs comprising the Quaternary Period (the past 2,000,000 years). Also the Post-Pliocene glacial age, which in the above terminology implies the glacial age is over. Also the series of sediments deposited during this period.

Riparian. Pertaining to anything connected with or adjacent to the banks of a river or stream.

Riprap. Rock material placed on stream banks to protect a structure or embankment from erosion.

Scarp. An escarpment, cliff, or steep slope along the margin of a plateau, terrace, or bench.

Scour. Erosion of streambed material by flowing water; usually considered as being localized as opposed to general bed degradation.

Shear Stress. Stress due to forces that tend to cause movement of strain parallel to the direction of those forces.

Sinuous. The "curviness" of planform of a river channel, the degree of meandering.

Stream Power. A technical term relating shear stress and velocity. The units signify power per unit area of stream bed.

Tectonic Forces. Geologic forces generated from within the earth the result in deformation of rock as well as vertical and horizontal movement of parts of the earth's crust.

Thalweg. The centerpoint or low flow channel of a stream.

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Section 1

Introduction

Study Description

In recent years, residential and industrial development has increased on land adjacent to the Jordan River. Additional development of the floodplain is currently being planned. Recent flooding and erosion damages along the river accentuate the need for a comprehensive management and river maintenance plan that will help Salt Lake County (hereafter, the County) and the ten incorporated cities that border the Jordan River manage and protect development near the Jordan River. The Jordan River Stability Study examines management strategies for one element of such a plan: river channel stability.

Location

The Jordan River flows north from Utah Lake in Utah County through the Jordan Narrows pass in the Traverse Mountains, ultimately discharging to the Great Salt Lake west of Salt Lake City. The study area on the Jordan River extends approximately 25 miles from the Surplus Canal diversion just downstream of 2100 South to Turner Dam, near the southern boundary of the County, as shown in Figure 1. (All figures are included in Attachment 1.) The study area includes unincorporated portions of the County as well as incorporated areas in South Salt Lake, West Valley City, Murray, South Jordan, Midvale, West Jordan, Riverton, Sandy, Draper, and Bluffdale.

Objectives

The primary objectives of this study are to:

- Develop a channel meander/bend migration corridor to be used in conjunction with the FEMA flood insurance rate maps to help the County and the cities manage and regulate development near the river.
- Identify river reaches with existing and potential channel stability problems and recommend potential solutions to stability problems with high potential to cause damage or disrupt essential services.
- Develop maintenance and management guidelines for the river. These guidelines may include recommendations regarding management or restriction of development, dredging, channel stabilization, and construction grade control structures on the river.

This report summarizes the results of a stability analysis of the Jordan River. Background information that describes the hydrologic, geologic, geomorphic, and historical setting of the study area will be presented. The background information presented provides the context for the analytical methods used in evaluating the stability of the river, as well as for the recommended management alternatives. The report also summarizes the results of an array of analytical methods that were used to evaluate existing river stability and to predict future river behavior. Finally, the report describes and recommends river stability management alternatives that may be used to regulate development in and near the Jordan River floodplain.

It is not the intent of this study to develop recommendations for a multiuse wetlands-recreation-land use corridor for the Jordan River, nor is it to design a stable river geometry for the entire study reach. However, it is likely that the results of this study will be used to help design a multiuse corridor when combined with additional information from other studies that may be prepared in the future.

Section 2
Reach Definition

For the purposes of this report, the study area was divided into nine reaches with similar geomorphic and hydraulic characteristics. The reach boundaries summarized in Table 2.1 will be used for the remainder of the report. Figure 2 shows the reach locations, as well as the locations of channel cross sections, channel stationing, sediment sampling locations, utility crossings, existing bank stabilization, and areas of historic dredging, as well as other information pertinent to this report.

Table 2.1
Jordan River Stability Study Reach Designations

Reach No.	Begin	End
1	Turner Dam	Joint Diversion
2	Joint Diversion	14600 South
3	14600 South	12600 South
4	12600 South	10600 South
5	10600 South	North Jordan Diversion
6	North Jordan Diversion	6400 South
7	6400 South	Brighton Diversion
8	Brighton Diversion	Mill Creek Confluence
9	Mill Creek Confluence	2100 South

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Section 3
Project Background

The Jordan River is unique. Some unusual factors have combined to create the river in its present form, which is different from many other rivers in Utah or the western region of the United States. Unless these factors are clearly understood, the stability of the Jordan River cannot be properly analyzed. Therefore, background information on the hydrology, geology, geomorphology, sediment characteristics, and history of the Jordan River is presented below to provide the context for the detailed stability analysis.

Hydrology

The hydrology of the Jordan River is the primary element that determines river stability. The unique hydrology of the Jordan River includes snowmelt flooding, pumped water supply, irrigation diversions, cyclical flood series, tributary flooding, and urban runoff. Water in the river is both the cause and mechanism for channel instability because it controls sediment transport, bank erosion, and growth of riparian vegetation. Understanding the hydrology of the Jordan River is critical to predicting future channel behavior and river instability.

General Hydrologic Information

The Jordan River bisects the Salt Lake Valley and flows northward from Utah Lake to the Great Salt Lake, a distance of approximately 50 miles. The stream gradient is very flat from Utah Lake to the Narrows, a natural restriction created as the river passes through the Traverse Mountains. The slope steepens perceptibly below the Narrows, then gradually flattens in the downstream direction.

Utah Lake is a natural lake with a drainage area of approximately 2,950 square miles. The Jordan River is the only natural outlet to the lake. In 1902, a gated outlet structure and pumping plant were constructed at the outlet to allow irrigation water to be stored and pumped from the lake during periods when natural releases were insufficient to meet irrigation requirements in the County. Since that time, the Utah Lake/Jordan River system has been operated as a managed irrigation facility.

Releases from Utah Lake into the Jordan River are governed by a legal agreement commonly known as the "Compromise Agreement." The normal management practices mandated by the agreement are summarized below:

- The gate at the Utah Lake outlet will be opened to release the lesser of the Utah Lake outlet capacity or the capacity of the Jordan River at 2100 South (in Salt Lake County) when the lake stage is above Elevation 4,489.045 (Compromise Elevation).

- Minimum flows are released into the Jordan River when the lake level falls below compromise elevation. These minimum flows are determined by the water rights of the canal and irrigation companies in Salt Lake County and their ability to distribute water for use. Irrigation releases generally occur between April 1 and October 15 of each year and vary according to water rights and demands.

The compromise agreement also includes some flood control operating options that are not pertinent to this study. A more detailed discussion of the compromise agreement is contained in the Jordan River Hydrology Report[1].

The study reach of the Jordan River receives flow from three major perennial streams: Little Cottonwood Creek, Big Cottonwood Creek, and Mill Creek. These three streams originate in the Wasatch Mountains southeast of Salt Lake City and traverse the suburban bench and valley lands en route to the Jordan River. Diversions are made near the canyon mouths on each of these streams for municipal and irrigation purposes. Other ephemeral streams convey surface runoff from the Oquirrh Mountains on the west side of the valley and several small drainage basins on the east side of the valley to the Jordan River. Groundwater, irrigation return flow, and urban stormwater also discharge to the Jordan River within the study area.

Most of the flow in the upper Jordan River is diverted into irrigation canals except during periods of high runoff from snowmelt events. The first significant diversions are made at Turner Dam near the Utah County line, where gravity diversions are made to the East Jordan and Utah and Salt Lake Canals and pumped diversions are made to the Utah Lake Distributing Canal, the Provo Reservoir Canal, and the Jordan Aqueduct. The Draper Irrigation Company pumps water from the East Jordan Canal at a point approximately 2 miles downstream from the diversion at Turner Dam. The Joint Diversion, located approximately 1.5 miles below Turner Dam, diverts water from the Jordan River into the South Jordan Canal and the Jordan and Salt Lake City Canal. Other diversions include the Mousley Ditch above 14600 South, the Beckstead Ditch at 12600 South, the North Jordan Canal near 9400 South, and the Brighton Canal near 4600 South. Figure 3 presents a schematic representation of the features of the Utah Lake/Jordan River hydrologic system.

Causes of Flooding

Historical records indicate that flooding on the Jordan River is closely associated with the stage of Utah Lake. Lake stage fluctuates from month to month, usually reaching its annual peak in May or June, and then falling steadily until the end of the irrigation season (usually around mid-October). These seasonal fluctuations are a result of heavy inflows from spring snowmelt, summer evaporation, and summer releases for irrigation, municipal, and industrial uses. There has been a wide variation of the peak annual lake stage over the approximate 110-year period of record. These cyclic variations are the result of varying

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[1] CH2M HILL, 1992, Hydrology Report for the Jordan River Flood Insurance Study, Prepared for FEMA Region 8, Denver, CO.

climatic conditions. Annual peak stages of the lake beginning in 1884 are shown in Figure 4. The annual maximum lake levels have fluctuated between a low of approximately 4,476.7 in 1935 to a high of 4,495.7 in 1862.

Historically, floods have occurred on the Jordan River during each year that the peak lake stage exceeded Elevation 4,491.1 (1862, 1884, 1885, 1886, 1893, 1907, 1909, 1910, 1921, 1922, 1923, 1952, 1953, 1983, 1984, 1985, and 1986). Flooding during these years was the most severe during the months of April, May, and June, the major annual snowmelt period, and was intensified in the lower portion of the study area by inflow from the tributary streams. Figure 5 shows the annual peak Utah Lake elevations and annual peak discharges on the Jordan River beginning in 1920.

Historical records indicate that high stages of Utah Lake and flooding on the Jordan River and its tributaries are most commonly associated with runoff from snowmelt. However, localized flooding on the Jordan River and flooding on the major tributaries have also resulted from cloudburst storms (summer thunderstorms), general rainstorms, and from a combination of rainfall and snowmelt. The flood characteristics for these storms are summarized in the Jordan River Hydrology Report[2].

Evaluation of the data presented in Figures 4 and 5 indicates several factors that are pertinent to the study of the stability of the Jordan River. These factors are listed below:

- The operational effects of the Compromise Agreement are evident. Due to pumping, there is little variation in annual peak flow rates at the Narrows gage from year to year during periods when the peak lake stage is below Compromise Elevation.

- Flood events on the Jordan River last for extended periods of time. Floods on the Jordan River are not "flashy" like those that occur on its major tributaries during spring snowmelt events. Because of spring runoff from wet cycles and the level of Utah Lake, floods on the Jordan River may last from several months to several years.

- Utah Lake has historically experienced approximately 30-year cyclic fluctuations in annual peak lake stage elevations as shown in Figure 4. These fluctuations are the result of long-term climatic trends or cycles. The information summarizing the cyclic highs and lows of Utah Lake are summarized in Table 3.1. Therefore, extended duration floods have occurred about every 30 years, with the most recent one occurring during the period between 1983 and 1987.

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[2] CH2M HILL, 1992, Hydrology Report for the Jordan River Flood Insurance Study, Prepared for FEMA Region 8, Denver, CO.

Table 3.1
Summary of Historic Highs and Lows of Utah Lake Stage

Peak High Years	Years Between Cyclic Peaks	Minimum Lake Level Years	Years Between Cyclic Lows
1862			
	22		
1884		1889	
	9		16
1893		1905	
	29		30
1922		1935	
	30		26
1952		1961	
	32		31
1984		1992	

Note: The wider variation in peak flows at the 2100 South gage is caused by flood peaks from snowmelt runoff in the major tributaries.

Geology and Geomorphology

Hydrologic impacts on the Jordan River act within the context of the geologic forces that occur on a geologic time scale. These geologic forces include tectonic uplift of mountain ranges, climatic changes associated with the glaciation of North America, and weathering and erosion of uplifted bedrock into the Salt Lake Valley with fluctuating ancient lake levels. These geologic forces continue to affect channel stability by controlling the types of channel behaviors that may occur as a result of the hydrologic processes. Therefore, understanding the geologic and geomorphic setting of the Jordan River is useful when attempting to predict future river behavior and to develop a meander corridor and a river management/maintenance plan. Pertinent geologic and geomorphic features of the river are summarized below.

Geologic History

The Jordan River reflects the complex tectonic and climatic geologic history of the Wasatch Front and the Salt Lake Valley. The tectonic forces that created the Wasatch Mountains occurred in two phases, the latter of which is still active today. This latter phase produced the dramatic mountain front through normal faulting along the Wasatch fault zone. Fresh fault scarps in the mouths of canyons to the east of the Jordan River testify of the ongoing forces of uplift. Tectonic uplift provides renewed energy for sediment transport into the Jordan River system. In the geologic past, these forces created alluvial fans that now underlie and are a sediment source for portions of the Jordan River floodplain. The effects of tectonism are also evident at the Jordan Narrows where the rising Traverse Mountains have created a steep, narrow river channel, where river erosion tries to keep pace with uplift.

Geoclimatic changes are also expressed in the geology of the Jordan River. Cooler, wetter climate in the late Pleistocene Period (100,000 to 10,000 years before present) resulted in high lake levels in glacial Lake Bonneville, the ancient predecessor of the Great Salt Lake. Peak lake levels were achieved about 10,000 to 14,000 years ago. These high lake levels affect the Jordan River in two ways. First, lake sediments underlie most of the river and comprise much of its bed and bank materials. Shore and delta sediment facies supply coarse-grained material, offshore facies supply more cohesive fine-grained material. Second, falling lake levels over the past 100,000 to 10,000 years left a series of broad inset riverine terraces (Figure 6). These terraces now define the geologic floodplain (river valley) of the Jordan River. The terrace margins also mark the limits of channel migration within their geologic period of formation. The lowest terrace, designated as Ofp on Figure 6, defines the limits of channel migration over the past 1,000 to 10,000 years. The terraces can often be identified by the canal systems that frequently follow their margins.

Geomorphology

In its current geomorphic configuration, the Jordan River is a perennial stream that is operated as an irrigation facility. As a result, discharges are generally much higher between April 15 and October 15 than during the rest of the year. The river is slightly sinuous, with sinuosity increasing upstream with slope in Reaches 5 through 9, except where river straightening has cut off meanders. The river takes on a transitional form in Reaches 3 and 4, with a meandering low-flow channel located within a braided high-flow channel. In Reaches 1 and 2, the river is contained within a shallow canyon in the Traverse Mountain foothills. Cut banks and incipient gravel bars that exist throughout the study area indicate that the river is attempting to reestablish a more sinuous planform in reaches that have been artificially straightened.

A longitudinal profile of the Jordan River shows a classic concave parabolic shape (Figure 7), with slope increasing in the upstream direction. Slope varies from about 2 feet per mile at 2100 South to about 27 feet per mile near Turner Dam. Four irrigation diversion structures, the Surplus Canal diversion structure, and one drop structure provide some control of channel slope and elevation. The elevation within the study area varies from about 4,494 feet above sea level at the Jordan Narrows to about 4,225 at the Surplus Canal diversion dam near 2100 South.

A series of riverine fill terraces that formed in response to the falling base level of glacial Lake Bonneville are found along the Jordan River. The escarpments, or bluffs, that mark the boundaries of these terraces define the limits of channel movement for the geologic time period when the floodplain was at the elevation of the terrace (Figure 6). The lowest terrace unit is comprised of land area that was the floodplain prior to the episode of channel degradation, which followed the river straightening and maintenance routines practiced over the past 40 years. This terrace supports several perched oxbow lakes and meander cutoffs that still contain water. The bank erosion currently taking place is the result of the newly degraded channel scouring out a floodplain that will form a new terrace.

The Jordan River has experienced radical changes in its geomorphology in the past 100 years. While the river remains a perennial, somewhat sinuous stream, some reaches have changed from a natural, meandering stream to a highly urban, channelized river. The river is crossed by 18 bridges, four active irrigation diversion structures, and approximately 34 pipeline and utility crossings. A large portion of the study reach has been straightened, dredged, relocated, stabilized, or otherwise modified. Significant portions of the natural floodplain have been replaced with high density development, mine tailings, industrial development, and other obstructions. River straightening resulted in a deepened channel, increased flow velocities, destabilized channel banks, and increased channel slope.

Recent activities such as regulating discharges, river straightening, dredging, channelization, diversion of stream flows, urbanization, and agriculture have overwritten much of the natural geologic and geomorphic history of the Jordan River. The pace of these recent activities is much more rapid than the geologic forces that shaped the river. Therefore, the Jordan River is undergoing a rapid adjustment in response to these changes. However, natural geologic and geomorphic factors will continue to affect long-term river conditions as it adjusts to a new equilibrium form.

Soil Types

The soils of the Jordan River valley have been mapped by the USDA Soil Conservation Service (SCS)[3] and several other investigators[4,5]. Upstream of 3100 South, Holocene floodplain soils form the geologic floodplain (Figure 6). Downstream of 3100 South, the soils units are comprised of the Jordan River floodplain/delta complex, a remnant of higher lake levels. The geologic floodplain is inset into the clays, silts, and sands of the late Pleistocene Provo Formation lake bottom sediments. The Provo Formation is in turn inset into the Provo Formation shore facies units and the Alpine-Bonneville Formations.

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[3] USDA Soil Conservation Service, 1974, Soil Survey of Salt Lake Area, Utah.

[4] Marsell, R.E., and Threet, R.L., 1960, Geologic map of Salt Lake County, Utah: Utah Geological and Mineral Survey Bulletin 69.

[5] Davis, F.D., 1983, Geologic Map of the Central Wasatch Front, Utah, Map 54-A: Utah Geological and Mineral Survey.

Soils in the geologic floodplain are comprised of poorly drained, gravelly alluvium and stony, fairly cohesive finer-grained alluvium. Recent local cultivation and prehistoric floodplain deposition has created a more fine-grained cap unit for the floodplain soils. Soil units located within the geologic floodplain, but distal from the channel, are typically silty or loamy units that are moderately well drained. Soil units mapped by the SCS include the Chipman-Magma-Ironton association in the floodplain, and the Bluffdale-Taylorsville-Hillfield-Bramwell association on the low terraces within the geologic floodplain.

Soil units as described and defined by the SCS were also considered in development of the corridor. The SCS describes soil units as floodplain soils or floodplain terraces. Terraces are formed over geologic time rather than engineering time by climatic changes, base level falls, or other changes in sediment supply. Therefore, it may be assumed that the terrace boundaries have generally been outside any active erosion area for hundreds to thousands of years. These terraces occur throughout the study area, but are most evident upstream of 14600 South where the stream impinges on the bluffs that outline the Pleistocene river valley.

Floodplain and stream bank soils affect channel stability. Coarse-grained sediment from gravel units are deposited in the stream as gravel bars, which often cause meandering and bank erosion to increase. Fine-grained soil units are more resistant to erosion and may form more stable vertical banks.

Geologic and Geomorphic Effects on Stability

Rivers are dynamic landforms. The concept of stability when applied to fluvial systems is more correctly referred to as dynamic equilibrium, since natural rivers are continually moving sediment, eroding their banks, and depositing sediment in low energy zones. Dynamic equilibrium is a state of constant, regular change. On "stable" rivers, it is natural for meanders to migrate and for bank locations to change with time, but the river pattern (straight, meandering, or braided) remains the same. For the Jordan River, migration of meander bends and erosion of banks is part of its dynamic equilibrium. Consideration of the geomorphic concept of dynamic equilibrium lends perspective to discussions of channel stability. Channel maintenance and management alternatives designed to stabilize isolated points may disrupt the overall dynamic equilibrium and may accelerate erosion in adjacent reaches.

Numerous geomorphic factors influence channel stability. These factors include peak discharge, flow duration, average discharge, channel slope, mean velocity, the velocity distribution within a channel section, flow width and depth, sinuosity, bank slope and height, water temperature, sediment supply, suspended sediment concentration, bank sediment cohesiveness, type and density of vegetative cover, urbanization within the contributing watershed, and land use practices within the floodplain, to name only a few. Obviously, the number and complexity of these variables makes prediction of river stability very difficult. The complex interaction of these variables also makes isolating the effect of a change in a single variable challenging.

Because of the complexity of the geomorphic variables affecting river stability, two simplified methods have been developed to predict river behavior. These methods are:

- Analyzing historical data to determine past river behavior
- Using established geomorphic relationships that attempt to relate specific geomorphic parameters

Both of these approaches were used to predict river behavior for the Jordan River, and are discussed in detail later in this report.

Sedimentation

The sediment characteristics of a river affect its stability. For example:

- Sand/gravel streams tend to be steeper, wider, and shallower than silt/clay bed streams.
- Channel banks composed of finer sediments tend to be steeper (have a higher angle of repose) than coarser-grained banks.
- Sudden addition or extraction of sediment may cause the channel pattern to drastically change, resulting in possible headcutting or possibly increasing flood water surface elevations.

Therefore, understanding the sediment characteristics of the Jordan River is critical in evaluating channel stability and in developing a meander corridor. Key sediment characteristics include sediment type, sources of sediment supply, and areas of sediment deposition or removal (sediment sinks).

Sediment Type

The Jordan River is a gravel bed stream with the median particle diameter in the fine gravel range throughout most of the study area (Figure 8). The lower reaches are somewhat finer grained with the median sediment size in the medium to fine sand range. The sediment comprising the banks of the river is relatively coarse, with the median sediment diameter in the fine gravel to coarse sand range throughout most of the study area. The downstream reaches have somewhat increased silt-clay content in the bank and bed sediments. The upstream reaches between Turner Dam and 14600 South have some cobble and boulder-sized sediment in the bed, not reflected in sediment sampling or in Figure 8.

Figure 8 shows the results of sediment sampling in the study area. (Individual sample analyses are included in the Appendix). Median particle diameter data summarized in

Figure 8 shows that bed and bank sediment are similar in the upstream reaches, but diverge downstream. The fact that bank sediments are generally finer in the downstream direction probably reflects long-term degradation and armoring of the streambed. These concepts are discussed in more detail later in this report.

Sources of Sediment

The primary sources of sediment in the Jordan River are the channel bed and banks. Some fine sediment flows into the study area from the reach upstream of the study area, although the peak 100-year sediment inflow was estimated at only 26 ppm (320 tons per day) at Turner Dam. Most of the bed load sediment being transported in the reach upstream of the study area is probably trapped by Turner Dam. The low slope of the Jordan River upstream of Turner Dam probably limits sediment inflow to the study area as well. The HEC-6 analysis described later in this report discusses sediment supply in more detail. Other sediment sources include inflow from Big Cottonwood Creek, Little Cottonwood Creek and Mill Creek, as well as several smaller tributary streams. Sediment supplied from Big and Little Cottonwood Creeks and Mill Creek is of particular concern and has necessitated periodic dredging operations near their mouths.

Sediment Sinks

Sediment sinks are areas of net sediment loss from the river system. Periodic dredging operations are the only existing sediment sinks in the Jordan River study area. There are currently no commercial sand and gravel operations, sedimentation basins, or other sediment removal operations on the river. Deposition and removal of sediment occurs upstream of irrigation diversion structures and in other reaches, as indicated by the HEC-6 sediment transport model described later in this report.

Historical Modifications

Historical modifications of the Jordan River have probably had the most profound impact on channel stability. Historical modifications include channelization, channel straightening, dredging, construction of bridges, installation of utility crossings, and urbanization. Urbanization impacts include land use changes from natural open space to agricultural and residential/industrial developments. These modifications generally cause fluvial responses such as bank erosion, long-term channel scour, headcutting, or sediment deposition. Therefore, understanding historical and land use impacts is critical for evaluating channel stability.

Channelization

Although the Jordan River is not completely channelized in the style of Los Angeles "rivers", with fully lined concrete sections, its natural form has been extensively modified by urbanization. Most significantly, the river was straightened during the 1950s as a flood control measure designed to increase channel conveyance. As part of this straightening, meanders were cut off and the channel slope was significantly steepened. Consequently, stream velocity and shear stresses increased, accelerating erosion. Since the major channelization in the 1950s, river channelization activities have consisted of localized dredging to improve conveyance, levee construction, and isolated meander cutoffs intended to improve bridge hydraulics.

According to the County, "recent" river dredging has been performed in the reaches summarized in Table 3.2 and shown in Figure 2. The most recent dredging took place during or after the 1983-87 floods. The County is required to dredge the channel downstream of Mill Creek as part of an agreement with the COE. Periodic surveys of the channel bottom downstream of the Mill Creek confluence are used to determine when dredging is needed. According to the County, recent dredging has been performed at other locations on the river only to protect structures or to control flood levels that threatened to exceed channel banks.

Table 3.2
Historical or Existing Dredging Locations

Reach No.	Approximate Location (Station)	Date of Activity
9	0 to 75	As required by COE agreement
8	100 to 120	As needed
8	225 to 250	As needed
7	298 to 305	As needed
7	430 to 445	As needed
6	610 to 680	As needed
5	680 to 770	As needed
4	770 to 820	As needed

Many reaches that were channelized or dredged in the past have required additional maintenance to mitigate other channel stability problems that formed after channelization. Evaluation of the impacts of channelization and dredging for specific reaches are described in more detail later in this report.

Stabilization

Two types of structural channel stabilization methods exists in the study reach: grade control structures and/or bank stabilization. Grade control structures provide vertical stabilization of the river by controlling long-term scour. Bank stabilization is designed to prevent lateral movement of the channel banks. Other naturally occurring forms of erosion control such as armoring, bank vegetation, and geologic control may also be present. Table 3.3 summarizes the location of various engineered stabilization structures in the study area.

Bank stabilization methods in the study reach include riprap bank protection on channel bends and at bridge sections. The bridge structures themselves also provide some degree of lateral channel stabilization. Two forms of vertical grade control currently exist in the study reach. One is located near the 6400 South Bridge, and the other is located downstream of 7800 South upstream of the railroad crossing. These structures are comprised of driven sheet piles, and dumped riprap. Grade control is also provided by the four check dams/irrigation diversion structures within the study reach (Turner Dam, Joint Diversion, North Jordan Diversion, and Brighton Diversion).

The presence of the stabilization structures listed in Table 3.3 and shown in Figure 2 limits the freedom of the river to adjust its geomorphology. Vertical grade control prevents headcutting and decreases the likelihood of bank collapse. Reaches with bank protection may not experience lateral erosion, but scour may be increased in adjacent reaches or on unprotected banks across the river. For example, installation of bank protection on only one bank may accelerate erosion on the opposite bank if the stream experiences a sediment deficit or if the bank protection directs higher velocities at the opposite bank. This situation may occur in Reach 3 near channel Station 945. Elsewhere, stabilization may interfere with natural long-term meander migration and cause accelerated meander development in upstream reaches. Therefore, existing stabilization measures must be considered in the detailed stability analysis and in the development management alternatives.

Channel Realignment

Another form of channelization that has occurred on the Jordan River is complete relocation of the river channel. This has occurred in several locations as part of major developments. Most notably, the river was shifted to the opposite side of the floodplain and straightened between 6400 South and 9000 South as part of smelter operations and industrial development in the 1950s. Elsewhere, short sections of the river were straightened to either improve bridge hydraulics or to increase developable land area.

Utility Crossings

Utility crossings are another form of development along the river that affects management of the river and river stability. Table 3.4 summarizes the type and approximate location of existing utility crossings. Only those utility crossings that are located under the river channel or are independently suspended over the river are shown in Table 3.4. Suspended utility lines attached to traffic bridges were not considered.

Utility crossings affect river stability management in several ways. First, some crossings may provide temporary grade control depending on the size and stability of the conduit. Second, unstable utility crossings subject to failure may initiate headcuts if long-term scour or bank erosion occurs and exposes the conduit to hydraulic forces. Therefore, management options must include either an evaluation of grade control to protect utility crossings or the cost of utility relocation.

Table 3.3
Location of Engineered Stabilization Structures

Reach No.	Structure	Approximate River Station	Install Date
9	Diversion-Surplus Canal	0	<1950
9	Levee-bank protection	0 - 72	1960
8	Riprap bank protection	90	1985
8	Riprap bank protection	137	1985
8	Riprap bank protection and concrete sewer cap: grade control	203	1985
8	Riprap bank protection	265	1985
8/7	Brighton diversion/Drop structure	278	<1950 and 1986
7	Riprap bank protection	290	1985
7	Riprap bank protection	365	1985
7	Riprap protection on east bank toe	435	1986
7/6	Sheet pile drop structure	461	1986
6/5	North Jordan diversion structure	678	<1950 and 1986
5	Riprap bank protection	680	1985
3	Riprap bank protection	950	1992
3	Rock-filled trench	980	1992
2	Riprap bank protection	1140	1985
2	Gabion slope protection	1220	1985
2	Riprap bank protection	1240	1985
2/1	Joint diversion structure	1253	<1950
1	Riprap bank protection	1340	1985
1	Turner Dam/diversion structure	1345	<1950

Table 3.4
Location of Buried Utility Crossings

Reach No.	Approximate Station	Type of Utility
9	3	Telephone
8	110	Sewer
8	127	Sewer (2)
8	187	Water
8	204	Sewer
8	270	Water
7	298	Telephone
7	373	Telephone, Water, Sewer
7	446	Water, Sewer
6	464	Water (2)
6	488	Sewer (Suspended Line)
6	491	Sewer (2)
6	545	Telephone
6	613	Sewer (Suspended Line)
6	628	Sewer
6	641	Water
6	671	Sewer Siphon
5	707	Sewer (Suspended Line)
4	771	Sewer (2)
4	825	Sewer
4	837	Water
4	887	Sewer
4	915	Telephone
3	970	Sewer
3	994	Sewer
3	1085	Natural Gas
1	1267	Water
1	1319	Water

Grazing

Overgrazing of riparian areas in the west has been demonstrated to lead to bank erosion as well as loss of the riparian habitat. Very little data were available from which to quantify grazing impacts on the Jordan River; what little data are available are conflicting. Field investigations conducted for this study indicated that in many reaches cattle are fenced out of the river bottom. However, anecdotal evidence provided by agency reviewers[6] indicate that cattle, horses, and sheep have extensively overgrazed the river banks between the narrows and 3300 South and that requests for grazing access are frequently received for the Jordan River. Certainly, the generally poor quality of riparian habitat supports the possibility that riparian areas have been overgrazed. Where overgrazing has occurred, the loss of vegetation decreases the resistance of the banks to erosion, making them more susceptible to flood damage.

SLC79/025.51

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[6] Personal communications from Michael Schwinn/Corps of Engineers on October 19, 1992 and from Steve Jensen/Salt Lake County Commission Staff on October 21, 1992.

Section 4
Analysis of River Stability

The stability of the Jordan River was evaluated using three approaches. These approaches included analytical techniques, historical analysis, and comparison with the conclusions from other studies of the Jordan River. Results from these approaches were combined to develop a meander corridor, predict the general river pattern that may exist in the year 2090, and determine areas of expected instability or channel change. The results were also used to evaluate and recommend river management alternatives.

Analytical Approach

The analytical approach used geomorphic and engineering equations to relate measurable stream characteristics and hydraulic parameters to expected channel responses and channel stability. Hydraulic parameters considered in this evaluation included channel width, water depth, velocity, shear, unit discharge, and flow rate. These hydraulic parameters were obtained from the HEC-2 model output from the draft FEMA Flood Insurance Study (FIS) for the Jordan River. Other stream characteristics such as meander wavelength, meander amplitude, sinuosity, channel and valley slope, bank height, bed and bank sediment size, and channel width/depth ratio were measured from aerial photographs and topographic maps, or were obtained from field data.

Caution must be exercised when using analytical approaches to evaluate river sedimentation and erosion. There is a wide variety of river types and river processes that may not be reflected by empirical relationships. The geomorphology of the Jordan River, in many ways, is unique due to its unusual hydrologic characteristics, geologic setting, and the varying types of channelization that occur along the river. Therefore, the results of the analytical evaluation should be viewed as general guidelines rather than engineering specifications.

Hydraulic Variables

Hydraulic data were obtained from HEC-2 model output prepared for the draft FIS for the Jordan River. Values of channel velocity, water depth, top width, channel width, shear stress, Froude number, energy slope, channel slope, and unit discharge for each cross section were obtained from HEC-2 model output for the 10- and 100-year floods. The HEC-2 reach-averaged hydraulic data are summarized in Table 4.1.

Hydraulic Geometry Variables

Hydraulic geometry variables are physical descriptions of key channel characteristics such as bank height and width between channel banks, sinuosity, and other meander characteristics of the river, as well as the sediment properties of the bed and banks.

Table 4.1 Jordan River Stability Study
Reach-Averaged Hydraulic Variables

Reach No.	Discharge (cfs)	Vel. (ft/s)	Flow Depth (ft)	Flow Topwidth (ft)	Channel Depth (ft)	Channel Width (ft)	Energy Slope (ft/ft)	Channel Slope (ft/ft)
100-Year Flood Hydraulic Variables								
9	4700	3.4	12.8	181	4.8	120	0.00026	0.00151
8	4369	4.5	13.4	354	5.5	82	0.00061	0.00282
7	2974	5.6	8.7	176	3.7	76	0.00123	0.00326
6	2790	5.1	10.2	156	4.9	68	0.00134	0.00294
5	3000	5.5	8.5	422	4.8	76	0.00099	0.00243
4	3000	5.0	7.5	425	4.7	109	0.00164	0.00292
3	3000	6.9	6.6	365	4.0	95	0.00222	0.00314
2	3000	6.4	8.6	140	5.1	73	0.00361	0.00539
1	3000	5.9	7.8	335	5.5	103	0.00474	0.00730
10-Year Flood Hydraulic Variables								
9	2000	2.6	8.1	132	4.8	120	0.00032	0.00151
8	1858	3.4	9.3	118	5.5	82	0.00072	0.00282
7	1252	4.0	6.0	88	3.7	76	0.00124	0.00326
6	1170	3.7	6.9	76	4.9	68	0.00155	0.00294
5	1260	3.5	6.6	143	4.8	76	0.00084	0.00243
4	1260	3.7	5.3	166	4.7	109	0.00170	0.00292
3	1260	5.3	4.6	138	4.0	95	0.00250	0.00314
2	1260	5.0	5.5	85	5.1	73	0.00424	0.00539
1	1260	4.7	5.8	212	5.5	103	0.00901	0.00730

Reach-averaged hydraulic geometry data are summarized in Table 4.2. Hydraulic geometry parameters were either measured from 1990 aerial photographs with topography that were prepared for the Jordan River FIS or were obtained from the FIS HEC-2 output. Channel meander amplitude and wavelength measured from 1937 aerial photographs were also used for comparison with more recent values. Channel sinuosity was measured for each year of record between 1856 and 1990.

Analytical Methodologies

Numerous equations have been developed that attempt to estimate channel stability from measurable parameters. There are two types of these equations. The first type of equation is well established in literature and describes general trends in river behavior (e.g., Lane's relation). The second type of equations are empirical equations, which were developed from specific data sets and which describe average relationships between two or more geomorphic or hydraulic parameters. These equations are used to predict specific numerical values of variables for design (e.g., Parker's meander equation, or Schumm's silt factor equation). Both types of equations were used to analyze the stability of the Jordan River.

Lane's Relation

Lane's[1] classic equation:

$$Q_sD_{50} \propto QS$$

This describes the relationship between the primary independent and dependent variables, which describe stream stability. These variables include:

Q_s = sediment discharge
D_{50} = mean sediment diameter
Q = water discharge
S = channel slope

Lane's equation predicts that an increase in water discharge must be accompanied by a decrease in slope (bed degradation), or an increase in sediment discharge (erosion) and/or sediment size (armoring) will result. Channel straightening along the Jordan River during the 1950s increased the channel slope without changing water discharge or sediment size. By applying Lane's equation to the 1950 channelization, an increase in sediment discharge ($Q_s^+D_{50}^0 \propto Q^0S^+$) is predicted. The increased sediment demand was supplied in part from the channel banks, resulting in bank migration, and in part by bed erosion, which caused long-term scour.

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[1] Lane, E.W., 1955, Design of Stable Channels. Trans. Am. Soc. of Civil Engineers, Vol. 120, p. 1234-1279.

Table 4.2
Jordan River Stability Study
Reach-Average Hydraulic Geometry Data

Reach No.	Dominant Discharge (cfs)	Unit Discharge (cfs/ft)	Width/ Depth Ratio	Depth (ft)	Width (ft)	Meander Wavelength (ft)	Meander Amplitude (ft)	Meander Radius (ft)	Sinuosity	Sediment D_{50}, Bank (mm)	Silt-Clay % Bank	Sediment D_{50}, Bed (mm)	Silt-Clay % Bed	Channel Slope (ft/ft)
9	1200	10.0	25	4.8	120	2085	66	0	1.10	0.1	51.0	5.1	1.0	0.00151
8	1100	13.4	15	5.5	82	1265	350	1541	1.37	0.1	51.0	5.1	1.0	0.00282
7	1000	13.1	21	3.7	76	2403	154	3443	1.07	7.6	0.7	8.4	1.0	0.00326
6	1000	14.7	14	4.9	68	2723	193	2488	1.08	5.8	0.8	8.4	0.7	0.00294
5	1000	13.2	16	4.8	76	2320	116	5171	1.05	6.0	1.1	6.4	0.2	0.00243
4	1100	10.1	23	4.7	109	1394	195	2716	1.06	6.1	1.4	19.1	9.5	0.00292
3	1100	11.5	24	4.0	95	1900	297	3008	1.15	10.2	2.5	10.9	1.7	0.00314
2	1200	16.4	14	5.1	73	1443	317	3687	1.20	7.6	8.7	8.9	1.9	0.00539
1	1200	11.6	19	5.5	103	764	138	2093	1.18	8.9	8.7	8.9	1.5	0.00730

Lane's equation also indicates that the operation of irrigation diversion structures on the Jordan River affects the sediment transport capacity of the river. Reductions of the average water discharge due to irrigation diversions result in a decrease in sediment discharge [the bed sediment in transport ($Q_s^- D_{50}^0 \propto Q^- S^0$)]. Historical irrigation diversions may have partially offset some tendency of the river to scour due to the imposed slope increase induced by channel straightening. During the floods of the 1980s, water discharge significantly increased for an extended period and the major impact of straightening (slope increase) resulted in extensive bank erosion ($Q_s^+ D_{50}^0 \propto Q^+ S^0$).

Future erosion and sedimentation trends of the Jordan River may also be predicted using the Lane relation. As urbanization of the area within the County extends southward, sediment supply to the Jordan River will probably decrease (Q_s^-) and long-term water discharge rates probably will not change significantly (Q^0). However, cyclical trends of drought and flood will continue. Further channelization and straightening is unlikely in the short term. Therefore, Lane's relation for the Jordan River future may be written as: $Q_s^- D_{50}^0 \propto Q^0 S^0$. As written, this equation is out of balance. In the short term, during the current dry cycle, the channel may be able to tolerate the decrease in sediment supply without significant erosion. However, during the next wet cycle, Q will increase (Q^+), requiring a decrease in slope and/or an increase in sediment discharge ($Q_s^+ D^0_{50} \propto Q^+ S^-$). These adjustments would be expressed as bank erosion, meandering, or long-term scour.

In summary, Lane's relation predicts further slope and sediment discharge adjustments that will result in scour. This tendency, considered in conjunction with the Jordan River's existing trend of scour, would exacerbate existing erosion problems in some reaches and cause further bank erosion.

Neill's Hydraulic Geometry Curves

Neill[2] developed a series of regression curves to predict the types of channel changes that may cause key channel variables to be altered. For the Jordan River, significant changes in key variables have occurred over the past 40 years. Reach-averaged values of depth, width, sediment size (D_{50}), channel forming discharge, and channel slope were plotted on Neill's curves. Bankfull capacity is normally used as the channel forming discharge. However, lacking more conclusive data, the channel forming discharge was assumed to be the 10-year peak flow rate. Note that in many cases the channel has capacity for the 100-year discharge, and in all cases contains the 10-year discharge.

Expected channel changes based on Neill's curves are summarized in Tables 4.3 and 4.4. Table 4.3 shows reach-averaged parameters for the existing channel. Table 4.4 shows predicted values of these parameters. Expected channel changes can be obtained by comparing predicted values to actual values. In general, Neill's curves predict that minor

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[2] Neill, C.R., Editor, 1990, Stability of Flood Control Channels: Draft document prepared for the Waterways Experiment Station and the Committee on Channel Stabilization of the US Army Corps of Engineers.

channel widening and slope reduction will continue. Slope decreases are expressed as long-term scour. Width increases are expressed as bank erosion.

Table 4.3
Jordan River Stability Study
Neill's Hydraulic Geometry Curves: Existing Channel Characteristics

Reach No.	Dominant Discharge (cfs)	Depth (ft)	Width (ft)	Sediment D_{50}, Bed (mm)	Channel Slope (ft/ft)
9	1,200	4.8	120	5.1	0.00151
8	1,100	5.5	82	5.1	0.00282
7	1,000	3.7	76	8.4	0.00326
6	1,000	4.9	68	8.4	0.00294
5	1,000	4.8	76	6.4	0.00243
4	1,100	4.7	109	10.2	0.00292
3	1,100	4.0	95	10.9	0.00314
2	1,200	5.1	73	8.9	0.00539
1	1,200	5.5	103	8.9	0.00730

Table 4.4
Jordan River Stability Study
Neill's Hydraulic Geometry: Predicted Width, Depth, and Slope

Reach No.	Depth (ft)	Width (ft)	Slope (ft/ft)
9	4.5	80	.0006
8	4	80	.0007
7	4	65	.0008
6	4	65	.0008
5	4	65	.0008
4	4	70	.0008
3	4	70	.0009
2	4	75	.0009
1	4.5	75	.0009

Expected width, depth, and slope values may be compared with measured values for these parameters. Data in Tables 4.3 and 4.4 indicate that the 1990 channel in Reaches 1, 4, and 9 is too wide. Channel depths are slightly high in all reaches, but are within Neill's range of equilibrium. Channel slopes, however, are approximately half an order of magnitude too steep according to Neill's curves. Neill's curves indicate that the channel slope should decrease to achieve equilibrium. Such a slope decrease could be achieved through increased meandering, installation of grade control structures, or long-term scour and deepening. In summary, Neill's curves predict width and slope decreases throughout most of the study area. Copies of Neill's curves are included in the Appendix.

Schumm's Silt Factor

Schumm[3] developed an equation relating the silt/clay content of streambed and bank to a stable width/depth ratio. This equation is:

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

where:

F = the width to depth ratio
M = the weighted mean percent silt-clay in the channel and banks

The predicted stable width-depth ratio from Schumm's equation can then be compared to the measured width-depth ratio to determine the direction of expected change. This equation was applied to each of the Jordan River study reaches. The results are summarized in Table 4.5.

As shown in Table 4.5, the Schumm equation indicates that the existing width to depth ratio is close to the predicted (equilibrium) value for Reaches 4, 8, and 9. For Reaches 1, 2, 3, 5, 6, and 7, the predicted width-depth ratio is an order of magnitude greater than the actual ratio. To achieve equilibrium, these reaches will need to increase width (bank erosion) or decrease depth (deposition), or some combination of both.

Equilibrium Slope Calculations

An equilibrium slope was estimated for each reach of the Jordan River using several established procedures, including Neill's hydraulic geometry curves for slope, the Schoklitsch equation, the Meyer-Peter Mueller equation, and the City of Tucson (Arizona) equation. Neill's equilibrium slope data were summarized previously in Table 4.4. Each of these equilibrium slope methodologies is summarized below.

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[3] Schumm, S.A., 1960, The Shape of Alluvial Channels in Relation to Sediment Type, USGS Professional Paper #325-B, US Gov't Printing Office, Washington, D.C., p. 17-30.

Table 4.5
Jordan River Stability Study
Predictions From Schumm Silt Factor Equation

Reach No.	Depth (D) (ft)	Width (W) (ft)	Silt-Clay % Bank	Silt-Clay % Bed	M	Predicted W/D	Existing W/D
9	4.8	120	51.0	1.0	4.7	48	25
8	5.5	82	51.0	1.0	6.9	32	15
7	3.7	76	0.7	1.0	1.0	263	21
6	4.9	68	0.8	0.7	0.7	368	14
5	4.8	76	1.1	0.2	0.3	930	16
4	4.7	109	1.4	9.5	8.9	24	23
3	4.0	95	2.5	1.7	1.8	138	24
2	5.1	73	8.7	1.9	2.7	86	14
1	5.5	103	.7	1.5	2.2	109	19

The Schoklitsch equation, recommended by the Bureau of Reclamation[4], is written as:

$$S_L = K\ (DB/Q_b)^{0.75}$$

where:

S_L = Equilibrium slope (ft/ft)
K = 0.00174
D = Mean particle size (mm)
B = Channel Width (ft)
Q_b = Bankfull Discharge (cfs)

The Meyer-Peter Mueller equation, recommended by the Bureau of Reclamation[5], is written as:

$$S_L = K\ (Q/Q_b)(n_s/D_{90}{}^{0.167})^{1.5}\ (D/d)$$

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[4] Pemberton, E.L., and Lara, J.M, 1984, Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation, Denver, Co., p. 17.

[5] Pemberton, E.L., and Lara, J.M, 1984, Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation, Denver, Co., p. 17.

where:

S_L = Equilibrium slope (ft/ft)
K = 0.19
D = Mean particle size (mm)
D_{90} = Particle size for which 90 percent is finer (mm)
Q = Total Discharge (cfs)
Q_b = Bankfull Discharge (cfs)
d = Channel depth (ft)
n_s = Manning's n value

The City of Tucson, Arizona's, equation[6] is written as:

$$S_L = (1.45 \ n_s / q^{0.11})^2$$

where:

S_L = Equilibrium slope (ft/ft)
q = Unit discharge (cfs/ft)
n_s = Manning's n value

The City of Tucson's equation is intended for clear water discharges with no sediment inflow. Therefore, its results are usually relatively conservative. Results of the four methodologies are summarized in Table 4.6.

The predicted reach-averaged equilibrium slopes listed in Table 4.6 indicate that Reaches 3 and 9 are unlikely to experience long-term degradation because of to slope adjustments. Long-term degradation predicted for Reaches 1 and 2 will probably be prevented by channel bed armoring and grade control provided by the Joint Diversion structure and the 14600 South Bridge. Reaches 5 and 6 should only degrade slightly, according to the data summarized in Table 4.6. Aggradation is predicted for Reach 4. The most significant predicted slope changes occur in Reaches 7 and 8, where significant long-term degradation may be experienced.

Channel Armoring

Channel armoring occurs when a layer of coarse sediment on the channel bed prevents bed scour. An armor layer develops as long-term degradation removes the finer bed sediment grains and leaves the sediment grains too large to be transported. Because these larger grains cannot be transported, they protect the channel bottom from further long-term degradation. The sediment size required to develop an armor layer is a function of the channel velocities, slope, and depth. Whether an armor layer can be formed is a function of the material sizes present in the channel bed sediments.

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[6] City of Tucson Dept. of Transportation, Engineering Division, 1989, Standards Manual for Drainage Design and Floodplain Management, (p. 6-31)

Table 4.6
Reach Average Stable Slope Prediction Analysis (ft/ft)

Reach No.	Neill	Schoklitsch	Meyer-Peter Mueller	Tucson	Average Predicted Slope	Existing Channel Slope
9	0.0006	0.0011	0.0038	0.0028	0.0021	0.0015
8	0.0007	0.0008	0.0027	0.0015	0.0014	0.0028
7	0.0008	0.0012	0.0052	0.0012	0.0021	0.0033
6	0.0008	0.0011	0.0050	0.0015	0.0021	0.0029
5	0.0008	0.0010	0.0031	0.0011	0.0015	0.0024
4	0.0008	0.0028	0.0112	0.0014	0.0040	0.0029
3	0.0009	0.0017	0.0076	0.0011	0.0028	0.0031
2	0.0009	0.0011	0.0093	0.0024	0.0034	0.0054
1	0.0009	0.0014	0.0095	0.0029	0.0037	0.0073

An equation developed by MacArthur[7] relates sediment gradation, velocity, and flood magnitude to the depth of scour required to obtain sufficient coarse sediment to develop an armor layer. The results of applying this equation to the Jordan River are shown in Table 4.7.

As indicated in Table 4.7, bed sediment in the Jordan River is generally coarse enough to develop an armor layer with less than 1 foot of scour. Therefore, armoring may prevent some of the long-term scour and slope decreases predicted by other analyses summarized elsewhere in this report. However, headcutting and dredging of the river bottom disturb the armor layers and may renew long-term degradation. In addition, bank erosion may expose new areas of the bed to scour.

Meander Geometry Equations

One of the objectives of developing a meander corridor is to allow the Jordan River to develop or reestablish a natural meander pattern that will not require substantial maintenance. To achieve this objective, several procedures that predict meander characteristics were used. These procedures included the Parker, the Ackers and Charlton, the Schumm, the Hey, and the Neill methodologies. Figure 9A defines the characteristics of meanders.

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[7] Water Engineering and Technology, 1990, Sediment Engineering Investigation of the Guadalupe River Parkway Flood Control Project, Report to the US Army Corps of Engineers, Sacramento District.

Table 4.7
MacArthur Method Armoring Calculations, 100-Year Flood

Reach Number	Mean Velocity (ft/s)	Critical Armor Size (mm)	Coarser Bed Fraction (%)	Depth to Armor (ft)
1	5.9	11	60	0.3
2	6.4	12	55	0.4
3	6.9	15	50	0.5
4	5.0	8	60	0.3
5	5.5	9	44	0.6
6	5.1	8	42	0.7
7	5.6	10	39	0.8
8	4.5	6	57	0.4
9	3.4	4	53	0.4

Parker's Equation. Parker's[8] meander relation is:

$$L/D = 8[\mathrm{PixB}/(\mathrm{fxD})]^{0.5}$$

where:

L = wavelength, ft
Pi = 3.14
B = width, ft
f = friction factor, dimensionless
D = depth, ft

This equation can be rewritten so that wavelength is expressed as a function of B, f, and D. Parker's equation may be applied to evaluate general historical channel changes and to predict the direction of future channel changes.

Historically, channel straightening has increased Jordan River meander wavelength by up to 144 percent, with only minor width changes. Therefore, an increase in depth and/or width was required. The Jordan River has experienced both.

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[8] Parker, G., Diplas, P., and Akiyama, J., 1983, "Meander Bends of High Amplitude", J. of Hydraulic Engineering ASCE, V. 109, no. 10, p. 1185-1201.

The existing meander pattern of the Jordan River was also examined using Parker's equation to predict potential changes in meander geometry. The results of this analysis, shown in Table 4.8, indicate that the measured wavelength is two to four times the expected wavelength, except in Reach 1. This is not surprising since river straightening removed most of the shorter meanders. It also indicates that the river will try to decrease meander wavelength by eroding banks and developing a more sinuous path.

Table 4.8
Jordan River Stability Study
Parker Meander Wavelength Equation Predictions

Reach No.	Channel Depth, D (ft)	Channel Width, B (ft)	Friction Factor, f	Predicted Meander Wavelength (ft)	Measured Meander Wavelength (ft)
9	4.8	120	18.1	720	2085
8	5.5	82	17.3	324	1265
7	3.7	76	16.0	484	2403
6	4.9	68	13.9	383	2723
5	4.8	76	13.4	525	2320
4	4.7	109	22.4	398	1394
3	4.0	95	14.6	846	1900
2	5.1	73	20.2	204	1443
1	5.5	103	41.3	90	764

Ackers and Charlton Equation. Ackers and Charlton[9] developed a series of curves that describe probable maximum and minimum values of meander wavelength relative to dominant discharge. Existing meander wavelength values for each reach are shown in Table 4.9. Where the actual wavelength is outside Acker's and Charlton's envelope values, it may be inferred that the channel pattern is unstable and will adjust.

As shown in Table 4.9, Ackers and Charlton's data indicate that the meander wavelength will decrease, except in Reaches 2, 4, and 8. Although the Ackers and Charlton equation predicts that Reaches 1 and 9 are unstable, low velocities and channelization in Reach 9 and geologic control in Reach 1 will probably prevent any significant change in meander pattern. Reaches 2 and 4 experienced significant meander development and bank erosion

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[9] Ackers, P., and Charlton, F.G., 1970, Meander Geometry Arising From Varying Flows.. Journal of Hydrology, V. 11, September, p. 230-252.

during the 1983-87 floods and probably have recovered much of this natural sinuosity. These changes occurred as the river naturally established a more stable meander pattern. The Acker and Charlton predicted channel responses are similar to those from the Parker equation.

Table 4.9
Jordan River Stability Study
Ackers and Charlton Wavelength Equation

Reach No.	Dominant Discharge (cfs)	Minimum Wavelength (ft)	Maximum Meander Wavelength (ft)	Measured Meander Wavelength (ft)	Predicted Stability
9	1200	1000	1500	2085	unstable
8	1100	1100	1600	1265	stable
7	1000	900	1300	2403	unstable
6	1000	900	1300	2723	unstable
5	1000	900	1300	2320	unstable
4	1100	1100	1600	1394	stable
3	1100	1100	1600	1900	unstable
2	1200	1000	1500	1443	stable
1	1200	1000	1500	764	unstable

Schumm's Meander Curve. Schumm's classic curve[10] relating channel slope, sinuosity, and bedload to channel pattern is shown in Figure 9B. From this curve, it can be seen that straight channels may begin to meander if the slope is increased, or meandering channels may become braided with increasing slope. Conversely, if meandering is decreased (i.e., by channel straightening), slope must decrease if the channel is to remain stable. Historically, the Jordan River was straightened, decreasing sinuosity and increasing slope. However, the magnitude of the slope increase and the size of the bedload sediment was not sufficient to support a braided channel downstream of Reach 3. Therefore, the channelized river pattern became unstable. During the floods in the 1980s, a more meandering channel pattern began to redevelop as banks eroded, channel bars formed, and the thalweg became more sinuous.

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[10] c.f. Schumm, S.A., 1971, Fluvial Geomorphology -- the Historical Perspective, H.W. Shen, ed., Water Resources Publ., Fort Collins, Colorado, p. 4-1 to 4-27.

Hey Meander Equation. Hey's[11] meander equation predicts meander characteristics based on the channel width and the average distance between inflection points (a distance equal to half the meander wavelength) on stable meandering rivers. This equation can be used to predict the radius of curvature for meanders. A summary of predicted and existing channel radii of curvature is shown in Table 4.10.

Table 4.10
Jordan River Stability Study
Hey Relation for Meander Radius: Predicted Stability

Reach No.	Width (ft)	Predicted Radius (ft)	Existing Radius (ft)	Stability
9	120	241	n/a	Unstable
8	82	164	1541	Unstable
7	76	153	3443	Unstable
6	68	136	2488	Unstable
5	76	152	5171	Unstable
4	109	218	2716	Unstable
3	95	191	3008	Unstable
2	73	146	3687	Unstable
1	103	207	2093	Unstable

According to the results shown in Table 4.10, the measured radii of curvature should be reduced by more than an order of magnitude to approach predicted equilibrium conditions. A decrease in the radius of curvature means that the channel bends become "tighter" and more sinuous. This change would be achieved by significant local bank erosion as the channel becomes more sinuous. This predicted response corresponds with predictions for wavelength, slope, and width-depth ratio. Note that where reaches are channelized, such as in Reach 9, no actual adjustment may occur to the channel planform, although continued maintenance may be required.

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[11] Hey, R.D., 1983, Plan Geometry of River Meanders. In River Meandering, ed. Elliot, American Society of Civil Engineers.

Neill/Schumm Stability Ratio. Data published by Neill and Schumm[12] indicate that meandering channels are stable when the ratio of meander amplitude to meander wavelength is between 0.5 and 1.5. In 1937, the year of the earliest aerial photographic record, the average ratio for the Jordan River was 0.4. By 1990, the ratio had been reduced to 0.1 due to channel straightening. Channel meander parameters for each reach of the Jordan River in 1937 and 1990 are shown in Table 4.11.

The stability of the existing river pattern can be assessed by comparing the values of wavelength and amplitude that would be required to reestablish the prechannelization amplitude to a ratio of 0.4. To achieve the prechannelization ratio of 0.4 with the existing meander wavelength, the average meander amplitude would have to be 724 feet. The existing average wavelength amplitude is 203 feet. Conversely, to achieve the prechannelization ratio of 0.4 with the existing meander amplitude, the meander wavelength would have been 507 feet. The existing average value is 1,881 feet. Reach by reach summaries of the meander ratio are given in Table 4.11. This summary indicates that an increase in amplitude and/or a decrease in wavelength is required to establish a stable meander pattern.

Allowable Velocity Curves

Channels that are not in equilibrium according to equations, such as those previously outlined, may not actually experience change. Sufficient stream power and energy are required to cause the erosion that produces the channel changes. Use of maximum allowable channel velocity has traditionally been used to assess the potential for erosion. Velocities in excess of the allowable maximum are likely to cause bank erosion unless special conditions are present. Special conditions could include dense vegetation with a strong root network on the banks, very cohesive soil material, short duration of the excessive velocity, or other factors. Table 4.12 summarizes allowable velocity values from several sources as well as reach-averaged velocities for the 10- and 100-year floods.

The data shown in Table 4.12 indicate that allowable velocities are exceeded for Reaches 1 and 2 during the 10-year flood, and in Reaches 1, 2, 3, 5, and 7 during the 100-year flood.

The reaches that are unstable during the 10-year flood are more likely to experience bed or bank erosion than reaches that are unstable only during the 100-year flood. A designation of instability in Table 4.12 probably indicates that the adjustments predicted by the geomorphic equations described in earlier sections of this report have a greater probability of occurring.

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[12] c.f. Neill, C.R., Editor, 1990, Stability of Flood Control Channels: Draft document prepared for the Waterways Experiment Station and the Committee on Channel Stabilization of the US Army Corps of Engineers.

Table 4.11
Jordan River Stability Study
Neill/Schumm Meander Amplitude/Wavelength Ratios for 1990 and 1937

Reach No.	Meander Amplitude, A (ft)	Meander Wavelength, L (ft)	Meander Ratio (A/L)	Sinuosity
1990				
9	66	2,085	0.0	1.1
8	350	1,265	0.3	1.4
7	154	2,403	0.1	1.1
6	193	2,723	0.1	1.1
5	116	2,320	0.0	1.1
4	195	1,394	0.1	1.1
3	297	1,900	0.2	1.2
2	317	1,443	0.2	1.2
1	138	764	0.2	1.2
1937				
9	464	1,043	0.4	1.7
8	307	842	0.4	1.6
7	287	676	0.4	1.6
6	220	603	0.4	1.5
5	232	626	0.4	1.4
4	228	569	0.4	1.6
3	248	690	0.4	1.5
2	307	1,226	0.3	1.2
1	217	962	0.2	1.3

Table 4.12
Jordan River Stability Study
Summary of U.S. Army Corps of Engineers (COE) and Neill's Allowable Velocity Criteria

Reach No.	Q_{100} Average Velocity (ft/s)	Q_{100} Depth (ft)	Q_{10} Average Velocity (ft/s)	Q_{10} Depth (ft)	Bed D_{50} (mm)	COE* Allowable Velocity (ft/s)	Neill's Allowable Velocity (ft/s)	Summary
9	3	13	3	8	5	6	4	Stable
8	4	13	3	9	5	6	4	Stable
7	6	9	4	6	8	6	5	Q_{100} Unstable
6	5	10	4	7	8	6	5	Stable
5	6	8	4	7	6	6	4	Q_{100} Unstable
4	5	7	4	5	19	6	5	Stable
3	7	7	5	5	11	6	5	Q_{100} Unstable
2	6	9	5	6	9	6	5	Unstable
1	6	8	5	6	9	6	5	Unstable

* U.S. Army Corps of Engineers (COE). 1970, Hydraulic Design of Flood Control Channels, EM 1110-2-1601.

Geomorphic Information

Geomorphologists study the development and evolution of landforms, including rivers. From years of observation and study, they have identified patterns of natural river evolution on meandering streams such as the Jordan River. Some of these patterns are summarized in equations such as the Lane Equation, described earlier. Other patterns simply are described as processes. Stream evolution processes that affect development of an erosion corridor for the Jordan River include:

- **Meander migration.** Meanders tend to migrate downstream. This process may cause meanders to overlap, increase in amplitude, or "bunch up" where the channel position is permanently stabilized by a bridge crossing or bank protection.

- **Bank erosion.** Bank erosion occurs on the outside of meander bends. Deposition occurs on the inside of bends. Therefore, there is some tendency for adjacent meander bends to overlap and develop cutoff chutes.

- **Bank slopes.** Bank slopes tend to be stable at the angle of repose of the sediment sizes that compose the bank material. Fine material generally has steeper angles of repose than coarser material. The vertical gravel banks of the Jordan River are generally unstable.

- **Low flow channels.** Low flow channels form within the floodplain, which convey about the 2- to 10-year discharge. When a stable low flow channel is present, floods exceeding the bankfull channel capacity may be less erosive than when a low flow channel is not present.

These general geomorphic principles were used in conjunction with the empirical relationships outlined above to help determine the limits of the meander corridor.

Local Scour

The analytical and geomorphic analyses previously described identified long-term trends in channel stability. Short-term scour can also impact bridges, utility crossings, and other hydraulic structures during a single flood event. Estimates of local scour were made to determine the stability of specific structures.

Local scour occurs at bridges and other hydraulic structures. Local scour consists of contraction scour, pier scour, and abutment scour. Equations recommended by the Federal Highways Administration[13] were used to estimate local scour at bridges over the Jordan River. Pier, contraction, and total local scour depths are given in Table 4.13. Total scour

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[13] U.S. Dept. of Transportation, Federal Highways Administration, "Evaluating Scour at Bridges," Hydraulic Engineering Circular No. 18, November, 1990.

Table 4.13
Predicted Scour at Bridge Crossings

Location	General Scour (ft)	Contraction Scour (ft)	Pier Scour (ft)	Total Scour (ft)	Potential for Long-Term Scour
RR Below Turner Dam	1.1	1.7	0.0	2.8	Moderate
RR Near X-Section 45	3.7	2.0	4.2	9.9	Moderate
RR Near X-Section 100	3.9	2.9	0.0	6.8	Moderate
14600 South	1.6	1.0	0.0	2.6	Minor
12600 South	1.9	1.5	0.0	3.3	Minor
12400 South	1.1	0.1	0.0	1.2	Minor
10600 South	1.0	1.9	0.0	2.9	Significant
9000 South	1.3	1.9	3.6	6.8	Moderate
7800 South	0.5	2.1	4.1	6.7	Minor
RR below 7800 South	1.0	3.7	3.9	8.6	Moderate
6400 South	1.7	1.1	2.2	5.0	Minor
I-215	0.7	0.7	3.3	4.7	Moderate
Bullion Road	2.3	2.2	0.0	4.6	Moderate
5400 South	0.0	1.0	4.3	5.2	Significant
4800 South	0.4	5.6	0.0	6.0	Moderate
4500 South	1.0	1.5	3.6	6.1	Significant
3900 South	0.0	0.4	5.1	5.5	Significant
3300 South	0.0	0.3	4.9	5.2	Significant
2100 South Expwy	0.1	0.5	3.7	4.4	Minor
Old 2100 South	0.1	3.4	4.0	7.5	Minor

at bridge structures is the sum of local scour and long-term scour. General scour was computed using HEC-6 as described later in this report. Long-term scour may be estimated from the results of the geomorphic analysis.

Contraction scour at stream crossings occurs at approach embankments on the floodplain or even into the main river channel. Concentration of flow and increased velocities at the contraction will result in an increase of channel depth due to scouring. The equation used to compute contraction scour assumes no overbank flow and an erodible channel bed with sediment transport (a "live bed").

$$y_2/y_1=(w_1/w_2)^{k1}$$

where:

y_1 = average depth in main channel, ft
y_2 = average depth in contracted section, ft
w_1 = bottom width of main channel, ft
w_2 = bottom width of bridge section, ft
k1 = an exponent related to the ratio of shear velocity of sediment D_{50} fall velocity

Pier scour is caused by turbulence that occurs around bridge piers. Bridge piers may direct flow at the streambed at the base of the piers and create a scour hole. The pier scour formula used, developed for live-bed scour, is given below:

$$y_s/y_1= 2.0k_1(a/y_1)^{0.65}(Fr)^{0.43}$$

where:

y_s = scour depth, ft
y_1 = flow depth just upstream of the pier, ft
k_1 = a correction factor for pier shape
a = pier width, ft
Fr = Froude number$=v/(gy_1)^{.5}$

As can be noted from Table 4.13, the bridge crossings show the potential for significant contraction and/or pier scour during a high flow event. The smallest value of local scour, 1.0 foot, occurs at 14600 South. The largest value, 7.4 feet, occurs at 2100 South. This potential for local scour, when combined with the predicted potential for long-term scour, indicates that grade control structures may be required in some reaches.

HEC–6: Sediment Continuity Analysis

The U.S. Army Corp of Engineers[14] HEC-6 computer program "Scour and Deposition in Rivers and Reservoirs" was used to provide qualitative sediment transport predictions. HEC-6 is a sediment continuity routing program that calculates net sediment deficit or surplus between adjacent cross sections based on the bedload sediment transport capacity. The net sediment deficit or surplus is uniformly removed or deposited over the entire channel width. This predictive bed load transport approach was used to identify river reaches that will be subject to scour or deposition during a major long-term flood event, such as the one that occurred in 1983-1987. Unfortunately, current state-of-the-art river mechanics and sediment transport computer models do not simulate or predict channel width changes (bank erosion) or lateral channel migration during a flow event. The HEC-6 program is designed to simulate the long-term impacts of control structures, channelization, and changing flow patterns on general scour and deposition. HEC-6 model data requirements include channel geometry, sediment size distributions, and hydrologic information.

Initial condition data for HEC-6 includes the channel geometry and bed and bank conditions. These include the movable bed limits for each cross section, which defines the portion of the cross section that will be subject to scour or deposition. Channel roughness coefficients are also required for each cross section. Jordan River cross section locations and orientation were obtained from the draft FIS HEC-2 model for the Jordan River. Minor modifications to the FIS HEC-2 model were required because HEC-6 does not directly model bridges. Movable bed limits were defined from the cross section geometry. In general, the movable portion of the bed was assumed to coincide with the wetted area of the channel at flood stage, except where bank stabilization is present. The lower limit of general scour, or the bed material depth, was assumed to be 8 feet.

Bed sediment data were obtained from several sources. Sediment size distributions of the material in the streambed are specified as percent finer versus grain size. HEC-6 computes transport rates for ten sand and gravel grain size classifications ranging from very fine sand (.0625 mm to 0.125 mm) to very coarse gravel (32 mm to 64 mm). Sediment inflow at the upstream boundary and at tributaries was estimated because no historical sediment transport data were available. Program default values for four basic sediment properties, grain shape factor, specific gravity, unit weight, and fall velocity were also utilized as part of the transport model. Bed sediment gradations were determined by sieve analyses of 27 bank and bed samples. Sediment sampling locations are shown in Figure 2. The Meyer-Peter Mueller sediment transport equation was used as the HEC-6 transport function.

Hydrologic input required for HEC-6 includes water discharge and flow duration. HEC-6 treats a continuous flow hydrograph as a sequence of discrete steady flows, each with a specified duration. Water temperature for all flow durations are also required due to its

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[14] U.S. Army Corps of Engineers, Scour and Deposition in Rivers and Reservoirs, HEC-6 Computer Program Users Manual, June, 1991.

affects on deposition of fine sands in reaches with low velocities. Water temperature data obtained from the Utah Division of Water Quality were used to estimate an average temperature of 66°F. Discharge data were obtained from USGS stream records. Two computational hydrographs were developed based on the 1952 and 1984 average daily flow records (15- and 100-year type events). The river experienced the highest average daily flows on record in 1984. The hydrographs used in the HEC-6 model had a duration of 85 days.

HEC-6 Modeling Results

HEC-6 output includes average depths of scour or deposition for each cross section. Detailed HEC-6 output files are provided in the Appendix. Scour and deposition results were calculated at the peak and at the end of two flood events described earlier. Predicted reach-averaged HEC-6 bed elevation changes are summarized in Tables 4.14 through 4.22. Reach by reach summaries of HEC-6 modeling results are discussed below. Cross sections referenced in Tables 4.14 through 4.22 are shown in Figure 2.

Reach 1. Reach 1 is a net scour reach (Table 4.14). Average scour is less than one-half foot for the reach. Maximum 100-year scour predicted by HEC-6 is 5.4 feet, which occurs at Section 30 at the end of the flood hydrograph. At the peak of the hydrograph, average scour is slightly less than at the end. Some deposition is predicted for the backwater area upstream of the Joint Diversion.

Reach 2. Reach 2 is a net scour reach (Table 4.15). Predicted average scour for the reach is close to one foot for both the 1952- and 1984-type floods. Maximum 100-year scour predicted by HEC-6 is 7.2 feet, which occurs at Section 235 at the peak of the hydrograph. Average scour at the peak is slightly greater at the peak than at the end of the hydrograph. Reaches with predicted maximum scour tended to fill by the end of the routed hydrographs.

Reach 3. Reach 3 is a net scour reach (Table 4.16) during a 100-year flood and in near equilibrium during a 1952-type event. Predicted average scour is about one foot for the 100-year flood, with peak scour occurring at the peak of the hydrograph. Maximum scour of about 7 feet occurs near the upstream end of Reach 3 at the flood peak. Average scour is slightly greater at the flood peak than at the end of the hydrograph. Alternating scour and deposition reaches may reflect channel braiding and bar deposition, which led to the bank instability witnessed during the 1983-1987 floods.

Reach 4. Reach 4 is a net depositional reach (Table 4.17). Predicted average deposition at the peak and end of both the 1952- and 1984-type floods is less than one-half foot. Deposition at the end of the hydrograph is slightly greater than the deposition experienced at the peak of the flood. Peak deposition of about 4 feet occurs at Section 485. Alternating scour and deposition reaches may reflect channel braiding and bar deposition, which led to the bank instability witnessed during the 1983-1987 floods.

Table 4.14
Reach 1: HEC-6 Results
Bed Elevation Change (ft)

	1952-Type Event (15-yr Flood)		1984-Type Event (100-yr Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
15	-0.1	-0.1	-0.7	-1.1
25	-0.5	-0.9	-0.8	-1.3
30	-1.1	-1.4	-5.3	-5.4
35	-1.0	-1.7	4.0	3.4
40	-2.3	-4.0	-2.2	-4.0
45	1.0	-0.3	-3.7	-3.4
50	2.3	2.8	2.0	1.2
55	0.0	0.3	-1.8	-0.5
60	0.0	3.1	0.7	-3.4
70	1.1	2.1	1.8	5.4
75	-0.8	-0.5	4.2	5.1
Reach Average	-0.1	0.0	-0.2	-0.4

Table 4.15
Reach 2: HEC-6 Predicted Bed Elevation Change (ft)

Section ID	1952-Type Event (15-yr Flood)		1984-Type Event (100-yr Flood)	
	End of Peak	End of Flood	End of Peak	End of Flood
80.4	4.7	0.0	0.0	14.9
80.1	-1.8	-2.7	-1.6	-2.0
85	0.3	0.3	-0.8	-1.1
90	-1.2	-1.7	-1.7	-2.9
110	-1.1	-1.9	-3.4	-3.9
190	-1.0	-1.9	2.2	-1.9
200	0.1	-0.1	0.4	1.5
205	-0.6	-0.8	0.0	0.0
210	-1.0	-1.0	-1.3	-1.2
220	1.0	0.5	0.8	2.1
225	-0.4	-0.4	0.4	3.9
230	-0.5	-0.7	-5.4	3.8
235	-0.9	-0.6	-7.2	-0.7
240	2.6	2.4	1.6	1.6
250	-0.5	-0.7	-1.1	-1.9
255	-1.1	-1.8	-1.0	-1.6
260	-0.8	-1.6	-1.0	-1.7
270	-0.8	-1.6	-1.4	-2.5
280	-0.3	-0.3	-0.5	-0.6
290	0.8	0.9	-0.2	0.1
295	-0.5	-0.5	0.0	-1.5
300	-0.9	-0.9	-0.9	-2.4
305	2.3	-1.0	-1.1	-1.6
310	-1.3	-1.7	-1.4	-3.8
Reach Average	-0.1	-0.7	-1.0	-0.8

Table 4.16
Reach 3: HEC-6 Predicted Bed Elevation Change (ft)

	1952-Type Event (15-yr Flood)		1984-Type Event (100-yr Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
315	-0.7	-0.8	-7.2	-6.6
320	-3.1	-3.5	-6.0	-6.4
325	-1.8	-1.9	-2.7	-3.4
333	0.6	0.0	3.6	2.3
335	1.0	-0.4	-7.0	-6.8
345	-1.0	0.3	-3.9	-4.4
355	0.1	-1	1.0	0.2
360	0.4	2.6	-0.9	-0.6
365	1.5	2.2	0.6	0.9
370	2.1	1.9	1.3	0.3
380	-0.6	-0.9	-0.7	-1.1
390	-1.1	-0.7	-0.9	-1.0
400	1.7	-0.8	0.6	0.6
410	0.7	3.7	-0.2	2.2
415	0.4	-0.2	0.5	2.0
420	0.4	1.6	0.1	1.3
425	-0.4	-0.5	0.6	-0.5
435	0.8	0.8	0.6	3.0
437	0.0	-0.2	0.5	1.0
445	-0.1	-0.3	0.1	-0.3
453	-0.5	-0.6	0.8	-0.5
455	-1.0	-1.1	-1.8	-1.9
Reach Average	-0.0	0.0	-0.9	-0.9

Table 4.17
Reach 4: HEC-6 Predicted Bed Elevation Change (ft)

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
470	1.2	1.2	0.2	0.5
475	1.6	0.8	0.7	2.4
480	-0.4	-0.4	-0.5	-0.9
480.1	-0.5	0.0	-0.7	-1.1
485	3.0	3.3	4.2	4.0
495	0.0	0.0	-0.2	-0.1
497	-0.8	-0.8	-1.1	-0.5
505	-0.2	0.5	0.1	1.5
510	0.1	0.6	1.2	1.3
515	0.0	0.2	0.5	0.8
535	0.6	1.5	0.6	1.0
540	-0.1	-0.1	-0.3	-0.4
550	-0.5	-0.6	-0.8	-0.8
555	0.1	0.5	-0.4	0.0
561	0.5	0.9	1.4	1.5
565	0.0	0.0	0.5	0.8
575	0.2	0.2	0.1	0.4
590	-1.2	-1.5	-1.0	-1.4
595	1.5	1.1	2.7	0.3
600	-0.6	-0.8	-1.0	-0.7
Reach Average	0.2	0.3	0.3	0.4

Reach 5. HEC-6 modeling predicted mixed results for Reach 5 (Table 4.18). During the 100-year hydrograph, the reach exhibits net equilibrium, with alternating scour and deposition. During the 1952-type flood, HEC-6 predicts net deposition for Reach 5. Maximum scour and deposition were 3.3 and 4.0 feet, respectively, during the 100-year flood. Predicted scour seems to be concentrated near the upstream end of the reach, with more deposition at the downstream end.

Reach 6. Reach 6 exhibits stability with insignificant net scour (Table 4.19). Predicted average scour for the reach is near zero for both the 1952- and 1984-type floods. Maximum 100-year scour predicted by HEC-6 is only 2.1 feet at Section 810 at the peak of the hydrograph. Average scour at the peak is replaced by slight deposition at the end of the hydrograph. Reaches with predicted maximum scour tended to fill by the end of the routed hydrographs.

Reach 7. Reach 7 is a net depositional reach (Table 4.20). Predicted average deposition at the peak of both the 1952- and 1984-type floods is less than one-half foot, although deposition at the end of the 100-year flood is about one foot. Deposition at the end of the hydrograph is slightly greater than the deposition experienced at the peak of the flood. Backwater deposition occurs upstream of the drop structure at 6400 South and the Brighton Diversion structure. Other deposition in Reach 7 may be due in part to the decreased slope caused by sediment deposition from Little Cottonwood Creek, although deposition from tributaries was not specifically modeled.

Reach 8. HEC-6 predicts no significant net scour or deposition for Reach 8 during the 1952-type flood and slight deposition during a 100-year flood (Table 4.21). Net deposition during the 100-year flood is less than one-half-foot. Maximum deposition occurs in backwater areas. Deposition from the Big Cottonwood Creek and Mill Creek tributaries is not modeled by HEC-6. This sediment supply from the tributaries would likely be in excess of the transport capacity and would cause further deposition.

Reach 9. HEC-6 predicts no significant net scour or deposition for Reach 9 during the 1952-type flood and slight deposition during a 100-year flood (Table 4.22). Predicted average scour for the reach is near zero for both the 1952-and 1984-type floods. Maximum 100-year scour predicted by HEC-6 is only 0.2 feet at section 1305 at the peak of the hydrograph. Sediment deposition downstream of Mill Creek (Sections 1250 to 1265) requires dredging nearly every year.

No physical data were available that could be used to verify modeling results. Several trial simulations were performed as "reality checks" on results in an effort to calibrate the model. The results of these calibration runs were compared against qualitative scour and deposition information from the floods of the 1980s to determine if results appeared reasonable.

Table 4.18
Reach 5: HEC-6 Predicted Bed Elevation Change (ft)

	1953-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
610	0.7	2.0	-0.3	0.4
615	0.4	0.6	-0.4	-0.1
621	0.8	1.1	0.7	0.3
625	0.3	0.6	-0.2	0.4
630	-0.6	-1.3	-3.1	-3.3
640	-2.5	-2.6	-2.4	-2.6
650	0.6	0.5	0.1	0.2
655	0.5	1.2	2.0	-1.6
660	2.2	2.3	1.0	1.9
670	2.7	4.3	3.2	4.0
673	-0.2	-0.1	-1.3	-0.7
676	0.3	1.4	-0.7	0.6
Reach Average	0.4	0.8	-0.1	0.0

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Table 4.19
Reach 6: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	End of Peak	End of Flood	End of Peak	End of Flood
685	-0.2	-0.2	0.9	0.7
690	-0.6	-1.1	0.3	-0.2
695	-0.1	-0.1	2.0	-0.8
700	-0.3	-0.6	-1.2	-0.5
705	-0.1	-0.1	-0.2	1.4
710	-0.9	-1.1	-1.3	-0.8
715	1.2	1.1	0.8	2.0
720	-0.7	-1.0	-0.7	-0.6
725	0.1	-0.1	0.3	0.4
730	-0.5	-0.5	-0.7	-0.8
735	0.0	0.0	-0.5	-0.5
740	-0.4	-0.9	1.4	0.6
745	-0.1	-0.1	-0.2	-0.2
750	-0.1	-0.2	1.3	0.9
760	-0.5	-0.5	-0.6	-0.6
770	-0.2	-0.3	0.4	0.5
780	1.3	1.6	-0.1	0.9
790	-0.2	-0.5	-0.9	-1.1
800	-0.1	0.0	-0.3	-0.2
805	0.0	-0.2	1.4	-0.4
810	-1.1	-1.7	-2.1	-1.7
815	-0.9	-0.5	-0.5	4.3
820	-0.8	-1.0	-0.8	-0.9
835	0.2	0.1	0.0	0.7

Table 4.19
Reach 6: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
840	-0.7	-0.9	-1.0	-0.9
845.1	0.8	0.3	-0.4	2.3
850	-0.6	-0.8	-0.6	-0.3
860	-0.1	-0.1	0.2	0.2
870	0.7	1.0	2.8	0.5
880	0.2	0.2	-0.3	1.8
890	-0.2	-0.4	-1.3	-1.5
900	-0.4	-0.8	-1.7	-1.6
Reach Average	-0.2	-0.3	-0.1	0.1

Table 4.20
Reach 7: HEC-6 Predicted
Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
903.1	-2.0	-0.8	1.4	1.3
904	0.6	2.3	3.6	14.5
905	1.6	0.7	-0.4	0.3
912	-0.4	-0.8	-0.1	0.1
913	-0.1	-0.1	-0.4	-0.6
923	-0.1	-0.1	0.2	0.0
925	0.0	0.0	0.7	0.3
930	-0.5	-1.1	-0.4	-0.8
935	-0.2	-0.2	-0.5	-0.7
940.1	0.0	-0.1	-0.6	-0.6
940	-0.9	-1.4	-1.0	-1.3
950	-0.5	-0.5	-0.4	-0.5
955	0.5	0.4	1.3	0.5
957.1	0.4	1.9	-2.3	-0.4
960	1.1	0.8	0.6	3.4
965	-0.2	-0.1	0.7	-0.5
970	-0.7	-0.8	-1.0	-1.1
975	-0.5	-0.5	0.7	-0.3
980	0.2	0.5	-0.4	0.4
985	-0.1	-0.1	0.2	-0.1
990	-0.3	0.1	-0.6	-0.3
995.1	0.2	1.0	0.5	3.8
1000	0.0	0.3	1.7	1.2
1005	-0.2	0.1	0.5	-0.1

Table 4.20
Reach 7: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
1010	0.0	0.5	1.2	1.6
1020	0.0	0.2	0.9	1.1
1030	0.4	0.3	0.5	2.2
1035	-0.9	-0.8	-0.7	0.6
1040	0.3	0.3	1.3	0.8
1050	-0.1	0.0	-0.4	-0.2
1055	0.8	1.1	1.1	1.1
1060	1.6	2.1	-0.4	0.0
1070	3.2	2.4	1.0	5.3
1075	0.1	0.0	-0.1	0.2
1077	0.3	0.5	0.6	0.9
Reach Average	0.1	0.2	0.3	0.9

Table 4.21
Reach 8: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
1083.2	-0.1	0.0	-0.6	-0.6
1085	0.0	0.0	11.2	7.1
1087.2	-0.1	0.8	-1.5	12.2
1087	0.0	0.1	-0.5	-0.6
1090	-0.5	-0.8	-0.9	-1.0
1095.1	0.1	0.1	-0.6	-0.6
1097	0.0	0.0	0.1	0.3
1107	0.1	0.1	0.0	0.1
1110	-0.7	-1.1	0.0	-0.1
1120	0.6	0.5	-0.1	-0.1
1125	0.1	0.0	-0.6	-0.5
1130	0.2	0.2	0.1	0.4
1140	0.4	0.6	-0.2	0.1
1145	-0.2	-0.2	-1.7	-2.3
1150	0.3	0.3	0.0	0.5
1160	-0.4	-0.6	0.2	0.0
1165	0.2	0.2	0.8	1.3
1170	-0.1	-0.1	0.1	0.2
1180	0.3	0.6	-0.3	-0.2
1185	0.0	-0.1	-0.3	-0.4
1190	-0.1	-0.2	-0.3	-0.3
1200	0.3	0.4	-0.2	-0.1
1205	0.0	-0.1	0.1	0.0
1207.1	0.4	0.4	1.5	1.3

Table 4.21
Reach 8: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
1210	-0.1	-0.1	-0.1	-0.2
1220	-0.1	-0.1	-0.2	-0.2
1230	-0.1	-0.1	0.2	-0.2
1235	0.0	0.1	-0.3	-0.2
1240	0.4	0.6	0.6	1.0
Reach Average	0.0	0.0	0.2	0.2

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Table 4.22
Reach 9: HEC-6 Predicted Bed Elevation Change

	1952-Type Event (15-Year Flood)		1984-Type Event (100-Year Flood)	
Section ID	**End of Peak**	**End of Flood**	**End of Peak**	**End of Flood**
1250	0.0	0.0	0.1	0.1
1260	0.1	0.1	0.4	0.6
1265	-0.1	-0.1	-0.1	-0.1
1270	0.3	0.4	0.4	0.8
1280	0.0	-0.1	0.0	-0.1
1290	0.0	0.0	0.1	0.2
1295	-0.1	-0.1	0.0	-0.1
1300	-0.1	-0.1	-0.1	-0.1
1300.4	-0.1	-0.1	-0.1	-0.1
1300.1	0.0	0.0	-0.1	-0.1
1305	-0.1	-0.1	-0.2	-0.2
1310.4	-0.1	-0.1	0.0	0.1
1310.1	-0.1	-0.1	-0.1	0.0
1310	-0.1	-0.1	-0.1	0.0
Reach Average	0.0	0.0	0.0	0.1

Historical Approach

The analytical procedures described in the previous sections use empirical equations developed from data from rivers other than the Jordan River. These data are averaged and manipulated into regression equations that use relationships between specific variables to predict river behavior. While use of the analytical approach is appropriate, the results must be used with caution due to the uncertainties created by averaging data from the types of rivers from which the equations were developed. Because there are so many variables that affect stream stability, there is a great deal of scatter in the data used to develop the equations. Thus, river reaches with hydraulic and geomorphic characteristics that the analytical equations predict to be stable may not actually be stable due to unique site-specific conditions. Conversely, river reaches that the equations predict to be unstable may actually be stable. When available, historical information is frequently used to identify these anomalous reaches. Where adequate historical data are available, evaluating historical changes on a river is usually the best indicator of what future changes may be.

Use of historical data has the following advantages over most empirical techniques:

- The data are directly applicable to the river being studied.
- The historical data should have minimal scatter.
- There is no regional bias or inappropriate climatic effects.
- Historical data show actual changes that have occurred in response to specific inputs. No extrapolation is needed.

A long, detailed historical record is available for the Jordan River that may be used to supplement the analytical analyses. The 136-year historical record includes flow data, topographic maps, aerial photographs, and channel cross section data. These data may be used to predict erosion, meander migration, slope changes, and channel pattern changes that may occur in response to specific flood events or periods of low flow. The historical data detail actual channel behavior for the Jordan River. Therefore, the historical data are the most reliable gage of channel stability on the Jordan River. The historical approach was used to predict the existing and future stability of the Jordan River by examining how the river responded to events in the past.

Channel Position, 1856-1990

The Jordan River has experienced both episodic and gradual channel movement throughout the past 136 years. Historical maps of channel position from 1856, 1901, and 1923, and aerial photography from 1937, 1946, 1958, 1965, 1982, 1983, 1984, 1986, 1988, and 1990 were used to track channel movement. A comparison of channel centerline locations in 1856, 1937, 1958, 1982, and 1990 is shown in Figure 10. A comparison of all the years of record is shown in Figure 11. Use of non-rectified aerial photography caused some distortion of the channel patterns shown in Figures 10 and 11. However, the significant changes in channel patterns and locations are evident.

Figure 11 illustrates that the river channel in the study reach has actively migrated throughout the 136-year period of record. The river straightening that took place in the 1950s stands out particularly well in Reach 6, although evidence of channel straightening can be seen everywhere downstream of 12600 South. It is significant that the channel migration that has occurred is confined within a relatively narrow portion of the river valley. In addition, the river has maintained a planform very similar to its predevelopment ancestor. Boundary lines that bracket all the channel location lines shown in Figure 11 may be used to define a "meander corridor."

Erosion that occurred in many areas during the floods of the 1980s can be seen in Figure 10. Note that many of the straightened reaches did not experience significant erosion between 1983 and 1987, particularly Reaches 1, 5, 6, 7, and 9. Measurements of maximum single event bank erosion in each reach is discussed later in this report.

Channel Bed Elevation, 1950-1990

Significant changes in channel bed elevation have occurred on the Jordan River during the past 40 years. Historical channel bed elevation data were available dating back to 1950. Channel bed elevation data from 1950 obtained from USGS quadrangle maps (pre-channelization) were compared to 1990 channel survey data obtained for the FIS. Table 4.23 shows the approximate progressive long-term scour, or degradation, which occurred at specific locations between 1950 and 1990. Long-term scour was greatest in Reaches 4 and 8, although all reaches except Reach 1 experienced measurable long-term scour. Some of the bed elevation changes in Reaches 6 through 9, shown in Table 4.23, may be due to dredging, rather than geomorphic processes. Evaluation of this historical data also indicates that aggradation has occurred near the mouth of Little Cottonwood Creek.

Bed elevation changes cause channel slope adjustments. Topographic data from 1950 and 1990 indicate that Reaches 1, 4, 5, 6, and 9 have decreased their average slopes since 1950 as shown in Table 4.24, while Reaches 2, 3, 7, and 8 have increased their average slopes. Slope increases were probably created when the channel was straightened in the 1950s. In Reaches 7 and 8, scour and lateral channel migration area likely to occur in areas where significant slope increases have occurred during the past 40 years, despite the recent measurable bed elevation decreases. In Reach 6, where the most severe channelization occurred, slope and bed elevations have not changed significantly in most places. These signs of stability are supported by the fact that the channel location in this reach has shown little lateral movement during the same period, as shown in Figures 10 and 11. Reaches 3 and 4 appear to be reestablishing toward their prechannelization slopes. As a result, the existing channel pattern in Reaches 3 and 4 may be approaching stability.

Table 4.23
Comparison of Channel Elevations, 1950-1990

Location	Reach No.	1950	1990	Difference (ft)
2100 South	9	4225.1	4225.0	-0.1
2100 South Expressway	9	4225.4	4225.1	-0.3
Mill Creek Confluence	9/8	4227.6	4225.6	-2.0
3300 South	8	4233.8	4226.1	-7.7
Big Cottonwood Creek Confluence	8	4236.8	4234.3	-2.5
4500 South	8	4239.1	4237.6	-1.5
Little Cottonwood Creek Confluence	7	4242.2	4244.8	2.5
5300 South	7	4254.7	4251.4	-3.4
Bullion Street	7	4260.0	4258.1	-1.9
6400 South	7/6	4268.0	4268.0	0.0
7800 South	6	4282.0	4278.8	-3.2
9000 South	6	4290.9	4290.8	0.0
North Jordan Diversion	6/5	4300.0	4296.0	-4.0
10600 South	5/4	4307.1	4305.7	-1.4
12300 South	4	4328.0	4325.7	-2.3
12300 South	4/3	4330.4	4327.6	-2.8
12600 South	3/2	4380.0	4374.9	-5.1
Joint Diversion	2/1	4400.0	4400.0	0.0
Turner Dam	1	4494.0	4494.0	0.0

Table 4.24
Channel Slope Changes, 1950 to 1990

Reach No.	1950 Slope (ft/ft)	1990 Slope (ft/ft)	Difference (%)
1	0.00757	0.00682	-10
2	0.00379	0.00527	39
3	0.00253	0.00264	4
4	0.00154	0.00144	-6
5	0.00271	0.00061	-77
6	0.00161	0.00143	-11
7	0.00107	0.00308	189
8	0.00050	0.00310	514
9	0.00034	0.00008	-78

Channel Bed Elevations at Structures

Channel bed elevation data were obtained from as-built and design drawings for hydraulic structures on the Jordan River. Top of pipe elevations for the utility crossings installed after 1983 were obtained from County records. Channel bottom elevations at bridge crossings were obtained from bridge design drawings collected during the Jordan River FIS. Bed elevation data from these sources are summarized in Table 4.25 and compared to estimated channel bottom elevation obtained from the FIS HEC-2 model.

The data in Table 4.25 indicate that significant degradation has occurred at all bridge crossings upstream of 3900 South since the bridges were constructed. Slight aggradation has occurred at the 2100 South and 3300 South bridges. Sewer line crossings at Stations 671 and 707 were constructed with the top of the pipe at or near the channel bottom. The sewer line crossing at Station 671 could be endangered if significant channel degradation were to occur. The other utility crossings listed in Table 4.25 are apparently in no imminent danger of being damaged by scour. However, they should be periodically monitored.

The utility crossings located in the study area that are not listed in Table 4.25, but listed in Table 3.4, should also be inspected and monitored. If some of those crossings have been in place for an extended period, channel degradation may have exposed them to scour.

The data presented in Tables 4.23 and 4.25 indicate that significant drops in bed elevation have occurred during the past 40 years. It is likely that this trend will continue, especially in reaches where slope increased between 1950 and 1990 (i.e., Reaches 3, 7, and 8). This

Table 4.25
Comparison of Channel Bed Elevations at Hydraulic Structures

Structure	River Station	Design Elevation (Channel Bottom or Top of Pipe)	Approximate Existing Channel Bottom Elevation
2100 South Bridge	3	4221, pile @ 4217	4218.2
2100 South Expressway	12	4220	4220.0
3300 South Bridge	134	4222, pile @ 4221	4225.3
3900 South Bridge	201	4227.5	4223.5
4500 South Bridge	268	4236	4234.4
4800 South Bridge	298	Not Available	4235.3
5400 South Bridge	372	4252, pile @ 4252	4244.8
Bullion Street Bridge	406	Not Available	4247.0
Interstate 215 Bridge	430	4265	4258.7
Sewer and Water Lines	446	4255	4260.0
6400 South Bridge	463	Not Available	4268.2
Sewer Line	491	4261	4270.5
Railroad Bridge	522	Not Available	4267.0
7800 South Bridge	544	4280	4272.3
Sewer Line	628	Not Available	4286.3
9000 South Bridge	642	4289	4285.7
Sewer Line	671	4291	4291.6
Sewer Line	707	4296	4296.5
10600 South Bridge	770	4303	4300.0
Sewer Line	771	4301	4303.0
Sewer Line	824	4304	4311.0
Water Line	837	4308	4314.0
Sewer Line	887	4315	4322.0
12300 South Bridge	914	Not Available	4321.1
12600 South Bridge	930	4329	4325.0

Table 4.25
Comparison of Channel Bed Elevations at Hydraulic Structures

Structure	River Station	Design Elevation (Channel Bottom or Top of Pipe)	Approximate Existing Channel Bottom Elevation
Sewer Line	970	4327	4333.5
Sewer Line	994	4332	4336.5
14600 South Bridge	1136	Not Available	4377.2
Denver-Rio Grande RR	1244	Not Available	4419.7

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degradation of bed elevation may be stabilized by installing grade control structures, increasing channel length to reduce slope (meandering), or by coarsening of channel bed sediment material (armoring).

Cross Section Resurveys

A 1992 resurvey of specific channel cross sections that were originally surveyed in 1981, 1984, or 1987 also confirms the general trend of long-term scour. Most scour during the period between 1981 and 1991 occurred in Reaches 7 and 8; most deposition occurred in Reaches 3, 4, 5, and 6. Most cross sections experienced several feet of scour during this time period. Other localized areas experienced some deposition. Many reaches widened considerably. Plots of resurveyed cross sections compared to historic cross sections are provided in the Appendix. Table 4.26 summarizes the geomorphic changes that occurred between 1981 and 1991.

Geomorphic Parameter Changes, 1856-1990

Historical stream characteristics, such as channel slope, sinuosity, meander wavelength, and meander amplitude, were quantified and compared. In general, since 1937, slope and meander wavelength have increased; sinuosity and meander amplitude have decreased. Most of these changes were induced by the river straightening that occurred in the 1950s. Reversal of these trends occurred in some reaches during the floods of the 1980s.

Slope

The channel slope increase induced by the channel straightening performed in the 1950s probably resulted in increased velocities and higher sediment transport rates. These factors acted to destabilize the channel bed and banks. Because little bank erosion was observed between 1958 and 1980, it is assumed that most of the natural stabilization adjustments during this period occurred as slope reduction caused by long-term scour. Slope adjustments caused by long-term scour can eventually destabilize the channel banks by undercutting and over-steepening.

Signs of slope adjustment and channel instability became much more evident between 1983 and 1986. During this 4-year period, the average daily discharge in the Jordan River was approximately equal to the peak discharge experienced during the 1952 flood. During these flood years, the increased velocities and higher sediment transport rates caused the channel slope to adjust more rapidly toward its prechannelization slope through scour and the redevelopment of meanders.

Sinuosity

Channel sinuosity, or the ratio of the stream length to the valley length, measures the "curviness" of a stream (See Figure 9A). The sinuosity of the river was measured for each year of record between 1856 and 1990. Table 4.27 summarizes the average sinuosity for

Table 4.26
Summary of Historical Channel Cross Section Data

Reach No.	Cross Section ID	Years That Cross Section Data Were Obtained for Comparison				General Geomorphic Changes Occurring During Period of Record
		1981	1984	1987	1992	
1	55	X	X		X	3 feet of erosion between 1981-84, 4 feet of deposition between 1984-92
1	60	X	X		X	Apparent deposition and channel widening
2	210	X	X			Some channel widening
2	235	X			X	Bank erosion and formation of gravel bars
2	290	X	X		X	Channel widening
2	300	X	X			Channel widening
2	305	X			X	Channel widening
3	320	X	X		X	Significant channel widening
3	325	X	X		X	Significant widening with deposition and formation of gravel bars
3	355	X	X	X		Significant channel widening caused by bank erosion and bend migration
3	400	X	X		X	Bank erosion and channel widening with deposition and formation of gravel bars
3	460	X	X		X	Channel widening and scour
4	485	X			X	Significant channel widening
4	497	X	X		X	Channel widening caused by bank erosion and bend migration, some sediment deposition.
4	561	X	X		X	Significant channel widening and formation of gravel bars.
4	575	X	X		X	Channel widening, bend migration, and formation of gravel bars.
5	621	X	X		X	Significant channel widening
5	670	X	X			Channel widening
5	676	X			X	Bend migration and stabilization
6	695	X		X	X	Channel widening
6	740	X	X		X	Channel widening
6	745	X		X	X	Channel widening

Table 4.26
Summary of Historical Channel Cross Section Data

Reach No.	Cross Section ID	Years That Cross Section Data Were Obtained for Comparison				General Geomorphic Changes Occurring During Period of Record
		1981	1984	1987	1992	
6	800	X	X			Channel widening
7	905	X			X	Significant scour and channel widening
7	923	X	X		X	Scour and channel widening
7	935	X			X	Scour
7	960	X	X		X	Scour and channel widening
7	990	X	X			Scour and channel widening
7	1000	X	X			Scour and channel widening
7	1070	X	X			Scour and channel widening
7	1077		X		X	Some depositions
8	1120	X	X		X	Channel widening
8	1150	X	X		X	Channel widening. Scour during 1983-84 Flood. Deposition after 1984.
8	1160	X	X		X	Channel widening
8	1180	X	X			Channel widening.
9	1265	X	X	X		Deposition since 1984

the entire study area between 1856 and 1990. Sinuosity remained relatively constant on the Jordan River between 1856 and 1946, reaching its peak in about 1946. In general, very little recovery of sinuosity has occurred since the channel was straightened in the 1950s. However, some localized areas have nearly completely recovered. Much of the sinuosity recovery has been prevented by channel maintenance practices, or by the lack of significant flood events. Although it is not illustrated well in Table 4.27, some sinuosity was recovered in the upstream reaches during the major floods of 1983-1987.

Table 4.27
Jordan River Stability Study
Average Jordan River Channel Sinuosity, 1856 to 1990

Year	1856	1901	1923	1937	1946	1958	1965
Sinuosity	1.4	1.4	1.4	1.6	1.6	1.3	1.2
Year	1982	1983	1984	1986	1988	1990	
Sinuosity	1.2	1.2	1.1	1.2	1.2	1.2	

It is interesting that according to some geomorphic definition of meandering (sinuosity less than 1.5 is considered straight), the Jordan River was changed from a meandering river to a straight river. The crossing of the threshold from sinuous to straight may also account for the lack of sinuosity recovery since the 1950s straightening. The channel straightening may have caused a new set of geomorphic rules to apply to the river.

Meander Wavelength

Changes in meander wavelength and amplitude were also observed from historic records. Since sinuosity was relatively stable between 1856 and 1937, and from 1958 to 1990, wavelength and amplitude were compared for the years 1937 and 1990, for each of the reaches to determine the extent of the changes. As shown in Table 4.28, between 1937 and 1990 meander wavelength increased an average of 150 percent, and meander amplitude decreased an average of 23 percent.

According to the data in Table 4.28, Reaches 5 and 7 experienced the greatest changes in meander characteristics between 1937 and 1990. This indicates that these reaches may also experience channel stability problems in the future. Reach 6, which was straightened and relocated, had only minimal decreases in amplitude, which may account for the stability of this reach. Reaches 1, 2, and 8 experienced only minor changes in overall meander characteristics and are the most stable reaches in the study area with respect to channel pattern.

Table 4.28
Comparison of Jordan River Meander Characteristics, 1937 - 1990

Reach No.	1937				1990				Percent Change		
	Amplitude	Wave Length	No. of Meanders in Reach	No. of Meanders per Mile	Amplitude	Wave Length	No. of Meanders	No. of Meanders per Mile	Amplitude	Wave Length	No. of Meander in reach
9	464	1043	6	4.4	66	2085	2	1.5	-86	100	-67
8	307	842	20	6.7	350	1265	12	4.0	14	50	-40
7	287	676	25	5.7	154	2403	7	1.6	-46	255	-72
6	220	603	32	7.9	193	2723	7	1.7	-12	351	-78
5	232	626	20	11.4	116	2320	3	1.7	-50	271	-85
4	228	569	24	8.6	195	1394	8	2.9	-14	145	-67
3	248	690	19	5.0	297	1900	8	2.1	20	175	-58
2	307	1226	8	3.6	317	1443	6	2.7	3	18	-25
1	27	962	7	4.3	138	764	9	5.6	-36	-21	29

Channel Movement During Floods

Single Event Flood Erosion

The most severe bank erosion on record occurred during the 1983-1987 floods. The maximum lateral channel movement at a location within each reach (not reach-averaged) was measured from aerial photographs. Table 4.29 summarizes the maximum 1983-1987 lateral channel movement distances caused by bank erosion in each reach. Reaches 3 and 4 experienced the most severe lateral channel movement. Reaches 5, 6, 7, and 9 experienced the least amount of lateral channel movement during the 1983-1987 floods.

Table 4.29
Maximum Lateral Channel Movement Distances, 1983-1987

Reach No.	Maximum Lateral Movement (ft)	Description of Area
1	101	Some Meander Cutoffs
2	68	Generally Stable
3	675	Widespread General Bank Erosion
4	506	Widespread General Bank Erosion
5	34	Stable
6	34	Stable
7	68	Isolated Erosion
8	371	Between 3300 - Mill Creek
9	0	Channelized

Long-Term Erosion

Bank erosion that occurred in the study area between 1983 and 1990 was not measurable within a reasonable margin of error for the map and photographic scales. However, some meander migration occurred between periods of photographic record as shown in Figure 11. In general, meander migration rates on stable rivers is less than 2 feet/year. This low rate of movement is not detectable on time-spaced aerial photographs. Historically, the most significant channel migration and bank erosion rates on the Jordan River have occurred during significant flood events, such as 1983-1987. During periods of normal discharge, only minor channel migration and bank erosion has been experienced. Given the cyclic history of flooding on the Jordan River, channel instability may also be assumed to be cyclic with flooding.

Although actual meander movement rates could not be accurately measured, other important information is available. The pattern of long-term bank erosion and meander migration is clearly shown in Figures 10 and 11. The historic meander pattern is probably more important than estimated meander migration rates in developing a meander corridor. Figures 10 and 11 show the location of the Jordan River channel centerline from 1856 to 1990 and indicate that while the locations of the banks have changed, the river pattern has remained essentially constant and the river has remained within a relatively narrow band of the river valley. This fact was used to develop the meander corridor because even though the channel has migrated, it has remained within a defined area.

Reaches of Maximum Lateral Movement

Significant historical bank erosion and lateral channel movement have occurred throughout the study area. During the past 30 years, significant bank erosion and channel migration occurred in Reaches 3 and 4 between 10600 South and 14600 South, and in Reach 8 between 3300 South and Mill Creek, and just downstream of 3900 South. Elsewhere in the study area, bank erosion and channel migration is virtually nondetectable within the margin of measurement error using the aerial photography. Field investigations indicate that cut banks have formed throughout the study area.

Long-term erosion and lateral migration rates for meandering streams are typically less than 2 feet per year. Numerous channel realignments, straightening projects, and other engineered river changes make precise measurement of long-term bank erosion and channel migration rates difficult for the Jordan River. However, the long-term rate of erosion appears to lie within expected rates for most of the study area.

Comparison With Other Studies

As part of this study, three studies performed by others were considered. These studies evaluated river channel stability for all or portions of the study area. These studies included: 1) Jordan River Channel Stability Evaluation[15]; 2) Jordan River Parkway: An Alternative[16]; and 3) Jordan River Hydraulics Study for the Riverton Golf Course Project[17]. The results of these studies are summarized on the following page.

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[15] Jensen, S.F., 1987, "Stream Reach Inventory and Channel Stability Evaluation for the Jordan River in Salt Lake County, Utah", Salt Lake City-Salt Lake County Health Department, Division of Environmental Health, Bureau of Water Quality

[16] Urban Technology Associates, 1971, "Jordan River Parkway: An Alternative", Report to the Salt Lake County Board of Commissioners.

[17] Resource Consultants & Engineers, Inc., 1992, "Jordan River Hydraulics Study for the Riverton Golf Course Project", Report to the Salt Lake County Parks and Recreation Department.

SLCo BWQ: Jordan R. Stability Evaluation

This comprehensive, well-done report uses the U.S. Forest Service's bank stability inventory methodology to assess channel conditions reach by reach from Turner Dam to 2100 South. The focus of the study was to determine locations of bank erosion that should be stabilized as part of the non-point source pollution control system, prioritize location of flood control bank stabilization, and identify key wetland areas along the river. The study concludes that bank erosion is primarily caused by undercutting and occurs in the steepest, high-velocity reaches at the upstream end of the study area. The report also concludes that much of the bank erosion on the river is caused by the decreasing river gradient (slope).

The study recommends bank regrading and revegetation, selective emplacement of rock riprap at channel bends that have experienced excessive erosion near public facilities, and oxbow restoration as best management practices for the river. The study recommends stabilization in the following reaches (listed in order of priority): 1) the reach from 10600 South to 12300 South, particularly areas near the bridges; 2) the reach from 9000 South to 10600 South, particularly the upper and extreme lower portions; and 3) the reach from 14600 South to a point about 2 miles upstream. Other areas requiring stabilization included short reaches between I-215 and 6400 South and just north of 4500 South. The report draws many of the same conclusions that were reached for the Jordan River Stability Study.

UTA: Jordan R. Parkway—An Alternative

This report presents the concept of managing the Jordan River as a river corridor with development setbacks, public ownership, and multiuse objectives for the floodplain. Although the report is largely conceptual, it makes recommendations to reduce dredging, regrade channel banks, and construct de-silting basins to improve water quality.

RCE: Jordan R. Hydraulics Study—Riverton Golf Course

This report includes a geomorphic and sedimentation evaluation of improvements proposed for a golf course located just upstream of 12600 South. The report concludes that the study reach will continue to increase in sinuosity. It also states that the study area has experienced bank erosion and channel movement of up to 460 feet in some places since 1946, and that a bank erosion rate of 60 feet per year was experienced between 1986 and 1990. The primary bank erosion mechanism was reported to be tensile failure due to undercutting of the coarser bank sediment unit. The report recommends riprap bank protection, rock-filled trench construction, and revegetation to stabilize segments of the reach. These stabilization improvements have reportedly been constructed.

Results of Stability Analysis

The results of the analytical, historical, and geomorphic methods of analyzing the Jordan River channel stability summarized above are combined and discussed in this section. Table 4.30 is a summary of the predicted channel changes for each reach. The predicted channel changes were used to develop the Jordan River meander corridor shown in Figure 12 and to develop river management alternatives discussed later in this report. The results from these analyses were also used to identify areas of channel instability.

Meander Corridor

The meander corridor for the Jordan River (Figure 12) identifies a zone within which the river channel may reasonably be expected to migrate during the next 100 years. The following conditions and assumptions were used in developing the corridor:

- The corridor represents the valley width required for the channel to reestablish a stable, natural channel pattern in dynamic equilibrium given the sediment load, water discharge rate, and other independent variables.

- The width of the corridor reflects the historic and predicted meander characteristics for each reach. The corridor width also accounts for possible repetition of maximum historical single-event channel erosion distances.

- The corridor has a minimum setback of 50 feet from the top of the existing channel banks to allow access, maintenance, and future parkway use. This minimum setback was applied even where engineered bank stabilization has been constructed.

- All existing structural channel stabilization was assumed to be permanent. It was also assumed that no additional measures would be implemented to stabilize the river, even those recommended later in this report. It was assumed that the river would be allowed to change and migrate freely within the corridor, to attain a state of dynamic equilibrium.

- The corridor limits do not explicitly reflect riparian or other wetland objectives, although recovery of riparian environment is likely as channel stability increases.

- Turner Dam, the Joint Diversion, the North Jordan Diversion, the 6400 South drop structure, and the Brighton Diversion Structures were assumed to be the only existing, permanent grade control structures.

Table 4.30
Summary of Predicted Channel Changes

Reach	Width	Depth	Meander Amplitude	Meander Wavelength	Sinuosity	Slope	Long-term Scour	Flood Scour	Past Dredge	Bank Erosion
9	0	-	0	0	0	0	Minor	Minor	Yes	Minor
8	0	-	0	0	+	-	Yes	Minor	Local	Local
7	+	-	+	-	+	-	Yes	Deposition	Local	Local
6	0	0	0	0	+	0	Minor	Minor	Yes	Minor
5	+	-	+	-	+	-	Yes	Minor	Yes	Yes
4	0	0	+	-	+	-	Yes	Deposition	Local	Yes
3	+	0	+	-	+	-	Minor	Scour	No	Yes
2	+	-	0	0	0	-	Minor	Scour	No	Local
1	+	-	0	0	0	-	Minor	Scour	No	Local

+ = Increase; - = Decrease; 0 = Minor or No Change

- The corridor generally was not narrowed significantly at bridge locations, although significant bank erosion immediately downstream of bridges is not likely.

Stability Problems

A reach-by-reach description of the meander corridor and the existing and potential stability problem areas follows.

Reach 1: Turner Dam to Joint Diversion

The Jordan River in Reach 1 is located in the bottom of a narrow, shallow canyon. A short section of this canyon widens considerably near Station 1335 before reentering a long, more narrow section at Station 1275. Although Reach 1 is considered stable, some historical channel migration, and bank erosion during the 1980s, has occurred within the wider sections between Stations 1275 and 1335.

The stability analysis indicates that the channel width-depth ratio may slightly increase, and that net scour occurs during floods. Geologic control and bed armoring will hinder these predicted river adjustments. In addition, channel slope is controlled by the grade control at the Turner Dam and the Joint Diversion structure, although high velocities and sediment deficits could cause progressive long-term scour immediately downstream of Turner Dam. Localized scour could destabilize portions of steep banks and cause erosion during major floods, but the banks will be relatively stable during normal flow periods. Existing riprap bank stabilization protects known problem areas.

Over a 100-year period, the channel may gradually migrate back and forth within the narrow geologic floodplain defined by the steep bluffs. Because of this potential for migration and because the geologic floodplain is undeveloped, the meander corridor occupies the entire geologic floodplain.

Channel stability problems in Reach 1 include net scour and local bank erosion during major floods. However, except for two railroad bridges, little development exists within Reach 1. Field investigations indicate that generally stable bank conditions and extensive riparian development exist in Reach 1. Where bank erosion or scour do occur, there should be minimal impact on overall channel stability. The railroad operators may wish to monitor scour at the bridges and along grades near the active channel. The erosion hazards in Reach 1 are considered minor.

Summary:

- No significant stability problems.

Reach 2: Joint Diversion to 14600 South

From the Joint Diversion to just upstream of 14600 South, the Jordan River flows in a narrow, shallow canyon. As the river leaves the confined canyon upstream of 14600 South, channel sinuosity increases. The sharp meander that impinges on the roadway embankment of 14600 South is protected by riprap bank protection. Historically, Reach 2 has been very stable with little channel migration. During the floods of the early 1980s, only isolated bank erosion occurred. Overall, Reach 2 is stable.

The stability analysis indicates that the width-depth ratio will increase and slope will decrease where not prevented by geologic control or channel armoring. HEC-6 modeling and the historical analysis indicate that net scour during floods and long-term scour may occur, probably due to the steep channel slopes, high velocities, and sediment trapping above the Joint Diversion. Local scour will tend to destabilize channel banks and cause local bank erosion during major floods, but the channel will be relatively stable during periods of normal flow.

The meander corridor in Reach 2 follows the limits of the geologic floodplain from the Joint Diversion to approximately Station 1190. Downstream of Station 1190, the corridor widens slightly to account for the expected increase in sinuosity, bank erosion, and long-term meander migration in the short reach upstream of 14600 South.

Potential channel stability problems in Reach 2 include general channel scour and isolated bank failures. Field investigations indicate that bank conditions are relatively stable. Bank stabilization has been installed at several locations in this reach to protect canals and railroad grades located above the bluffs of the geologic terraces, as well as along the south side of the roadway embankment of 14600 South. No development exists within the meander corridor, except the railroad bridge and the 14600 South bridge, which is a free span structure. Elsewhere in Reach 2, channel instability probably will have no significant impact on existing development. Erosion hazards are considered minor.

Summary:

- No significant stability problems.
- Possible long-term degradation may occur near 14600 South.

Reach 3: 14600 South to 12300 South

In Reach 3, the Jordan River becomes more sinuous with numerous gravel bars, cut banks, and perched oxbow lakes. Reach 3 was straightened and dredged during the channelization project of the 1950s. This reach has experienced historical long-term channel migration and severe short-term bank erosion during the floods of the 1980s. Much of the bank erosion that occurred on the Jordan River during the 1980s occurred within Reach 3. Field data suggest that cutbanks are present throughout this reach and that bank erosion is continuing. A rock-filled trench and riprap bank protection have been constructed as part of the recent golf course improvements located upstream of 12600 South. Elsewhere in Reach 3, excluding the bridges at 12300 South and 12600 South, channel movement is currently unrestricted by development or geologic controls.

The stability analysis indicates that the channel will increase its width and sinuosity, and decrease its slope. The HEC-6 modeling and historical data predict net scour and long-term degradation in Reach 3, especially upstream of Station 980. Some deposition is predicted between Stations 975 and 945. Meander wavelength will decrease and amplitude will increase as sinuosity increases. The combination of scour during significant flood events, long-term degradation, and increase in sinuosity will result in active bank erosion, channel bar formation, and channel meander migration.

The meander corridor for Reach 3 is wider than in Reaches 1 and 2 to account for the active scour, deposition, and bank erosion that make it one of the more unstable reaches in the study area. Bluffs on the west side of the corridor near 12600 South will prevent channel migration to the west and could accelerate erosion of the east bank. The meander corridor is wider in this area to reflect the increased potential for erosion.

Channel stability problems in Reach 3 include severe bank erosion, minor long-term degradation, and net flood scour. A utility line located near 12600 South (See Figure 2 and Tables 3.4 and 4.25) may be at risk of failure due to bank erosion. This sewer line may face additional risk due to bank stabilization that was recently constructed on the opposite bank. No other structures, except the 12600 South bridge, exist within the meander corridor. The upstream face of the roadway embankment grade at the 12600 South bridge will eventually require stabilization as the meanders migrate toward and impinge on the embankment. Where bank erosion does occur, it is unlikely to impact existing development or structures within the corridor. Mitigation for scour erosion hazards near utilities may become a priority in Reach 3. Bank erosion hazards exist, but are currently a low priority in Reach 3.

Summary:

- Significant bank erosion has occurred in this reach and will likely continue in the future.
- The sewer line in the east overbank between Stations 935 and 970 is in risk of failure due to bend migration and the bank stabilization recently constructed on the opposite bank.
- The sewer line crossings at Stations 968 and 993 may be in risk of failure due to channel degradation.
- Embankment stabilization may be required upstream of the 12600 South bridge.

Reach 4: 12300 South to 10600 South

The Jordan River channel pattern in Reach 4 is similar to that of Reach 3; relatively sinuous with gravel bars and cut banks. Reach 4 was also straightened and dredged as part of the channelization project of the 1950s. Reach 4 has experienced significant historical meander migration, as well as significant short-term bank erosion and channel migration during the floods of the 1980s. Field data suggest bank failure and long-term degradation will continue in the future. No bank stabilization has been constructed in Reach 4, but the lower portion of this reach from Stations 770 to 820 was dredged during the floods of the 1980s.

The stability analysis indicates that sinuosity will increase through bank erosion and slope may decrease slightly due to increased meandering. HEC-6 sediment transport simulations predict that slight net deposition occurs during floods. Bank erosion with associated bar formation is likely to continue in Reach 4, unless vegetation is reestablished on existing channel banks, and banks are regraded to more stable cross slopes.

Channel stability problems in Reach 4 include bank erosion and some minor local scour. Apparently, most utility crossings (shown in Figure 2 and listed in Tables 3.4 and 4.25) are currently stable; however, there could be at risk if headcuts were to move upstream from Reaches 5 through 9. No information on the utility crossing at Station 915 was available. Erosion hazards will have little significant impact on existing development within the corridor. Erosion mitigation is given a low priority for this reach.

Summary:

- Significant bank erosion has occurred in this reach and will likely continue in the future.
- The sewer line crossings at Station 771 may be at risk from scour and degradation.

Reach 5: 10600 South to North Jordan Diversion

In Reach 5, the Jordan River has retained the channel geometry, sinuosity, and alignment created by the straightening project of the 1950s. Reach 5 has experienced relatively little channel migration since the 1950s, even though some natural river migration occurred on the formerly sinuous channel prior to 1958. Field data indicate that vertical cut banks have formed and are forming in a significant portion of this reach. The apparent long-term channel stability may be due to periodic dredging of the entire reach. Channel bank stabilization exists only in the downsteam portion of the reach, near the sharp channel bend upstream of the North Jordan Diversion.

Geomorphic indicators predict that the channel width/depth ratio and sinuosity will increase, and that channel slope will decrease. The HEC-6 analysis predicts little net flood scour or deposition for the existing channel except for backwater deposition upstream of the North Jordan Diversion. Grade control provided by the North Jordan Diversion will prevent severe long-term degradation. Measured degradation at 10600 South may be the result of dredging. Bank erosion will create a more sinuous, stable channel.

The width of the meander corridor reflects the predicted instability of Reach 5, assuming dredging is discontinued. The meander corridor encompasses the remnants of pre-1958 meander paths, which are still visible on aerial photographs (See Figures 10, 11, and 12). The corridor width allows the channel sufficient area to develop a more sinuous path.

Channel stability problems in Reach 5 include potential bank erosion, minor long-term degradation in the upstream section of the reach, and sediment deposition upstream of the North Jordan Diversion. Field data indicate that the channel may be in the process of reestablishing its prechannelization meandering channel pattern. If dredging operations are discontinued, bank erosion will increase until dynamic equilibrium is achieved. However, since no structures are located within the meander corridor in Reach 5, erosion hazards are of minor significance.

Summary:

- Bank erosion has occurred in this reach and may continue in the future.
- Sediment deposition will occur in the backwater above the North Jordan diversion dam.

Reach 6: North Jordan Diversion to 6400 South

Reach 6 is one of the most highly urbanized reaches within the study area. Reach 6 was straightened and dredged as part of the channelization project of the 1950s, and completely relocated in much of the reach. From the bank protected reach at the North Jordan Diversion to the near-linear, dredged channel extending to 6400 South, the natural channel pattern has been obscured. In spite of these changes to the natural channel, Reach 6 has been one of the most stable reaches in the study area. Reach 6 experienced little historical channel migration, and very little flood scour during the 1980s floods. Field evidence also suggests that the channel banks in this reach are relatively stable. A sheet pile grade control structures has been constructed at 6400 South. The portion of Reach 6 from Stations 610 to 678 was dredged during the 1980s.

The stability analysis indicates that the channel may not adjust to a more natural sinuous pattern, except upstream of Station 600 where a higher width-depth ratio and sinuosity and decreased slope may develop. HEC-6 modeling and historical data indicate that no net scour occurs. Some increases in meander amplitude and associated bank erosion may occur in the previously dredged reach if dredging is discontinued. Overall, most of the reach should remain stable.

The relatively narrow meander corridor in Reach 6 reflects the historical, observed, and predicted channel stability. A slightly wider corridor is proposed for the dredged reach near 9000 South to account for increased meandering and bank erosion if dredging is discontinued.

Development has encroached on the meander corridor at two locations in Reach 6. The first is located in the dredged reach at approximately Station 617. This area may experience bank erosion in the future. The second, a residential subdivision located on the east bank upstream of 6400 South, is on the outside of a meander bend. Although the outside banks of meander bends are potential erosion areas, the low velocities and existing grade control should help prevent bank erosion. Neither area has a history of significant channel migration.

A long section of the east bank of Reach 6 is comprised of tailings and slag from the smelter operation sites. While channel stability is relatively high in this reach, consideration of adding engineered slope and bank protection should be made for water quality reasons. A field report prepared by Salt Lake County staff indicates that some discharge from these areas may be entering the Jordan River. Evaluation of the quality of this reported discharge should be made to assess the need for slope stabilization.

Channel stability problems in Reach 6 include bridge scour at the 7800 South, Station 522 railroad, and 9000 South bridges, and bank erosion in the upper portion of the reach if dredging is discontinued. The grade control structure at 6400 South will prevent most long-term degradation. Long-term degradation will be most significant at the 9000 South bridge. A number of utility crossings are found within the reach, but no structure elevation was available from which to estimate their probable stability. Channel stability problems in Reach 6 are considered to be of low significance.

Summary:

- Significant bank erosion, has occurred between Stations 610 and 678 and may continue in the future.
- Minor bridge scour potential exists at 6400 South due to the existing drop structure located immediately downstream from the bridge.
- Significant bridge scour potential exists at 7800 South and should be monitored.
- Significant bridge scour potential exists at railroad bridge, Station 522 and should be monitored.

- Significant bridge scour potential exists at 9000 South and should be monitored.

Reach 7: 6400 South to Brighton Diversion

Reach 7 encompasses most of the Jordan River Parkway in Murray City, which has been designated as an open space corridor. Reach 7 was straightened and dredged as part of the channelization project of the 1950s. Currently, the reach is characterized by a relatively straight channel with relatively stable banks and numerous perched oxbow lakes. Historically, there has been some meander migration in Reach 7, but little occurred during the floods of the 1980s. Bank stabilization has been constructed in a portion of the reach between the bridges at 6400 South and I-215, on the west bank downstream of 5400 South, and on portions of both banks between the Brighton Diversion and 4800 South. Portions of the reach near I-215, 5400 South, and the Little Cottonwood Creek confluence were dredged during the 1980s.

The stability analysis indicates that the width-depth ratio and channel sinuosity will probably increase, and that a decrease in slope is likely. HEC-6 modeling indicates net deposition between the Bullion Street bridge and 4800 South. Deposition can also be expected downstream of the confluence with Little Cottonwood Creek. Bridge scour of 4 to 6 feet may occur at all four bridges in the reach during the 100-year flood. Historical data suggest long-term degradation will occur between periods of deposition during flood events. The geomorphic and HEC-6 analyses indicate that the historical and recent channel stability characteristics in Reach 7 may change as the reach gradually recovers from the straightening that occurred in the 1950s.

The meander corridor shown in Figure 12 reflects the expected adjustment of slope, meander amplitude, and bank erosion that may occur over the next 100 years. Most of the area in the corridor is already within the Murray City Parkway. The meander corridor also envelopes the historical meander pattern between 4800 South and 6400 South, which is still visible in aerial photographs (See Figure 12).

Development within the meander corridor is found at several places within Reach 7. First, the Murray Golf Course is located on the river banks upstream of I-215. The golf course experienced significant erosion of the fairways and tee boxes during the floods of the 1980s. Additional erosion may be expected over the next 100 years unless the banks are stabilized and grade control is established. A second area of development in the corridor is at the Bullion Street bridge. The Bullion bridge should provide stability to the channel near these structures. A third area is the residential subdivision located on the west bank of the river just upstream of 5400 South. Channel bed degradation at 5400 South makes bank failure more likely in this area. Because the subdivision is located on the inside of the meander, bank erosion is somewhat less likely than on the opposite bank. The final development area is located on a small bluff between Stations 320 and 330. This area is technically out of the corridor and the geologic floodplain, but should be monitored due to its position relative to meander bends and predicted depositional areas.

Channel stability problems in Reach 7 include probable bank erosion, sediment deposition, bridge scour at 5400 South and 4800 South, and long-term degradation. Significant bank erosion is not presently occurring, but could occur within the 100-year planning period. As a more sinuous channel pattern recurs, bank erosion may become more significant, particularly if channel deposition occurs. Because most of the reach is located within the Murray City Parkway, bank erosion may not affect development except in the four areas noted above. Long-term degradation will impact bridges and utility crossings, particularly those most distant from the grade control provided by the Brighton Diversion structure. Piles supporting the 5400 South bridge pier are currently exposed. Flood deposition near the mouth of Little Cottonwood Creek and between 4800 South and 5400 South may cause some increased bank erosion if left unchecked. Several significant stability problems are found in Reach 7.

Summary:

- Long-term channel degradation will likely occur in this reach.
- Significant bank erosion has occurred in this reach and may continue in the future.
- Significant bridge scour potential exists at 5400 South and 4800 South.
- Sediment deposition will likely occur in the lower portion of this reach, particularly near the Little Cottonwood Creek confluence during flood events.

Reach 8: Brighton Diversion to Mill Creek

In Reach 8, the Jordan River has retained much of its sinuous channel pattern, though the effects of encroachments, development, and channelization can be seen throughout the reach. Three bridges, six utility crossings, several development encroachments, and numerous riprap sections impact the reach. Historically, portions of Reach 8 have experienced high meander migration rates. Local areas near sharp channel bends, tributary confluences, and areas near constricted reaches experienced significant bank erosion in the floods of the 1980s. Field data indicate that numerous cutbanks exist in Reach 8, and that gravel bars may be found in several locations. Periodic dredging has been required at the mouths of Big Cottonwood and Mill Creeks to remove tributary sediment deposition in the channel.

The stability analysis indicates that the reach is relatively stable, although some increase in sinuosity and decrease in slope may be expected. The HEC-6 modeling predicted no significant scour or deposition, although historical data suggest that relatively significant long-term degradation has occurred. Sediment supplied by Big Cottonwood Creek is excess sediment not considered in the HEC-6 model. This sediment would be deposited in the reach and would need to be removed by dredging. If this sediment is not removed, flood water surface elevations and bank erosion would likely increase.

The meander corridor proposed for Reach 8 reflects the potential for scour at channel bends and for bank erosion induced by channel deposition. Existing flood levees, low geologic terraces, and engineered bank protection control the dimensions of the corridor in several sections.

Development within the erosion corridor occurs at several places in Reach 8. A large manufactured housing development located upstream of 3300 South, between Stations 135 and 160, has encroached on the channel as well as the corridor. This development is located on the inside of a meander bend. However, long-term degradation that has occurred may make the banks less stable and subject to failure. A jail, a power substation facility, and some residential buildings are also located within expected erosion areas on the outside of three consecutive meander bends between 3300 South and the Mill Creek confluence.

Channel stability problems in Reach 8 include bank erosion and sediment deposition at the mouth of Big Cottonwood Creek, and long-term degradation. Bank erosion has the potential of undermining portions of several residential and industrial developments that have encroached on the floodplain in the reach. Bridge scour may be significant at the 4500 South, 3900 South, and 3300 South bridges, particularly when combined with the potential for continued long-term degradation. No information was available from which to evaluate the stability of the utility crossings. The presence of high density residential and industrial development within or near the erosion corridor gives Reach 8 a higher priority for erosion hazard mitigation.

Summary:

- Significant bank erosion has occurred at channel bends and will likely continue in the future.
- Sediment deposition will likely occur near the Big Cottonwood Creek confluence, particularly during flood events.

Reach 9: Mill Creek to 2100 South

The Jordan River is channelized in Reach 9. Flood control levees have been constructed on both banks of the river. Grade control is provided by the Surplus Canal Diversion downstream of 2100 South. Salt Lake County dredges the reach periodically as part of a maintenance agreement with the COE. The trend of historical meander migration is checked by the bank protection. No significant bank erosion occurred during the floods of the early 1980s. Geomorphic indicators predict that some channel adjustment will occur, but the channelization will probably prevent these adjustments from occurring. HEC-6 modeling predicts no net scour or deposition. The narrow meander corridor shown in Figure 12 reflects the engineered stability of the reach.

Reach 9 has no significant channel stability problems except periodic deposition of tributary sediment. This sediment deposition is removed by dredging when necessary.

Summary: No significant problems.

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Section 5

River Management

The detailed stability analysis summarized in Section 4 indicates that sections of the Jordan River are unstable. Channel stability problems include long-term channel bed degradation, bank erosion, bridge scour, sediment deposition, and meander migration. A range of management alternatives were evaluated that may be used to mitigate these stability problems.

This section of the report evaluates potential erosion management alternatives for the Jordan River. The types of existing and future stability problems and their potential effects on the Jordan River will be described, problem reaches will be identified, and a range of generic management alternatives will be discussed and evaluated. Additional information such as relative cost opinions is also provided. Finally, management alternatives for each of the problem reaches will be recommended and prioritized.

Channel Stability Problems

Types of Stability Problems

The types of river stability problems found on the Jordan River include the processes of bank erosion, long-term channel bed degradation, bridge scour, sediment deposition, and meander migration. These processes fall into two basic categories:

1) Channel stability problems resulting from the river's response to channelization, urbanization of the watershed, and changing land use along the river corridor.

2) Erosion processes that are part of the river's natural dynamic equilibrium.

Management alternatives can be developed to mitigate the effects of the first type of processes. Attempts to "manage" the second type of processes in the past has sometimes resulted in additional stability problems. The second type of processes should be expected to occur long after the river becomes "stable."

The most significant erosion problem affecting the stability of the Jordan River is long-term degradation. The primary cause of long-term degradation is the artificial straightening of the river that has occurred during the last 40 years. The long-term degradation is the cause of many stability problems including bank erosion, excessive bridge scour, and loss of riparian vegetation. Long-term degradation is progressive channel scour, which lowers the channel bottom. Table 4.23 shows cumulative bed degradation between 1950 and 1990 for key locations within the study area. Long-term degradation between 1981 and 1991 can also be inferred from data in Table 4.25. All reaches except Reach 1 in the study area have experienced measurable long-term degradation.

Channel stability problems associated with long-term degradation include oversteepening and undercutting of the channel banks, destabilizing of bank vegetation, increasing channel capacity and velocity, and undermining bridge piers and utility crossings. Lowering of the channel bed removes the soil material that provides lateral support for the banks. Without lateral support, banks are more susceptible to tensional failures (bank sloughing), which leave vertical cut banks. Vertical cut banks do not support vegetative growth and therefore are more likely to erode. Vertical cut banks are currently found throughout most of the study area. Long-term degradation also increases channel capacity, causing flood flow velocities to increase. Increased flow velocities increase erosion of the bed and banks. The higher channel capacity may also increase the magnitude of the flood peak downstream by reducing floodplain attenuation. Therefore, control of long-term degradation is essential in managing flood and bank erosion hazards.

Channel bank erosion is the most visible form of instability on the Jordan River. Some bank erosion is caused by long-term degradation as described above. Elsewhere, bank erosion is the result of the channel attempting to reestablish a more natural channel pattern. The river straightening project of the 1950s removed most of the Jordan River's natural sinuosity. Because other geomorphic and hydraulic variables did not change when the river was straightened, the river has tried to recover its sinuous channel pattern. In some reaches, factors such as soil cohesiveness, vegetative cover, and low velocities have prevented the sinuous channel pattern from returning. However, as more floods occur and as sufficient time passes, a more sinuous channel pattern can be expected to return. Principles illustrated in Figure 9B and some of the equations reviewed in the Stability Analysis section of this report indicate that changes in sinuosity are unlikely to be stable, unless the channel slope and sediment supply conditions change appropriately.

Sediment deposition is also a problem on some sections of the Jordan River, such as at tributary confluences, upstream of diversion structures, and in Reaches 4, 7, and 8. Continual sediment deposition can cause channel instability by redirecting flow velocities directly against the banks. Sediment deposition may also cause increased water surface elevations during floods. Local deposition that occurs where banks collapse may result in gravel bar formation. This latter form of deposition is less of a stability problem than the river's attempt to return to a more stable form.

The second type of expected erosion is the natural equilibrium processes of erosion that occur on all natural rivers. A stable river will gradually erode its banks, deposit sediment, and experience local scour in floods. However, net erosion will approximately equal net deposition. These equilibrium processes cause meander migration. However, the magnitude of these forms of erosion are low, and do not need to be specifically addressed in a management plan. Attempts to prevent these natural forms of erosion often cause stability problems in adjoining reaches. For example, lining a river reach with riprap (to prevent meander migration) may stop meander migration in that reach, but may increase bank erosion in the reach immediately downstream.

Channel Instability Reaches

Sections of the Jordan River that were found to have stability problems are listed below by reach. This summary assumes that the bank erosion that occurs within the meander corridor does not threaten existing development and is not a stability problem.

Reach 1: Turner Dam to Joint Diversion

Although some local scour will occur in Reach 1, no significant stability problems were identified. Bridge scour at the railroad crossing should be monitored by the appropriate agency.

Reach 2: Joint Diversion to 14600 South

Bank stabilization has already been installed to protect railroad grades and canals located above banks that showed signs of failure during the 1983-1987 floods. Some potential for long-term degradation exists near 14600 South.

Reach 3: 14600 South to 12600 South

In recent years, severe bank erosion has occurred within the corridor limits in Reach 3. Bank erosion could impact the sewer line in the east overbank area just upstream of 12600 South. In addition, some potential for erosion damage due to long-term degradation exists at 12600 South and at utility crossings.

Reach 4: 12600 South to 10600 South

Severe bank erosion that occurred during the 1980's will continue to affect Reach 4. Net deposition predicted by HEC-6 should not cause additional significant stability problems. Bank erosion will have little significant impact outside the corridor.

Reach 5: 10600 South to North Jordan Diversion

No significant channel stability problems were identified in Reach 5. Some deposition will continue to occur upstream of the North Jordan Diversion. Bank erosion will increase, but can be contained within the corridor.

Reach 6: North Jordan Diversion to 6400 South

Channel stability problems in Reach 6 include bridge scour at the 7800 South, Station 522 railroad, and 9000 South bridges. Long-term degradation may worsen the effects of bridge scour at the 9000 South bridge. Another potential stability problem is bank erosion at a subdivision located on the east bank of the river upstream of 6400 South. Potential water quality problems may be prevented by stabilizing the tailings embankment near the abandoned smelter operations site most recently operated by Sharon Steel. Finally, increased bank erosion may occur in the reach between Stations 600 and 676 upstream of the Sharon Steel site if dredging is discontinued. Bank erosion in the channelized reach between the Sharon Steel site and 6400 South should be contained within the meander corridor during the next 100 years.

Reach 7: 6400 South to Brighton Diversion

Channel stability problems in Reach 7 include probable bank erosion, sediment deposition, bridge scour at 5400 South and 4800 South, and long-term degradation. Severe bank erosion is not presently occurring, but is likely to occur as a more sinuous channel pattern develops. Predicted flood sediment deposition may be offset by historical long-term degradation, which has threatened bridge piers at 5400 South. Sediment deposition near the mouth of Little Cottonwood Creek and between 4800 South and 5400 South may cause some increased bank erosion and increased flood levels if left unchecked. Bank erosion may impact the Murray City Golf Course upstream of I-215, and a subdivision located on the west bank of the river upstream of 5400 South. Channel bed degradation at 5400 South makes bank failure more likely in this area. Another area potentially impacted by bank erosion is a residential area located on a small bluff between Stations 320 and 330.

Reach 8: Brighton Diversion to Mill Creek

Channel stability problems in Reach 8 include bank erosion and sediment deposition at the mouth of Big Cottonwood Creek, and long-term degradation elsewhere in the reach. Bank erosion has the potential of undermining portions of several residential and industrial developments and a large manufactured housing development located upstream of 3300 South, between Stations 135 and 160, and in the reach between 3300 South and Mill Creek. Bridge scour may be significant at 4500 South, 3900 South, and the 3300 South bridges, particularly when combined with the potential for continued long-term degradation.

Reach 9: Mill Creek to 2100 South

Reach 9 has no significant channel stability problems other than sediment deposition. Sediment deposition is removed by periodic dredging as required by a COE maintenance agreement.

River Stability Management Alternatives

Management strategies to mitigate erosion hazards on the Jordan River were evaluated. Evaluation criteria included effectiveness for controlling erosion, cost, and political feasibility. Alternative management strategies included structural and nonstructural methods.

Existing Management Strategies

Management Authority

There is currently no formal program for managing the stability of the Jordan River. Numerous political entities including federal, state, and county agencies, and local communities have varying degrees of jurisdiction over development near the river. These agencies include:

Federal Agencies:

- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency, Region VIII
- U.S. Bureau of Reclamation
- U.S. Fish & Wildlife Service
- U.S. Geological Survey
- Federal Emergency Management Agency
- Department of Agriculture/Soil Conservation Districts

State Agencies:

- Department of Natural Resources
    - Division of Water Rights/State Engineer
    - Division of Wildlife Resources
    - Division of Parks & Recreation
    - Division of State Lands and Forestry
- Department of Environmental Quality
- Division of Natural Resources
- Department of Agriculture
- Department of Transportation
- Division of Comprehensive Emergency Management
- River Enhancement Board
- Resource Development Coordinating Committee

Local Agencies:

- Board of Salt Lake County Commissioners
- Salt Lake County Public Works
- Salt Lake County Parks & Recreation
- City of Bluffdale
- City of Riverton

- City of Draper
- City of South Jordan
- City of West Jordan
- City of Sandy
- City of Midvale
- City of South Salt Lake
- City of Salt Lake
- Murray City
- West Valley City

River maintenance for flood control purposes has generally been performed by the Salt Lake County Department of Public Works. Recent maintenance activities include construction of bank protection near some bridge crossings and along unstable banks at approximately ten locations and dredging of portions of Reaches 3, 4, 5, 6, 7, 8, and 9. Most of the bank protection and dredging activities occurred during the floods of the 1980s. Floodplain management responsibility is shared by the local communities and the County, and is administered by the state, although Salt Lake County has primary floodplain management responsibility for the Jordan River.

Relevant legislation and policies that impact river management are similarly distributed at the federal, state, and local level. These include the Federal Clean Water Act [Section 404(a) permitting], NFIP enabling legislation and promulagated rules (floodplain management), Central Utah Project (CUP) Completion Act (funding for wetlands acquisition), the 1992 Utah State Comprehensive Outdoor Recreation Plan, the Utah River Enhancement Act, the Public Trust Doctrine (governing state ownership of navigatible waters), the Jordan River Parkway enabling legislation, and floodplain management ordinances for each of the local jurisdictions. Various other federal and state rules grant review authority to the numerous agencies listed above.

There are several disadvantages to the current river management scheme. First, management authority is not centralized. Therefore, apparent conflicts between local objectives and state/federal goals may not be resolved in a consistent manner. Also, planning efforts are not well coordinated under the existing scheme. Second, river management is done reactively, rather than proactively. Proactive management anticipates future problems and resolves the cause of the problem (e.g. allowing the Jordan River to reestablish a stable natural meander pattern). Reactive management waits for a problem to develop and treats the symptoms of the problem (e.g. constructing bank protection and dredging where meanders are developing). Under the existing management scheme, stability problems are likely to continue or increase as development pressures increase on property near the river. Other disadvantages of the existing management scheme include continued need for maintenance for the river, long-term commitments of capital expenditures for river improvements, potential increased bank erosion and destruction of riparian habitat, and increased bridge scour.

Nonstructural Methods

Nonstructural methods are management strategies that do not use engineered facilities to limit erosion damage. In general, nonstructural methods attempt to keep development away from potential erosion, rather than keeping potential erosion away from development. Nonstructural methods include developing zoning restrictions to limit development within the meander corridor, acquisition of land within the corridor by public agencies, monitoring and inspection of key structures and stream reaches, and the "do-nothing" alternative.

General benefits of properly operated nonstructural approaches include:

- Enhanced recreational opportunities
- Inexpensive flood control
- Flood peak attenuation
- Increased habitat for wildlife
- Improved water quality
- Sediment transport, rather than mechanical removal
- Credits for reduction of NFIP flood insurance rates
- Preference by federal and state review agencies
- Preserves and enhances wetlands functions

Restrict Development/Zoning

Zoning and development restrictions is an approach commonly used for many types of public resource management. It consists of developing a list of acceptable land uses within the corridor and restricting other types of undesirable development. This approach is used for floodway and floodplain management programs associated with National Flood Insurance Program (NFIP). Acceptable uses typically include: open space, parks, golf courses (except greens), parking, temporary storage of nonhazardous materials, and some agricultural uses. Because most structural improvements would be prohibited within the meander corridor, site design of parcels partially within the meander corridor should be consistent with river management goals and should keep development and unallowable land uses outside the corridor. A sample erosion control ordinance is attached in the Appendix.

An important component of zoning restrictions will be to prevent excessive grazing of riverbanks and riparian areas. Overgrazing of such areas can lead to removal of vegetation and cause channel bank instability. At a minimum, public lands or acquired properties should be fenced to prevent access by cattle and horses.

Advantages of the zoning management alternative include legal precedent for the management approach, familiarity for local officials, flexibility of zoning restrictions between local entities along a multi-jurisdictional river, and low capital cost. Disadvantages include reliance on local entities for achieving management objectives, potential for zoning variances that compromise management goals, and potential legal action over "taking" issues.

Costs for this alternative include some labor by public agencies to develop zoning ordinances or overlays, and possible survey costs where corridor boundaries do not follow existing property lines.

Existing floodplain management ordinances and master plans were requested from the communities that border the Jordan River. Ordinances from Sandy City, South Jordan, West Jordan, West Valley City, Murray City, Riverton, and South Salt Lake were reviewed. Some zoning changes would be required to incorporate the meander corridor concept in all of the communities except Murray City. Most of the floodplain ordinances already require protection of structures from erosion hazards. No direct conflicts with the meander corridor concept were found. Responses to public presentations and the draft report from federal and state agencies, Salt Lake County, and the communities of South Salt Lake, West Valley City, Murray City, Salt Lake City, Midvale, Sandy City, West Jordan, South Jordan, Riverton City, and Bluffdale City indicate support the parkway/corridor concept. However, some concerns were raised regarding the costs to acquire, develop, and regulate the parkway. No comments were received from Draper City. Another common theme raised in public comment was the need for centralized management of the corridor, perhaps by a committee comprised of members from each of the communities.

Acquisition

Acquisition is a management alternative that has been successfully used elsewhere in the west. Public funding would be used to condemn and purchase land within the meander corridor. Advantages to the acquisition alternative include complete management control, flexibility of long-term use, ability to achieve multiobjective management goals, centralized management, and minimized "taking" concerns. Several communities and agencies participating in this study have indicated that management of a natural corridor may not be feasible without acquisition. In particular, nonstructural management goals will conflict with desired uses of private landowners. Once land is acquired by agencies, it may developed according to specific management goals that may include nature interpretive parks, public recreational parks, natural open space, and trails. The primary disadvantage is the cost of acquiring the land. However, much of the land area within the proposed Jordan River corridor is already publicly held. Traditionally, federal funding has been available from a variety of sources that may be used to defray the cost of acquisition. Acquisition is a viable option for management of the Jordan River system.

There are several potential sources of funding for acquisition as well as other factors that would aid acquisition plans. These include:

- CUP Completion Act. This bill was signed by President Bush in late 1992. The proposed funding will provide money for the acquisition of wetlands along the Jordan River.

- Flood Control Funds. Acquisition of floodprone lands is an acceptable use of flood control funds and would also garner credits under the NFIP Community Rating System (CRS). CRS credits help reduce flood insurance rates for all communities impacted by the acquisition. If acquired lands remain natural, they serve flood control purposes by helping to attenuate flood peaks and reduce flood velocities.

- Wetland Designation. The Jordan River Wetlands Advance Identification Study identified approximately 2,000 acres along a 22-mile stretch of the Jordan River as wetlands. This designation makes these lands "presumptively unsuitable for issuance of [Section 404] discharge permits."[1] Such lands probably could be acquired at costs substantially reduced from the market value of adjacent lands not so designated. The wetland areas identified in this study are shown in Figure 13.

- Public Lands. Much of the area within the proposed meander corridor is currently under public ownership. In addition, the state claims ownership of the existing riverbed and abandoned oxbows under the Public Trust Doctrine. Several local communities such as South Jordan, Murray City, and Riverton already have acquisition programs in place as part of local parkway plans.

Monitoring and Inspection

A regular monitoring and inspection plan should be a key element in the Jordan River stability management plan. Inspection is a one-time detailed field investigation to determine the condition of hydraulic structures located in the study area. Monitoring refers to a continuing program of regular measurement of key channel conditions in specific target areas. While monitoring and inspection do little to mitigate existing erosion hazards, they may help focus management efforts where they are most critically needed.

Structures targeted for inspection include bridges, utility crossings, bank protection, and diversion dams. Inspection parameters for bridges are outlined in HEC-18: *Evaluation of Scour at Bridges*, published by the Federal Highways Administration. The bridge inspection procedures may also be applied to other hydraulic structures along the Jordan River.

Monitoring programs should be designed to track changes in channel bed and bank conditions in key reaches. The series of monumented cross sections already established on the Jordan River could be used to identify short- and long-term changes in channel characteristics, as well as determine the rate of deposition, long-term degradation, or bank

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[1] Personal communication from Steve Jensen/SLCo to Craig Bagley/CH2M HILL dated June 24, 1992.

erosion. When imminent instability problems are identified, specific management or mitigation plans can be selected to correct the problem. Monitoring of channel beds and banks should be performed in reaches identified earlier as having potential stability problems.

There are no disadvantages to regular inspection and monitoring of hydraulic structures, except possibly the cost of staff time to perform these activities. The benefits of reduction in liability, prevention of bridge or dam failure, identification of instability prior to damage, and maintenance of adequate flow conveyance outweigh the costs of inspection and monitoring.

Do Nothing

For the "do-nothing" alternative, the river would be allowed to adjust without intervention. The current practices of dredging and installation of piece-meal bank protection simply would be discontinued. The primary advantage of this approach is the low initial cost. However, the disadvantages include factors that could far exceed the initial cost savings. Bank erosion and long-term degradation would continue in areas that could impact or damage existing development. If this occurs, increase costs could be incurred by: 1) potential lawsuits from property owners who may believe dredging or other previously practiced river management programs protected their land from flooding; 2) conflicts with property owners who wish to develop riverfront property or construct bank protection; and 3) potential damage to bridges or other structures within the meander corridor. The do-nothing alternative is no longer a feasible option for the Jordan River.

Structural Methods

Structural methods use engineered improvements to alter expected stream processes. Structural methods include channel straightening; dredging; bank stabilization with riprap, gabions, soil cement, meander vanes, or revegetation; construction of offset levees; and grade control.

The advantage of structural management methods is that they are easy to implement and to justify; a problem is identified and a solution is designed. The disadvantage of all structural erosion control measures is that resolution of one problem by structural methods may create another problem. For instance, construction of bank protection on one bank may accelerate bank erosion on the opposite bank, or may direct high velocity flows at downstream reaches and increase erosion in that reach. Also, most structural improvements require a stream alteration permit from the Utah Department of Natural Resources. Structural methods should always be used in conjunction with non-structural management schemes in order to solve both the cause and the effect of a stability problem.

Channel Straightening

The stability analysis demonstrated that, in general, channel straightening did not improve channel stability. In fact, many of the ongoing stability problems are a response to the straightening that occurred during the 1950s. Channel straightening is used to increase channel conveyance, to lower flood levels, and to improve bridge hydraulics. Large scale channel straightening projects are generally out of favor in most areas of the west because of the long-term stability problems they cause.

Straightening can be a long-term solution, but it requires inordinately high capital investment. It may also cause bank erosion upstream and downstream, increased flood peaks, decreased water quality, and destruction of riparian environment along the river. On the Jordan River, straightening should only be considered for short stabilized reaches upstream of undersized bridges with right of way constraints, as a measure to improve bridge hydraulics and reduce bridge scour. In general, channel straightening is not recommended as a stability measure for the Jordan River.

Dredging

Dredging involves removal of sediment deposited in a stream reach. Sediment is deposited because of low velocities in the reach, excess sediment supplied to the reach, artificially low channel slopes, backwater conditions, or increased channel roughness. Historical dredging of the Jordan River has affected channel stability. In some reaches, dredging has increased channel capacity, resulting in long-term impacts similar to those caused by straightening. In long-term aggradation areas, dredging may have prevented bank erosion by reducing gravel bar formation that can direct flow against the channel banks.

Dredging on the Jordan River has been conducted for several reasons, although no formal program for dredging exists, except in Reach 9. Dredging during the 1983-1987 floods increased channel capacity in reaches where water surface elevations were exceeding expected levels. Dredging of some other reaches was conducted to increase channel capacity near bridge or utility crossings. The Jordan River downstream of the confluences of Big and Little Cottonwood Creeks, and Mill Creek, was dredged to remove sediment transported to the river these tributaries. Apparently, the sediment transport capacity of the Jordan River in these areas is not sufficient to convey the tributary sediment imported into the system. Dredging of Reach 9 is mandated by an agreement with the COE.

Dredging may be required to maintain engineered channel geometry and capacities at bridge approaches and in other reaches where channel geometry changes are unacceptable. If dredging is discontinued in these types of reaches, the channel would eventually adjust to convey the "excess" sediment supply, but bank erosion or flood level increases could affect developed areas not currently impacted. Advantages of dredging include allowing an engineered channel geometry to be maintained and maintaining flood conveyance capacity to prevent levee overtopping and overbank flooding. Disadvantages of dredging include disruption of aquatic environment, short-term increases in turbidity, disruption of riparian habitat in dredge spoil areas, and continued cost. Most importantly, dredging only mitigates the effect of a stability problem, it does not correct the cause of the problem. Therefore, dredged reaches require continual maintenance and annual capital investment.

If dredging is discontinued in Reaches 7, 8, and 9 near the mouths of major tributaries, other management alternatives such as acquisition of floodprone property or construction of offset levees will be required to mitigate the expected channel response. Acquisition of floodprone properties near the mouths of the major tributaries is not feasible. As shown in Figure 12, a large portion of the property that is located in the 100-year floodplain contains substantial development that would make acquisition for flood control purpose cost prohibitive. Outside of Reaches 7, 8, and 9, dredging is recommended only to remove sediment deposition in backwater upstream of diversion dams. Alternatively, backwater deposition may be removed by controlled periodic flushing.

Offset Levees

Offset levees are not strictly a channel stability measure; they do nothing to prevent on-going bank erosion or long-term degradation. However, offset levees are becoming an increasingly popular flood control measure when used in conjunction with nonstructural channel stability measures because they preserve a natural channel within a restricted corridor while still providing flood control. Offset levees are constructed at a distance outside the expected bank erosion area. Natural channel processes and riparian areas are allowed to develop along the channel. Decreases in channel conveyance are accounted for by conveyance between the channel banks and the levees.

Offset levees could be constructed in Reaches 7, 8, and 9 if dredging at tributary mouths were discontinued. However, offset levees in these reaches are not very feasible because existing bridges and development near the river restrict the land that is available for increased floodplain area and meandering. Offset levees could also be constructed where increased meandering and riparian vegetation growth decreased conveyance and increased flood water surface levels to unacceptable levels. However, the flood limits from the Jordan River FIS shown in Figure 12, indicate that outside of Reaches 7, 8, and 9, it is unlikely that sediment deposition in the channel would significantly increase flood levels to a degree that would impact existing development.

Bank Stabilization

Alternative bank stabilization measures include riprap, gabions, meander vanes, soil cement, and revegetation. Riprap bank protection is currently the only stabilization method in general use on the Jordan River. Several communities are considering proposals to use vegetation as a stabilization measure in river parks.

Riprap. Riprap is a common form of bank protection used on the Jordan River and throughout the west. Dumped angular riprap is an effective means of preventing isolated bank erosion. Riprap should be installed using angular (not rounded) material at 2:1 or flatter slopes, with a filter fabric and granular sublayer. Riprap also should be toed into the channel bed to prevent undermining by scour. Trees and other vegetation can be planted in between riprap material to minimize the visual impacts. Riprap on the Jordan River has effectively prevented bank erosion in the stabilized reaches in the short period since its construction.

Advantages of riprap include low cost compared to structural concrete or gunite (if a source of rock material is readily available), flexibility (resists failure from frost heave, hydrostatic pressure, or other forces if properly installed), ease of installation, and low environmental and aesthetic impact. Most importantly, riprap seems to have been effective in preventing bank erosion in the past.

Disadvantages to riprap are susceptibility to scour damage if improperly constructed or underdesigned and infeasibility for use throughout the entire length of the corridor. Riprap is best applied in isolated problem areas. Failure of riprap is usually related to use of rounded rock, undersized rock, failure to use a filter blanket, or bed scour. Bed scour failures can be prevented by using grade control structures, and by installing riprap to the depth of expected scour. Use of construction rubble is not recommended for riprap material. Figure 14 illustrates key characteristics of a typical riprap installation. Use of riprap is recommended in localized areas as part of an effective plan to manage Jordan River stability.

Gabions. Gabions, sometimes called "rock and wire mattress" or "railbank protection," are riprap in wire-tied baskets. Gabions are typically used in place of rip-rap where bank slopes are too steep for dumped riprap, or where rip-rap material of sufficient diameter is not available. While gabions have been successfully used throughout the west in the past, applications in the more humid areas with perennial streams in the west have had problems with wire rust and failure. Elsewhere, wire has been broken by sediment impact or floating debris. Once the wire fails, the rock material is usually lost. Installation of gabions is also more labor intensive and expensive than dumped riprap. Gabions are not recommended as an alternative for the Jordan River.

Soil Cement. Soil cement bank protection is a mixture of aggregate and soil obtained from the channel bed and portland cement. Soil cement has been used successfully in the more arid portions of the west as slope protection, grade controls, foundation support, landfill protection, highway paving material, and seepage control. It is primarily used as channel bank protection as a substitute for riprap in areas lacking a source of rock material. There are no known areas of soil cement bank protection on the Jordan River, or elsewhere in Salt Lake County.

The advantages of soil cement include its strength, resistance to lateral erosion and bed scour, and use of native material in the admixture. Disadvantages include the cost (usually estimated at $1,000,000 per mile per bank), unfamiliarity to local contractors, inability to support vegetative material, disruption of riparian habitat, and low aesthetic value. Use of soil cement is most appropriate for large scale applications where the cost of setting up an on-site batch plant is justified. Soil cement is not recommended as a stability measure for the Jordan River.

Meander Vanes. Meander vanes are a series of jetties constructed on the outside of meander bends, aligned slightly in the downstream direction. The jetties, whether permeable or impermeable, are designed to prevent bank erosion by creating a lower velocity zone adjacent to the eroding bank. Jetties may be constructed from rock, brush, steel jacks, or similar material. Meander vanes are not currently used on the Jordan River as a stability measure.

The primary advantages of meander vanes are that natural channel banks may remain somewhat undisturbed during construction and overbank flooding is not impeded. Disadvantages include labor intensive construction and obstruction of needed effective flow area on a small river such as the Jordan River. On the Jordan River, most of the banks in need of stabilization are currently vertical cut banks, which support very little vegetation. Therefore, there is no need to avoid disturbing the banks. Bank protection measures implemented on the Jordan River should include regrading and vegetation. Therefore, the primary advantage of meander vanes is moot for the study area. Meander vanes are not recommended for stability management of the Jordan River.

Revegetation . Well functioning, vegetated banks provide two primary benefits to a meadering river system:

1) The river maintains an adequate single channel for water conveyance (especially during floods).

2) Quantities of sediment and bedload are reduced to quantities that can travel through the river system.

Regrading and vegetation of channel banks also increases channel stability by adding cohesiveness to bank soils, and by reducing effective velocities flowing against the banks. Hydraulic data for the river indicate that reach-averaged channel velocities slightly exceed estimated stable velocities for unvegetated soil material. Therefore, it is likely that revegetation of channel banks would create sufficient stability in the more stable reaches of the Jordan River to prevent bank erosion as well as provide the more important benefits listed above. However, revegetation in localized areas that have velocities much higher than reach-averaged velocities may not be effective in preventing erosion, especially during floods with extended durations. Bank vegetation may die and become ineffective during flood events similar to the 1983-1987 event. Revegetation would probably not be effective in reaches that have shown recent signs of instability. Several communities along the Jordan River have developed, or are developing, channel revegetation plans. Murray City is the first to implement such a plan on the channel west of the Murray Parkway Golf Course.

Additional advantages of the vegetation alternative are the aesthetic appeal of using natural materials and processes to check bank erosion, and the likelihood that riparian habitat would be expanded. Vegetation could also help reestablish more natural channel meandering processes on the river. Possible disadvantages of the option are increased flood levels due to lower flood velocities, undermining of vegetation if long-term degradation is not checked, and increase debris accumulation on bridge piers during floods. As with other structural bank protection measures, grade control may be required in some reaches to prevent long-term degradation from undercutting banks and causing bank sloughing and destruction of vegetation.

Vegetation is a viable alternative for controlling erosion on the Jordan River. Costs associated with the vegetation option include acquisition of riverfront property, plant costs, planting, bank regrading, and design fees. However, revegetation should take place after a more stable channel pattern is established.

Grade Control

Establishment of grade control will be an important element of the plan to reestablish channel stability on the Jordan River. All of the structural bank protection measures previously evaluated would be susceptible to failure over the 100-year planning period if long-term degradation continues at projected or historical rates. The stability analyses indicated that all reaches may experience some long-term degradation. This degradation could undermine channel banks and bridge piers. Existing grade control on the Jordan River is shown in Figure 2. Bridge crossings make ideal locations for installation of grade control because no new constriction of flow or bank stabilization is needed. Typical grade control is installed at the existing bed elevation, so that no increase in water surface elevation is created.

If the use of grade control structures is to be compatible with future and existing parkway uses, grade control structures will have to meet the following restrictions:

- Review of proposed designs by appropriate federal and state agencies.
- Provision for safe boat passage. Boat passage can be provided through design of portages, or use of low (hydraulic) head structures that look more like riffles than dams.
- Provision for fish passage.
- Prevention of dangerous undercurrents downstream of the drop structure.
- Prevention of significant sediment trapping.
- Provision for trail access at bridge crossings.

The advantages to using grade control are that banks, bridges, and other structures in degrading reaches are less likely to fail. There are no significant disadvantages, although grade control should be designed to minimize impacts to fish passage and river recreation. Other design considerations include preventing the grade control structure from being outflanked by bank erosion, spacing grade control to minimize the height of vertical drops, and prevention of seepage and piping under the structure.

Materials commonly used for grade control structures include concrete headwalls and weirs, soil cement, gabions, dumped riprap, grouted riprap, and driven sheet piles. Dumped riprap is most appropriate to create riffles, but may fail during migration of larger headcuts. Other, less flexible materials have been successfully used in a variety of environments throughout the west. Because of the potential for meander migration and the need to provide lateral stability at grade controls, grade control structures on the Jordan River should be constructed at bridge crossings wherever possible. This strategy will allow the river freedom to adjust between bridge crossings. Some typical grade control structures are illustrated in Figure 15. The State Engineer's office has an alternative drop structure design in the "Administrative Rules for Stream Channel Alterations."

Recommended Management Alternatives

No single management alternative is adequate to manage the unique stability problems on the entire Jordan River. Some sections of the river need immediate structural bank and bed stabilization. However, nonstructural alternatives offer the most feasible solution for managing the long-term stability of the entire river. Therefore, a range of management strategies were evaluated and proposed to reflect site-specific conditions in each reach.

Existing bank erosion and long-term degradation problems are found throughout the study area. The channel stability analysis indicated that new stability problems could develop during the 100-year planning period in almost every reach. Implementation of structural solutions for every existing and potential problem is not feasible. Therefore, the most practicable approach is to allow the river to gradually return to a more stable dynamic equilibrium pattern and geometry through bank erosion and meander development. Structural solutions are proposed only for short sections in areas where erosion would threaten existing development.

Recommended Stability Measures

The recommended management plan includes the following elements, in order of priority:

- **Zoning Restrictions/Land Use Control.** Zoning restrictions within the meander corridor will be the primary element of the management plan. Most forms of development will be restricted within the proposed meander corridor. Land uses such as unrestricted grazing will be minimized on channel banks, especially on public lands. A copy of a sample land use control ordinance is attached in the Appendix. Legal descriptions of the corridor limits should be prepared or the limits surveyed for use on zoning and planning documents.

- **Bank Erosion.** Bank erosion and channel migration will be allowed to naturally occur within the meander corridor until the channel or reach has reestablished the prechannelization sinuosity and meander amplitude, unless existing development becomes threatened. Redevelopment of a meandering channel will circumvent the need for many structural measures, including bank protection and grade control.

- **Bridge Monitoring and Inspection.** A regular program of inspection should be established for all bridges along the Jordan River. Inspections should include assessment of structural stability. Monitoring should include determination of bed elevations and progress of long-term degradation.

- **Channel Monitoring.** Channel banks near areas where development exists within the meander corridor should be monitored annually and during flood events for signs of failure or change since the previous survey. Monumented cross sections should be periodically resurveyed to determine whether degradation, aggradation, or bank erosion has occurred.

- **Grade Control.** Grade control structures should be installed at key bridge locations to provide channel slope stability and prevent headcut migration. Reinforced concrete or driven sheet pile grade controls should be used at bridge locations. Temporary grade control in reaches with no bank stabilization may be provided by constructed riprap riffles. Grade control design should consider fish passage and recreational boat passage.

- **Bank Stabilization.** Riprap bank protection should be installed where existing structures are threatened by ongoing or predicted future erosion. The top of riprap protection should extend above the 50-year water surface elevation, and be revegetated, wherever possible.

- **Dredging.** Dredging will be limited to only those sections of Reaches 7, 8, and 9 that are immediately downstream of the confluences of the major tributaries and the short backwater reaches upstream of diversion structures. Dredging shall be limited to material deposited above the surveyed 1990 flowline. Disposal of dredged material should be conducted in a manner that will minimize disruption of riparian ecosystems.

- **Bank Vegetation.** As sinuosity increases to desired levels, banks should be regraded to 3:1 or flatter slopes and planted with native vegetation. Vegetation will include riparian species trees and grasses. Fibrous mat may be used to stabilize bank slopes during early plant growth. Vegetation should be completed in conjunction with river parkway planning and in areas where the river pattern is relatively stable.

- **Coordinate Corridor with Wetlands and Park Plans.** The proposed corridor limits should be reviewed by wetlands specialists to ensure that all critical wetlands areas are included within the ultimate river management corridor. The management corridor limits should also include the area required for the existing trails and parks plans.

- **Centralize Management.** Management of the corridor once adopted and acquired should be by a single agency or planning council. A planning council should have representation from local as well as county, state, and federal agencies.

- **Permitting.** Structural improvements and river alterations will require permits by county, state, and federal agencies.

Prioritized Recommended Management Alternatives

Prioritized reach-specific recommended management alternatives for the study reach are summarized below and shown in Figure 16.

Reaches 1 to 9: Entire Study Area

- Explore development of a centralized river management authority.
- Coordinate meander corridor limits with existing wetlands designations.
- Coordinate meander corridor limits with existing and future parks and trails plans.
- Restrict development within meander corridor.
- Restrict excessive grazing of riverbanks and riparian areas.
- Allow bank erosion to occur within meander corridor until prechannelization sinuosity is reestablished.
- Revegetate and regrade channel banks after stable channel pattern is established.
- Establish bridge inspection and monitoring program.
- Establish channel monitoring program using monumented cross sections.

- Survey, or prepare legal descriptions of meander corridor limits for use on zoning and community development plans.

- Acquire key parcels within corridor.

- Regulate design of future bridge and utility crossings to ensure that scour, flood conveyance, and conformance with goals of the river corridor are accounted for in design process.

Reach 1: Turner Dam to Joint Diversion

- Monitor bank stability near railroad grades and canals.

Priority for structural solutions: No structural measures recommended.

Reach 2: Joint Diversion to 14600 South

- Monitor bank erosion near canals.

Priority for structural solutions: No structural measures recommended.

Reach 3: 14600 South to 12600 South

- Construct riprap bank protection to protect sewer line in overbank area upstream of 12600 South. An alternative improvement would be to relocate the sewer line.

- Construct riprap bank protection to stabilize bridge approach section at 12600 South.

Priority for structural solutions: HIGH (sewer line protection)
LOW (bridge approach)

Reach 4: 12600 South to 10600 South

- Construct grade control at 10600 South to prevent headcut migration.

Priority for structural solutions: LOW (grade control)

Reach 5: 10600 South to North Jordan Diversion

- No special considerations.

Priority for structural solutions: No structural measures recommended.

Reach 6: North Jordan Diversion to 6400 South

- Construct grade control at 7800 South, 9000 South.
- Construct riprap bank protection on east bank, Stations 462 to 475.
- Stabilize former smelter operations tailings embankment.

Priority for structural solutions:	MODERATE (grade control) LOW (bank protection) LOW (tailings embankment)

Reach 7: 6400 South to Brighton Diversion

- Construct grade control at 5400 South, 4800 South, and I-215.
- Construct riprap bank protection on west bank, Stations 373 to 385.
- Monitor bank erosion, Stations 320 to 330
- Monitor sediment deposition at monumented cross sections.
- Dredge deposition near mouth of Little Cottonwood Creek to surveyed 1990 flow line, as needed.

Priority for structural solutions:	HIGH (grade control at 5400 South) HIGH (dredge near Little Cottonwood Creek confluence) MODERATE (bank protection, Stations 373 to 385) LOW (grade control and 4800 South, I-215) LOW (bank protection, Stations 320 to 330)

Reach 8: Brighton Diversion to Mill Creek

- Construct grade control at 3900 South and 3300 South.
- Construct riprap bank protection on east bank, Stations 120 to 127.
- Construct riprap bank protection on west bank, Stations 95 to 100.
- Monitor bank erosion from Stations 140 to 157. If required, extend riprap bank protection on west bank, Stations 140 to 157.
- Monitor sediment deposition at monumented cross sections.
- Dredge deposition near mouth of Big Cottonwood Creek to surveyed 1990 flow line, as needed.

Priority for structural solutions:	MODERATE (dredge Big Cottonwood Creek confluence) MODERATE (grade control) MODERATE (bank protection, Stations 140 to 157) LOW (bank protection, Stations 95 to 100 and Stations 120 to 127)

Reach 9: Mill Creek Confluence to 2100 South

- Dredge sediment deposition in accordance with COE maintenance agreement.

Priority for structural solutions: MODERATE (dredge channel to COE standards)

Cost Opinions: Recommended Alternatives

Cost opinions for the recommended management alternatives for the Jordan River were developed. Recommended management alternatives included land acquisition, zoning, inspection and monitoring, dredging, riprap bank protection, grade control, and revegetation. The cost opinions developed represent generic preliminary values. Values presented are intended to be used for comparative purposes only. Included in the cost opinions are capital expenses, materials, construction, design, and contingencies. Not included in costs are items such as labor by public employees, construction of trails or parkway facilities, fencing of public land, enforcement and regulation costs, and survey/legal description of corridor boundaries. Cost opinions are summarized in Table 5.1.

Table 5.1
Cost Opinions for Recommended Alternatives

Management Alternative	Unit Cost	Quantity	Total Project Cost
Acquisition Wetland Property Non-wetland Property	 $6,500/acre $15,000/acre	 720 Acres 320 Acres	$4,700,000 $4,800,000 $9,500,000
Loss of Tax Revenue from Retiring Private Land	1.65%	$9,500,000	$157,000/year
Zoning	0	0	$0
Inspection/Monitoring	0	0	$0
Dredging	$4.20/CY	5,000 CY	$21,000/year
Riprap	$150/LF	264,000 LF	$40,000,000
Grade Control	$90,000/EA	6	$540,000

Acquisition

Acquisition of private land within the corridor may be required to achieve the ultimate management objectives of a multiuse natural river corridor. Approximately 1,900 acres fall within the meander corridor limits, approximately 600 acres of which are located between the channel banks of the river, and thus may already be owned under the public trust doctrine. For comparison, the County's Wetland Advanced Identification Study (WAIDS) delineated about 2,000 acres of wetlands along the river. Approximately 900 acres of these wetlands are located within the meander corridor. Land cost estimates prepared for the WAIDS study ranged from $6,500 to $20,000 per acre for private land, except for land designated as wetlands, which ranged from $0 to $200 per acre. For the CUP wetland acquisition legislation and for this study, an average value of $6,500 per acre was used to estimate the costs to acquire wetlands within the corridor. An average value of $15,000 per acre was used to estimate the acquisition costs for non-wetland private lands. Assuming 80 percent private ownership within the corridor, a total acquisition cost was estimated to be approximately $9.5 million. This value translates to an average cost of $380,000 per river mile, or $72 per linear river foot. Assuming a tax rate of 1.65 percent of the full appraised value, County tax revenue would decrease by approximately $157,000 per year by retiring the private land in the meander corridor.

Zoning

There are no direct costs associated with zoning. Possible indirect costs include legal activities to prepare and adopt zoning changes, conflict resolution over zoning changes, and public agency staff time for enforcement.

Inspection and Monitoring

There are no direct costs associated with inspection and monitoring. It was assumed that county or other agency personnel would perform the inspections. Numerous publications such as HEC-18, *Evaluating Scour at Bridges*, describe the activities required for bridge and channel inspections.

Dredging

Limited dredging was recommended in Reach 9 and near tributary mouths in Reaches 7 and 8. A rate of $3.50 per cubic yard of material removed, plus mobilization and contingencies, was used to determine dredging costs. Annual amounts of sediment deposition in these areas was estimated from HEC-6 modeling results and from engineering judgement. A total annual cost of about $21,000 for the areas recommended for dredging was determined. This value translates to about $2 per linear foot per year, or $11,000 per river mile per year. Dredging costs are the only costs that must be applied on an annual basis.

Riprap

Riprap was the recommended form of bank stabilization. Unit costs were based on the typical installation illustrated in Figure 14. Cost opinions assumed rock material with an average diameter (D_{50}) of 12 inches placed 2 feet thick, bank height of 7 feet, toe down of 3 feet, 3:1 side slopes, and a 1-foot-thick granular layer. In addition, earthwork costs required to regrade vertical banks to the assumed side slope were included. No costs for revegetation of riprap slopes were included. Based on these assumed conditions, a total unit cost of $150 per linear foot of river bank was determined. For comparison, this rate translates to a cost of approximately $40 million ($1.6 million per mile) to riprap both banks of the entire river corridor.

Grade Control

A maximum of six grade control structures were recommended, primarily in the lower reaches of the river. For the purpose of developing cost opinions, it was assumed that the grade control structures would be driven sheet piles, as illustrated in Figure 15. Cost opinions assumed a 100-foot channel width, a 35-foot reinforced concrete apron, and angular riprap extending 10 feet downstream of the apron. Costs also included design, mobilization, and contingency fees. Using these figures, the cost per structure was determined to be $90,000. Additional costs would be accrued to provide boat portaging docks, fish passage, and trails compatibility.

Recommendations for Further Study

Complete exploration of the full ramifications of implementing the recommended management alternatives was outside the scope of this study. However, many of the comments received after public meetings and review of the draft documents by public agencies concerned the implementation phase of river management plan. Therefore, the following topics are recommended for additional study:

- **Coordination with Other River Studies.** Ongoing or recently completed studies with similar objectives as the Jordan River Stability Study include wetlands identification studies, floodplain mapping, trails and parkway plans, nonpoint source pollutant management plans, and open-space/outdoor recreation plans. When considered individually, proponents of these plans may find implementation difficult. If the plans were combined, adoption and enforcement may become easier, and loopholes for compliance may be eliminated. Also, conflicting objectives between such plans should be resolved, such as the possible conflict between flood control and restoration of natural channels.

- **Develop Management Implementation Plan.** This study recommended management alternatives that are intended to improve channel stability problems. Implementation of these alternatives with the current political and regulatory climate will require cooperation and input from federal, state, and local entities. Several comments were received that recommended establishing a multijurisdictional committee that would oversee implementation of a river management plan and recommend strategies for plan enforcement and regulation. Centralized control of the river corridor will be essential for effective implementation of the river corridor management plans.

- **Permitting Requirements.** Numerous state, federal, and local agencies claim review authority for various aspects of the proposed river management plan. Preparation of all of the required permit applications will be required once a formal river management implementation plan is adopted.

- **Funding Sources.** Several sources of funding for land acquisition and/or river restoration exist. However, before any funds are spent, comprehensive river management plan should be finalized, a river management authority should be established, and the required permits should be obtained. Then funds can be properly categorized and dispersed.

- **Land Ownership.** The public trust doctrine states that the river is owned by the state. However, it is unclear how this doctrine will be applied to a meandering river. The State Attorney General should provide an opinion regarding ownership of former, present, and future river beds along the corridor.

- **Technical Issues.** Several technical issues remain to be fully resolved. These include impacts of altering sedimentation on fisheries habitat, quantifying water quality impacts of the proposed plan, quantifying the historical impacts of grazing, establishing safe limits for seasonal grazing densities for land that will remain private, and assessing potential impacts on erosion of streambanks with contaminated soils.

- **River Restoration.** Some comments were received that recommended that river restoration be performed on test sections of the Jordan River as a demonstration project. River restoration would require a more focused analysis of stable channel geometry that considers site-specific stream characteristics such as density of existing riparian habitat, local soil properties, channel slope relative to pools and riffles, bank conditions, and other factors. Such a demonstration project could be used as a public rallying point to inspire additional restoration projects on adjacent reaches as well as other rivers in the Salt Lake area.

Agency Review Comments

Officials from the 10 cities that border the Jordan River in the study area, as well as from Salt Lake City, Salt Lake County, and various federal and state agencies were given at least two opportunities to comment on the Jordan River Stability Study. The first opportunity was provided after provided near the beginning of the study. The second opportunity was provided after the draft report was prepared. The time and effort of those who made comments and suggestions on this report is greatly appreciated. Numerous excellent suggestions were received and, where possible, comments were incorporated into the final report. All agency comments and a memorandum responding to those comments are included in the Appendix.

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Section 6
Conclusions

This report summarizes the results of analyses performed to evaluate the stability of the Jordan River from the Surplus Canal diversion to the Utah/Salt Lake County line. The primary purpose of this study was to develop a stability management plan that could be used by Salt Lake County and the ten incorporated cities that border the Jordan River to manage and protect the river, as well as development along the river. Channel instability problems experienced during the floods of 1983-1987 and recent development of the Jordan River floodplain accentuate the need for a comprehensive management and river maintenance plan that will help the County, the ten cities that border the Jordan River, and numerous state and federal agencies manage and protect development near the Jordan River. Detailed historical, empirical, and geomorphic analyses were conducted to assess the existing river stability and to identify existing and potential future stability problems. These detailed analyses confirm that major portions of the Jordan River are unstable and will continue to experience channel stability problems.

The major findings of the detailed stability analyses include:

- The Jordan River is more like a managed irrigation facility than a natural river that floods in response to rainfall and snowmelt. River management impacts from the Utah Lake Compromise Agreement, irrigation releases and diversions, and riverine development give the Jordan River unique hydrologic and geomorphic characteristics.

- The channel stabilization work performed in the 1950s between 2100 South and 14600 South contributed to many of the existing river stability problems. The channel slope increase induced by this channel straightening resulted in increased flow velocities and caused higher sediment transport rates. These factors acted to destabilize the channel bed and cause accelerated bank and bed erosion.

- The future equilibrium characteristics of the Jordan River include increased meander amplitude, decreased meander wavelength and radius of curvature, slightly flatter channel slopes, bank slopes of 3:1 or flatter, increased riparian vegetation, and an increased channel width-depth ratio.

- Much of the channel instability witnessed during the 1983-1987 floods was probably the result of the river trying to reestablish its prechannelization slope, width, and meander pattern. Efforts to prevent the river from returning to an equilibrium form will require increasing levels of structural improvements such as riprap bank protection, grade control structures, and scour protection.

A river stability management plan was developed to prioritize river management efforts intended to control stability problems. This plan, outlined in Section 5, stresses nonstructural management techniques such as acquisition of land within the meander corridor, zoning restrictions and control of land use within the meander corridor, regular monitoring and inspection of existing structures and monumented cross sections to quantify river stability, and coordinated management of the river. The minimal structural elements of the river management plan are intended to be used to enhance natural, ongoing processes that are reestablishing a more natural channel pattern, as well as protect existing development from erosion hazards. Recommended structural elements include riprap bank protection, fish and boat compatible grade control structures, minimal dredging only at targeted locations, and revegetation of stream banks. Specific prioritized channel stability measures were proposed for each of nine river reaches. The management plan may be used as one element in an overall river parkway management plan for the Jordan River.

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