Lake Powell Pipeline Project

Final Study Report 04
Geology and Soil Resources

April 2016

Table of Contents

Page

Executive Summary **1**

ES.1 Introduction 1
ES.2 Methodology 1
ES.3 Key Results of the Geology and Soil Resources Impact Analyses 1
ES.3.1 South Alternative 1
ES.3.2 Existing Highway Alternative 1
ES.3.3 Southeast Corner Alternative 2
ES.3.4 Natural Gas Pipeline and Generators Alternative 2
ES.3.5 No Lake Powell Water Alternative 2
ES.3.6 No Action Alternative 2

Chapter 1 Introduction **1-1**

1.1 Introduction 1-1
1.2 Summary Description of LPP Project Alignment Alternatives 1-1
1.2.1. South Alternative 1-1
1.2.2. Existing Highway Alternative 1-8
1.2.3. Southeast Corner Alternative 1-8
1.2.4. Transmission Line Alignments 1-10
1.2.5. Natural Gas Pipeline and Generators Alternative 1-13
1.2.5.1 Natural Gas Transmission Line Connection 1-15
1.2.5.2 Natural Gas Supply Line 1-15
1.2.5.3 Natural Gas Generators 1-18
1.3 Summary Description of No Lake Powell Water Alternative 1-18
1.3.1. WCWCD No Lake Powell Water Alternative 1-19
1.3.1.1 Background 1-19
1.3.1.2 WCWCD No Lake Powell Water Alternative Features 1-19
1.3.2. KCWCD No Lake Powell Water Alternative 1-23
1.4 Summary Description of the No Action Alternative 1-23
1.4.1. WCWCD No Action Alternative 1-23
1.4.2. KCWCD No Action Alternative 1-23
1.5 Identified Issues 1-24
1.5.1. Purposes of Study 1-24
1.5.2. Identified Issues 1-24
1.6 Impact Topics 1-25

Chapter 2 Methodology **2-1**

2.1 General 2-1
2.2 Assumptions 2-1
2.3 Data Used 2-1
2.4 Impact Analysis Methodology 2-4
2.4.1. Fault Movement Impacts 2-4
2.4.2. Seismic Activity Impacts 2-4
2.4.3. Unstable Slope Impacts 2-4
2.4.4. Subsidence, Expansion, or Collapsible Soils Impacts 2-4
2.4.5. Geologic Hazards to Human Health and Safety Impacts 2-5
2.4.6. Impacts on Important Structures or Mineral Resources 2-5

2.4.7. Borrow and Spoil Impacts 2-5

Chapter 3 Affected Environment (Baseline Conditions) 3-1

3.1 Area of Potential Effect 3-1
3.1.1. Regional Geology 3-1
3.1.2. Area of Potential Effect 3-1
3.2 Overview of Baseline Conditions along Lake Powell Pipeline 3-2
3.2.1. Fault Movement 3-2
3.2.2. Seismic Activity 3-2
3.2.3. Unstable Slopes 3-2
3.2.4. Subsidence, Expansion, and Collapsible Soils 3-15
3.2.5. Geologic Hazards to Human Health and Safety 3-26
3.2.6. Important Structures and Mineral Resources 3-26
3.2.6.1 Intake System Tunnels and Vertical Shafts 3-30
3.2.6.2 Hurricane Cliffs Waterways 3-34
3.2.6.2.1 Hurricane Cliffs Low Pressure Tunnel, Vertical Shaft, and High Pressure Tunnel 3-34
3.2.6.2.1.1 Alluvium and Highly Weathered Mudstone 3-34
3.2.6.2.1.2 Moenkopi Formation – Lower Red Member 3-34
3.2.6.2.1.3 Moenkopi Formation – Timpoweap Member. 3-34
3.2.6.2.1.4 Moenkopi Formation – Rock Canyon Conglomerate Member. 3-36
3.2.6.2.1.5 Kaibab Formation. 3-36
3.2.6.2.1.6 Kaibab Formation – Harrisburg Member. 3-36
3.2.6.2.1.7 Kaibab Formation – Fossil Mountain Member. 3-36
3.2.6.2.2 Middle Portion of Hurricane Cliff – Pressure Shaft and Pressure Tunnel. 3-36
3.2.6.2.2.1 Toroweap Formation – Woods Ranch Member. 3-37
3.2.6.2.2.2 Toroweap Formation – Brady Canyon Member. 3-37
3.2.6.2.2.3 Toroweap Formation – Seligman Member 3-37
3.2.6.2.3 Lower Hurricane Cliff – Pressure Tunnel, Portal, Transition. 3-37
3.2.6.2.3.1 Queantoweap Sandstone 3-37
3.2.6.2.4 Below Hurricane Cliff - Penstock, Powerhouse, Tailrace, Afterbay 3-37
3.2.6.2.4.1 Colluvial Deposits. 3-38
3.2.6.2.4.2 Young Alluvial Fan Deposits. 3-38
3.2.6.2.4.3 Old Alluvial Fan Deposits. 3-38
3.2.6.2.4.4 Eolian-Sand Deposits. 3-38
3.2.6.3 Sand Hollow Tunnel 3-38
3.2.6.3.1 Navajo Sandstone. 3-38
3.2.7. Borrow and Spoil 3-39

Chapter 4 Environmental Consequences (Impacts) 4-1

4.1 Significance Criteria 4-1
4.1.1. Fault Movement 4-1
4.1.2. Seismic Activity 4-1
4.1.3. Unstable Slopes 4-1
4.1.4. Expandable, Collapsible, or Subsiding Soils or Rocks 4-1
4.1.5. Geologic Hazards to Human Health and Safety 4-2
4.1.6. Important Structures and Mineral Resources 4-2
4.1.7. Borrow and Spoil 4-2
4.2 Potential Impacts Eliminated From Further Analysis 4-2
4.3 South Alternative Impacts 4-2
4.3.1. Construction Impacts 4-2

4.3.1.1 Fault Movement 4-2
4.3.1.2 Seismic Activity 4-2
4.3.1.3 Unstable Slopes 4-3
4.3.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-3
4.3.1.5 Geologic Hazards to Human Health and Safety 4-3
4.3.1.6 Important Structures and Mineral Resources 4-3
4.3.1.7 Borrow and Spoil 4-3
4.3.2. Operation and Maintenance Impacts 4-4
4.3.2.1 Fault Movement 4-4
4.3.2.2 Seismic Activity 4-5
4.3.2.3 Unstable Slopes 4-5
4.3.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-5
4.3.2.5 Geologic Hazards to Human Health and Safety 4-5
4.3.2.6 Important Structures and Mineral Resources 4-5
4.3.2.7 Borrow and Spoil 4-5
4.4 Existing Highway Alternative Impacts 4-6
4.4.1. Construction Impacts 4-6
4.4.1.1 Fault Movement 4-6
4.4.1.2 Seismic Activity 4-6
4.4.1.3 Unstable Slopes 4-6
4.4.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-6
4.4.1.5 Geologic Hazards to Human Health and Safety 4-6
4.4.1.6 Important Structures and Mineral Resources 4-6
4.4.1.7 Borrow and Spoil 4-7
4.4.2. Operation and Maintenance Impacts 4-7
4.4.2.1 Fault Movement 4-7
4.4.2.2 Seismic Activity 4-7
4.4.2.3 Unstable Slopes 4-8
4.4.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-8
4.4.2.5 Geologic Hazards to Human Health and Safety 4-8
4.4.2.6 Important Structures and Mineral Resources 4-8
4.4.2.7 Borrow and Spoil 4-8
4.5 Southeast Corner Alternative 4-8
4.5.1. Construction Impacts 4-8
4.5.1.1 Fault Movement 4-8
4.5.1.2 Seismic Activity 4-8
4.5.1.3 Unstable Slopes 4-8
4.5.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-8
4.5.1.5 Geologic Hazards to Human Health and Safety 4-8
4.5.1.6 Important Structures and Mineral Resources 4-9
4.5.1.7 Borrow and Spoil 4-9
4.5.2. Operation and Maintenance Impacts 4-10
4.5.2.1 Fault Movement 4-10
4.5.2.2 Seismic Activity 4-10
4.5.2.3 Unstable Slopes 4-10
4.5.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks 4-10
4.5.2.5 Geologic Hazards to Human Health and Safety 4-10
4.5.2.6 Important Structures and Mineral Resources 4-10
4.5.2.7 Borrow and Spoil 4-10
4.6 Natural Gas Pipeline and Generators Alternative 4-10
4.7 No Lake Powell Water Alternative 4-10

4.7.1. WCWCD No Lake Powell Water Alternative 4-10
4.7.1.1 Fault Movement 4-10
4.7.1.2 Seismic Activity 4-11
4.7.1.3 Unstable Slopes 4-11
4.7.1.4 Expandable, Collapsible or Subsiding Soils or Rocks 4-11
4.7.1.5 Geologic Hazards on Human Health and Safety 4-11
4.7.1.6 Important Structures and Mineral Resources 4-11
4.7.1.7 Borrow and Spoil 4-11
4.7.1.8 Soil Resource Impacts 4-12
4.7.2. KCWCD No Lake Powell Water Alternative 4-12
4.8 No Action Alternative 4-12

Chapter 5 Mitigation and Monitoring 5-1

5.1 LPP Project Alignment Alternatives, Natural Gas Pipeline and Generators Alternative, and No Lake Powell Water Alternative 5-1
5.1.1. Fault Movement 5-1
5.1.2. Unstable Slope Mitigation 5-1
5.1.3. Expandable, Collapsible or Subsiding Soils Mitigation 5-1
5.1.4. Important Structures Protection 5-1
5.1.5. Borrow and Spoil Management 5-1
5.1.6. Blasting Management 5-2
5.1.7. Erosion and Sediment Control 5-2
5.1.8. Soil Stockpiling and Management 5-2
5.1.9. Access Roads 5-2
5.2 No Action Alternative 5-2
5.2.1. Mitigation 5-2
5.2.2. Monitoring 5-3

Chapter 6 Unavoidable Adverse Impacts 6-1

6.1 South Alternative 6-1
6.2 Existing Highway Alternative 6-1
6.3 Southeast Corner Alternative 6-1
6.4 Natural Gas Pipeline and Generators Alternative 6-1
6.5 No Lake Powell Water Alternative 6-1
6.6 No Action Alternative 6-1

Chapter 7 Cumulative Impacts 7-1

7.1 South Alternative 7-1
7.2 Existing Highway Alternative 7-1
7.3 Southeast Corner Alternative 7-1
7.4 Transmission Line Alternatives 7-1
7.5 Natural Gas Pipeline and Generators Alternative 7-1
7.6 No Lake Powell Water Alternative 7-1
7.7 No Action Alternative 7-2

References 1

Glossary 1

Abbreviations and Acronyms 1

List of Preparers 1

Appendix A – Lake Powell and Cedar Valley Pipelines Fault Assessment
Appendix B – Hurricane Cliffs Hydropower Pump Storage Project Preliminary Geotechnical Report, Forebay and Afterbay Reservoir Sites
Appendix C – Highway 89 Cockscomb Cut Projected Pipeline Road Cut Calculations
Appendix D – BMPs for Geology and Soil Resources Protection

List of Figures

Figure Number	Figure Title	Page
Figure 1-1	Lake Powell Proposed Project	1-2
Figure 1-2	Lake Powell Pipeline Water Intake and Conveyance Systems	1-4
Figure 1-3	Pipeline and Penstock Right-of-Way	1-5
Figure 1-4	Lake Powell Pipeline Hydro System South Alternative	1-7
Figure 1-5	Lake Powell Pipeline Hydro System Existing Highway Alternative	1-9
Figure 1-6	Lake Powell Pipeline Hydro System Southeast Corner Alternative	1-11
Figure 1-7	Lake Powell Pipeline Proposed Transmission Lines East	1-12
Figure 1-8	Lake Powell Pipeline Proposed Transmission Lines West	1-14
Figure 1-9	Lake Powell Pipeline Natural Gas Supply Line and Generators West Alternatives	1-16
Figure 1-10	Lake Powell Pipeline Natural Gas Supply Line and Generators East Alternative	1-17
Figure 1-11	No Lake Powell Water Alternative Primary Infrastructure	1-20
Figure 3-1	Lake Powell Pipeline Rock Characteristics Points Water Conveyance System	3-9
Figure 3-2	Lake Powell Pipeline Rock Characteristics Points Hydro System	3-10
Figure 3-3	Lake Powell Pipeline Rock Hazards Water Conveyance System	3-13
Figure 3-4	Lake Powell Pipeline Rock Hazards Hydro System	3-14
Figure 3-5	Lake Powell Pipeline Soil Characteristics Points Water Conveyance System	3-20
Figure 3-6	Lake Powell Pipeline Soil Characteristics Points Hydro System	3-21
Figure 3-7	Lake Powell Pipeline Soil Hazards Water Conveyance System	3-22
Figure 3-8	Lake Powell Pipeline Soil Hazards Hydro System	3-23
Figure 3-9	Lake Powell Pipeline Drainages & Structures Water Conveyance System	3-28
Figure 3-10	Lake Powell Pipeline Drainages & Structures Hydro System	3-29
Figure 3-11	Lake Powell Pipeline Intake System Aerial View (looking north)	3-32
Figure 3-12	Lake Powell Pipeline Intake System Site Plan	3-33
Figure 3-13	Hurricane Cliffs Waterway Features Geological Plan & Cross Section	3-35

List of Tables

Table Number **Figure Title** ..... **Page**

Table 3-1 Lake Powell Pipeline Fault Intersection Assessment 3-3
Table 3-2 Field Survey of Rock Characteristics 3-4
Table 3-3 Lake Powell Pipeline Water Conveyance System Rock Hazards 3-11
Table 3-4 Lake Powell Pipeline Hydro System-Highway Alternative Rock Hazards 3-11
Table 3-5 Lake Powell Pipeline Hydro System-South Alternative Rock Hazards 3-12
Table 3-6 Lake Powell Pipeline Hydro System Rock Hazards 3-12
Table 3-7 Lake Powell Pipeline Field Survey of Soil Characteristics 3-16
Table 3-8 Lake Powell Pipeline Water Conveyance System Soil Hazards 3-24
Table 3-9 Lake Powell Pipeline Hydro System Soil Hazards 3-24
Table 3-10 Lake Powell Pipeline Hydro System-Highway Alternative Soil Hazards 3-25
Table 3-11 Lake Powell Pipeline Hydro System-South Alternative Soil Hazards 3-26
Table 3-12 Lake Powell Pipeline Field Survey of Physical Characteristics 3-27
Table 3-13 Lake Powell Pipeline Summary of Borrow, Fill and Spoil Quantities 3-40

Geology and Soil Resources Study Report

Executive Summary

ES.1 Introduction

This study report describes the results and findings of an analysis to evaluate geology and soil resources impacts along the proposed and alternative alignments of the Lake Powell Pipeline Project (LPP Project), Natural Gas Pipeline and Generators Alternative, No Lake Powell Water Alternative, and No Action Alternative. The purpose of the analysis, as defined in the 2008 Geology and Soils Study Plan prepared for the Federal Energy Regulatory Commission (Commission), was to identify potential impacts of geologic and soil conditions on the LPP Project during construction and operation, document the potential influence of soil and geologic conditions on LPP Project features, and identify measures to mitigate impacts of the geology and soils conditions.

ES.2 Methodology

The analysis of impacts on geology and soil resources follows methodology identified and described in the Preliminary Application Document, Scoping Document No. 1 and the Geology and Soil Study Plan filed with the Commission.

ES.3 Key Results of the Geology and Soil Resources Impact Analyses

Significance criteria were established based on fault movement, seismic activity, unstable slopes, expandable, collapsible, or subsiding soils or rocks, geologic hazards to human health and safety, important structures and mineral resources, and borrow and spill. The following sections summarize the key results of the geology and soil resources impact analyses.

ES.3.1 South Alternative

No significant impacts associated with the impact topics are expected to occur during construction and operation of the South Alternative. Fault movement along the alignment is expected to be below 75 mm during the LPP Project design life. The alignment is not within a zone of high projected Peak Ground Acceleration (PGA) (USGS 2014). Construction and operation of the pipeline and associated features would not cause slope failures that could result in injury to humans, damage to major human structures, or damage to the environment. Geologic hazards would not cause deformation or failure of foundation conditions sufficient to cause pipeline rupture or failure of associated pipeline features. The impacts of geologic hazards along the alignment would not result in human injury or death, present a serious risk to human health, or cause major damage to structures. Borrow and spoil associated with the South Alternative would not cause new and substantial disturbance of land or cause substantial changes in runoff patterns, turbid runoff that would discharge to rivers, streams, or lakes, or create unstable slope conditions.

Precautions may be necessary during construction and operation to preclude significant impacts, such as conducting site stabilization measures, trench shoring or sloping, removal of rock and soil at risk of failure prior to heavy earthwork or blasting, and other standard construction safety practices. In addition, special design considerations may be necessary, such as using appropriate seismic design standards for pipelines and associated facilities, and over excavating and placing additional bedding when constructing in expandable, collapsible, or subsiding soils or rocks.

ES.3.2 Existing Highway Alternative

Most impacts would be the same as for the South Alternative. The Existing Highway Alternative may not produce sufficient usable material for pipeline and penstock bedding, which could result in using more than one million cubic yards of commercial borrow material. This would be a significant impact caused by land disturbance to commercial gravel resources.

ES.3.3 Southeast Corner Alternative

Most impacts would be the same as for the South Alternative.

ES.3.4 Natural Gas Pipeline and Generators Alternative

Impacts would be the same as for the South Alternative. No significant impacts would occur during construction and operation.

ES.3.5 No Lake Powell Water Alternative

The No Lake Powell Water Alternative would have long-term impacts on soil resources in the St. George metropolitan area because use of potable water for outdoor landscape watering would be eliminated. Unvegetated or desert soil resources resulting from eliminating outdoor watering with potable water would become susceptible to erosion from wind and precipitation events. These soil resource impacts would be significant.

ES.3.6 No Action Alternative

Impacts would be the same as described for the No Lake Powell Water Alternative.

Chapter 1
Introduction

1.1 Introduction

This chapter presents a summary description of the Lake Powell Pipeline (LPP) Project alignment alternatives, the No Lake Powell Water Alternative, and the No Action Alternative. It introduces the area studied for environmental resources. It provides an overview of the proposed LPP Project, including each alignment alternative and locator maps.

The LPP Project would deliver Utah's Colorado River water from Lake Powell to the service areas of Washington County Water Conservancy District (WCWCD) and Kane County Water Conservancy District (KCWCD). The LPP Project action alternatives studied include various pipeline and penstock system configurations. Each action alternative would deliver 86,249 acre-feet of municipal and industrial (M&I) use water to the following southwest Utah water conservancy district service areas:

- WCWCD would receive 82,249 acre-feet annually.
- KCWCD would receive up to 4,000 acre-feet annually.

One of the LPP systems previously studied included a conveyance system for the Central Iron County Water Conservancy District (CICWCD), which would have delivered approximately 13,249 acre-feet annually to the Cedar Valley area. The various alternatives were under study when the CICWCD decided to withdraw from the LPP Project, and this conveyance system is no longer being considered.

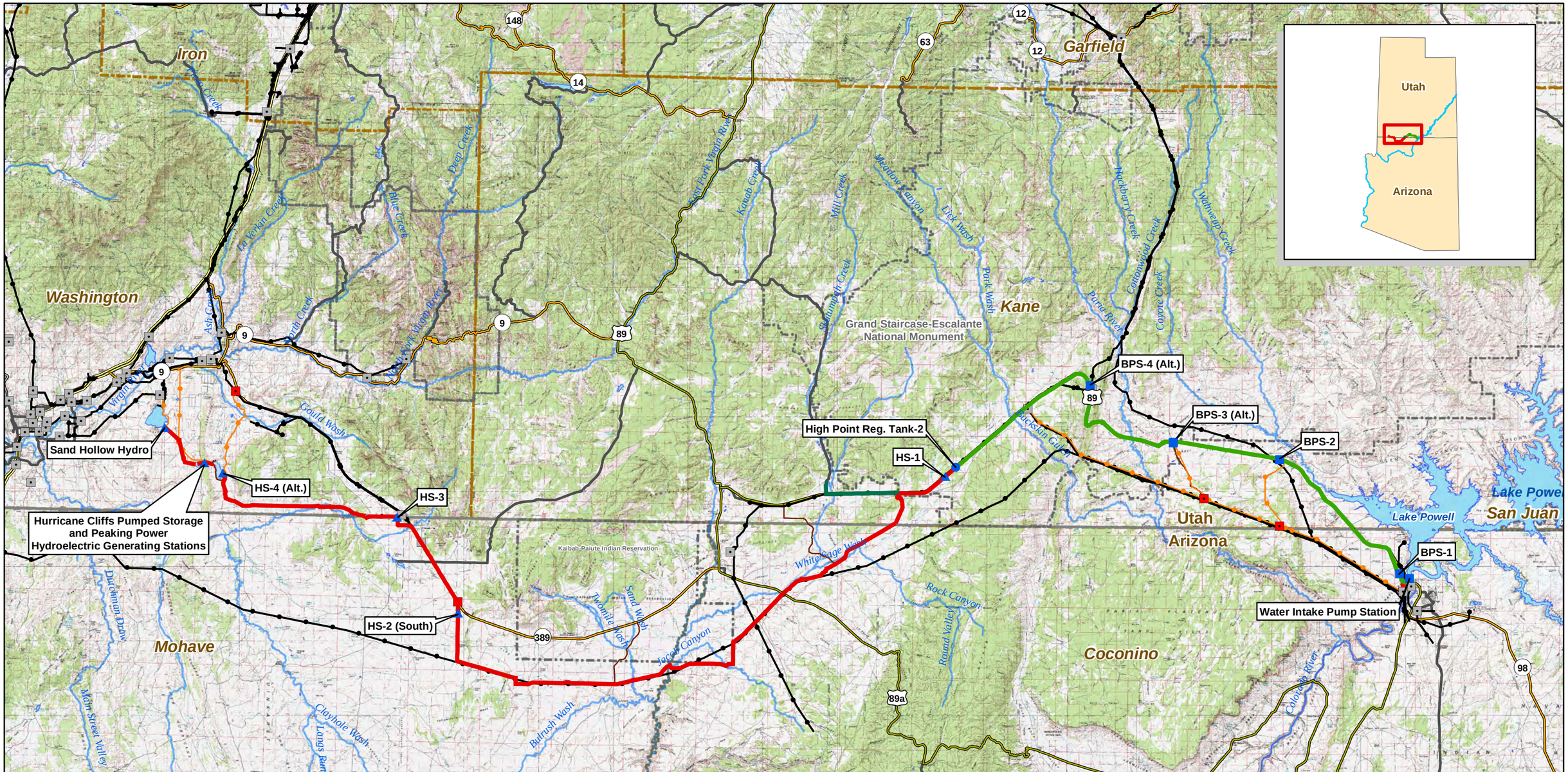
1.2 Summary Description of LPP Project Alignment Alternatives

Three primary pipeline and penstock alignment alternatives are described in this section, along with the electrical power transmission line alignments for providing power to the pump stations and a natural gas supply line alignment alternative. The pipeline and penstock alignment alternatives share common segments between the intake at Lake Powell and delivery at Sand Hollow Reservoir, and they differ spatially in, through and around Kaibab-Paiute Indian Reservation.

The South Alternative (Proposed Action) extends south around Kaibab-Paiute Indian Reservation. The Existing Highway Alternative follows an Arizona state highway through Kaibab-Paiute Indian Reservation. The Southeast Corner Alternative follows the Navajo-McCullough Transmission Line corridor through the southeast corner of Kaibab-Paiute Indian Reservation. The Electric Transmission Line alignments are common to all the pipeline and penstock alignment alternatives. The Natural Gas Supply Line Alignment Alternative is common to all pipeline and penstock alignment alternatives. The natural gas pipeline alignment would be coincident to the buried waterline and would not have a different alignment, as compared to transmission line alignments. Figure 1-1 shows the overall proposed project from Lake Powell near Page, Arizona to Sand Hollow Reservoir, Utah.

1.2.1. South Alternative

The South Alternative consists of four systems: **Water Intake, Water Conveyance, Hydro,** and **KCWCD** (see Figure 1-1).



Project Pump Station
Project Regulating Tank
Project Hydro Station
Substation
Proposed Substation

Water Conveyance System
Hydro System - South Alternative (Penstock Segment)
KCWCD System
Project Transmission Lines
Existing Transmission Lines

Interstate
US Highway
ST Highway
Hwy
Major Road
Access Roads

Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams

National Park/Monument
GSENM-Boundary
Tribal Lands
State Boundaries
County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 2.5 5 10 15 20 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-1** MWH

Lake Powell Pipeline Proposed Action

The **Water Intake System** would pump Lake Powell water via submerged horizontal tunnels and vertical shafts into the LPP. The intake pump station would be constructed and operated adjacent to the west side of Lake Powell, approximately 2,000 feet northwest of Glen Canyon Dam in Coconino County, Arizona. An enclosed pump station building would house vertical turbine pumps with electric motors, electrical controls, and other equipment at a ground level elevation of 3,745 feet above mean sea level (AMSL).

The **Water Conveyance System** would convey water diverted from Lake Powell at the Intake System through a buried 69-inch diameter pipeline for about 51 miles, parallel with Highway 89 in Coconino County, Arizona and Kane County, Utah, to a buried regulating tank (High Point Regulating Tank-2) along Highway 89 at ground level elevation 5,691 feet AMSL. The pipeline would be a line of connected pipes used for carrying water over a long distance. Figure 1-2 shows the LPP Project Water Intake and Water Conveyance systems. The High Point Regulating Tank-2 would be the LPP Project topographic high point (Figure 1-2). The pipeline would be sited within a utility corridor established by Congress in 1998 that extends 500 feet south and 240 feet north of the Highway 89 centerline on public land administered by Bureau of Land Management (BLM) (U.S. Congress 1998). Figure 1-3 shows the typical 100-foot-wide right-of-way and 20-foot-wide temporary construction easement for the water conveyance system pipeline, adjacent to and away from the highway.

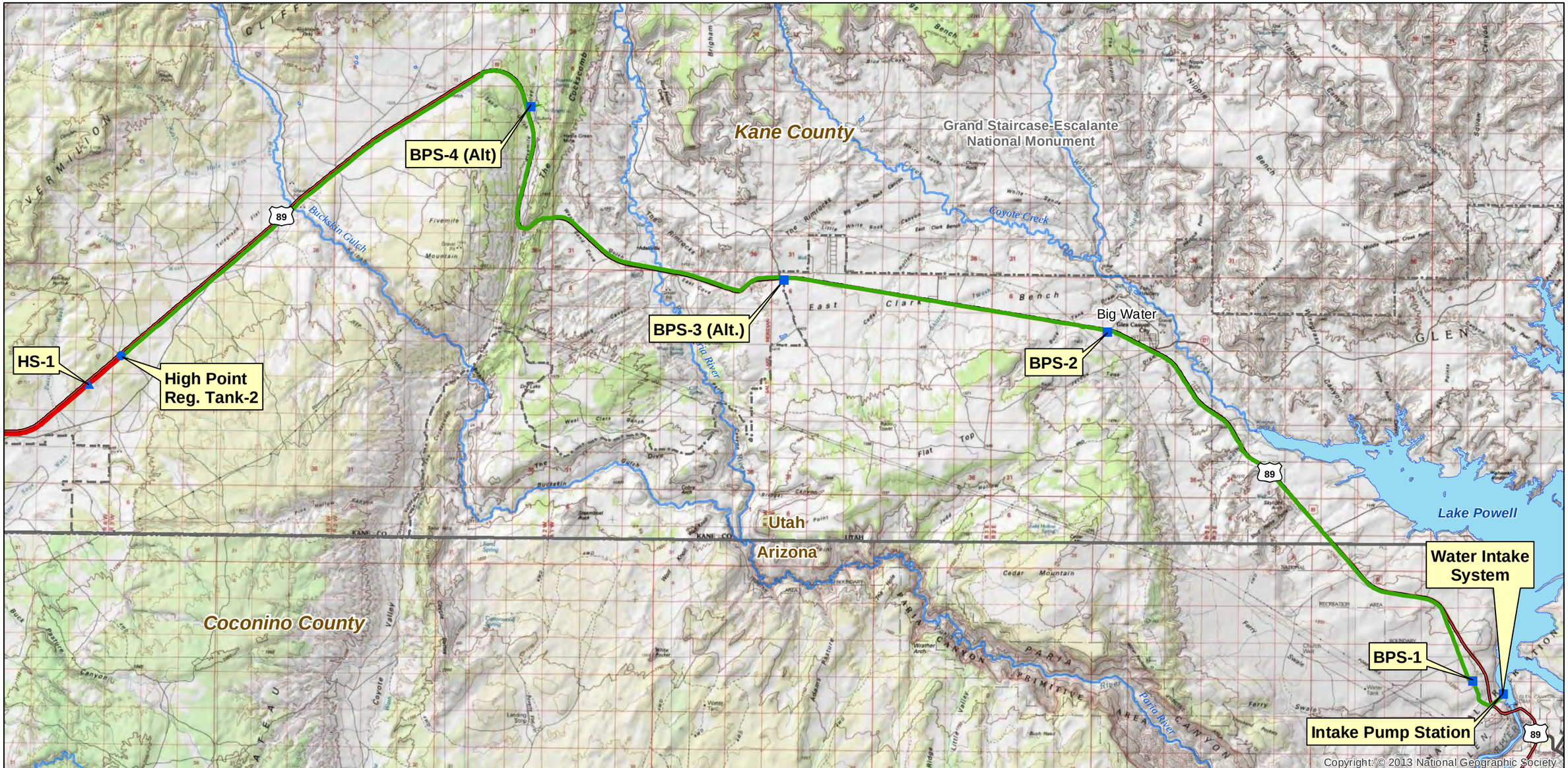
Four booster pump stations (BPS) along the pipeline would pump water to the high point regulating tank. Each BPS would house vertical turbine pumps with electric motors, electrical controls, and other equipment. Additionally, each BPS site would have a buried forebay tank, buried surge tanks, pig retrieval and launching stations, and a surface emergency overflow detention basin. BPS-1 would be located within Glen Canyon National Recreation Area (GCNRA) adjacent to an existing Arizona Department of Transportation maintenance facility, along a segment of abandoned highway, west of Highway 89. The BPS-1 site would cover about six acres and be surrounded by security fencing.

BPS-2 would be on land administered by Utah School and Institutional Trust Lands Administration (SITLA) near Big Water, Utah, on the south side of Highway 89. The BPS-2 site would cover about five acres and be surrounded by security fencing.

BPS-3 (Alt.) would be on land administered by BLM Kanab Field Office, near the east boundary of Grand Staircase-Escalante National Monument (GSENM) on the south side of Highway 89, within the Congressionally-designated utility corridor. The BPS-3 (Alt.) site would cover about five acres and be surrounded by security fencing.

BPS-4 (Alt.) would be located on private land east of Highway 89 and west of the Cockscomb geologic feature (Figure 1-2). The BPS-4 (Alt.) site would cover about six acres and be surrounded by security fencing. The proposed pipeline alignment west of the Cockscomb geologic feature would be situated adjacent to the south boundary of the Congressionally-designated utility corridor.

The proposed pipeline alignment would continue parallel to Highway 89 to the buried High Point Regulating Tank-2 at 5,691 feet AMSL, which would be the topographic high point of the LPP Project (Figure 1-2). The Water Conveyance System would terminate at High Point Regulating Tank-2. The buried High Point Regulating Tank-2 would cover about four acres and be surrounded by security fencing.



- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Water Conveyance System
- Hydro System - South Alternative (Penstock Segment)
- KCWCD System
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- Lakes & Reservoirs
- Major Rivers & Streams
- National Park/Monument
- GSENM Boundary
- State Boundaries

FERC Project Number: 12966-001
BLM Serial Numbers: AZA-34941 UTU-85472

N

0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-2** MWH

Lake Powell Pipeline Intake and Water Conveyance System

Figure 1-3 shows the typical 100-foot-wide right-of-way and 20-foot-wide temporary construction easement for the hydro system penstock adjacent to, and away from, the highway. Four in-line hydro generating stations (HS-1, HS-2 [South], HS-3, and HS-4 [Alt.]), with substations located along the penstock, would generate electricity and help control water pressure in the penstock. Each in-line hydro station would consist of a building housing the generator units, an afterbay reservoir, retention basin, pig retrieval and launching stations, switchyard, and maintenance parking area, all surrounded by perimeter security fencing.

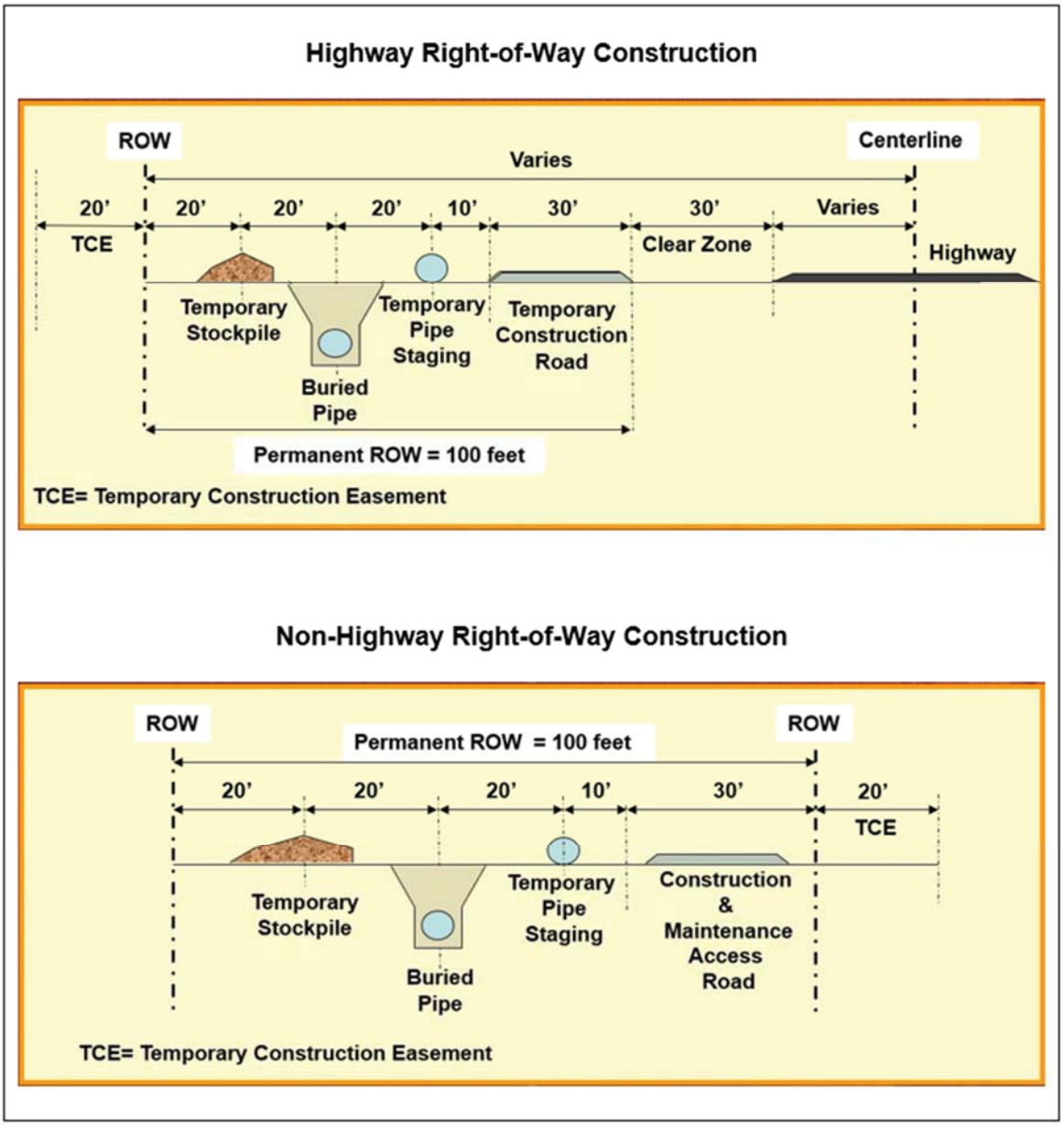


Figure 1-3
Pipeline and Penstock Right-of-Way

The **Hydro System** would convey the water from High Point Regulating Tank-2, at a topographic high point in the LPP Project with ground level elevation 5,691 feet AMSL, for about 87.5 miles through a buried 69-inch diameter penstock in Kane and Washington counties, Utah, and Coconino and Mohave counties, Arizona, to Sand Hollow Reservoir near St. George, Utah (Figure 1-4). A penstock is an enclosed pipe that delivers water to hydroelectric turbines.

A short penstock segment would convey the water to HS-1. This in-line hydro station would generate up to one megawatt (MW) of electricity at a site along Highway 89 within GSENM, and the penstock would continue west along Highway 89 to the GSENM west boundary. The HS-1 site would cover about five acres.

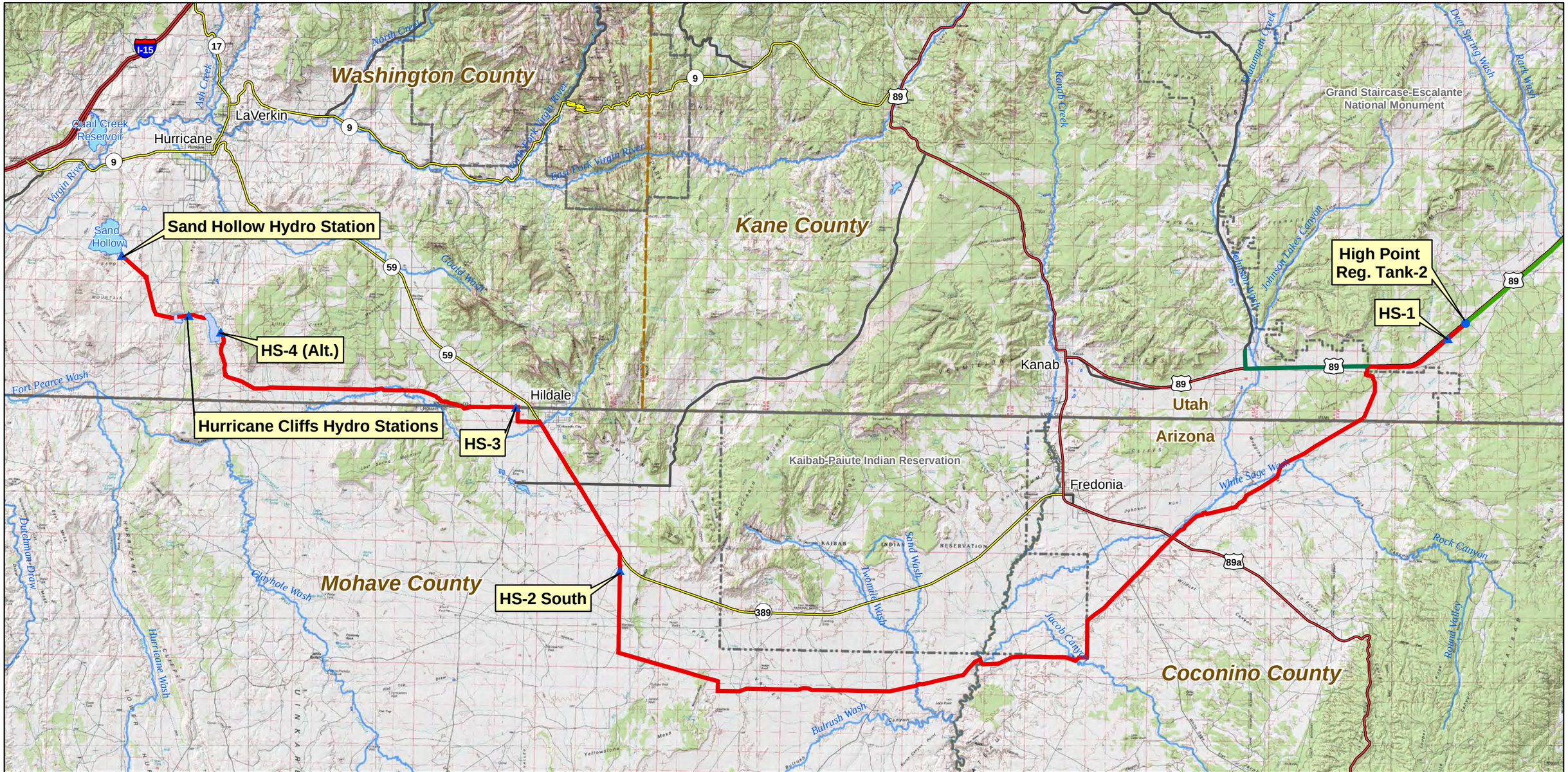
The penstock alignment would turn south from Highway 89 through private land and BLM-administered public lands into White Sage Wash. It would continue across White Sage Wash and then parallel Navajo-McCullough Transmission Line, crossing Highway 89 Alt. and Forest Highway 22 toward the southeast corner of Kaibab-Paiute Indian Reservation. The penstock alignment would run parallel to and south of the Kaibab-Paiute Indian Reservation south boundary, crossing Kanab Creek and Bitter Seeps Wash. It would continue across Moonshine Ridge and Cedar Ridge to Yellowstone Road. At this point, the penstock alignment would run north along Yellowstone Road to Arizona State Route 389 west of Kaibab-Paiute Indian Reservation. HS-2 (South) would be located west of Kaibab-Paiute Indian Reservation on private land east of Yellowstone Road. HS-2 (South) would generate up to one MW of electricity. The HS-2 (South) site would cover about five acres. The penstock alignment would continue northwest along the south side of Arizona State Route 389 past Colorado City to Hildale City, Utah, and HS-3. HS-3 would be located on private land west of Hildale City, Utah, north of and adjacent to Uzona Road. HS-3 would generate up to one MW of electricity. The HS-3 site would cover about five acres. A turnout for future delivery of 13,249 acre-feet of WCWCD's allocation of LPP Project water to Apple Valley would be located immediately west of HS-3.

The penstock alignment would follow Uzona Road west through Canaan Gap and south of Little Creek Mountain, turning north to HS-4 (Alt.) above the proposed Hurricane Cliffs forebay reservoir. HS-4 (Alt.) would be located on about three acres of public land administered by the BLM. HS-4 (Alt.) would generate up to 1.7 MW of electricity and would discharge into the forebay reservoir.

The forebay reservoir would be contained in a valley between two dams (south and north), maintaining active storage of 11,255 acre-feet of water. The forebay reservoir and two dams would cover about 500 acres of public land administered by BLM and would be surrounded by security fencing. A low-pressure tunnel would convey the water to a high-pressure vertical shaft in the bedrock forming the Hurricane Cliffs, connected to a high-pressure tunnel near the bottom of the Hurricane Cliffs. The high-pressure tunnel would connect to a penstock conveying the water to a 35-MW-capacity peaking power hydroelectric generating station and a 300-MW-capacity pumped storage hydroelectric generating station.

The Hurricane Cliffs hydroelectric generating stations and tailrace channel would cover about 50 acres of public land administered by BLM and would be surrounded by security fencing. The tailrace channel would discharge into an afterbay reservoir with 3,551 acre-feet of operating capacity, which is contained by a single dam in the valley below the Hurricane Cliffs. The afterbay reservoir and dam would cover about 200 acres of public land administered by BLM and would be surrounded by security fencing.

Water would be released from the forebay reservoir through the hydro generating system to meet peak power demands. Water would be pumped from the afterbay reservoir into the forebay reservoir during periods of off-peak power demand. The forebay and afterbay reservoirs would not be open to public access because the water levels would fluctuate rapidly during daily operations. A low pressure tunnel would convey the water northwest from the afterbay reservoir to a penstock, continuing to the Sand



Project Pump Station
Project Regulating Tank
Project Hydro Station
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs

Water Conveyance System
Hydro System - South Alternative (Penstock Segment)
KCWCD System
Major Rivers & Streams

Interstate
US Highway
ST Highway
Hwy
Major Road

National Park/Monument
GSENM Boundary
Tribal Lands
State Boundaries
County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 1 2 4 6 8 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-4** MWH

Lake Powell Pipeline Hydro System South Alternative

Hollow Hydro Station, which would generate up to 4.2 MW of electricity. The Sand Hollow Hydro Station would be located on land owned by WCWCD and cover about five acres adjacent to Sand Hollow Reservoir. The LPP Project water would discharge from the Sand Hollow Hydro Station into the existing Sand Hollow Reservoir.

The **KCWCD System** would convey water diverted from Lake Powell through the LPP at the west GSENM boundary for about eight miles through a buried 24-inch diameter pipeline in Kane County, Utah, near the mouth of Johnson Canyon. The pipeline would parallel the south side of Highway 89 across Johnson Wash and then run north for 5000 feet to the mouth of Johnson Canyon (Figure 1-4).

1.2.2. Existing Highway Alternative

The Existing Highway Alternative consists of four systems: **Water Intake, Water Conveyance, Hydro,** and **KCWCD**. The **Water Intake** and **Water Conveyance** systems would be the same as described for the South Alternative. The **Hydro System** would convey water diverted at Lake Powell from High Point Regulating Tank 2 at the LPP Project topographical high point (5,691 feet AMSL) for about 80.5 miles through a buried 69-inch diameter penstock in Kane and Washington counties, Utah, and Coconino and Mohave counties, Arizona, to Sand Hollow Reservoir near St. George, Utah (Figure 1-5). The alternative alignment parallels Highway 89 to the west and south boundary of GSENM and continues along Highway 89 to Lost Spring Gap. Four in-line hydro generating stations (HS-1, HS-2 [Hwy], HS-3, and HS-4 [Alt.]) located along the penstock would generate electricity and help control water pressure in the penstock. The HS-1, HS-3 and HS-4 (Alt.) hydro stations would be the same as described for the South Alternative.

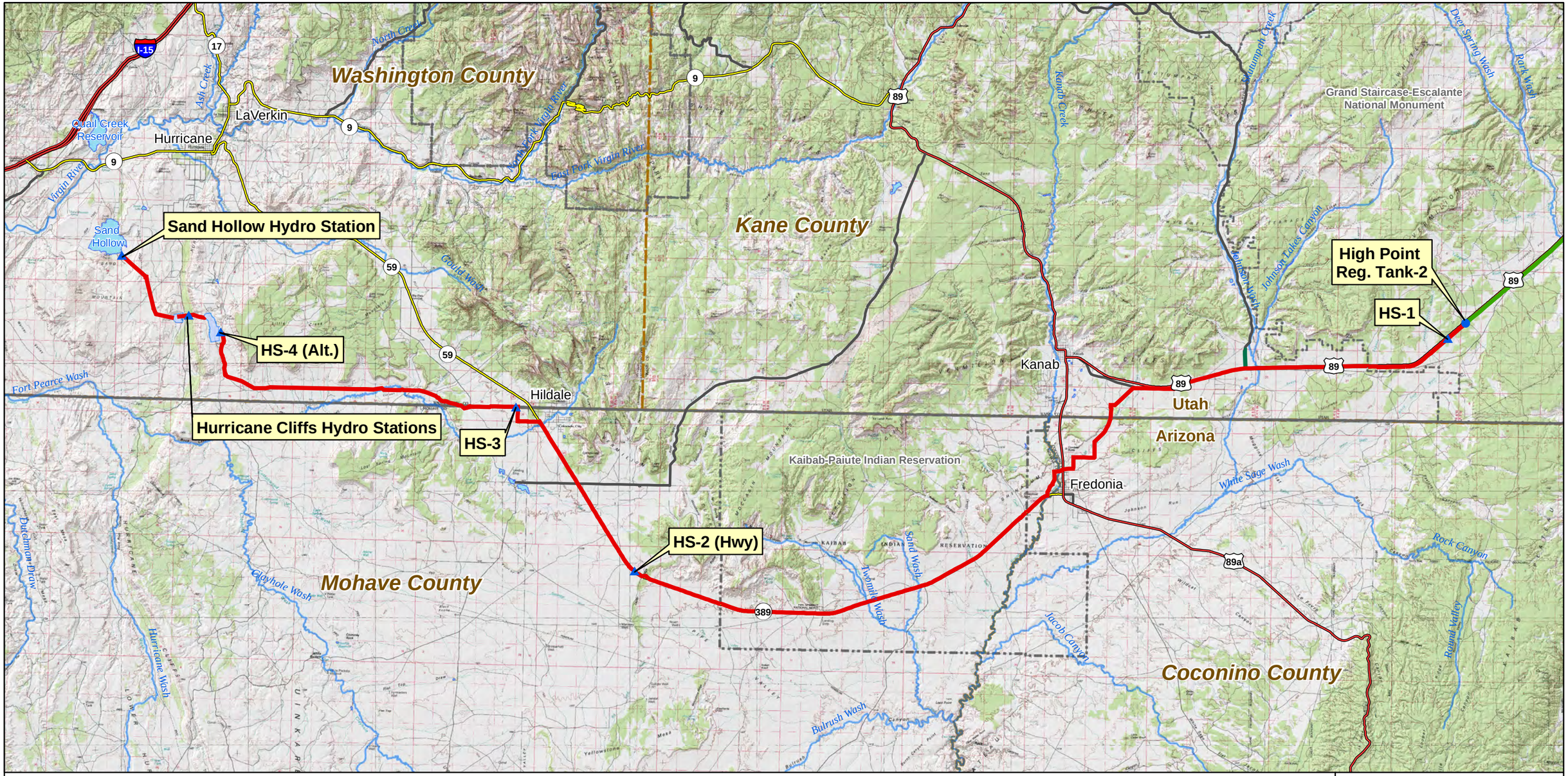
The penstock downstream from the proposed HS-1 would be sited along the south side of Highway 89 within GSENM. The penstock would parallel the south side of Highway 89 west of GSENM, continue past Johnson Wash and follow Lost Spring Gap southwest, crossing Highway 89 Alt. and Kanab Creek in the north end of Fredonia, Arizona. It would continue south, paralleling Kanab Creek to Arizona State Route 389, where it would run west, adjacent to the north side of Route 389 through Kaibab-Paiute Indian Reservation past Pipe Spring National Monument. The penstock would continue along the north side of Arizona State Route 389 through the west half of Kaibab-Paiute Indian Reservation to 1.8 miles west of Cedar Ridge (intersection of Yellowstone Road with Highway 89), where it would then follow the same alignment as the South Alternative to Sand Hollow Reservoir. HS-2 (Hwy) would be sited 0.5 miles west of Cedar Ridge along the north side of Arizona State Route 389. HS-2 (Hwy) would generate approximately 0.8MW of electricity and cover 8.7 acres of private land.

The **KCWCD System** would convey water diverted at Lake Powell from the LPP Project along Highway 89 north along Johnson Canyon Road for 5,000 feet through a buried 24-inch diameter pipeline in Kane County, Utah to the mouth of Johnson Canyon (Figure 1-5).

1.2.3. Southeast Corner Alternative

The Southeast Corner Alternative consists of four systems: **Water Intake, Water Conveyance, Hydro,** and **KCWCD**. The **Water Intake**, **Water Conveyance**, and **KCWCD** systems would be the same as described for the South Alternative.

The **Hydro System** would be the same as described for the South Alternative from High Point Regulating Tank 2 at the LPP Project topographical high point (5,691 feet AMSL) to the east boundary of Kaibab-Paiute Indian Reservation. At the east boundary of Kaibab-Paiute Indian Reservation, the penstock alignment would parallel the north side of the Navajo-McCullough Transmission Line corridor in Coconino County, Arizona, through the southeast corner of the Kaibab-Paiute Indian Reservation for about 3.8 miles. The penstock would then follow the



Project Pump Station
Project Regulating Tank
Project Hydro Station
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs

Water Conveyance System
Hydro System - Existing Highway Alternative (Penstock Segment)
KCWCD System
Major Rivers & Streams

Interstate
US Highway
ST Highway
Hwy
Major Road

National Park/Monument
GSENM Boundary
Tribal Lands
State Boundaries
County Boundaries

FERC Project Number: 12966-001
BLM Serial Numbers: AZA-34941 UTU-85472

N

0 1 2 4 6 8 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-5** MWH

Lake Powell Pipeline Hydro System Existing Highway Alternative

South Alternative alignment south of the south boundary of the Kaibab-Paiute Indian Reservation, continuing to Sand Hollow Reservoir (Figure 1-6). The Southeast Corner Alternative would be about 85.7 miles long from High Point Regulating Tank-2 to Sand Hollow Reservoir.

1.2.4. Transmission Line Alignments

Transmission line alignments have been identified to transmit electric power to pump stations in the Water Intake and Water Conveyance systems, and to transmit electric power generated by hydroelectric stations in the Hydro System. The transmission lines that would serve the Water Intake and Water Conveyance systems are located in the east half of the LPP Project. The transmission lines that would serve the Hydro System are located in the west half of the LPP Project.

The proposed new **Water Intake Transmission Line** would begin at Glen Canyon Substation and run parallel to Highway 89 for about 2,500 feet to a new switch station, cross Highway 89 at the Intake access road intersection, and continue northeast to a new electrical substation on the Intake Pump Station site. This 69 kV transmission line would be 0.9 mile long in Coconino County, Arizona (Figure 1-7).

The proposed new **BPS-1 Transmission Line** would begin at the new switch station located on the south side of Highway 89 and parallel the LPP Project Water Conveyance System alignment to a new electrical substation on the BPS-1 site west of Highway 89. The 69 kV transmission line would be about one mile long in Coconino County, Arizona (Figure 1-7).

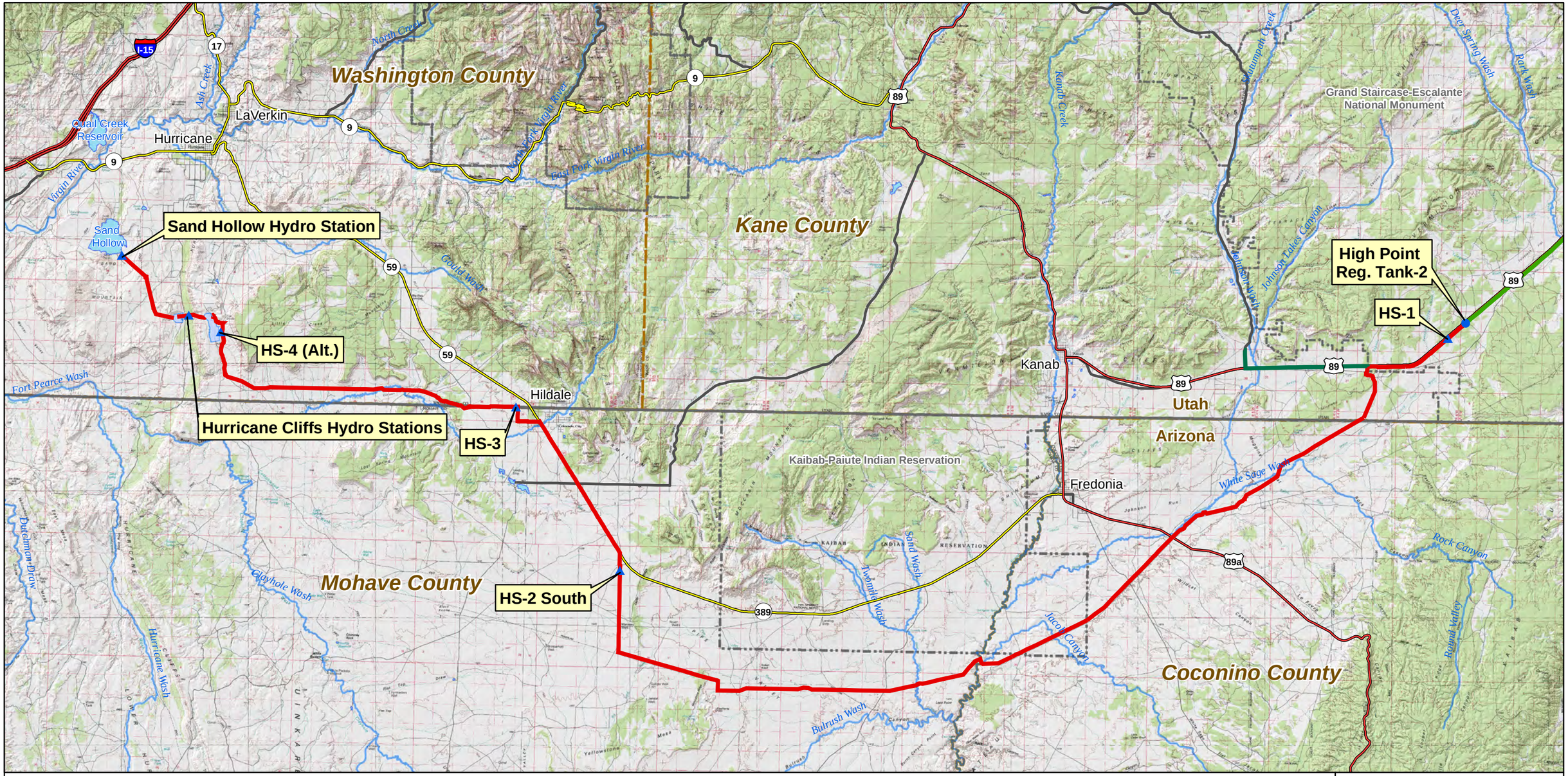
The proposed new **Glen Canyon to Buckskin Transmission Line** would consist of a 230 kV transmission line from the Glen Canyon Substation to the Buckskin Substation, running parallel to the existing 138 kV transmission line. This transmission line upgrade would be about 36 miles long through Coconino County, Arizona, and Kane County, Utah (Figure 1-7).

The existing **Buckskin Substation** would be upgraded as part of the proposed project to accommodate the additional power loads from the new 230 kV Glen Canyon to Buckskin transmission line. The substation upgrade would require an additional five acres of land within GSENM adjacent to the existing substation in Kane County, Utah (Figure 1-7).

The existing **Paria Substation** would be upgraded as part of the proposed project to accommodate the additional power loads to BPS-4 (Alt.). The substation upgrade would require an additional two acres of privately-owned land adjacent to the existing substation in Kane County, Utah (Figure 1-7).

The proposed new **BPS-2 Transmission Line** would consist of a new three-ring switch station along the new 230 kV Glen Canyon to Buckskin Transmission Line, a new transmission line from the switch station to a new substation west of Big Water, and a connection to BPS-2 substation in Kane County, Utah. The new transmission line would parallel an existing distribution line that runs northwest, north, and then northeast to Big Water. This new 138 kV transmission line alignment would be about seven miles long across Utah SITLA-administered land, with a 138 kV connection to a new electrical substation on the BPS-2 site (Figure 1-7).

The proposed new **BPS-3 Alt. Transmission Line South** would consist of a new three-ring switch station along the new 230 kV Glen Canyon to Buckskin Transmission Line, and a new transmission line from the switch station north along an existing BLM road to a new electrical substation on the BPS-3 (Alt.) site near the GSENM east boundary and within the Congressionally-designated utility corridor. This new 138 kV transmission line alignment would be about 5.9 miles long in Kane County, Utah (Figure 1-7).



- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Hurricane Cliffs Forebay/Afterbay
- Lakes & Reservoirs
- Water Conveyance System
- Hydro System - Southeast Corner Alternative (Penstock Segment)
- KCWCD System
- Major Rivers & Streams
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- National Park/Monument
- GSENM Boundary
- Tribal Lands
- State Boundaries
- County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
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UTU-85472

N

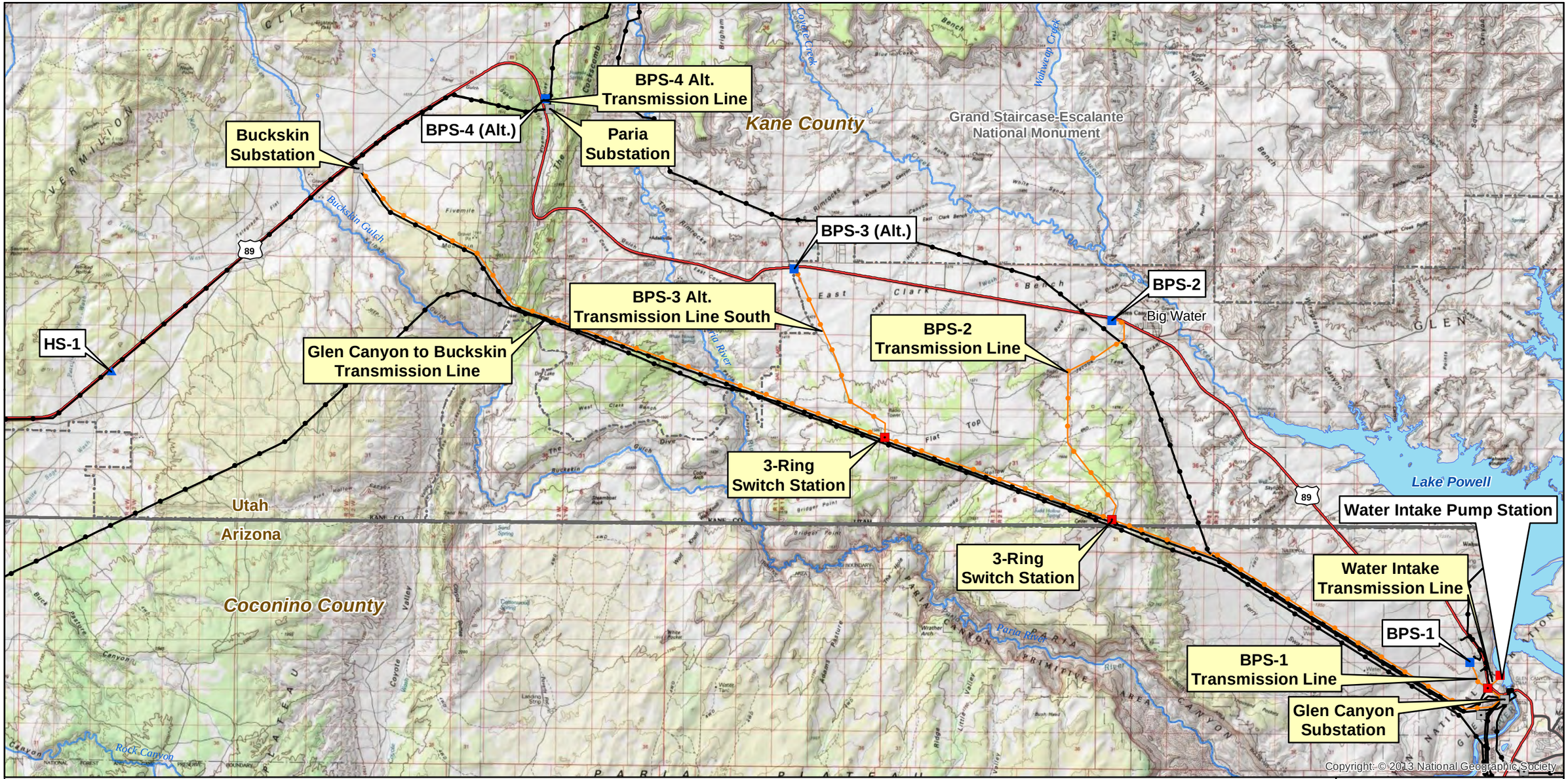
0 1 2 4 6 8 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-6** MWH

Lake Powell Pipeline
Hydro System
Southeast Corner Alternative



Project Intake Pump Station
Project Pump Station
Project Hydro Station
Substation
Proposed Substation
Project Transmission Lines
Existing Transmission Lines
Interstate
US Highway
ST Highway
Hwy
Major Road
Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
GSENM Boundary
State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

0 0.5 1 2 3 4 Miles

N

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-7** MWH

Lake Powell Pipeline Proposed Transmission Lines East

The proposed new **BPS-4 Alt. Transmission Line** would begin at the upgraded Paria Substation and run north to a new electrical substation on the BPS-4 Alternative site. This 69 kV transmission line would be about 0.4 mile long in Kane County, Utah (Figure 1-7).

The proposed new **HS-1 Transmission Line** would begin at the new HS-1 and tie into the existing 69 kV transmission line along Highway 89 from the Buckskin Substation to the Johnson Substation. The HS-1 69 kV transmission line would be about 400 feet long in Kane County, Utah (Figure 1-8).

The proposed new **HS-2 (South) Transmission Line** would connect the HS-2 hydroelectric station and substation along the South Alternative to an existing 138 kV transmission line paralleling Arizona State Route 389. This new 34.5 kV transmission line would be about 0.9 mile long in Mohave County, Arizona (Figure 1-8).

The new **HS-2 (Highway) Transmission Line** alternative would directly connect the HS-2 hydroelectric station and substation along the Existing Highway Alternative to an existing 138 kV transmission line paralleling Arizona State Route 389. This new 34.5 kV transmission line would be about 200 feet long in Mohave County, Arizona.

The proposed new **HS-3 Transmission Line** would connect the HS-3 hydroelectric station and substation to the existing Twin Cities Substation in Hildale City, Utah. The new 12.47 kV transmission line would be about 0.6 mile long in Washington County, Utah (Figure 1-8).

The proposed new **HS-4 (Alt.) Transmission Line** would connect the HS-4 (Alt.) hydroelectric station and substation to an existing transmission line parallel to Utah State Route 59. The new 69 kV transmission line would be about 7.5 miles long in Washington County, Utah (Figure 1-8).

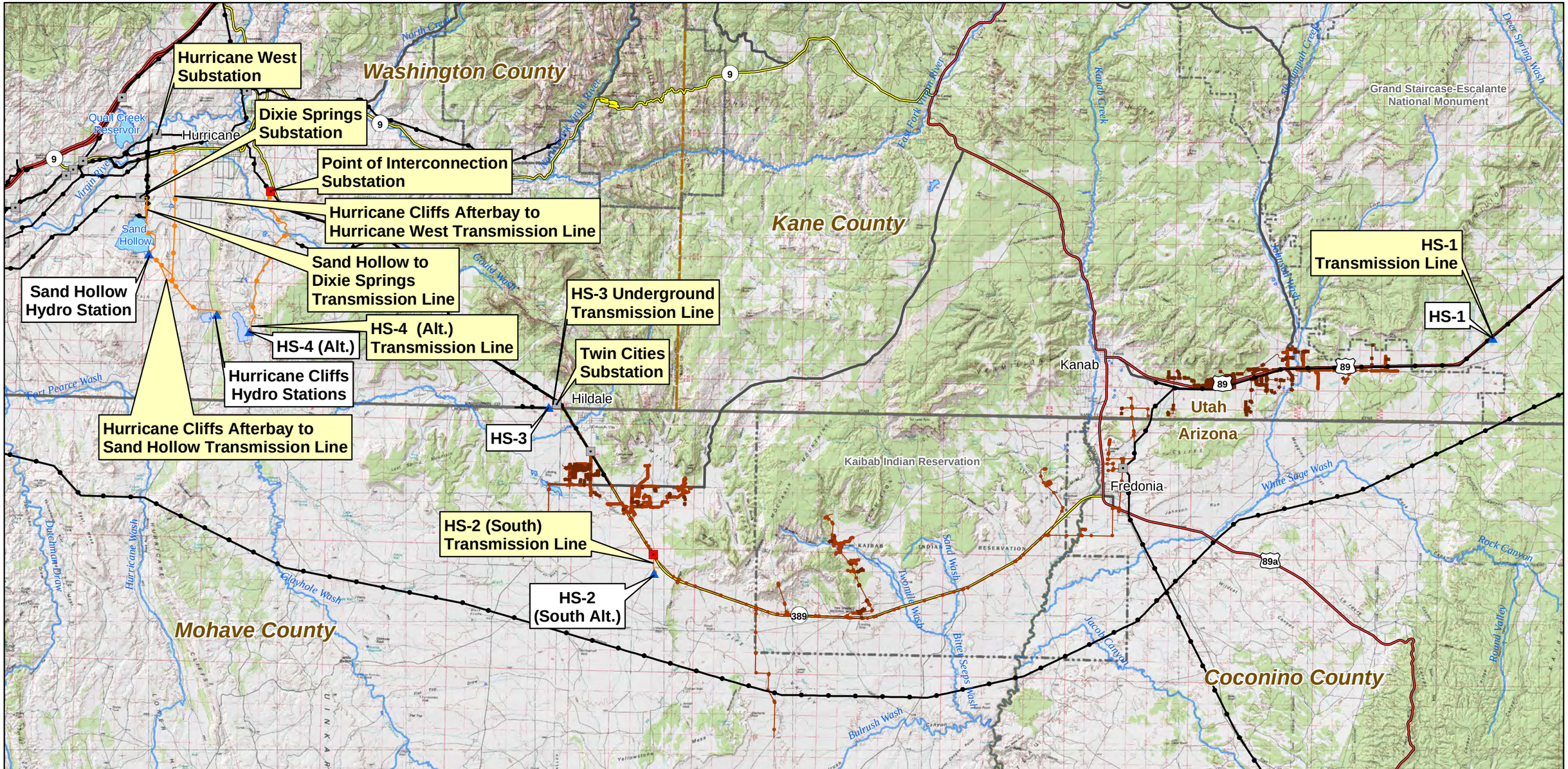
The proposed new **Hurricane Cliffs Afterbay to Sand Hollow Transmission Line** would consist of a new 69 kV transmission line, which would run northwest from the Hurricane Cliffs peaking power plant and substation to the Sand Hollow Hydro substation. This new 69 kV transmission line would be about 4.9 miles long in Washington County, Utah (Figure 1-8).

The proposed new **Hurricane Cliffs Afterbay to Hurricane West Transmission Line** would consist of a new 345 kV transmission line, running from the Hurricane Cliffs pumped storage power plant northwest and then north to the planned Hurricane West 345 kV substation. This new 345 kV transmission line would be about 10.9 miles long in Washington County, Utah (Figure 1-8).

The proposed new **Sand Hollow to Dixie Springs Transmission Line** would consist of a new 69 kV transmission line, running from the Sand Hollow Hydro substation around the east side of Sand Hollow Reservoir and north to the existing Dixie Springs Substation. This new 69 kV transmission line would be about 3.4 miles long in Washington County, Utah (Figure 1-8).

1.2.5. Natural Gas Pipeline and Generators Alternative

Natural gas engine-driven generation systems to power electric pumps would be an alternative to powering the LPP Project pump stations by electricity via transmission lines. Recent discussions with Questar Gas Company (local natural gas supplier) indicated that capacity would be available in the Kern River natural gas pipeline, which is located west of St. George, Utah, to supply natural gas for this alternative. Questar Gas Company indicated the company has future plans to extend a high pressure natural gas pipeline from the Kern River line to Hurricane, Utah. The Questar Gas pipeline would be



Project Hydro Station
Substation
Proposed Substation
Project Transmission Lines
Existing Transmission Lines
Existing OH Primary Line
Existing UG Primary Line
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams
Interstate
US Highway
ST Highway
Hwy
Major Road
National Park/Monument
GSENM Boundary
Tribal Lands
State Boundaries
County Boundaries

FERC Project Number:
12966-001
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AZA-34941
UTU-85472

N

0 1 2 4 6 8 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-8** MWH

Lake Powell Pipeline Proposed Transmission Lines West

sized to supply natural gas to the LPP Project if it is determined that a single-purpose, dedicated high pressure gas line would be extended to service the LPP pump stations. Based on the preliminary pump selection and fuel requirements, the natural gas supply pipeline would be 12 inches in diameter to provide natural gas supply for the LPP Project pump stations. The pipeline would likely be successively reduced in size as it delivers gas to each of the pump stations.

1.2.5.1 Natural Gas Transmission Line Connection

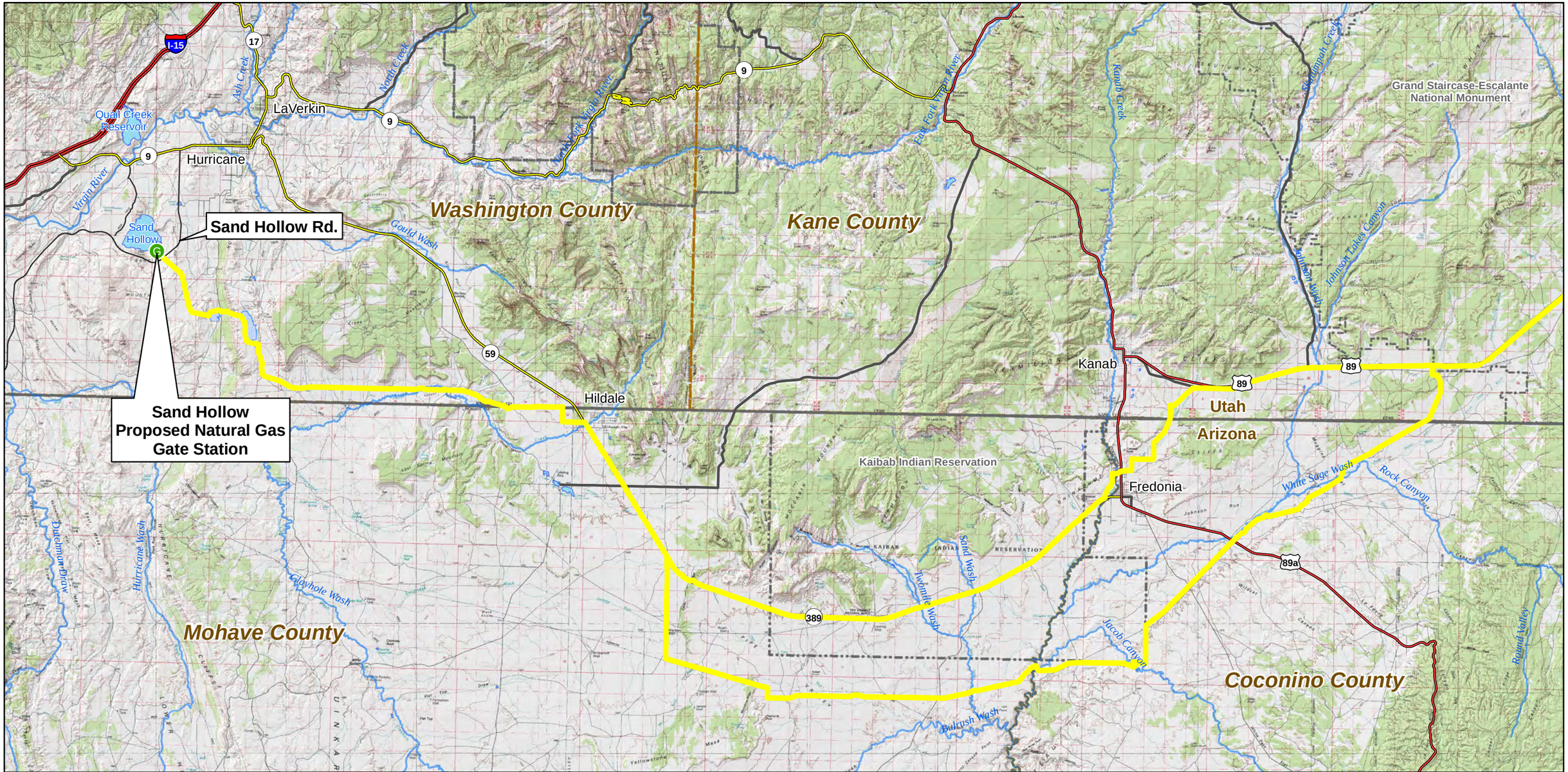
The natural gas supply line alternative would connect to the proposed Questar Gas Transmission Line from the existing Kern River line to Hurricane City. The natural gas supply line would connect to the high pressure gas transmission line at a proposed gate station southeast of Sand Hollow Reservoir. The proposed gate station would be located adjacent to the alignment of the extension of the Southern Corridor Highway, which is the existing alignment of Sand Hollow Road east of Sand Hollow Reservoir (Figure 1-9).

1.2.5.2 Natural Gas Supply Line

The proposed natural gas supply line would be an intermediate high pressure line and would operate between approximately 250 to 300 psi at the gate station connection. Because of pressure losses in the pipeline it is anticipated that the pressure at each of the LPP pump stations would vary between 50 and 100 psi, which would meet the requirements of the natural gas generators. The pipeline would be constructed of strong carbon steel and have a dielectric coating, such as a fusion bonded epoxy or extruded polyethylene. It would be installed with a minimum four feet of cover and be provided with cathodic protection (a technique that involves inducing an electric current through the pipe to ward off corrosion and rusting). The pipeline would be designed, constructed, tested, and operated at a minimum in accordance with all applicable requirements included in the U.S. DOT regulations in 49 CFR Part 192, “Transportation of Natural Gas and other Gas by Pipeline: Minimum Federal Safety Standards,” and other applicable federal and state regulations.

The natural gas supply line would follow the proposed LPP ROW from the Sand Hollow Gate Station to the intake pump station near Page, Arizona. The line would be about 138.5 miles long and installed a minimum of 10 feet from the edge of the proposed water pipeline in a separately excavated trench within the LPP ROW. Figure 1-9 shows the west alignment of the natural gas supply line as proposed and an alternative alignment along Arizona State Route 389 and through Fredonia, Arizona, parallel to the Existing Highway Alternative alignment, both to the west GSENM boundary. Figure 1-10 shows the east alignment of the natural gas supply line as proposed from the west GSENM boundary to the water intake pump station.

Sectionalizing valves would be required along the natural gas supply line alignment. These valves are safety devices used for emergency shut down or maintenance. The natural gas supply line sectionalizing valves would be required at approximately 20-mile intervals because of the gas line’s remoteness. The main line valve sites would cover a 40-foot by 40-foot area surrounded by a chain link fence within the confines of the permanent LPP pipeline ROW. The valves would be above ground and connected to the buried natural gas supply line. Additionally, pig launching or receiving equipment would be installed within the fenced areas. Pigs are devices that are placed into a natural gas supply line to clean the inside walls or to monitor its internal and external condition. Launching and receiving equipment is connected to the natural gas supply line to enable pigs to be inserted into or removed from the pipeline.



Natural Gas Gate Station
Natural Gas Supply Line Alignment
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams
Interstate
US Highway
ST Highway
Hwy
Major Road
National Park/Monument
GSENM Boundary
Tribal Lands
State Boundaries
County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

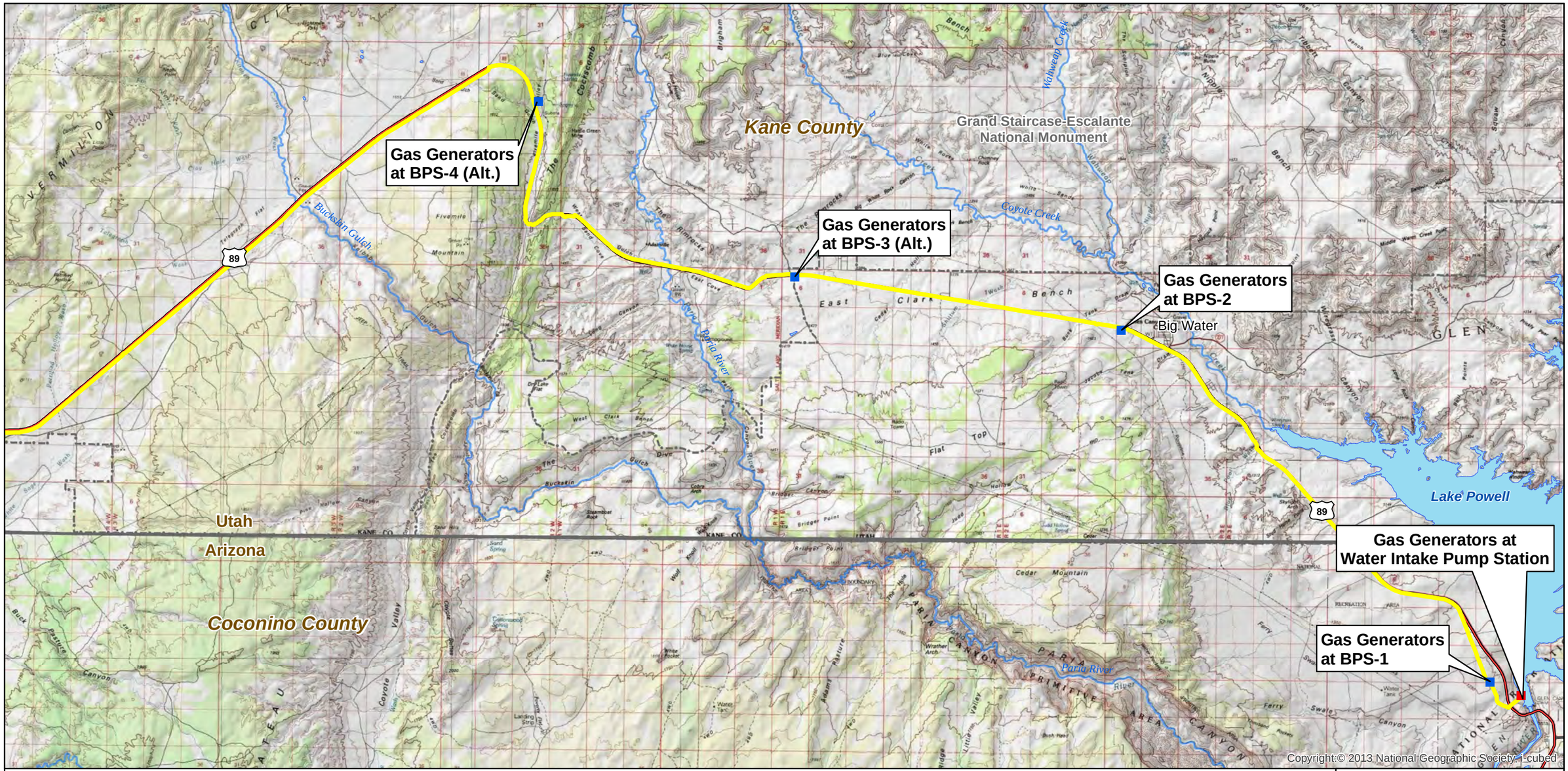
0 2 4 6 8 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-9** MWH

Lake Powell Pipeline
Natural Gas Supply Line and Generators West Alternatives



Project Water Intake Pump Station
Gas Generators at Booster Pump Station
Natural Gas Supply Line Alignment

Interstate
US Highway
ST Highway
Hwy
Major Road

Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
GSENM Boundary
State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-10** MWH

Lake Powell Pipeline Natural Gas Supply Line and Generators East Alternative

1.2.5.3 Natural Gas Generators

Natural gas generators would be used to supply power to operate the electric pumps at the LPP pump stations. The size of the electric pumps is approximately 18 feet from center to center when configured. The overall pump station building size would be 14 feet wider and 18 feet longer than the pump stations which are powered by electricity from transmission lines.

The natural gas generators would be approximately 35 feet long by eight feet wide by nine feet high. The intake pump station building size for the natural gas generators would be approximately 65 feet wide by 170 feet long by 50 feet high, and located adjacent to the pump station electrical room within the five-acre site designated for each pump station. The booster pump station building size for the natural gas generators would be 65 feet wide and 39 feet high, with lengths ranging from 114 feet to 162 feet long. Each natural gas generator would require a 24-inch diameter stack, with guide wires, extending above the building roof to disperse the exhaust gases. The five stacks (four operating natural gas generators plus one standby natural gas generator) at the intake pump station would extend 20 feet above the top of the 55-foot tall building. The stacks at BPS-1, BPS-2, BPS-3 (Alt.), and BPS-4 (Alt.) would extend 61 feet above the top of the buildings to a total height of 100 feet above the ground surface. The natural gas generators at the intake pump station and BPS-4 (Alt.) would require emission control systems to meet air quality standards.

The natural gas generators alternative at the LPP pump stations would require an annual natural gas supply of 2,855,400 million British thermal units (MMBtu). Table 1-1 shows the annual natural gas consumption at the proposed project intake pump station and booster pump stations 1 through 4.

Table 1-1
Water Conveyance System Natural Gas Generator Annual Fuel Consumption

Pump Station	Site Elevation Feet MSL	Number of Pumps	Motor (HP)	Total Motor (kW)	Natural Gas Generator GE Model	# of Units[1]	Emission Control Required	Generator Total kW[2]	Annual Fuel Consumption (MMbtu)[3]
IPS	3,750	5	3000	11,190	JGS 620 F09	4+1	Yes	12,120	729,000
BPS-1	4,111	5	1500	5,595	JGS 620 F09	2+1	No	5,992	364,500
BPS-2	4,311	5	1750	6,530	JGS 620 F09	3+1	No	8,895	425,400
BPS-3 Alt.	4,657	5	2500	9,325	JGS 620 F09	4+1	No	11,652	607,500
BPS-4 Alt.	5,001	5	3000	11,190	JGS 620 F09	5+1	Yes	14,430	729,000
Total		**25**		**43,830**		**18+5**		**53,089**	**2,855,400**

Notes:
[1] Number of operating units plus standby generator
[2] Total generator capacity without standby generator
[3] The annual fuel consumption is based on all pumps operating at rated motor horsepower, 8400 hours/year operation with generators loaded at 87 percent on the average.

1.3 Summary Description of No Lake Powell Water Alternative

The No Lake Powell Water Alternative would involve a combination of developing remaining available surface water and groundwater supplies, developing reverse osmosis treatment of existing low quality water supplies, and eliminating residential outdoor water use in the WCWCD service area. This alternative could provide a total of 86,249 acre-feet of water annually to WCWCD and KCWCD for M&I use without diverting Utah's water from Lake Powell.

1.3.1. WCWCD No Lake Powell Water Alternative

1.3.1.1 Background

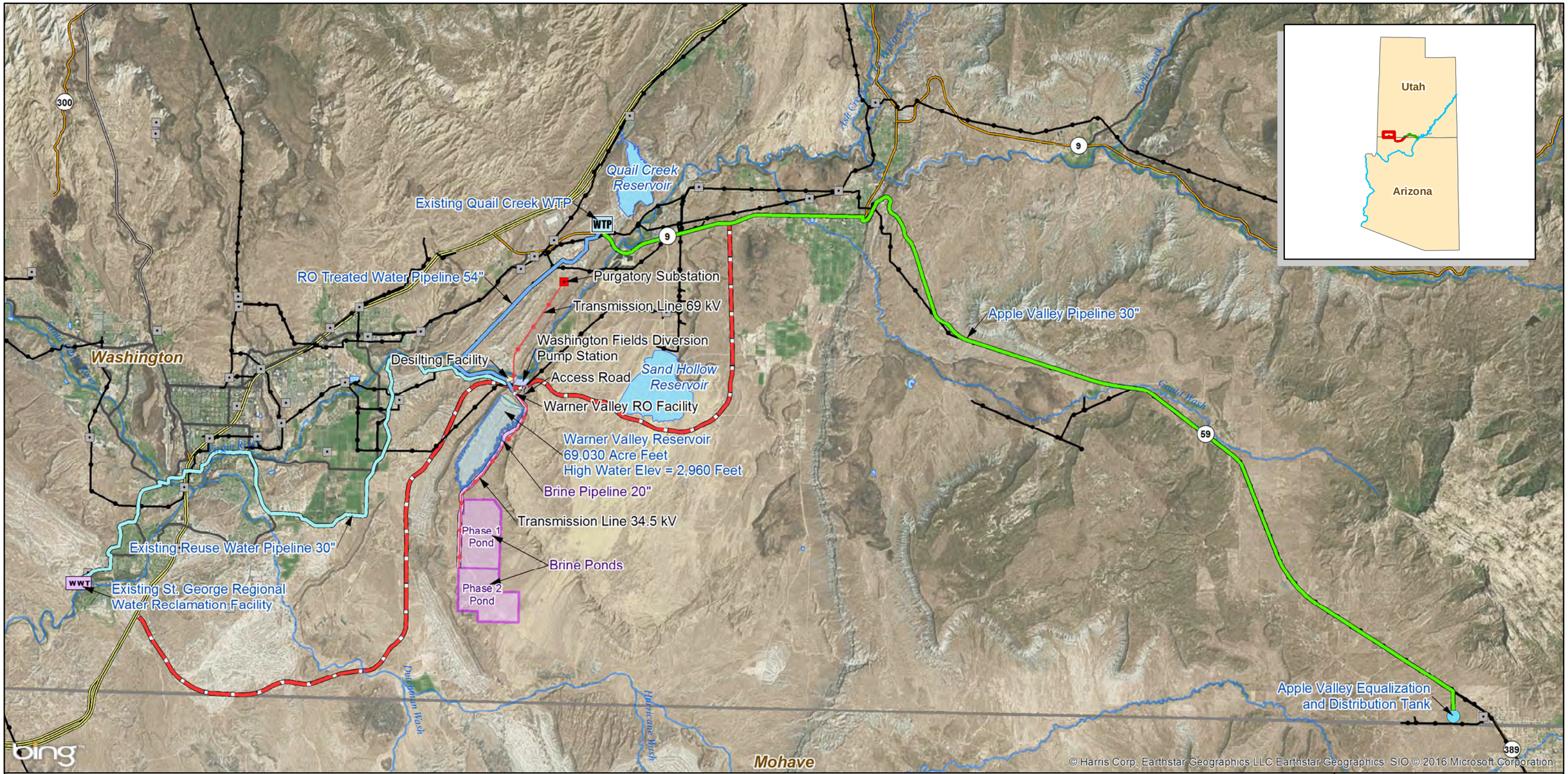
The WCWCD LPP allocation would be 82,249 acre-feet per year, and the WCWCD No Lake Powell Water alternative would need to supply 82,249 acre-feet per year to meet the same future water demands. In addition to the direct supply from Utah's Colorado River water, the water supplied by the LPP Project would provide additional wastewater reuse supply provided that sufficient storage is available.

The No Lake Powell Water Alternative would serve the same population as the LPP Project. WCWCD would implement other future water development projects currently planned by the District, develop additional water reuse/reclamation programs, continue to implement new water conservation measures, and convert additional agricultural water use to M&I use as a result of urban development in agricultural areas through 2028. Remaining planned and future water supply projects include the Ash Creek Pipeline (2,840 acre-feet per year), Sand Hollow recharge/recovery (3,000 acre-feet per year), Westside groundwater wells arsenic treatment (5,000 acre-feet per year), and development/yield increase of existing groundwater wells (2,830 acre-feet per year). Along with existing supplies, these future water supplies would yield an estimated 72,842 acre-feet per year of potable water and 8,505 acre-feet per year secondary water by 2028.

Under the No Lake Powell Water Alternative, actions in addition to the currently planned WCWCD projects would be taken to meet the water demand that would have been supplied by the Lake Powell Pipeline, as described below.

1.3.1.2 WCWCD No Lake Powell Water Alternative Features

Beginning in 2025, Washington County residential outdoor potable water use would be permanently re-purposed to indoor potable water use to help meet increasing indoor potable water demands. The WCWCD would develop a reverse osmosis (RO) advanced water treatment facility near the Washington Fields Diversion in Washington County, Utah, to treat up to 50,000 acre-feet per year of diverted Virgin River water, which has a high total dissolved solids (TDS) concentration, mixed with an additional 19,030 acre-feet per year of reuse water. WCWCD would develop the Warner Valley Reservoir to store the reuse water and diverted Virgin River water prior to RO treatment. A water distribution pump station and pipeline would be constructed to convey 13,249 acre-feet of potable water from Quail Creek Water Treatment Plant to the Apple Valley area of Washington County. Figure 1-11 shows the primary conceptual components of the No Lake Powell Water Alternative. Table 1-2 summarizes available supplies and projected demands under the No Lake Powell Water Alternative and the LPP Project alternatives.



WTP Quail Creek WTP (Existing)
WWT St. George Regional Water Reclamation Facility (Existing)
Substation
Substation (Future)
Warner Valley Transmission Line
Existing Transmission Lines
Desilting Facility
RO WTP
Washington Fields Diversion Pump Station
Lakes & Reservoirs
Brine Evaporation Ponds
Access Road
Apple Valley Pipeline 30"
Brine Pipeline 20"
Existing Reuse Water Pipeline 30"
RO Treated Water Pipeline 54"
Major Rivers & Streams
Interstate
US Highway
ST Highway
Hwy
Major Road
Southern Corridor Highway
State Boundaries
County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 0.75 1.5 3 4.5 6 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 1-11** MWH

No Lake Powell Water Alternative Primary Infrastructure

Table 1-2 Available Supplies and Projected Demands Under the No Lake Powell Water and Lake Powell Pipeline Project Alternatives		
	No Lake Powell Water Alternative	**Lake Powell Pipeline Project Alternative**
Existing Supplies	67,677	67,677
Planned Projects	13,670	13,670
Lake Powell Pipeline Project	0	82,249
RO Treatment of Virgin River and Reuse Water	57,883	0
Agricultural Conversion	0[1]	10,080
Reuse	17,100[2]	36,130
2060 Total Supply	156,330	209,806
2060 Total Demand	133,119[3]	185,285
Surplus in 2060	**23,211**	**24,521**

Notes:
[1]Agricultural conversion water included in RO treatment.
[2]19,030 acre-feet per year additional reuse included in RO treatment.
[3]Demand reduced 52,166 acre-feet per year from elimination of residential outdoor watering.

1.3.1.2.1 Re-Purposing Potable Water Use. The No Lake Powell Water Alternative would permanently eliminate residential outdoor potable water use in Washington County, re-purposing the portion of potable water used for residential outdoor watering to indoor potable use. Projections of future water use through 2060 account for population growth, climate change (projected 6 percent reduction of Virgin River flows by 2050 [Reclamation 2014]), and water conservation (35 percent reduction in per capita water use from 2000 to 2060). Potable water in Washington County is consumed for residential indoor and outdoor uses, commercial uses, institutional uses, and industrial uses. These potable water uses would total 130,245 acre-feet per year by 2052, the year the LPP Project water is anticipated to be fully utilized (UDWRe 2015). Gradually eliminating residential outdoor potable water use starting in 2025 would provide the growing population with potable water for indoor use through 2045; however, re-purposing residential outdoor potable water use to indoor use would not increase the water supply and would have to be accompanied by adding another water supply to meet the growing demand. Re-purposing residential outdoor potable water use to indoor potable use would require converting traditional residential outdoor landscapes and uses to either landscaping requiring no irrigation or desert landscapes compatible with the local climate. Residential water users would be responsible for converting their traditional outdoor landscapes to non-irrigated or desert landscapes. If no additional water supply was added in Washington County after 2025 and potable water use continued to meet residential indoor and outdoor purposes, then the projected population would completely utilize the potable water supply of 72,842 acre-feet per year by 2028.

1.3.1.2.2 Reverse Osmosis Water Treatment. Washington County's additional future water supply under the No Lake Powell Water Alternative would be dependent on two water sources: 1) Virgin River water diverted at the Washington Fields Diversion; and 2) reuse water from an expanded St. George Regional Water Reclamation Facility. WCWCD would develop a RO advanced water treatment facility near Washington Fields Diversion in Washington County, Utah. The RO facility would be designed to treat 50,000 acre-feet of de-silted water per year diverted from the Virgin River at Washington Fields Diversion. St. George Regional Wastewater Reclamation Facility would provide an additional 19,030 acre-feet of water per year to be treated at the RO facility. The RO wfacility would be necessary to remove the high concentrations of TDS present in both the Virgin River and the effluent from the St. George Regional Wastewater Reclamation Facility. The reuse facility has a current capacity of approximately 7,800 acre-feet per year, with a future design capacity of 11,760 acre-feet per year. An additional 7,830 acre-feet per year of future wastewater reclamation capacity would need to be added to meet the total reuse water requirement of 19,030 acre-feet per year for RO processing inflow. The RO process would separate the TDS from the water, resulting in two products: 1) a treated water product; and 2) a brine product

consisting of highly concentrated salts. A two-stage RO process would be applied to the brine solution to recover additional water and reduce the brine volume for enhanced evaporation. The RO-treated water product would be pH-adjusted to neutral pH, dosed with sodium silicate, mixed with conventionally-treated water from the Quail Creek Water Treatment Plant, and disinfected for distribution throughout the WCWCD service area. The RO advanced water treatment facility would process up to 64,313 acre-feet per year and produce up to 57,883 acre-feet per year of water suitable for M&I potable indoor use. The two-stage RO process would remove 90 percent of the TDS. The remaining 10 percent rejection (6,430 acre-feet per year) of brine by-product from the RO treatment process would require evaporation and disposal meeting State of Utah water quality regulations. The RO water treatment plant would process approximately 64,313 acre-feet per year of inflow water from Warner Valley Reservoir storage to meet the 2052 water demand under the No Lake Powell Water Alternative.

The RO water treatment plant processes would consist of pressurized, parallel ultra-filtration units, an influent storage tank with acid added to adjust the pH, pressurized cartridge filtration to remove additional particles from the water, high pressure pumping to pass the water through the parallel RO membrane units, a product water storage tank with saturated lime solution added to adjust the pH of the treated product water prior to disinfection and distribution as potable water, and brine storage tanks in series with the two-stage RO process units for further brine reduction. These water treatment processes would be housed in a water treatment building with electrical, mechanical, chemical storage and metering, heating/air conditioning/ventilation, and SCADA systems. A seven-mile long buried 54-inch diameter pipeline would convey the product water from a pump station at the RO water treatment plant to the Quail Creek Water Treatment Plant. The RO water treatment plant would add RO membrane units in phases as necessary to meet the growing water demand. The RO water treatment plant would be powered by electricity, requiring a 2.8-mile long 69-kV power transmission line from the proposed Purgatory Substation.

The concentrated brine product (6,430 acre-feet per year) would be pumped from the brine tanks through a pipeline to an evaporation apron, spray system and double-lined pond, and then pumped into spray headers over a series of double-lined ponds with leak detection and recovery systems. The enhanced evaporation ponds would be located south of Warner Valley Reservoir and would cover approximately 2,000 acres, developed in two phases. A buried brine conveyance pipeline approximately 4.4 miles long would convey the concentrated brine to the enhanced evaporation ponds. A 4.4-mile long 34.5-kV power transmission line would be extended from the RO water treatment plant to the enhanced evaporation ponds to provide electricity for the pumps spraying the brine solution. The brine solids would be evaporated for approximately 25 years in the Phase 1 ponds, and then dried, collected and disposed in an approved solid waste landfill. The Phase 2 enhanced evaporation ponds would be used during the following 25 years to continue evaporating the brine by-product. Additional infrastructure would be required as part of this alternative, including a de-silting facility, pump stations, pipelines, switch stations and substations, blending and storage tanks, and other associated earthwork.

1.3.1.2.3 Secondary Water Storage in Warner Valley Reservoir. WCWCD would develop the Warner Valley Reservoir to store diverted Virgin River water and reuse water from the St. George Regional Water Reclamation Facility, which would be delivered as inflow to the RO advanced water treatment facility. Warner Valley Reservoir would be located south-southwest of the Washington Fields Diversion. An earth-fill embankment with a clay core and rock-riprap facing would be constructed across the north entrance to the natural valley. The reservoir would have a maximum active storage volume of 69,030 acre-feet and would cover approximately 1,130 acres, including the earth-fill embankment. A large pump station would be constructed at the Washington Fields Diversion to pump the diverted Virgin River water into the Warner Valley Reservoir. The pump station would be powered by electricity via the 69-kV transmission line from the Purgatory Substation to the RO water treatment plant. The reservoir would store Virgin River water diverted at the Washington Fields Diversion (50,000 acre-feet per year) mixed with St. George Regional Water Reclamation Facility effluent (19,030 acre-feet per year), accounting for annual average evaporation (4,717 acre-feet per year), to produce up to 57,883 acre-feet of RO product water (assuming 90 percent recovery). The brine product from RO treatment would total approximately 6,430 acre-feet per year.

1.3.1.2.4 Water Distribution to Apple Valley. The largest remaining contiguous land area available for development in Washington County would be in Apple Valley. WCWCD would develop a pump station and 28-mile long pipeline to deliver 13,249 acre-feet per year of potable water from the Quail Creek Water Treatment Plant near Hurricane City to the Apple Valley area to meet future residential and commercial water demands.

1.3.2. KCWCD No Lake Powell Water Alternative

The KCWCD No Lake Powell Water Alternative would rely on existing water supplies, water conservation measures resulting in reduced water use, and future water development projects consisting of new groundwater production. Reliable water supplies (projected to be 2,170 acre-feet per year in 2035) for the area served by KCWCD (Kanab City and Johnson Canyon), adjusted for projected stream flow reductions (4.2 percent in 2035) resulting from climate change and a planning reserve (10 percent), would be exceeded by projected M&I water demands by 27 acre-feet per year within the KCWCD service area in 2035. KCWCD projected potable water demand in 2060 would be 3,435 acre-feet per year, with a potable water deficit of 1,334 acre-feet per year. Additional groundwater in the Kanab Creek drainage basin could be developed to provide up to 6,615 acre-feet per year of potable water within the aquifer's estimated safe yield. The quality of this water would likely require advanced water treatment. The developed groundwater from the Kanab Creek drainage basin would be pumped and conveyed through an eight-mile long pipeline to the Johnson Canyon drainage basin. The Johnson Canyon drainage basin comprises the potable water supply service area served by KCWCD in the area that could be served by the LPP Project.

1.4 Summary Description of the No Action Alternative

No new intake, water conveyance or hydroelectric features would be constructed or operated under the No Action Alternative. FERC would not issue a license for the LPP Project. The Utah Board of Water Resources' Colorado River water rights consisting of 86,249 acre-feet per year would not be diverted from Lake Powell and would continue to flow into the lake until the water is used for another State of Utah purpose.

1.4.1. WCWCD No Action Alternative

Under the No Action Alternative, WCWCD would complete the Ash Creek Project, planned groundwater development and continue to implement planned conservation programs. Wastewater reuse would be utilized to the maximum extent storage allows. Existing and future water supplies totaling 72,840 acre-feet per year potable and 8,505 acre-feet per year secondary would meet projected M&I water demand within the WCWCD service area through approximately 2028, exhausting all water planning reserves. Each supply source would be phased in to meet the M&I potable and secondary water demand associated with the forecasted population.

The No Action Alternative would not provide WCWCD with any reserve water supply (e.g., water to meet annual shortages because of drought, emergencies, and other losses). The No Action Alternative would not provide adequate water supply to meet projected water demands beyond 2028. There would be a projected water shortage of approximately 102,903 acre-feet per year in 2060 within the WCWCD service area under the No Action Alternative.

1.4.2. KCWCD No Action Alternative

KCWCD would use existing water supplies to meet potable water demands through 2035. Reliable water supplies are projected to be 2,101 acre-feet per year in 2060.

The No Action Alternative would not provide KCWCD with any reserve water supply (e.g., water to meet annual shortages because of drought, emergencies, and other losses). The No Action Alternative would not provide

adequate water supply to meet projected water demands beyond 2035. There would be a projected water shortage of approximately 1,334 acre-feet per year in 2060 within the KCWCD service area under the No Action Alternative.

1.5 Identified Issues

1.5.1. Purposes of Study

This technical report describes the results and findings of a preliminary geologic survey performed to evaluate conditions along the proposed alternative pipeline alignments of the LPP Project (Project). The purpose of the survey, as defined in the 2008 Geology and Soils Study Plan (UBWR 2008) prepared for the Federal Energy Regulatory Commission (FERC), was to identify potential impacts of geologic and soil conditions on the Project during construction and operation, document the potential influence of soil and geologic conditions on Project features, and identify measures to mitigate impacts of the geology and soils conditions.

The primary objectives of the geology and soils survey with regard to geology included elements intended to help provide information for pipeline design, as well as to determine the impacts of construction, operation, and maintenance of the Project on geologic resources and, conversely, the impact of geologic features on the Project. While these two needs included substantial overlap, they have been documented in separate reports. This report documents the components of the geology and soils survey that addressed the impacts of the Project on geologic resources, as well as the impact of geologic resources on the Project.

Additional studies were undertaken to evaluate impacts associated with groundwater resources and to evaluate engineering conditions at tunnels, shafts, and reservoirs. These are documented in separate reports.

1.5.2. Identified Issues

The geologic and soils issued identified in the Geology and Soils Study Plan for analyses include the following:

- Estimating fault locations and determination of fault activity
- Field survey for potential unidentified fault locations (minor faults, fault zone displacements, fault spurs, etc.)
- Determining known seismic activity – magnitude and acceleration
- Determining rates and magnitudes of past and probable future fault displacements at locations where the Project would cross faults where a risk of fault activity has been identified
- Identifying locations and types of soil and rock conditions subject to liquefaction
- Risk of liquefaction occurrence
- Identifying landslides, potentially unstable slopes, and related features
- Identifying locations along the alternative alignments where soil and/or rock conditions have been or may be conducive to subsidence, expansion, or collapse, including soluble rock and soil such as gypsum deposits and limestone with solution cavities, clay deposits, alluvial fans, and loess.
- Characterizing locations at risk of landslides, rock falls, debris flows, and other geologic hazards
- Characterizing the possible risks to Project features and to human safety associated with geologic hazards that could be affected by Project features
- Identifying potential effects of construction blasting on nearby rock and soil stability, buildings and other structures, natural gas or municipal pipelines, water wells, and other features

- Characterizing specific types of soils along alternative alignments
- Estimating engineering characteristics of soils at selected locations along alternative alignments
- Identifying rock engineering characteristics pertaining to excavation, tunneling, removal and disposal along alternative alignments
- Determining the presence of groundwater, at what levels and within what range of fluctuations within the alternative alignments
- Estimating groundwater inflow rates into excavations and tunnels
- Estimating soil and rock strength characteristics at the Lake Powell Intake and Hurricane Cliffs Hydropower Facilities
- Recommending mitigation measures for problems and hazards associated with geologic and soils features
- Identifying best methods and locations for reuse and/or disposal of waste rock and soil resulting from Project construction
- Identifying best methods and locations for obtaining rock and soil for Project construction
- Identifying mineral deposits within the pipeline alignments subject to mineral disposal rules under the requirements of 43 CFR 3600, and identify characteristics of mineral deposits required for permitting (free use or sale)

Issues associated with engineering requirements for construction of the pipeline, intake, shafts, and other features were addressed during the study but are not included in this report unless the results pertain directly to geology and soil resources impacts. A separate engineering report was prepared to facilitate engineering requirements and provide more extensive descriptions of general rock and soil characteristics. Groundwater resource impacts are presented in a separate resource technical report (MWH 2010).

1.6 Impact Topics

The following impact topics are addressed in the Geology and Soil Resources Study Report:

- Would fault movement damage the LPP or CVP pipelines, resulting in releases that would have a significant impact on geology and soils? If so, what impacts would occur?
- Would seismic activity create conditions that would damage the LPP or CVP pipelines, resulting in releases that would have a significant impact on geology and soils? If so, what impacts would occur?
- Are potentially unstable slopes found in the areas of impact of the LPP or CVP pipelines that would be at risk for failure (landslides, rockfalls, debris flows, or other geologic hazards) due to construction or operation of the pipelines? Would the failure cause risk to human life or the environment?
- Do conditions along the LPP or CVP pipelines present a significant risk of subsidence due to collapsible soils, dissolution of gypsum or other soluble rock or soil, or collapse of subsurface cavities that would damage the pipelines, resulting in releases that would have a significant impact on geology and soils? If so, what impacts would occur?
- Would construction or operation of the LPP or CVP pipelines result in conditions that would present a risk to human health or safety associated with geologic hazards? If so, what impacts would occur?
- Would construction activities, in particular but not limited to blasting, present a significant risk to important human structures, including but not limited to existing pipelines, buildings, wells, and major roads? If so, what impacts would occur?

- Is there a significant risk of pipeline, tunnel, shaft, or appurtenance failure due to rock and/or soil characteristics? If so, why, and what impacts would occur?
- Will excess or unsuitable excavated rock or soil occur during construction of the LPP or CVP pipelines? If so, which materials will be unsuitable, and how and where will the materials be disposed of? Will this have a significant impact on geology and soils?
- Will it be necessary to import rock or soil for pipeline and/or appurtenance construction? If so, from where will this material come, and will this have a significant impact on geology and soils?

Chapter 2
Methodology

2.1 General

Information was obtained and developed for this study by performing a review of relevant available reports and maps and by performing a field survey of geologic conditions along the alternative pipeline alignments. These activities are described hereafter.

2.2 Assumptions

The following assumptions were used in performing this study:

- Stable soil and rock conditions would continue to remain stable
- Dormant or inactive faults and fault zones (no activity in the past 10,000 years) would remain so for the lifetime of the Project
- No significant additional human development would occur in the pipeline right of way before construction of the pipeline and appurtenances
- Future development near the pipeline right of way and appurtenances will be subject to restrictions to prevent construction near blowoff valves and other active features and to allow unobstructed access for operations and maintenance
- Rock and soil for construction materials, primarily bedding for pipe and structures and backfill, will be derived from rock and soil excavated for construction
- Disposal of spoils will be allowed on-site by spreading of excess excavated materials in a thin layer across the pipeline right-of-way on both public and private land, as indicated for lands under its jurisdiction by U.S. Department of Interior, Bureau of Land Management (BLM) personnel during performance of this study
- Stream channels and washes that are dry most of the year flow as a direct result of specific precipitation events and/or snowmelt runoff and do not intercept groundwater
- All construction and operations/maintenance (O&M) activities would be performed using Best Management Practices (BMPs) to minimize or prevent slope instability or erosion caused by construction, operations, or maintenance of the pipeline and appurtenances
- All construction and O&M activities will comply with health and safety requirements of the Occupational Safety and Health Administration (OSHA)
- Project design will be performed using appropriate design parameters to minimize risks associated with fault displacement, seismic activity, expansive and collapsible soils, subsidence, compaction requirements, etc.
- Spoils and areas disturbed during construction will be covered with topsoil as available, and revegetated with an endemic plant seed mixture to stabilize surface particles and avoid erosion.

2.3 Data Used

The information that was reviewed for this study included the following maps and documents. The complete references are found in in the reference section at the end of this study report:

- Arizona Bureau of Mines (ABM). 1959. Geologic map of Mohave County, Arizona

- ABM. 1960. Geologic map of Coconino County, Arizona
- Fugro William Lettis and Associates (FWLA). 2009a. Geologic Characterization of Multiple Fault Crossings along the Proposed Lake Powell and Cedar Valley Pipelines, Hurricane Cliffs Hydropower Facility, Iron, Washington and Kane Counties, Utah and Mohave and Coconino Counties, Arizona
- FLWA. 2009b. Phase 1 Geologic Characterization and Hazard Investigation, Hurricane Cliffs Hydropower Facility, Washington County, Utah
- MWH Americas (MWH). 2009a. Lake Powell Pipeline Phase I – Preliminary Engineering and Environmental Studies, Task 5 – Develop and Analyze Alternatives, Technical Memorandum 5.11 - Geological, Geotechnical and Foundation Conditions
- MWH. 2009b. Lake Powell Pipeline Phase II – Preliminary Engineering and Environmental Studies, Task 6 – Conceptual Design Report
- MWH. 2009c. Lake Powell Pipeline Phase II – Preliminary Engineering and Environmental Studies, Task 6 – Conceptual Design Report, Appendix B – Special Crossings Details
- MWH. 2015. Groundwater Resources Technical Report.
- Natural Resources Conservation Service (NRCS). 1971. Soil survey of Washington County area, Utah
- NRCS. 1983. Soil survey of Coconino County area, Arizona, North Kaibab Part
- NRCS. 1996. Soil survey of Iron-Washington area, parts of Iron, Kane, and Washington Counties
- NRCS. 2003. Soil survey of Grand Staircase-Escalante National Monument area, parts of Kane and Garfield Counties, Utah
- NRCS. 2007a. Soil survey of Coconino County area, Arizona, north Kaibab part
- NRCS. 2007b. Soil survey of Grand Staircase-Escalante National Monument area, parts of Kane and Garfield Counties, Utah
- NRCS. 2007c. Soil survey of Iron-Washington area, parts of Iron, Kane, and Washington Counties
- NRCS. 2007d. Soil survey of Washington County area, Utah
- U.S. Geological Survey (USGS). 1963. Geology of the Lees Ferry area, Coconino County, Arizona: U.S. Geological Survey Bulletin 1137
- USGS. 2004a. Geologic map of the Kanab 30’ x 60’ quadrangle, Utah and Arizona: U.S. Geological Survey Geologic Investigations Series I-2655
- USGS. 2004b. Geologic map of the Pipe Spring National Monument and the western Kaibab-Paiute Reservation, Mohave County, Arizona: U.S. Geological Survey Scientific Investigations Map 2863
- USGS. 2009. Hazard Mapping Images and Data: USGS National Seismic Hazard Maps, Data, and Documentation.
- USGS. 2013. National Elevation Dataset 10m data.
- Utah Geological and Mineral Survey (UGMS). 1989. Geology of Kane County, Utah – Geologic Hazard Map. Bulletin 124
- Utah Geological Survey (UGS). 1995a. Geologic map of the Hildale quadrangle, Washington and Kane Counties, Utah and Mojave County, Arizona: Utah Geological Survey Map 167
- UGS. 1995b. Geologic map of the New Harmony Quadrangle, Washington County, Utah: Utah Geological Survey Miscellaneous Publications 95-2

- UGS. 1999. Digital geologic map of the Kanab 30’ x 60’ quadrangle, Kane and Washington Counties, Utah and Coconino County, Arizona: Utah Geological Survey Open-File Report 366
- UGS. 2001. Geologic map of the Smithsonian Butte quadrangle, Washington County, Utah: Utah Geological Survey Miscellaneous Publication 01-1
- UGS. 2003a. Geologic map of the Harrisburg Junction 7.5’ quadrangle, Washington County, Utah: Utah Geological Survey Map 191
- UGS. 2003b. Geologic map of the Hurricane 7.5’ quadrangle, Washington County, Utah: Utah Geological Survey Map 187
- UGS. 2003c. Geologic map of the Pintura quadrangle, Washington County, Utah: Utah Geological Survey Map 196
- UGS. 2004a. Geologic Map of the Divide quadrangle, Washington County, Utah: Utah Geological Survey Map 197
- UGS. 2004b. Geologic Map of the Little Creek Mountain quadrangle, Washington County, Utah: Utah Geological Survey Map 204
- UGS. 2005. Geologic Map of the Washington Dome Quadrangle, Washington County, Utah: Utah Geological Survey Map 209
- UGS. 2006a. Geologic Map of the Smoky Mountain 30’ x 60’ quadrangle, Kane and San Juan Counties, Utah, and Coconino County, Arizona: Utah Geological Survey Map 213
- UGS. 2007. Interim Geologic Map of the St. George 30’ x 60’ Quadrangle and the east part of the Clover Mountain 30’ x 60’ Quadrangle, Washington and Iron Counties, Utah: Utah Geological Survey Open-File Report 478
- UGS. 2008a. Collapsible-Soil-Susceptibility Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 7
- UGS. 2008b. Expansive-Soil-and Rock-Susceptibility Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 6
- UGS. 2008c. Gypsiferous-Soil-and Rock-Susceptibility Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 8
- UGS. 2008d. Landslide-Hazard Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 4
- UGS. 2008e. Shallow-Bedrock-Susceptibility Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 10
- UGS. 2008f. Surface-Fault-Rupture-Hazard Map for the St. George-Hurricane Metropolitan Area. Special Study 127, Plate 1
- Washington County Water Conservancy District (WCWCD). 2005. Geology along the route of the Lake Powell water pipeline, Utah and Arizona: Washington County Water Conservancy District Report WCWCD-02.

2.4 Impact Analysis Methodology

2.4.1. Fault Movement Impacts

Faults were identified as part of the field survey. Major faults were evaluated for hazard potential by Fugro William Lettis and Associates (FWLA). Their findings are incorporated into this report. A report of FWLA's findings is included as Appendix A.

2.4.2. Seismic Activity Impacts

The hazards associated with seismic activity were evaluated by identifying locations where the potential for a large-magnitude earthquake could occur in vicinity of the pipeline alignments using seismic hazard maps prepared by the U.S. Geological Survey (USGS 2014). Specifically, locations where the pipeline alignments were within zones of high probability of Peak Ground Acceleration (PGA) were identified with a two-percent probability of exceedance within 50 years. Locations were identified where liquefaction risk is high, i.e. pipeline or facilities in sandy, saturated soils and within zones of high PGA potential within the two-percent probability of exceedance over a 50-year period. These risks were assessed by comparing pipeline alignments with USGS earthquake hazard maps, as well as NRCS soils maps and field descriptions of soils, and by identifying locations where shallow soils would most likely be saturated. Locations along the alignments with high likelihoods of saturation were identified from the Groundwater Resources Technical Report (MWH 2016).

2.4.3. Unstable Slope Impacts

Geologic hazards were identified where possible during the field survey. Potential hazards include unstable slopes, rockfall, and landslides. Potential hazard indicators on the ground surface have been documented in this field survey. During the field survey, the geologic units mapped by the USGS and others were verified at outcrops along the alignment. In general the mapped units correlated with the rock observed in the field. Rock characteristics were described using the Classification of Rocks and Description of Physical Properties system found in the U.S. Bureau of Reclamation's Engineering Geology Field Manual (USBR 1998). The properties identified included the formation name, lithologic description, hardness, weathering, alteration, strength, color, texture, bedding orientation, discontinuities (faults, joints, sheering, etc.), and a summary description. Where feasible and applicable, rock-mass field characterization was performed using the Geologic Strength Index (Hoek et al. 1998).

2.4.4. Subsidence, Expansion, or Collapsible Soils Impacts

During the field survey, the soil types encountered in the field were compared to the available mapped soil descriptions. The mapped soil descriptions were based on the National Cooperative Soil Survey, operated by the Natural Resource Conservation Service (NRCS). Field soil descriptions were prepared using the Unified Soil Classification System (USCS) method (ASTM 2000, 2006) and are consistent with the U.S. Bureau of Reclamation's Engineering Geology Field Manual. Soil characteristics, including grain size and distribution, color, plasticity, toughness, consistency, angularity, cementation, and dilatancy were estimated and recorded. Characterization occurred along each alignment at major changes in soil or rock types and at important pipeline feature locations, such as pump stations and surge tanks.

Potential hazards identified during characterization of rock and soil included expansive rock and soil, collapsible soils, and subsidence caused by dissolution of minerals (most notably gypsum) or by overpumping of groundwater. There are some indicators that can be identified in the field for expansive and collapsible soils, but the presence of a hazard at the pipeline foundation level is only identifiable with drilling or trenching. In the case of this survey, potential hazard indicators on the ground surface have been documented. The characteristics for

potential subsidence, including the presence of gypsum and soil fissures, were noted if observed. The characteristics of potentially expansive soils, primarily the presence of plastic clays and desiccated soils, also were observed and recorded. Potentially collapsible soils were identified where loosely compacted deposits were observed, most probably occurring in alluvial fans or windblown deposits such as loess.

2.4.5. Geologic Hazards to Human Health and Safety Impacts

Locations where loose rock on steep slopes overlying the alignment and unstable slopes that could be affected by pipeline trench excavation or blasting, were noted.

Infiltration of groundwater into trenches, tunnels and shafts during construction were assumed to occur at perennial stream crossings, and in tunnels and shafts below likely groundwater elevations. Infiltration rate estimates at the Intake System were developed using pump test data collected from exploration core holes. Infiltration rates into trenches near perennial streams were estimated using standard methods (Anderson 1998) and simplifying assumptions.

2.4.6. Impacts on Important Structures or Mineral Resources

The presence of buildings and other structures (such as wells and underground utilities) may be impacted by pipeline construction. The locations of structures within approximately 1,000 feet of each alignment were recorded where possible during the field survey. Common features that are unlikely to be disrupted by pipeline construction or operation, such as roads and telephone poles were not recorded unless they were determined to lie directly within the trench path. Road crossings were not noted because these would be repaired as necessary.

The nature and locations of mineral resources, including gravel pits and stone quarries, were noted and recorded if they were within approximately 1,000 feet of the alignments.

Sites of proposed major tunnel and shaft excavations were noted and the types of rock were observed from field observations and geologic reports and maps, and from exploration coring at the Intake System (MWH 2009d and 2011), Hurricane Cliffs and Sand Hollow Tunnel sites (RB&G 2010) (See Appendix B). The Bureau of Land Management did not allow collection of subsurface geological data from federal lands they administer except in the vicinity of the Hurricane Cliffs. Rock strength characteristics were evaluated from core samples collected at the Intake Pump Station (IPS) site, at the Hurricane Cliffs site, and in the vicinity of the Sand Hollow Tunnel.

2.4.7. Borrow and Spoil Impacts

It is assumed that all construction material will be derived from excavation associated with construction earthwork, and that spoils will be spread across the Pipeline and Penstock right-of-way (ROW). Under this scenario, borrow sites will not be required for construction material, and spoil will not be placed in spoil placement areas.

Chapter 3
Affected Environment (Baseline Conditions)

3.1 Area of Potential Effect

3.1.1. Regional Geology

Based on characteristic landforms, North America has been divided into areas called physiographic provinces, with substantial transition zones (zones at boundaries that share characteristics of the adjoining provinces) occurring in some places. The proposed LPP Project alignment alternatives extend from Lake Powell (near Page, Arizona) to St. George, Utah. The LPP Project alignments are planned to be constructed through two physiographic provinces: approximately 78 percent of the pipeline is proposed to be located in the Colorado Plateau Province and the remaining 22 percent is proposed to be located in the transition zone between the Colorado Plateau and the Basin and Range provinces. For a more detailed description of the regional geology of this area, see TM 5.11 Geological, Geotechnical, and Foundation Conditions (MWH 2009a).

The Colorado Plateau province is generally characterized by a thick sequence of largely undeformed, nearly flat-lying sedimentary rocks. The Colorado Plateau is occasionally interrupted by large-scale northerly-trending structural uplifts or basins (folds). The limbs of some of these folds are locally steep (40 degrees to vertical) but relatively narrow (a few miles). The narrow folds are typically monoclines, characterized by all rocks dipping steeply in one direction, and then flattening out east and west on either side. In general, the monocline folds have resulted from the propagation of deep basement reverse faults that offset deep rock units and deform the overlying sedimentary layers. Active faults in the Colorado Plateau are relatively rare at the surface although they are abundant at depth in older rocks, as exposed in the Grand Canyon part of the Colorado Plateau and specifically at the Cockscomb and the Sevier fault near the Coral Pink Sand Dunes State Park.

The boundary between the Colorado Plateau and the Great Basin is not a single line but instead is a zone up to 62 miles wide, known as a transition zone, in which faults become more abundant and larger farther to the west. The transition zone extends from the Hurricane fault zone at the town of Hurricane westward 30 to 50 miles to the Gunlock fault zone at Gunlock State Park, Utah. The Colorado Plateau proper is generally considered to lie east of the Hurricane Cliffs and the Great Basin proper lies west of Gunlock. The LPP Project is proposed to enter and cross into this transition zone at the proposed Hurricane Cliffs Hydropower (HCH) facility.

3.1.2. Area of Potential Effect

The area of potential effect for Geology and Soil Resources includes a corridor encompassing both sides of each of the alignments identified and described in Sections 1.2.1 (South Alternative), 1.2.2 (Existing Highway Alternative), and 1.2.3 (Southeast Corner Alternative). The corridor extended 200 feet on either side of each alternative alignment, and 1,000 feet on each side of each alignment for evaluating potential impacts on important structures and mineral resources to allow for the possible effects of blasting or limited access during construction.

For all action alternatives, the Transmission Line Alternatives described in Section 1.2.3 would include the following activities that would affected geology and soil resources:

- Auguring for placement of poles
- Construction of foundations for towers
- Improvement of existing roads for access

Auguring for placement of holes is a localized activity that will disturb and permanently displace a small area at each pole location. Construction of tower foundations will disturb and permanently displace a slightly larger area for each foundation. Existing roads will be used for construction and maintenance access, including public highways, gravel roads, and dirt roads. Some roads, primarily "two-track" dirt roads or gravel roads in poor condition, will be improved by adding crushed rock where needed for stability or by widening to 10 feet where too narrow for safe operation. These represent both construction impacts and operation effects. The Transmission Line Alternatives were not included in the Geology and Soil Resources Study Report because these alternatives would have a negligible effect on geology and soils resources.

3.2 Overview of Baseline Conditions along Lake Powell Pipeline

3.2.1. Fault Movement

The fault crossings evaluated by FWLA for the LPP Project section of the pipeline are summarized in Table 3-1. Figures showing the locations of the crossings relative to the pipeline are included in the FWLA report (FWLA 2009a; 2009b) (See Appendix A). The fault crossings evaluated to be of potentially high relevance for the LPP Project section of the pipeline were the Sevier fault, the Hurricane fault, and the West Grass Valley fault. The Sevier fault crosses the Highway, South and Southeast Corner alternatives of the LPP Project. The Sevier fault hazard was designated as potentially high relevance by FWLA based on evidence of displacement and the presence of a 3- to 4-foot scarp just south of the Highway alternative alignment and the displacement of 5-6 feet of alluvium near the South Alternative. The Hurricane Fault is crossed by the LPP Project Hydro alignment common to all alternatives. It is designated as potentially high relevance due to its potential for generating high-magnitude earthquakes, recent movement and relatively high recurrence intervals. The West Grass Valley fault hazard was designated as potentially high relevance based on displacement of the Grass Valley Basalt and the potential for reactivation of the fault because of its proximity to the main trace of the Hurricane fault. These fault crossings are not located near populated areas, decreasing the potential risk of impacts associated with a pipeline rupture.

3.2.2. Seismic Activity

Review of USGS seismic hazard maps shows that the LPP Project alternatives lie within zones of low to moderate potential seismic activity (0.1 to 0.4 gravity Peak Ground Acceleration) with a two-percent probability of exceedance over a 50-year period.

3.2.3. Unstable Slopes

Rocks along the LPP Project alternatives alignments are primarily sedimentary but include some basalt. Sedimentary rocks include sandstone, siltstone, limestone, shale, and evaporites. Sandstone from the Navajo, Entrada, Page, and Carmel formations is the most common rock type in the eastern part of the LPP Project alternatives whereas siltstone, limestone, shale, and other sedimentary rocks of the Moenkopi, Chinle, and Kaibab formations are more common further westward. Navajo Sandstone re-appears west of the Hurricane Fault Zone due to westward downthrown displacement. Basalt outcrops are present primarily near the end of the LPP Project alternatives and in the section from the bottom of the Hurricane Cliffs to Sand Hollow Reservoir.

The rock characteristics observed in the field were compared to existing geologic maps. The rock characteristics observed during the field survey are included in Table 3-2. The locations of survey points are shown on Figures 3-1 and 3-2.

Potential geologic hazards exist along the proposed LPP Project alternatives. During the field survey, where potential hazard indicators were observed, the area was noted. Upon completing the field survey, the data was

extrapolated between survey points using the geologic maps, soil maps and, where available (Washington and Kane Counties, Utah), existing hazard maps. The hazards were separated into ‘rock’ and ‘soil’ categories.

Table 3-1
Lake Powell Pipeline Fault Intersection Assessment

Fault Name	Alignment	Station Range	Rupture Assessment	Urban development	Preliminary Impact Risk	Remarks
Glen Canyon City fault	HWY	820 + 00	Not significant	No	Low	
East Kaibab fault – Cockscomb	HWY	1729 + 20	Not significant	No	Low	
Central Kaibab fault	HWY	2270 + 00	Low significance	No	Low	
West Kaibab fault	HWY	2570 + 00 and 2579 + 00	Low significance	No	Low	Fault locations inferred
Paunsaugunt fault	HWY	2950 + 00	Low significance	Yes	Low	Fault locations inferred
	South	3030+00 to 3060+00	Low significance	No	Low	Fault locations inferred
Johnson Canyon fault	HWY	3250 + 00 to 3300 + 00	Not significant	No	Low	
	South	3360 + 00	Not significant	No	Low	
Quikwater fault	South	4300 + 00	Not significant	No	Low	
Sevier fault (N. Toroweap)	HWY	4704 + 10	High significance	No	Low	
	South	4985 + 35	High significance	No	Low	
Short Creek fault	HWY	5920 + 00 to 5940 + 00	Not significant	No	Low	
Hurricane fault	LPP Hydro	7192+00	High significance	Yes	Moderate	
West Grass Valley fault	LPP Hydro	44+00	High significance	No	Low	Avoids community
Remnants Basalt faults	LPP Hydro	76 + 00	Not significant	No	Low	
	LPP Hydro	110 + 00	Not significant	No	Low	
Western Sand Mountain fault	LPP Hydro	200 + 00	Not significant	No	Low	

Table 3-2
Field Survey of Rock Characteristics

Station	Northing	Easting	Symbol	Formation	Lithology	Hardness	Unconfined Compressive Strength (psi)	Weathering	Alteration	Strength	Color	Texture
Water Conveyance System												
4+00	4088436.3N	456406.9E	Jn	Navajo Sandstone	sandstone	H/MH	7,250-14,500/ 1,810-7,250	M	SA	S/MS	red, pink, white	MG
45+00	4088382.4N	455423.4E	Jn	Navajo Sandstone	sandstone	H/MH	7,250-14,500/ 1,810-7,250	M	SA	S/MS	red, pink, white	MG
50+00	4088538.9N	455464.5E	Jn/Jc Contact	Carmel Formation	dark brown weathered shale	M/S	725-1,810/ 180-725	MS	MA	MS/W	white, tan, maroon	A/FG
50+00	4088538.9N	455464.5E	Jn/Jc Contact	Navajo Sandstone	red sandstone	H/MH	7,250-14,500/ 1,810-7,250	M	SA	S/MS	red, pink, white	MG
85+00	4089350.3N	454931.6E	Jc	Carmel Formation	dark red/ brown sandstone	M/S	725-1,810/ 180-725	MS	MA	MS/W	white, tan, maroon	A/FG
200+00	4092583.3N	453610.5E	Je	Entrada Sandstone	cross-bedded sandstone	MH	1,810-7,250	M	SA	MS	gray, tan, white	FG
880+00	4104734.9N	438028.4E	Jpt	Thousand Pockets Tongue of the Page Sandstone	cross-bedded, poorly cemented sandstone	MH/M	1,810-7,250/ 725-1810	M	SA	MS	tan, gray, pink	CG
1170+00	4106278.5N	429298.5E	Jcu	Upper Unit, Carmel	sandstone over weathered limestone, maroon banding	M/S	725-1,810/ 180-725	MS	MA	MS/W	white, tan, maroon	A/FG
1390+00	4106438.4N	423109.2E	Jcu	Upper Unit, Carmel	sandstone over weathered limestone, maroon banding	M/S	725-1,810/ 180-725	MS	MA	MS/W	white, tan, maroon	A/FG
1685+00	4109475.4N	414797.6E	Jcu/Je contact	Upper Unit, Carmel	weathered shale	M/S	725-1,810/ 180-725	MS	MA	MS/W	white, tan, maroon	A/FG
1685+00	4109475.4N	414797.6E	Jcu/Je contact	Entrada Sandstone	sandstone	MH	1,810-7,250	M	SA	MS	gray, tan, white	FG
1710+00	4109330.3N	414137.5E	Jn	Navajo Sandstone	massive eolian sandstone	H/MH	7,250-14,500/ 1,810-7,250	M	SA	S/MS	red, pink, white	MG
1745+00	4109133.5N	413217.0E	Jmo	Moenave Sandstone		MH	1,810-7,250	M	SA	S/MS	red, brown, white	FG
1770+00	4109988.9N	413240.5E	TRml/Pk contact	Lower Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
1770+00	4109988.9N	413240.5E	TRml/Pk contact	Kaibab	limestone	VH	14,500-36,250	M	MA	VS	tan, gray	MG
1905+00	4113985.8N	413682.5E	TRmm	Middle Red Member, Moenkopi	sandstone/ siltstone	S/VS	180-725/ 90-180	VS	MA/HA	W/VW	red, brown, gray, white, green	FG
1935+00 BPS-4 (Alt.)	4114806.4N	413463.3E	TRml/TRmt contact	Lower Red Member, Moenkopi	red sandstone/ shale	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG

Table 3-2
Field Survey of Rock Characteristics

Station	Northing	Easting	Symbol	Formation	Lithology	Hardness	Unconfined Compressive	Weathering	Alteration	Strength	Color	Texture
Water Conveyance System (cont.)												
1935+00 BPS-4 (Alt.)	4114806.4N	413463.3E	TRml/TRmt contact	Timpoweap Member, Moenkopi	yellow limestone	VH	14,500-36,250	F/VS	F	ES	tan, yellow, brown	FG
1980+00	4115691.4N	412914.2E	TRmt	Timpoweap Member, Moenkopi	limestone	H	7,250-14,500	S/M	SA/MA	VS	tan, gray	FG
2059+00	4115183.8N	410520.4E	TRml	Lower Red Member, Moenkopi	angular, platy, broken red shale	S/VS	180-725/ 90-180	VS	CA	W/VW	red, brown, white, green	A
2060+00	4115140.4N	410453.6E	TRmt	Timpoweap member, Moenkopi	limestone/ sandstone	H	7,250-14,500	S/M	SA/MA	VS	tan, gray	FG
2270+00	4111654.2N	405237.7E	TRmt	Timpoweap Member, Moenkopi	limestone/ sandstone	H	7,250-14,500	S/M	SA/MA	VS	tan, gray	FG
2350+00	4109960.8N	403387.7E	TRmt	Timpoweap Member, Moenkopi	massive dolomite	H	7,250-14,500	M/MS	SA	S	tan	A/FG
2400+00	4108881.9N	402026.2E	TRml	Lower Red Member, Moenkopi	thin platy sandstone with some shale	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
2566+30	4105766N	398917E	TRml/TRmm contact	Middle Red Member, Moenkopi	siltstone	S	90-180	VS	MA	W/VW	red, brown	FG
2674+20 HPRT-2	4102952N	397331E	TRmm	Middle Red Member, Moenkopi	siltstone	S	90-180	VS	MA	W/VW	red, brown	FG
2915+40	4099966N	391090E	TRmm	Middle Red Member, Moenkopi	siltstone	S	90-180	VS	MA	W/VW	red, brown	FG
Hydro System												
2736+60 HS-1	4101494N	396146E	TRmm	Middle Red Member, Moenkopi	siltstone	S	90-180	VS	MA	W/VW	red, brown	FG
2800+80	4100625N	394468E	TRmm	Middle Red Member, Moenkopi	siltstone	S	90-180	VS	MA	W/VW	red, brown	FG
5950+00	4093084.5N	324388.0E	JTRm	Moenave Sandstone	sandstone/ siltstone	MH	1,810-7,250	M	SA	S/MS	red, brown, white	FG
6270+00	4096842.1N	317795.3E	TRcs	Shinarump Member, Chinle	sandstone and conglomerate	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
6970+00	4100838.7N	297842.5E	TRmv	Virgin Limestone	limestone boulders	H/MH	7,250-14,500/ 1,810-7,250	VS/S	SA	S	white, gray, tan, green	FG
6990+00	4101331.4N	297731.9E	Qa	Alluvium	large boulders	NA		NA	NA	NA	NA	NA
7030+00	4102429.5N	297892.5E	TRmv/TRml contact	Virgin Limestone	limestone	H/MH	7,250-14,500/ 1,810-7,250	VS/S	SA	S	white, gray, tan, green	FG
7030+00	4102429.5N	297892.5E	TRmv/TRml contact	Lower Red Member, Moenkopi	red shale and sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG

Table 3-2
Field Survey of Rock Characteristics

Station	Northing	Easting	Symbol	Formation	Lithology	Hardness	Unconfined Compressive Strength (psi)	Weathering	Alteration	Strength	Color	Texture
Hydro System-Existing Highway Alternative												
3670+00	4096916.5N	367886.3E	TRcs	Shinarump Member, Chinle	sandstone/ conglomerate	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
3685+00	4096532.3N	367859.7E	TRcs	Shinarump Member, Chinle	sandstone/ conglomerate	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
3750+00	4094829.5N	367280.7e	TRm	Lower or Middle Red Member, Moenkopi	sandstone and shale	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
4200+00	4086685.0N	359216.7E	TRmm	Middle Red Member, Moenkopi	weathered shale	S/VS	180-725/ 90-180	VS	MA/HA	W/VW	red, brown, gray, white, green	FG
5110+00	4082753.1N	332822.3E	TRcp	Petrified Forest Member, Chinle	claystone/ siltstone with gypsum	M/S	725-1,810/ 180-725	VS	HA	W	red, purple, tan	A/FG
Hydro System-Proposed Action												
3000+00	4099328.2N	388045.3E	TRcs	Shinarump Member, Chinle	med to coarse grained sandstone with conglomerate layer	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
3010+00	4099306.8N	388268.3E	TRcs/TRmu contact	Shinarump Member, Chinle	sandstone and conglomerate	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
3010+00	4099306.8N	388268.3E	TRcs/TRmu contact	Upper Red Member, Moenkopi	red shale	S/VS	180-725/ 90-180	VS	MA/HA	W/VW	red, brown, gray, white, green	FG
3552+00	4088851.4N	377181.9E	TRm	Lower or Middle Red Member, Moenkopi	hard sandstone and some platy siltstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
3755+00	4085999.5N	372353.0E	TRm	Lower or Middle Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
3880+00	4083471.9N	369665.4E	TRm	Lower or Middle Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
4005+00	4081417.2N	367931.5E	TRmt/PK	Timpoweap Member, Moenkopi or Kaibab	limestone	VH	14,500-36,250	M	MA	VS	tan, gray	MG
4060+00	4079350.1N	365921.2E	TRmt/TRmt/Pkh	Virgin Limestone, Timpoweap, or Harrisburg Member, Kaibab	massive gray limestone with chert nodules	VH	14,500-36,250	M	MA	VS	tan, gray	MG
4150+00	4077276.4N	365367.0E	TRmt/Pk	Timpoweap Member, Moenkopi or Kaibab	limestone	VH	14,500-36,250	M	MA	VS	tan, gray	MG
4180+00	4077021.0N	364591.1E	Pkh	Harrisburg Member, Kaibab	limestone/ sandstone	M	725-1,810	M	SA	MS	tan	FG
4190+00	4077113.7N	364364.7E	Pk	Kaibab	sandstone/ limestone	M	725-1,810	M	SA	MS	tan	FG

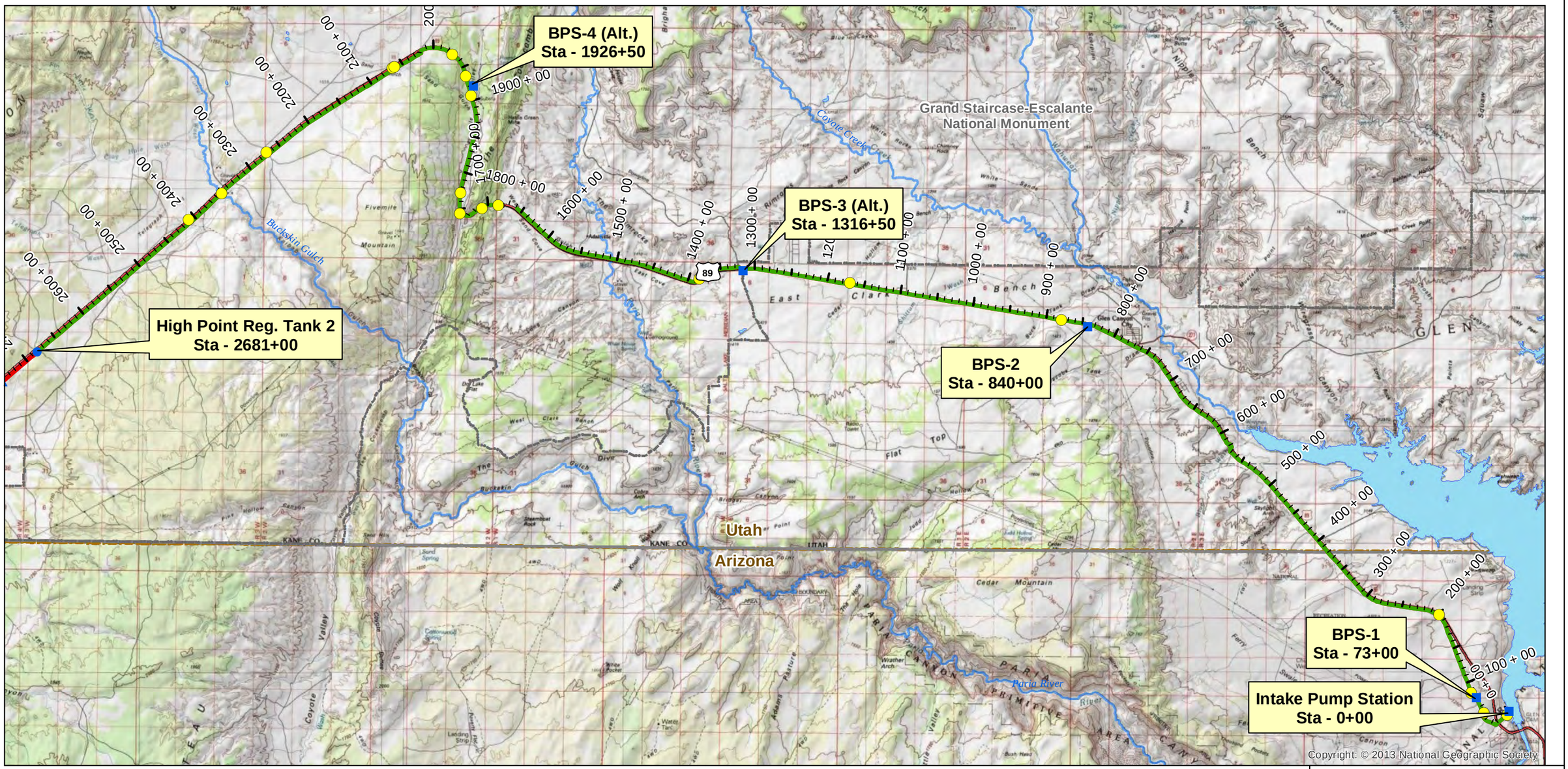
Table 3-2
Field Survey of Rock Characteristics

Station	Northing	Easting	Symbol	Formation	Lithology	Hardness	Unconfined Compressive	Weathering	Alteration	Strength	Color	Texture
Hydro System-Proposed Action (Cont.)												
4200+00	4077304.7N	363905.7E	Pk	Kaibab	red and yellow limestone/ sandstone	M	725-1,810	M	SA	MS	tan	FG
4250+00	4077316.2N	362648.4E	Pk	Kaibab	linestone outcrop	M	725-1,810	M	SA	MS	tan	FG
4275+00	4077348.2N	361248.5E	Pkh	Harrisburg Member, Kaibab	limestone/ dolomite	M	725-1,810	M	SA	MS	tan	FG
4418+00	4076828.0N	357564.7E	Pk	Kaibab	limestone	M	725-1,810	M	SA	MS	tan	FG
4420+00	4076890.8N	357558.9E	Pkh	Harrisburg Member, Kaibab	cherty, fossiliferous limestone, weathered, blocky	M	725-1,810	M	SA	MS	tan	FG
4440+00	4076753.0N	357120.3E	TRml	Lower Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
4602+00	4075023.2N	352695.2E	Pk	Kaibab	rockfall hazard	M	725-1,810	M	SA	MS	tan	FG
4608+00	4074951.6N	352567.7E	Pk	Harrisburg Member or Fossil Mountain Member, Kaibab	cherty, fossiliferous limestone, weathered, blocky	M	725-1,810	M	SA	MS	tan	FG
4610+00	4074647.9N	352525.5E	TRml over Pkh	Lower Red Member, Moenkopi	red sandstone	H/MH	7,250-14,500/ 1,810-7,250	S/M	SA	S	light red	CG
4610+00	4074647.9N	352525.5E	TRml over Pkh	Harrisburg Member, Kaibab	massive limestone	VH	14,500-36,250	M	MA	VS	tan, gray	MG
4680+00	4074279.1N	350329.9E	TRml	Lower Red Member, Moenkopi	thin platy sandstone	H/MH	7,250-14,500/ 1,810-7,250	S/M	SA	S	light red	CG
5155+00	4075466.2N	336076.4E	TRcs over TRmu	Shinarump Member, Chinle	sandstone and conglomerate	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
5155+00	4075466.2N	336076.4E	TRcs over TRmu	Upper Red Member, Moenkopi	red shale	S/VS	182-725/ 90-180	VS	MA/HA	W/VW	red, brown, gray, white, green	FG
5170+00	4075549.3N	335216.8E	TRcs	Shinarump Member, Chinle	coarse grained sandstone	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
5170+00	4075719.8N	335269.5E	TRcs	Shinarump Member, Chinle	medium grained sandstone	MH	1,810-7,250	M	F/SA	VS/S	tan, yellow, gray	MG/CG
Hydro System-Southeast Corner Alignment Alternative												
4100+00	4078902.9N	364032.8E	TRml	Lower Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
4130+00	4078888.3N	363628.8E	TRml	Lower Red Member, Moenkopi	red sandstone with white/ yellow weathered surface	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG

Table 3-2
Field Survey of Rock Characteristics

Station	Northing	Easting	Symbol	Formation	Lithology	Hardness	Unconfined Compressive Strength (psi)	Weathering	Alteration	Strength	Color	Texture
Hydro System-Southeast Corner Alignment Alternative												
4160+00	4078270.3N	362765.1E	TRml	Lower Red Member, Moenkopi	red sandstone	VH/H	14,500-36,250/ 7,250-14,500	MS	SA	VS/S	tan, brown, red	FG/MG/CG
4200+00	4077719.2N	361312.3E	Pkh	Harrisburg Member, Kaibab	limestone/ dolomite	M	725-1,810	M	SA	MS	tan	FG
Hurricane Cliffs Pump Storage Forebay and Afterbay, and Sand Hollow Peaking Alignment Section of Hydro System												
N Forebay Embankment	4104247.8N	296489.2E	Qb	Basalt	basalt boulders	VH	14,500-36,250	S	SA	VS	black, cream	A
Between Forebay and Afterbay	4104765.5N	296169.9E	Pk/TRmt	Kaibab Limestone/ Timpoweap	massive limestone	H	7,250-14,500	S	MA	ES	tan	FG
Hurricane Cliffs	4104808.6N	295824.5E	Pk	Kaibab	massive, cherty, fossiliferous limestone	VH	14,500-36,250	M	MA	VS	tan, gray	MG
40+00 N of Afterbay	4106914.1N	294554.3E	Qb	Basalt	basalt flow	VH	14,500-36,250	S	SA	VS	black, cream	A
Sand Hollow Pump Storage Alignment Section of Hydro System												
41+80	4104099N	292795E	Qb/Jn	Basalt/Navajo Sandstone	basalt boulders overlying sandstone and sand	VH/MH	100-14,500/ 1,810-7,250	F/M	F/MA	VS/MS	black, dark gray /red, pink	A/MG
84+80	4105213N	292285E	Qb	Basalt	basalt boulders in sand	VH	14,500-36,250	VS	F	VS	dark gray	A
90+80	4105392N	292250E	Qb	Basalt	basalt boulders (E. of alignment)	VH	14,500-36,250	F	F	VS	black	A
195+90	4108056	290736	Jn	Navajo Sandstone	sandstone outcrop in gulley, overlain by sand	M	725-1,810	MS	SA	MS	red, pink	MG

Notes. Hardness: VH=Very Hard, H=Hard, MH=Medium Hard, M=Medium, S=Soft, VS=Very Soft. Weathering: F=Fresh, VS=Very Slight, S=Slight, M=Moderate, MS=Moderately Severe. Alteration: F=Fresh, SA=Slight Alteration, MA=Medium Alteration, HA=High Alteration, CA=Complete Alteration. Strength: ES=Extremely Strong, VS=Very Strong, S=Strong, MS=Medium Strong, W=Weak, VW=Very Weak. Texture: CG=Coarse Grained, MG=Medium Grained, FG=Fine Grained, A=Amorphous. General: NA=Not Applicable.



Rock Characteristics Points
Project Pump Station
Project Regulating Tank
Project Hydro Station
Water Conveyance System
Hydro System - South Alignment Alternative

Interstate
US Highway
ST Highway
Hwy
Major Road

Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

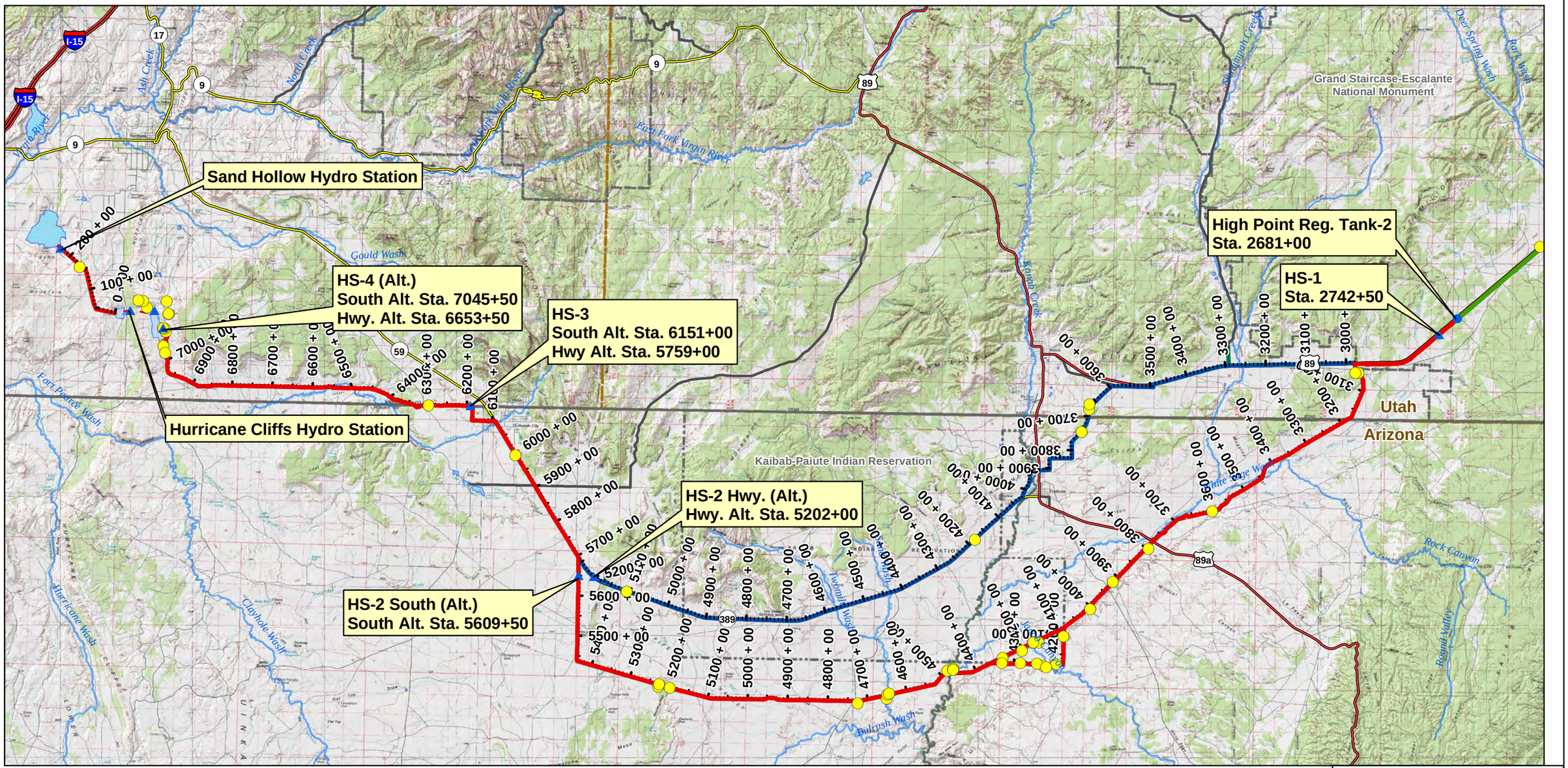
0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-1** MWH

Lake Powell Pipeline
Rock Characteristics Points
Water Conveyance System



- Rock Characteristics Points
- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Water Conveyance System
- Hydro System - South Alignment Alternative
- Hydro System - Highway Alignment Alternative
- Hurricane Cliffs Forebay/Afterbay
- Lakes & Reservoirs
- Major Rivers & Streams
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- National Park/Monument
- Tribal Lands
- State Boundaries
- County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 1.25 2.5 5 7.5 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-2** MWH

Lake Powell Pipeline
Rock Characteristics Points
Hydro System

The geology and/or rock hazards are shown on Figures 3-3 and 3-4, and include the presence of gypsum in rock, expansive clay bedrock, rockfall, landslides, unstable slopes and steeply dipping bedrock. Areas where geologic hazards were not identified in the field were designated as low risk. However, as-yet unidentified rock hazards may still be present. Rock hazards have been broken up into segments where they are likely to exist along the alignment, and are shown in Tables 3-3 through 3-6 below.

Table 3-3
Lake Powell Pipeline Water Conveyance System Rock Hazards

From Station:	To Station:	Description
50+00 WCS	100+00 WCS	possible gypsum
570+00 WCS	580+00 WCS	rockfall hazard
1030+00 WCS	1230+00 WCS	possible gypsum
1370+00 WCS	1400+00 WCS	gypsum observed
1400+00 WCS	1685+00 WCS	possible gypsum
1685+00 WCS	1800+00 WCS	rockfall hazard and steeply dipping bedrock
1800+00 WCS	1845+00 WCS	possible gypsum
1845+00 WCS	1870+00 WCS	gypsum observed
1870+00 WCS	1935+00 WCS	possible gypsum
2150+00 WCS	2660+00 WCS	possible gypsum
2660+00 WCS	2680+00 WCS	gypsum observed

Table 3-4
Lake Powell Pipeline Hydro System-Highway Alternative Rock Hazards

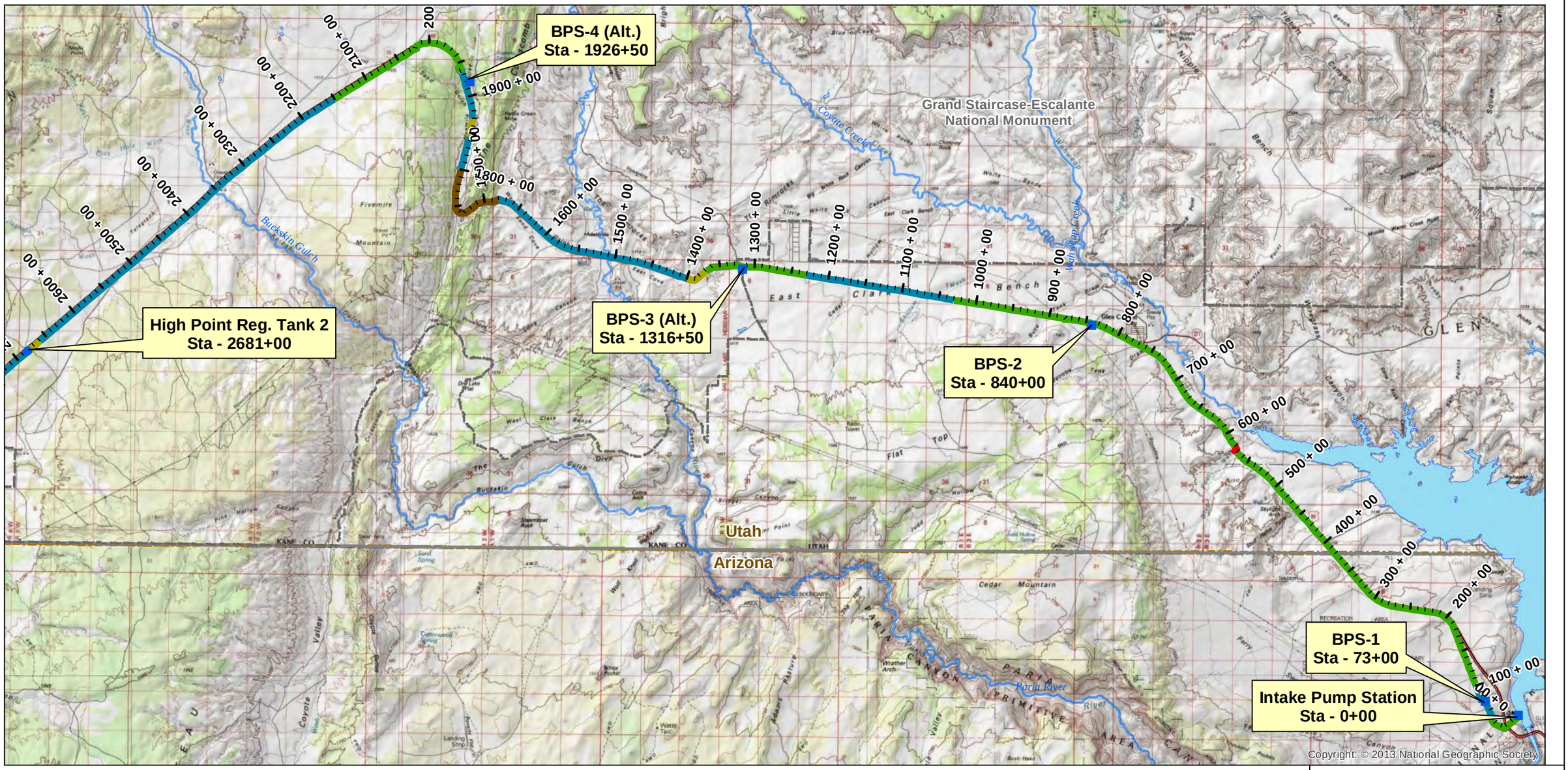
From Station:	To Station:	Description
2980+00 HS	3700+00 HWY	expansive potential
3700+00 HWY	3750+00 HWY	rockfall hazard
3850+00 HWY	3960+00 HWY	possible gypsum
3960+00 HWY	4020+00 HWY	gypsum observed
4020+00 HWY	4130+00 HWY	possible gypsum
4130+00 HWY	4700+00 HWY	gypsum observed
4700+00 HWY	4800+00 HWY	possible gypsum
4800+00 HWY	5100+00 HWY	expansive potential
5100+00 HWY	5120+00 HWY	gypsum observed

Table 3-5
Lake Powell Pipeline Hydro System-South Alternative Rock Hazards

From Station:	To Station:	Description
2980+00 HS	2990+00 SOUTH	expansive potential
2990+00 SOUTH	3015+00 SOUTH	rockfall hazard
3015+00 SOUTH	3200+00 SOUTH	possible gypsum
4165+00 SOUTH	4180+00 SOUTH	rockfall hazard and slope stability
4390+00 SOUTH	4440+00 SOUTH	rockfall hazard and slope stability
4600+00 SOUTH	4610+00 SOUTH	rockfall hazard and slope stability
5000+00 SOUTH	5030+00 SOUTH	possible gypsum
5030+00 SOUTH	5045+00 SOUTH	gypsum observed
5045+00 SOUTH	5152+00 SOUTH	possible gypsum
5152+00 SOUTH	5154+00 SOUTH	rockfall

Table 3-6
Lake Powell Pipeline Hydro System Rock Hazards

From Station:	To Station:	Description
2680+00 WCS	2915+00 HS	possible gypsum
2915+00 HS	2950+00 HS	gypsum observed
2950+00 HS	2980+00 HS	expansive potential
6150+00 HS	6250+00 HS	expansive potential
6290+00 HS	6370+00 HS	rockfall hazard
6370+00 HS	6780+00 HS	possible gypsum
7010+00 HS	7045+00 HS	rockfall hazard



Rock Hazards

- Low Risk
- Possible Gypsum
- Gypsum Observed
- Expansive Potential
- Rockfall Hazard
- Rockfall Hazard / Possible Gypsum
- Rockfall Hazard / Gypsum Observed
- Rockfall Hazard / Slope Stability
- Rockfall Hazard / Steeply Dipping Bedrock
- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- Lakes & Reservoirs
- Major Rivers & Streams
- National Park/Monument
- State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

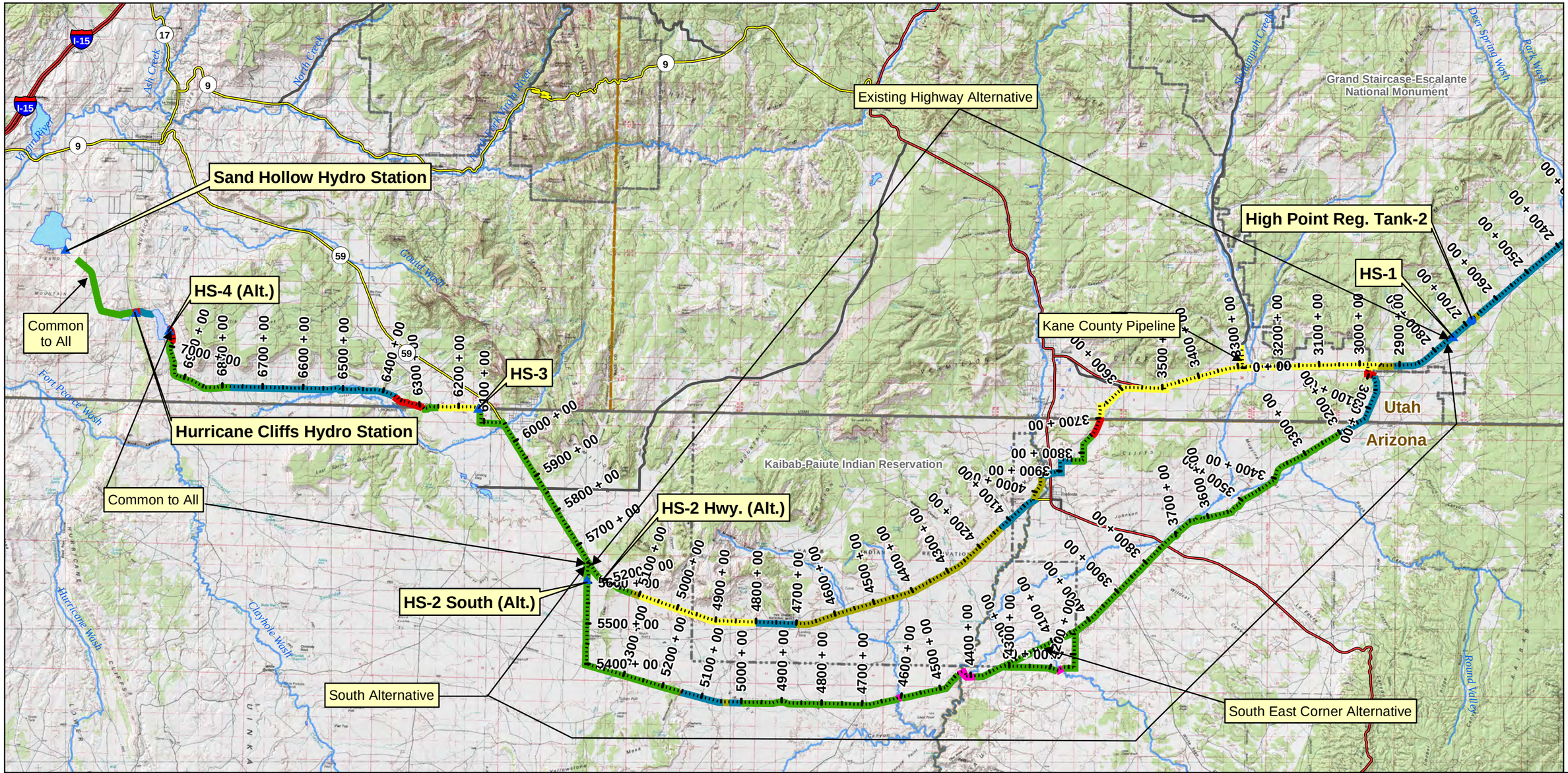
0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-3** MWH

Lake Powell Pipeline
Rock Hazards
Water Conveyance System



Rock Hazards

- Low Risk
- Possible Gypsum
- Gypsum Observed
- Expansive Potential
- Rockfall Hazard
- Rockfall Hazard / Possible Gypsum
- Rockfall Hazard / Gypsum Observed
- Rockfall Hazard / Slope Stability
- Rockfall Hazard / Steeply Dipping Bedrock
- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Hurricane Cliffs Forebay/Afterbay
- Lakes & Reservoirs
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- Major Rivers & Streams
- National Park/Monument
- Tribal Lands
- State Boundaries
- County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 1.25 2.5 5 7.5 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-4** MWH

Lake Powell Pipeline
Rock Hazards
Hydro System

3.2.4. Subsidence, Expansion, and Collapsible Soils

Soils along the LPP Project alignments are typically composed of alluvial, eolian and fluvial deposits and terraces. Some soils are weathered-in-place residual soils over shallow sedimentary bedrock. Soils east of the Cockscomb are typically eolian sand derived from the Navajo Sandstone, Entrada Sandstone and Page Sandstone formations. Soils over the Carmel Formation are typically weathered shale, limestone and sandstone and the shale typically contains gypsum. Soils along the Highway, South and Southeast Corner alignment alternatives typically consist of clay, silty loam, silty clay loam, or sandy loam. The soils are mostly weathered from the Moenkopi Formation and are shale, sandstone, or limestone derived. Soils in the Shinarump Member of the Chinle Formation consist of coarse sand and gravel weathered from the sandstone and well-rounded gravel conglomerate. Soils in the Petrified Forest Member of the Chinle Formation are primarily plastic clays (often bentonite clays with shrink/swell potential), or occasionally, fine sands. The soil near Sand Hollow Reservoir consists of variable depths of windblown sand derived from weathering of Navajo Sandstone outcrops.

Cryptobiotic soils are present along much of the LPP Project alignments. Cryptobiotic soil crusts consist of soil cyanobacteria, lichens and mosses that live on and within the soil matrix. Cryptobiotic crusts protect and stabilize soils against wind erosion and promote water infiltration, and can provide nutrients for other plant growth.

The soil characteristics observed in the field were compared to the NRCS descriptions. The soil characteristics observed during the field survey are provided in Table 3-7. The locations of the field survey points are shown on Figures 3-5 and 3-6.

Potential geologic hazards exist along the proposed LPP Project alignment alternatives. During the field survey, where potential hazard indicators were observed, the area was noted. Upon completing the field survey, the data was extrapolated between survey points using the geologic maps, soil maps and, where available (Washington and Kane Counties, Utah), existing hazard maps. The hazards were separated into ‘rock’ and ‘soil’ categories.

Soil hazards are shown on Figures 3-7 and 3-8 and include the presence of gypsiferous soils and soil with expansive or collapsible potential. Areas where geologic hazards were not identified were designated as low risk. However, as-yet unidentified soil hazards may still be present. Soil hazards have been divided into segments where they are likely to exist along the alignment, and are shown in Tables 3-8 through 3-11.

Table 3-7
Lake Powell Pipeline Field Survey of Soil Characteristics

Station	Northing	Easting	Soil Name	USCS Class	% Cobble	% Gravel	% C. Sand	% M. Sand	% F. Sand	% Fines	Color	Fines Dilatancy	Toughness	Plasticity	Fines Consistency	Sand/Gravel Angularity	Cementation	Origin
54+00	4088618.7N	455367.0E	Pagina-Wahweap complex	SP	0	0	0	0	100	0	Red	NA	NA	NA	NA	R	W	derived from Navajo SS
74+50 BPS-1	4089219.9N	455127.5E	Pagina-Wahweap complex	SP	0	0	0	0	100	0	Red	NA	NA	NA	NA	R	W	derived from Navajo SS
100+00	4089635.3N	454824.2E	Pagina-Wahweap complex	SP	0	0	0	0	100	0	Red	NA	NA	NA	NA	R	W	derived from Navajo SS
550+00	4098818.8N	445524.6E	Rock Outcrop - Moenkopi	SP	0	0	0	50	50	0	Red	NA	NA	NA	NA	R	W	weathered Moenkopi
790+30	4104003N	440509E	Wayneco-Sazi-Rock outcrop-Rizno-Palma-Mespun (most like Mespun soils)	SP	0	TR	TR	10	90	0	Red	NA	NA	NA	NA	R	W	
1315+50 Reg Tank 1	4106795.7N	424793.8E	Nakai-Sheppard complex	SM	0	0	0	0	60	40	Red	NA	NA	NA	NA	R	W	limestone derived, weathered Jcu
1905+00	4113981.0N	413681.6E	Barx-Radnik	SP	0	0	0	0	100	0	Red	NA	NA	NA	NA	R	W	eolian
2030+00	4115584.0N	411334.6E	Barx fine sandy loam	SP	0	0	0	0	100	0	Red	Rapid	Low	Non-Plastic	NA	R	None	alluvium/ eolian
2090+00	4114860.5N	410168.7E	Barx fine sandy loam	SP	0	0	0	0	100	0	Red	Rapid	Low	Non-Plastic	NA	R	None	alluvium/ eolian
2540+00	4106194.0N	399089.9E	Ruinpoint-Barx complex	SC	0	0	0	60	0	40	Red, Brown	NA	NA	NA	NA	SR	W	weathered Moenkopi
2680+00	4103412.6N	395774.4E	Kenzo-Retsabal-Progresso Complex	CL	0	0	0	0	0	100	Pale Tan, Pale Red	Rapid	Low	Low	Hard	NA	None	alluvium from Moenkopi/ Chinle
2741+00 HS-1	4102274.4N	394311.4E	Kenzo-Retsabal-Progresso Complex	CL	0	0	0	0	0	100	Pale Tan, Pale Red	Rapid	Low	Low	Hard	NA	None	weathered Moenkopi
2920+00	4100067.2N	389563.9E	Kenzo-Retsabal-Progresso Complex	CL	0	0	0	0	0	100	Pale Tan, Pale Red	Rapid	Low	Low	Hard	NA	None	alluvium from Moenkopi/ Chinle
5880+00	4090724.6N	325815.4E	Barx fine sandy loam	SP	0	0	0	0	80	20	Pale Red	Rapid	Low	Low	Firm	R	M	alluvium/ eolian
5950+00	4093084.5N	324388.5E	Mido fine sand	SC	0	10	0	10	40	40	Pale Red	Rapid	Low	Medium	Firm	R - SR	W	alluvium/ eolian/ weathered in place ss
6050+00	4095657.7N	322692.3E	Mido loamy fine sand	SC/CL	0	0	0	0	40 - 60	40 - 60	Brown, Pale Red	Rapid	Low	Medium	Hard	R - SR	M-S	alluvium
6090+00	4095689.7N	321777.7E	Palma loamy fine sand	SP	0	0	0	50	50	0	Red	NA	NA	Non-Plastic	NA	SR - R	None	eolian
6148+50	4096810.3N	321103.4E	Palma loamy fine sand	SP	0	0	0	50	50	0	Red	NA	NA	Non-Plastic	NA	SR - R	None	eolian
6210+00	4096810.3N	321103.4E	Mespun Fine Sand/Radnik Fine Sandy Loam	SP	0	5	0	0	95	0	Pale Red	NA	NA	Non-Plastic	NA	R	W	wind-blown sand over Petrified Forest member

Table 3-7
Lake Powell Pipeline Field Survey of Soil Characteristics

Station	Northing	Easting	Soil Name	USCS Class	% Cobble	% Gravel	% C. Sand	% M. Sand	% F. Sand	% Fines	Color	Fines Dilatancy	Toughness	Plasticity	Fines Consistency	Sand/Gravel Angularity	Cementation	Origin
6275+00	4096825.2N	317303.4E	Bidonia-Bond Rock outcrop complex	SC	0	0	0	35	35	30	Red, Brown	Rapid	Low	Low to Medium	Firm to Hard	SR - R	W, some caliche	alluvium
6440+00	4098129.9N	312524.9E	Naplene Silt loam	CH	0	<5	0	0	0	95	Red	Rapid	Low	High	Firm	NA	None	alluvium from Moenkopi
6450+00	4097750.5N	311879.9E	Naplene Silt loam	CH	0	<5	0	0	0	95	Red	Rapid	Low	High	Firm	NA	W	alluvium from Moenkopi
6550+00	4098207.8N	309105.2E	Schmutz Loam	ML	5	TR	0	0	10	85	Pale Brown	Rapid	Low	Low	Soft	NA	W	old alluvium
6920+00	4099229.1N	298223.6E	Schmutz Loam	ML	5	TR	0	0	10	85	Pale Brown	Rapid	Low	Low	Soft	SR	None	old alluvium
3130+00	4099907.1N	383222.9E	Yarts/Palma/ Neville Family - Barx Atchee	SM	0	5	0	0	70	25	Red	Rapid	Low	Non-Plastic	Firm	SA (gravel) R (sand)	None	alluvium from Jm/TRcp
3230+00	4099906.8N	380408.5E	Yarts/Palma/ Neville Family - Barx Atchee	SM	0	5	0	0	70	25	Red	Rapid	Low	Non-Plastic	Firm	SA (gravel) R (sand)	None	alluvium from Jm/TRcp
3380+00	4099316.1N	376007.0E	Yarts/Palma/ Neville Family - Barx Atchee	ML	0	0	0	0	0	100	Red	Rapid	Low	Non-Plastic	Soft	NA	None	alluvium
3500+00	4098259.9N	372599.9E	Yarts/Palma/ Neville Family - Barx Atchee	ML	0	0	0	0	0	100	Red	Rapid	Low	Non-Plastic	Soft	NA	M	eolian or alluvium
3610+00	4098085.9N	369348.3E	Skos - Rock Outcrop	CL/CH	0	0	0	0	0	100	Red, Brown	unknown	unknown	unknown	unknown	NA	unknown	alluvium
3665+00	4096965.1N	367943.2E	Yarts/Palma/ Neville Family - Barx Atchee	CL/CH	0	0	0	0	0	100	Red, Brown	unknown	unknown	unknown	unknown	NA	unknown	alluvium
3750+00	4094828.6N	367280.1E	Torriorthents	ML, CL	0	0	0	0	5	95	Pale Tan, Gray, Pale Green	Rapid	Low	Non-Plastic	Hard	SR	M	alluvium derived from limestone
3780+00	4093829.7N	366506.6E	Glenyon silty clay loam	CH	0	0	0	0	0	100	Red	None	Low	High	Firm	NA	W	alluvium
3820+00	4093022.1N	366573.4E	Torriorthents	ML	0	0	0	0	5	95	Pale Tan, Gray, Pale Green	Rapid	Low	Non-Plastic	Hard	SR	M	alluvium derived from limestone
3950+00	4091804.0N	363468.3E	Jocity loamy fine sand	CH	0	0	0	0	0	100	Pale Red	None	Medium	High	Hard	NA	M	alluvium
4005+00	4090301.9N	362966.3E	Gypsiorthids shallow complex	ML	0	0	0	0	30	70	Pale Red	Rapid	Low	Non-Plastic	Hard	R	M	eolian or alluvium
4110+00	4088167.4N	360856.4E	Sheppard fine sand	SP	0	0	0	0	90	10	Red	Rapid	Low	Non-plastic	NA	SR	W	alluvium
4280+00	4084773.2N	357085.7E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red, Brown	Slow	Low	High	Firm	NA	S	alluvium
4370+00	4083445.0N	354687.5E	clayhole loam	ML	0	0	0	0	20	80	Pale Red	Rapid	Low	Non-Plastic	Firm	R	S	alluvium
4420+00	4082686.3N	353141.5E	Kinan gravelly loam	SM	0	5	0	65	30	0	Brown, Red	NA	NA	NA	NA	R	M	alluvium
4570+00	4081411.4N	348778.9E	Mido loamy fine sand	SP	0	0	0	100	0	0	Pale Red	NA	Low	Non-Plastic	NA	SR	W	alluvium/ eolian
4650+00	4080495.0N	345878.8E	Gypsiorthids shallow complex	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Soft	NA	S	weathered TRmm
4695+00	4080623.7N	345201.8E	Monue fine sandy loam	SP	0	0	0	50	50	0	Pale Red	Rapid	Low	Non-Plastic	NA	R	W	alluvium from sandstone
4755+00	4080566.6N	343178.8E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Firm to Hard	NA	M	clay alluvium
5150+00	4083202.6N	331539.7E	Torriorthents rock outcrop complex/Campanile clay	CH	5	0	0	0	0	95	Tan, Red, Purple	None	Low	High	Soft	NA	None	weathered in place shale
5202+00 HS-2 Highway	4083915.3N	330234.3E	Barx fine sandy loam	SP	0	0	0	0	80	20	Pale Red	Rapid	Low	Low	Firm	R	M	alluvium

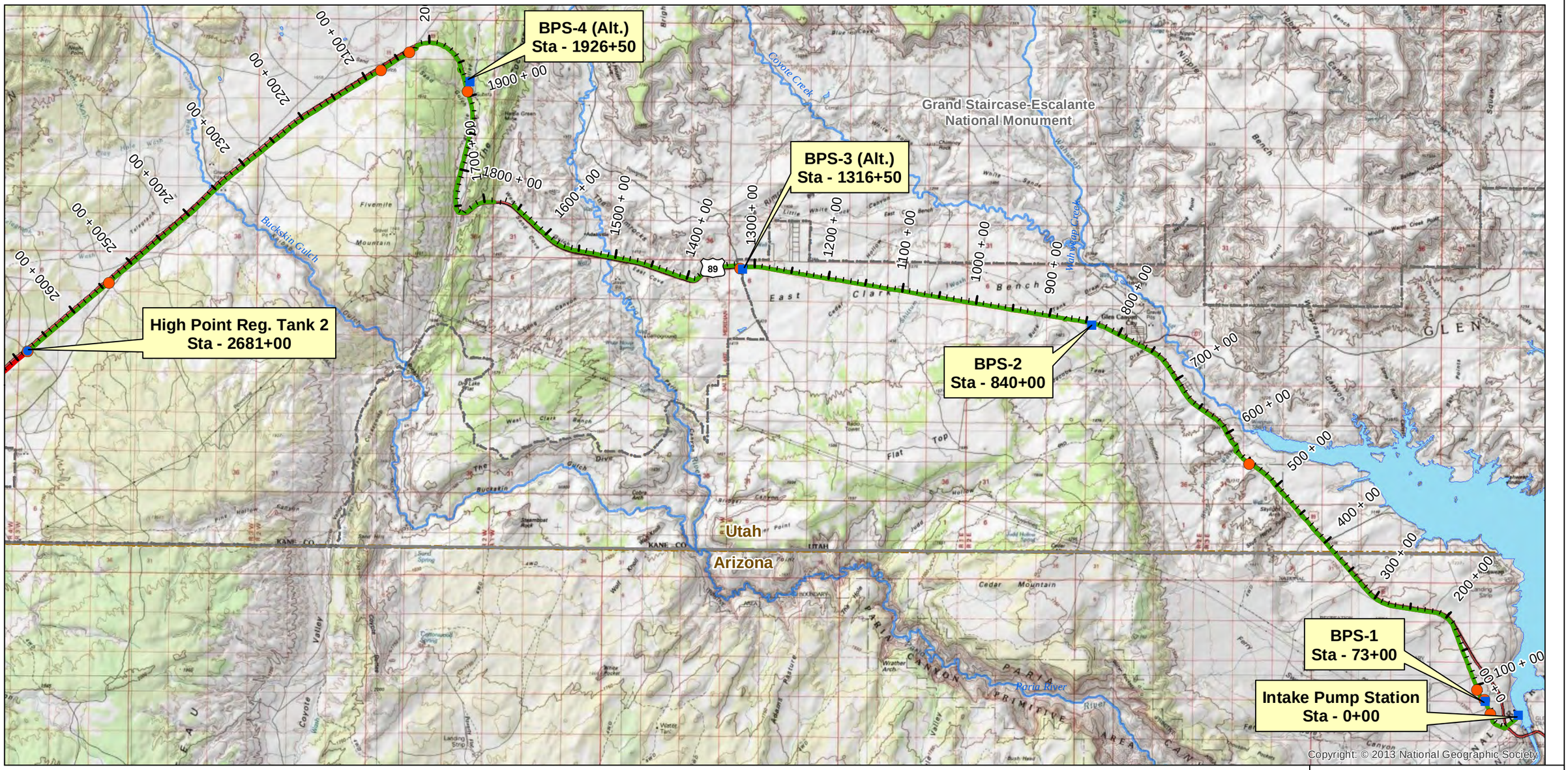
Table 3-7
Lake Powell Pipeline Field Survey of Soil Characteristics

Station	Northing	Easting	Soil Name	USCS Class	% Cobble	% Gravel	% C. Sand	% M. Sand	% F. Sand	% Fines	Color	Fines Dilatancy	Toughness	Plasticity	Fines Consistency	Sand/Gravel Angularity	Cementation	Origin
3060+00	4097824.0N	388554.0E	Yarts/Palma/ Neville Family - Barx Atchee	CL/ML	0	0	0	0	0	100	Red	unknown	unknown	unknown	unknown	NA	unknown	alluvium from Upper Red Moenkopi
3130+00	4095892.6N	387619.7E	Skos - Rock Outcrop	CL/ML	0	0	0	0	0	100	Red	unknown	unknown	unknown	unknown	NA	unknown	rounded gravel from Shinarump. Weathered Upper Red Moenkopi
3190+00	4094912.6N	385927.2E	Clayhole silty loam	SM	0	0	0	0	20	80	Pale Red	Rapid	Low	Non-Plastic	Firm	R	M	weathered Moenkopi
3300+00	4093444.0N	383863.7E	Torriorthents	CH	0	0	0	0	0	100	Pale Red, Brown	unknown	unknown	unknown	unknown	NA	M	alluvium derived from limestone
3400+00	4091583.7N	381021.4E	Jocity silty clay loam	CL	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Firm to Hard	NA	M	partially derived from limestone
3455+00	4090504.4N	379665.3E	Klondike sandy clay loam	CH	0	0	0	0	0	100	Red	None to Slow	Low	High	Hard	NA	W	alluvium
3550+00	4088859.5N	377279.6E	Jocity silty clay loam/Klondike sandy clay loam	CH	0	0	0	0	0	100	Red	None to Slow	Low	High	Hard	NA	M	note chert gravel
3680+00	4087699.4N	374203.4E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Hard	NA	M	alluvium, no gravel
4000+00	4081837.8N	368058.2E	Clayhole loam	ML	0	20	0	0	5	75	Tan, Pale Brown	Rapid	Low	Non-Plastic	Soft	SA	None	alluvium derived from limestone
4695+00	4074473.5N	350015.5E	Pennell gravelly loam or Jocity silty clay loam	CH	0	TR	0	0	0	100	Pale Red, Brown	None	Low	High	Firm	NA	None	possibly eolian clay
4815+00	4074530.7N	346360.8E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Hard	NA	None	clay alluvium
4830+00	4074361.0N	345906.0E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Hard	NA	None	clay alluvium
4830+00	4074527.6N	345875.8E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Hard	NA	None	clay alluvium
4880+00	4074425.7N	344271.9E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Hard	NA	None	clay alluvium
4950+00	4074434.9N	342205.1E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Firm to Hard	NA	None	clay alluvium
5020+00	4074510.5N	340196.0E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Firm to Hard	NA	None	clay alluvium
5040+00	4074524.4N	339474.9E	Jocity silty clay loam	CH	0	0	0	0	0	100	Pale Red	Rapid	Low	High	Firm to Hard	NA	None	white caliche crust
5090+00	4074952.9N	338027.4E	Grieta fine sandy loam	ML	0	TR	0	0	0	100	Pale Red	Rapid	Low	Non-Plastic	Hard	NA	None	eolian loess?
5125+00	4075042.8N	337004.4E	Grieta fine sandy loam	ML	0	TR	0	0	0	100	Pale Red	Rapid	Low	Non-Plastic	Hard	NA	None	eolian loess?
5140+00	4075394.0N	336337.7E	Grieta fine sandy loam	ML	0	TR	0	0	0	100	Pale Red	Rapid	Low	Non-Plastic	Hard	NA	None	eolian loess?
5220+00	4075962.7N	333724.8E	Grieta fine sandy loam or Barx fine sandy loam	ML	0	TR	0	0	0	100	Pale Red	Rapid	Low	Non-Plastic	Hard	NA	None	eolian loess?
5310+00	4076672.2N	331926.6E	Campanile clay	CH	0	TR	0	0	0	100	Red, Brown	Rapid	Low	High	Firm to hard	NA	M	alluvium
5315+00	4076807.9N	331418.9E	Barx fine sandy loam	SP	0	10	90	0	0	0	Pale Brown, Red	NA	NA	Non-Plastic	NA	R	None	alluvium

Table 3-7
Lake Powell Pipeline Field Survey of Soil Characteristics

Station	Northing	Easting	Soil Name	USCS Class	% Cobble	% Gravel	% C. Sand	% M. Sand	% F. Sand	% Fines	Color	Fines Dilatancy	Toughness	Plasticity	Fines Consistency	Sand/Gravel Angularity	Cementation	Origin
5315+00	4076628.7N	331393.7E	Campanile clay	CL	0	0	0	0	25	75	Pale Brown, Pale Red	Rapid	Low	Low	Firm	R	M	alluvium
5390+00	4077313.1N	329053.2E	Grieta loam	ML	0	0	0	0	25	75	Pale Brown, Pale Red	Rapid	Low	Low	Firm to Hard	SR - R	W	alluvium/ eolian
5607+50 HS-2 South	4083914.6N	329129.3E	Barx fine sandy loam	SC	0	0	0	0	80	20	Pale Red	Rapid	Low	Low	Firm	R	M	alluvium/ eolian
4070+00	4079293.3N	364850.5E	Havasupai-Mellenthin Complex	ML, CL	0	0	0	0	0	100	Red	NA	NA	Non-Plastic	NA	NA	NA	partially derived from limestone
Hurricane Cliffs Hydro Station	4104781.7N	295166.9E	Nikey-Ison Complex	GC	10	40	5	5	5	35	Brown, Red	None	Low	Low to Medium	Soft	SA	None	alluvium/ slopewash from ss and limestone
10+00 (N of afterbay)	4106034.1N	294585.8E	Nikey-Ison Complex	ML	0	0	0	0	0	100	Pale Red, Tan	Rapid	Low	Low	Firm	NA	None	alluvium transported far from source
165+00 Sand Hollow	4107316.4N	291357.6E	Harrisburg fine sandy loam	ML/GM	0	25	10	5	5	55	Red	None	Low	Low	Soft	SA	None	eolian/ alluvium
210+00 Sand Hollow	4108439.3N	291357.6E	Pintura Loamy Fine Sand	SP	0	0	0	50	50	0	Red	NA	NA	Non-Plastic	NA	SR - R	None	eolian-derived from Navajo SS
42+85 HCHF Penstock at Powerhouse	4104045N	295244E	Nikey-Ison Complex	SP	5	20	TR	5	60	10	Tan	NA	NA	Non-Plastic	NA	Gravel - A Sand - R	L	alluvial fan outwash / eolian
54+75 HCHF Powerhouse Penstock Tailrace	4104013N	294880E	Nikey-Ison Complex	SP/SM	2	15	5-8	TR	50	20	Pale Brown	NA	NA	Non-Plastic	NA	Gravel - A Sand - R	L	alluvium / eolian
63+50 Pump Storage Tunnel Alignment	4104579N	292431E	Pintura Fine Sand	SP	0	0	TR	10	90	TR	Pale Red	NA	NA	Non-Plastic	NA	R	None	alluvium / eolian
90+80 Pump Storage Tunnel Alignment	4105392N	292250E	Pintura Fine Sand	SP	0	0	TR	5	90	5	Pale Red	NA	NA	Non-Plastic	NA	R	None	alluvium / eolian
116+15 Pump Storage Tunnel Alignment	4106144N	292073E	Pintura Loamy Fine Sand	SP/SM	0	TR	TR	TR	90	10	Red	NA	NA	Low	NA	R	L	alluvium / eolian
Kane County	4101627.7N	378477.7E	Yarts/Palma/ Neville Family - Barx Atchee	SM	0	0	0	0	60	40	Red	NA	NA	NA	NA	R	M	weathered Morrison?

Notes. USCS Classification: GM=Silty Gravel, GC=Clayey Sand, SW=Well Sorted Sand, SP=Poorly Sorted Sand, SM=Silty Sand, SC=Clayey Sand, ML=Silt, CL=Low-Plasticity Clay, CH=High-Plasticity Clay. Angularity: R=Round, SR=Sub-Round, SA=Sub-Angular, A=Angular. Cementation: W=Weak, M=Moderate, S=Strong, L=Lithified. General: NA=Not Applicable, SS=Sandstone, TR=Trace.



Soil Characteristics Points
Project Pump Station
Project Regulating Tank
Project Hydro Station
Water Conveyance System
Hydro System - South Alignment Alternative

Interstate
US Highway
ST Highway
Hwy
Major Road

Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

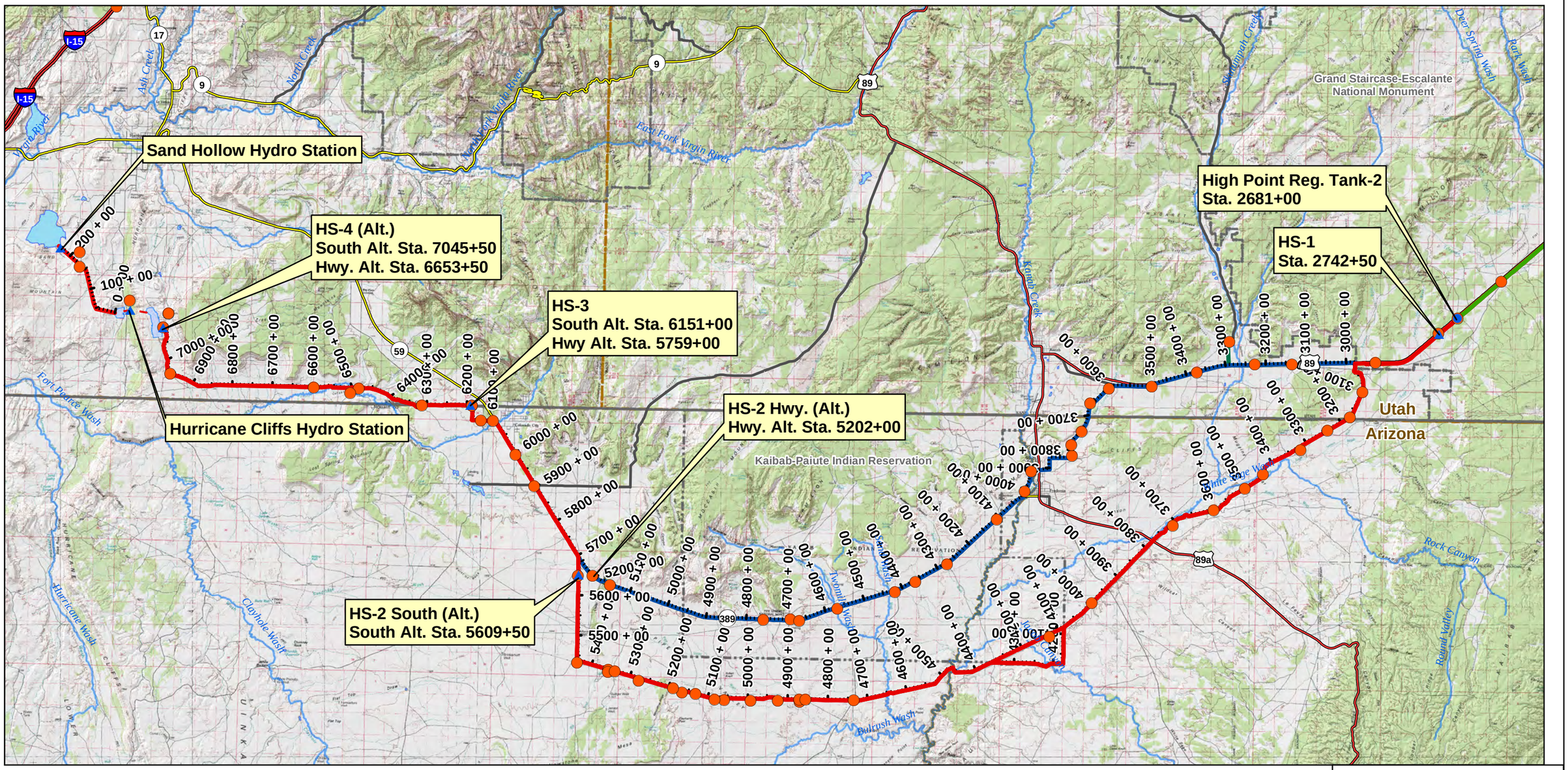
0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-5** MWH

Lake Powell Pipeline
Soil Characteristics Points
Water Conveyance System



FERC Project Number:
12966-001
BLM Serial Numbers:
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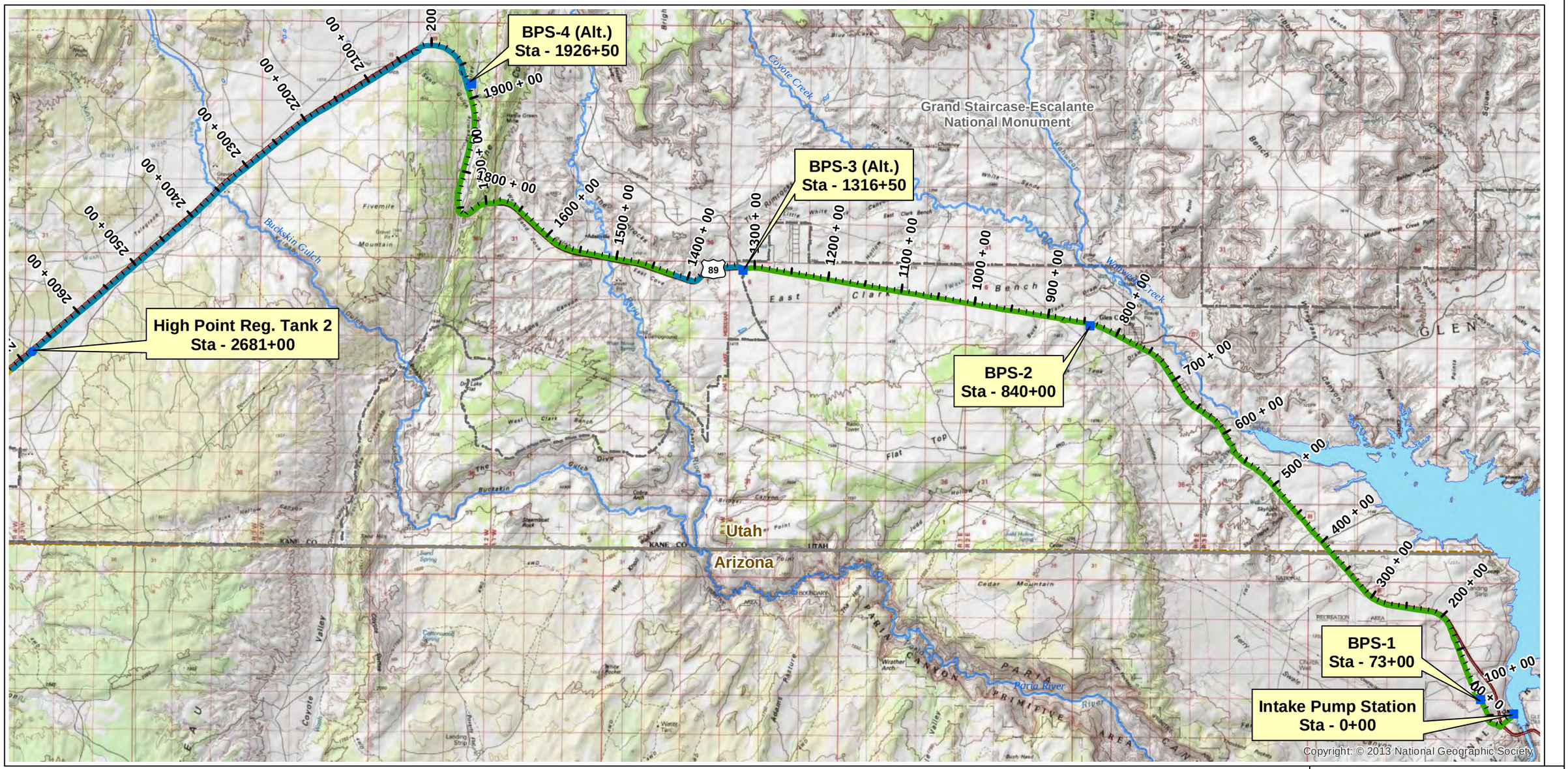
UTU-85472

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-6** MWH

Lake Powell Pipeline
Soil Characteristics Points
Hydro System



Soil Hazards

- Low Risk
- Possible Gypsum
- Gypsum Observed
- Expansive Potential
- Collapsible Potential
- Expansive Potential / Possible Gypsum
- Expansive Potential / Gypsum Observed
- Collapsible Potential / Gypsum Observed
- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- Lakes & Reservoirs
- Major Rivers & Streams
- National Park/Monument
- State Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

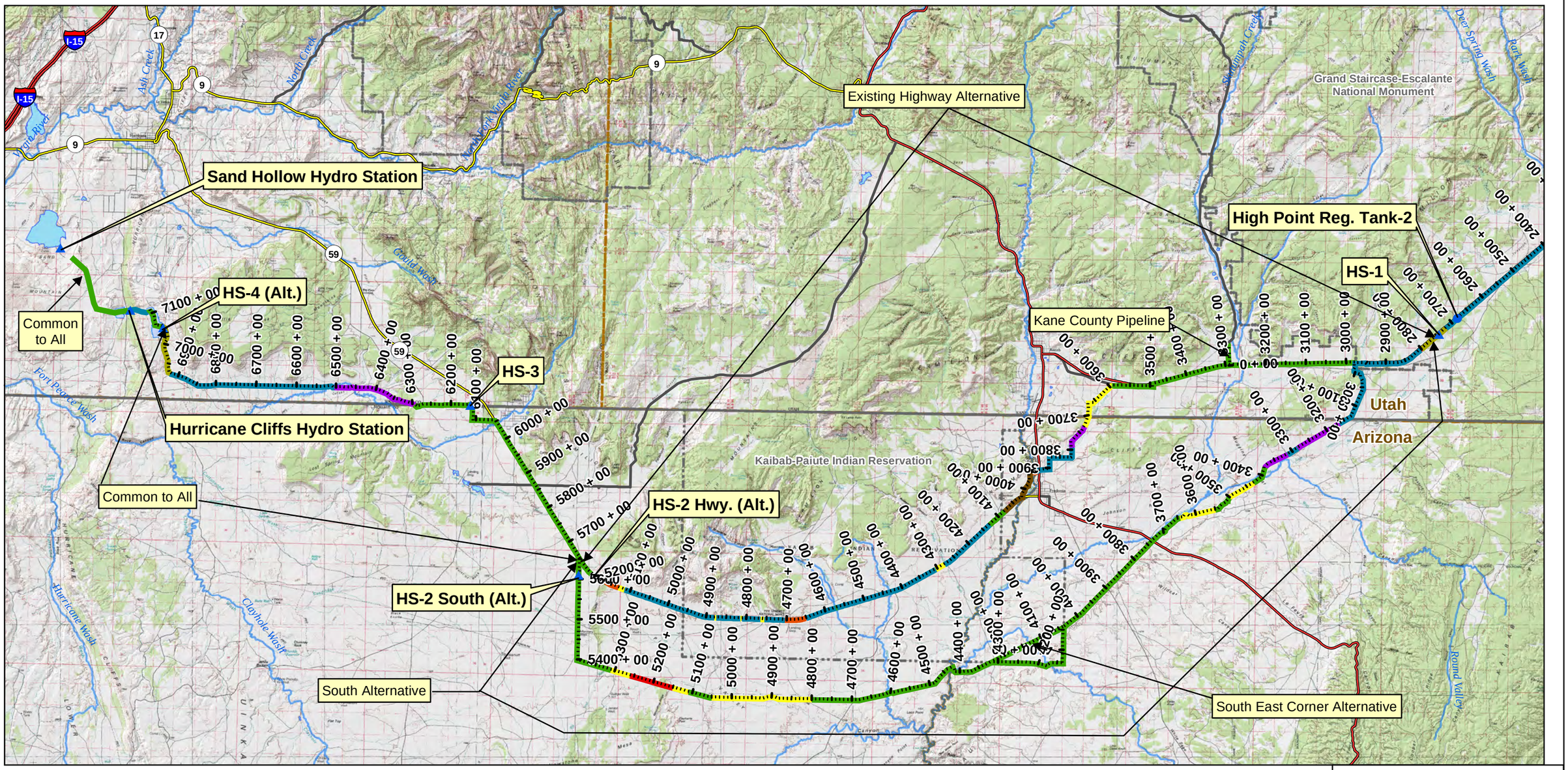
0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-7** MWH

Lake Powell Pipeline
Soil Hazards
Water Conveyance System



Soil Hazards

- Low Risk
- Possible Gypsum
- Gypsum Observed
- Expansive Potential
- Collapsible Potential
- Expansive Potential / Possible Gypsum
- Expansive Potential / Gypsum Observed
- Collapsible Potential / Gypsum Observed
- Project Pump Station
- Project Regulating Tank
- Project Hydro Station
- Hurricane Cliffs Forebay/Afterbay
- Lakes & Reservoirs
- Interstate
- US Highway
- ST Highway
- Hwy
- Major Road
- Major Rivers & Streams
- National Park/Monument
- Tribal Lands
- State Boundaries
- County Boundaries

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

N

0 1.25 2.5 5 7.5 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-8** MWH

Lake Powell Pipeline
Soil Hazards
Hydro System

Table 3-8
Lake Powell Pipeline Water Conveyance System Soil Hazards

From Station:	To Station:	Description
1320+00 WCS	1420+00 WCS	possible gypsum
1910+00 WCS	2680+00 WCS	possible gypsum

Table 3-9
Lake Powell Pipeline Hydro System Soil Hazards

From Station:	To Station:	Description
2680+00 HS	2720+00 HS	possible gypsum
2720+00 HS	2800+00 HS	gypsum observed
2800+00 HS	2980+00 HS	possible gypsum
6295+00 HS	6505+00 HS	expansive potential and possible gypsum
6505+00 HS	6920+00 HS	possible gypsum
6920+00 HS	7045+00 HS	gypsum observed

Table 3-10
Lake Powell Pipeline Hydro System-Highway Alternative Soil Hazards

From Station:	To Station:	Description
3595+00 HWY	3730+00 HWY	expansive potential
3595+00 HWY	3795+00 HWY	expansive potential and possible gypsum
3795+00 HWY	3940+00 HWY	possible gypsum
3940+00HWY	3955+00 HWY	expansive potential and gypsum observed
3955+00 HWY	4070+00 HWY	collapsible and gypsum observed
4130+00 HWY	4270+00 HWY	possible gypsum
4270+00 HWY	4305+00 HWY	expansive potential
4305+00 HWY	4570+00 HWY	possible gypsum
4573+00 HWY	4650+00 HWY	possible gypsum
4650+00 HWY	4705+00 HWY	expansive potential and gypsum observed
4705+00 HWY	4755+00 HWY	possible gypsum
4755+00 HWY	4765+00 HWY	expansive potential
4765+00 HWY	4810+00 HWY	possible gypsum
4810+00 HWY	4815+00 HWY	expansive potential
4815+00 HWY	4875+00 HWY	possible gypsum
4875+00 HWY	4880+00 HWY	expansive potential
4880+00 HWY	5115+00 HWY	possible gypsum
5115+00 HWY	5130+00 HWY	expansive potential
5130+00 HWY	5170+00 HWY	expansive potential and gypsum observed

Table 3-11 Lake Powell Pipeline Hydro System-South Alternative Soil Hazards		
From Station:	**To Station:**	**Description**
131+00 SOUTH	210+00 SOUTH	Expansive potential and possible gypsum
2980+00 SOUTH	3165+00 SOUTH	possible gypsum
3165+00 SOUTH	3285+00 SOUTH	expansive potential and possible gypsum
3285+00 SOUTH	3315+00 SOUTH	possible gypsum
3315+00 SOUTH	3380+00 SOUTH	expansive potential and possible gypsum
3430+00 SOUTH	3500+00 SOUTH	expansive potential
3550+00 SOUTH	3645+00 SOUTH	expansive potential
4800+00 SOUTH	5050+00 SOUTH	expansive potential
5110+00 SOUTH	5150+00 SOUTH	expansive potential
5210+00 SOUTH	5260+00 SOUTH	collapsible potential
5260+00 SOUTH	5310+00 SOUTH	expansive potential

3.2.5. Geologic Hazards to Human Health and Safety

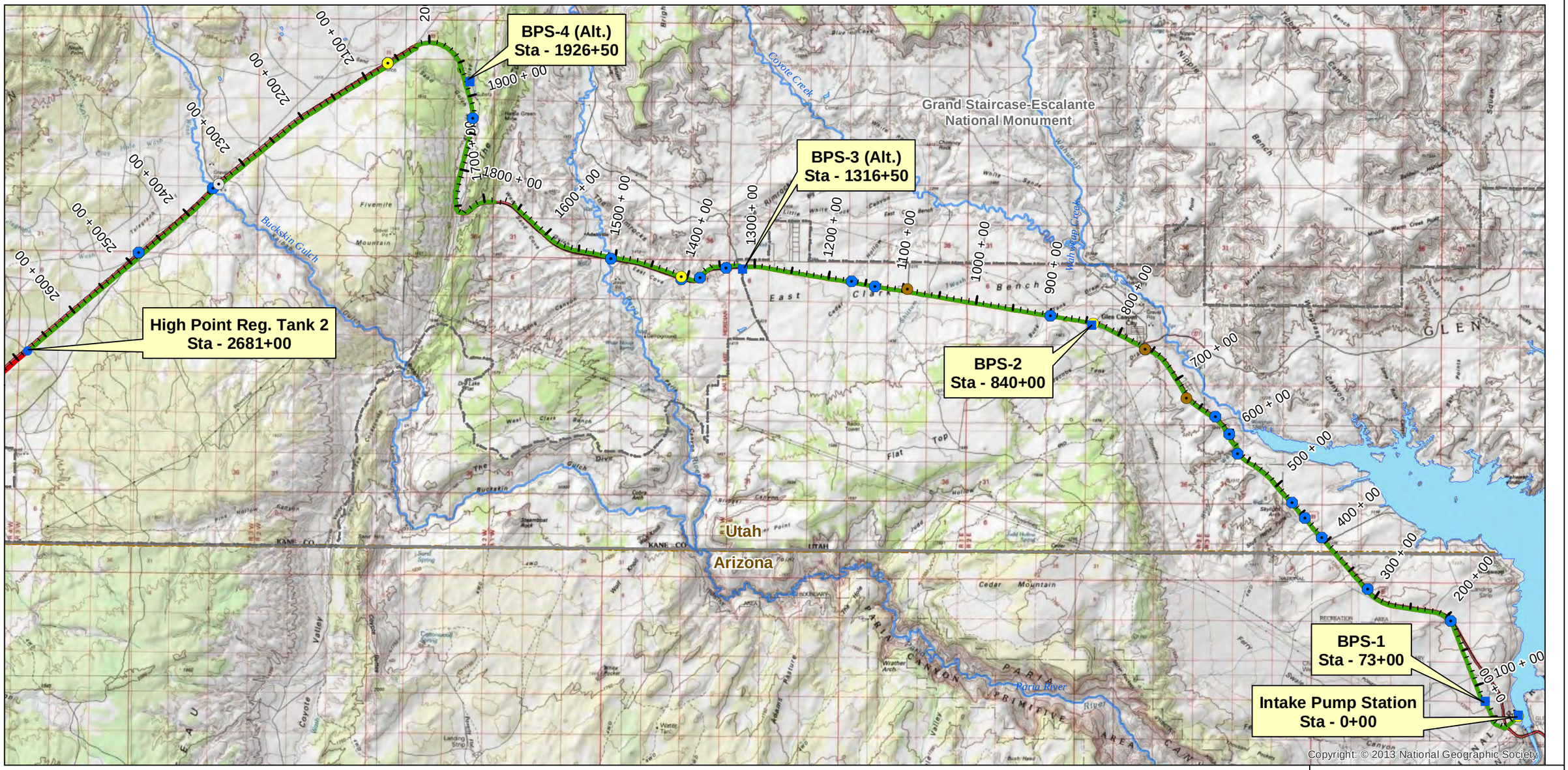
No geologic hazards to human health and safety were identified in the study area, except for possible risks of slope stability or rockfall that have been addressed previously.

3.2.6. Important Structures and Mineral Resources

The location coordinates of buildings and other structures encountered during the field survey that are within 1,000 feet of the proposed alignments and therefore at some risk from the project as noted in Section 3.2.1, Area of Potential Effect, are summarized in Table 3-12 and shown in Figures 3-9 and 3-10. The structures have been generalized into categories; buildings, quarries, utilities, wells or other.

Table 3-12
Lake Powell Pipeline Field Survey of Physical Characteristics

Station	Northing	Easting	Type	Description
Lake Powell Water Conveyance System				
0+00	4088541.8N	456505.0E	Other	Construction staging area at intake
672+00	4101517.0N	442978.8E	Building	In Town of Bigwater
755+00	4103504.2N	441291.0E	Building	BLM Welcome Center building
835+00	4104529.0N	439179.3E	Other	Brass cap survey marker, State Road Right of Way
1092+00	4105941.2N	431625.2E	Building	In Town of Churchwells
1415+00	4106462.8N	422409.3E	Other	Brass cap, survey marker
2060+00	4115140.5N	410453.9E	Other	Bench mark, Range R138
2340+00	4110219.3N	403558.5E	Quarry	Gravel quarry
Hydro System-Existing Highway Alternative				
3980+00	4090779.9N	363240.2E	Building	House
4695+00	4080531.5N	345245.7E	Building	Tribal Headquarters Building and gas station
Hydro System- South Alternative				
4100+00	4077951.2N	365894.6E	Other	Survey marker, brass cap
4280+00	4077357.3N	361117.7E	Other	Survey marker, brass cap
5480+00	4079470.7N	329041.0E	Other	Windmill
5580+00	4082673.7N	329104.5E	Well	Two water tanks
Lake Powell Hydro System				
5790+00	4088981.0N	326880.4E	Building	Five houses
6080+00	4095681.7N	321936.8E	Building	2 houses
6270+00	4096825.2N	317303.4E	Other	Windmill
6400+00	4098111.3N	413374.9E	Building	House
6440+00	4098129.9N	312524.9E	Well	Well
6450+00	4097754.2N	311667.3E	Well	Well
6550+00	4098207.8N	309105.2E	Other	Brass cap



Drainages	Project Pump Station	Interstate	Lakes & Reservoirs
Building	Project Regulating Tank	US Highway	Major Rivers & Streams
Other	Project Hydro Station	ST Highway	National Park/Monument
Quarry	Water Conveyance System	Hwy	State Boundaries
Utility	Hydro System - South Alignment Alternative	Major Road	
Well			

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12966-001
BLM Serial Numbers:
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UTU-85472

N

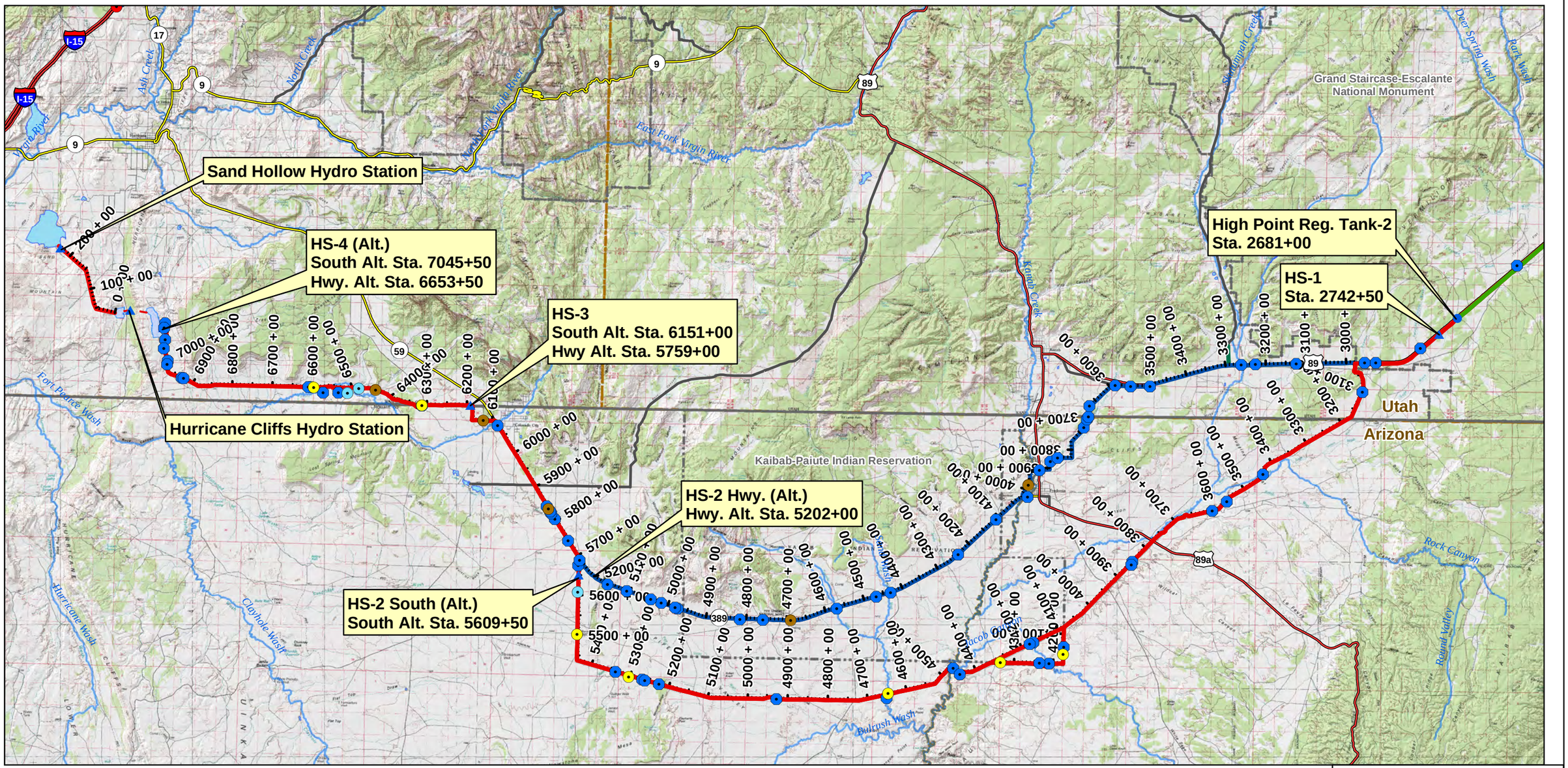
0 0.5 1 2 3 4 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-9** MWH

Lake Powell Pipeline
Drainages & Structures
Water Conveyance System



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Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-10** MWH

Lake Powell Pipeline Drainages & Structures Hydro System

3.2.6.1 Intake System Tunnels and Vertical Shafts

The conceptual design for the LPP Project Intake System includes several major underground components:

- Two vertical intake shafts
- Six horizontal intake tunnels
- Two forebay connector tunnels
- One forebay chamber
- Six pump well shafts
- One isolation gate shaft

Figures 3-11 and 3-12 show the location of the Intake System relative to the Glen Canyon Dam and the Lake Powell Reservoir.

Subsurface investigations at the Intake determined that conditions are suitable for foundations for surface structures (MWH 2011). Based on the Rock Mass Rating (RMR) system (Bieniawski 1989) and the rock quality classification for tunnels of Barton et al. (1974), the Navajo Sandstone at the Intake System tunnels and shafts location was determined to have a RMR of 73, corresponding to a good to fair rock mass quality, and a Tunnel Quality Index of 30, corresponding to fair tunnel conditions.

Detailed design of these structures will include any foundation preparations necessary to protect the facilities from settling and other potential structural damage. It is anticipated that additional subsurface investigations at these locations will be required to more fully characterize conditions for design. Subsurface characterization at the locations of proposed facilities and along the pipeline alignment of the selected alternative will be performed prior to the detailed design. A preliminary assessment of possible stabilization methods for tunnel and shaft construction is provided by MWH (2011); it is anticipated that tunnel and shaft stabilization can be achieved by standard tunneling methods.

Excavations at the intake site, which is generally at or very near the ground surface (generally less than 10 feet of overburden) would encounter the Navajo Sandstone (Jn). The Navajo Sandstone represents a spatially expansive and thick (1,200 to 1,800 feet) sequence of sandstone layers developed from huge dune beds (i.e., layers of windblown sand). The quartzose sandstone is generally pale to moderate reddish brown with spots and zones that are very dark reddish brown, dark brown, and white; the depositional bedding is very thickly bedded to massive (depositional bedding is mostly greater than three feet, typically greater than 10 feet thick and dipping 2- to 5-degrees to the northeast and east). Between the depositional bedding, the rock exhibits pronounced, laminated to thin, high-angle cross-bedding (dipping 0- to 40-degrees in varying directions, but dominantly toward the southeast). The rock is composed of very fine to medium-grained, well-rounded to sub-rounded, well-sorted, frosted quartz sand grains that are clast supported (i.e., grain-to-grain contact) and moderately- to well-cemented primarily with silica and to a lesser degree with hematite, limonite, and calcite that appear as coatings on individual sand grains.

The type of ground behavior and conditions anticipated to be encountered during shaft and tunnel excavation for the Intake System has been characterized using several rock mass classification systems. These systems are based on quantifiable rock mass characteristics such as rock quality designation (RQD); rock hardness; rock strength; discontinuity orientation, spacing, and condition; weathering; alteration; and groundwater conditions as input data for rock mass classification that was derived from the geotechnical drilling and testing program. Although these classification methods have been used successfully for underground design project there is inherent uncertainty and subjectivity with the rock

mass systems and therefore a degree of conservatism is warranted in their use depending on the quality and quantity of the input data. Based on a rock mass analysis of the data obtained from the site geotechnical drilling and testing program, the Navajo Sandstone bedrock was classified as having a Rock Mass Rating (RMR) of 73, which is consistent with a rock quality of Type II - good to fair rock conditions; and a Tunnel Quality Index (Q) of 30, which is classified as fair quality rock (MWH 2009d and 2011). The interpretation of these rock strength characteristics for the suitability for foundation of the proposed facilities is beyond the scope of this analysis because design loads and requirements have not yet been developed.

Figure 3-11. Lake Powell Pipeline Intake System Aerial View (looking north)

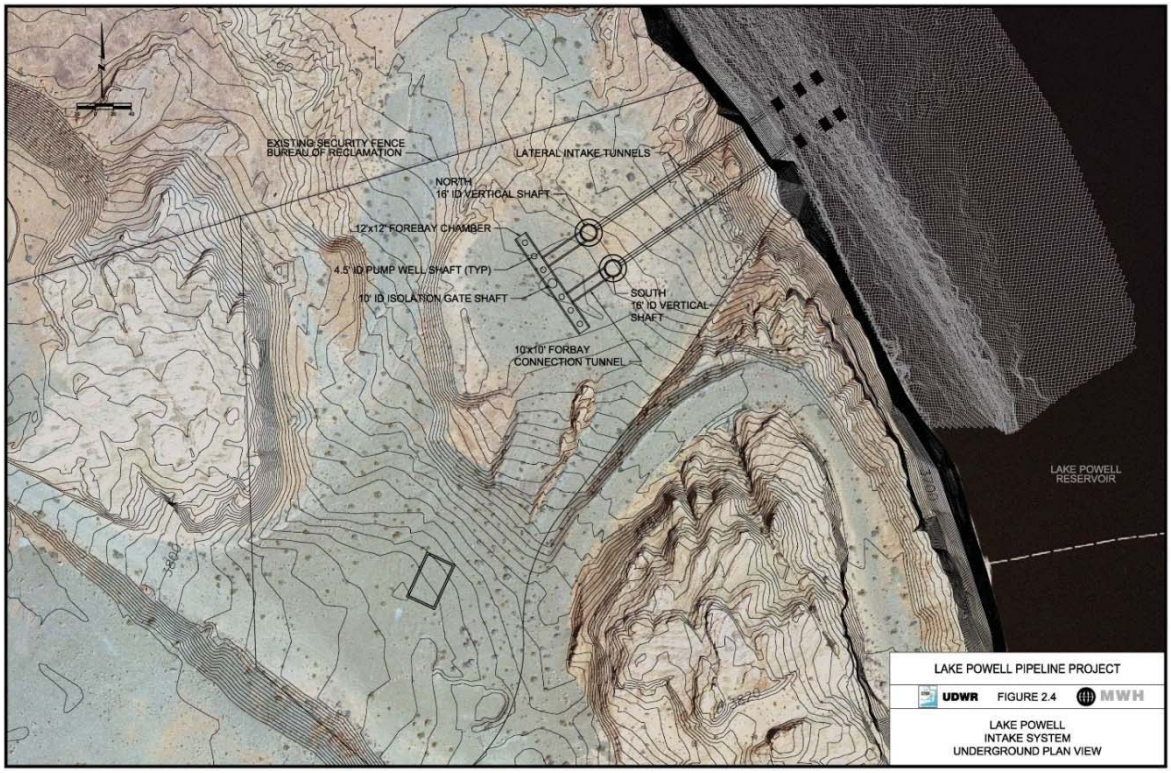


Figure 3-12. Lake Powell Pipeline Intake System Site Plan

3.2.6.2 Hurricane Cliffs Waterways

3.2.6.2.1 Hurricane Cliffs Low Pressure Tunnel, Vertical Shaft, and High Pressure Tunnel. Figure 3-13 shows the conceptual design for the Hurricane Cliffs Peaking and Pumped Storage Hydro System to include a low pressure tunnel and vertical surge and pressure shaft that shall be excavated through the bedrock units consisting primarily of hard, strong, and fractured limestone (and possibly conglomerates with chert clasts) with formations containing significant quantities of interbedded gypsum, sandstone, shale and siltstone. Subsurface investigations at the HCH Forebay and Afterbay determined that conditions are suitable for foundations for surface structures at these locations. A detailed evaluation of rock quality for tunnels and shafts has not been performed for the HCH tunnels and shaft or for the nearby Sand Hollow Tunnel.

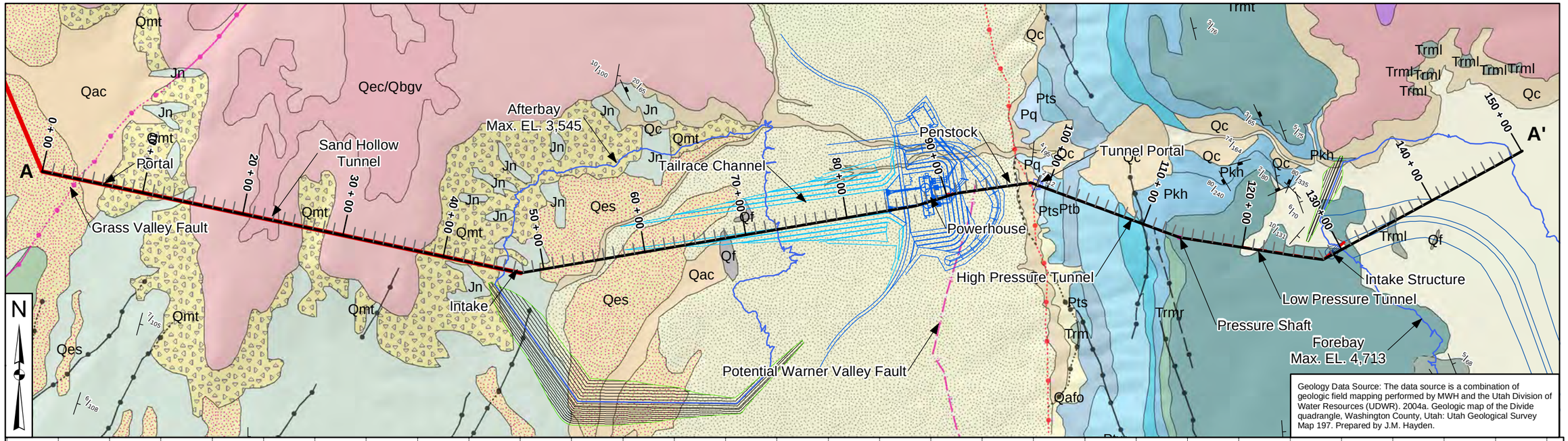
Detailed design of these structures will include any foundation preparations necessary to protect the facilities from settling and other potential structural damage. It is anticipated that additional subsurface investigations at these locations will be required to more fully characterize conditions for design. Subsurface characterization at the locations of proposed facilities and along the pipeline alignment of the selected alternative will be performed prior to the detailed design.

The waterway system to convey water collected in the forebay to the power generating unit and then to the afterbay will cross a number of mapped geologic units described below (RB&G 2010).

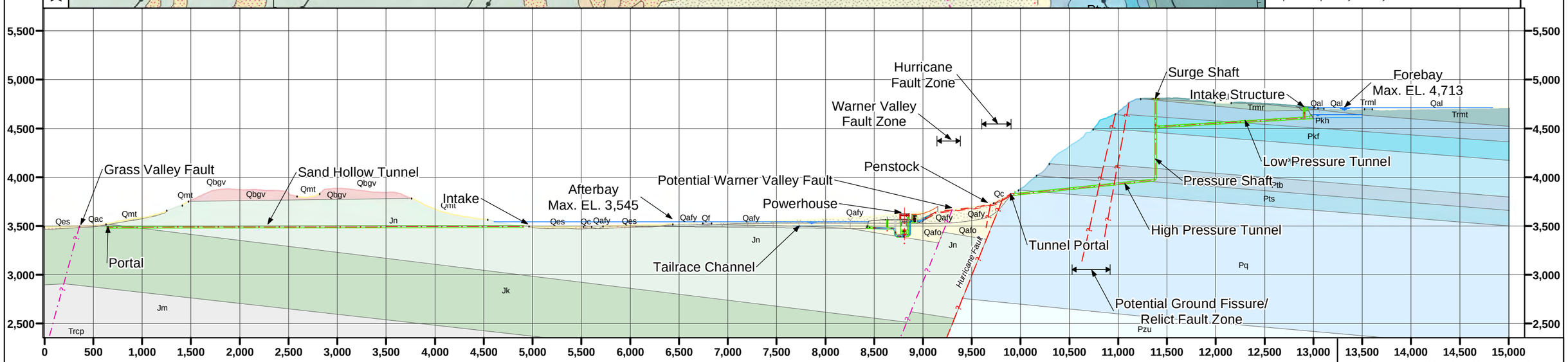
3.2.6.2.1.1 Alluvium and Highly Weathered Mudstone. The upper portion of the waterway alignment would include excavation of the approach channel (headrace channel), the intake structure and gate shaft, and the low pressure tunnel. These waterway components will likely involve excavations in alluvium (Qal) and highly weathered mudstone of the Moenkopi (Lower red member, Trml, and upper Timpoweap, Trmt) deposits in the forebay reservoir basin, which were classified as being predominantly silty clay with clayey sand and silty sand layers ranging in thickness from 1 to 18 feet.

3.2.6.2.1.2 Moenkopi Formation – Lower Red Member. Excavations for the upper portion of the waterway components, including the forebay, will likely encounter the lower red member of the Moenkopi Formation, TRml, which was observed at the upper portion of Hurricane Cliffs, and the lower Timpoweap limestone and Rock Canyon Conglomerate Member.

3.2.6.2.1.3 Moenkopi Formation – Timpoweap Member. The Timpoweap Member of the Moenkopi formation, TRmt, consists of limestone and dolomite with thin interbeds (i.e., seams, ¼ inch to 3 feet thick) of calcareous claystone, argillaceous limestone and sandy limestone that is yellowish brown to light gray in color, moderately weathered, moderately fractured, with traces of gypsum along bedding planes and thinly bedded to laminated clay seams. Fracture zones characterized during drilling by water loss and recorded high permeability zones may have identified sub-vertical joint sets.



Geology Data Source: The data source is a combination of geologic field mapping performed by MWH and the Utah Division of Water Resources (UDWR). 2004a. Geologic map of the Divide quadrangle, Washington County, Utah: Utah Geological Survey Map 197. Prepared by J.M. Hayden.



Hydro System
Joint Dip/Dip Direction

Contact Type
Certain
Un-Certain

Faults
Approximate, West
Certain, East
Certain, West
Concealed, East
Concealed, Unk
Concealed, West
Certain, West, Warner Valley Fault
Concealed, West, Hurricane Fault
Concealed, West, Warner Valley Fault
Concealed Potential Warner Valley Fault

Quaternary
Qal - Alluvial deposit
Qafy - Young alluvial fan deposits
Qafo - Old alluvial fan deposits
Qf - Artificial-fill deposits
Qc - Colluvial deposits
Qes - Eolian-sand deposits
Qmt - Talus deposits
Qac; Qaco - Mixed alluvial & colluvial deposits
Qbd - The Divide basalt flow
Qbgv - Grass Valley basalt flow
Qec/Qbd
Qec/Qbgv

Jurassic
Jn - Navajo Sandstone
Jk - Kayenta Formation

Triassic
Trm - Moenkopi Formation
Trml - Lower red member
Trmt - Timpoweap Member
Trmr - Rock Canyon Conglomerate Member

Permian
Pkh - Harrisburg Member
Pkf - Fossil Mountain Member
Ptw - Woods Ranch Member
Ptb - Brady Canyon Member
Pts - Seligman Member
Pq - Queantoweap Sandstone

FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472

0 500 1,000 1,500 2,000 Feet

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWRe **Figure 3-13** MWH

Hurricane Cliffs Waterway Features Geological Plan & Cross Section for Pump Storage

3.2.6.2.1.4 Moenkopi Formation – Rock Canyon Conglomerate Member. The Rock Canyon conglomerate member of the Moenkopi Formation, TRmr, consists of massive, moderately well cemented, channelized pebble conglomerate composed of highly silicified and calcareous matrix supporting coarse, rounded clasts composed of chert and limestone rip-up clasts. This unit is highly channelized and is not spatially extensive. It was observed that this formation was approximately 120 feet thick under the proposed left abutment of the forebay reservoir south dam that is closest to the Hurricane Cliffs intake structure, and it thins out towards the east to approximately 10-feet thick in the forebay reservoir basin under the south dam. The unit is mapped in the upper cliff face to the west of the south dam up to 50-75 feet thick in outcrops at the Hurricane Cliffs.

3.2.6.2.1.5 Kaibab Formation. The Kaibab Formation, Pk, consists of the Harrisburg Member and the Fossil Mountain Member. The Harrisburg and Fossil Mountain Members will likely need to be excavated to construct the following waterway features (Figure 3-13):

- Forebay intake structure
- Gate shaft
- Low-pressure tunnel
- Surge shaft (pumped storage option)
- Construction and inspection shaft (peaking option)
- Pressure shaft

3.2.6.2.1.6Kaibab Formation – Harrisburg Member. The Harrisburg Member, Pkh, is made up of cherty limestone with thin interbeds (seams, ¼ inch to 3 feet thick) of calcareous claystone and argillaceous limestone (marl); yellowish brown to light brownish gray in color with chert clasts and gypsum nodules, interbeds of mudstone and clay seams, with occasional gypsum layers, trace pyrite crystals and hydrocarbons in pits and vugs. This member will likely need to be excavated to construct portions of the forebay intake structure, gate shaft, low-pressure tunnel, and the surge, construction/inspection shaft. It was observed that there may be a potential paleo-karst contact zone between the Rock Canyon Conglomerate Member of the Moenkopi Formation and Harrisburg Member of the Kaibab Formation. Sub-vertical joint sets and fracture zones characterized by drilling water loss and high permeability (at about 67 feet below ground surface).

3.2.6.2.1.7 Kaibab Formation – Fossil Mountain Member. The underlying, cliff-forming Fossil Mountain Member, Pkf, consists of massive, fossiliferous limestone with few small (3- 4-inches thick) interbeds of calcareous mudstone at intervals of 3 to 5 feet as much as 200 feet thick. This member will likely need to be excavated to construct portions of the low-pressure tunnel, surge and construction/inspection shaft, and pressure shaft. It is estimated that this formation may be excavated with difficulty. Gypsum was noted as common in this formation; however, significant outcrop exposures of gypsum were not observed during the reconnaissance. The gypsum appears to be present only in the western part of the map area.

3.2.6.2.2 Middle Portion of Hurricane Cliff – Pressure Shaft and Pressure Tunnel. The pressure shaft and the eastern portion of the pressure tunnel components of the waterway alignment will likely involve excavations in the Toroweap Formation, Pt, which was observed during field reconnaissance; however, this formation was not drilled or tested as part of preliminary subsurface investigation. This formation was observed as the lower portion of Hurricane Cliffs and is made up of the following members (Figure 3-13):

- Woods Ranch Member, Ptw
- Brady Canyon Member, Ptb
- Seligman Member, Pts

The high pressure tunnel will be excavated through the shallow east dipping layers of limestone and sandstone with minor interbeds of gypsum, shale, and siltstone. The lower portal location was selected such that the pressure tunnel could transition into the penstock through a concrete encasement structure completely on the east side of the Hurricane fault and away from significant rockfall hazard and accumulations of talus and landslide debris. The penstock section of the waterways would cross the Hurricane fault and Warner Valley fault before entering the powerhouse.

3.2.6.2.2.1 Toroweap Formation – Woods Ranch Member. The Woods Ranch Member of the Toroweap Formation, Ptw, appears to be composed of thin bedded limestone and gypsiferous siltstone and silty sandstone with calcareous mudstone interbedded with white laminated gypsum and gray thin bedded limestone, intensely fractured, with up to 70% of the unit containing massive gypsum beds that are as much as 10 feet to 30 feet thick. Bedding is locally distorted due to dissolution of gypsum.

3.2.6.2.2.2 Toroweap Formation – Brady Canyon Member. The underlying, cliff-forming Brady Canyon Member of the Toroweap Formation, Ptb, appears to be limestone with chert and interbeds of calcareous siltstone and fine sandstone; yellowish brown to light brownish gray in color with chert clasts and gypsum nodules, interbeds of mudstone and clay seams, with occasional gypsum layers. The limestone is potentially very hard and very strong with two sub-vertical, orthogonal joint sets plus random joints and sub-horizontal bedding. This member will likely need to be excavated to construct portions of the pressure shaft and high-pressure tunnel.

3.2.6.2.2.3 Toroweap Formation – Seligman Member. The basal Seligman Member of the Toroweap Formation, Pts, appears to be silty sandstone and gypsifereous siltstone, interbedded with white laminated gypsum and gray thin bedded limestone. This member will likely need to be excavated to construct portions of the high-pressure tunnel. Reconnaissance of the Hurricane Cliffs face found deposits of gypsum beds. The presence of gypsum beds could potentially result in squeezing ground and potential roof support issues as the tunnel crosses alternating sub-horizontally bedded units.

3.2.6.2.3 Lower Hurricane Cliff – Pressure Tunnel, Portal, Transition. The high pressure tunnel and tunnel portal are likely to encounter the Brady Canyon Member and Seligman Member of the Toroweap Formation, as well as the Queantoweap Sandstone. The Brady Canyon Member and Seligman Member are described in Sections 3.2.6.2.2.2 and 3.2.6.2.2.3, respectively. The Queantoweap Sandstone is described below.

3.2.6.2.3.1 Queantoweap Sandstone. The Queantoweap Sandstone, Pq, is a massive, moderately resistant, cross bedded, slightly weathered calcareous, fine-grained sandstone with silica and/or calcium carbonate cementation that is yellowish-brown in color and locally called the Coconino Sandstone. It is moderately hard, moderately strong, and massive with at least two sub-vertical, widely spaced, orthogonal joint sets and sub-horizontally dipping bedding. The thickness is at least 1000 feet, but it's estimated that only the upper 75 feet are exposed at the base of the Hurricane Cliffs in the mapped area. Thus, the high pressure tunnel will encounter only the top of the Queantoweap Sandstone. It is anticipated that the portion of the high pressure tunnel that is constructed in the Queantoweap Sandstone will encounter competent rock.

3.2.6.2.4 Below Hurricane Cliff - Penstock, Powerhouse, Tailrace, Afterbay. The lower portal and transition (i.e., "transition" = concrete encasement connecting the high pressure tunnel segment to the penstock segment) should be located entirely on the east side of the main Hurricane fault. The penstock section of the waterway shall then be constructed across the fault zone and extend to the powerhouse and constructed in colluvial (Qc), and younger alluvial fan deposits (Qafy) (this configuration is the same for peaking and pumped storage). The powerhouse shall be constructed through about 90 feet of younger alluvial fan deposits, and about 120 feet of older alluvial deposits (Qafo) with the bottom 55 feet constructed

in the Navajo Sandstone (Jn). Waterway features below the powerhouse will likely be located in eolian-sand (Qes), young and old alluvial fan deposits.

The surficial deposits were observed in the valley bottom at the afterbay reservoir location. These deposits will likely need to be excavated to construct the following waterway features:

- Penstock
- Powerhouse
- Draft tube extension
- Draft tube gate shaft
- Tailrace channel
- Afterbay intake structure
- Sand Hollow tunnel

3.2.6.2.4.1 Colluvial Deposits. The colluvial deposits, Qc, are expected to be encountered near the base of Hurricane Cliffs during the penstock excavation. The colluvial deposits are poorly sorted, angular to rounded blocks in a muddy to sandy matrix, deposited by sheet wash and soil creep on moderate slopes. Colluvial deposits are generally less than 50 feet thick.

3.2.6.2.4.2 Young Alluvial Fan Deposits. The young alluvial fan deposits, Qafy, are classified as being predominantly silty/clayey gravel with sand and cobbles ranging in thickness from 10 feet on the west side of the valley to more than 100 feet on the east side of the valley toward Hurricane fault and approximately 90 feet thick at the proposed powerhouse location.

3.2.6.2.4.3 Old Alluvial Fan Deposits. The old alluvial fan deposits, Qafo, were observed in drill holes underlying the young alluvial fan deposits and typically on the eastern side of proposed afterbay reservoir basins. The old alluvial fan deposits are classified as being darker in color, denser, and have larger quantities of fines than the young alluvial fan deposits. The old alluvial fan deposits are sometimes semi-consolidated, and at times are classified as “mudstone” on some of the field logs because of the high degree of consolidation and density.

3.2.6.2.4.4 Eolian-Sand Deposits. The eolian sand deposits, Qes, are expected to be encountered at the west exit portion of the tailrace channel. The eolian sand deposits are unconsolidated windblown sand and silty sand deposits, now mostly stabilized by vegetation. The thickness of the deposit is expected to be less than 15 feet.

3.2.6.3 Sand Hollow Tunnel

3.2.6.3.1 Navajo Sandstone. The Navajo Sandstone is expected to be the main rock type that will likely be encountered in the Sand Hollow Tunnel (Figure 3-13), although bedded sandstones and sandy siltstones of the Kayenta Formation (Jk) may be encountered at the west end to the tunnel and portal area. The Grass Valley basalt flow (Qbgv) provides a resistant capping layer above the Navajo Sandstone.

Navajo Sandstone is generally pale to moderate reddish brown with spots and zones that are very dark reddish brown, dark brown, and white; the depositional bedding is very thickly bedded to massive (bedding is mostly greater than 3 feet, and typically greater than 10 feet thick and dipping 5- to 10-degrees to the east, and exhibits pronounced laminated to thin, high-angle cross-bedding (dipping 0- to 40-degrees in varying directions). The rock is composed of very fine to medium-grained, well-rounded to sub-rounded, well-sorted, frosted quartz sand grains that are clast supported (grain-to-grain contact) and moderately- to well-cemented primarily with silica and to a lesser degree locally with hematite, limonite, and calcite that appear as coatings on individual sand grains. The rock is moderately weathered with iron

oxide coating sand grains and staining throughout the rock mass; moderately soft to moderately hard but can be locally soft and friable; intact rock is mostly weak but can be locally medium strong (up to 3,600-7,200 psi); the sand grains and cement have no reaction with hydrochloric acid (HCL) with the exception of occasional, very small, limonite and/or calcite blebs that exhibit a minor reaction with hydrochloric acid (RB&G 2010).

3.2.7. Borrow and Spoil

The soil and rock materials excavated from the trenches, road cuts, tunnels and shafts would be reused for pipeline bedding and backfill, construction of maintenance roads, and dam construction to the extent economically practical. All excavated rock would be used for bedding, backfill, and road construction. Assuming that 75 percent of the excavated rock would be usable for bedding and the remaining rock could be used for maintenance road construction, all rock would be used.

Construction of the North Dam and South Dam for the Forebay reservoir, and construction of the Afterbay Dam for the Afterbay reservoir, will use all rock excavated from the tunnels and shafts for the Hurricane Cliffs hydrosystem (36,710 cubic yards) and for the Sand Hollow Tunnel (40,291 cubic yards), for a total of 77,001 cubic yards. Borrow requirements are anticipated to be needed for certain specialized materials. If necessary, specialized material, such as the clay for dam core construction (515,300 cubic yards for all three dams), may have to be obtained from sources outside of the project boundary. It is anticipated that the clay pit near the City of Hurricane, owned by WCWCD, would be used as the clay source. The remaining dam construction material requirements, including sand for filters, general fill, and riprap, would be obtained using excavated rock and soil at the dams, with the deficit of fill material supplemented from excess soil from the trenches excavated during construction of the pipeline and penstock. The total excavated rock and soil for all three dams is estimated at 2,592,600 cubic yards. Excluding the clay core, the remaining material required for sand filters, fill, and riprap is 2,823,200 cubic yards. After accounting for the 77,001 cubic yards from tunnels and shafts, this leaves a net deficit of material for fill of 153,600 cubic yards that would come from excess soil associated with the trenches for the pipeline and penstock.

Cross-sections that include construction activities through the Cockscomb Cut area were developed as part of the conceptual design. These sections are provided in Appendix C. The cross-sections are provided for 13 stations between Project Station 1689+80 and 1734+15 (a total alignment length of 4,435 feet) and show the approach, passage through the cut, highway crossing, and exit from the cut. Using the cross-sections, an estimate of rock that would be removed on the cut slope was made. Potential slope modifications to the north cut slope are shown in some of the cross sections. Slope modifications would probably require controlled drill and blast methods (common to the highway construction industry). Rock material suitable for crushing and use as pipe bedding will be processed and used for that purpose. The remaining material will be used as backfill and/or spread as spoils along the ROW outside of the cut area.

Because the Utah Department of Transportation would be unlikely to approve an open cut highway crossing in this reach, the pipeline crossing under Highway 89 in the Cockscomb Cut would either be bored and jacked, or microtunneled with a casing pipe. The primary factor controlling this choice is whether groundwater is present and, if so, how effectively it can be dewatered. Groundwater is not expected to be encountered in the Cockscomb Cut.

A preliminary comparison between the excavated volumes and the volumes of materials needed for construction of all alternatives is shown in Table 3-13. The volumes used for construction assume that excavated soils would expand and would then be recompacted to 90 percent of their pre-excavated volume. Similarly, construction volumes for rock assume that excavated rock material would expand and would be recompacted to 65 percent of pre-excavated volume. The comparison indicates a surplus of soil

for all alternatives, including 2,053,924 cubic yards for the South Alternative; 1,039,878 cubic yards for the Existing Highway Alternative, and 1,846,413 cubic yards for the Southeast Corner Alternative. Rock for bedding material would be sufficient for the total required volume for the South and Southeast Corner alternatives. The amount of soil that would need to be used for bedding is estimated at 0 percent for the South Alternative, 48.5 percent for the Existing Highway Alternative, and 0 percent for the Southeast Corner Alternative. The surplus soil would be spread across the ROW along the pipeline and penstock alignments. The preliminary analysis indicates the spread spoils would be approximately 5.5 inches thick for the South Alternative, 4.4 inches thick for the Existing Highway Alternative, and 7.1 inches thick for the Southeast Corner Alternative. The spoils would be spread in a manner to blend with original topography and drainages with periodic swales or rolling dips to promote natural drainage patterns.

Table 3-13
Lake Powell Pipeline Summary of Borrow, Fill and Spoil Quantities

Page 1 of 2

	South Alternative	Existing Highway Alternative	Southeast Corner Alternative	Remarks
Total Blasted Rock from Trenches (CY)	1,983,270	910,370	1,913,040	
Total Ripped Rock from Trenches	1,264,720	1,876,000	1,443,700	
Total Rock from Intake Tunnels and Shafts (CY)	10,820	10,820	10,820	Assumes rock from other tunnels and shafts used for dam construction
Total Rock from Cockscomb Cut Slope Reductions	154,560	154,560	154,560	
Total Excavated Soil (CY)	2,837,010	3,358,600	2,660,800	
Total Ripped Rock + Excavated Soil	4,101,830	5,234,700	4,104,500	
Total Excavated Material (CY)	6,250,380	6,310,350	6,182,920	
Total Bedding Required (CY)	2,081,050	2,114,180	1,696,380	
Total Backfill Required (CY)	3,267,830	3,338,670	2,677,220	
Total Rock Volume after Swell and Recompaction (CY)	2,900,680	1,452,260	2,805,880	Recompacted to 65 percent of original volume. Estimate based on typical recompaction limits after swell (USDOT/FHA 2007)
Remaining Rock Used for Backfill (CY)	809,850	354,550	1,099,710	

Table 3-13
Lake Powell Pipeline Summary of Borrow, Fill and Spoil Quantities

	South Alternative	Existing Highway Alternative	Southeast Corner Alternative	Remarks
Total Soil and Ripped Rock Volume after Swell and Recompaction (CY)	4,511,900	5,758,080	4,511,900	Recompacted to 90 percent of original volume
Excess Blasted Rock (CY)	94,460	0	417,020	
Total Soil Volume Used for Bedding (CY)	0	1,024,980	0	
Total Soil Volume Used for Backfill (CY)	2,363,520	2,984,120	1,565,510	
Total Soil Volume Used in Dams (CY)	153,600	153,600	153,600	Recompacted to 90 percent of original volume
Total Excess Soil Volume to be Spread as Spoil (CY)	2,089,250	1,595,380	2,529,370	Recompacted to 90 percent of original volume
Total Right-of-Way Area (Acres)	2,848	2,724	2,823	Based on 120-ft wide ROW on BLM and Tribal lands, 100 ft ROW on all other lands
Thickness of Compacted Soil Spread on Right-of-Way (inches)	5.5	4.4	7.1	

Construction activities, including the pipeline, pump stations, hydro facilities, reservoirs, transmission lines, excavation, hauling, spoils disposal, and other features would require a Right of Way (ROW) grant from the BLM as specified in 43 CFR Parts 2800 and 2880 and in Sections 501 through 506 of the Federal Lands Policy Management Act of 1976, Amended October 2001 (FLPMA) (BLM 2001). Permits for excavation, hauling, and disposal of spoils may be granted by the BLM under Section 302 of FLPMA. As required under 43 CFR Subtitle B.1.429, a Use Authorization may be required from the U.S. Bureau of Reclamation for excavation and construction activities and removal of spoils from the Lake Powell Intake Structure site. The Utah Department of Transportation and the Arizona Department of Transportation may both require truck haul permits when using public roadways to transport excavated materials. These would be the responsibility of the individual construction contractors.

Chapter 4
Environmental Consequences (Impacts)

4.1 Significance Criteria

The following criteria were used in this evaluation to determine whether impacts associated with the LPP Project appurtenances would be significant. Significance criteria were established based on the impact topics identified herein, which were identified in the Study Plan. Impacts are considered significant only if they would occur within the design life of the Project (75 years), and could not be mitigated by design.

4.1.1. Fault Movement

Fault movement impacts would be considered significant if the rate of displacement would result in pipeline rupture. The minimum total allowable displacement that would result in pipeline rupture has not been determined, but for large diameter steel pipe the displacement tolerance is likely to be at least 75 mm (about three inches). Thus, an average displacement rate of 1 mm/year or more would be more likely to result in pipeline rupture during the design life of the Project and therefore could cause a significant impact.

4.1.2. Seismic Activity

Seismic activity would have a significant impact if an earthquake would create unstable foundation conditions for the pipeline or associated features, resulting in pipeline deformation or rupture, or pipeline feature failure. This instability could include liquefaction of underlying soils or slope failure above or below the pipeline or associated features. Proper seismic design would prevent substantial damage to the pipeline or associated features in the event of an earthquake under most circumstances. A risk of a significant impact would be high if all or part of an alignment alternative is located in a zone with high (greater than about 0.4 gravity) Peak Ground Acceleration (PGA) with a two percent or greater probability of exceedance within 50 years, and this would occur in a location with a high probability of liquefaction (saturated, sandy soil within the pipeline trench depth or excavated depth of pipeline facilities; for practical purposes a depth of 15 feet was assumed for the LPP Project).

4.1.3. Unstable Slopes

Slope failure along the pipeline alignments would be considered a significant impact if the slope failure were caused by construction or operation of the pipeline or associated features, and if the slope failure resulted in injury to humans, damage of major human structures, or damage to the environment (significant and long-term erosion; discharges to streams, rivers, lakes or reservoirs causing degradation of water quality as defined by Utah or Arizona state law; or long-term loss of important wildlife habitat).

4.1.4. Expandable, Collapsible, or Subsiding Soils or Rocks

Geologic hazards from soil or rock conditions would have a significant impact if such conditions would occur and would cause deformation or failure of foundation conditions underlying the pipeline or associated features sufficient to cause pipeline rupture or failure of associated pipeline features.

4.1.5. Geologic Hazards to Human Health and Safety

Impacts associated with geologic hazards to human health or safety associated with construction or operation of the pipeline and associated features would be considered significant if the impacts of geologic hazards resulted in human injury or death, or presented a serious risk to human health.

4.1.6. Important Structures and Mineral Resources

Construction or operation impacts on important human structures would be significant if they would result in major damage to the structures. Major damage includes damage requiring replacement, or repairs that would cost more than 25 percent of the value of the structure, or damage which renders the structure inoperable or unusable.

4.1.7. Borrow and Spoil

Impacts associated with borrow of material for pipeline or structure bedding would be significant if extraction of borrow material causes new and substantial disturbance of land from the extraction source areas.

Impacts associated with disposal (spoil) of excess excavated material would be significant if disposal of spoils would cause substantial changes in runoff patterns, turbid runoff that would discharge to rivers, streams, or lakes, or create unstable slope conditions.

4.2 Potential Impacts Eliminated From Further Analysis

No impacts were eliminated from further analysis.

4.3 South Alternative Impacts

4.3.1. Construction Impacts

4.3.1.1 Fault Movement

The rate of fault movement on faults crossed by the South Alternative alignment and associated hydraulic conveyance and hydropower segments of the LPP Project are believed to be no more than 0.2 mm/year on average for the Paunsaugunt Fault and less than that for the Sevier Fault. The vertical slip rate for the Hurricane fault in the proposed pipeline crossing has been estimated to be 0.2 to 0.4 mm/year. The vertical slip rate on the Sand Mountain - West Grassy Valley fault is estimated to be 0.1 to 0.2 mm/year. The displacement rate for other faults crossed by the South Alternative alignment is unknown but this is probably because the remaining faults appear to be less active. The duration of construction activities is too short to be affected by such low rates of displacement. Therefore, no impacts would occur during construction.

4.3.1.2 Seismic Activity

Major earthquakes can occur associated with faults along the South Alternative alignment and are likely to occur during the design life of the LPP Project; however, most measured earthquakes in the vicinity have been associated with the Basin and Range Province or the transition zone between the Colorado Plateau and the Basin and Range, both of which are west of the South Alternative alignment. This probably would diminish the potential impacts of earthquake activity on the South Alternative alignment. Proper bedding and pipeline design and construction would further minimize seismic effects. The

alignment lies within a zone of low to moderate projected PGA (0.2 to 0.4 gravity PGA) with a two-percent probability of exceedance over a 50-year period. Therefore, no impacts would occur.

4.3.1.3 Unstable Slopes

Locations where rockfall and steep slopes exist along the various alignments, including the South Alternative and associated alignment sections, are shown in Tables 3-3, 3-5, and 3-6. Nine locations were identified that are subject to rockfall hazards on steep slopes. These locations are primarily associated with channel crossings or adjacent loose rock outcrops on steep slopes. These locations may be subject to failure, particularly in the event of an earthquake. Individual locations would need to be examined before heavy earthwork, especially blasting, could take place, and site stabilization measures or removal of rock and soil at risk of failure may need to occur before proceeding. A minimum of three feet cover would be required for buried pipeline and penstock to protect against damage to the facilities; the actual depth burial would be determined during detailed design. If these precautions are followed, no measurable impacts and no significant impacts would occur.

4.3.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Substantial sections of the South Alternative may be subject to expandable, collapsible, or subsiding soils or rocks, as identified in Tables 3-8, 3-9, and 3-11. These are primarily associated with gypsiferous soils, which are susceptible to subsidence if gypsum is frequently or extensively exposed to water because gypsum can dissolve, leaving voids. Expansive soils occur in some places along the alignment and are associated with clay deposits, primarily montmorillonite derived from basalts. Construction in such materials may require special design considerations, such as over-excavation and placement of additional bedding, may be necessary. If design considerations are implemented where appropriate, no measurable and no significant impacts would occur.

4.3.1.5 Geologic Hazards to Human Health and Safety

Geologic hazards to human health and safety would be minimized by following appropriate and site-specific precautions, including trench shoring or sloping, slope stabilization where applicable, and other standard construction safety practices. Therefore, no measurable and no significant impacts would occur.

4.3.1.6 Important Structures and Mineral Resources

Human structures within 1,000 feet of the South Alternative are shown in Table 3-14. The primary risk of damage is associated with the effects of blasting during trenching, since none of the structures are in the direct alignment (excluding highway crossings, which are not included as part of this evaluation and in any event would be repaired as necessary). Approximately 48 percent of the alignments for the South Alternative may require some blasting during trenching. Most of the lengths of the alternative alignments are not near structures that would be susceptible to damage from the effects of blasting. Structures or groups of structures that may be at risk from damage caused by blasting include the Town of Big Water, Utah and a windmill at Station 6270+00; all other important structures are not near trench sections that would require blasting. Special blasting methods may need to be employed to minimize the transfer of energy through rock and soil to the structures. At Big Water, most of the town overlies several feet of soil. This would help to absorb and therefore help minimize the transfer of energy to the buildings. Therefore, no measurable and no significant impacts would occur.

4.3.1.7 Borrow and Spoil

The South Alternative would have no measurable impacts on borrow material development for pipeline and penstock bedding or spoil material disposal. It is anticipated that the material for the pipe zone, underlying bedding, and backfill would be obtained from materials extracted during construction. Rock

excavated along the alignment suitable for crushing would meet the pipeline and penstock bedding requirements and no bedding material would need to be imported from commercial gravel pits. The South Alternative would not require expanding or developing additional gravel resources to meet construction demands for the LPP pipeline and penstock alignments. Therefore no measurable impacts would occur with obtaining borrow materials. No significant impacts would occur associated with obtaining borrow materials.

The material generated as part of the pipeline and penstock construction consists of the following categories:

- Blastable (hard rock such as hard limestone and well-cemented sandstone)
- Rippable (soft rock such as shale, mudstone, soft limestone, and poorly-cemented sandstone)
- Mixed Soil over Blastable (soil - assumed 5' thick - over blastable material as described above)
- Mixed Soil over Rippable (soil - assumed 5' thick – over rippable material as described above)
- Excavatable (soil and highly decomposed rock)

The volumes of material generated (neat lines excluding expansion) in cubic yards are summarized below:

- Blastable 1,666,300
- Rippable 1,122,500
- Mixed Soil over Blastable 806,600 (489,600 soil - 317,000 rock)
- Mixed Soil over Rippable 382,300 (240,100 soil – 142,200 rock)
- Excavatable 2,107,300

Disposal of South Alternative spoils is expected to be primarily by spreading within the alignment right-of-way. In most locations, approximately 5.5 inches of spoils is anticipated to be spread across the alignment right of way. No additional spoil disposal areas would be required and spoil disposal along the pipeline and penstock alignments would be within the excavated trenches, covered with topsoil as available, and revegetated with an endemic plant seed mixture to stabilize surface particles and avoid erosion, and graded, at approximate original contours. Rolling dips will be built into the spoils in the alignment right-of-way where needed to promote natural drainage, and culverts will be installed if needed where maintenance roads exist. All spoiled materials would be reclaimed by standard stabilization practices and seeding with an approved seed mix. Therefore, no measurable impacts would occur associated with spoil disposal. The South Alternative would have no significant impacts resulting from spoil material disposal.

4.3.2. Operation and Maintenance Impacts

4.3.2.1 Fault Movement

The Paunsaugunt fault has a projected displacement rate of <0.2 mm/year, and the Sevier fault displacement rate is 0.04 to 0.18 mm/year. Projected displacement of the Hurricane fault is estimated at 0.2 to 0.4 mm/year. The displacement rates for the other faults crossed by the South Alternative alignment are not known, but these faults appear to be less active, which is why displacement rates have not been determined. A displacement of 0.2 mm/year, which exceeds average displacement rates for the most active faults (including the Paunsaugunt and Sevier faults) would result in a total displacement of 15 mm over the Project design life. A displacement of 0.4 mm/year would result in a total displacement of 30 mm over the project design life. These would be less than half of the significance criterion of 75 mm over 75 years. Therefore, no measurable and no significant impacts associated with fault movement would occur.

4.3.2.2 Seismic Activity

Major earthquakes can occur associated with faults along the South Alternative alignment and are likely to occur during the design life of the Project; however, most measured earthquakes in the vicinity have been associated with the Basin and Range Province or the transition zone between the Colorado Plateau and the Basin and Range, both of which are west of the South Alternative alignment. This probably would diminish the potential impacts of earthquake activity on the South Alternative alignment. Proper bedding and pipeline design and construction, and other appropriate mitigation measures developed during detailed design, would further minimize seismic effects. The alignment lies within a zone of low to moderate projected PGA with a two-percent probability of exceedance over a 50-year period. Therefore no measurable impacts would occur.

Saturated sandy soils may be encountered at the crossing of the Paria River. However, the projected PGA is low, and proper design and construction would minimize the risks of impacts associated with liquefaction at this location. Therefore, no measurable and no significant impacts would occur associated with liquefaction.

4.3.2.3 Unstable Slopes

General locations where rockfall and steep slopes exist along the various alignments, including the South Alternative and associated alignment sections, are shown in Tables 3-3 through 3-6. These locations may be subject to failure, particularly in the event of an earthquake, but because the pipeline would be buried with a minimum of three feet of cover (to be determined during detailed design) this probably would not affect the pipeline operations or maintenance, and conversely the operation and maintenance of the pipeline is unlikely to affect the slope stability. Therefore, no measurable impacts and no significant impacts would occur.

4.3.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Substantial sections of the South Alternative alignment may be subject to expandable, collapsible, or subsiding soils or rocks, as identified in Tables 3-8, 3-9, and 3-11. These are primarily associated with gypsiferous soils, which are susceptible to subsidence if gypsum is extensively wetted because gypsum can dissolve, leaving voids. Expansive soils occur in some places along the alignment and are associated with clay deposits, primarily montmorillonite derived from basalts and from regional volcanic ash, rock, or debris associated with the Petrified Forest Member of the Chinle Formation. If design considerations are implemented where appropriate, no measurable impacts and no significant impacts would occur associated with operations and maintenance.

4.3.2.5 Geologic Hazards to Human Health and Safety

Geologic hazards to human health and safety during operations and maintenance would be minimized if appropriate design and construction practices are followed. Therefore, no measurable impacts and no significant impacts would occur.

4.3.2.6 Important Structures and Mineral Resources

No measurable impacts and no significant impacts would occur in connection with operations and maintenance.

4.3.2.7 Borrow and Spoil

No measurable impacts and no significant impacts would occur associated with operations and maintenance.

4.4 Existing Highway Alternative Impacts

4.4.1. Construction Impacts

4.4.1.1 Fault Movement

The rate of fault movement on faults crossed by the Existing Highway Alternative alignment and associated hydraulic conveyance and hydropower segments of the LPP Project are believed to be no more than 0.2 mm/year on average. The vertical slip rate for the Hurricane fault in the reach of the proposed pipeline crossing has been estimated to be 0.2 to 0.4 mm/year. The vertical slip rate on the Sand Mountain - West Grassy Valley fault is estimated to be 0.1 to 0.2 mm/year. The duration of construction activities is too short to be affected by such low rates of displacement. Therefore, no impacts would occur during construction.

4.4.1.2 Seismic Activity

Impacts associated with seismic activity for the Existing Highway Alternative would be similar to impacts for the South Alternative. No measurable impacts and no significant impacts would occur.

4.4.1.3 Unstable Slopes

Locations where rockfall and steep slopes exist along the Existing Highway Alternative alignment and associated alignment sections, are shown in Table 3-3, 3-4, and 3-6. Five locations were identified that are subject to rockfall hazards on steep slopes. These locations are primarily associated with channel crossings or adjacent loose rock outcrops on steep slopes. The slope failure hazards are similar to the hazards for the South Alternative; therefore, no impact would occur if appropriate precautions are taken.

4.4.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Impacts associated with expandable, collapsible, or subsiding soils or rocks for the Existing Highway Alternative alignment would be similar to impacts for the South Alternative alignment and are a result of gypsiferous soils, expansive clays, or gypsiferous or clay-mineral rocks, as identified in Table 3-8, 3-9, 3-10, and 3-11. If design considerations are implemented where appropriate, no measurable impacts and no significant impacts would occur.

4.4.1.5 Geologic Hazards to Human Health and Safety

Geologic hazards to human health and safety would be minimized by following appropriate and site-specific precautions, including trench shoring or sloping, slope stabilization where applicable, and other standard construction safety practices. This would be the same as for the South Alternative. Therefore, no measurable impacts and no significant impacts would occur.

4.4.1.6 Important Structures and Mineral Resources

Human structures within 1,000 feet of the Existing Highway Alternative alignment are shown in Table 3-12. Approximately 24 percent of the alignment of the Existing Highway Alternative may require some blasting during construction. The primary risk of damage is the same as for the South Alternative and includes the same structures, which are located on sections that are common to both alternatives. Therefore, no measurable impacts and no significant impacts would occur if appropriate precautions are taken.

4.4.1.7 Borrow and Spoil

The excavation associated with construction of the Existing Highway Alternative would require an estimated 1,181,478 cubic yards of bedding that would originate from soil excavated from the pipeline and penstock trenches, about 56 percent of the total bedding material required. Because subsurface characterization could not be performed along most of the alternative alignments, it is not known whether sufficient volume of suitable bedding material could be obtained, and the deficit may need to be supplemented from commercial gravel pits. The removal of more than one million cubic yards of material from commercial pits would be a significant impact on existing commercial gravel pits and currently undisturbed land areas suitable for producing construction bedding materials.

The material generated as part of the pipeline and penstock construction consists of the following categories:

- Blastable (hard rock such as hard limestone and well-cemented sandstone)
- Rippable (soft rock such as shale, mudstone, soft limestone, and poorly-cemented sandstone)
- Mixed Soil over Blastable (soil - assumed 5’ thick - over blastable material as described above)
- Mixed Soil over Rippable (soil - assumed 5’ thick – over rippable material as described above)
- Excavatable (soil and highly decomposed rock)

The volumes of material generated (neat lines excluding expansion) in cubic yards are summarized below:

- Blastable 732,600
- Rippable 1,712,500
- Mixed Soil over Blastable 452,300 (274,500 soil – 177,800 rock)
- Mixed Soil over Rippable 439,900 (276,300 soil – 163,600 rock)
- Excavatable 2,807,800

Disposal of South Alternative spoils is expected to be primarily by spreading within the alignment right-of-way. In most locations, approximately 4.4 inches of spoils is anticipated to be spread across the alignment right of way. No additional spoil disposal areas would be required and spoil disposal along the pipeline and penstock alignments would be within the excavated trenches covered with topsoil as available, and revegetated with an endemic plant seed mixture to stabilize surface particles and avoid erosion, and graded at approximate original contours. Rolling dips will be built into the spoils in the alignment right-of-way where needed to promote natural drainage, and culverts will be installed if needed where maintenance roads exist. The Existing Highway Alternative would have no significant impacts resulting from spoil material disposal.

4.4.2. Operation and Maintenance Impacts

4.4.2.1 Fault Movement

Impacts associated with fault movement for the Existing Highway Alternative alignment would be similar to the South Alternative. Therefore, no measurable impacts and no significant impacts associated with fault movement would occur.

4.4.2.2 Seismic Activity

Impacts associated with seismic activity for the Existing Highway Alternative alignment would be the same as for the South Alternative. Proper bedding and pipeline design and construction would further minimize seismic effects. Therefore, no measurable impacts would occur.

4.4.2.3 Unstable Slopes

Impacts associated with slope failure during operation and maintenance for the Existing Highway Alternative are the same as for the South Alternative. No measurable impacts and no significant impacts would occur.

4.4.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Substantial sections of the Existing Highway Alternative alignment may be subject to expandable, collapsible, or subsiding soils or rocks, as identified in Table 3-8, 3-9, and 3-10. These are primarily associated with gypsiferous soils, which are susceptible to subsidence if gypsum is frequently or extensively exposed to water because gypsum can dissolve, leaving voids. Expansive soils occur in some places along the alignment and are associated with clay deposits, primarily montmorillonite derived from basalts and from regional volcanic ash, rock, or debris associated with the Petrified Forest Member of the Chinle Formation. If design considerations are implemented where appropriate, no measurable impacts and no significant impacts would occur associated with operations and maintenance activities.

4.4.2.5 Geologic Hazards to Human Health and Safety

No measurable impacts and no significant impacts would occur.

4.4.2.6 Important Structures and Mineral Resources

No measurable impacts and no significant impacts would occur.

4.4.2.7 Borrow and Spoil

No measurable impacts and no significant impacts would occur.

4.5 Southeast Corner Alternative

4.5.1. Construction Impacts

4.5.1.1 Fault Movement

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.2 Seismic Activity

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.3 Unstable Slopes

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.5 Geologic Hazards to Human Health and Safety

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.6 Important Structures and Mineral Resources

Impacts would be the same as for the South Alternative. No impacts would occur during construction.

4.5.1.7 Borrow and Spoil

The Southeast Corner Alternative would have no measurable impacts on borrow material development for pipeline and penstock bedding or spoil material disposal. It is anticipated that the material for the pipe zone, underlying bedding, and backfill would be obtained from materials extracted during construction. Rock excavated along the alignment suitable for crushing would meet the pipeline and penstock bedding requirements and no bedding material would need to be imported from commercial gravel pits. The Southeast Corner Alternative would not require expanding or developing additional gravel resources to meet construction demands for the LPP pipeline and penstock alignments. Therefore, no measurable impacts would occur with obtaining borrow materials. No significant impacts would occur associated with obtaining borrow materials.

The material generated as part of the pipeline and penstock construction consists of the following categories:

- Blastable (hard rock such as hard limestone and well-cemented sandstone)
- Rippable (soft rock such as shale, mudstone, soft limestone, and poorly-cemented sandstone)
- Mixed Soil over Blastable (soil - assumed 5’ thick - over blastable material as described above)
- Mixed Soil over Rippable (soil - assumed 5’ thick – over rippable material as described above)
- Excavatable (soil and highly decomposed rock)

The volumes of material generated (neat lines excluding expansion) in cubic yards are summarized below:

- Blastable 1,604,900
- Rippable 1,122,500
- Mixed Soil over Blastable 784,000 (475,900 soil – 308,100 rock)
- Mixed Soil over Rippable 863,400 (542,200 soil – 321,200 rock)
- Excavatable 1,626,200

Disposal of Southeast Corner Alternative spoils is expected to be primarily by spreading within the alignment right-of-way. In most locations, approximately 7.1 inches of spoils is anticipated to be spread across the alignment right of way. No additional spoil disposal areas would be required and spoil disposal along the pipeline and penstock alignments would be within the excavated trenches, covered with topsoil as available, and revegetated with an endemic plant seed mixture to stabilize surface particles and avoid erosion, and graded at approximate original contours. Rolling dips will be built into the spoils in the alignment right-of-way where needed to promote natural drainage, and culverts will be installed if needed where maintenance roads exist. All spoiled materials would be reclaimed by standard stabilization practices and seeding with an approved seed mix. Therefore, no measurable impacts would occur associated with spoil disposal. The Southeast Corner Alternative would have no significant impacts resulting from spoil material disposal.

4.5.2. Operation and Maintenance Impacts

4.5.2.1 Fault Movement

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.2 Seismic Activity

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.3 Unstable Slopes

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.4 Expandable, Collapsible, or Subsiding Soils or Rocks

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.5 Geologic Hazards to Human Health and Safety

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.6 Important Structures and Mineral Resources

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.5.2.7 Borrow and Spoil

Impacts would be the same as for the South Alternative. No impacts would occur during operations and maintenance.

4.6 Natural Gas Pipeline and Generators Alternative

The Natural Gas Pipeline and Generators Alternative would have the same impacts on geology and soil resources as described for construction and operation of the South Alternative.

4.7 No Lake Powell Water Alternative

4.7.1. WCWCD No Lake Powell Water Alternative

4.7.1.1 Fault Movement

The rate of fault movement on potential faults near the Warner Valley Reservoir embankment are believed to be no more than 0.2 mm/year on average. The vertical slip rate for the nearby Sand Mountain - West Grassy Valley fault, is estimated to be 0.1 to 0.2 mm/year. The displacement rate for other faults crossed by or near the Warner Valley Reservoir embankment is unknown but this is probably because the faults appear to be less active. The duration of construction activities is too short to be affected by such low rates of displacement. Therefore, no impacts are expected to occur during construction.

4.7.1.2 Seismic Activity

Major earthquakes can occur associated with faults near the Warner Valley Reservoir embankment and are likely to occur during the design life of the No Lake Powell Water Alternative; however, most measured earthquakes in the vicinity have been associated with the Basin and Range Province or the transition zone between the Colorado Plateau and the Basin and Range, both of which are west of the Warner Valley Reservoir embankment. This probably would diminish the potential effects of earthquake activity on the Warner Valley Reservoir embankment. Proper embankment design and construction would further minimize seismic effects. The alignment lies within a zone of low to moderate projected PGA (0.2 to 0.4 gravity PGA) with a two-percent probability of exceedance over a 50-year period. Therefore, no impacts are expected to occur.

4.7.1.3 Unstable Slopes

Rockfall and steep slopes occur within and near the Warner Valley Reservoir. These unstable slopes may be subject to failure, particularly in the event of an earthquake. Individual locations would need to be examined before heavy earthwork, especially blasting, could take place, and site stabilization measures or removal of rock and soil at risk of failure may need to occur before proceeding. If these precautions are followed, no measurable impacts and no significant impacts would occur.

4.7.1.4 Expandable, Collapsible or Subsiding Soils or Rocks

Portions of the Warner Valley Reservoir area may be subject to expandable, collapsible, or subsiding soils or rocks. These conditions are primarily associated with gypsiferous soils, which are susceptible to subsidence if gypsum is extensively wetted because gypsum can dissolve, leaving voids. Construction in such materials may require special design considerations, such as over-excavation, placement of bedding materials, and clay liners may be necessary. If design considerations are implemented where appropriate, no measurable impacts and no significant impacts would occur.

4.7.1.5 Geologic Hazards on Human Health and Safety

Geologic hazards on human health and safety would be minimized by following appropriate and site-specific precautions, including trench shoring or sloping, slope stabilization where applicable, and other standard construction safety practices. Therefore, no measurable impacts and no significant impacts would occur.

4.7.1.6 Important Structures and Mineral Resources

The only important structure within 1,000 feet of the Warner Valley Reservoir and Reverse Osmosis (RO) water treatment plant is the Washington Fields Diversion. The primary risk of damage is associated with the indirect effects of blasting during construction because the structure is in the vicinity. Special blasting methods may need to be employed to minimize the transfer of energy through rock and soil to the structure. Use of lower-energy blasting methods at closer spacings would minimize the impacts of blasting near the Washington Fields Diversion structure. Therefore, no measurable impacts and no significant impacts would occur.

4.7.1.7 Borrow and Spoil

Borrow materials for the Warner Valley Reservoir embankment dam would be supplied from local gravel pits and other material sources in the St. George metropolitan area which are owned and operated by the WCWCD, and from excavation associated with the Warner Valley dam and reservoir construction. There would be no measurable impacts and no significant impacts on borrow materials supplied from St. George area sources.

4.7.1.8 Soil Resource Impacts

The No Lake Powell Water Alternative would have long-term impacts on soil resources in the St. George metropolitan area. Soils would no longer be irrigated with potable water and would transition to either unvegetated conditions or support only desert vegetation, and the soil resources would be susceptible to erosion from wind and precipitation events. These soil resource impacts could be significant.

4.7.2. KCWCD No Lake Powell Water Alternative

The KCWCD No Lake Powell Water Alternative would have no measurable impacts on geology and soil resources from construction or operation.

4.8 No Action Alternative

The No Action Alternative would have no measurable impacts on geology and soil resources.

Chapter 5
Mitigation and Monitoring

All pipelines and associated features will be constructed in accordance with Best Management Practices (BMPs) to minimize any negative impacts on the surrounding areas under Special Use Permits that would be obtained from the National Park Service and Bureau of Land Management. It is assumed that site specific BMPs for activities like mobilization, clearing and grubbing, earthwork, stockpile management, landscaping, erosion control, drainage work, temporary stream crossing construction, road construction, dewatering and trenching operations will be implemented during construction. Typical BMPs implemented include, but are not limited to, filter fences, straw bales, interceptor dikes, swales, sediment traps, detention basins, mulching, seeding and/or re-vegetation as applicable. A list of types of BMPs that are likely to be used are included in Appendix D.

5.1 LPP Project Alignment Alternatives, Natural Gas Pipeline and Generators Alternative, and No Lake Powell Water Alternative

5.1.1. Fault Movement

Pipeline and penstock crossings of potentially active faults would incorporate design features to maintain pipe integrity, including features such as flexible couplings, increased pipe wall thickness, and/or pipe sleeves. These design features would be determined during detailed geotechnical investigations performed to support final pipeline and penstock design. There would be no adverse impacts on resources associated with this protection measure.

5.1.2. Unstable Slope Mitigation

Unstable slopes with potential rockfall would be examined before heavy earthwork, especially blasting, could take place, and site stabilization measures or removal of rock and soil at risk of failure and replacement with appropriately designed materials would occur before proceeding. There would be no adverse impacts on resources associated with this mitigation measure.

5.1.3. Expandable, Collapsible or Subsiding Soils Mitigation

Construction in expandable, collapsible, or subsiding soils would involve special design considerations, such as over-excavation and placement of additional bedding to provide appropriate drainage, to mitigate these types of soil conditions. Unsuitable soils would be stabilized within the ROW and re-vegetated as applicable. There would be no adverse impacts on resources associated with this mitigation measure.

5.1.4. Important Structures Protection

If required, blasting methods would be employed to minimize the transfer of energy through rock and soil to important structures. There would be no adverse impacts on resources associated with this protection measure.

5.1.5. Borrow and Spoil Management

Soil and rock materials unsuitable for use as pipeline and penstock trench backfill would be disposed in previously excavated borrow pits to avoid disturbing additional public and private land. Spoil disposed in previously excavated borrow pits would be partially compacted, the surface reclaimed to match

approximate original topography (surrounding landscapes), covered with topsoil as available, and planted with seeds from endemic plant species to stabilize the surface particles and avoid erosion.

5.1.6. Blasting Management

Blasting determined as necessary based on final design would involve preparing a site-specific blasting plan for approval by the land management agency or land owner in advance of construction. The blasting plan would specify safety measures, safe distances from the blasting site, the type of blasting to be performed, controls and measures to prevent aerial particle movement, blasting phases (as applicable), and necessary traffic controls. Blasting would be performed as unobtrusively as possible and managed to avoid damage to nearby structures, facilities and properties.

5.1.7. Erosion and Sediment Control

Erosion and sediment control would be implemented using non-structural and structural methods as applicable on disturbed soils subject to erosion and sediment mobilization. Non-structural methods would involve contractor education, standard construction management practices, good housekeeping practices, and construction sequencing. Structural methods would involve physical devices or means for removing, reducing, retarding or preventing stormwater runoff constituents, pollutants, contaminants, and soil particles from being mobilized and reaching receiving waters. Typical erosion and sediment control methods include filter berms, siltation berms, filter or silt fencing, detention basins, sediment traps, interceptor berms, sediment barriers (e.g., sand bags, hay bales, straw wattles, excelsior bundles, excelsior blankets, and excelsior bales or rolls), rock or gravel mulches, wood chip mulches, straw and bark mulches, jute netting, synthetic netting, and synthetic blankets.

5.1.8. Soil Stockpiling and Management

All recoverable growth medium and topsoil would be salvaged prior to surface excavation. Salvaged topsoil and native plant materials would be windrowed along the ROW edge or placed in temporary stockpiles. Topsoil stripped from areas with varying surface conditions would be segregated and stockpiled separately to preserve seedbank integrity (natural seeds incorporated into the soils). Segregated topsoil stockpiles would be used following construction completed to restore the same areas the topsoil was stripped from. All soil stockpiles would be maintained within the construction ROW.

5.1.9. Access Roads

During construction, all upaved access roads used by construction personnel, equipment, and materials delivery trucks would be maintained. Following construction, previous existing access roads would be restored to pre-construction conditions or better. Improvements made during construction would be left in place. Access roads in areas of silty soil would be restored to pre-construction conditions or better.

5.2 No Action Alternative

5.2.1. Mitigation

The No Action Alternative would have no impacts on geology and soil resources, therefore, no mitigation measures would be necessary.

5.2.2. Monitoring

The No Action Alternative would have no impacts on geology and soils resources, therefore, no monitoring would be required under the No Action Alternative.

Chapter 6
Unavoidable Adverse Impacts

6.1 South Alternative

No unavoidable adverse impacts would occur.

6.2 Existing Highway Alternative

The Existing Highway Alternative would have a significant unavoidable adverse effect on borrow material development from commercial sources of bedding material for pipeline and penstock construction. If soils excavated from the pipeline and penstock trenches are largely unsuitable for bedding, more than million cubic yards of bedding material would have to be developed and imported to the pipeline and penstock construction alignments, resulting in additional land disturbance on private and/or public land in southwest Utah and northern Arizona.

6.3 Southeast Corner Alternative

No unavoidable adverse impacts would occur.

6.4 Natural Gas Pipeline and Generators Alternative

No unavoidable adverse impacts would occur.

6.5 No Lake Powell Water Alternative

The No Lake Powell Water Alternative would have long-term unavoidable adverse effects on soil resources in the St. George metropolitan area. Soils would no longer be irrigated with potable water and would transition to either unvegetated conditions or support only desert vegetation, and the soil resources would be susceptible to erosion from wind and precipitation events.

6.6 No Action Alternative

No unavoidable adverse impacts would occur.

Chapter 7
Cumulative Impacts

This chapter analyzes cumulative impacts that may occur from construction and operation of the proposed LPP project when combined with the impacts of other past, present, and reasonably foreseeable future actions and projects after all proposed mitigation measures have been implemented. Only those resources with the potential to cause cumulative impacts are analyzed in this chapter.

7.1 South Alternative

Interrelated actions include the continued construction and operation of the Southern Corridor Highway, the development of the Jackson Flat Reservoir, and the construction of the Kern River – Hurricane Natural Gas Pipeline.

The Southern Corridor Highway is a four-lane highway, part of which has already been constructed from I-15 south of St. George to State Route 9 in Hurricane. Construction of the highway has, and will, eliminate the soil resources within the footprint of the roadway. Ongoing operation of the highway will permanently remove access to soil resources within the footprint of the roadway. This would be a cumulative impact for both construction and operation when combined with the impacts of the LPP Project South Alternative.

The Kern River – Hurricane Natural Gas Pipeline will be constructed along one of two routes. In either case, soil resources will be temporarily removed during construction of the buried pipeline. This would be a cumulative impact during construction. Once constructed, soil will be replaced and the alignment revegetated, so no cumulative impacts would occur during operation.

7.2 Existing Highway Alternative

The cumulative effects would be the same as described for the Proposed Action in Section 7.1.Additionally, Jackson Flat Reservoir construction is complete near Kanab. It permanently occupies land and removes the availability of soil resources underlying the reservoir and dam. This would be a cumulative impact for both construction and operation when combined with the impacts of the LPP Existing Highway Alternative alignment on soil resources.

7.3 Southeast Corner Alternative

The cumulative effects would be the same as described for the Proposed Action in Section 7.1.

7.4 Transmission Line Alternatives

The cumulative effects would be the same as described for the Proposed Action in Section 7.1.

7.5 Natural Gas Pipeline and Generators Alternative

The cumulative effects would be the same as described for the Proposed Action in Section 7.1.

7.6 No Lake Powell Water Alternative

The cumulative effects would be the same as described for the Proposed Action in Section 7.1. In addition, the No Lake Powell Water Alternative would have significant effects on soil resources in the St. George metropolitan area; however, none of the interrelated actions would combine with these effects to cause cumulative effects on soil resources.

7.7 No Action Alternative

The No Action Alternative would have no cumulative impacts.

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Glossary

Alluvium. A deposit of soil particles transported by flowing water.

Alluvial Fan. Deposits of alluvium at the mouth of canyons and gullies which result from water-borne materials in high-energy flows that drop out of the flows when the flows enter a valley where the slope is flatter and the energy is lower. Alluvial fans typically consist of randomly sorted material.

Borrow. Excavated material that is removed from one location, such as a pit, and used as foundation material, bedding, or backfill at another location to facilitate construction.

Calcareous. Rocks or soil containing high amounts of calcium carbonate.

Collapsible Soil. A loosely deposited soil that collapses into a denser, more compact soil, usually after saturation. Collapsible soils typically include porous alluvial fans and windblown soil deposits.

Colluvium. Materials that accumulate at the base of slopes, typically as a result of gravitational forces on materials further upslope.

Expansive Soil. A type of clay that absorbs and retains moisture between platy particles, causing the particles to be pushed apart and resulting in an increase in occupied soil volume. Over time, the clay may dry out from drainage or evaporation, and the resulting contraction of soil particles causes cracking and desiccation.

Fault. A plane of displacement caused by one part of the earth's crust relative to the adjacent part. A normal fault is a fault where the downthrown side moves on a plane dipping at less than 180 degrees. A reverse fault is a fault where the downthrown side moves on a plane dipping at greater than 180 degrees.

Fossiliferous. Rocks containing fossils.

Graben. A geologic feature caused by two adjacent, parallel faults which result in a downward movement of a block of the earth's crust between the faults.

Groundwater. Water found in interstitial spaces or fractures in rock or soil.

Gypsiferous. Soil or rock containing high enough fractions of gypsum (calcium sulphate) that it exhibits properties of gypsum, such as high solubility in water, limited ability to support plant growth, and expansion.

Holocene Epoch. A unit of geologic time corresponding to the period from approximately the end of the last Ice Age until the present time, roughly 11,700 years.

Liquefaction. Process whereby granular, saturated or wet soils change from a solid state to a liquid state as a result of loading, most often caused by an infusion of energy acceleration associated with an earthquake.

Loess. A windblown soil deposit. Loess deposits tend to be loosely deposited and are often subject to collapse when extensively saturated.

Seepage. Groundwater flowing from a saturated medium into open, unsaturated conditions, such as from rock fractures into caves, shafts, or tunnels, or from rock or soil onto a slope face.

Seismic Activity. An earthquake that releases energy as opposing sides of a fault move against each other, resulting in propagation of energy waves through rock and soil.

Spoil. Excess excavated material that is not suitable for foundations, bedding, or backfill and must be disposed of.

Subsidence. Lowering of a part of the land surface as a result of compaction of underlying soils, usually caused by either dissolving of materials within the soil or by removal of groundwater and the associated reduction in pressures within the soil pores.

Abbreviations and Acronyms

ABM	Arizona Bureau of Mines
ASTM	American Society for Testing and Materials
BLM	U.S. Department of the Interior, Bureau of Land Management
BMP	Best Management Practices
BPS	Booster Pump Station
CFR	Code of Federal Regulations
FERC	Federal Energy Regulatory Commission
FLPMA	Federal Lands Policy Management Act of 1976, Amended October 2001
FWLA	Fugro, Williams, Lettice and Associates
GOPB	Utah Governor's Office of Planning and Budget
gpcd	Gallons per capita day
GSENM	Grand Staircase-Escalante National Monument
HS	Hydropower Station
HWY	Highway
Hydro	Hydropower
KCWCD	Kane County Water Conservancy District
kV	kilovolt
LPP	Lake Powell Pipeline
M&I	Municipal and Industrial
MSL	Mean Sea Level (feet above)
NPS	U.S. Department of the Interior, National Park Service
NRCS	U.S. Department of Agriculture, Natural Resource Conservation Service
O&M	Operations and Maintenance
OSHA	Occupational Safety and Health Administration
PGA	Peak Ground Acceleration
Project	Lake Powell Pipeline Project
RO	Reverse Osmosis
SITLA	Utah School and Institutional Trust Lands Administration
Study Plan	FERC Geology and Soils Study Plan
TDS	Total Dissolved Solids
UBWR	Utah Board of Water Resources
UDWR	Utah Department of Water Resources
USCS	Unified Soil Classification System
UGS	Utah Geological Survey
UGMS	Geological and Mineralogical Survey (now UGS)
USBR	U.S. Department of the Interior, Bureau of Reclamation
USGS	U.S. Department of the Interior, Geological Survey
WCS	Water Conveyance System
WCWCD	Washington County Water Conservancy District

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Appendix A
Lake Powell and Cedar Valley Pipelines
Fault Assessment

TASK ORDER 3
LAKE POWELL AND CEDAR VALLEY PIPELINES
FAULT ASSESSMENT

Lake Powell and Cedar Valley Pipelines

Utah and Arizona

SUBMITTED TO
MWH Americas
1801 California Street
Denver, CO 80202

PREPARED BY
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December, 2009

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December 23, 2009

Mr. Patrick Naylor
MWH Americas
671 E. Riverpark Lane
Boise, ID 83706

RE: Geologic Characterization of Multiple Fault Crossings along the Proposed Lake Powell and Cedar Valley Pipelines, Hurricane Cliffs Hydropower Facility, Iron, Washington and Kane Counties, UT and Mohave and Coconino Counties, AZ

Dear Mr. Naylor:

The attached technical memorandum is a resubmittal of the Task Order 3 investigations of Fugro William Lettis & Associates (WLA) for fault crossings of the proposed Lake Powell and Cedar Valley Pipeline alignments. Our original submittal from November 23, 2009 has been updated to include information and data for the recently added Alternative 2C alignment to Sand Hollow Reservoir.

It has been a pleasure assisting you with this challenging and interesting project. If you have any questions regarding this technical memorandum, please do not hesitate to contact us.

Respectfully,
FUGRO WILLIAM LETTIS & ASSOCIATES, INC

LICENSED PROFESSIONAL GEOLOGIST
12/22/09
SEAN T. SUNDERMANN
7270308-2205
STATE OF UTAH

Dean Ostenaa
Principal Geologist

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Senior Project Geologist
P.G. 7270308 (UT)

Cc: Todd Loar, MWH Americas, Denver, CO

TECHNICAL MEMORANDUM

Date: December 23, 2009

To: Patrick Naylor and Todd Loar
MWH Americas

From: Dean Ostenaa, Sean T. Sundermann (P.G.), Mark Zellman, Tim Glidden
Fugro William Lettis & Associates, Inc.

Subject: Geologic Characterization of Multiple Fault Crossings along the Proposed Lake Powell and Cedar Valley Pipelines, Hurricane Cliffs Hydropower Facility, Iron, Washington and Kane Counties, Utah and Mohave and Coconino Counties, Arizona

1.0 INTRODUCTION

This technical memorandum presents the results of Fugro William Lettis & Associates, Inc. (FWLA) fault crossing and geologic investigation for the proposed Lake Powell and Cedar Valley Pipelines, Washington County, Utah (Figure 1-1).

The results of this fault investigation will be used to evaluate potential seismic issues and fault crossing specific mitigation design for the LPP and CVP. Under Task Orders # 1 and 2, FWLA completed a separate evaluation of seismic hazard issues for the Hurricane Cliffs Hydropower facility components. Those results are contained in a separate technical memorandum and are not repeated here.

Work for this investigation was conducted as described under MSA dated November 20, 2008 through Task Order #3, effective July 24, 2009. The FWLA Task Order #3 investigations were performed under subcontract to MWH Americas (Denver, CO) and under the direction of Supervising Geologist Mr. Patrick Naylor. Field work for this task

order was completed in September and October of 2009 by Sean Sundermann (Utah P.G. 7270308-2205), Dean Ostenaa and Tim Glidden. Our analysis consisted of several activities spread over desktop studies and field reconnaissance components for both the LPP and CVP. Primary activities included:

- Compilation and analysis of available existing geologic and geotechnical data in the site vicinity, including data from previous field geologic mapping, geotechnical boreholes, paleoseismic investigations (including exploratory trenching and argon age dating), and geophysical surveying;
- Analysis of aerial photography and imagery, including stereo-paired images;
- Field geologic mapping of surficial deposits and, where appropriate, bedrock units along fault strands intersecting the pipelines;
- Photo documentation of postulated fault-pipeline intersections;
- Development of geologic input for the final analyses.

Task Order #4, effective November 23, 2009, included investigations of a new Option 4 afterbay for the Hurricane Cliffs Hydropower facilities and a new pipeline alignment, Alternative 2c, to Sand Hollow Reservoir. Additional fault crossings for the new pipeline alignment were compiled, evaluated, and added to the Task Order #3 report scope.

1.1 Location

As currently planned, the overall project is comprised of two major pipeline alignments and several smaller secondary lines, ultimately connecting Lake Powell Reservoir to the St. George area and Cedar City (Figure 1-1). The Lake Powell Pipeline (LPP) begins at the proposed intake structure at Lake Powell reservoir near Page, Arizona and extends westward to Sand Hollow reservoir near St. George, Utah along an approximate 130-mile transect. The Hurricane Cliffs Hydropower Facility is located near the western end of this alignment, about 4 miles from the western terminus. The second major alignment, the Cedar Valley Pipeline (CVP), connects with the LPP about 2 miles southeast of the Hurricane Cliffs Hydropower Facility and continues northward approximately 50-miles to Cedar City. Preliminary design drawings dated July 29, 2009 (transmitted to WLA on August 17, 2009 and updated December 11, 2009 for alignments west of the Hurricane Cliffs) show the pipeline alignment has not yet been finalized with several alternative

alignments (Figure 1-1). This evaluation includes potential fault crossing along the alternative alignments depicted on Figure 1-2.

1.1.1 Regional Setting

The project area lies within the tectonic structural transition zone between the Basin and Range Province (BRP) to the west and the Colorado Plateau Province (CP) to the east. In southern Utah, this transition coincides with the southern end of the 150-km wide Intermountain Seismic Belt (ISB), a region characterized by high seismicity rates and numerous Quaternary faults. No earthquakes with surface rupture have occurred in southwest Utah in historic time. However, at least 20 earthquakes with a magnitude greater than a 4.0 have occurred in historic time, including the **M**5.8 St. George event in 1992 (Christenson, 1995) and the **M**6.0 Pine Valley EQ in 1902.

Geodetic data indicate a high rate of east-west oriented horizontal strain of approximately 1 mm/yr across the numerous faults in the CP-B&R transition (Holland and Bennett, 2009). However the rate is a measurement of purely the horizontal stress component. Considering most of the seismogenic faults within this region probably have moderate dips within the upper crust (50 – 70°), the total cumulative fault slip rate across the transition may be somewhat greater.

The Lake Powell Pipeline Project area is within the Grand Canyon Subprovince, characterized by a series of major west-down normal faults forming a ‘staircase’ transition between the BRP and CP, where the higher elevation CP steps down to the BRP across a series of normal faults. This includes the mapped traces of the Grand Wash, Washington, and Hurricane (intersected by the CVP), Sevier and the Paunsaugunt faults (intersected by the LPP), from west to east. The normal faults were likely activated over the last 5 million years along pre-existing compressional structures of the Cenozoic. Normal faulting likely began in the early Pliocene at the latest (Anderson and Mehnert, 1979). The braided and interconnected normal faults trend north-northeast, stepping to the east in a large scale *en echelon* pattern, with slip likely transferring between structures.

1.2 Objective

The primary objective of this investigation was to provide a system-wide assessment of seismic hazard issues for the LPP Project. Major objectives defined in the Task Order included:

1) Delineate the location and geometry of active strands in the vicinity of the pipelines through desktop analyses and literature reviews;
2) Perform field surveys for fault characterization and potential unidentified fault locations;
3) Assessment of fault activity and distribution of past surface rupture;
4) Review of FERC and State of Utah seismic design parameters for system-wide consistent application of design criteria for the LPP and CVP project features;
5) Provide recommendations for seismic design parameters (i.e., estimated displacement amount, direction and width of deformation zone, estimated frequency).

1.3 Approach

The initial task for this evaluation was to identify from prior geologic mapping potential seismic hazards to the pipeline by faults which may intersect, or be proximal to, the proposed alignments. The starting point for the seismic evaluation of the LPP Project was three prior compilations of potentially active faults: 1) USGS Quaternary fault and fold database (USGS, 2006); 2) the UGS Quaternary fault and fold database and map of Utah (Black et al., 2003), and 3) faults of Washington County (Lund et al., 2008b). These compilations include a specific focus on identification of faults with evidence of Quaternary (past 1.6 Ma years) activity. Other potentially significant fault locations for the Project were compiled from prior geologic mapping of the region. This initial effort defined approximately 48 locations along the LPP and CVP where previously mapped faults could potentially intersect or be significant to the alignments (Figure 1-2).

The initial fault locations were further evaluated and characterized with imagery, geologic map data, and field reconnaissance. For each potential fault crossing, the location accuracy along the alignment as well as the potential hazard posed by fault displacement was separately characterized. The basis for these evaluations on each fault crossing location are discussed in Section 2 (eastern LPP alignments), Section 3 (western LPP alignments), and Section 4 (CVP alignments). Section 5 includes summary tables of fault crossing data for the entire alignment. The Hurricane fault

crossing associated with the Hurricane Cliffs Hydropower facility is discussed separately in other reports submitted by FWLA.

For the eastern LPP in particular, some of the faults which are evaluated have extents of potential Quaternary deformation that are greater, and closer to LPP alignment facilities than indicated by existing fault databases. For ground motion estimates at sites along the alignment, inclusion of these additional faults in the seismic source models may be of significance for sites where these faults are close to the alignment. A general assessment of the potential seismic source significance of the evaluated faults is included in Section 5.

1.3.1 Fault Crossing Evaluation Basis

Two aspects of the fault crossing are evaluated: 1) location uncertainty, and 2) surface rupture or deformation assessment.

Fault location uncertainty is evaluated separately because for many fault crossing, the present map data provide only weak constraints on the exact stationing of fault crossing locations. For crossings where hazard mitigation is considered, the location uncertainty will influence the potential extent along the alignment over which these measures need to be implemented. All fault crossing locations in the present evaluation are defined on the basis of published map accuracy. In general, for most areas the most detailed mapping available is an original scale of 1:24,000 and in many cases these data have been recompiled to 1:100,000 products. Figures associated with each fault crossing discussion provide reference to the map data source used.

Three classes of fault crossing location confidence are defined: 1) low, 2) moderate, and 3) high. The basis for each classification is described below.

Low confidence fault crossing locations are generally shown on published maps as concealed traces for some distance from the alignment and have the greatest location uncertainty. In many cases these traces have few actual outcrop or physical constraints in the immediate vicinity of the alignment crossing. Actual fault crossing locations for

faults in this category may be as much as 1000 ft or more from the indicated crossing locations.

Moderate confidence fault crossing locations may include concealed traces which are more constrained by mapping near the alignment. This location confidence category also include fault traces from less detailed maps, and faults shown on the original maps as approximately located. Uncertainty in the actual crossing locations on the alignments for faults in this category is estimated to be in the range of 100 to 500 feet from existing mapping.

High confidence fault crossing locations are faults defined from detailed mapping, shown as certain, with solid lines. These locations are estimated to be accurate within the locations standards of the original mapping, but in some cases, this may be as large as about 100 ft.

Surface rupture or deformation hazards include an assessment of the likelihood that deformation might be expected at each crossing, as well as the relative amount or magnitude of that deformation. The second component of this assessment is the width or distance over which deformation might be distributed at each fault crossing location. Four categories of potential significance for fault crossing deformation are defined for this assessment: 1) Not Significant, 2) Low Significance, 3) Moderate Significance, and 4) High Significance.

Each category includes a potential range of fault crossing deformation characteristics that primarily reflect the relative likelihood of deformation at the site. These characteristics are determined from the geologic assessments of the age of most recent displacement on a fault and rates of displacement, first based on a regional assessment, but then including consideration of differences at the site. A secondary consideration for each category is the estimated amount or magnitude of displacement that might be expected for a fault at a specific crossing location.

Fault crossings in the Not Significant category are not recommended for further consideration as potential seismic hazard issues at the alignment locations. This

category includes locations where our evaluation found one or more of the following: 1) identified faults do not cross the alignment, 2) identified faults lack geomorphic or geologic evidence of Quaternary activity near the pipeline, 3) identified faults have deformational characteristics associated with regional pre-Quaternary structures, and 4) there is positive evidence for an absence of late Quaternary surface deformation on the identified fault in the immediate vicinity of the pipeline alignment.

Fault crossings judged to be in the Low to High Significance categories are recommended for some further consideration in the design, depending on the seismic design considerations relevant for a particular Project component. Fault crossings in these categories are associated with faults which may: 1) have significant to high likelihood to cross the alignment, and 2) have a direct structural association to a fault with Quaternary displacement.

Fault crossings judged to be in the Low Significance category include those where the mapped faults may have evidence of Quaternary displacement at locations some distance from the alignment, but for which that evidence is absent, or displacement is significantly diminished at the actual alignment crossing. In many cases, these are fault traces which are the inferred or concealed continuations of fault traces mapped with greater certainty some distance from the alignment. This category also includes those secondary or antithetic fault traces associated with primary seismic source fault such as the Hurricane fault for which there is evidence to suggest either very small or infrequent displacements might occur. Faults associated with this category of crossing have recurrence intervals that are likely to be tens of thousands of year or greater at the crossing location and estimated slip rates that are most likely near 0.01 mm/yr or less. No fault traces with known Holocene or late Quaternary displacement are included in this category. The range of potential deformation on individual fault crossing traces in the Low Significance category not likely to exceed 1 foot during individual faulting events.

Fault crossings judged to be in the Moderate Significance category includes those associated with faults which have evidence for Quaternary displacement and are judged likely to have late Quaternary displacement. Slip rates at the crossing locations are estimated to be near 0.05 mm/yr. Included are secondary and antithetic fault traces with

larger displacements than faults in the Low Significance category, and some primary fault traces. Based on fault trace length and considerations of slip rates, deformations associated with these fault traces during individual faulting events are most likely to be in the range of 1 to 3 feet. Larger displacement events on faults in this category are likely to have recurrence intervals that are longer than about 10,000 years.

Fault crossings judged to be in the High Significance category are those associated with fault traces for which there is known or direct linkage to fault traces with evidence of Holocene to latest Quaternary displacement. Slip rates on these faults are likely to be 0.1 mm/yr or greater, or these traces represent major antithetic or secondary traces on a major fault like the Hurricane fault. The range of potential deformation on individual fault crossing traces is likely to be in the range of 3 to 12 feet.

Based on our current understanding of the pipeline design, it is expected that the constructed pipeline will have some significant tolerance to fault displacements. Thus, implementation of specific design mitigation measures will need to consider that tolerance, along with the potential consequences of a pipeline rupture as part of a design decision to adopt specific fault crossing parameters.

2.0 LPP FAULT CROSSINGS

The LPP intersects several mapped, major extensional faults accommodating down-to-the-west offset in an en echelon northeast-stepping pattern (Figure 2-1), including the Sevier, Paunsaugunt and Kaibab faults. These faults mark the eastern portion of a series of faults marking the transition between the CP (east) and the B&R (west). These faults are reactivated Laramide structure reversing its sense of displacement to accommodate the current extensional stress regime. In general these faults characteristically accommodate larger offsets on the northern sections than the southern. Several of these faults (i.e. the Sevier and Paunsaugunt faults) displace resistant Jurassic rock into fault contact with more erosive Triassic rock, resulting in an apparent inverted sense of motion with the western Jurassic units forming a topographic high over the Triassic to the east. A second class of smaller faults intersecting the

pipeline are overprinted on the reactivated Laramide structures, accommodating small displacements. These smaller faults are of no significance to the alignment.

Existing Quaternary fault compilations only identify one fault, the Sevier fault, which actually intersects the eastern LPP alignments. Between Lake Powell and the Hurricane Cliffs Hydropower Facility previously identified locations of Quaternary offset on other major faults, such as the Paunsaugunt, West Kaibab, and Central Kaibab faults, are not shown in existing compilations to intersect the eastern LPP alignments (Figure 2-1). As part of this assessment, additional mapping and data were evaluated to determine if any of these faults might pose a significant hazard to the LPP alignment.

2.1 Unnamed faults near Glen Canyon City

Just west of Glen Canyon City, north and south of the LPP Highway alignment near station 820+00 (Figure 2 -2), are a series of unnamed, short normal faults with strikes ranging from N20E to N42W mapped by Doelling and Willis,(2006). Overall, this zone of faults accommodates down-to-the-northeast displacement, and individual fault traces have lengths of 1-5 km and varied strikes. The zone of faults trends roughly parallel with the Echo Monocline (to the east) and the Cedar Mountain anticline (to the west) and appears to be associated with flexural warping within these structures during the Laramide (~65 Ma ago). As mapped, the fold structures plunge to the north and die out near the alignment location (Doelling and Willis, 2006).

Looking south from the LPP crossing near station 830+00, the Thousand Pockets Tongue of the Middle Jurassic Page Sandstone can be seen in fault contact with the Judd Hollow Tongue of the Middle Jurassic Carmel Formation, confirming mapped location and sense of offset. These faults have no geomorphic expression in Quaternary eolian deposits or in bedrock units near the alignment.

Based on the absence of prior mapping information suggesting Quaternary displacement, the lack of geomorphic expression associated with these faults near the alignment, and the decreasing structural relief on the older associated fold structures towards the alignment, these faults do not appear to pose a displacement hazard for the

LPP alignment and are judged as Not Significant. These faults are not shown in the USGS Quaternary fault and fold database (USGS, 2006).

2.2 Northern Kaibab Plateau faults

The Kaibab Plateau uplift lies mostly to the south of the LPP alignment in northern Arizona and dies out to the north in southern Utah (Figure 2-3). Several faults within and along the margin of the Plateau are included within the USGS Quaternary fault and fold database (USGS, 2006) in Arizona, but not in Utah (Figure 2-3). Published maps show that these faults continue from Arizona into Utah and intersect the LPP alignment. From east to west, these structures include the 1) East Kaibab Monocline (Cockscomb) fault system, 2) Central Kaibab faults, and 3) West Kaibab faults (Figure 2-4).

2.2.1 East Kaibab Monocline (Cockscomb) fault system

Doelling and Willis (2006) depict numerous faults within and parallel to the East Kaibab Monocline (also dubbed the Cockscomb), the eastern bounding structure of the Kaibab uplift. Faults within this structure proximal to the LPP crossing are mapped entirely within the lower Jurassic Navajo Sandstone, or forming a fault contact between the lower Jurassic Navajo Sandstone and the upper Jurassic Kayenta Formation. An unnamed, down-to-the-east normal fault trending about N5E in this group of faults intersects the LPP alignment near station 1729+20 (Figure 2-5).

Bedrock expression of this fault is visible in the road cut and in a road-parallel drainage 0.2 miles south of the LPP crossing. The road-cut expression is visible as extensively sheared and chemically altered zones of Navajo Sandstone up to 5 feet wide, subparallel to bedding. In the drainage, the fault is evidenced by a locally-distributed zone of shearing and an anomalous claystone bed, possibly lithified fault gouge, located in a bedrock notch orthogonal to the active drainage. Orientation on this shear zone is N9E, 76SE. Approximately 0.1 mile south of the drainage, a bedrock saddle lies on trend with this bedrock shear zone. A Quaternary alluvial terrace with minor desert pavement occurs on the either side of this drainage, crossing the mapped and observed fault trend. No offset is visible in this terrace.

Existing mapping (e.g., Doelling and Willis, 2006; and USGS, 2006) has not identified evidence of Quaternary displacement elsewhere along the East Kaibab Monocline within roughly 20 miles of the LPP alignment. The overall geomorphic expression of this structure is dominated by the effects of differential erosion of the folded bedrock units along the structure, but there are few locations where Quaternary deposits are preserved which could be used to definitively assess the age of most recent faulting.

Potential fault crossings associated with the East Kaibab Monocline are judged to be Not Significant because there is no mapping or geomorphic evidence in the alignment area that suggests Quaternary activity associated with this structure.

2.2.2 Central Kaibab faults

Pearthree (1998) identifies a discontinuous group of faults on the central Kaibab Plateau of northern Arizona as probable Quaternary faults based on their geomorphic expression on the bedrock erosional surface of the plateau and the presence of local accumulations of Quaternary deposits along several of these faults (Figure 2-3). Overall, the faults in Arizona generally strike north to northeast, but have significant variability. The overall zone extends over a length of about 40 miles, but consists of a series of individual faults and grabens which are generally 5 to 10 miles in length. In Utah, Doelling (2008) shows a similar series of faults which extend about 6 miles south from the LPP alignment near station 2270+00 (Figure 2-4). The southern-most extent of the faults mapped by Doelling is about 12 miles north of the closest faults in Arizona shown by Pearthree (1998).

As mapped by Doelling (2008) at the LPP alignment (Figure 2-3), a fault trends roughly north-south, is approximately located, and mapped entirely within the Middle red member of the Lower Triassic Moenkopi Formation at the LPP crossing, and entirely within the underlying Timpoweap member of the Lower Triassic Moenkopi approximately 1 mile south of the LPP crossing. Two miles south of the LPP crossing, this approximately-located feature merges with a mapped fault trending N5E (Doelling, 2008). This latter fault is mapped as bringing the Middle red member of the Lower Triassic Moenkopi Formation and the underlying Timpoweap member of the Lower Triassic Moenkopi Formation in fault contact. Sense of offset is not mapped on this more southern fault, but unit offset as mapped implies a down-to-the-east normal fault. A

zone of numerous subparallel unnamed faults, approximately to definitely located, extends approximately 6 miles south of the LPP crossing point. With the exception of the fault-contacted units described above, all other faults within this zone are mapped entirely within the Timpoweap member of the Lower Triassic Moenkopi Formation or the lower Permian Kaibab Formation.

The Middle red member of the Lower Triassic Moenkopi Formation at the LPP crossing is primarily red mudstone, forming gentle slopes and few outcrops. Occasional yellowish gray sandstone caprock is present at local topographic highs. Field investigation to the south of the LPP crossing yields the inference that elevation irregularities in the sandstone caprock in this area are the impetus for an approximate mapping of normal offset at this location. The faults generally follow a low escarpment, which increases in height to the south near Kaibab Gulch, about 2 mile south of the LPP alignment. The main zone of faults steps to the west at Kaibab Gulch and extends south about 4 miles. Geomorphic expression on the bedrock erosional surface also diminishes to the south. No evidence of offset or ponded Quaternary deposits is evident on imagery or from existing mapping along this section of the fault.

North of the LPP alignment, Doelling (2008) continues this fault as approximately located or concealed for about 1 mile (Figure 2-4). There is no geomorphic expression or obvious lineaments that might be associated with the fault in this area, but faults are defined by scattered areas of bedrock outcrop covered by late Quaternary fan and wash deposits.

The Central Kaibab faults are judged as Low Significance for the LPP fault crossing because of the absence of geomorphic or stratigraphic evidence for late Quaternary displacement at the LPP crossing location. South of the LPP alignment, the faults mapped by Doelling (2008) have some geomorphic expression, that may potentially be consistent with Quaternary displacement, similar to apparently related faults further south in Arizona. However, within the LPP crossing area, we observed no evidence that suggests the possibility that this displacement would cross the LPP alignment.

2.2.3 West Kaibab fault

As depicted in the USGS fault and fold database (Pearthree, 1998) the West Kaibab fault system extends nearly 50 miles south from the Utah border into Arizona (Figure 2-3). Although no detailed studies have been done along this system of faults, the prominent escarpments and ponded Quaternary deposits along the fault trace are highly suggestive of late Quaternary displacement. In Utah, Doelling (2008) maps the continuation of the West Kaibab faults along a west-facing bedrock escarpment placing Triassic bedrock in fault contact with Quaternary deposits (Figure 2-6) to within about 0.8 mile south of the LPP alignment. From that location, the fault is continued as a concealed trace which splits into a northwest trending trace (intersecting near station 2579 + 00) and a trace continuing the southern trace trend of north-northeast (intersecting near station 2570 + 00) about 0.2 miles south of the LPP alignment (Figure 2-6). Interpreted Jurassic bedrock contours (Doelling, 2008) indicate a large down-to-the-west offset of 1000 to 1500 feet across the fault near the pipeline intersection.

Both of these concealed faults cross the LPP pipeline, with an along-line map separation of 0.1 miles. Both are mapped as concealed by Quaternary alluvium and are not associated with lineaments or topographic escarpments near the alignment. In contrast, 1.7 miles to the south, along the trace of the West Kaibab fault which the fault is expressed by a 2 meter, west-facing scarp within the Timpoweap Member of the Lower Triassic Moenkopi Formation. The geomorphic expression along the fault steadily increases south toward Arizona. Thus, it appears that potential Quaternary displacement along this fault dies out just to the south of the LPP alignment.

The West Kaibab fault system is judged to be of Low Significance for the LPP fault crossing because evidence of Quaternary displacement appears to die out on this fault just south of the proposed alignment.

2.3 Paunsaugunt fault

The LPP alignment intersects the mapped ultimate southern extension of the Paunsaugunt fault, one of the major faults accommodating down to the west displacement (Figure 2-7). As characteristic of this fault system, the Paunsaugunt accommodate larger offsets on the northern sections than the southern, with no

Quaternary expression near the pipeline alignment. Toward the northern termination of the fault, 5.0 to 6.4 Ma basalts predating initiation of the fault are displaced 1,600 feet (Hecker, 1993). The fault expression toward the central and southern extents of the fault are sporadic at best, with the last noted expression on a Pleistocene pediment in Bryce Canon National Park, over 30 km north of the pipeline alignment (Bowers, 1991).

The Paunsaugunt fault, as mapped by Doelling (2008), crosses the LPP near the split of the Existing Highway and Southern Alternative Alignments, intersecting any of the potential alternatives at various locations (Figure 2-7). Through this area, the Paunsaugunt fault is mapped as a generally N-S trending concealed fault with down-to-the-west normal offset, obscured by young Quaternary alluvium along Seaman Wash (Doelling, 2008), so the exact location of the crossing is not well constrained. The fault would cross the Existing Highway Alignment near station 2950+00. The Southern Alternative Alignment lies on, or is subparallel to the fault between approximate stations 3030+00 and 3060+00 (Figure 2-7).The southern termination of the mapped fault trace is about 1 mile south of the LPP alignments (Billingsley et al., 2007), but a similar set of small-displacement normal faults step to the southeast and may appear to join the West Kaibab fault a few miles southeast (Figure 2-3).

In the immediate vicinity of the LPP alignments, and like the Sevier fault to the west, the Paunsaugunt fault displaces resistant Jurassic rock into fault contact with more erosive Triassic rock, resulting in an apparent inverted sense of motion with the western Jurassic units forming a topographic high over the Triassic to the east. This is shown by the expression of the fault about 2.0 miles north of the highway alignment along Seaman Wash. In that area the Lower Jurassic Kayenta Formation is in fault contact with the Petrified Forest member of the Upper Triassic Chinle Formation at the mouth of the canyon, and beds of hanging wall Kayenta Formation are modestly down-warped to the west at the mapped fault. The fault trace, with west-down displacement, is mapped beneath the east-sloping late Quaternary pediments and fans below the cliffs of Jurassic rocks. From this area, extrapolated contours on the Navajo Sandstone (Doelling, 2008) indicate that displacement decreases to the south to roughly 80 to 100 feet at the Highway Alignment (Figure 2-7).

The bedrock cliffs to the west of the Alternative Alignment are comprised of the Triassic Shnabkaib overlain by the cliff forming Purgatory sandstone (Figure 2-7). In this area along Seaman Wash, a large gully exposes the top of the Triassic Middle Red member. All of these units are in stratigraphic sequence. The Shnabkaib member is mapped as 160 to 210 feet thick on average in this proximity. The elevation between the top of the mapped Middle Red and the base of the Purgatory is approximately 140 feet, indicating no to minimal displacement across the fault at this location within mapping error of ±40 feet, and consistent with the southward decrease in displacement shown by Doelling (2008). The mapped, concealed trace ends about 0.5 mile into Arizona, about 1 mile south of the South Alternative Alignment (Billingsley et al., 2007).

Displacement on the Paunsaugunt fault increases significantly to the north away from the LPP alignment. North of Seaman Wash, and more than 5 miles north of the LPP Highway Alignment, the fault-line scarp in more resistant Jurassic rocks is gradually increasing in height, and is comparable to the estimated displacement of these rocks. Much further north, toward the northern termination of the fault, 5.0 to 6.4 Ma basalts predating initiation of the fault are displaced 1,600 feet (Hecker, 1993). The fault expression between these locations is variable, reflecting the contrasts in erosion resistance of rocks on either side of the fault. The closest known location to the LPP alignment with Quaternary displacement is in Bryce Canyon National Park where the fault apparently offsets a Pleistocene pediment (Bowers, 1991), about 30 miles north of the LPP alignment.

All of the Paunsaugunt fault crossings with the three alignments are within late Quaternary alluvium from Seaman Wash, which generally parallels the fault in this area. No geomorphic expression of young faulting is apparent between the western bedrock cliffs, and east-sloping fans through this area, although low rates of fault displacement and small displacements would likely not be preserved and be difficult to detect. However, observations are consistent with the southward decrease in total displacement along the fault. Based on these factors, the fault is judged to be of Low Significance for the LPP Crossing locations.

2.4 Johnson Canyon faults

The Johnson Canyon fault system is an interpolation between multiple unnamed subparallel faults mapped in Utah by Doelling (2008) and in Arizona by Billingsley et al. (2008) and separated by about 7 miles. Concealed traces of these faults cross the LPP Existing Highway alignment near stations 3300+00 to 3250+00 and interpolated to cross the LPP South Alternative alignment near station 3360+00 (Figures 2-8). The closest confirmed locations for these faults are about 1.5 miles north and south of the respective alignments. Continuation of the faults across and between both alignments is strongly suggested by bedrock mapping of the Chinle and Shnabkaib stratigraphic contact across the fault, but Doelling's Jurassic bedrock contours illustrate minimal bedrock offset.

In the eroded Jurassic bedrock units north of the LPP Existing Highway alignment (Figure 2-8), the down-to-the-east geomorphic expression of the fault is weakly expressed. The down-to-the-east normal fault mapped between the LPP Existing Highway alignment and the LPP South Alternative alignment is concealed in Quaternary alluvium and eolian deposits. The concealed fault lies east of a highly degraded escarpment in the lower members of the Triassic Chinle formation. South of the LPP South Alternative alignment, the fault mapped by Billingsley et al. (2008) follows a low escarpment which dies out about 1.5 miles south of the alignment. Closer to the LPP South Alternative alignment, the continuation of the fault is mapped beneath a series of Quaternary alluvial deposits (Qgo, Qgy) by Billingsley et al. (2008) along White Sage Wash (Figure 2-8). No lineaments or scarps are evident in these deposits, which provide positive evidence for an absence of late Quaternary displacement on this fault system near the alignment.

The Johnson Canyon faults are judged as Not Significant for the LPP fault crossings on both the Existing Highway and South Alternative alignments based on the absence of evidence for Quaternary displacement in the alluvial deposits along White Sage Wash.

2.5 Quikwater fault and monocline

The Quikwater fault, herein named for exposures in the Quikwater drainage about 1 miles south of the alignment, is an unnamed down-to-the-west normal fault trending N14E to N4W, entirely within the Lower Permian Kaibab Formation (Figure 2-9)

(Billingsley et al, 2008). The fault is collinear or overprinted on the northern termination of a west facing monocline mapped for a distance of 2.4 miles south of the LPP alignment. The Quikwater fault intersects the LPP alignments just east of the western junction of the South Alternative and Preferred South Alignments (Figure 2-9). The fault and monocline are not mapped in Utah, at comparable scale due to the absence of published maps for this area of the Kaibab Paiute Indian Reservation. Review of available digital imagery suggests that the structure continues at least 1-2 miles north onto the Reservation.

The South Alternative Alignment crosses the fault at about station 4300+00, where a prominent west-facing monocline face stands approximately 60 feet tall. At this location, the South Alternative Alignment coincides with the northern limit of detailed geologic maps in this area. About 0.2 miles north, the projection of the fault would cross the Preferred South Alignment near station 4220+00. Approximately one mile south of the LPP alignments, the Quikwater drainage exposes a stepped bedrock offset placing the red, slope-forming sandstone of the Harrisburg Member of the Kaibab Formation into fault contact with the cliff-forming cherty limestone of the Fossil Mountain Member of the Kaibab Formation. A thin zone of vertical shear fabric, up to 1 foot wide, is apparent at the contact. An approximately 3 meter, down-to-the-west bedrock fault offset was observed within a Fossil Mountain limestone bed to the east. Overlying bedrock was not offset, although the slope is draped in colluvium in most locations. No offset was observed within the bedrock exposure along the projected fault trend on the southern side of the drainage.

Quaternary deposits along and across the trace of the Quikwater fault are of limited extent in the small washes and drainages that cross the fault, and no evidence of young faulting was observed in these deposits. Near the LPP, the extent of faulting along the monocline appears to be limited to less than 1 mile. Based on the short length of this structure, absence of geomorphic expression for young displacement along the length of the monocline, and absence of young faulting in Holocene deposits on the fault near the LPP alignment, the Quikwater fault is judged a Not Significant to the LPP Alignment crossing.

2.6 Sevier fault (Northern Toroweap section)

The Sevier-Toroweap fault is one of several major normal faults forming the stair-step provincial boundary between the CP and B&R. Evidence of Quaternary displacement is recognized along most of the 250-km long fault which extends from south of the Grand Canyon in Arizona northward to Panguitch, Utah. Traditionally, the fault is often referred to as the Toroweap fault in Arizona, and the Sevier fault in Utah. Although most of the fault has been studied on only a reconnaissance level, studies near the Grand Canyon (Jackson, 1990; Fenton et al., 2001) and in southern Utah (Lund et al., 2008a) establish a clear basis for differing slip rate and recency of movement along the length of the fault. The fault has long been divided into several sections based on structural characteristics, geomorphic expression, inferred slip rate and recency of movement (e.g. Jackson, 1990; Black and Hecker, 1997; Lund et al., 2008a). The LPP alignments cross near the midpoint of the ~ 50-mile long northern Toroweap section, one of the central sections of the much longer Sevier-Toroweap fault,

Total displacement within the northern Toroweap section may be as little as 380 feet near the LPP Southern Alternative alignment, but increases to about 2100 feet just north of Pipe Spring and the LPP Existing Highway Alignment (Billingsley et al., 2004). Elsewhere, reported total displacements are >1500 feet on the central Toroweap section near the Grand Canyon and the Sevier section in southern Utah (Black and Hecker, 1997; Lund et al., 2008a). Slip rates on the central Toroweap section near the Grand Canyon are 0.04 – 0.18 mm/yr (Fenton et al., 2001). Slip rates in southern Utah on the Sevier section appear to increase to the north from about 0.04 mm/y to 0.4 mm/yr at the northern end of the Sevier section near Panguitch, UT (Lund et al., 2008a). Based on these variations, and differences in the geomorphic expression of Quaternary faulting along the northern Toroweap and Sevier sections, Lund et al. argue that lengths of these sections are anomalous compared to other Basin and Range faults based on comparison to historic surface faulting events. Based on the left step between the northern Toroweap and Sevier sections of the fault at Clay Flat, a significant component of left-lateral slip on the fault is suggested (Black and Hecker, 1997; Lund et al., 2008a).

The evidence for slip rate and recency of displacement on the northern Toroweap section of the fault is not well documented. Pearthree (1998) identified a location south

of Pipe Spring National Monument where late Pleistocene alluvium fans were offset about 3.5 m (12 ft), which implied relatively long return periods and a low slip rate along this section of the fault. Lund et al. (2008) report that to the north in Utah they observed no fault scarps in unconsolidated deposits along the northern Toroweap section, but there is no similar evaluation of the continuity or existence of fault scarps along the Toroweap section in Arizona. Mapping by Billingsley et al. (2004) shows the fault as concealed by Quaternary deposits near Pipe Spring and the LPP alignments.

The Sevier fault intersects both the Existing Highway and Southern Alternative Alignments (Figure 2-10). Observations and mapping data for each of these sites are discussed separately below.

2.6.1 Existing Highway Alignment

The Existing Highway Alternative, the northern of the two crossings, passes about 0.4 miles south of Pipe Spring National Monument (PSNM). North of PSNM the Sevier-Toroweap fault has an inverted sense of topography, with a hangingwall elevated over the footwall. This topographic reversal is a result of more resistant Jurassic units on the hangingwall not eroding as quickly as the erosive Moenkopi units on the footwall (Figure 2-10a). South of PSNM, no resistant rocks are present adjacent to the fault, drainage flows generally west to east across the fault, and only scattered low hills are present along the footwall block.

The crossing location for the Existing Highway Alternative, at about Station 4704+10 appears to relatively well-defined (Figure 2-10a). The original Pipe Spring is the byproduct of a groundwater barrier formed by the Sevier-Toroweap fault, and the adjacent fault-parallel Moccasin Monocline, which place the brecciated, water-bearing Jurassic Navajo Sandstone and Kayenta Formation in fault contact with the Triassic Chinle and Moenkopi Formations (Billingsley et al., 2004). The original spring daylights at the base of the Vermilion Cliffs (Figure 2-10a) suggesting a fault location slightly west of that shown by Billingsley et al. (2004). South of Pipe Spring, and across the LPP highway crossing, the main trace of the Sevier fault is mapped as concealed by Quaternary deposits (Billingsley et al., 2004), but is well constrained by bedrock outcrops and the distribution of Quaternary units (Figure 2-10a). Further, south of the

alignment, the trace of the fault is evident as a lineament defined by juxtaposition of bedrock and Quaternary units. Just south of the highway, this is expressed as a 3-4 foot, down-to-the-west inflection, which extends down the alluvial fan slope and strikes parallel to fault. Similar slope breaks and lineaments extend for about 0.5 mile south from the highway. Potential antithetic or secondary faults are not expressed geomorphically near this alignment, but series of parallel fold-related fractures with minimal (< 1 ft) to no apparent offset are visible in the cliff face proximal to Pipe Spring.

Based on the reported evidence for Quaternary displacement at many locations along the Sevier-Toroweap fault and the presence of a 3-4 foot scarp just south of the Existing Highway alignment, the Sevier-Toroweap fault is judged to be of High Significance to the alignment crossing. The location is well-constrained by existing mapping (Figure2-10a) and geomorphic data. The age of the most recent displacement at this site is unknown, but is potentially Holocene based on sites near the Southern Alternative Alignment (discussed below).

2.6.2 Southern Alternative Alignment

Near the Southern Alternative Alignment, the Sevier-Toroweap fault location is well-defined along a low fault-line escarpment which extends nearly 2 miles south from the alignment (Figure 2-10b). Along this escarpment, southeast-flowing drainage is deflected and ponded, including Pipe Valley Wash, adjacent to the alignment. This compelling evidence, as seen on aerial photographs for the location of the fault provides a high level of certainty for the fault crossing location. Although the mapped fault (Figure 2-10b) in this area is shown as concealed by Billiingsley et al. (2004), the distribution of young alluvium appears to be strongly fault controlled, suggesting that their Holocene to Late Pleistocene unit Qa2 is faulted. The low slope, bedrock controlled scarp in this area is at least 5 to 6 feet in height over a 60 to 75 foot wide, northwest facing slope. Because the Qa2 deposits do not extend unbroken to the fault, but are generally buried on the hangingwall or eroded on footwall, estimates of the actual offset of the Qa2 unit projected to the fault would likely be significantly greater.

Our best estimate of the fault crossing location for the Southern Alternative Alignment is at Station 4985+35. There is no geomorphic expression of secondary or antithetic faults

at the alignment location, but 2 miles south of the alignment, Billingsley et al. (2004) show a significant antithetic fault, with down-to-the-east displacement, about 1 mile west of the Sevier-Toroweap fault (Figure 2-10b). This fault is evident on imagery, and like the main trace, appears to control the depositional patterns of unit Qa2, suggesting that the youngest displacement on this fault is also likely Holocene.

Based on the geomorphic evidence for drainage deflections and the apparent faulting of Holocene to Late Pleistocene alluvium adjacent to the Southern Alternative Alignment, the Sevier-Toroweap fault is judged to be of High Significance for that crossing. The location is well-constrained by existing mapping (Figure2-10b) and geomorphic data. The age of the most recent displacement at this site is unknown, but is potentially Holocene based on our observations. The amount of displacement of unit Qa2 would appear to be at least 5 to 6 feet, and if projected to the fault in profiles could be much greater and consistent with the 3.5 m (12 ft) displacement of late Quaternary alluvium reported by Pearthree (1998) for an unspecified location south of Pipe Spring.

2.6.3 Sevier-Toroweap fault deformation zone assessment

There is no detailed paleoseismic data on any part of the Sevier-Toroweap fault system (Lund et al., 2008). Thus, assessment of fault displacement parameters must be based on indirect and global evidence. It is uncertain whether the apparent fault scarps near the LPP alignments are the product of one or more surface faulting earthquakes. Likewise, the exact age and amount of recent displacement is also uncertain. However, if the observed geomorphic evidence were the result of a single-event displacement of 10-12 ft, this could be consistent with return periods of at least several thousand years, and potentially as much as tens' of thousands of years. A single event displacement of this amount is also consistent with potential fault rupture lengths of 20 to 50 miles based on regressions in Wells and Coppersmith (1994). This would imply rupture of approximately one-half or all of the northern Toroweap section of the fault.

A conservative assessment of the surface rupture hazard for the Sevier – Toroweap fault at both the Existing Highway and Southern Alternative Alignments would consider net offset of about 12 ft. Existing mapping indicates a general location for the main fault trace, but without site-specific trenching does not distinguish whether this displacement

is concentrated on a single fault trace, or distributed over a broader zone on several traces. Based on the level of information presently available, a potential deformation zone of distributed faulting up to 500 feet west of the preferred locations on downthrown side of fault, and up to 250 feet east of the preferred locations on the upthrown side of the fault is suggested. This range is analogous to setback recommendations for surface-faulting hazards of well-defined faults (Christenson et al., 2003).

2.7 Short Creek fault

The Short Creek fault is an unnamed down-to-the-east normal fault completely within Triassic bedrock (Billingsley et al., 2002, Moore and Sable, 2001; Biek et al., 2007) which intersects the LPP Existing Highway alignment between stations 5912+00 and 5918+00 (Figure 2-11). In this area, the alignment follows an unnamed wash, which also coincides with the state line and map boundary. Thus, mapped fault traces north and south of the alignment have similar northwest strike, but the traces intersect the alignment at two locations separated by roughly 600 feet. The total mapped length of the fault is less than 2 miles.

Based on review of available imagery, the fault has limited geomorphic expression in the bedrock on either side of the alignment, but there is some fault-parallel drainage drainage development. No fault scarps or lineaments were identified within the late Quaternary alluvium in the wash which the alignment follows.

Based on the absence of geomorphic evidence for late Quaternary deformation, and the limited fault length, the Short Creek fault is judged Not Significant to the LPP crossing.

3.0 WESTERN LPP FAULT CROSSINGS

The Western LPP alignments lie entirely west of the Hurricane fault, and three different alignments were evaluated. The LPP western and CVP Alternative 2c alignments extend west from the Hurricane Cliffs Hydropower Facility to Sand Hollow Reservoir. The CVP Alternative C alignment branches from the western LPP alignment and extends north to

the town of Hurricane (Figures 1-1 and 3-1). Faults crossed by the three alignments are compiled from maps by Hayden (2004), Lund et al. (2006) and Biek et al. (2007).

3.1 Sand Mountain - West Grass Valley fault

South and west of the Hurricane Cliff Hydropower Facilities, there are several North to Northeast striking faults inferred to transfer slip between the Washington and Hurricane faults. Holocene offset is shown for the Warner Valley fault based on mapping by Hayden (2004) at a location about 2 miles south of the current Hurricane Cliff Hydropower facilities. Within about 2 miles west of the Warner Valley fault, Hayden maps a broad zone of faults in Jurassic Navajo and Kayenta rocks with varied sense of displacement (Figure 3-1). The western most of these faults, herein termed the Sand Mountain – West Grass Valley fault offsets the Grass Valley Basalt flows just west of the Hurricane Cliff Hydropower Facilities (Figure 3-2). The fault extends several miles southwest of this area, and has prominent geomorphic expression in the Navajo bedrock of Sand Mountain. The structural and paleoseismic relations between these faults and the Hurricane fault are unclear from present data, but scenarios that link paleoseismic events between the Hurricane, Washington, and the North to Northeast striking faults are plausible given the few constraints currently available.

The Sand Mountain – West Grass Valley fault trace is shown by Hayden (2004) as concealed along the steep northwest side of the volcanic edifice from which the Grass Valley basalts were erupted (Figure 3-2). Cumulative vertical displacement of the ~1 Ma Grass Valley basalts across the two fault traces in this area increases from north to south in this area, from ~126 m to 171-196 m (Figure 3-3). This implies a vertical slip rate on this fault of 0.1 – 0.2 mm/yr, approaching the low end of rates on the Hurricane fault (0.2 – 0.4 mm/yr). In addition, because the region is dominated by east-west extension (Holland and Bennett, 2009), with the northeast strike of these faults, slip may include a significant component of left-oblique motion. The Sand Mountain – West Grass Valley fault appears to extend about 6 miles to the southwest from the project area (Figures 3-1 and 3-4).

The fault would intersect the LPP Western alignment near station 50+00 and the CVP Alternative C alignment near station 2+00. At both of these locations, the fault should be merging with or intersecting the west-dipping Hurricane fault at shallow depths.
The Sand Mountain – West Grass Valley fault would intersect the Alternative 2c alignment in two locations. The eastern trace would intersect the Alternative 2c alignment near station 45+00, and the western trace would intersect the alignment near station 65+00. Beyond and south of the limits of the Grass Valley basalt, there is no expression of the western trace, and it appears that most slip is transferred to the eastern trace. The eastern trace is well expressed in the Grass Valley basalt north of the alignment, and south of the alignment has strong geomorphic expression in the Jurassic bedrock and eolian deposits on the eastern edge of Sand Mountain.

East of the Sand Mountain – West Grass Valley fault, and west of the Warner Valley fault (Figures 3-1 and 3-2) Hayden (2004) shows several faults with very limited displacement in the Jurassic Navajo and Kayenta formations. As mapped, none of these faults actually extend to the Alternative 2c alignment, and displacement appears to be decreasing to the north along all of these faults. One fault, just south of Alternative 2c station 10+00, has a small offset in the edge of the Grass Valley basalt, but this decreases to the north and is not evident a few hundred feet north of the flow edge.

No sites have been identified along the Sand Mountain – West Grass Valley faults where scarps or expression of these faults is evident in Quaternary eolian or alluvium. Along the Grass Valley Basalt outcrops, the fault is located along the base of a steep escarpment and colluvial ramp. Southwest of the extent of the Grass Valley Basalts, the fault is well expressed as a series of sharp topographic lineaments which bound a slightly higher area within the Jurassic Navajo and Kayenta bedrock, but this area is mantled by extensive, young and active eolian deposits.

The Sand Mountain - West Grass Valley fault is judged to be of High Significance due to the significant nearby displacement of the ~1 Ma Grass Valley Basalt, the prominent geomorphic expression along strike to the south near Sand Mountain, and the potential for reactivation due to its proximity and intersection with the main trace of the Hurricane fault. The remaining, unnamed faults between the Sand Mountain – West Grass Valley

fault and the Warner Valley fault, along the eastern part of the Alternative 2c alignment, are judged to be Not Significant because they do not appear to extend across the alignment and because the small bedrock displacements associated with individual traces appear to decrease to the north.

3.2 Faults near Sand Hollow Reservoir

Northeast of Sand Hollow Reservoir Hayden (2004) and Biek et al.(2007) map a short, down-to-the-east fault cutting the ~ 1 Ma old Ivans Knoll Basalt (Figure 3-4). The maximum mapped extent of this fault is less than two miles, does not extend into similar flows to the north, and the southern extension towards the LPP alignment is shown as concealed. The fault is evident as a subdued scarp on the Ivans Knoll flow, but has no expression in the eolian sand covered Jurassic bedrock landscape south of the more resistant basalt. The concealed traces shown on maps by (2004) and Biek et al. (2007) do not extend to the present LPP alignment. Projection to the south of these concealed traces would intersect the alignment near station 200+00.

Based on the limited extent of this fault, and the absence of geomorphic or stratigraphic evidence for the extension to the alignment, it is judged Not Significant for the western LPP alignment.

3.3 Remnants Basalt faults

Biek et al.(2007) depict several faults in the ~ 1 Ma old Remnants Basalt that intersect the western LPP alignments at 76 + 00 and 100 + 00, and the Alternate C alignment between stations 98+00 and 150+00 (Figure 3-4). All of these faults are very short, and are only mapped or inferred within or adjacent to outcrops of the Remnants Basalt. The faults that intersect the LPP alignment have little topographic expression. The western-most fault, near station 100 + 00 may be the western margin of the Grass Valley flow in this area. For the faults crossing the Alternative C alignments, the southern most of these faults is shown as certain, and is the only one also mapped by Hayden (2004). This fault is expressed as a west-facing anti-slope scarp on the east tilted Remnants Basalt. This scarp does not extend away from the basalt outcrop onto the younger Quaternary alluvium and fan deposits. The remaining faults have no topographic expression, and are mapped as concealed or inferred. The northern most fault extends

north beneath late Quaternary alluvium and has no surface expression. This group of faults may be related to the volcanic eruptive centers of the basalt flows, or may be secondary structures related to displacement on the Hurricane fault. None of them have expression in Quaternary deposits, and although displacement amounts are uncertain, they appear to be less than 30-50 feet on any structure based on the outcrop relations.

Based on the short fault lengths, absence of geomorphic expression, and small apparent displacements, most of these faults are judged to be Not Significant to the Alternative C and western LPP alignments. The exception is the fault which intersects Alternative C alignment at station 99 + 00 which is judged to be of Low Significance based on the preservation of a traceable scarp along its length.

4.0 CVP FAULT CROSSINGS

The Cedar Valley Pipeline (CVP) begins at LPP station 6653 + 20 just east of the proposed forebay and Hurricane Cliffs Hydropower Facility and extends north to Cedar City, UT (Figure 1-1). The entire length of the CVP follows within a few miles of the Hurricane fault, but does not cross any mapped faults until it begins to drop down over the Hurricane Cliffs, beyond station 900+00 a few miles north of Hurricane, UT. From there to the terminus at Cedar City, the alignment is mostly on the down thrown block of the Hurricane fault within 1-2 mile of the main trace, and intersects numerous other mapped faults with Quaternary displacement that are likely associated with the Hurricane fault. Discussion of the potential fault crossing proceeds from south to north along the CVP alignment and focuses on specific groupings of faults as outlined on the index map Figure 4-1.

4.1 Hurricane fault

Of the major normal faults, the Hurricane fault is the longest at 256 km (Hintze, 1980), with the most mapped total displacement and is the eastern boundary of the BRP (Lund et al., 2008b). The Hurricane fault is considered capable of generating large-magnitude earthquakes, and associated surface rupture, within a time period of concern to critical

engineered facilities (Lund et al., 2006; 2008b). Total displacement on the Hurricane has been estimated to be greater than 2,000 meters (ESA, 1982).

Lund et al. (2006) proposed paleoseismic segment boundaries for the Hurricane fault based on variations in slip rate, structural features, and age of most recent movement. The CVP follows or intersects three separate segments of the Hurricane fault from south to north, 1) Anderson Junction, 2) Ash Creek, and 3) Cedar City (Figure 4-1). No trenching investigations have been conducted on any of these segments in Utah, and there are only a small number of sites where fault scarps in alluvial deposits provide a potential record for the characteristics of the most recent surface-faulting events. On the Ash Creek segments these data indicate a late Holocene age for the most recent surface faulting. The age of most recent faulting on the Cedar City and Anderson Junction segments in Utah is also likely Holocene, but has not been demonstrated as such. Long-term slip rates of 0.4 – 0.6 mm/yr are estimated primarily from reconstructed displacements of Quaternary basalt flows at several locations on the Ash Creek and Cedar City segments. Slip rates on the Anderson Junction segment may be somewhat less, and decrease to the south in Arizona, but are still likely greater than 0.3 mm/yr (Lund et al., 2006). Based on a range of estimated single-event displacements and average slip rates, Lund et al. estimated average recurrence intervals on several locations along the Utah segments of the Hurricane fault that ranged from 1000 to 11,900 years.

The proximity of the Hurricane fault to the CVP alignment, along with the recency of movement and potential short recurrence intervals for surface-rupture events indicate that the potential significance of the Hurricane fault to the CVP is high along the entire length of the CVP. The CVP alignment crosses all the potential traces of the Hurricane fault within a wide, complex zone of faults near La Verkin and Toquerville (Figure 4-2a). This zone of faults is associated with a left step in the main trace of the Hurricane fault at the Anderson Junction – Ash Creek segment boundary. The segment boundary was originally identified by Stewart and Taylor (1996) based on this fault complexity, along with observed shortening structures and a variance in scarp morphology across the segments. South of La Verkin, on the Anderson Junction segment, the strike of the Hurricane fault is generally N 0 - 20°E. In this area, the fault has a minor right lateral

component supported by slickenlines with a 86° rake to the north at a site southeast of Hurricane (Lund et al., 2006). However, between La Verkin and Anderson Junction (Figure 4-2a), most fault traces strike N 0 - 20°W, which would imply a potential for a larger lateral components on more west-striking faults. However, no field evidence has been observed to support this. Fault traces north of Toquerville on the Ash Creek segment have generally northeast strikes.

North of Anderson Junction (Figure 4-1), the Ash Creek segment of the Hurricane fault is generally subparallel to the CVP alignment. Numerous fault crossing locations north of Anderson Junction are associated with faults that are most likely linked to the Hurricane fault rather than being independent seismic sources. Most of these faults have relatively short trace lengths, and are located within 1-3 miles of the main trace of the Hurricane fault. About 10 miles southwest of Cedar City, another significant strike change in the Hurricane fault defines the boundary between the Ash Creek and Cedar City segments (Figure 4-1). Faults on crossings of the northern-most sections of the alignment appear to be linked to events on the Cedar City segment of the Hurricane fault, based on the proximity of these fault crossings to the main trace of the Hurricane fault.

4.2 Toquerville Area and Segment Boundary faults (Map 1)

The CVP alignment crosses the Hurricane fault and numerous individual traces within the Anderson Junction - Ash Creek segment boundary, near Toquerville between stations 900+00 and 1050+00 (Figures 4-2a and 4-2b). Individual faults within this complex zone accommodate displacement in both down to the east and west directions (Figure 4-2b, map 1). On Figure 4-2b, the main zone of faults are numbered individually 1 through 10, to facilitate discussion below.

Fault crossing 1 appears to be primarily a gravitational driven fault at the top of the escarpment associated with fault crossing 2 (Figure 4-2b). The faults mark the eastern limit of the broad zone of faults associated with the segment boundary deformation zone at the alignment. Large blocks of Triassic Timpoweap limestone are actively toppling along the fault 1 trace. East of this fault, the unfaulted Triassic and Permian bedrock has near horizontal or gently east-dipping bedding. The fault trace intersection is near station 911 + 45.

Fault crossing 2 near station 913 + 00 (Figure 4-2b) accommodates significant down-to-the-west displacement along a marked topographic escarpment. The fault defines a major change in bedrock dip. East of the fault, bedding is near horizontal to gently east-dipping. West of the fault, tilted beds of Triassic Virgin limestone and Middle red member dip 30°-45° west. The faults at crossings 2 and 3 define the limits of a significant topographic trough, of either erosional or tectonic origin.

Fault crossings 3, 4 and 5 are within a repeated sequence of internally deformed, Moenkopi Middle Red (TRmm) member fine-grained units capped by beds of the Virgin limestone. The limestone marker beds indicate relatively modest, down-to-the-east displacement across these east-dipping, steep faults. The intersection for each fault trace crossing is: FC-3 near station 919 + 15; FC-4 near station 925 + 85; FC-5 near station 931 + 50. The fault at crossing 3 has significant topographic expression along strike, but faults at crossings 4 and 5 do not.

Fault crossings 6 and 7 appear to be much lower angle faults accommodating moderate down-to-the-west displacement within the Triassic footwall block. The intersection for each fault crossing is: FC-6 near station 935 + 50 and FC-7 near station 937 + 60. Neither fault is associated with obvious topographic relief near the alignment, and as mapped by Biek (2003), appear to merge with or be truncated by the major fault trace to the west.

Near station 940+00 (Figure 4-2b), fault crossings 8 and 9 mark the major bedrock shear zone of the Hurricane fault. Just south of the alignment, Quaternary basin fill is strongly deformed and juxtaposed against the Triassic bedrock. The topographic relief between the bedrock units on the footwall and the Quaternary units on the hangingwall increases rapidly to the south of the alignment along these faults. However, 0.2 miles north of the alignment, this relief is diminished as the highest elevation Qafo mapped by Biek (2003) overlaps these faults with no apparent displacement. This indicates the rapid transfer of displacement between the many subparallel fault strands within the segment boundary transfer zone. Based on the geomorphic expression of the main fault line scarp south of

the alignment, these fault crossings likely represent the most likely locations for large displacements within the segment boundary transfer zone.

The pipeline intersection at fault crossing 10 near station 956 + 00 (Figure 4-2b) is mapped as concealed by Quaternary alluvium by Biek (2003). At the alignment location, this fault juxtaposes west-dipping Jurassic units (Navajo and Kayenta), and may also be the western limit of more strongly tilted and deformed sections of the Qafo units mapped by Biek. The eastern limit of down-faulted Pintura basalt is mapped just west of this trace as well, suggesting that significant Quaternary displacement is present along this trace. However, there is no surface expression of this fault in the Qafo and younger units, and no topographic or geomorphic expression along the trace near the alignment.

Just north of La Verkin Creek (Figure 4-2b), near station 1000+00, a section of the CVP alignment is parallel to and may overlie a northwest-striking, concealed fault trace labeled by Biek (2003) as “Hurricane fault” near Toquerville. The fault trace is at the based of a steep, colluvial covered slope beneath a ridge capped with Pintura Basalt (Qtb). The alignment location is on the back edge of an alluvial terrace, Qta6, at the base of this slope. The Qta6 terrace overlies Pintura Basalt (Qtb) which appears in scattered outcrops along the road at this location and is extensively exposed in the creek just to the west. The Qtb outcrops at the top of the hill to the east demonstrate nearly 200 feet of displacement on this fault trace. At the alignment near station 1000+00, outcrops along the road appear to imply the main trace is most likely slightly east of the trace location shown by Biek. This would imply a fault crossing location further south, between stations 995+00 and 990+00. The Qta6 terrace surface just south of the alignment is extensively modified and re-terraced for pastures, but a least two terrace steps (3-4 feet high) are possibly coincident with fault scarps.

A fault with down-to-the-east displacement (Lund et al., 2008b; Biek, 2003) intersects the alignment near station 1039 + 40 on the west side of Toquerville (Figure 4-2b, map 1). This fault is expressed as a broad gentle scarp completely within the Pintura basalts that are exposed along the ridge, with no expression in the surrounding Quaternary alluvial/eolian deposits. Apparent, total offset along this trace, based on the topographic

scarp height is probably 20 ft. Based on the strike and proximity to the Hurricane fault, this fault appears to be a secondary, antithetic structure to the Hurricane fault.

4.2.1 Segment Boundary Summary

Faults within the segment boundary are reasonably well located, intersecting the alignment at multiple locations. The most apparent deformation occurs on the boundaries of the segment deformation zone at crossings 1,2 and 3 on the east and crossings 8 and 9 on the west. These fault crossings likely represent the most likely locations for large displacements within the segment boundary transfer zone and are therefore judged to be of High Significance. The significance of the remaining faults is supported by the pervasive evidence for deformation throughout the segment boundary and consideration that most rupture scenarios would include some coseismic deformation on more than one trace during a single event. However, the remaining fault traces lack specific associations to stratigraphic or geomorphic evidence of significant Quaternary displacement. The remaining faults within the segment boundary are judged as Moderate – Low Significance.

4.3 Anderson Junction Area (Map 2)

South of Wet Sandy Creek, the mapped traces of the Hurricane fault split on either side of a east-sloping mesa capped by Pintura Basalt (Biek and Hurlow, 2003) (Figure 4-3, map 2). The eastern traces strike N0° - N15°W and follow the base of the Permian bedrock cliffs. The western-most trace strikes about N40°E near Anderson Junction and CVP stations 1200+00 to 1300+00, but has a N-S strike further south. The western trace is mapped as concealed along the base of a ~200-ft high escarpment capped by Pintura Basalt. No young scarps are evident along the base of this escarpment, but Pintura Basalt must be offset by >200 feet along this fault, and the Qafo units of Hurlow and Biek (2003) appear to be truncated along this trace. The geomorphic expression of potential faulting along this trace decreases to the south and west. This area is the segment boundary transition between the Anderson Junction segment to the south and the Ash Creek segment to the north (Figure 4-1).

The western trace is mapped as concealed (Figure 4-3, map 2), and thus has significant location uncertainty, but as mapped would intersect the CVP alignment in two locations

at about stations 1185+00 and 1215+00. From these locations north to station 1300+00, the mapped trace is generally within 0.25 mile of the alignment. However, based on the absence of scarps on the near these crossings, and the locations of these crossings near the end of concealed fault traces which comprise the southern extent of the Ash Creek segment, surface rupture hazards at these crossing locations are judged to be Not Significant.

4.4 Pintura and Ash Creek Graben Area (Map 3)

In the Pintura area, the main traces of the Hurricane fault are east of Ash Creek and generally more than 0.5 miles from the CVP alignment (Figure 4-4, map 3). A complex of faults and grabens on the hangingwall, subparallel to the Hurricane fault, are termed the Ash Creek graben (Lund et al., 2006). The Ash Creek graben faults displace Quaternary basalts, and several also displace late Quaternary alluvial deposits. The relationship of these faults to the Hurricane fault is uncertain. Displacements on these faults may or may not be independent of large events on the adjacent Hurricane fault.

Near CVP station 1400+00, a large outcrop of Pintura Basalt is bounded on the east by a curvilinear, north-striking fault which extends north and crosses the alignment near station 1431 + 40. This fault continues north across I-15 as a prominent scarp on Qafo units of Hurlow and Biek (2003). Fault scarps on the mid to late Pleistocene Qafo surface northwest of the highway are 20 to 30 m high. The scarp at the alignment is of similar scale, but is near the transition to a larger scarp cored by basalt. This fault trace forms one of the longer continuous faults within the Ash Creek graben, extending at least 3 miles north of the CVP alignment crossing. Displacement is down-to-the-east, suggesting that it must be antithetic to the Hurricane fault at relatively shallow depth. Thus, the most likely scenario is that this fault would rupture co-seismically with large events on the Hurricane fault.

For fault crossing hazards, the significance of this fault crossing to the CVP alignment appears to be high because of the apparent association of this trace with the Hurricane fault. Most likely rupture scenarios would include coseismic rupture on this fault trace as part of large events on the Hurricane fault.

An additional fault mapped along the southern extent of the Pintura basalt block on Biek et al. (2007) interim St. George quadrangle geologic map, would cross near station 1370+00. This fault does not appear on more detail mapping by Hurlow and Biek (2003) and the mapped, sinuous linework appears to be a geologic contact that was misdrawn as a fault.

4.5 Hurricane fault - Kolob Arch area (Map 4)

Through this area, just south of Ash Creek Reservoir, the CVP alignment generally lies 0.2 – 0.4 miles west of the main trace of the Hurricane fault (Figure 4-5, map 4). Locally, existing mapping shows subparallel secondary and antithetic faults defined from bedrock structure, in addition to the main trace. However, extensive landslides obscure the detailed location of the fault through much of this area.

The Pintura basalts, deposited on both the footwall and hangingwall from separate cones, provide a local estimate for long term vertical slip rates. The basalts at the North Black Ridge site are dated 0.84 $\pm$0.03 and 0.88 $\pm$0.05 Ma, and have a magnetic signature reversal that is unique to other basalts in the area (Lund et al., 2006). Lund et al. estimate a total vertical displacement across these basalts of 486 m, which indicates to a vertical slip rate of 0.57 mm/yr for this immediate area.

However, the mapped extent of the Pintura Basalt on the footwall locally defines which of the many secondary faults may be significant surface rupture hazards to the CVP alignment. Throughout much of this area the Pintura basalt is tilted east by recurrent displacements on the Hurricane fault.

Between CVP stations 1700+00 to 1850+00, the alignment follows the east margin of the Pintura Basalt where it is buried by younger alluvial fans derived from the upthrown block of the Hurricane fault. In this area Biek (2007) generally maps three traces of the Hurricane fault (Figure 4-5, map 4). The two eastern traces generally coincide with fault-line scarps and sharp topographic breaks in the alluvial fans. The western trace is shown mostly within 0.1 mile to the alignment and intersects at locations near 1790+00 to 1815+00. No scarps are evident along this western trace in this area, and mapping by

Biek (2007) and our reconnaissance suggests that this section of the alignment is underlain by unfaulted Pintura Basalt.

Based on the mapped extent of the unfaulted Pintura Basalt near these fault crossings, they are judged as Not Significant for the CVP alignment. However, the Pintura Basalts are significantly tilted toward the Hurricane fault throughout this section of the alignment, and the main trace of the fault is commonly within 0.2 mile of the CVP alignment. The potential gradient changes associated with coseismic tilting may increase with proximity to the main fault trace.

4.6 Kanarraville area (Map 5)

The northern termination of the Ash Creek segment of the Hurricane fault is expressed as steep scarps within the alluvial fans draining the steep cliffs along the fault (Figure 4-6, map 5). Several fans along this section show evidence of multiple events with fault-related scarps up to 20 m high and single event scarps up to 3 m (Lund et al., 2006). Although no fault crossings are mapped between stations 1850+00 and 2200+00, the alignment is generally within about 1 mile of, and parallels the main trace of the Hurricane fault through this area. Surface rupture events on the Hurricane fault could result in coseismic tilting towards the Hurricane fault, and local secondary ground deformation.

The two faults identified as having intersections with the CVP west of Kanarraville form a quarter-mile wide graben trending approximately N15°E, roughly subparallel with the Hurricane-fault (Figure 6, map 5). The pipeline is roughly spatially coincident with the western fault between stations 2230 + 00 and 2370 + 00 and crosses the eastern fault near station 2218 + 46. The assumed basis for this graben structure is to explain the late Quaternary Qap2 deposits bounded on the east and west by Plio-Pleistocene and topographically higher QTafp3 deposits. Based on airphoto interpretation and field reconnaissance it appears this graben is plausibly interpreted as fluvial erosion related to Kanarra Creek, a southward flowing creek draining the northern basin and Murie Creek. Whether the drainage is coincident with relatively minor secondary faults is unclear, but it appears that tilting of the Quaternary fan deposits and fluvial erosion by

Kanarra Creek are sufficient to explain the geomorphology of this area without any faulting.

The short faults near Kanarraville are judged to be of Low Significance to surface hazard for the CVP alignment. Geomorphology of this site is plausibly explained by tilting related to the Hurricane fault and fluvial erosion, without resorting to significant faulting along this short graben. If secondary faults are present in these locations, displacements of late Quaternary deposits are likely substantially less than suggested by the heights of the fluvially-modified scarps along Kanaraa Creek.

4.7 Cross Hollow Hills Area (Map 6)

Near Cedar City, the North Hills and the Cross Hollow Hills are two collinear highs composed of pre-Quaternary basin fill and Quaternary basalts, on the hangingwall of the Hurricane fault (Figure 4-1). The segment boundary between the Ash Creek and Cedar City segments lies just south of the North Hills. Long-term slip rates on these segments are similar, about 0.5 – 0.6 mm/yr, but late Quaternary rates on the Cedar City segment may be less than 0.3 mm/yr, and the most recent event is undated, but possibly Holocene (Lund et al., 2006).

The CVP alignment is mostly 2 to 4 miles west of the Hurricane fault along the Cedar City segment, so potential fault crossing issues are limited to crossing of faults mapped near the Cross Hollow Hills. The numerous faults mapped within both the Cross Hollow and North Hills have distinct geomorphic expression (Figure 4-1), and cut or rotate Quaternary basalts, but no scarps or faults have been mapped on the alluvium surrounding these hills. The northern extension of the CVP alignment wraps around and through the Cross Hollow Hills and crosses several of these faults just prior to reaching the termination point of the CVP (Figure 4-7 map 6).

Most of the Cross Hollow Hills consists of Tertiary basin fill, apparently capped by Quaternary basalt (Rowley et al, 2008). This basalt caps the eastern flank of the hills up to the water tanks atop the hills, and is extensively tilted and broken by faulting. Our reconnaissance suggests that the portion of this basalt along Cross Hollow Road, which caps the northern flank under the middle school and also extends south near the retail

development fronting I-15, is mostly flat-lying and is inset into the older basalt. However, both basalts appear to be cut by faulting. Because the major tilting of the basalts within the Cross Hollow Hills is to the east, it appears that many of the faults within the Cross Hollow Hills are likely antithetic to the Cedar City section of the Hurricane fault, and most have net down-to-the-east displacement. However, there are several secondary, down-to-the-west faults which form smaller-scale, north-northeast trending graben structures within the hills.

The faults dissecting the Cross Hollow Hills as mapped by Rowley et al. (2008) on the Cedar City quadrangle are roughly accurate based on our field reconnaissance, but have been modified on Figure 4-7 to more accurately locate the faults in relation to the alignment at a higher resolution. In general the faults are more sinuous and a far more complex interconnected fault system than portrayed at the larger 100k scale. When examined in detail, the Cross Hollow Hills faults appear to be a complex system of interconnected ramp and relay structures with persistent basalt cored scarps, and rapid changes in displacement along strike. These faults are discussed in sequence from west to east, as they would be encountered moving up the CVP stationing.

The fault crossing at CVP station 2785+90 is a concealed fault mapped by Rowley et al. (2006) which extends northeast and bounds the northwest side of the Cross Hollow Hills (Figure 4-7). Displacement on this fault is inferred to be down to the west. We observed no scarp or obvious expression of this fault in the late Quaternary alluvium along the length of the fault or near the pipeline. Based on these observations, this fault is judged to be of Low Significance to the CVP alignment.

The fault crossing near station 2872+80 is the western most of the series of faults within the Cross Hollow Hills mapped by Rowley et al. (2006) which extends to the CVP alignment. Within the basin fill and basalt of the Cross Hollow Hills, the fault is evident as a irregular, west-facing, fault line scarp, but it has no expression within any alluvial units south of the hills. At the alignment, the fault is concealed by alluvium. Because this fault has some geomorphic expression north of the alignment, it is judged to be of Low – Moderate Significance.

The geomorphic expression of the fault crossing at station 2885+00 is minimal at the alignment, but is more evident to the south of I-15 where a low ridge of Tertiary basin fill appears to block or deflect drainage of Schurtz Creek (Figure 4-7). About 1 mile south, along the east margin of North Hills, this fault may continue and appears to cut and backtilt a large alluvial debris fan. Displacement of this fault is down-to-the-east, as evidenced by a conspicuous shear zone cutting alluvium and truncating the basalt in the I-15 roadcut. Thus, in part, the expression of the fault to the north and adjacent to the alignment may be due to the relatively greater erosion resistance of the basalt compared to the basin fill. Because this fault is apparently associated with offset Quaternary alluvium near the alignment, it is judged to be of Low - Moderate Significance.

A pair of faults, crossing at stations 2899+00 and 2903+50, forms a narrow graben (Figure 4-7). The western fault, with down to the east displacement, has significant topographic expression at the alignment, but no apparent continuity to the north. The extension of this fault to the south may merge with the fault trace crossing at 2885+00 and discussed above. The eastern fault, with down-to-the-west displacement, has minimal expression at the pipeline alignment near station 2903 + 50, but a clear zone of displacement in exposures along I-15 and just north of the highway. Here basalt overlying alluvium and loess is offset approximately 20 to 25 feet vertically over a 25 to 30 foot deformation zone. There is no fault evident on the alluvial surface to the south of the highway. North of the alignment, this fault continues through the Cross Hollow Hills. Because this fault is apparently associated with offset Quaternary alluvium near the alignment, it is judged to be of Low - Moderate Significance.

As mapped, the fault trace with the most significant geomorphic expression crosses the alignment in two locations: 1) station 2932+00, 2) station 2984+00, and 3) station 3027+00. Based on field reconnaissance, the trace of this fault is modified slightly from that shown by Rowley et al. (2008) and is shown on Figure 4-7. At the southern end of this fault, near the alignment and north of I-15, the fault trace is relatively subdued but there is a low scarp in bedrock which increases dramatically in height to the north. Rowley et al. maps the trace maintaining a straight, northeast trend and intersecting the pipeline at station 2990+00. To the southwest of the alignment the bedrock scarp takes a more northerly trend to the west of the pipeline, and dying out just east of the water

tank atop the hill. The fault trace steps to the right (east) across a closed depression and continues north across Cross Hollow Road. The main fault trace does not intersect the pipeline at station 2990+00, but the intersection is judged to be of Low Significance due to a potential for deformation within the fault step. North of the road, the scarp appears to be in younger, relatively flat-lying basalt which is inset into the strong tilted and older basalt which forms most of the Cross Hollow Hills. Just on the west side of the middle school, this scarp in the younger basalt appears to have approximately 23 feet of vertical displacement (Figure 4-7). The basalt is vertically offset approximately 23 feet, which results in a minimum vertical slip rate of 0.07 mm/yr (for an assumed minimum age of 100k). This trace is obliterated to the north by the quarry and urban development. The alignment intersects this fault trace for the final time near station 3027 + 06. The significance of the fault at the two alignment crossings is judged to be Moderate.

5.0 LPP-CVP FAULT CROSSING SUMMARY

Identified fault crossings intersecting the proposed LPP and CVP alignments have been assessed for their potential seismic hazard significance to the pipeline. Assessments for individual fault crossing locations are summarized in the tables below as follows: LPP alignment (Table 1); LPP West and CVP C alternative alignment (Table 2) and CVP alignment (Table 3).

For potential ground motion hazard assessment of pipeline facilities near the LPP alignments, only the Hurricane and the Sevier-Toroweap fault are presently included in the USGS National Map as fault sources. The Utah extents of the Kaibab and West Kaibab faults are not included in USGS compilations, but as shown in Figure 2-3, these faults do extend closer to the LPP alignments than depicted in USGS fault source compilations. The most significant potential seismic sources for the western LPP and CVP alignments are the various segments of the Hurricane fault and the Sand Mountain – West Grass Valley fault. Other nearby faults would either be directly associated with Hurricane fault earthquake rupture scenarios, or have slip rates that are much lower. Table 4 summarizes potential seismic source characterization data for faults within about

20 miles of the alignments which may be potentially significant as sources for ground motions at specific facilities along the alignments.

Table 1. Lake Powell Pipeline-Fault Intersection

		Fault Crossing Assessment		
Fault Name	**Alignment**	**Station Range**	**Location Confidence**	**Rupture Assessment**
Glen Canyon City fault	HWY	820 + 00	Low	Not significant
East Kaibab fault – Cockscomb	HWY	1729 + 20	High	Not significant
Central Kaibab fault	HWY	2270 + 00	Low - Moderate	Low significance
West Kaibab	HWY	2570 + 00 and 2579 + 00	Moderate - Low	Low significance
Paunsaugunt fault	HWY	2950 + 00	Low - Moderate	Low significance
	South	3030+00 to 3060+00	Low - Moderate	Low significance
	GSENM Y	166 + 50	Low - Moderate	Low significance
Johnson Canyon fault	HWY	3250 + 00 to 3300 + 00	Low	Not significant
	South	3360 + 00	Low	Not significant
Quikwater fault	South	4300 + 00	Low - Moderate	Not significant
Sevier fault (N. Toroweap)	HWY	4704 + 10	High	High significance
	South	4985 + 35	High	High significance
Short Creek fault	HWY	5920 + 00 to 5940 + 00	Low - Moderate	Not significant

Table 2. Western Lake Powell Pipeline-Fault Intersection

		Fault Crossing Assessment		
Fault Name	**Alignment**	**Station Range**	**Location Confidence**	**Rupture Assessment**
Sand Mountain -West Grass Valley fault	Western LPP	50 + 00	Low	High significance
	CVP Alternative C	2 + 00	Low	High significance
	CVP Alternative 2C	45+00	Moderate	High significance
	CVP Alternative 2C	65+00	Low -Moderate	High significance
Unnamed faults between Sand Mountain – West Grass Valley and Warner Valley faults	CVP Alternative 2C	0+00 to 35+00	Low	Not significant
Unnamed Sand Hollow Reservoir faults	Western LPP	200 + 00	Low	Not significant
Remnants Basalt faults	Western LPP	76 + 00	Low	Not significant
	Western LPP	110 + 00	Low	Not significant
	CVP Alternative C	97 + 00	Low	Not significant
	CVP Alternative C	99 + 00	Low	Low significance
	CVP Alternative C	109 + 00	Low	Not significant
	CVP Alternative C	112 + 00 to 116 + 00	Low	Not significant
	CVP Alternative C	150 + 00	Low	Not significant

Table 3. Cedar Valley Pipeline-Fault Intersection

		Fault Crossing Assessment		
Map Area	**Alignment**	**Station Range**	**Location Confidence**	**Rupture Assessment**
Segment Boundary (Map 1)	CVP	Crossing 1 911 + 45	High	High significance
	CVP	Crossing 2 913 + 00	High	High significance
	CVP	Crossing 3 919 + 15	High to Moderate	High significance
	CVP	Crossing 4 925 + 85	High to Moderate	Moderate - Low significance
	CVP	Crossing 5 931 + 50	High to Moderate	Moderate - Low significance
	CVP	Crossing 6 935 + 50	High to Moderate	Moderate - Low significance
	CVP	Crossing 7 937 + 60	High to Moderate	Moderate - Low significance
	CVP	Crossing 8 938 + 65	High to Moderate	High significance
	CVP	Crossing 9 941 + 75	High to Moderate	High significance
	CVP	Crossing 10 956 + 00	Moderate	Moderate - Low significance
	CVP	995 + 00 to 990 + 00	High-Moderate	Low significance
	CVP	1039 + 40	Moderate	Not significant
Anderson Junction (Map 2)	CVP	1185+00	Low	Not significant
	CVP	1215+00	Low	Not significant
Pintura & Ash Creek Graben (Map 3)	CVP	1431 + 40	High	High significance
Kolob Arch (Map 4)	CVP	1790 + 00 to 1815 + 00	Moderate	Not significant
Kanarraville area (Map 5)	CVP	2218 + 46	Low - Moderate	Low significance
	CVP	2230 + 00 to 2370 + 00	Low - Moderate	Low significance
Cross Hollow Hills (Map 6)	CVP	2785 + 90	Low	Low - Moderate significance
	CVP	2872 + 80	Low - Moderate	Low - Moderate significance
	CVP	2885 + 00	Low	Low - Moderate significance
	CVP	2899 + 00 and 2903 + 50	Moderate	Low - Moderate significance
Cross Hollow Hills (Map 6)	CVP	2932 + 50	Moderate	Moderate significance
	CVP	2972 + 00	Moderate	Not significant
	CVP	2990 + 00	Moderate	Low significance
	CVP	3027 + 00	High	Moderate significance

Table 4. LPP-CVP Seismic Source Assessment

	Seismic Source Significance	
Fault	**Age**	**Slip Rate**
Glen Canyon City fault	Pre Quaternary?	n.a.
East Kaibab -Cockscomb	Pre Quaternary?	n.a.
Central Kaibab fault	Mid and Late Quaternary?	unknown
West Kaibab	Late Quaternary?	unknown
Paunsaugunt fault	Late Quaternary?	<0.2 mm/yr (North of Bryce canyon)
Johnson Canyon fault	Pre - Late Quaternary?	unknown
Quikwater fault	Pre Quaternary?	unknown
Sevier fault (N. Toroweap)	Late Quaternary - Holocene?	0.04 - 0.18 mm/yr
Short Creek fault	Pre Quaternary?	unknown
Hurricane Fault (Anderson Junction Segment)	Late Quaternary - Holocene?	0.2 - 0.4 mm/yr
Hurricane Fault (Ash Creek Segment)	Holocene	0.4 - 0.6 mm/yr
Hurricane Fault (Cedar Valley Segment)	Late Quaternary - Holocene?	0.12 - 0.40 mm/yr
Sand Mountain – West Grass Valley fault	Late Quaternary?	0.1 - 0.2 (?) mm/yr

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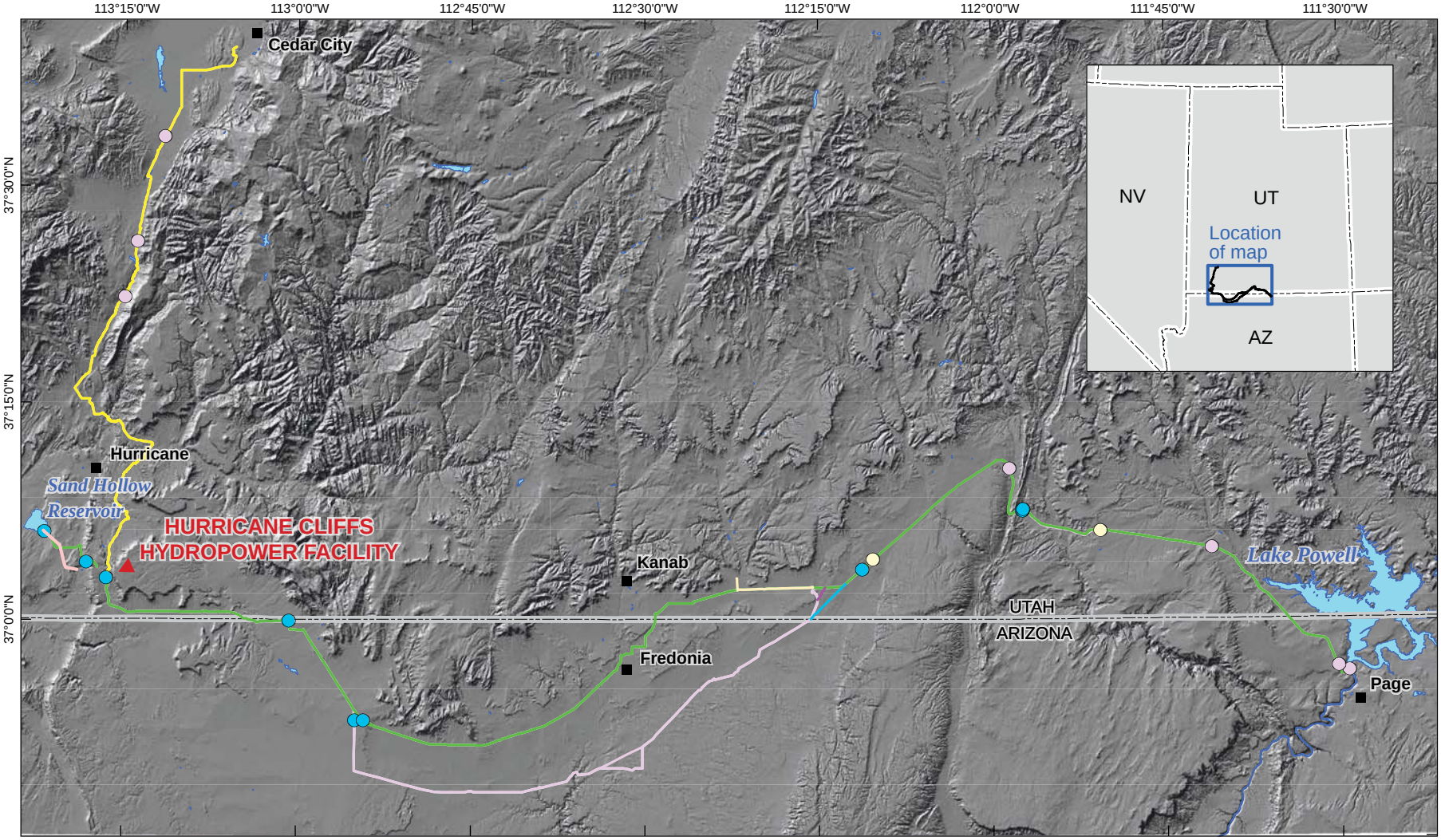


Explanation

- Hydro station
- Pump station
- Regulating tank
- CVP G Alternative
- KCWCD Pipeline Spur
- LPP GSENM Alternative
- LPP GSENM Alternative Y
- LPP Preferred HWY Alignment
- LPP Preferred South Alignment
- LPP Sand Hollow 2C Alternative

N

0 10 mi

WLA

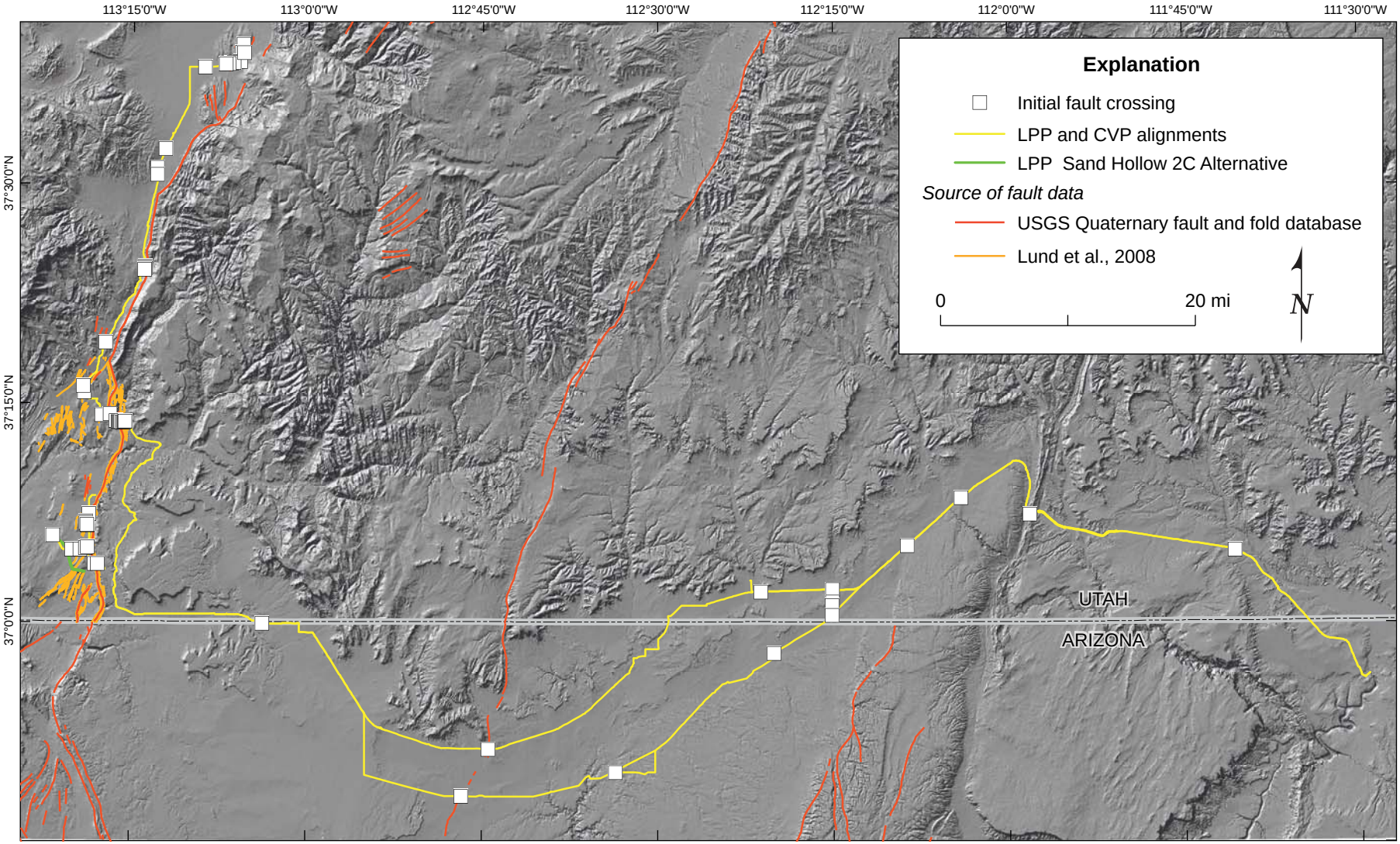
Lake Powell Pipeline and Cedar Valley Pipeline and Facilities Location Map

LPP - CVP FAULT ASSESSMENT

Figure 1-1

2042_LOCATIONMAP_20091120.MXD

23 DEC 2009, 2042, LPP AND CVP LOCATION MAP, FIGURE 1-1, MSZ



WLA

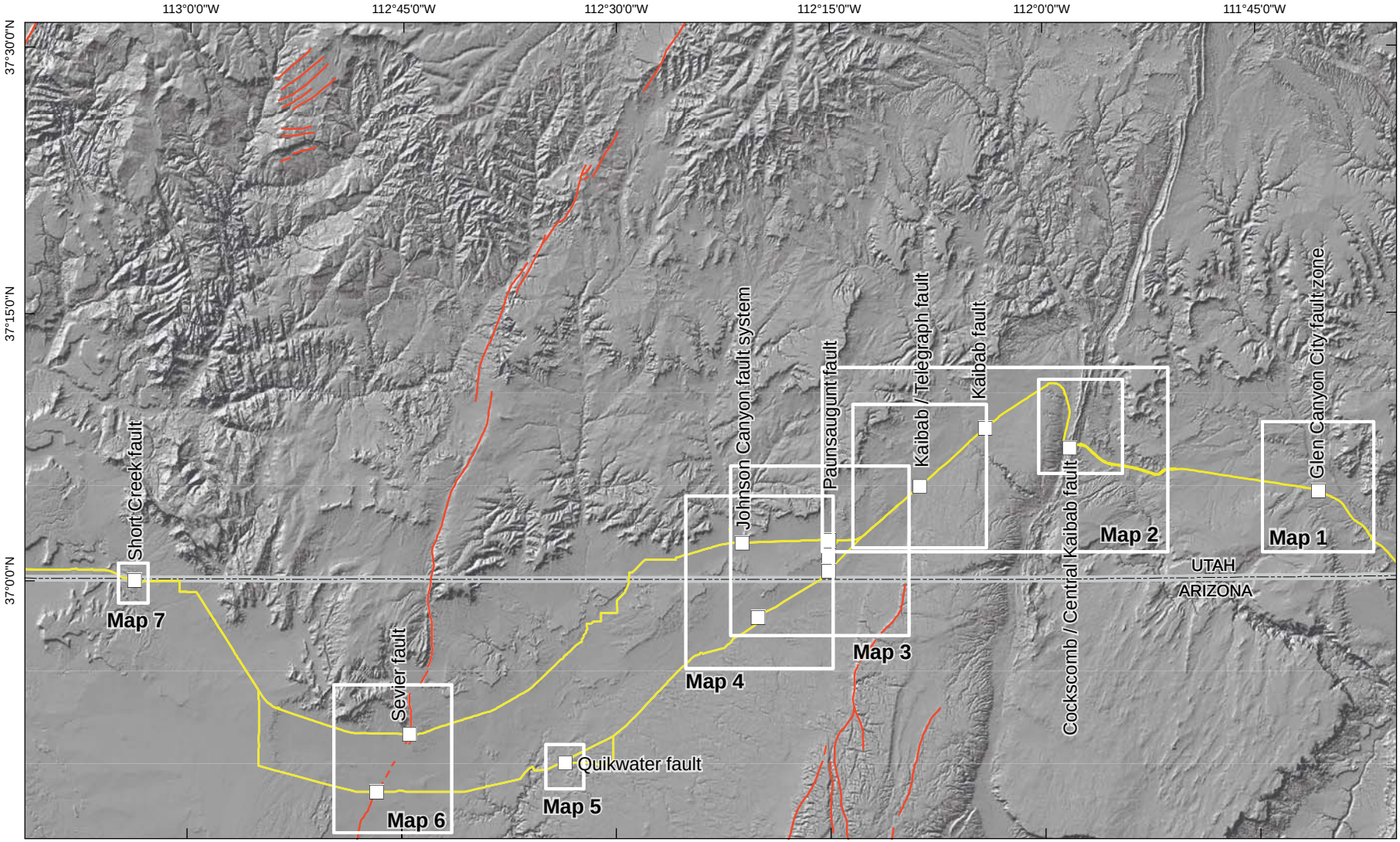
Initial LPP and CVP Fault Crossings

LPP - CVP FAULT ASSESSMENT

Figure 1-2

2042_FAULT_CROSSING_INITIAL_20091120.MXD

23 DEC 2009, 2042, INITIAL FAULT CROSSING MAP, FIGURE 2, MSZ



Explanation

- Initial fault crossing
- LPP and CVP alignment
- USGS Quaternary fault and fold database

N

0 10 mi

WLA

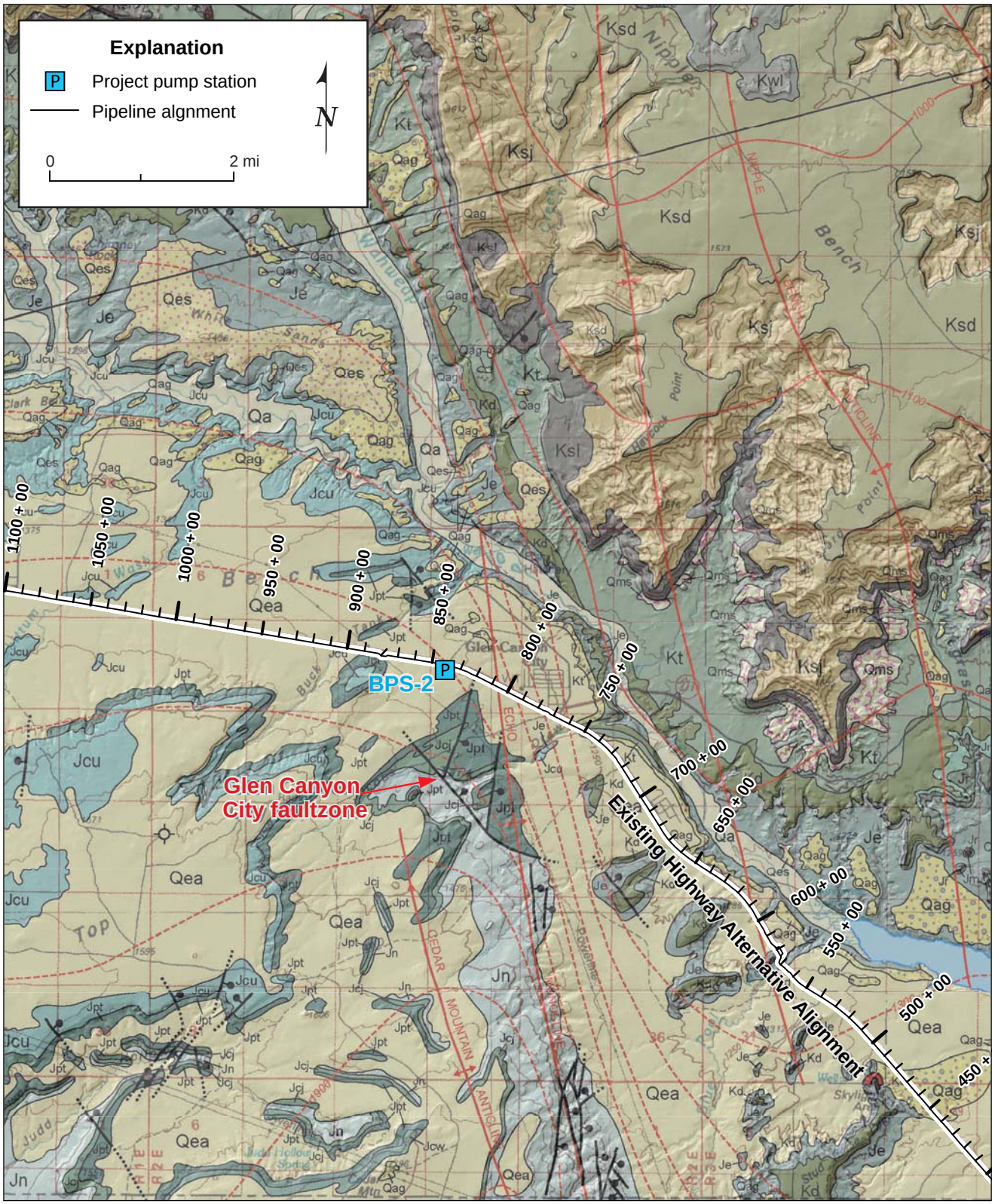
Lake Powell Pipeline - Fault Crossing Index Map (East)

LAKE POWELL PIPELINE PROJECT

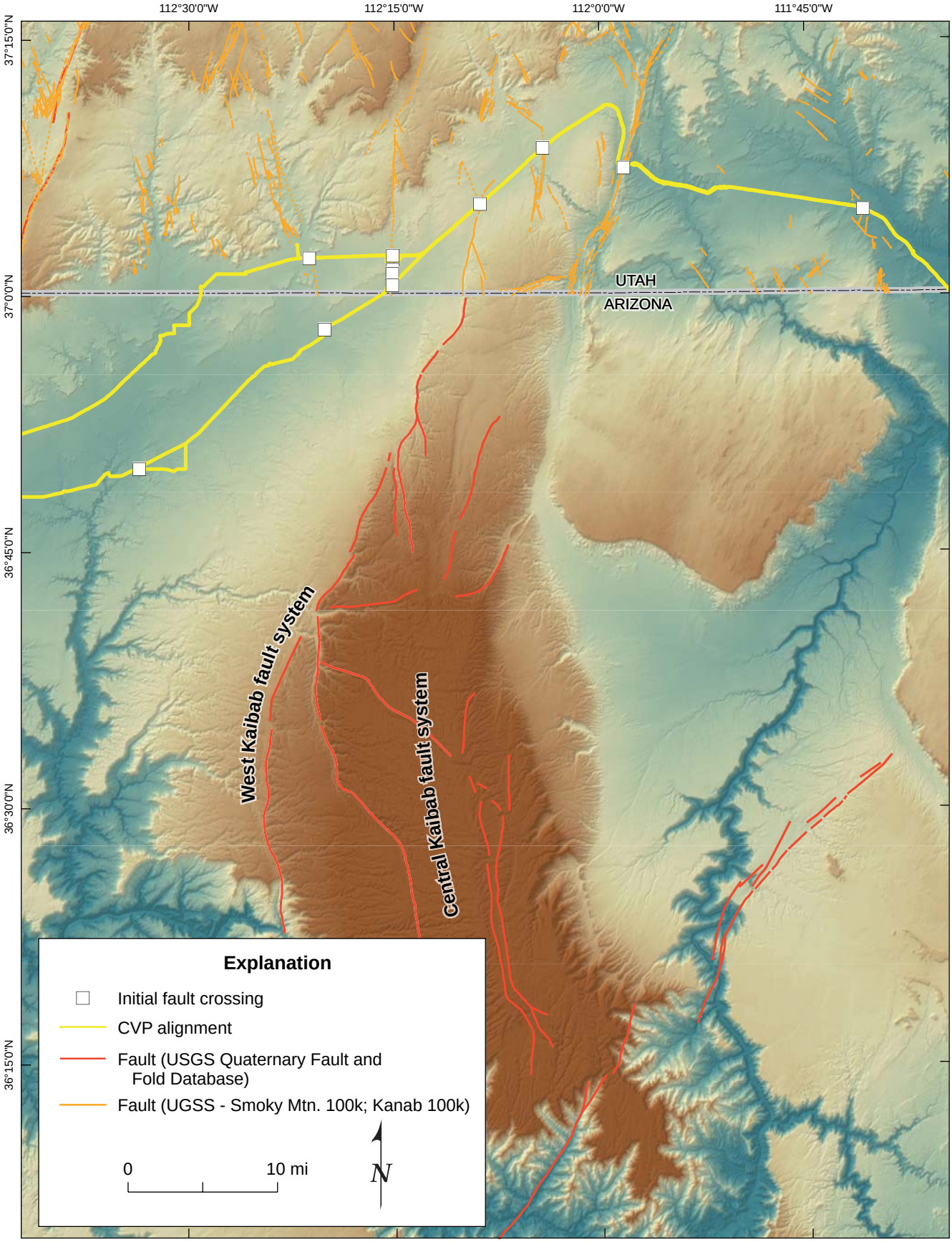
Figure 2-1

2042_LPP_FAULT_XING_INDEX_E_20091120.MXD

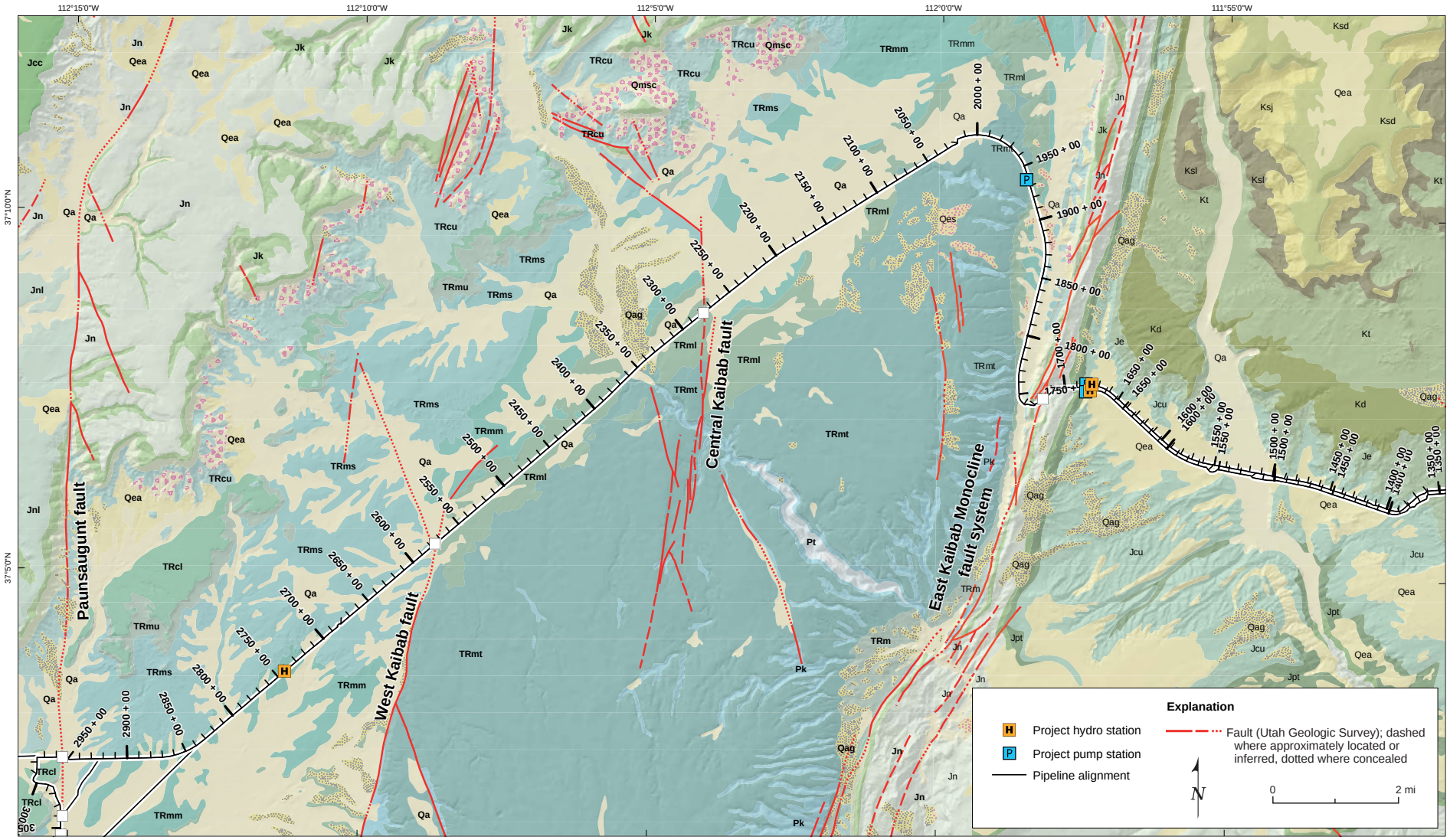
23 NOV 2009, 2042, LPP FAULT CROSSING INDEX E, DRAFT, MSZ



Note: Geologic base from Smoky Mountain 100k - Doelling and Willis, 2006



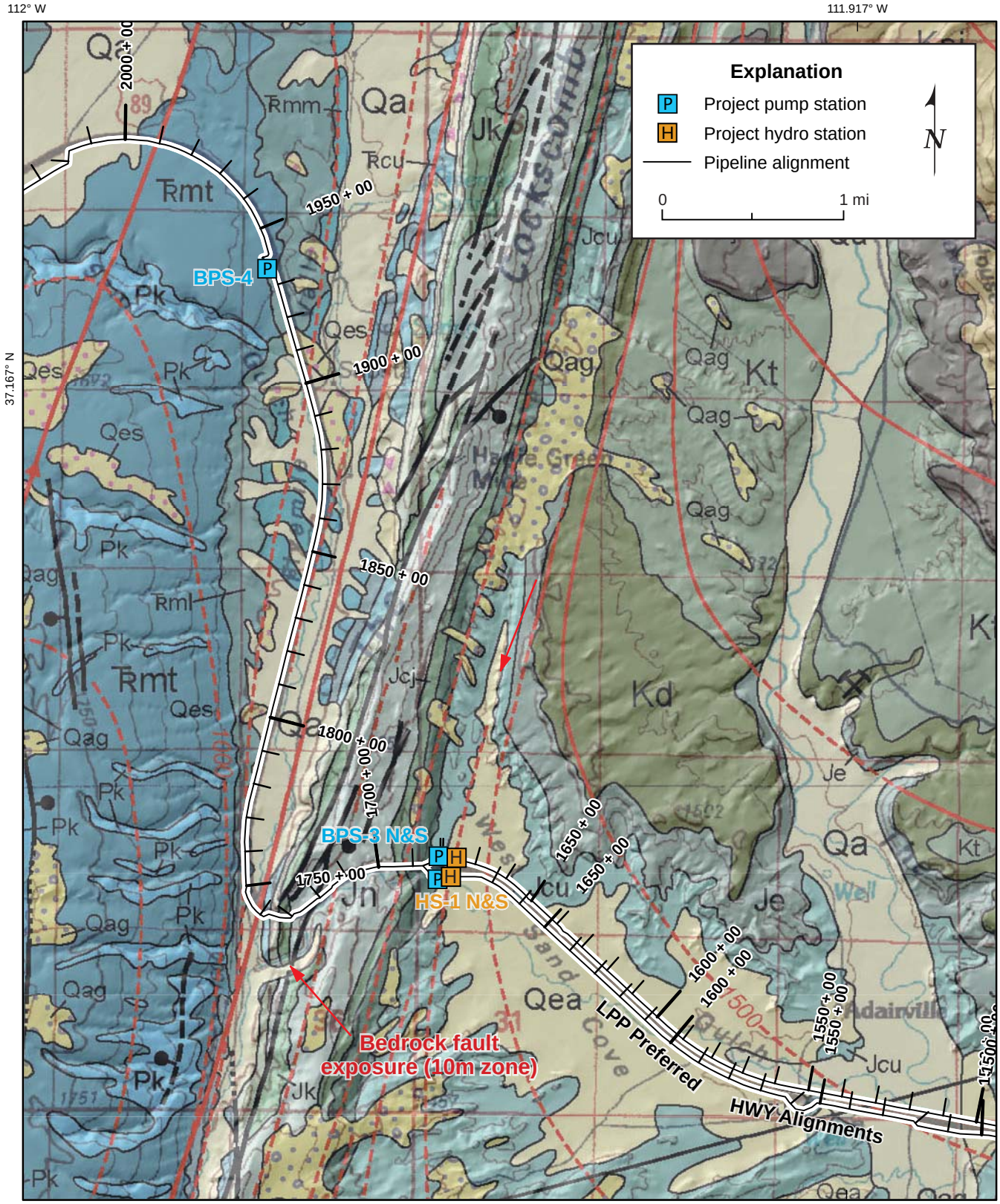
Geology: Smoky Mountain, 100k; Doelling and Willis, 2006



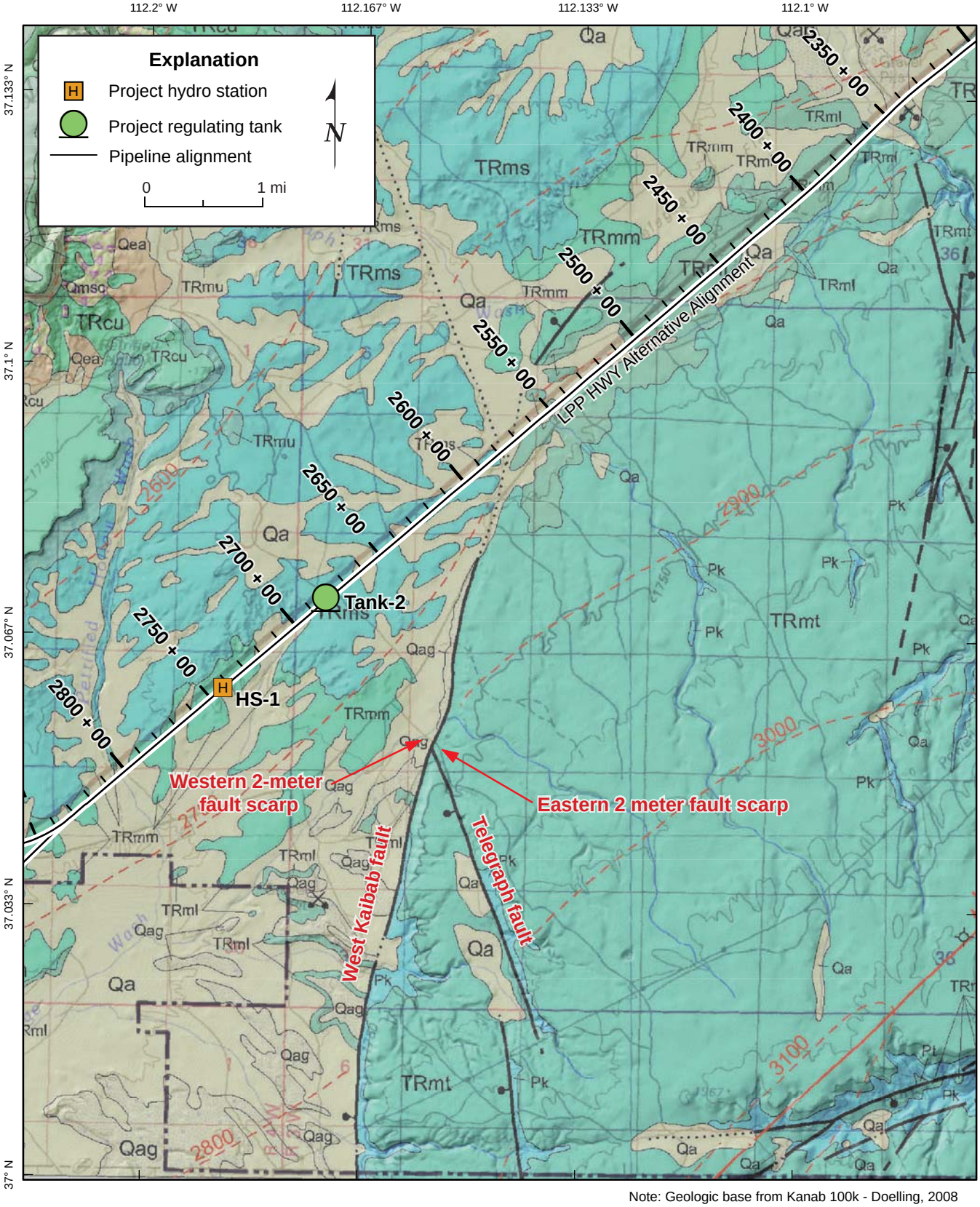
Geology: Kanab, 2008; 100k; Doelling, 2008 / Smoky Mountain, 2006; 100k; Doelling and Willis, 2006

Kaibab Plateau Faults

Figure 2-4

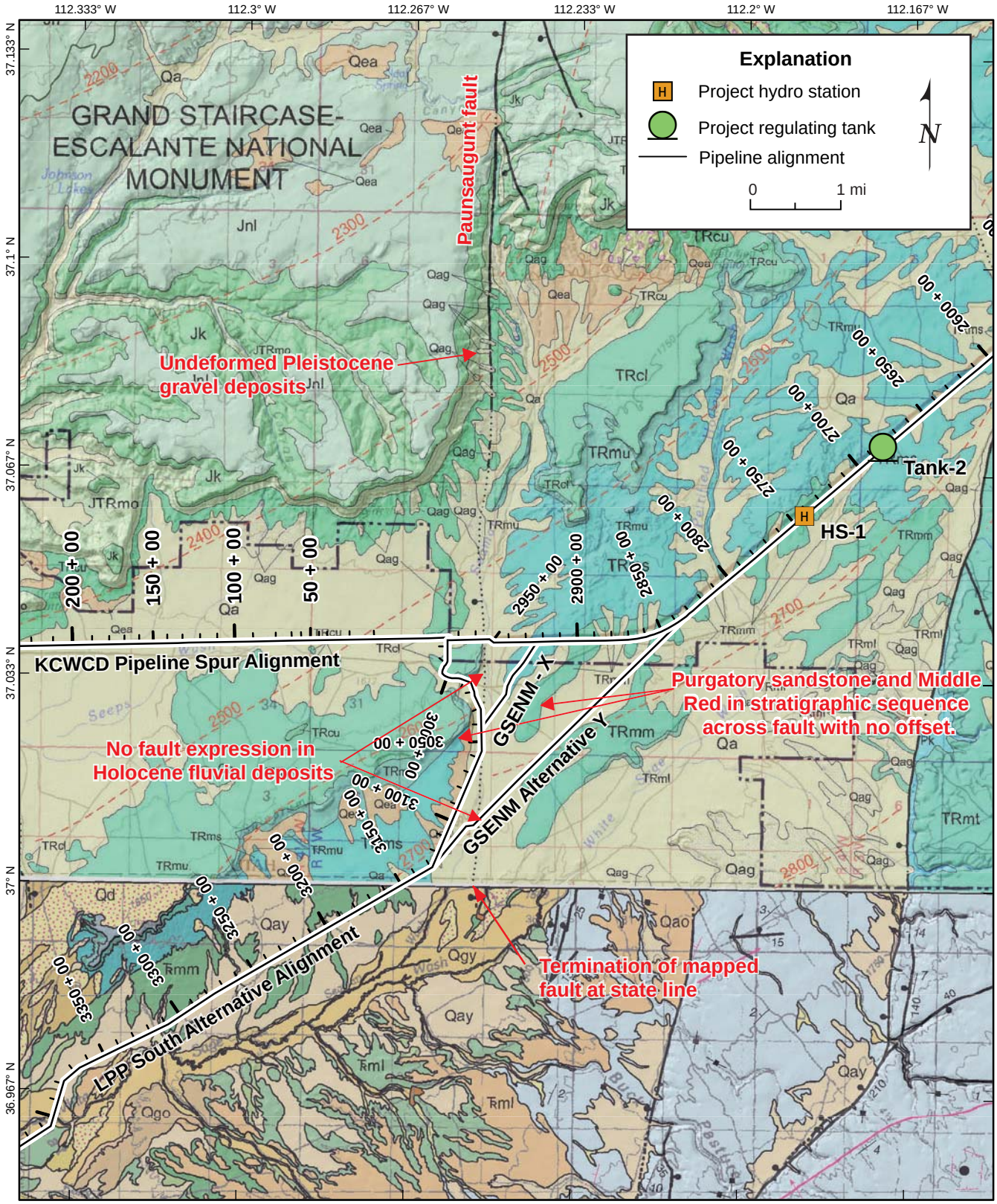


Note: Geologic base from Smoky Mountain 100k - Doelling and Willis, 2006

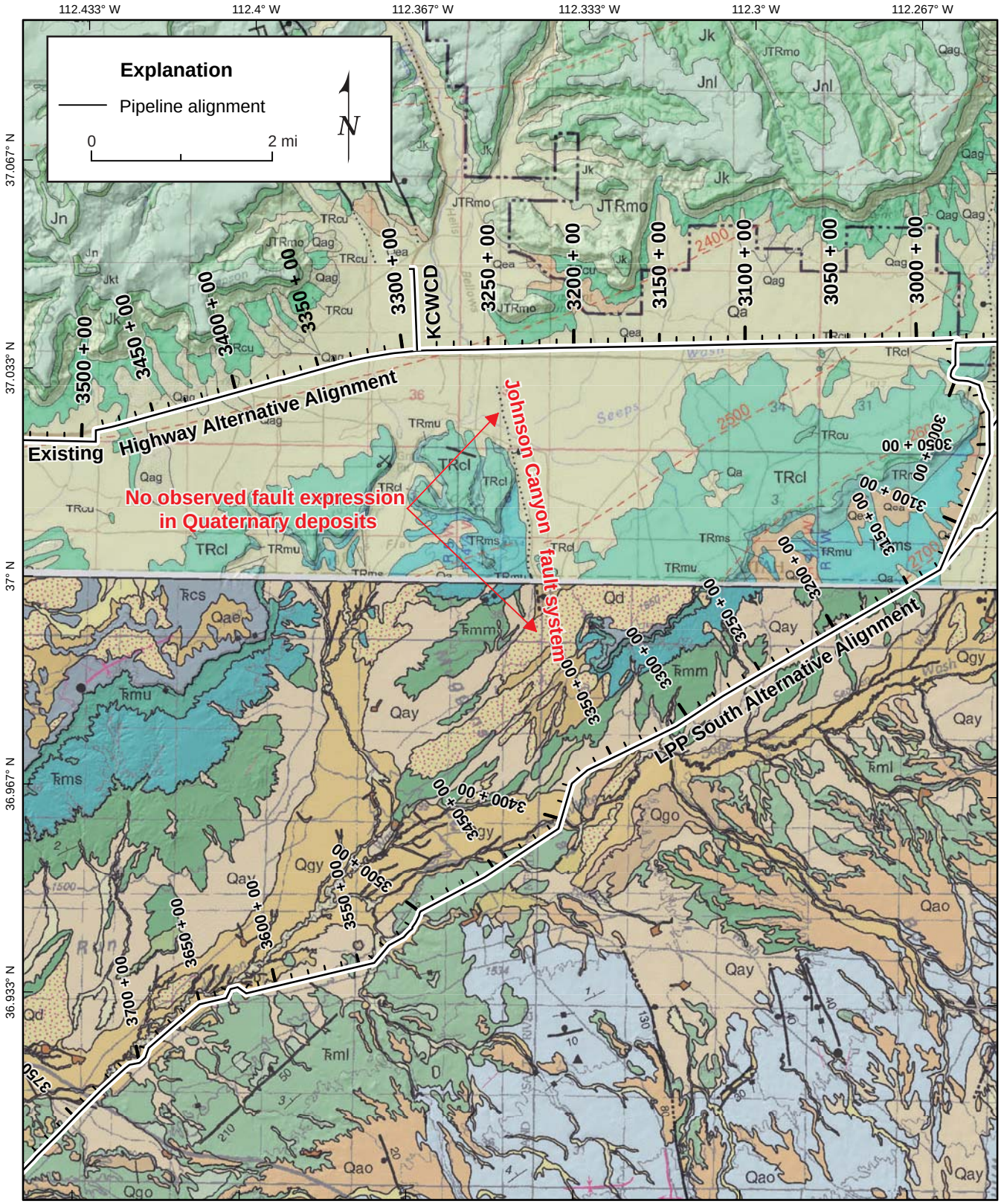


Note: Geologic base from Kanab 100k - Doelling, 2008

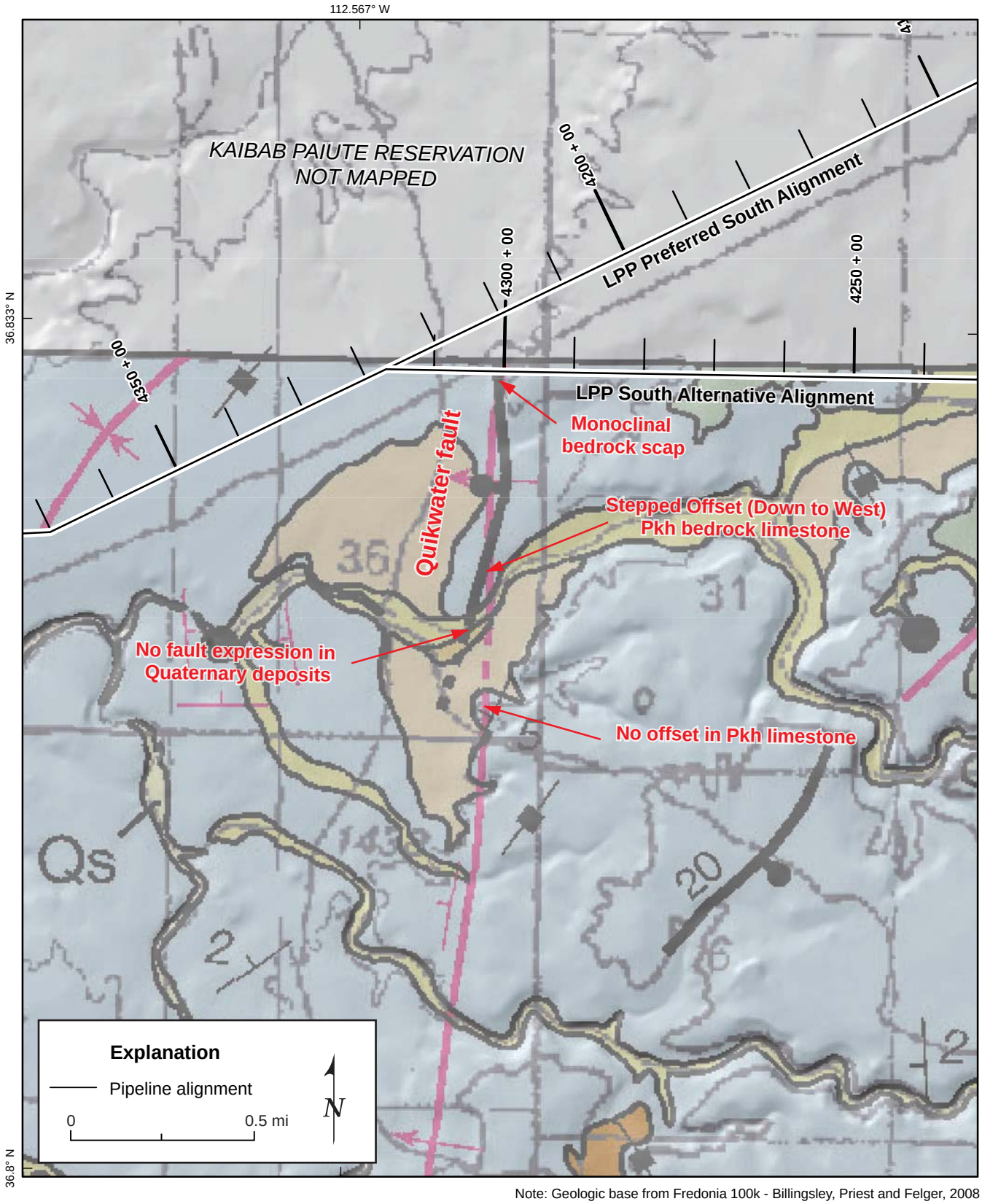
Lake Powell Pipeline -
West Kaibab Fault Crossing



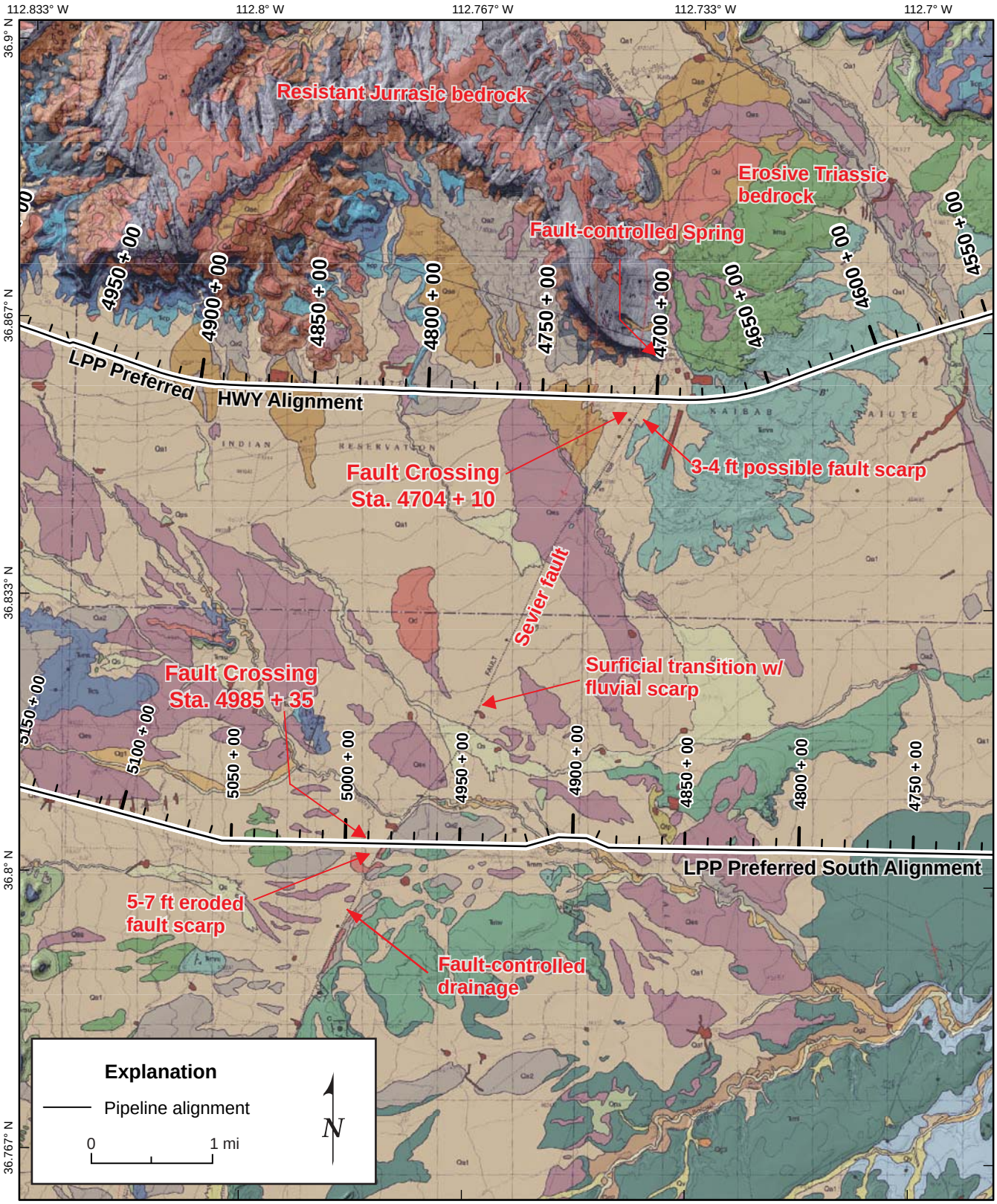
Note: Geologic base from Kanab 100k - Doelling, 2008 and Fredonia 100k - Billingsley, Priest and Felger, 2008



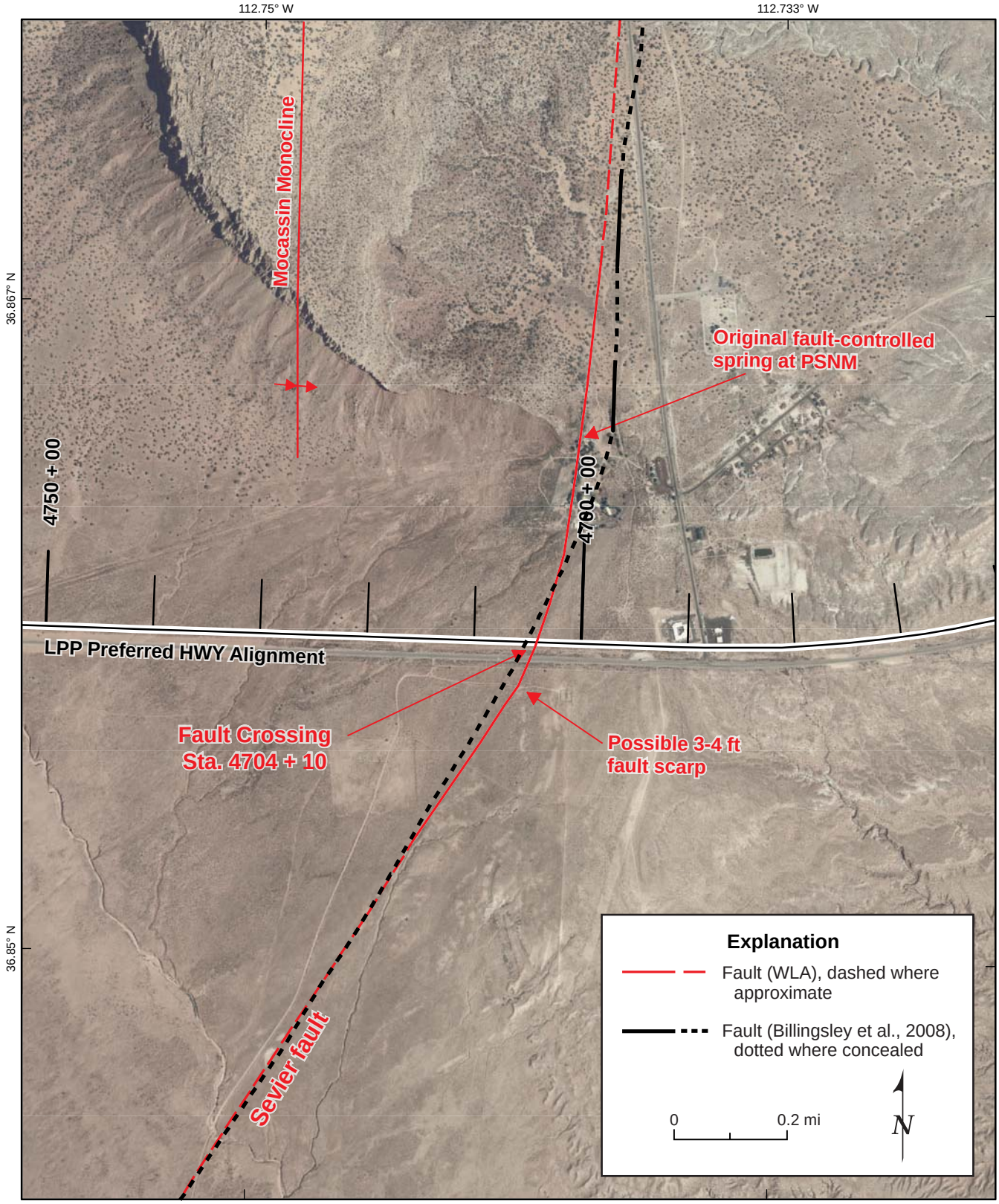
Note: Geologic base from Kanab 100k - Doelling, 2008 and Fredonia 100k - Billingsley, Priest and Felger, 2008



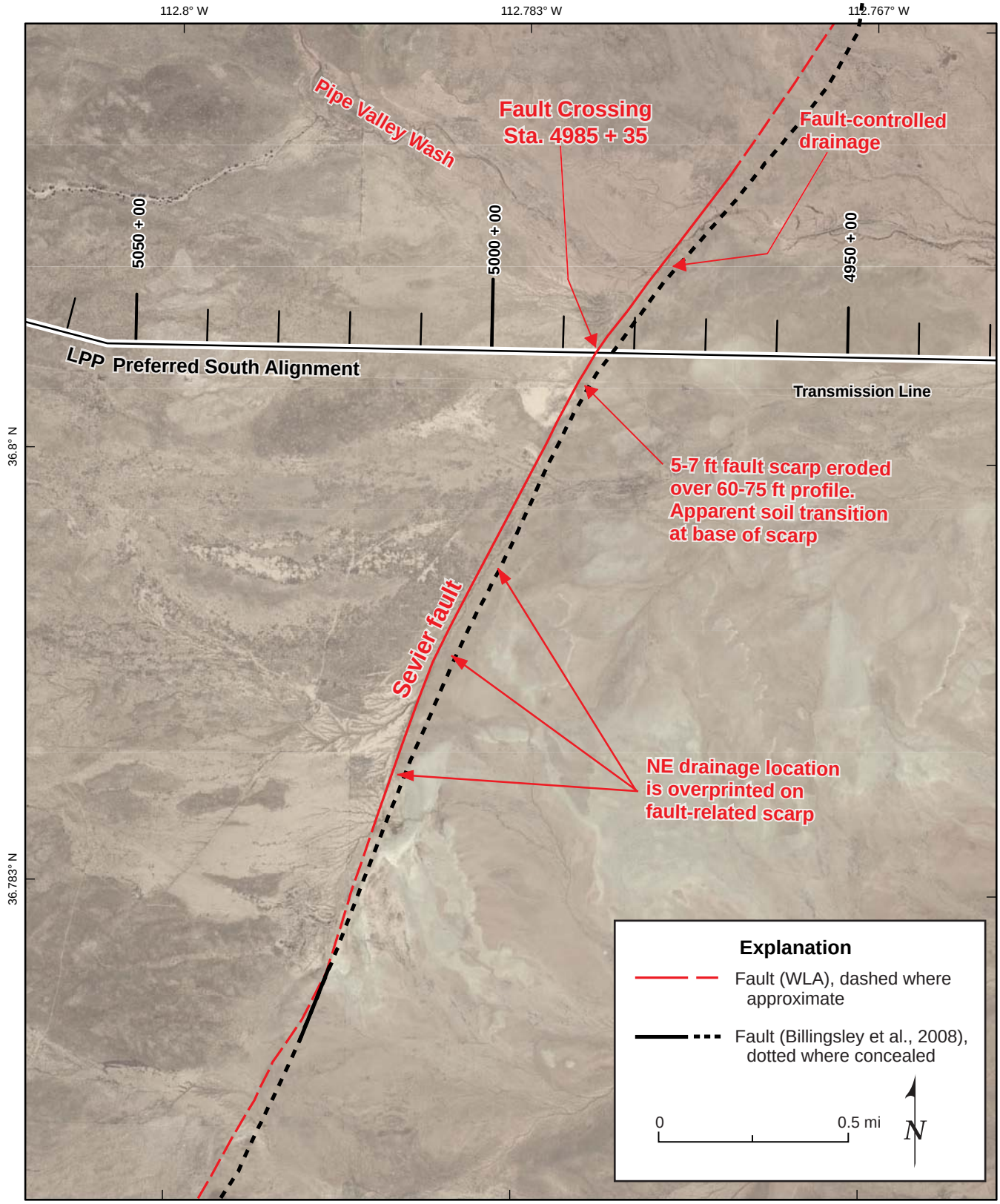
Note: Geologic base from Fredonia 100k - Billingsley, Priest and Felger, 2008



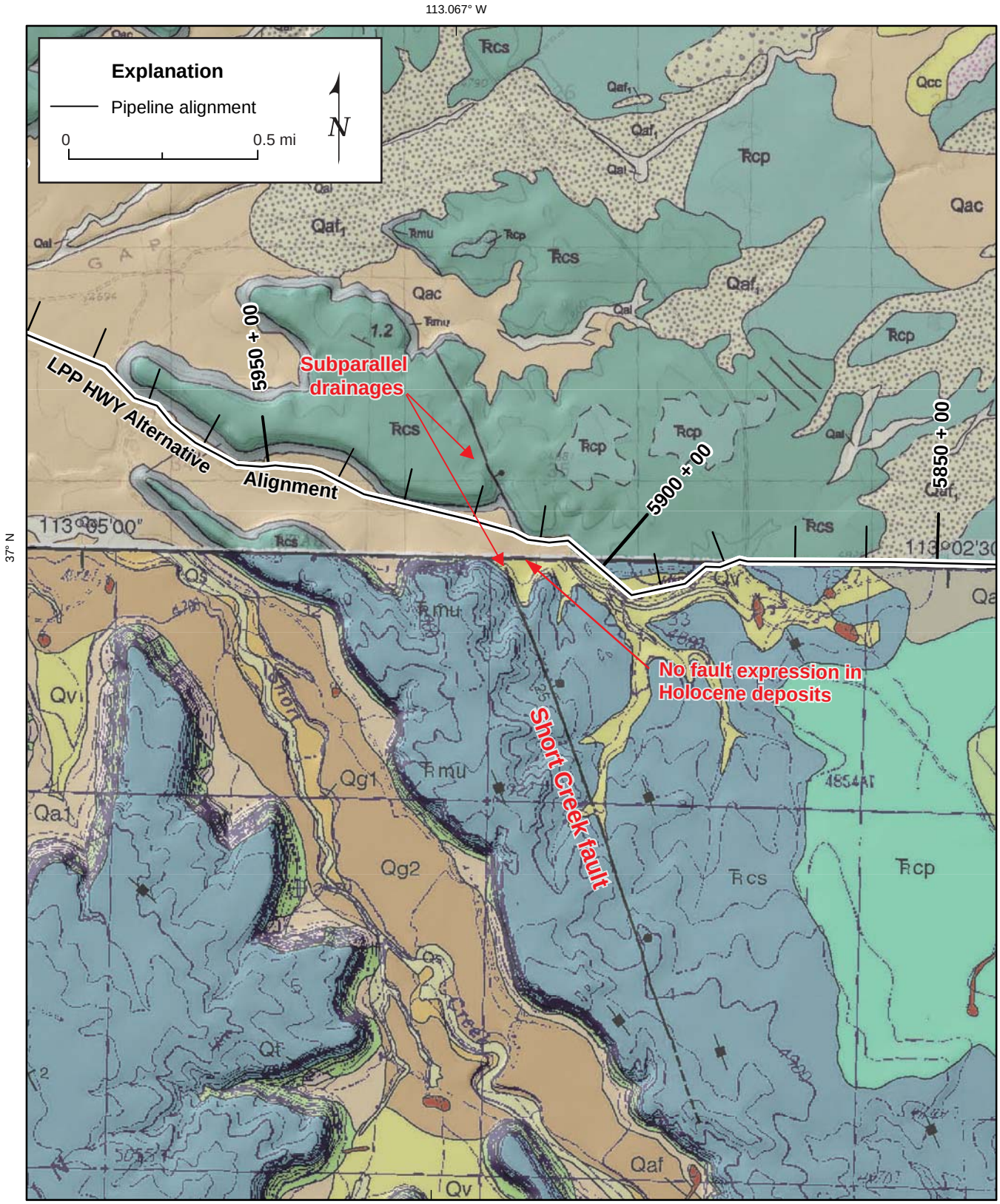
Note: Geologic base from PSNM and the Western Kaibab-Paiute Indian Reservation - Billingsley, Priest and Felger, 2004 (1:31680)



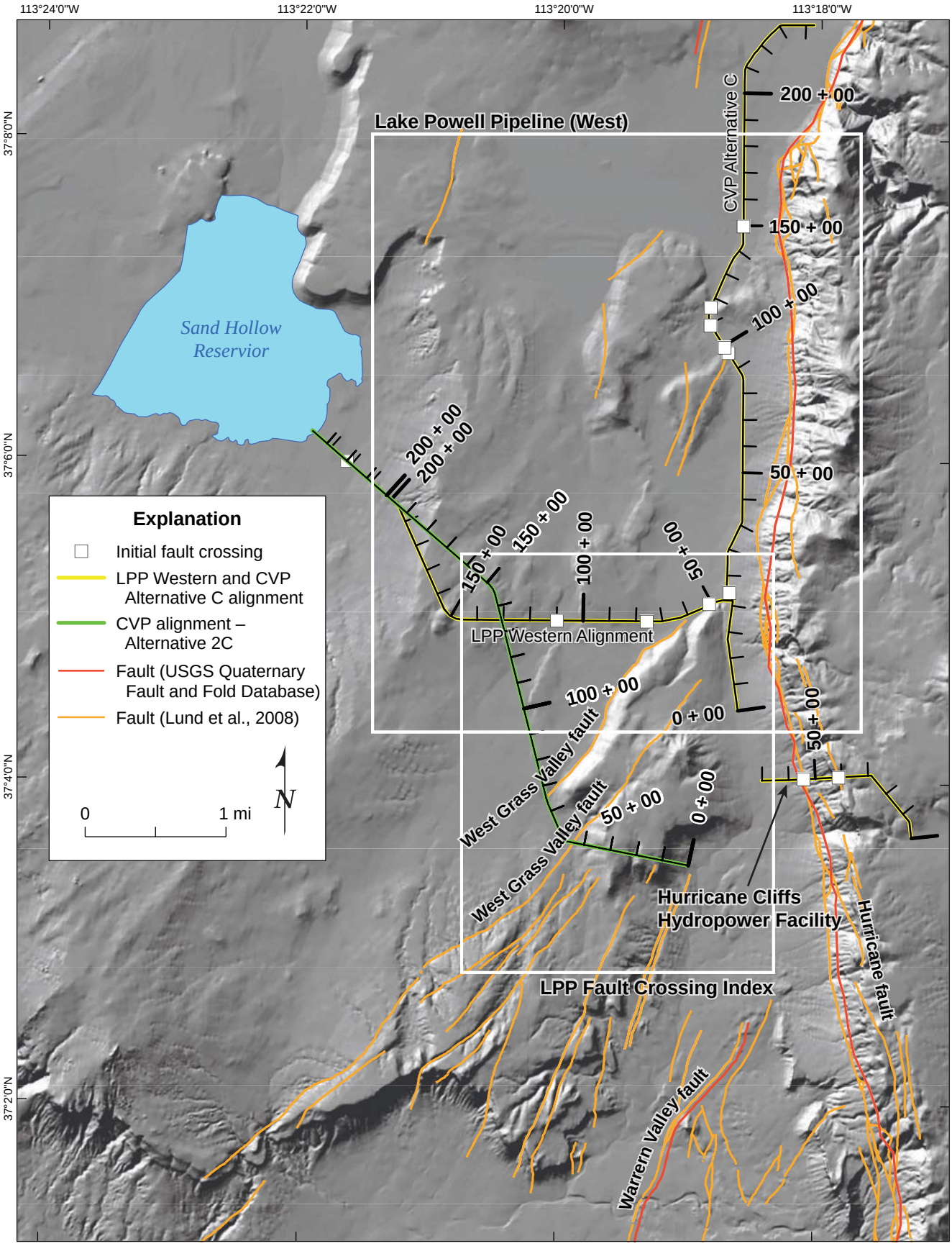
Note: NAIP 2007 DOQQ Airphoto base



Note: NAIP 2007 DOQQ Airphoto base



Note: Geologic base from Clay Hole Wash, 31k - Billingsley, Priest and Dudash2002 and Smithsonian Butte, 24k - Moore and Sable, 2001



WLA

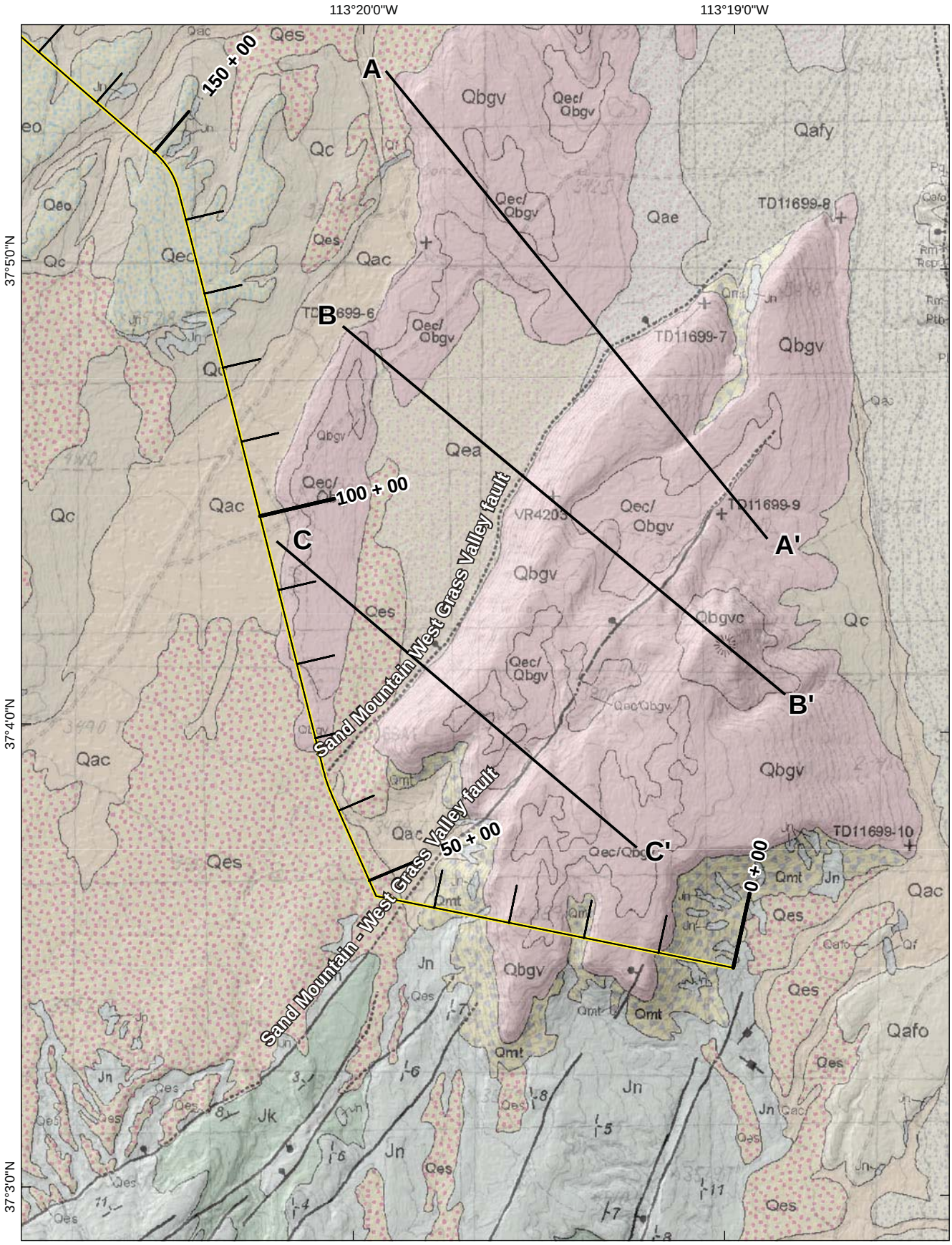
Lake Powell Pipeline
Fault Crossing Index Map (West)

LPP - CVP FAULT ASSESSMENT

Figure 3-1

2042_LPP_FAULT_XING_INDEX_W_20091120.MXD

23 DEC 09, 2042, LPP FAULT XING INDEX WEST, DRAFT, MSZ

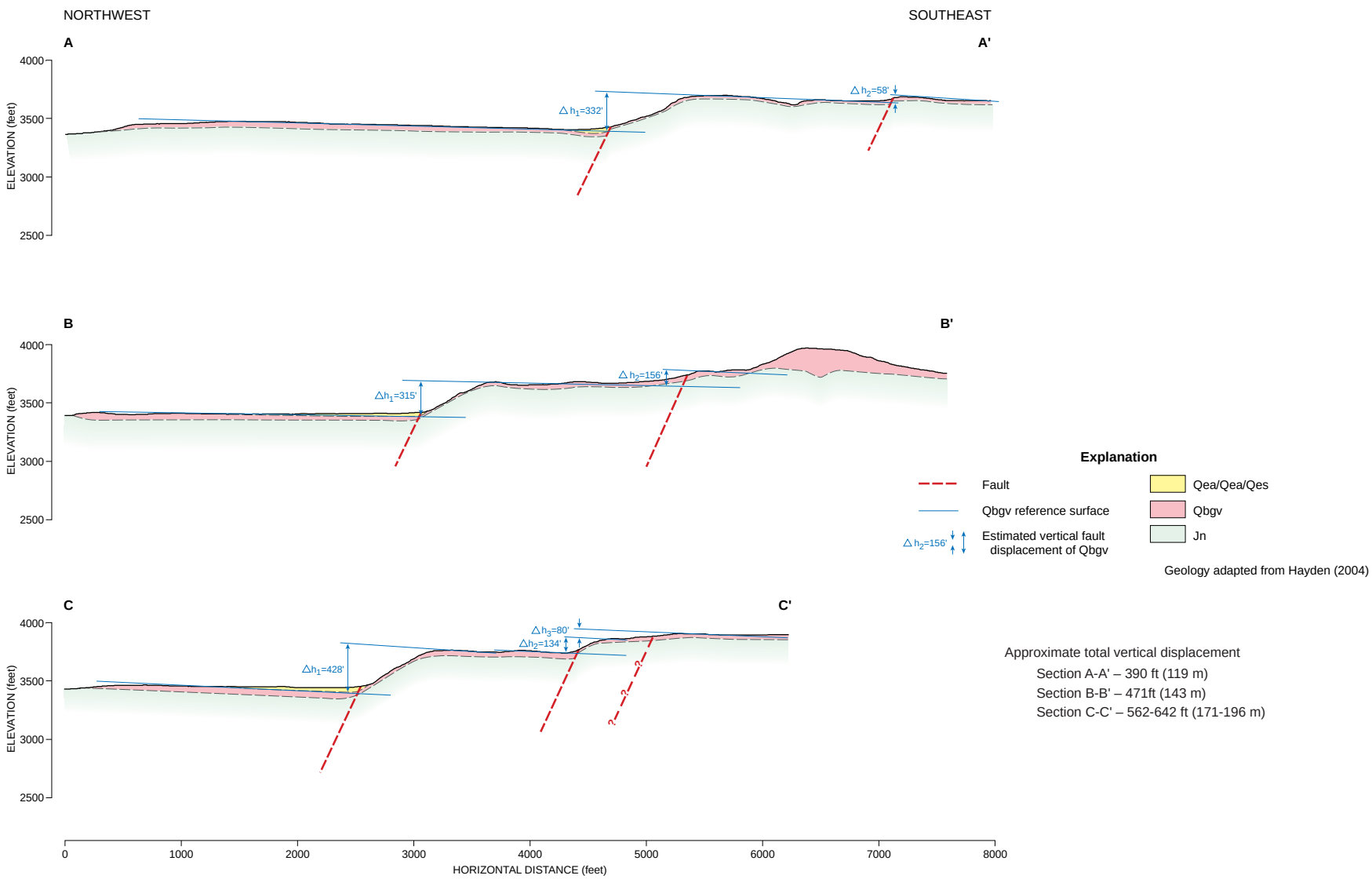


Lake Powell Pipeline
Fault Crossing Index Map (West)

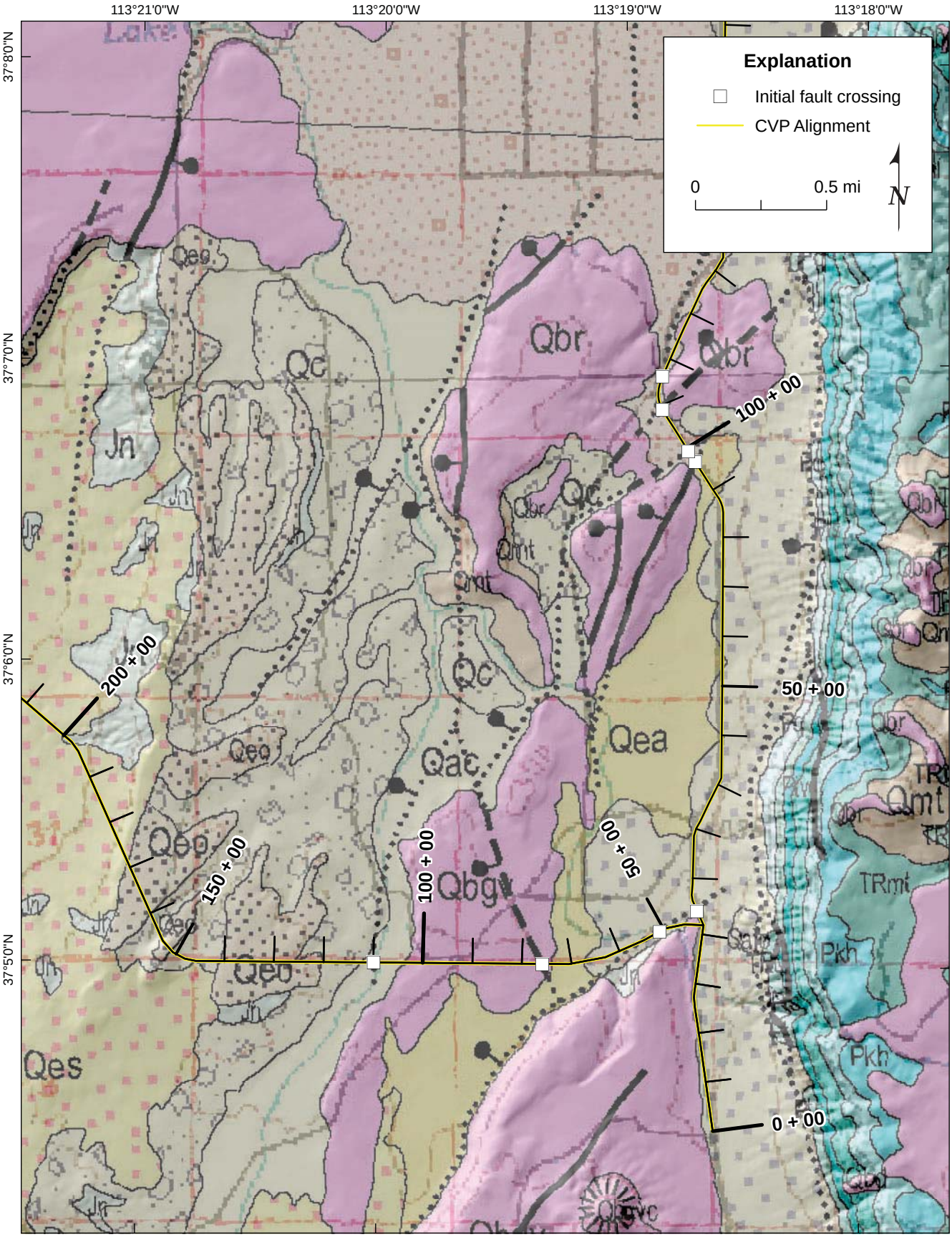
LPP - CVP FAULT ASSESSMENT
Figure 3-2

2042_LPP_FAULT_XING_INDEX_W_20091218.MXD

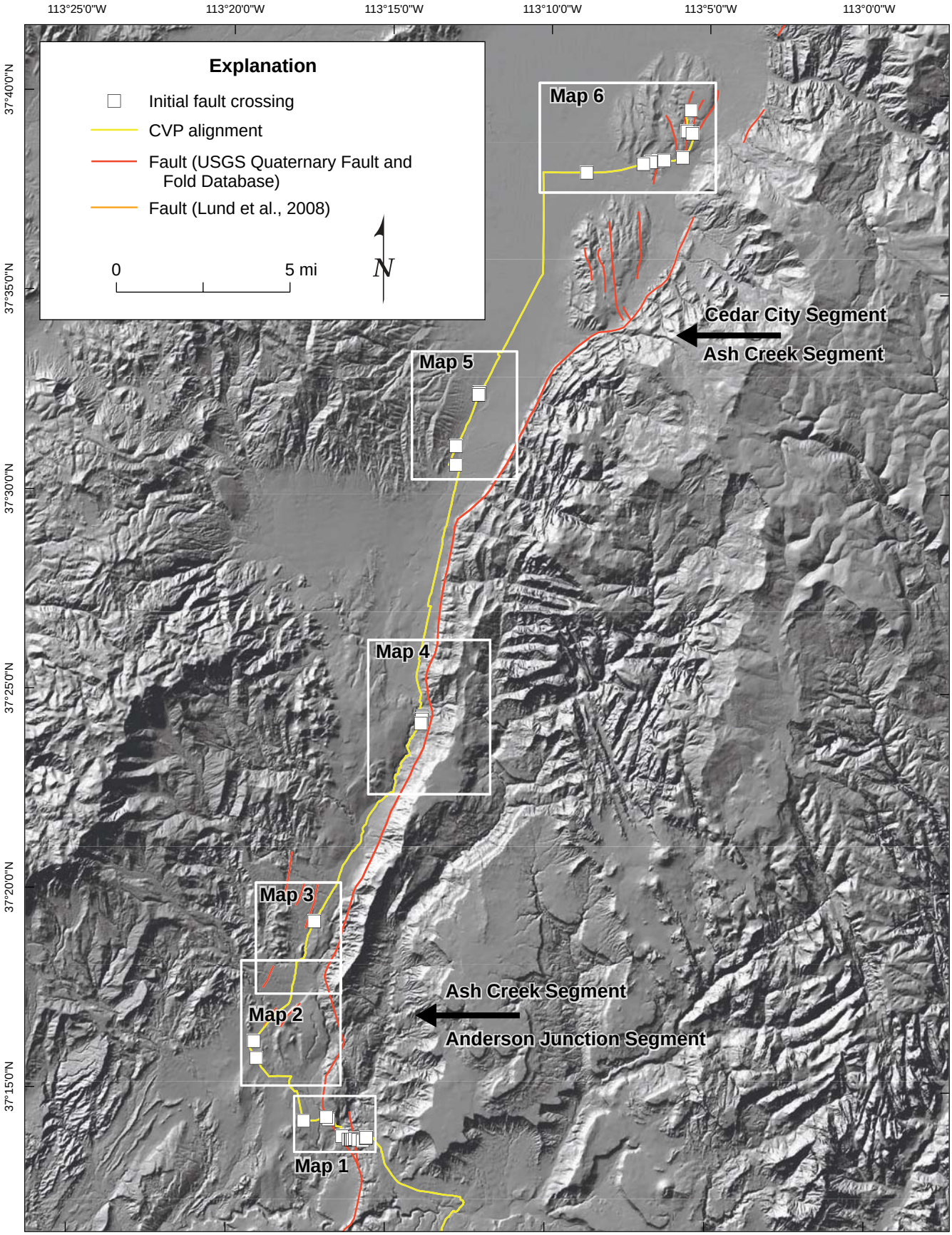
18 DEC 09, 2042, LPP FAULT XING INDEX WEST, DRAFT, MSZ



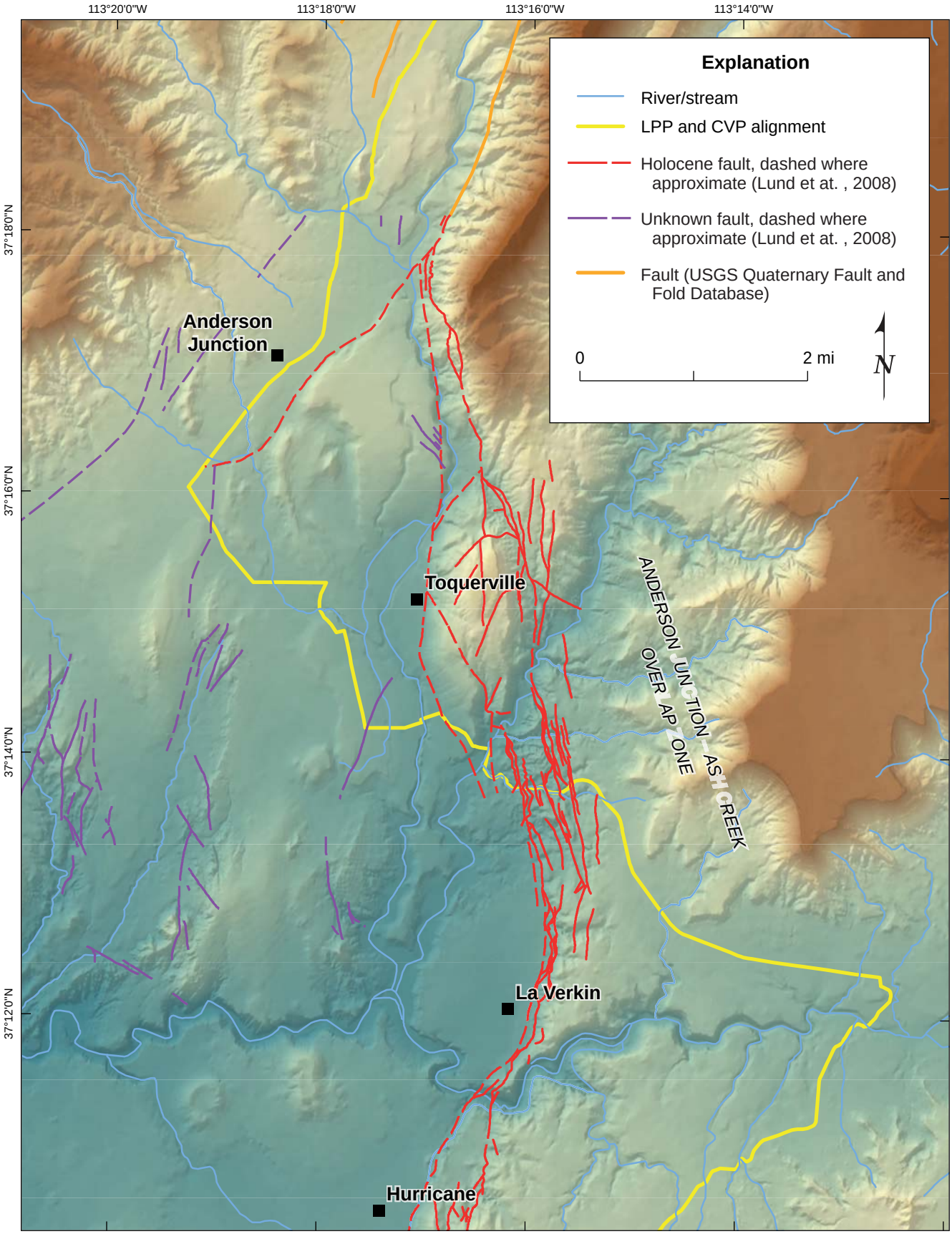
Profiles and Estimated Displacement Across Sand Mountain–West Grass Valley Fault



Geology: St. George, 100k; Beik et al., 2007



Cedar Valley Pipeline
Fault Crossing Index Map



WLA

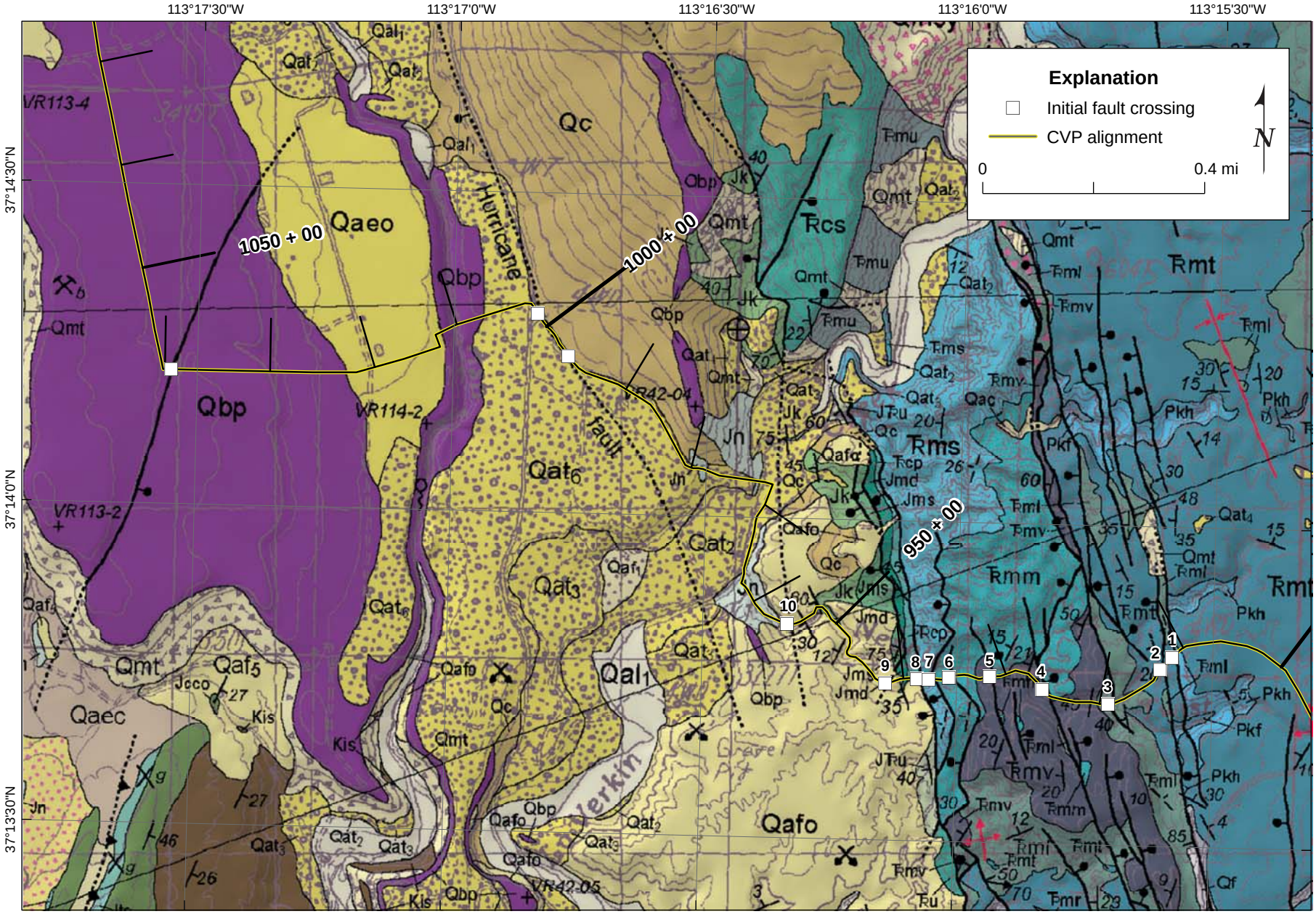
Hurricane Fault Anderson Junction–Ash Creek Segment Boundary Area

LPP-CVP FAULT ASSESSMENT

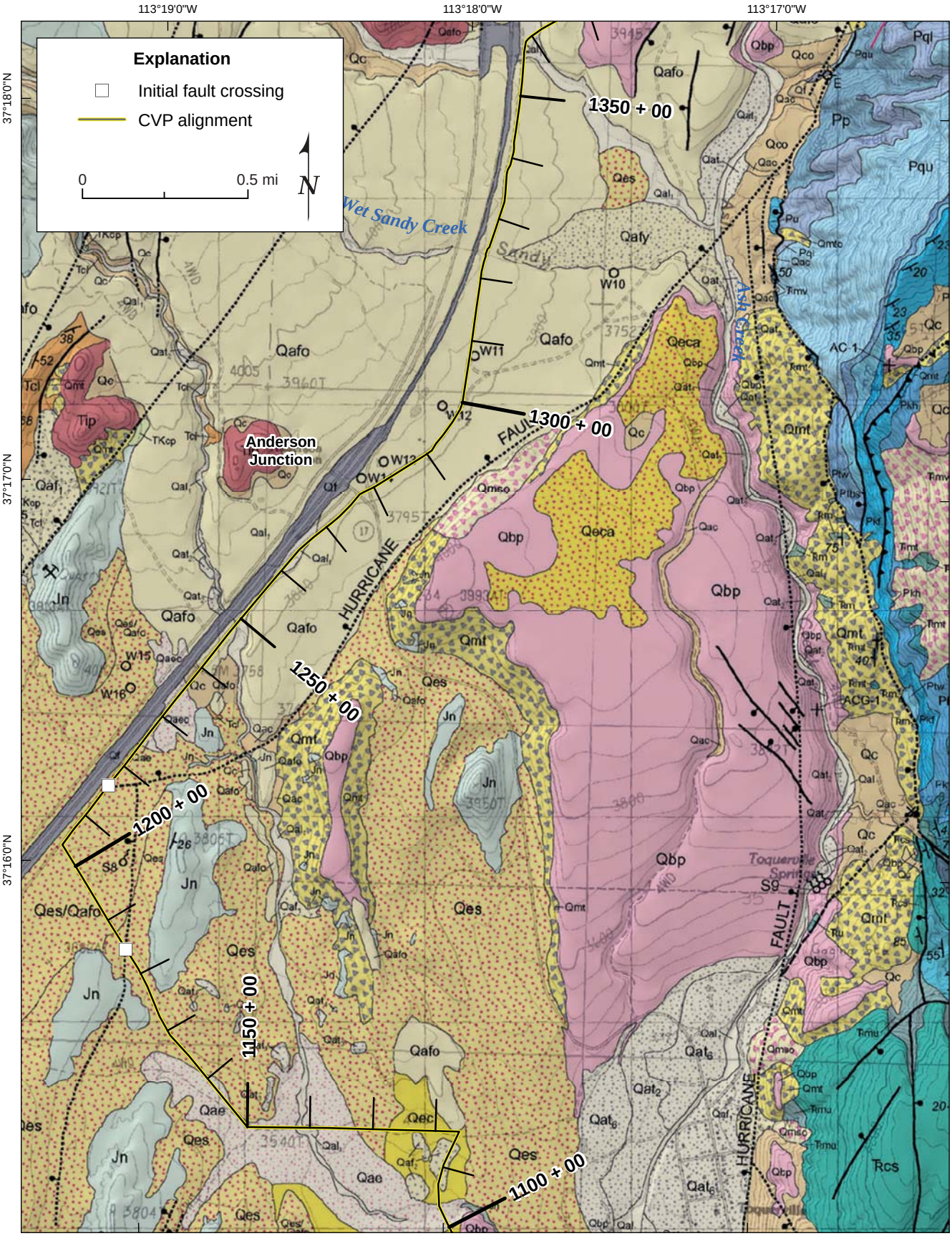
Figure 4-2a

2042_HURRICANEFAULT_ASHCRKANDJNCT_20091120.MXD

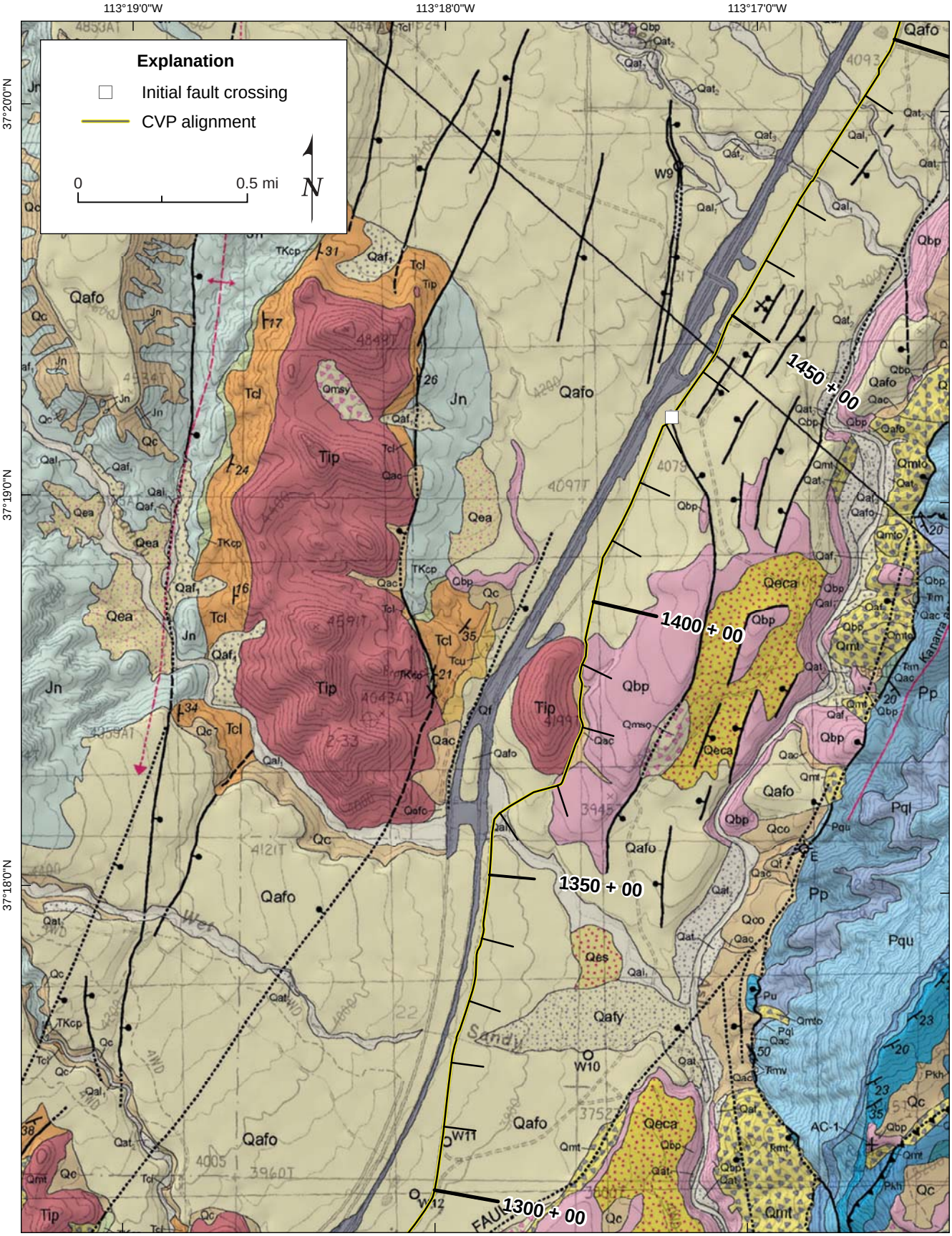
24 NOV 09, 2042, HF ASH CREEK - ANDERSON JNCT, MSZ



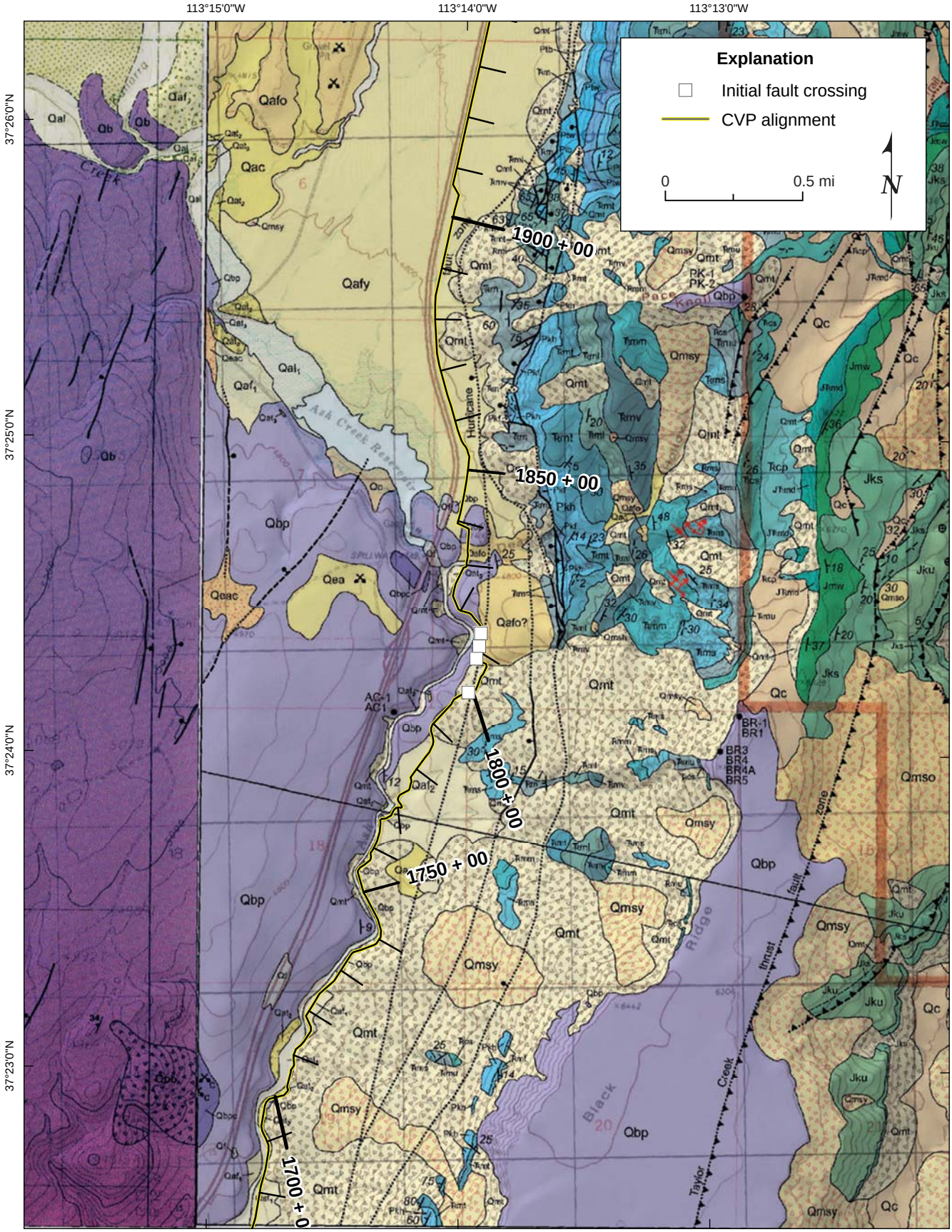
Geology: Hurricane 24k - Biek, 2003



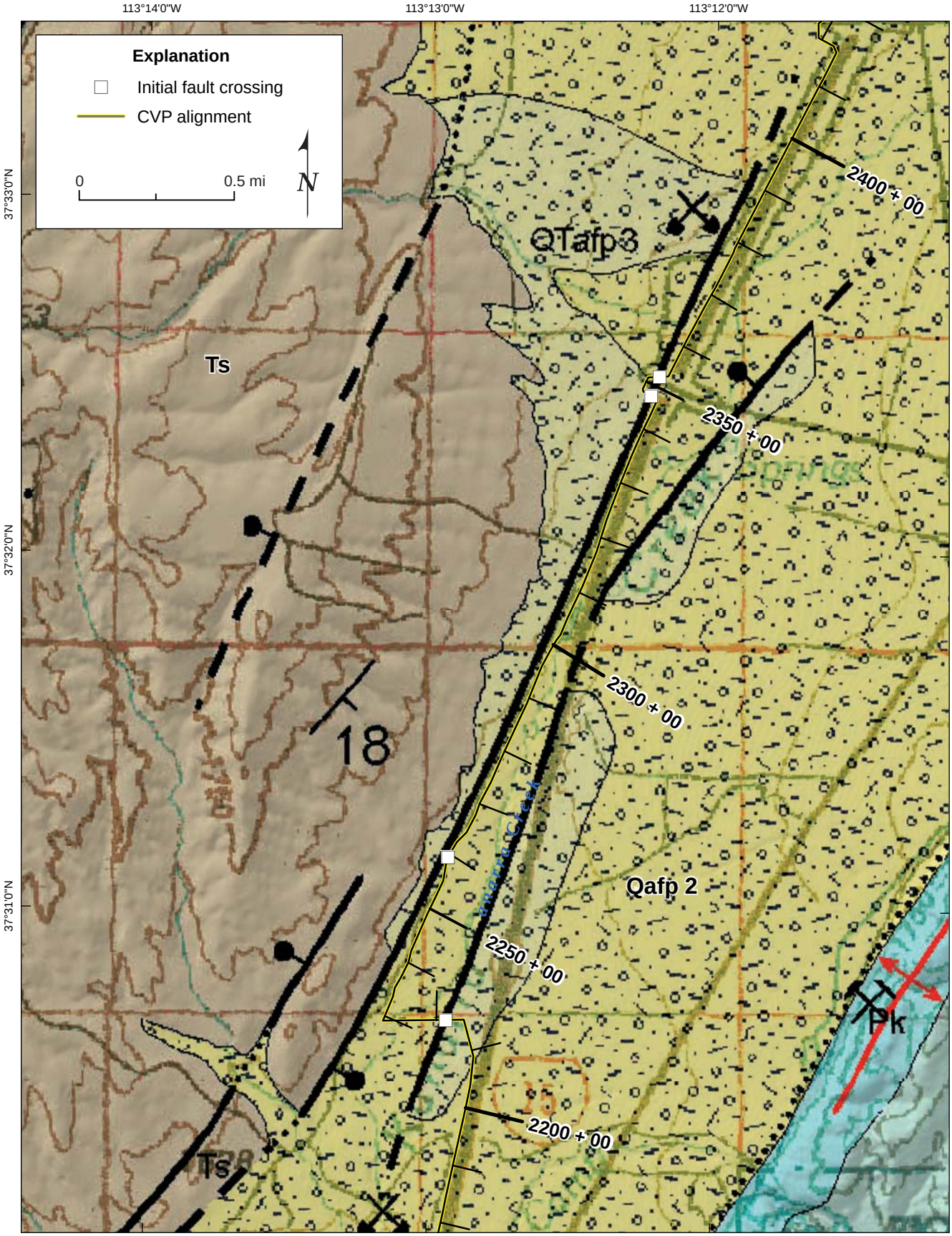
Geology: Pintura, 24k - Hurlow and Biek, 2003



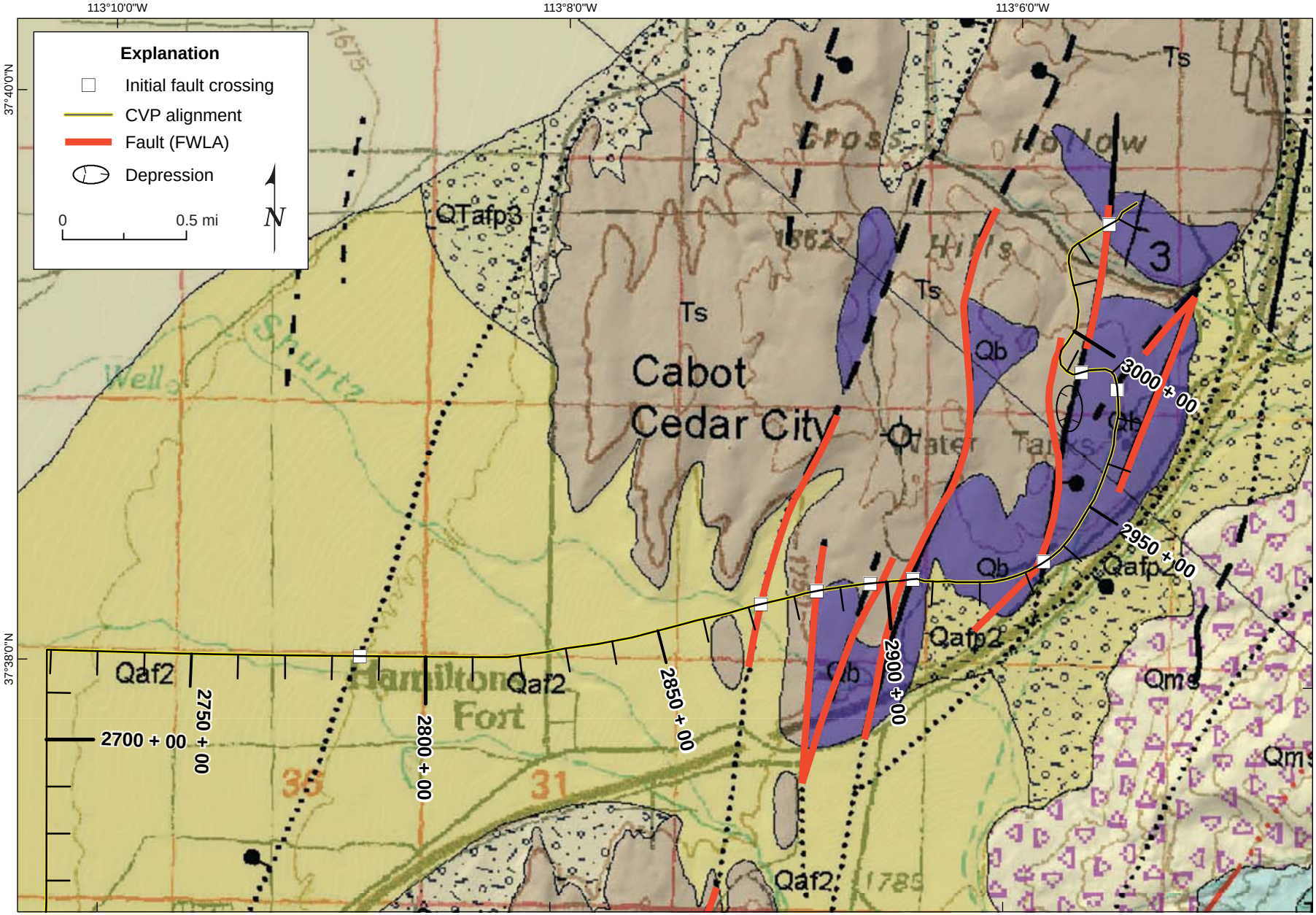
Geology: Pintura, 24k - Hurlow and Biek, 2003



Geology: Kolob Arch, 24k - Biek, 2007
New Harmony, 24k - Grant, 1995



Geology: Cedar City, 100k - Rowley et al., 2008



Geology: Cedar City, 100k - Rowley et al., 2008

Cedar Valley Pipeline
Map 6a - Cross Hollow Hills fault interpretation