Lake Powell Pipeline

Draft Study Report 18
Surface Water Resources

March 2011

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Surface Water Resources Study Report
Executive Summary

ES-1 Introduction

This study report describes the results and findings of an analysis to evaluate surface water resource impacts along the proposed alternative alignments of the Lake Powell Pipeline Project (LPP Project), No Lake Powell Water Alternative, and No Action Alternative. The purpose of the analysis, as defined in the 2008 Surface Water Resources Study Plan prepared for the Federal Energy Regulatory Commission (Commission), was to identify potential surface water resource impacts from construction, maintenance, and operation of the alternatives, and identify and document measures to mitigate potential impacts as necessary.

ES-2 Methodology

The analysis of impacts on surface water resources follows methodology identified and described in the Preliminary Application Document, Scoping Document No. 1 and the Surface Water Resources Study Plan filed with the Commission.

ES-3 Key Results of the Surface Water Resources Impact Analyses

Reclamation's CRSS model showed negligible differences in storage in Lake Powell and releases to the Colorado River when the Proposed Action was compared to the No Action for the Final Planning Study analysis where total depletions are equal. For the No Additional Depletions analysis, there were some minor effects, particularly at lower storage levels and higher release rates at Glen Canyon Dam. Table ES-1 shows the simulated differences of Lake Powell releases and water storage in Lake Powell for the 86K depletions and both inflow hydrology scenarios. Differences in releases are minor for all of the cases evaluated. The minor differences in releases would have a negligible effect on stage in the lower Colorado River. Differences between the Proposed Action and No Action Alternative storage were greater for the No Additional Depletions analysis. The relatively minor effects on Lake Powell storage are unlikely to affect Reclamation's ability to make planned high flow releases from Lake Powell for downstream habitat and geomorphology purposes.

The Virgin River Daily Simulation Model is a FORTRAN based yield model used to evaluate potential changes in operations on the Virgin River in southwest Utah. Two simulations were performed with the model. Scenario 1 simulated the Base Case with full utilization of Virgin River water rights, without any additional storage or Lake Powell Pipeline deliveries. Scenario 2 represents the Proposed Action and simulates future conditions with the expanded secondary system utilizing 2,500 acre feet of re-regulating storage and 69,000 acre feet of annual Lake Powell Pipeline deliveries. The model simulates the maximum yield in the St. George Area with a specified maximum shortage in the worst year (10 percent in the LPP Project simulations), while providing firm secondary water supplies to Hurricane, LaVerkin and Washington Fields. Model results show similar Virgin River streamflows between LaVerkin and the Utah-Arizona state line for the scenarios simulated. Table ES-2 shows average annual values and Figure ES-1 shows average monthly flows.

Table ES-1
86K AF Simulations, Summary of Lake Powell Simulation Average of Annual Differences

	Absolute Difference			Percent Difference		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
Final Planning Study						
DNF Release Difference (AFY)	0	0	3,164	0%	0%	0%
NPC Release Difference (AFY)	-497	-34	-3,503	0%	0%	0%
DNF Storage Difference (AF)	-32,000	-25,000	-1,000	0%	0%	0%
NPC Storage Difference (AF)	-17,000	-10,000	-2,000	0%	0%	0%
No Additional Depletions						
DNF Release Difference (AFY)	0	0	-65,382	0%	0%	0%
NPC Release Difference (AFY)	-19	-8,462	-90,150	0%	0%	-1%
DNF Storage Difference (AF)	-334,000	-292,000	-12,000	-3%	-1%	0%
NPC Storage Difference (AF)	-313,000	-134,000	-6,000	-5%	-1%	0%

Notes: Difference = Proposed Action – No Action (for storage = average of difference each December of model period)
Percent Difference = Difference/No Action
DNF = Direct Natural Flow
NPC = Nonparametric Paleo-conditioned

Table ES-2
Average Simulated Virgin River Flows

	Virgin River below Quail Creek		**Virgin River below Washington Fields Diversion**		**Virgin River at UT-AZ State Line**	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Annual Average (cfs)	153	150	67	64	136	140
Average Annual (AFY)	110,756	108,848	48,569	46,685	98,556	100,996

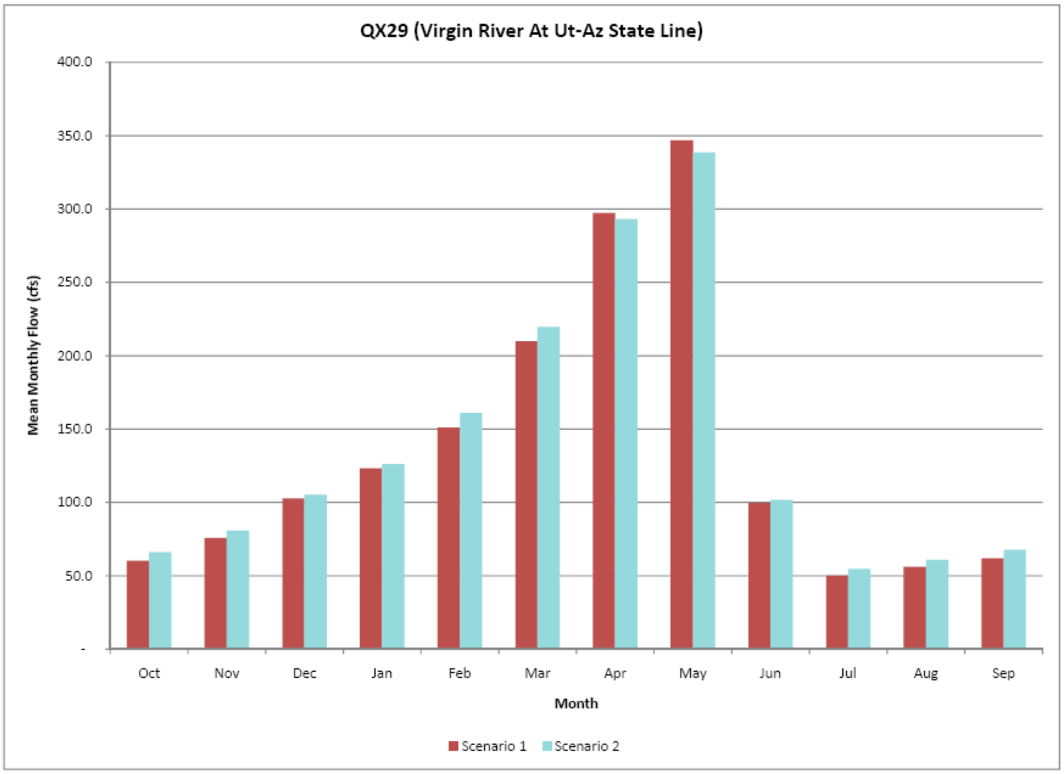
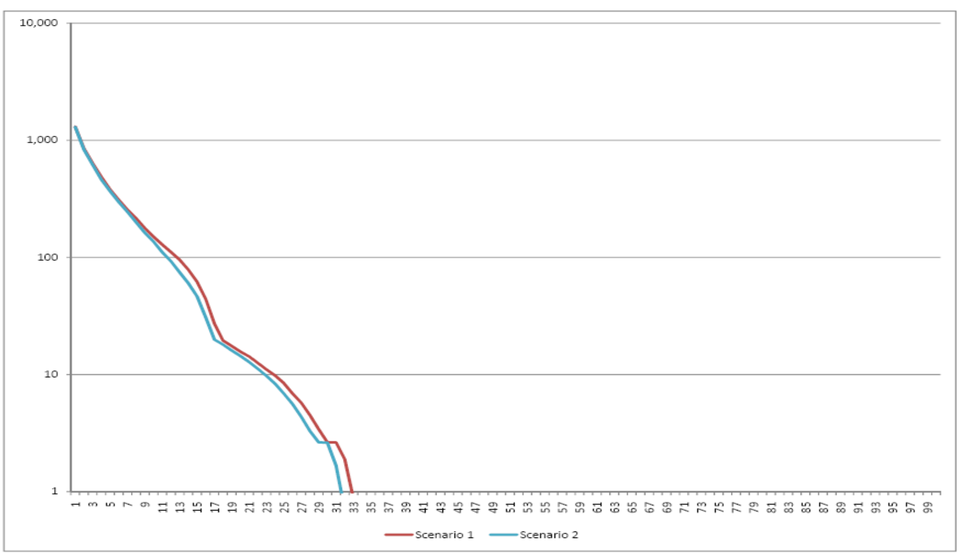


Figure ES-1
Virgin River at UT-AZ State Line – Simulated Monthly Flows

The Virgin River Daily Simulation model shows that flow duration curves are similar for the two scenarios all along the river. Flow duration curves are shown in
Figure **ES-2** and Figure ES-3 for the Virgin River below Washington Fields and the Virgin River at the Utah-Arizona State line. Flow duration curves for the other simulated model nodes show very little difference between scenarios.

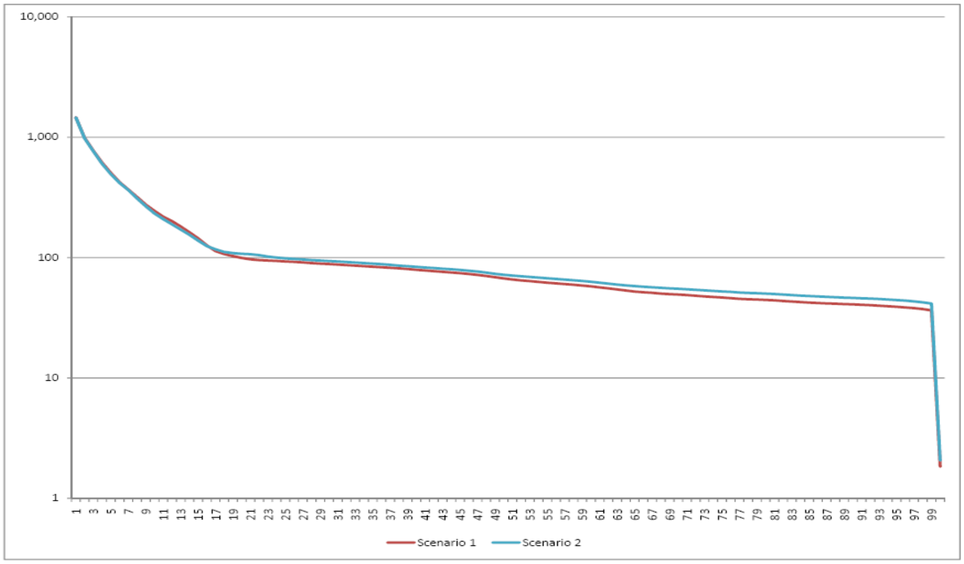
Flow

(cfs)



Percent Exceedance

Figure ES-2
Simulated Flow Duration Curves for Virgin River Below Washington Fields Diversion



Flow

(cfs)

Percent Exceedance

Figure ES-3
Simulated Flow Duration Curves for Virgin River at UT-AZ State Line

The LPP Project does not include the construction of any on-channel reservoirs and the pipeline would be buried below the channel inverts. The impacts on peak flows of streams and rivers would be negligible. Erosion and stream movement in southwest Utah are primarily attributed to peak flow events, and the LPP Project would not have ongoing effects on geomorphology.

Chapter 1
Introduction

1.1 Introduction

This chapter presents a summary description of the alternatives studied for the Lake Powell Pipeline (LPP) project, located in north central Arizona and southwest Utah (Figure 1-1) and identifies the issues and impact topics for the Surface Water Resources Study Report. The alternatives studied and analyzed include different alignments for pipelines and penstocks and transmission lines, a no Lake Powell water alternative, and the No Action alternative. The pipelines would convey water under pressure and connect to the penstocks, which would convey the water to a series of hydroelectric power generating facilities. The action alternatives would each deliver 86,249 acre-feet of water annually for municipal and industrial (M&I) use in the three southwest Utah water conservancy district service areas. Washington County Water Conservancy District (WCWCD) would receive 69,000 acre-feet, Kane County Water Conservancy District (KCWCD) would receive 4,000 acre-feet and Central Iron County Water Conservancy District (CICWCD) could receive up to 13,249 acre-feet each year.

1.2 Summary Description of Alignment Alternatives

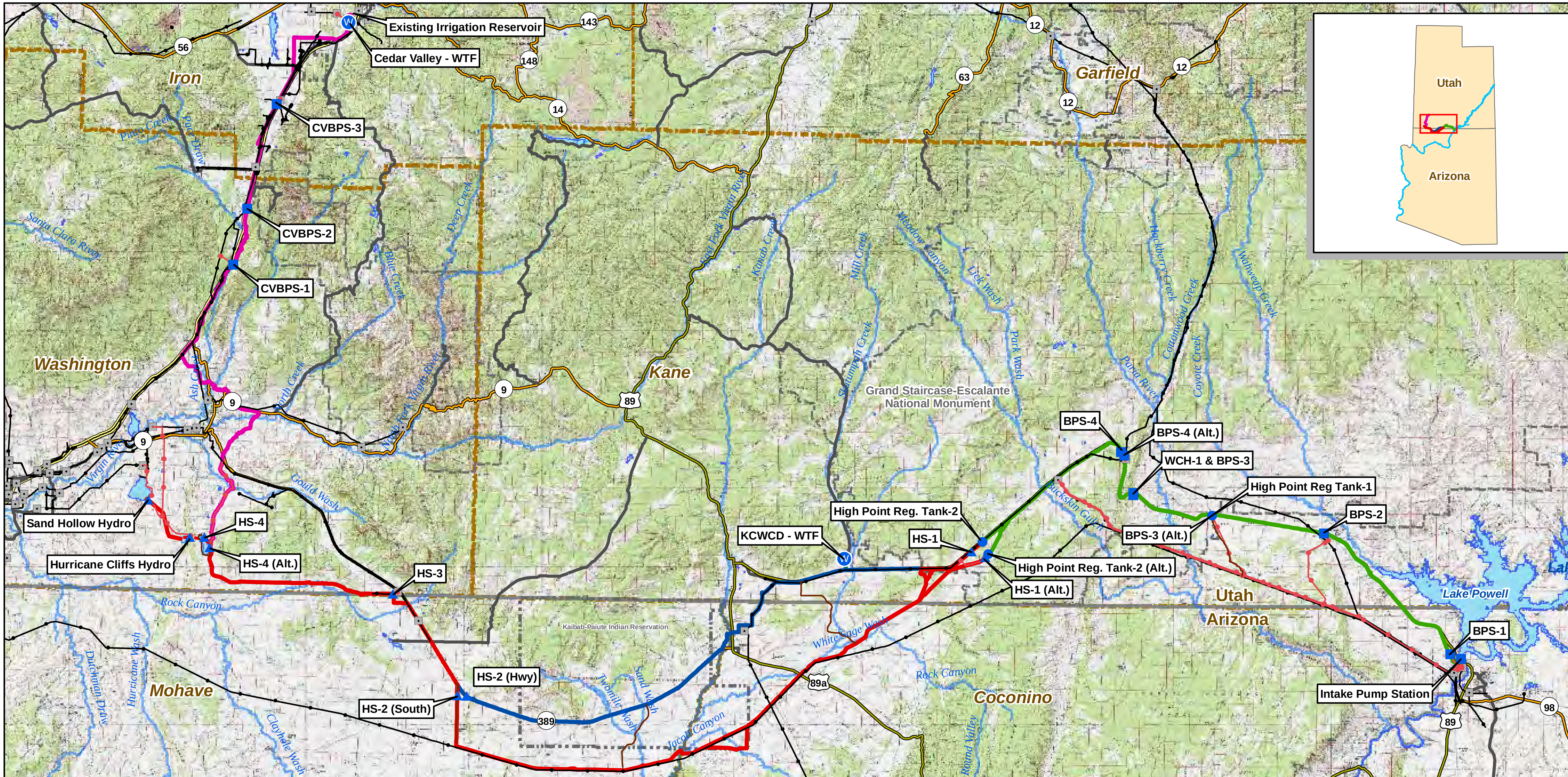
Three primary pipeline and penstock alignment alternatives are described in this section along with the electrical power transmission line alternatives. The pipeline and penstock alignment alternatives share common segments between the intake at Lake Powell and delivery at Sand Hollow Reservoir, and they are spatially different in the area through and around the Kaibab-Paiute Indian Reservation. The South Alternative extends south around the Kaibab-Paiute Indian Reservation. The Existing Highway Alternative follows an Arizona state highway through the Kaibab-Paiute Indian Reservation. The Southeast Corner Alternative follows the Navajo-McCullough Transmission Line corridor through the southeast corner of the Kaibab-Paiute Indian Reservation. The transmission line alignment alternatives are common to all the pipeline and penstock alignment alternatives. Figure 1-1 shows the overall proposed project and alternative features from Lake Powell near Page, Arizona to Sand Hollow and Cedar Valley, Utah.

1.2.1 South Alternative

The South Alternative consists of five systems: Intake, Water Conveyance, Hydro, Kane County Pipeline, and Cedar Valley Pipeline.

The **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 (Figure 1-2). The pump station enclosure would house vertical turbine pumps with electric motors, electrical controls, and other equipment at a ground level elevation of 3,745 feet mean sea level (MSL).

The **Water Conveyance System** would convey the Lake Powell water from the Intake System for about 51 miles through a buried 69-inch diameter pipeline parallel with U.S. 89 in Coconino County, Arizona and Kane County, Utah to a buried regulating tank (High Point Regulating Tank-2) on the south side of U.S. 89 at ground level elevation 5,695 feet MSL, which is the LPP project topographic high point



Water Treatment Facility
Project Pump Station
Project Regulating Tank
Project Hydro Station
Project Transmission Line
Existing Substation
Existing Transmission Line
Water Conveyance
Hydro System - South Alignment Alternative
Hydro System - Highway Alignment Alternative
KCWCD Pipeline System
Cedar Valley Pipeline
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

UDWR **Figure 1-1** MWH

Lake Powell Pipeline Proposed Project and Alternative Features

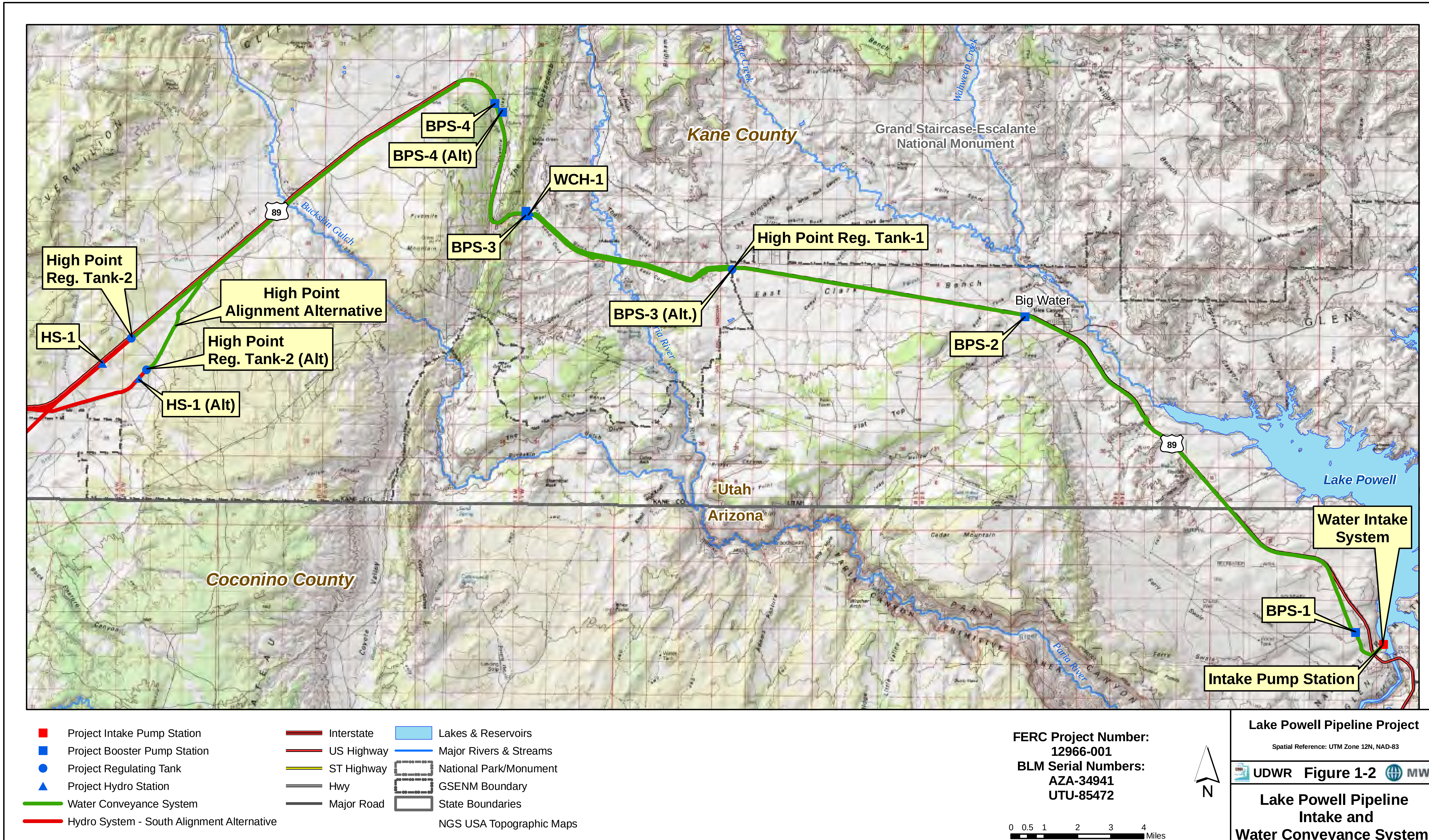


Figure 1-2

Lake Powell Pipeline Intake and Water Conveyance Systems

(Figure 1-2). The pipeline would be sited within a utility corridor established by Congress in 1998 which extends 500 feet south and 240 feet north of the U.S. 89 centerline on public land administered by the Bureau of Land Management (BLM) (U.S. Congress 1998). Four booster pump stations (BPS) located along the pipeline would pump the water under pressure 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 substation, buried forebay tank and a surface emergency overflow detention basin. BPS-1 would be sited within the Glen Canyon National Recreation Area adjacent to an existing Arizona Department of Transportation maintenance facility located west of U.S. 89. BPS-2 would be sited on land administered by the Utah School and Institutional Trust Lands Administration (SITLA) near the town of Big Water, Utah on the south side of U.S. 89. BPS-3 and an in-line hydro station (WCH-1) would be sited at the east side of the Cockscomb geologic feature in the Grand Staircase-Escalante National Monument (GSENM) within the Congressionally-designated utility corridor. BPS-3 (Alt) is an alternative location for BPS-3 on land administered by the BLM Kanab Field Office near the east boundary of the GSENM on the south side of U.S. 89 within the Congressionally-designated utility corridor. Incorporation of BPS-3 (Alt.) into the LPP project would replace BPS-3 and WCH-1 at the east side of the Cockscomb geologic feature. BPS-4 would be sited on the west side of U.S. 89 and within the Congressionally-designated utility corridor in the GSENM on the west side of the Cockscomb geologic feature.

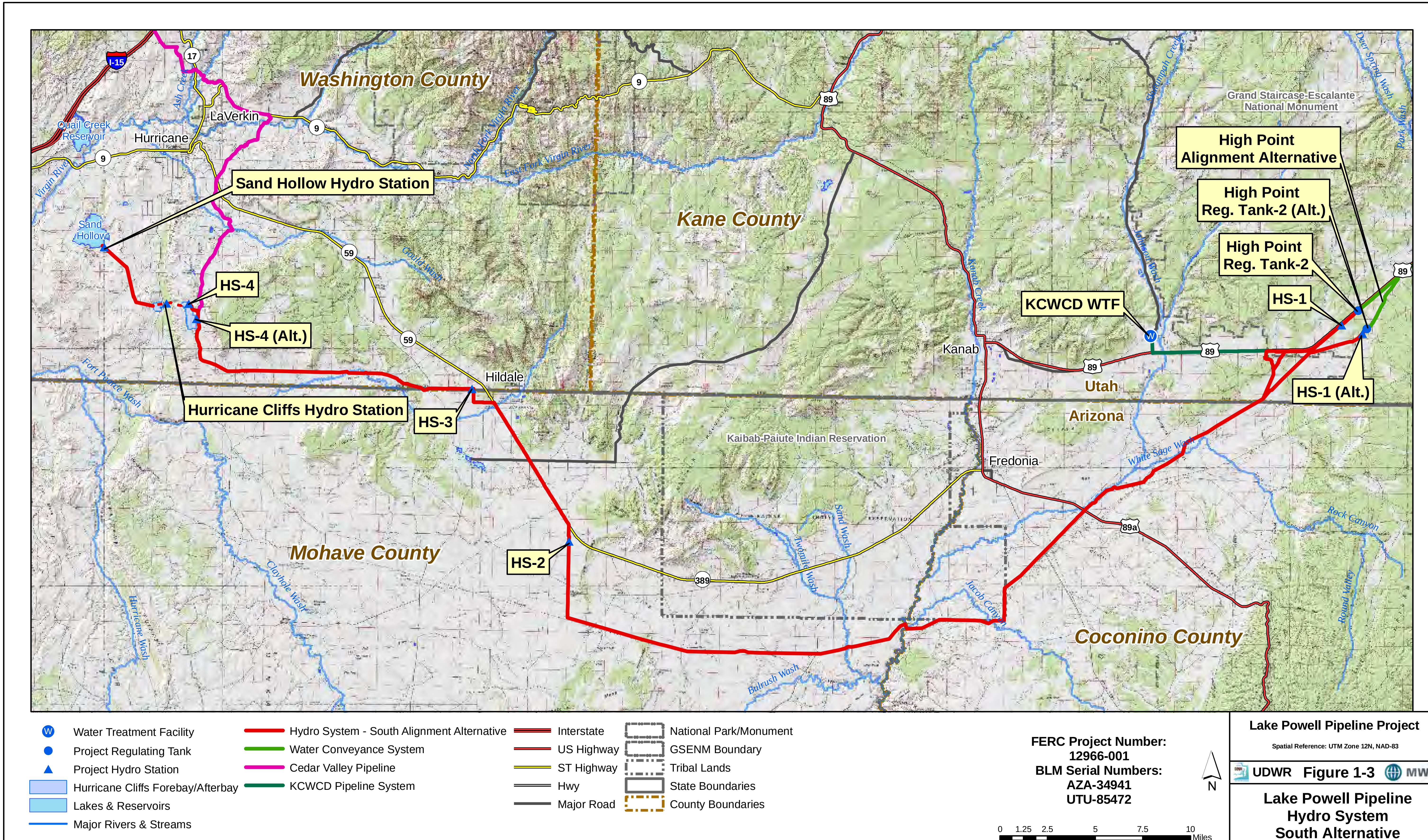
The High Point Alignment Alternative would diverge south from U.S. 89 parallel to the K4020 road and continue outside of the Congressionally-designated utility corridor to a buried regulating tank (High Point Regulating Tank-2 (Alt.) at ground level elevation 5,630 feet MSL, which would be the topographic high point of the LPP project along this alignment alternative (Figure 1-2). The High Point Alignment Alternative would include BPS-4 (Alt.) on private land east of U.S. 89 and west of the Cockscomb geologic feature (Figure 1-2). Incorporation of the High Point Alignment Alternative and BPS-4 (Alt.) into the LPP project would replace the High Point Regulation Tank-2 along U.S. 89, the associated buried pipeline and BPS-4 west of U.S. 89.

A rock formation avoidance alignment option would be included immediately north of Blue Pool Wash along U.S. 89 in Utah. Under this alignment option, the pipeline would cross to the north side of U.S. 89 for about 400 feet and then return to the south side of U.S. 89. This alignment option would avoid tunneling under the rock formation on the south side of U.S. 89 near Blue Pool Wash.

A North Pipeline Alignment option is located parallel to the north side of U.S. 89 for about 6 miles from the east boundary of the GSENM to the east side of the Cockscomb geological feature.

The **Hydro System** would convey the Lake Powell water from High Point Regulating Tank-2 at the high point at ground level elevation 5,695 feet MSL for about 87 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 1-3). The High Point Alignment Alternative would convey the Lake Powell water from High Point Regulating Tank-2 (Alt.) at the high point at ground level elevation 5,630 feet MSL 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 1-3). Four in-line hydro generating stations (HS-1, HS-2 HS-3 and HS-4) with substations located along the penstock would generate electricity and help control water pressure in the penstock. HS-1 would be sited on the south side of U.S. 89 within the Congressionally-designated utility corridor through the GSENM. The High Point Alignment Alternative would include HS-1 (Alt.) along the K4020 road within the GSENM and continue along a portion of the K3290 road.

The proposed penstock alignment and two penstock alignment options are being considered to convey the water from the west GSENM boundary south through White Sage Wash. The proposed penstock



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

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR Figure 1-3 MWH

Lake Powell Pipeline Hydro System South Alternative alignment would parallel the K3250 road south from U.S. 89 and follow the Pioneer Gap Road alignment around the Shinarump Cliffs. One penstock alignment option would parallel the K3285 road southwest from U.S. 89 and continue to join the Pioneer Gap Road around the Shinarump Cliffs. The other penstock alignment option would extend southwest through currently undeveloped BLM land from the K3290 road into White Sage Wash.

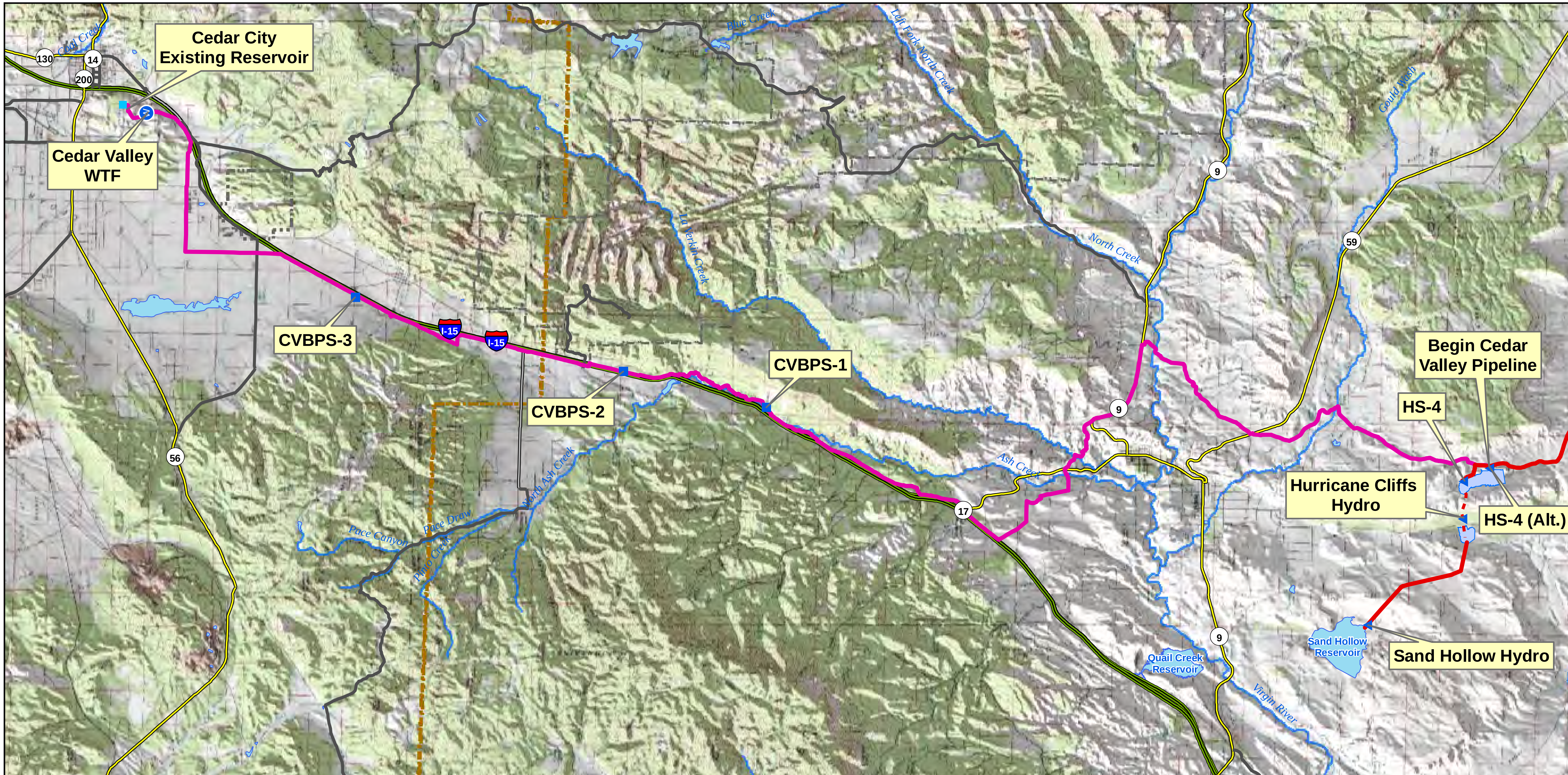
The penstock alignment would continue through White Sage Wash and then parallel to the Navajo-McCullough Transmission Line, crossing U.S. 89 Alt. and Forest Highway 22 toward the southeast corner of the Kaibab Indian Reservation. The penstock alignment would run parallel to and south of the south boundary of the Kaibab Indian Reservation, crossing Kanab Creek and Bitter Seeps Wash, across Moonshine Ridge and Cedar Ridge, and north along Yellowstone Road to Arizona State Route 389 west of the Kaibab Indian Reservation. HS-2 would be sited west of the Kaibab Indian Reservation. 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.

The penstock alignment would follow Uzona Road west through Canaan Gap and south of Little Creek Mountain and turn north to HS-4 (Alt.) above the proposed Hurricane Cliffs forebay reservoir. The forebay reservoir would be contained in a valley between a south dam and a north dam and maintain active storage of 11,255 acre-feet of water. 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 pumped storage hydro generating station. The pumped storage hydro generating station would connect to an afterbay reservoir contained by a single dam in the valley below the Hurricane Cliffs. A low pressure tunnel would convey the water northwest to a penstock continuing on to the Sand Hollow Hydro Station. The water would discharge into the existing Sand Hollow Reservoir.

The peaking hydro generating station option would involve a smaller, 200 acre-foot forebay reservoir with HS-4 discharging into the forebay reservoir, with the peaking hydro generating station discharging to a small afterbay connected to a penstock running north along the existing BLM road and west to the Sand Hollow Hydro Station. 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 peaking hydro generating station, which would discharge into a 200 acre-foot afterbay reservoir. A penstock would extend north from the afterbay reservoir along the existing BLM road and then west to the Sand Hollow Hydro Station. The water would discharge into the existing Sand Hollow Reservoir.

The **Kane County Pipeline System** would convey the Lake Powell water from the Lake Powell Pipeline at the west GSENM boundary for about 8 miles through a buried 24-inch diameter pipe in Kane County, Utah to a conventional water treatment facility located near the mouth of Johnson Canyon. The pipeline would parallel the south side of U.S. 89 across Johnson Wash and then run north to the new water treatment facility site (Figure 1-3).

The **Cedar Valley Pipeline System** would convey the Lake Powell water from the Lake Powell Pipeline just upstream of HS-4 or HS-4 (Alt.) for about 58 miles through a buried 36-inch diameter pipeline in Washington and Iron counties, Utah to a conventional water treatment facility in Cedar City, Utah (Figure 1-4). Three booster pump stations (CVBPS) located along the pipeline would pump the water under pressure to the new water treatment facility. The pipeline would follow an existing BLM road north from HS-4, cross Utah State Route 59 and continue north to Utah State Route 9, with an aerial crossing of the Virgin River at the Sheep Bridge. The pipeline would run west along the north side of Utah State Route 9 and parallel an existing pipeline through the Hurricane Cliffs at Nephi's Twist. The pipeline



Water Treatment Facility
Project Pump Station
Project Hydro Station
Hydro System - South Alignment Alternative
Water Conveyance System
Hurricane Cliffs Pressure Tunnel
Cedar Valley Pipeline
Interstate
US Highway
ST Highway
Hwy
Major Road
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
County Boundaries
Tribal Lands

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

0 1 2 4 6 8 Miles

N

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR Figure 1-4 MWH

Cedar Valley Pipeline System

would continue across LaVerkin Creek, cross Utah State Route 17, and make an aerial crossing of Ash Creek. The pipeline would continue northwest to the Interstate 15 corridor and then northeast parallel to the east side of Interstate 15 highway right-of-way. CVBPS-1 would be sited adjacent to an existing gravel pit east of Interstate 15. CVBPS-2 would be sited on private property on the east side of Interstate 15 and south of the Kolob entrance to Zion National Park. CVBPS-3 would be sited on the west side of Interstate 15 in Iron County. The new water treatment facility would be sited near existing water reservoirs on a hill above Cedar City west of Interstate 15.

1.2.2 Existing Highway Alternative

The Existing Highway Alternative consists of five systems: Intake, Water Conveyance, Hydro, Kane County Pipeline, and Cedar Valley Pipeline. The Intake, Water Conveyance and Cedar Valley Pipeline systems would be the same as described for the South Alternative.

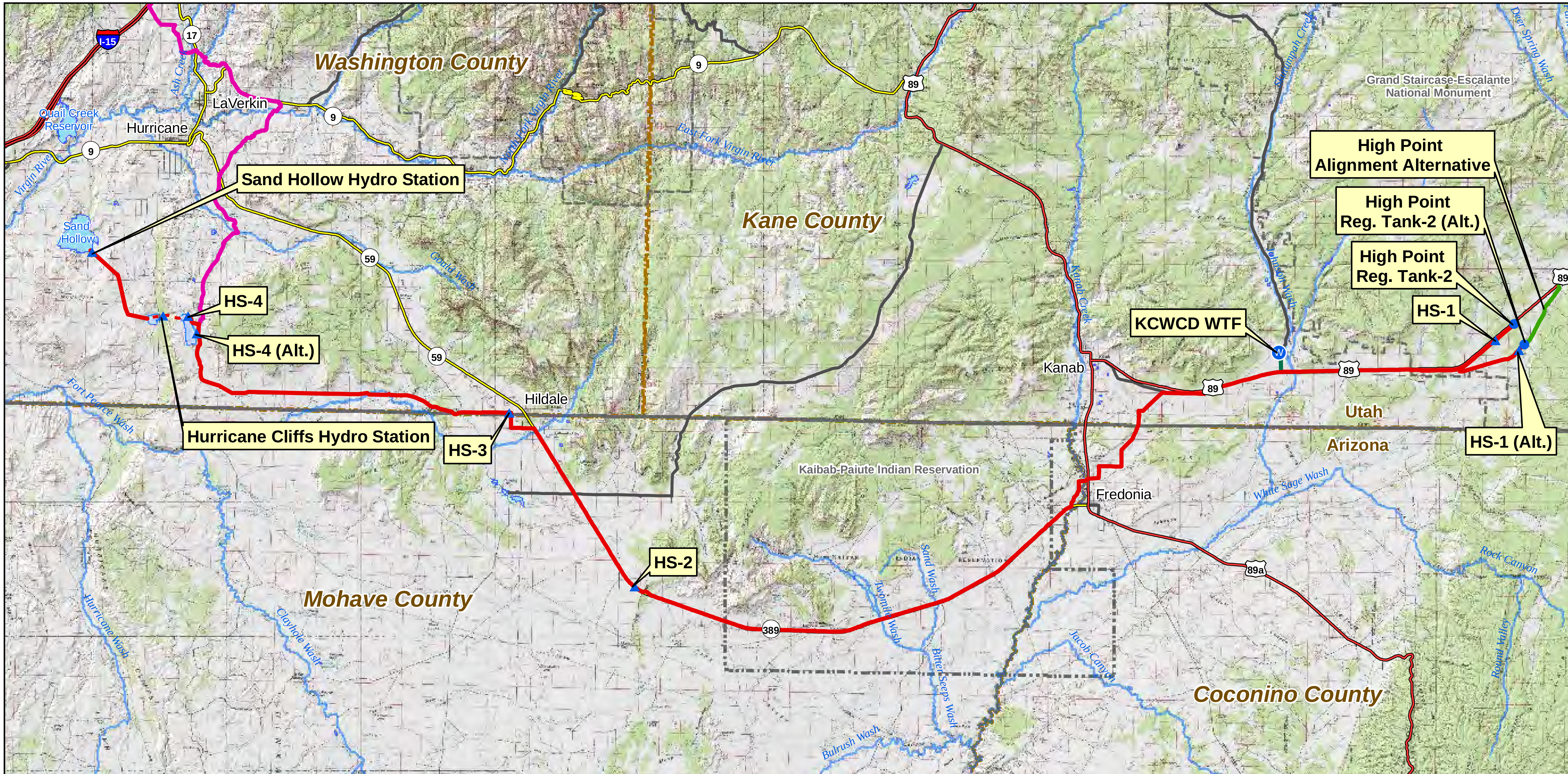
The **Hydro System** would convey the Lake Powell water from the regulating tank at the high point at ground elevation 5,695 feet MSL for about 80 miles through a buried 69-inch diameter penstock in Kane and Washington counties, Utah and Coconino and Mohave counties, Arizona to Sand Hollow Reservoir near St. George, Utah (Figure 1-5). The High Point Alignment Alternative would convey the Lake Powell water from High Point Regulating Tank-2 (Alt.) at the high point at ground level elevation 5,630 feet MSL 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 1-3). The High Point Alignment Alternative would rejoin U.S. 89 about 2.5 miles east of the west boundary of the GSENM. Four in-line hydro generating stations (HS-1, HS-2 HS-3 and HS-4) located along the penstock would generate electricity and help control water pressure in the penstock. HS-1 would be sited on the south side of U.S. 89 within the Congressionally-designated utility corridor through the GSENM. The High Point Alignment Alternative would include HS-1 (Alt.) along the K4020 road within the GSENM and continue along a portion of the K3290 road to its junction with the pipeline alignment along U.S. 89.

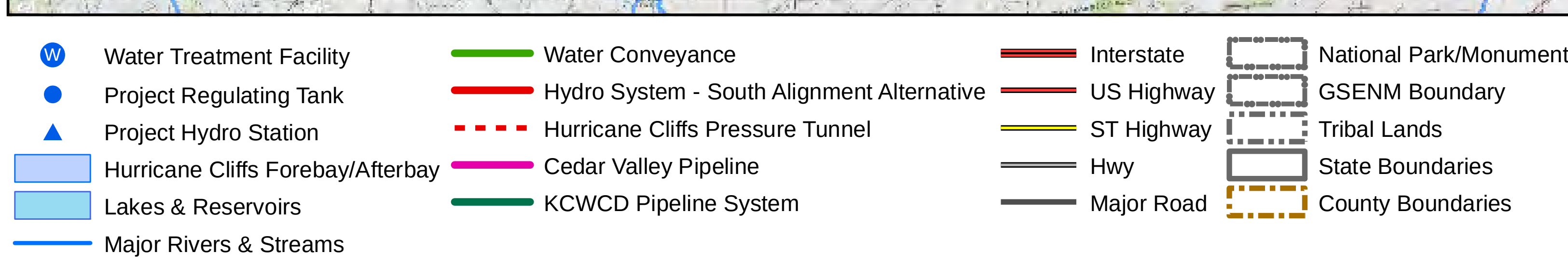
The penstock would parallel the south side of U.S. 89 west of the GSENM past Johnson Wash and follow Lost Spring Gap southwest, crossing U.S. 89 Alt. and Kanab Creek in the north end of Fredonia, Arizona. The penstock would run south paralleling Kanab Creek to Arizona State Route 389 and run west adjacent to the north side of this state highway through the 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 the Kaibab-Paiute Indian Reservation to 1.8 miles west of Cedar Ridge (intersection of Yellowstone Road with U.S. 89), from where it would follow the same alignment as the South Alternative to Sand Hollow Reservoir. HS-2 would be sited 0.5 mile west of Cedar Ridge along the north side of Arizona State Route 389.

The **Kane County Pipeline System** would convey the Lake Powell water from the Lake Powell Pipeline crossing Johnson Wash along U.S. 89 for about 1 mile north through a buried 24-inch diameter pipe in Kane County, Utah to a conventional water treatment facility located near the mouth of Johnson Canyon (Figure 1-5).

1.2.3 Southeast Corner Alternative

The Southeast Corner Alternative consists of five systems: Intake, Water Conveyance, Hydro, Kane County Pipeline, and Cedar Valley Pipeline. The Intake, Water Conveyance, Kane County Pipeline and Cedar Valley Pipeline systems would be the same as described for the South Alternative.





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UTU-85472

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 1-5** MWH

Lake Powell Pipeline Hydro System Existing Highway Alternative

The **Hydro System** would be the same as described for the South Alternative between High Point Regulating Tank-2 and the east boundary of the 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 Indian Reservation for about 3.8 miles and then follow the South Alternative alignment south of the south boundary of the Kaibab-Paiute Indian Reservation, continuing to Sand Hollow Reservoir (Figure 1-6).

1.2.4 Transmission Line Alternatives

Transmission line alternatives include the Intake (3 alignments), BPS-1, Glen Canyon to Buckskin, Buckskin Substation upgrade, Paria Substation upgrade, BPS-2, BPS-2 Alternative, BPS-3 North, BPS-3 South, BPS-3 Underground, BPS-3 Alternative North, BPS-3 Alternative South, BPS-4, BPS-4 Alternative, HS-1 Alternative, HS-2 South, HS-3 Underground, HS-4, HS-4 Alternative, Hurricane Cliffs Afterbay to Sand Hollow, Hurricane Cliffs Afterbay to Hurricane West, Sand Hollow to Dixie Springs, Cedar Valley Pipeline booster pump stations, and Cedar Valley Water Treatment Facility.

The proposed new **Intake Transmission Line** would begin at Glen Canyon Substation and run parallel to U.S. 89 for about 2,500 feet to a new switch station, cross U.S. 89 at the Intake access road intersection and continue northeast to the Intake substation. This 69 kV transmission line would be about 0.9 mile long in Coconino County, Arizona (Figure 1-7). One alternative alignment would run parallel to an existing 138 kV transmission line to the west, turn north to the new switch station, cross U.S. 89 at the Intake access road intersection and continue northeast to the Intake substation. This 69 kV transmission line alternative would be about 1.2 miles long in Coconino County, Arizona (Figure 1-7). Another alternative alignment would bifurcate from an existing transmission line and run west, then northeast to the new switch station, cross U.S. 89 at the Intake access road intersection and continue northeast to the Intake substation. This 69 kV transmission line alternative would be about 1.3 miles long in Coconino County, Arizona (Figure 1-7).

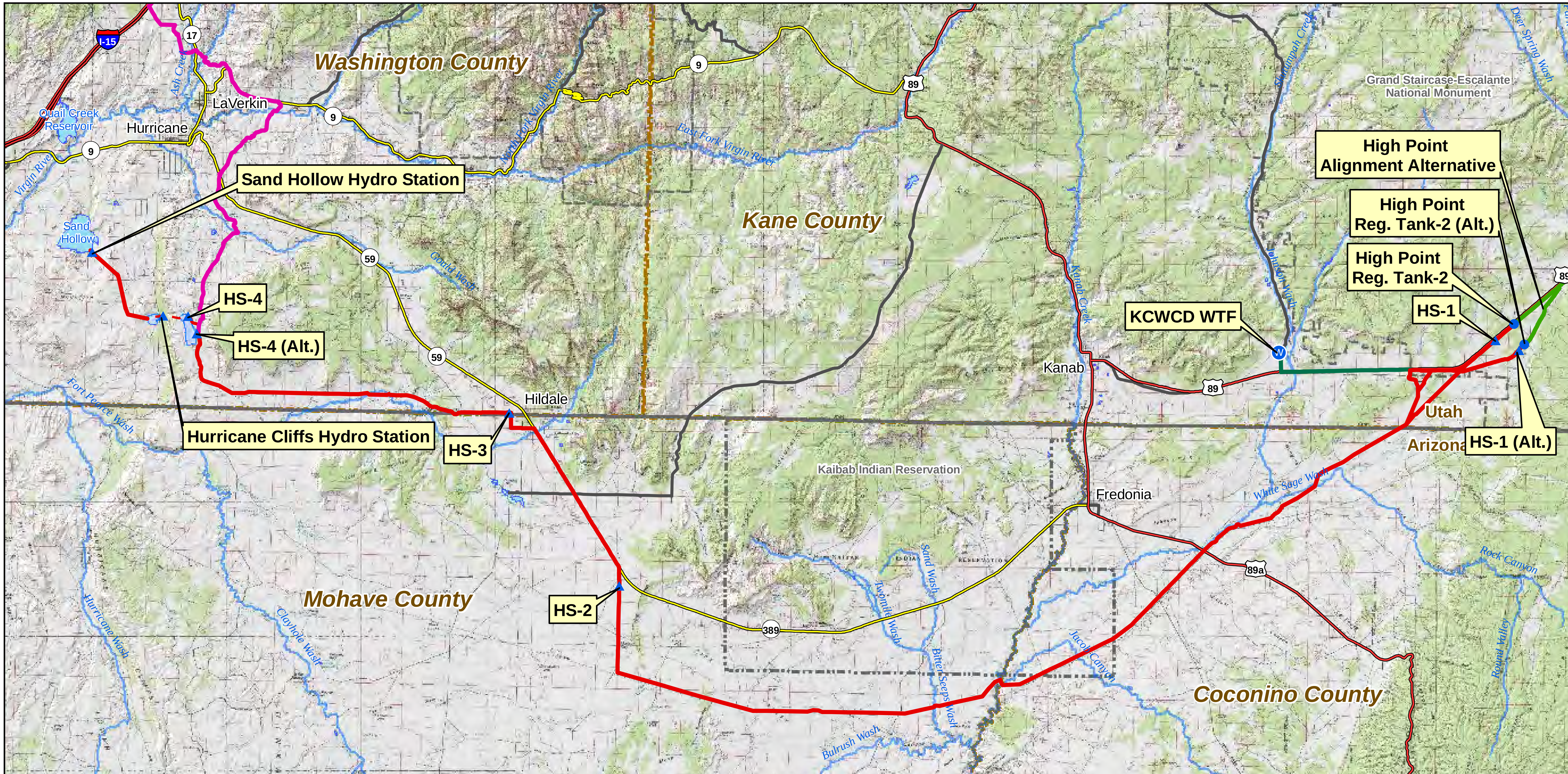
The proposed new **BPS-1 Transmission Line** would begin at the new switch station located on the south side of U.S. 89 and parallel the LPP Water Conveyance System alignment to the BPS-1 substation west of U.S. 89. This 69 kV transmission line would be about 1 mile long in Coconino County, Arizona (Figure 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 5 acres of land within the 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 Alternative. The substation upgrade would require an additional 2 acres of privately-owned land adjacent to the existing substation in Kane County, Utah (Figure 1-7).

The proposed new **BPS-2 Transmission Line** alternative would consist of a new 3-ring switch station along the existing 138 kV Glen Canyon to Buckskin Transmission Line and 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



Water Treatment Facility
Project Regulating Tank
Project Hydro Station
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams
Water Conveyance System
Hydro System - Southeast Corner Alternative
Kane County Pipeline System
Cedar Valley Pipeline System
Interstate
US Highway
ST Highway
Hwy
Major Road
National Park/Monument
GSENM Boundary
Tribal Lands
State Boundaries
County Boundaries

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UTU-85472

N

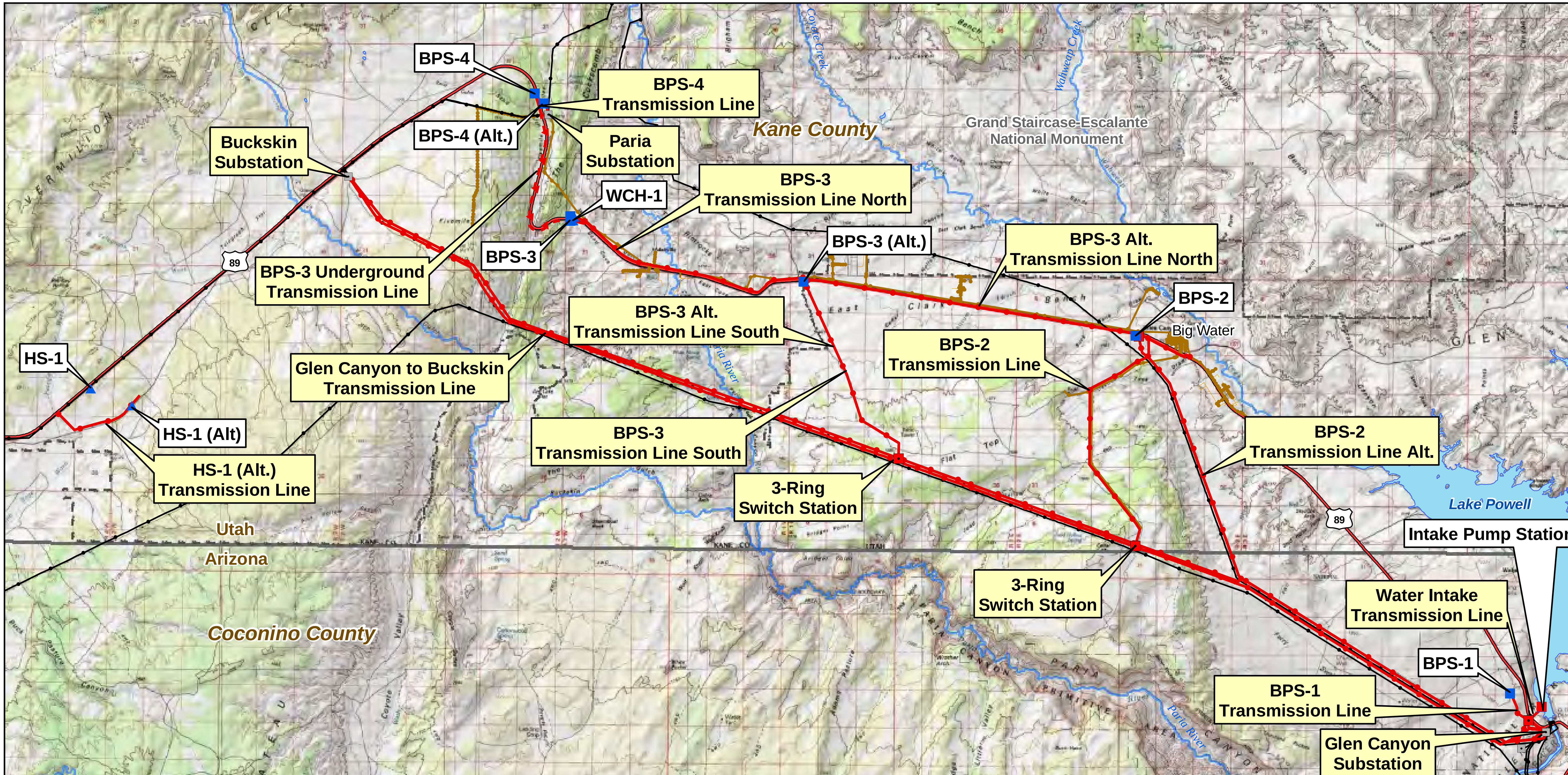
0 1.25 2.5 5 7.5 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 1-6** MWH

Lake Powell Pipeline
Hydro System
Southeast Corner Alternative



Project Intake Pump Station
Project Booster Pump Station
Project Hydro Station
Existing Substation
Proposed Substation
Project Transmission Line
Underground Project Transmission Line
Existing Transmission Line
Existing OH Primary Line
Existing UG Primary Line
Interstate
US Highway
ST Highway
Hwy
Major Road
Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
GSENM Boundary
State Boundaries
NGS USA Topographic Maps

FERC Project Number:
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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

UDWR **Figure 1-7** MWH

Lake Powell Pipeline Transmission Line Alternatives East

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 alternative would be about 7 miles long across Utah SITLA-administered land, with a 138 kV connection to the BPS-2 substation (Figure 1-7).

The new **BPS-2 Alternative Transmission Line** would consist of a new 138 kV transmission line from Glen Canyon Substation parallel to the existing Rocky Mountain Power 230 kV transmission line, connecting to the BPS-2 substation west of Big Water. This new 138 kV transmission line alternative would be about 16.5 miles long in Coconino County, Arizona and Kane County, Utah crossing National Park Service-administered land, BLM-administered land and Utah SITLA-administered land (Figure 1-7).

The new **BPS-3 Transmission Line North** alternative would consist of a new 138 kV transmission line from BPS-2 paralleling the south side of U.S. 89 within the Congressionally designated utility corridor west to BPS-3 at the east side of the Cockscomb geological feature. This new 138 kV transmission line alternative would be about 15.7 miles long in Kane County, Utah (Figure 1-7).

The new **BPS-3 Transmission Line South** alternative would consist of a new 3-ring switch station along the existing 138 kV Glen Canyon to Buckskin Transmission Line and a new transmission line from the switch station north along an existing BLM road to U.S. 89 and then west along the south side of U.S. 89 within the Congressionally designated utility corridor to BPS-3 at the east side of the Cockscomb. This new 138 kV transmission line alternative would be about 12.3 miles long in Kane County, Utah (Figure 1-7).

The new **BPS-3 Underground Transmission Line** alternative would consist of a new buried 24.9 kV transmission line (2 circuits) from the upgraded Paria Substation to BPS-3 on the east side of the Cockscomb geological feature. This new underground transmission line would be parallel to the east and south side of U.S. 89 and would be about 4.1 miles long in Kane County, Utah (Figure 1-7).

The new **BPS-3 Alternative Transmission Line North** alternative would consist of a new 138 kV transmission line from BPS-2 paralleling the south side of U.S. 89 west to BPS-3 Alternative near the GSENM east boundary within the Congressionally-designated utility corridor. This new 138 kV transmission line alternative would be about 9.3 miles long in Kane County, Utah (Figure 1-7).

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

The new **BPS-4 Transmission Line** alternative would begin at the upgraded Paria Substation and run parallel to the west side of U.S. 89 north to BPS-4 within the Congressionally designated utility corridor. This new 138 kV transmission line would be about 0.8 mile long in Kane County, Utah (Figure 1-7).

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

The proposed new **HS-1 Alternative Transmission Line** would begin at the new HS-1 Alternative and run southwest parallel to the K4020 road and then northwest parallel to the K4000 road to the U.S. 89 corridor where it would tie into the existing 69 kV transmission line from the Buckskin Substation to the

Johnson Substation. This 69 kV transmission line would be about 3 miles long in Kane County, Utah (Figure 1-7).

The proposed new **HS-2 South Transmission Line** alternative 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 proposed new **HS-3 Underground 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 underground circuit would be about 0.6 mile long in Washington County, Utah (Figure 1-8).

The proposed new **HS-4 Transmission Line** would consist of a new transmission line from the HS-4 hydroelectric station and substation north along an existing BLM road to an existing transmission line parallel to Utah State Route 59. The new 69 kV transmission line would be about 8.2 miles long in Washington County, Utah (Figure 1-8).

The new **HS-4 Alternative Transmission Line** alternative would connect the HS-4 Alternative 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).

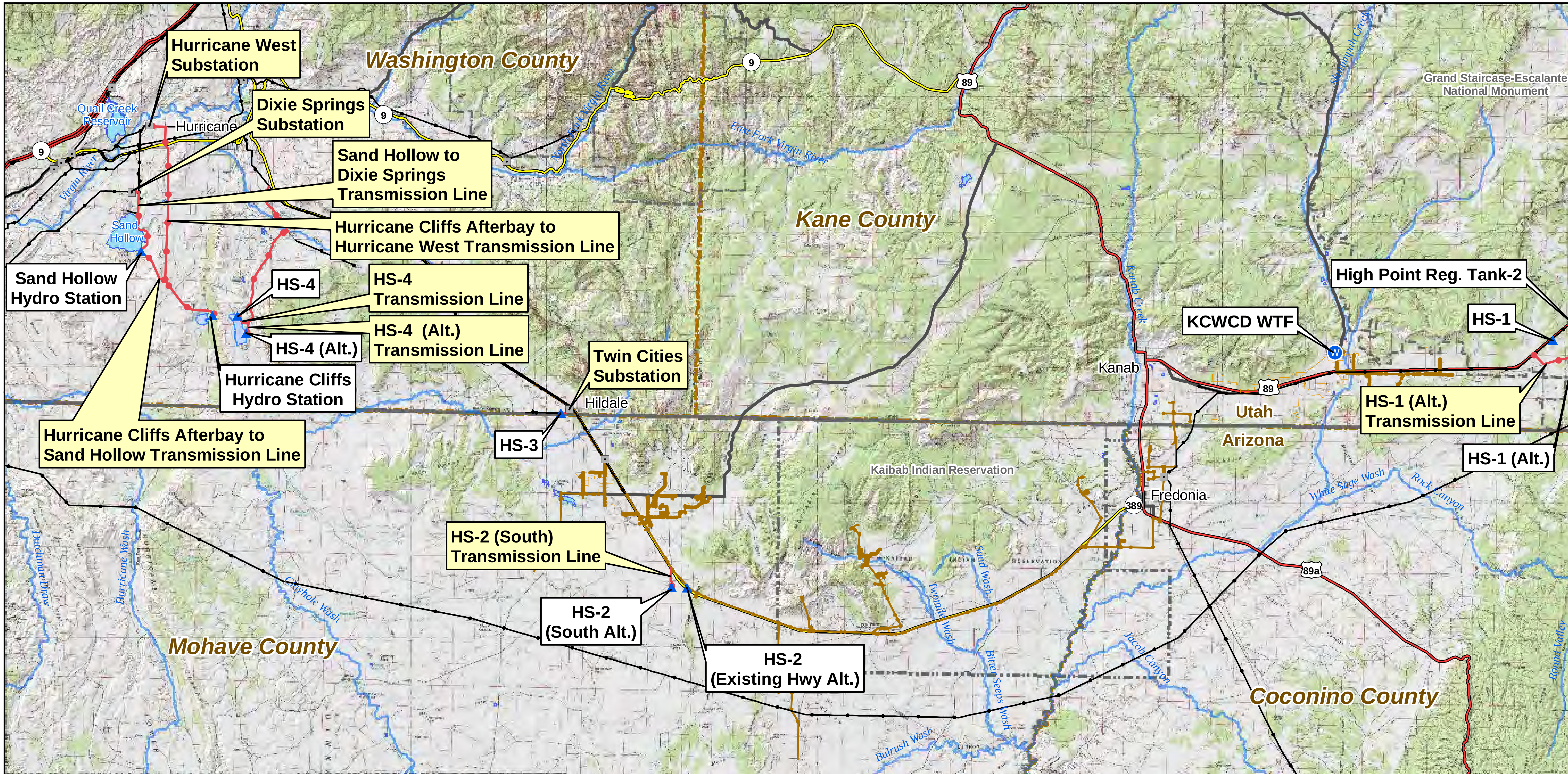
The proposed new **Hurricane Cliffs Afterbay to Sand Hollow Transmission Line** would consist of a new 69 kV transmission line from the Hurricane Cliffs peaking power plant and substation, and run northwest to the Sand Hollow Hydro Station substation. This new 69 kV transmission line would be about 4.9 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 from the Hurricane Cliffs pumped storage power plant and run 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 from the Sand Hollow Hydro Station 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).

The three **Cedar Valley Pipeline** booster pump stations would require new transmission lines from existing transmission lines paralleling the Interstate 15 corridor. The new CVBPS-1 transmission line would extend southeast over I-15 from the existing transmission line to the booster pump station substation for about 1.3 miles in Washington County, Utah (Figure 1-9). The new CVBPS-2 transmission line would extend east over I-15 from the existing transmission line to the booster pump station substation for about 0.2 mile in Washington County, Utah (Figure 1-9). The new CVBPS-3 transmission line would extend west over I-15 from the existing transmission line and southwest along the west side of Interstate 15 to the booster pump station substation for about 0.6 mile in Iron County, Utah (Figure 1-9).

The **Cedar Valley Water Treatment Facility Transmission Line** would begin at an existing substation in Cedar City and run about 1 mile to the water treatment facility site in Iron County, Utah (Figure 1-9).



Water Treatment Facility
Project Regulating Tank
Project Hydro Station
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams

Existing Substation
Project Transmission Line
Existing Transmission Line
Existing OH Primary Line
Existing UG Primary Line

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

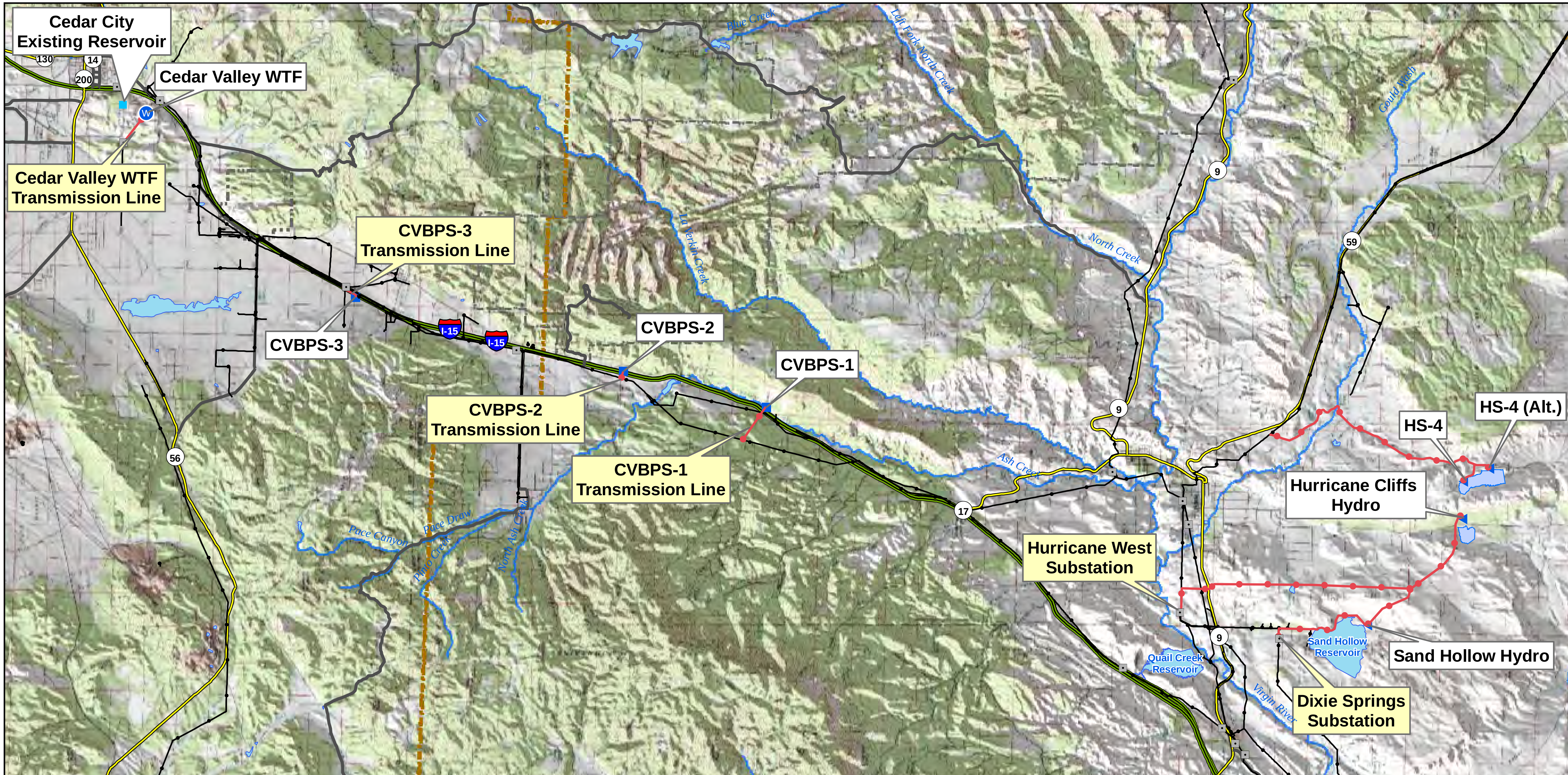
0 1.25 2.5 5 7.5 10 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 1-8** MWH

Lake Powell Pipeline Transmission Line Alternatives West



Water Treatment Facility
Project Pump Station
Project Hydro Station
Existing Substation
Project Substation
Project Transmission Line
Existing Transmission Line
Existing OH Primary Line
Existing UG Primary Line
Interstate
US Highway
ST Highway
Hwy
Major Road
Hurricane Cliffs Forebay/Afterbay
Lakes & Reservoirs
Major Rivers & Streams
National Park/Monument
County Boundaries
Tribal Lands

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

UDWR **Figure 1-9** MWH

Cedar Valley Transmission Line Alternatives

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 reducing residential outdoor water use in the WCWCD and CICWCD service areas. This alternative could provide a total of 86,249 acre-feet of water annually to WCWCD, CICWCD and KCWCD for M&I use without diverting Utah's water from Lake Powell.

1.3.1 WCWCD No Lake Powell Water Alternative

The WCWCD would implement other future water development projects currently planned by the District, develop additional water reuse/reclamation, and convert additional agricultural water use to M&I use as a result of urban development in agricultural areas through 2020. Remaining planned and future water supply projects through 2020 include the Ash Creek Pipeline (5,000 acre-feet per year), Crystal Creek Pipeline (2,000 acre-feet per year), and Quail Creek Reservoir Agricultural Transfer (4,000 acre-feet per year). Beginning in 2020, WCWCD would convert agricultural water to secondary use and work with St. George City to maximize existing wastewater reuse, bringing the total to 96,258 acre-feet of water supply per year versus demand of 98,427 acre-feet per year, incorporating currently mandated conservation goals. The WCWCD water supply shortage in 2037 would be 70,000 acre-feet per year, 1,000 acre-feet more than the WCWCD maximum share of the LPP water. Therefore, the WCWCD No Lake Powell Water Alternative needs to develop 69,000 acre-feet of water per year to meet comparable supply and demand requirements as the other action alternatives.

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 40,000 acre-feet per year of Virgin River water with high total dissolved solids (TDS) concentration and other contaminants. The RO advanced water treatment facility would produce up to 36,279 acre-feet per year of water suitable for M&I use. The WCWCD would develop the planned Warner Valley Reservoir to store the diverted Virgin River water, which would be delivered to the RO advanced water treatment facility. The remaining 3,721 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 remaining needed water supply of 32,721 acre-feet per year to meet WCWCD 2037 demands would be obtained by reducing and restricting outdoor residential water use in the WCWCD service area. The Utah Division of Water Resources (UDWR) estimated 2005 culinary water use for residential outdoor watering in the communities served by WCWCD was 97.4 gallons per capita per day (gpcd) (UDWR 2009). This culinary water use rate is reduced by 30.5 gpcd to account for water conservation attained from 2005 through 2020, yielding 66.9 gpcd residential outdoor water use available for conversion to other M&I uses. The equivalent water use rate reduction to generate 32,721 acre-feet per year of conservation is 56.6 gpcd for the 2037 population within the WCWCD service area. Therefore, beginning in 2020, the existing rate of residential outdoor water use would be gradually reduced and restricted to 10.3 gpcd, or an 89.4 percent reduction in residential outdoor water use.

The combined 36,279 acre-feet per year of RO product water and 32,721 acre-feet per year of reduced residential outdoor water use would equal 69,000 acre-feet per year of M&I water to help meet WCWCD demands through 2037.

1.3.2 CICWCD No Lake Powell Water Alternative

The CICWCD would implement other future groundwater development projects currently planned by the District, purchase agricultural water from willing sellers for conversion to M&I uses, and convert additional agricultural water use to M&I use as a result of urban development in agricultural areas through 2020. Remaining planned and future water supply projects through 2020 include additional groundwater development projects (3,488 acre-feet per year), agricultural conversion resulting from M&I development (3,834 acre-feet per year), and purchase agricultural water from willing sellers (295 acre-feet per year). Beginning in 2020, CICWCD would have a total 19,772 acre-feet of water supply per year versus demand of 19,477 acre-feet per year, incorporating required progressive conservation goals. The CICWCD water supply shortage in 2060 would be 11,470 acre-feet per year. Therefore, the CICWCD No Lake Powell Water Alternative needs to develop 11,470 acre-feet of water per year to meet comparable supply and demand limits as the other action alternatives.

The remaining needed water supply of 11,470 acre-feet per year to meet CICWCD 2060 demands would be obtained by reducing and restricting outdoor residential water use in the CICWCD service area. The UDWR estimated 2005 culinary water use for residential outdoor watering in the communities served by CICWCD was 84.5 gpcd (UDWR 2007). A portion of this residential outdoor water would be converted to other M&I uses. The equivalent water use rate to obtain 11,470 acre-feet per year is 67.8 gpcd for the 2060 population within the CICWCD service area. Therefore, the existing rate of residential outdoor water use would be gradually reduced and restricted to 16.7 gpcd beginning in 2023, an 80 percent reduction in the residential outdoor water use rate between 2023 and 2060. The 11,470 acre-feet per year of reduced residential outdoor water use would be used to help meet the CICWCD demands through 2060.

1.3.3 KCWCD No Lake Powell Water Alternative

The KCWCD would use existing water supplies and implement future water development projects including new groundwater production, converting agricultural water rights to M&I water rights as a result of urban development in agricultural areas, and developing water reuse/reclamation. Existing water supplies (4,039 acre-feet per year) and 1,994 acre-feet per year of new ground water under the No Lake Powell Water Alternative would meet projected M&I water demand of 6,033 acre-feet per year within the KCWCD service area through 2060. The total potential water supply for KCWCD is about 12,140 acre-feet per year (4,039 acre-feet per year existing culinary plus secondary supply, and 8,101 acre-feet per year potential for additional ground water development up to the assumed sustainable ground water yield) without agricultural conversion to M&I supply. Short-term ground water overdrafts and new storage projects (e.g., Jackson Flat Reservoir) would provide reserve water supply to meet demands during drought periods and other water emergencies.

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. 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 or released according to the operating guidelines. Future population growth as projected by the Utah Governor's Office of Planning and Budget (GOPB) would continue to occur in southwest Utah until water and other potential limiting resources such as developable land, electric power, and fuel begin to curtail economic activity and population in-migration.

1.4.1 WCWCD No Action Alternative

The WCWCD would implement other future water development projects currently planned by the District, develop additional water reuse/reclamation, convert additional agricultural water use to M&I use as a result of urban development in agricultural areas, and implement advanced treatment of Virgin River water. The WCWCD could also limit water demand by mandating water conservation measures such as outdoor watering restrictions. Existing and future water supplies under the No Action Alternative would meet projected M&I water demand within the WCWCD service area through approximately 2020. The 2020 total water supply of about 96,528 acre-feet per year would include existing supplies, planned WCWCD water supply projects, wastewater reuse, transfer of Quail Creek Reservoir supplies, and future agricultural water conversion resulting from urban development of currently irrigated lands. Each future supply source would be phased in as needed to meet the M&I 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). Maximum reuse of treated wastewater effluent for secondary supplies would be required to meet the projected M&I water demand starting in 2020. The No Action Alternative would not provide adequate water supply to meet projected water demands from 2020 through 2060. There would be a potential water shortage of approximately 139,875 acre-feet per year in 2060 under the No Action Alternative (UDWR 2008b).

1.4.2 CICWCD No Action Alternative

The CICWCD would implement future water development projects including converting agricultural water rights to M&I water rights as a result of urban development in agricultural areas, purchasing “buy and dry” agricultural water rights to meet M&I demands, and developing water reuse/reclamation. The Utah State Engineer would act to limit existing and future ground water pumping from the Cedar Valley aquifer in an amount not exceeding the assumed sustainable yield of 37,600 ac-ft per year. Existing and future water supplies under the No Action Alternative meet projected M&I water demand within the CICWCD service area during the planning period through agricultural conversion of water rights to M&I use, wastewater reuse, and implementing “buy and dry” practices on irrigated agricultural land. Each future water supply source would be phased in as needed to meet the M&I demand associated with the forecasted population. The CICWCD No Action Alternative includes buying and drying of agricultural water rights covering approximately 8,000 acres between 2005 and 2060 and/or potential future development of West Desert water because no other potential water supplies have been identified to meet unmet demand. The No Action Alternative would not provide CICWCD with any reserve water supply (e.g., water to meet annual shortages because of drought, emergencies, and other losses) after 2010 (i.e., after existing supplies would be maximized).

1.4.3 KCWCD No Action Alternative

The KCWCD would use existing water supplies and implement future water development projects including new ground water production, converting agricultural water rights to M&I water rights as a result of urban development in agricultural areas, and developing water reuse/reclamation. Existing water supplies (4,039 acre-feet per year) and 1,994 acre-feet per year of new ground water under the No Action Alternative would meet projected M&I water demand of 6,033 acre-feet per year within the KCWCD service area through 2060. The total potential water supply for KCWCD is about 12,140 acre-feet per year (4,039 acre-feet per year existing culinary plus secondary supply, and 8,101 acre-feet per year potential for additional ground water development up to the assumed sustainable ground water yield) without agricultural conversion to M&I supply. Short-term ground water overdrafts and new storage projects (e.g., Jackson Flat Reservoir) would provide reserve water supply to meet demands during drought periods and other water emergencies.

1.5 Impact Topics

The following impact topics are addressed in the Surface Water Resources Study Report:

- Streams
- Return Flows
- Reservoirs
- Peak Flows
- Geomorphology

Chapter 2
Methodology

The following sections describe the methodology for analyzing the study area and the effects of the LPP on surface water resources.

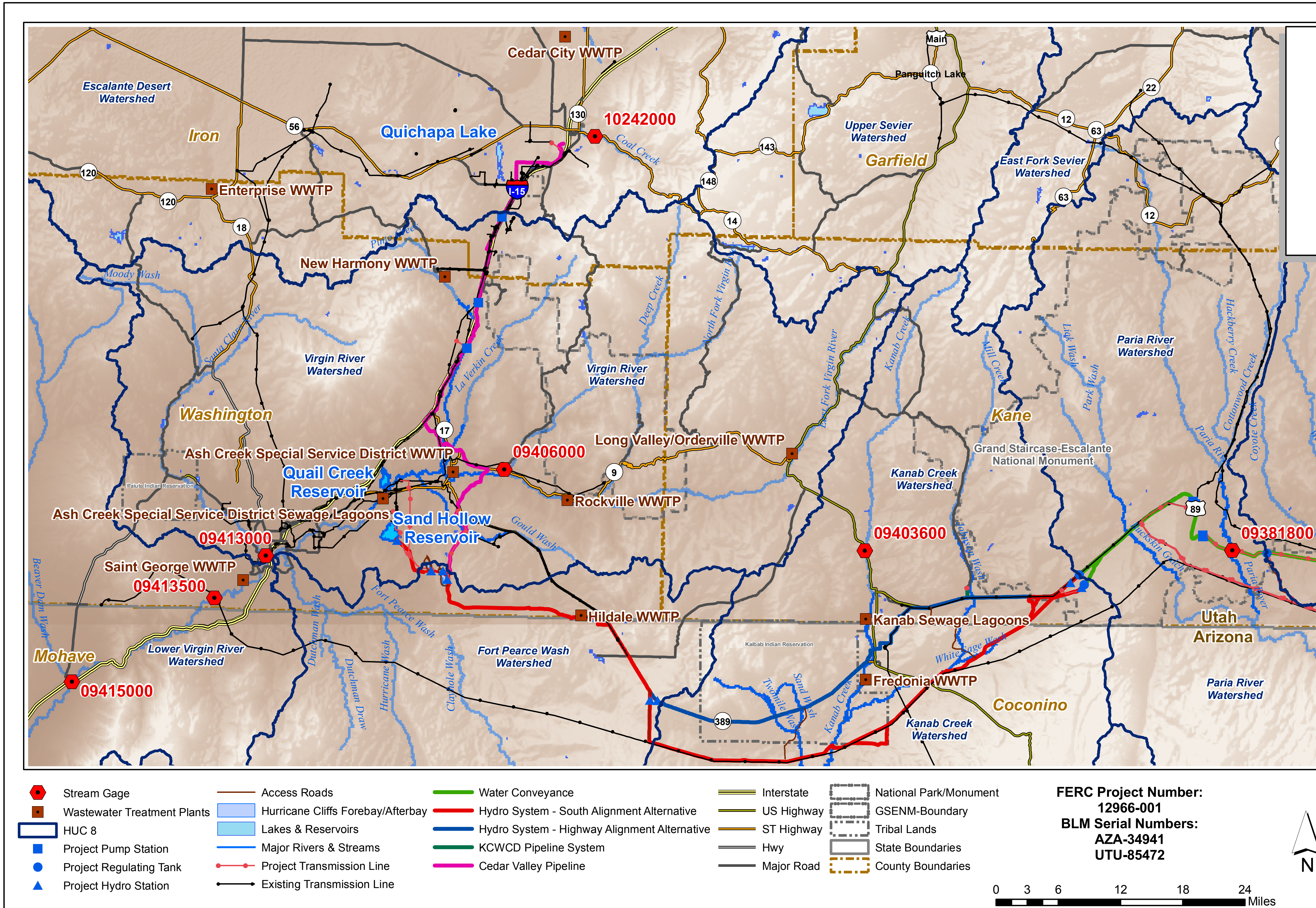
2.1 Study Area

The surface water study area encompasses the surface waters potentially affected by the LPP project and the No Lake Powell Water Alternative. Figure 2-1 shows the HUC 8 watershed boundaries and stream gage locations in the surface water resources study area.

Table lists the streams that could be affected by any of the pipeline alignments of the LPP project. Causes of potential effects range from the pipeline physically crossing the stream channel, to changes in diversion of streamflows, to changes in the flow regime from return flows.

Table 2-1
List of Potentially Affected Streams by LPP Alternatives

Creek	Intermittent/Perennial	County	Cause of Potential Effect
Colorado River	Perennial	Coconino	Change in flows due to effects on storage in Lake Powell
Virgin River	Perennial	Washington	Sewered and non-sewered return flows, crossing (aerial)
Kanab Creek	Intermittent (downstream of Kanab)	Kane, Mohave	Sewered and non-sewered return flows, crossing
Santa Clara River	Perennial	Washington	Non-sewered return flows
Coal Creek	Perennial	Iron	Non-sewered return flows
Johnson Creek	Intermittent	Iron	Sewered return flows
Paria River	Perennial	Kane	Crossing
Buckskin Gulch	Intermittent	Kane	Crossing
Coyote Wash	Intermittent	Kane	Crossing
Johnson Wash	Intermittent	Kane	Crossing
White Sage Wash	Intermittent	Coconino	Crossing
Sandy Canyon Wash	Intermittent	Mohave	Crossing
Sand Wash	Intermittent	Mohave	Crossing
Two-Mile Wash	Intermittent	Mohave	Crossing
Bitter Seeps Wash	Intermittent	Mohave	Crossing
Gould Wash	Intermittent	Washington	Crossing, non-sewered return flows
LaVerkin Creek	Perennial	Washington	Crossing, non-sewered return flows
Ash Creek	Perennial	Washington	Crossing (aerial), non-sewered return flows
Fort Pierce Wash	Perennial	Washington	Non-sewered return flows, runoff captured in Hurricane Cliffs Forebay and Afterbay



Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 2-1** MWH

HUC 8 Watershed Boundaries and Stream Gage Locations

The following reservoirs could potentially be affected because of changes in operations: Lake Powell, Quail Creek Reservoir and Sand Hollow Reservoir. In addition, Quichapa Lake and Rush Lake in Iron County could potentially be affected by additional runoff and return flows.

2.2 Streams

2.2.1 Existing Conditions

Historical streamflows in areas that could potentially be affected by the Proposed Action or No Lake Powell Water Alternative are documented using historical streamflow data to document the existing surface water conditions. Data were obtained from the USGS NWIS database for locations on the Colorado River, Paria River, Virgin River, Kanab Creek, Santa Clara River, and Coal Creek with the longest periods of record and/or in key locations (USGS 2009a). Streamflows at all locations where enough data are available were summarized using the following charts:

- Flow exceedance curve
- Daily flows time series
- Daily mean and range of flows
- Monthly mean flows
- Annual mean flows

2.2.2 Direct Effects

The effects on Colorado River streamflows are based on the results of water resources modeling performed by the Bureau of Reclamation. The effects on streamflows in Washington County are based on the results of a local system water resources model developed by Utah Division of Water Resources. Effects on the remaining streams are based on a qualitative analysis.

2.2.2.1 Virgin River Daily Simulation Model

The Virgin River Daily Simulation Model (VRDSM) is a mean daily simulation model of the Virgin River developed by the Utah Division of Water Resources. At present it is a FORTRAN-based yield model used to evaluate potential changes in operations on the Virgin River in Southwest Utah. The model simulates the river system from the Virgin River at Virgin gage to the Utah-Arizona state line for a 68-year period from 1941-2008. The model simulates the Quail Creek project, Sand Hollow Reservoir, pump-back from the Washington Fields diversion to Sand Hollow Reservoir, hydropower plants in operation within the district and instream flow requirements (UDWR 1998). The model has the capability to simulate additional regulating storage, an expanded secondary system for the St. George Area and the importation of Lake Powell reservoir water to Sand Hollow Reservoir by the proposed Lake Powell Pipeline. The model is not explicitly adjusted with ungaged gains and losses to match historical gaged streamflows.

Inflow to the model includes streamflow records from the Virgin River at the Virgin gage and the main Virgin River tributary inflow, including Ash Creek/LaVerkin Creek, Quail Creek/Leeds Creek and the Santa Clara River. The U.S. Geological Survey (USGS) streamgage located on the Virgin River near the town of Virgin (USGS 09406000) provides long-term records for the Virgin River at Virgin (1909-1971 and then 1979 to the present). Discontinued streamflow records (1972-1978) were estimated using the

Virgin River near Hurricane gage, which began in 1967, and equations from the model. Short-term records are available on Ash Creek and LaVerkin Creek. Missing data were estimated with correlations to the Virgin gage. Missing years at the Santa Clara River gage (1941-1950 and 1955-1983) were filled in from the Division of Water Resources monthly model of the Santa Clara River. The monthly flows from the model were divided by the number of days in the month to obtain the daily inflows (UDWR 1998).

The model simulates the maximum yield in the St. George Area with a specified maximum shortage in the worst year (10 percent in the Lake Powell Pipeline project simulations), while providing firm secondary water supplies to the Hurricane, LaVerkin and Washington Fields areas. Flow is diverted year-round in the Quail Creek pipeline to provide flows to the Hurricane and LaVerkin diversions, Pah Tempe hydropower flows and flow to Quail Creek Reservoir. If the flow is less than 86 cfs at the Washington Fields Diversion, no water is diverted to Quail Creek Reservoir (DWRe 1998). A schematic of the model is provided in Figure 2-2.

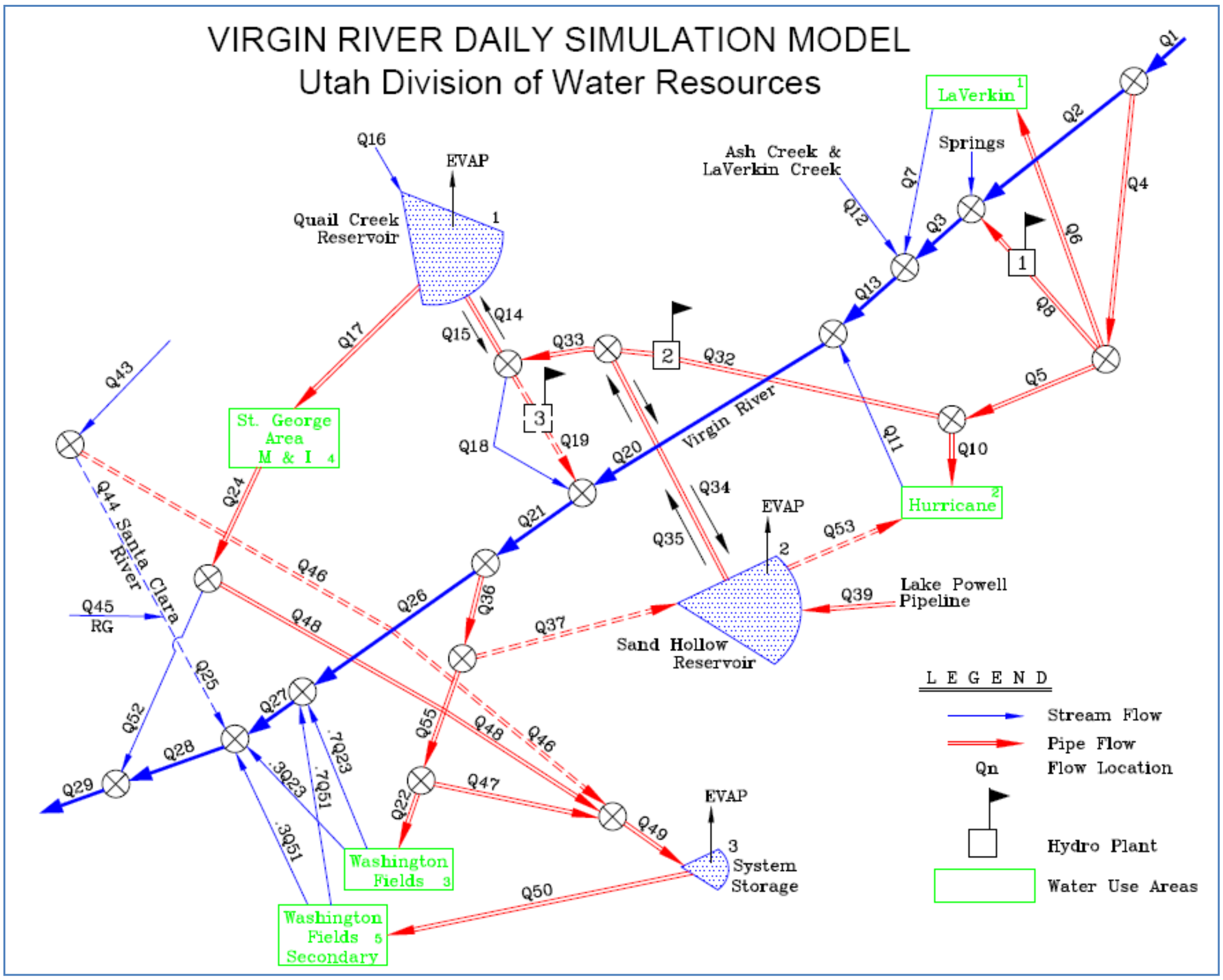


Figure 2-2
Virgin River Daily Simulation Model Schematic (DWR 2011)

2.2.2.1.1 Virgin River Daily Simulation Model Scenarios. Two simulations were performed with the VRDSM. Scenario 1 simulated the Base Case conditions of full utilization of Virgin River water rights, without any additional storage or Lake Powell Pipeline deliveries. Scenario 2 represents the Proposed Action future conditions with the expanded secondary system utilizing 2,500 acre feet of re-regulating storage and 69,000 acre feet of annual Lake Powell Pipeline deliveries into Sand Hollow Reservoir. The scenarios incorporated the following assumptions (UDWR 2011):

1) No water delivered through re-regulating storage will return to the river
2) Capacity on the re-use treatment plant will accommodate all return flow from the St. George Area M&I and no Virgin River Water will be used for new secondary demands
3) Carrying capacity of the infrastructure at the Washington Fields Diversion will not limit what can be diverted there

Annual demands remained the same for the LaVerkin, Hurricane, and Washington Fields service areas (1, 2 and 3) in all scenario simulations. Demands for service areas 4 and 5, labeled in Figure as St George Area M&I and Washington Fields Secondary, varied between scenarios as these areas were optimized for yield by the model's solver. Service area 4 represents the Municipal and Industrial demands in the St. George metropolitan area. Service Area 5 includes all new secondary demands that will be placed on the reuse system in the St. George metropolitan area (UDWR 2010b). Daily demand distributions remained the same for all service areas, in all scenarios simulated.

2.2.2.2 Lower Colorado River and Lake Powell Model

The State of Utah contracted with Reclamation to perform additional simulations using the CRSS. The model simulates storage effects on Lake Powell and streamflow effects on the Colorado River with a monthly timestep.

Three scenarios were simulated:

- Lake Powell Pipeline with maximum depletions of 86,249 AFY (86k scenario); depletions begin with 1,975 AFY in 2020 and increase annually until 2042 when they are held constant at 86,249 AFY.

- Lake Powell Pipeline with maximum depletions of 99,970 AFY (100k scenario); depletions begin with 1,975 AFY in 2020 and increase annually until 2046 when they are held constant at 99,970 AFY.

- No pipeline out of Lake Powell

Two future conditions were simulated:

- Final Planning Study – future water development in the Upper Colorado River basin would occur according to projections provided by the Upper Basin States to the Upper Colorado River Commission (UCRC). In this analysis the No Action alternative assumes that if the State of Utah does not develop the Lake Powell Pipeline; Utah's unallocated water would be developed somewhere else in the state. This analysis isolates the impact of the geographic location of the water use from the Colorado River system; Utah's total water use remains the same in the

Proposed Action and No Action alternatives. All existing and future depletions are included in the simulations.

- No Additional Depletions - water use in the Colorado River basin would remain constant at current levels, except for reasonably foreseeable future project depletions. A reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). In the No Additional Depletions analysis the No Action alternative assumes that if the Lake Powell Pipeline is not developed, Utah's unallocated water would not be developed somewhere else in the state. This analysis isolates the effect of adding a new project (Lake Powell Pipeline) to the mix of existing and reasonably foreseeable depletions in the Colorado River system.

Two input hydrology scenarios were evaluated:

- Direct Natural Flow, Index Sequential Method (DNF) – Developed from the observed streamflow record from 1906 to 2006. The ISM results in a number of different future hydrologic sequences that allows calculation of uncertainty. This scenario was the primary inflow dataset used for the 2007 Shortage EIS. DNF results in 101 simulated outcomes for each month, which are summarized using non-parametric statistics including the 10^{th}, 50^{th}, and 90^{th} percentiles.

- Nonparametric Paleo-conditioned (NPC) Inflows – Developed from tree-ring information dating back to the year 762. The technique generates flows with the same magnitudes as the historic record but with more variety in the sequencing of wet and dry periods. NPC results in 125 simulated outcomes for each month, which are summarized using non-parametric statistics.

The results of Reclamation's 86K scenario simulations are summarized in Chapter 4, Sections 4.3 and 4.4 as they represent the State of Utah's current water right for the LPP Project. Reclamation's full report, which also discusses a 100K scenario, is included as Appendix B.

2.3 Reservoirs

Reservoirs are analyzed using historical storage data and area-elevation-capacity curves for existing and potentially affected facilities including Lake Powell, Quail Creek Reservoir, and Sand Hollow Reservoir. The impact analyses for reservoirs is based on the results of the local system model and the CRSS model described in Section 2.2.

2.4 Peak Flows

The flood flow discussion summarizes Federal Emergency Management Agency (FEMA) Flood Insurance Study estimates of peak flows. For locations with no recent FEMA Flood Insurance Study, estimates of peak flows developed by the USGS based on regression equations are summarized.

The impact analyses discuss potential effects of the project on peak flows. The effects on peak flows are expected to be minor because the project does not include any permanent changes to stream channels.

However, the analysis discusses how changes in drainage area and storage, such as those caused by construction of the Hurricane Cliffs Hydropower facilities, could affect peak flows downstream.

2.5 Geomorphology

The geomorphic discussion includes a summary of general geomorphic characteristics described in existing studies. The impact analyses include a qualitative discussion of how the estimated changes in baseflows, based on modeling results, and peak flows, based on the peak flow discussion, might affect stream stability.

2.6 Cumulative Effects

Cumulative effects are based on the effects of the action alternatives combined with the effects of other "reasonably foreseeable" actions. A formal list of reasonably foreseeable actions, activities independent of the LPP that could result in cumulative effects when combined with the effects of the LPP, will likely be developed for the NEPA process. The only reasonably foreseeable action likely to affect surface waters within Kane, Washington, and Iron counties is urban development. Urban development and land use activities would occur with the projected population growth in these counties. This would result in increased water runoff from impermeable surfaces in the urban centers in Kane, Iron, and Washington counties. These effects are discussed qualitatively in Chapter 7.

For Lake Powell and the Lower Colorado River, other actions that could result in cumulative effects have already been incorporated into the CRSS modeling Future Planning Study scenario. Such actions include future increases in consumptive use of the Colorado River water in the Upper Division states, intrastate water transfers in the Lower Division states and other constraints on operation of the Colorado River system (Reclamation 2007).

2.7 Study Period

There is a different study period for the affected environment and effects analysis. Historical streamflow and storage data are summarized for October 1940 through September 2008 (water years 1941 through 2008) to document the affected environment. The Virgin River Daily Simulation Model utilizes the same study period. Total demand for the VRDSM is optimized for yield based on supply and a 10 percent maximum shortage occurring in any one year at a given service area.

Reclamation's CRSS model uses historical hydrology to develop numerous inflow hydrology traces that are applied as simulated inflow hydrology for the years 2009 through 2060. Proposed Action runs include future demand scenarios with increasing depletions from Lake Powell from when LPP comes online in 2020 through 2037 for an 86K maximum depletion.

Chapter 3
Affected Environment

Utah's surface waters are prone to extremes of floods and droughts. Five major floods have occurred in recent history, the most recent in 2005. In addition, six multi-year statewide droughts have been recorded, the most recent from 1999-2002 (USGS 2003 and JE Fuller 2007). The following summaries of streamflows and reservoir storage reflect this variability. Figure 2-1 depicts the locations of USGS gages where streamflows are summarized.

3.1 Water Regulation

The Utah Division of Water Rights regulates water allocation and distribution. Utah abides by the prior appropriation system. The State Engineer administers Utah's water law. Surface and groundwaters in most of the study area are considered fully appropriated, meaning that there is no additional water available to be claimed for beneficial use.

3.2 Streams

Table summarizes the period of record for daily streamflows dating back to 1941. All streamflow data and stream gage photographs were obtained from the USGS NWIS database (USGS 2009) unless otherwise noted. Conditions of streams potentially affected by the LPP Project without recent daily flow records are described based on available information such as drainage area.

Table 3-1
Streamflow Periods of Record for Locations of Interest

Gage Number	Location	Period of Record (Water Years)	Drainage Area (square miles)	Mean Flow (cfs)
09403600	Kanab Creek near Kanab, UT	1979 – 2008	194	11.8
09406000	Virgin River at Virgin, UT	1941 – 1972, 1979 – 2008	956	198
09413500	Virgin River near St. George, UT	1951 – 1957, 1992 – 2008	4,123	188
09415000	Virgin River at Littlefield, AZ	1941 - 2008	5,090	241
09413000	Santa Clara at St. George, UT	1951 – 1956, 1985 – 2008	541	14.8
09380000	Colorado River at Lees Ferry, AZ	1941 – 2008	111,800	13,791
10242000	Coal Creek near Cedar City, UT	1941 - 2008	80.9	33.7
09381800	Paria River near Kanab	2002 – 2008	647	19.8

Source: 2008 water data reports, Mean Flow calculated for period of record summarized in report with exception of Colorado River which is calculated for water years 1965 – 2008 (after Glen Canyon Dam construction).

3.2.1 Colorado River

The Colorado River is an important resource for the southwest United States. It drains an area of over 244,000 square miles and passes through seven states and Mexico. Many reservoirs have been constructed in the Colorado River system to regulate the water for various uses. More than 24 million people from Salt Lake City, to Phoenix, to Denver, to San Diego rely on the river for water supply (UDWR 2002). The river is also used for agricultural irrigation, recreation, and power generation. Figure 3-1 depicts the Colorado River Basin.

Source: UDWR (2002)

Figure 3-1
Colorado River Basin

The rules pertaining to division of the flow of the Colorado River are referred to as the Law of the River. The Law of the River is comprised of compacts (e.g., Colorado River Compact), court decisions and decrees, and regulatory guidelines. The Colorado River Compact (Compact) is one of many documents constituting the Law of the River. It divides the river basin into the Upper Basin (comprised of Colorado, New Mexico, Utah and Wyoming) and the Lower Basin (comprised of Nevada, Arizona and California). The Lee Ferry[1] Compact Point divides the system into the Upper Basin and Lower Basin. In general, each basin is allocated 7.5 MAF per year. The Upper Basin states cannot deplete the flow of the river below 7.5 MAF during any period of ten consecutive years. The Law of the River allocates the State of Utah 23 percent of the Upper Basin apportionment (Reclamation 2007), which equates to 1.725 MAF of the 7.5 MAF Upper Basin allocation.

The Colorado River below Lake Powell is part of the study area because it is located downstream of the LPP intake. At this point, the Colorado River flows through a narrow part of Glen Canyon. Flows are greatly modified from natural streamflows because of the impoundment of Lake Powell behind Glen Canyon Dam, which began filling in 1963, and many other storage facilities located on the Colorado River and its tributaries upstream of Lake Powell. The Lees Ferry gage is located on the Colorado River 15.5 miles downstream of Glen Canyon Dam. Flows at Lees Ferry are primarily the result of releases made from the dam. Releases are made by Reclamation based on complicated guidelines developed to fulfill multiple purposes that are consistent with the Law of the River as briefly described below.

Releases from the Glen Canyon Dam are scheduled on an annual, monthly, and hourly basis. Annual release volumes are made according to the Long Range Operating Criteria (LROC) of Colorado River Reservoirs, which includes a minimum objective release of 8.23 MAF, storage equalization between Lake Powell and Lake Mead under prescribed conditions, and the avoidance of spills. Annual releases greater than the minimum can be made for a variety of reasons based on operation requirements (Reclamation 2007).

Each spring, the Secretary of the Interior declares the Colorado River water supply availability for the Lower Basin States in terms of Normal, Surplus, or Shortage. This declaration affects the operation of Lake Powell for the following year. Operating guidelines for the Normal and Surplus conditions have long been established. Interim Guidelines for Shortage conditions were established in 2007. The Interim Guidelines will be in effect for operating decisions through 2026. These guidelines direct the Annual Operating Plan, which determines the water supply available to the Lower Basin water users and annual releases from Lake Powell. The four operational tiers for Lake Powell and Lake Mead and releases from Lake Powell are as follows (Reclamation 2008):

- Equalization Tier – greater than 9.5 MAF
- Upper Level Balancing Tier – between 7.48 and 9.5 MAF
- Mid-Elevation Tier – 7.48 MAF
- Lower Elevation Balancing Tier - between 7.48 and 9.5 MAF

Shorter-term Glen Canyon Dam release constraints are currently based on the 1996 Glen Canyon ROD, which was developed consistent with the Grand Canyon Protection Act of 1992 (Reclamation 2007). These constraints are summarized in Table 3-1. .

[1] The spelling of the gage location and compact point is different

Table 3-2
Glen Canyon Dam Release Constraints

Parameter	Release (cfs)	Conditions
Maximum Flow [1]	25,000	
Minimum Flow	5,000	Nighttime
	8,000	7 am to 7 pm
Ascending Ramp Rate	4,000	Per hour
Descending	1,500	Per hour
Daily fluctuations [2]	5,000 to 8,000	

Notes:
[1] Non-emergency, non-extreme hydrological conditions
[2] Daily fluctuation limit is 5,000 cfs for months with release volumes less than 0.6 maf; 6,000 cfs for monthly release volumes of 0.6 MAF to 0.8 maf; and 8,000 cfs for monthly volumes over 0.8 maf.
Source: Reclamation (2007)

Figure 3-2 summarizes daily streamflow for the Colorado River at Lees Ferry gage. This gage is located upstream of the Lee Ferry Compact Point with a tributary, Paria River, entering the Colorado River in between (Figure 3-3). The hydrograph of the Colorado River changed drastically after Lake Powell began to fill. Glen Canyon Dam operation has reduced peak flows, increased minimum flows, and increased the diurnal range in discharge because of hydropower operations. Figure 3-4 shows the daily mean and daily range of flows over the calendar year since 1970.

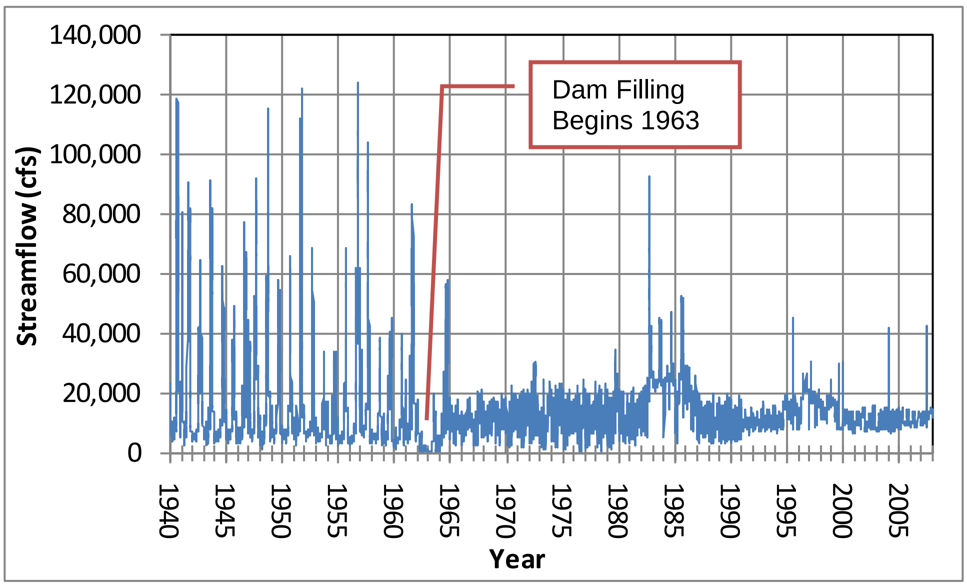
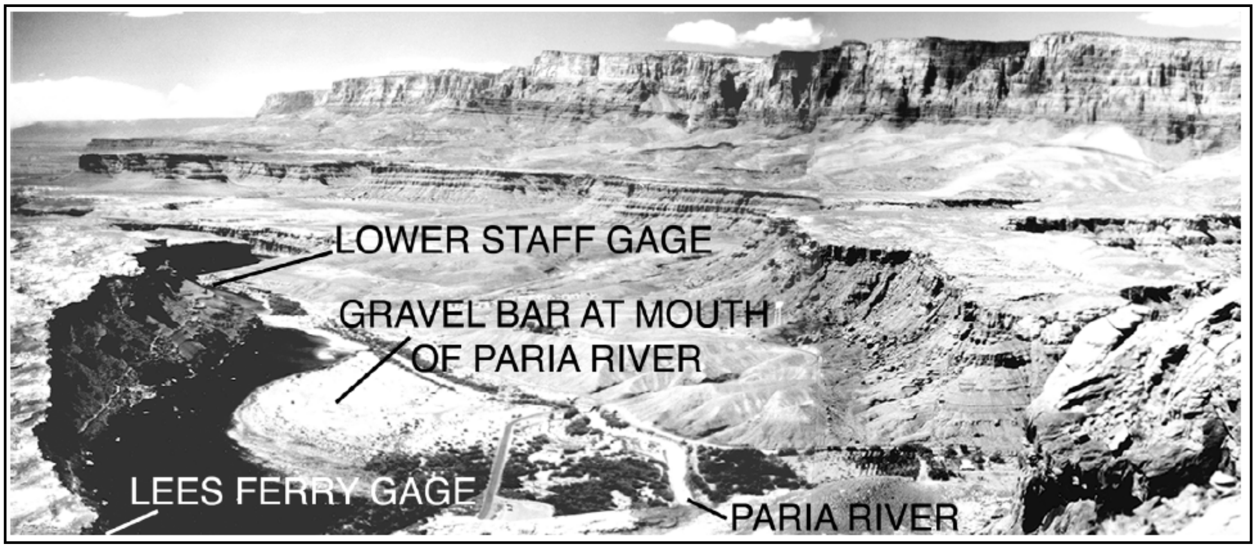


Figure 3-2
Colorado River at Lees Ferry Daily Flows



Source: Topping et al (2003)

Figure 3-3
Colorado River at Lees Ferry Facing Downstream (1995), Flow of 9,500 cfs

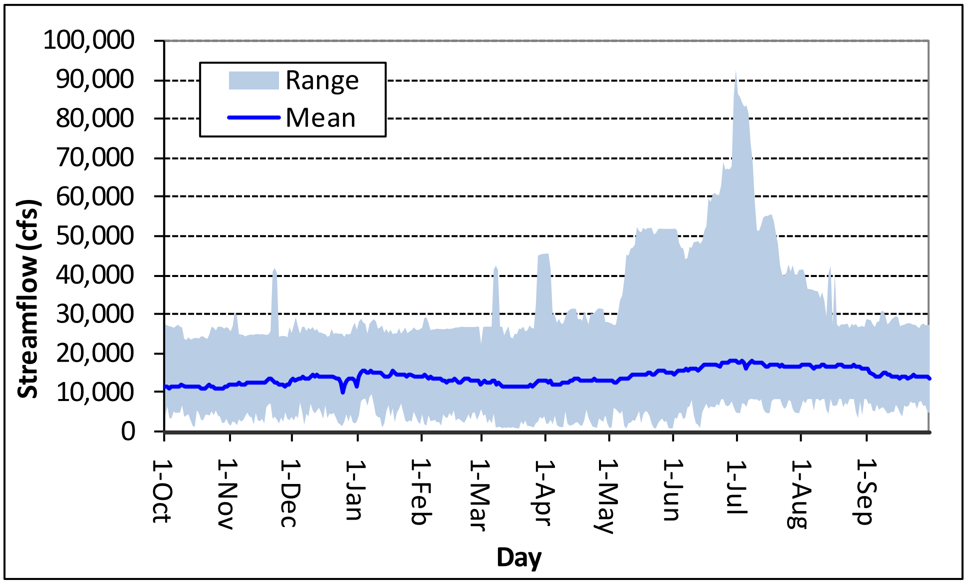


Figure 3-4
Colorado River at Lees Ferry Daily Mean and Range of Flow (1970-2008)

Figure 3-5 summarizes annual mean water year flows. Since 1968, the annual mean has equaled or exceeded 11,000 cfs. Figure 3-6 depicts the flow exceedance curve, limited to 1970 to 2008 to capture flows after the filling of Lake Powell. The curve shows a median flow of the Colorado River at Lees Ferry of about 13,000 cfs for this period.

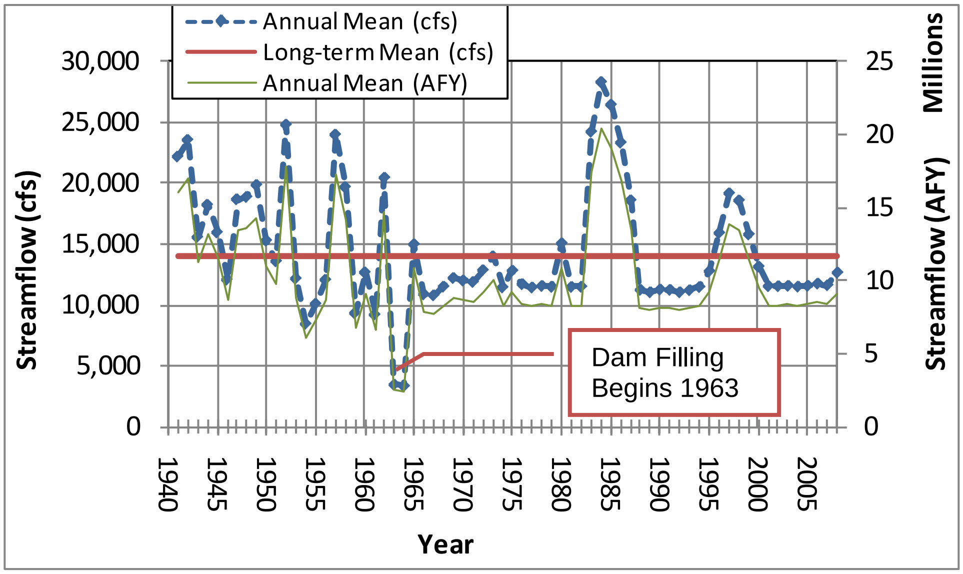


Figure 3-5
Colorado River at Lees Ferry Annual Mean Flows

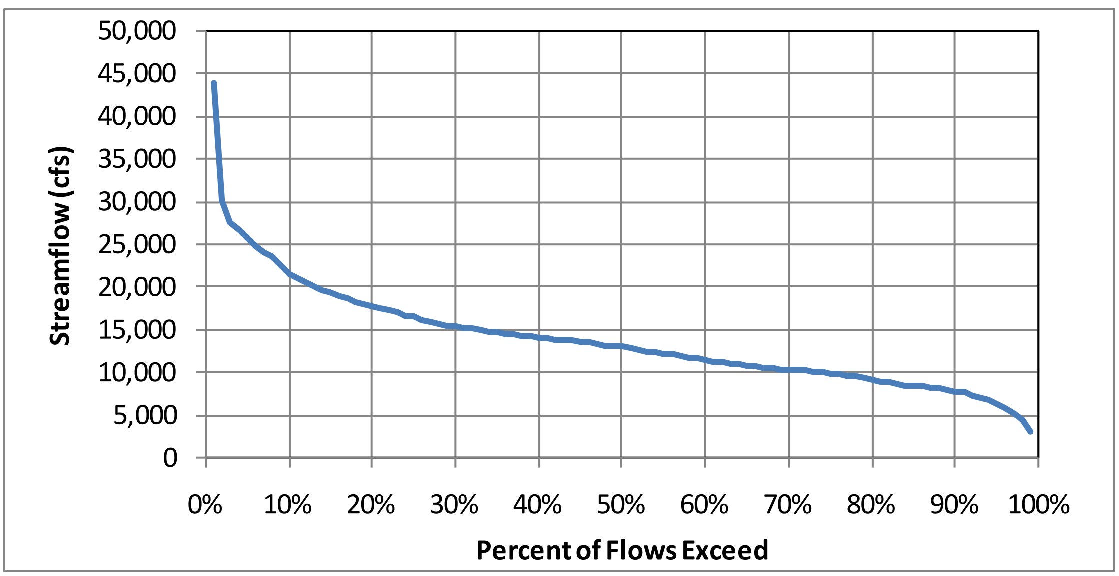


Figure 3-6
Colorado River at Lees Ferry Flow Exceedance (1970 – 2008)

Flows in the Colorado River at Lees Ferry can vary considerably from year to year. Figure 3-7 and Figure 3-8 depict historical flows for a year with the minimum flow, 2004, and a year with higher flows, 1998. Depending on the month, Surplus years can result in sustained flows more than 10,000 cfs higher than flows occurring under Shortage or Normal conditions. Figure 3-9 depicts the stage-discharge rating curve for the Colorado River at Lees Ferry gage.

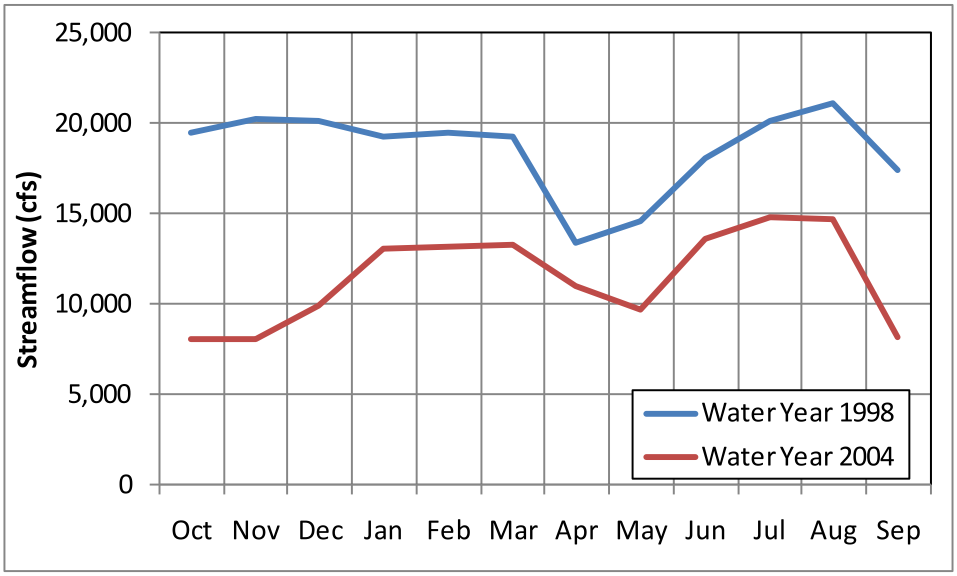


Figure 3-7
Colorado River at Lees Ferry Monthly Mean Flows (Wet and Dry Year)

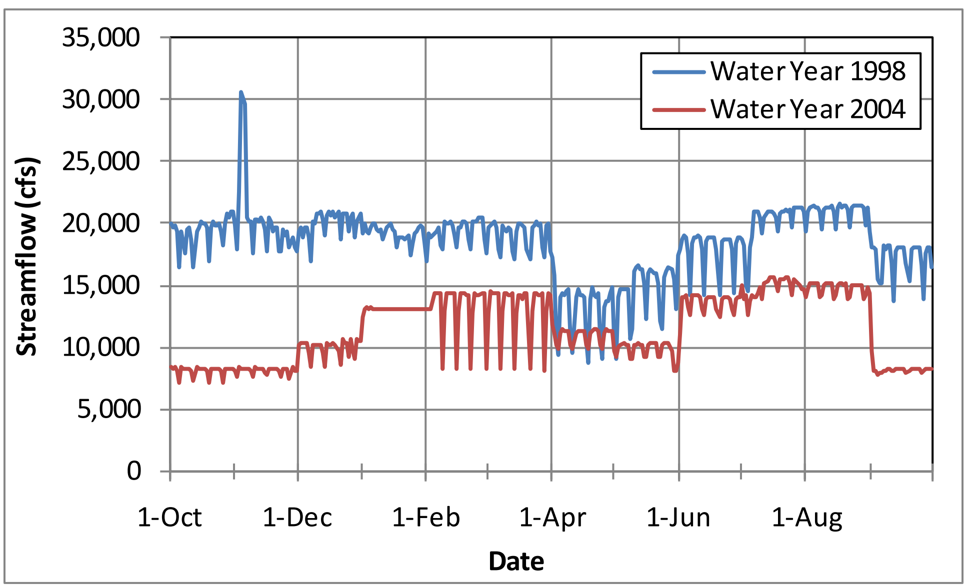


Figure 3-8
Colorado River at Lees Ferry Daily Flows (Wet and Dry Year)

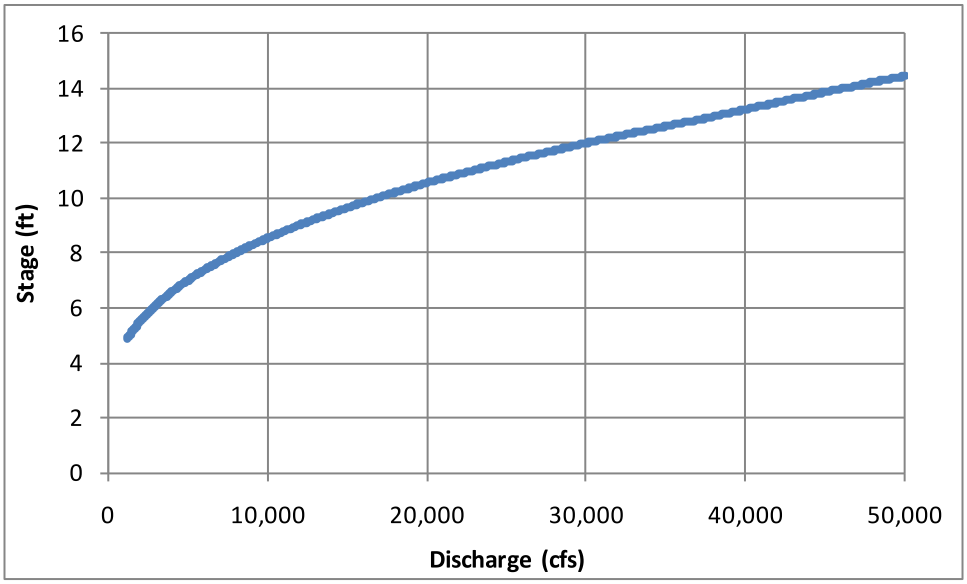
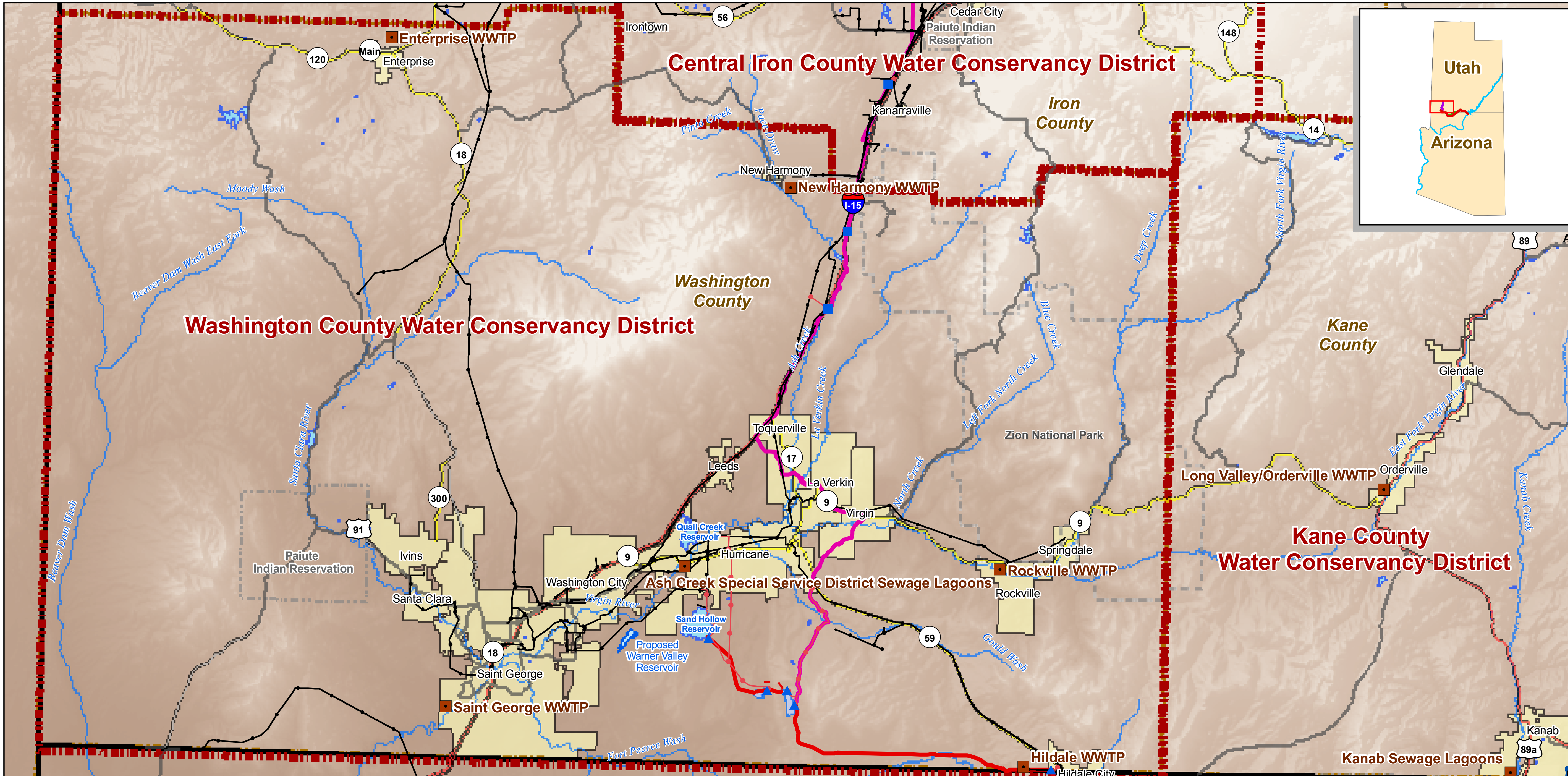


Figure 3-9
Colorado River at Lees Ferry – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.2 Virgin River Drainages

The Virgin River lies within the lower Colorado River basin. The Virgin River basin is bound by mountains with elevations reaching over 10,000 feet with the Bull Valley and Beaver Dam mountains to the west, the Harmony Mountains to the north, the Glendale Bench and Block Mesas to the east. The lowest elevation is about 2,500 feet where the Virgin River crosses the state line with Arizona. Most Virgin River streamflow originates as snow with runoff resulting in high flows from March through May. The greatest water producing area is the headwaters of the North Fork of the Virgin River (UDWR 1993). In the Virgin River Watershed in Utah, most of the public water supply is provided through the WCWCD. Figure 3-10 depicts the WCWCD service area along with the cities and surface water features.
Figure 3-11 is a schematic of the Virgin River basin in Utah. The map is valid through 1990 and there have been some changes in river operation in that time including the construction of Sand Hollow and Quail Creek reservoirs. Therefore, the volumes shown in the figure, particularly downstream of the diversion to the reservoirs, do not necessarily represent current conditions. However, it provides a general idea of the magnitude of streamflow in the Virgin River system.



Project Pump Station
Project Regulating Tank
Project Hydro Station
Project Transmission Line
Existing Transmission Line
Water Conveyance System
Hydro System - South Alignment Alternative
Hydro System - Highway Alignment Alternative
Kane County Pipeline System
Cedar Valley Pipeline System
Interstate
US Highway
ST Highway
Hwy
Major Road
Water Conservancy Districts
State Boundaries
Hurricane Cliffs Forebay/Afterbay
Lakes/Reservoirs
Major Rivers & Streams
National Park/Monument
Tribal Lands
County Boundaries
Cities
Wastewater Treatment Plants

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

0 2 4 8 12 Miles

N

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 3-10** MWH

Washington County Water Conservancy District

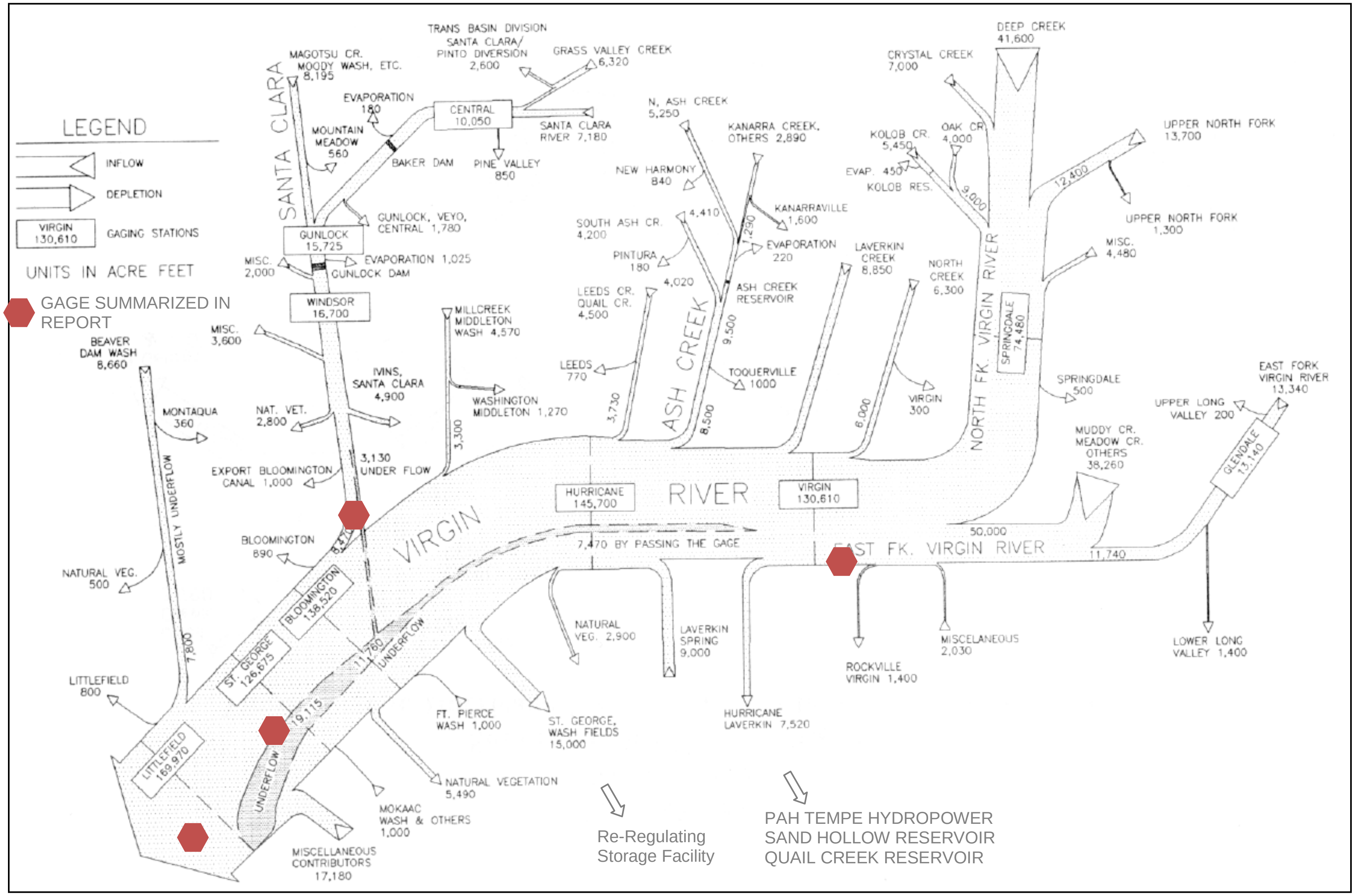


Figure 3-11
Virgin River System in Utah – Streamflow and Depletion Chart (1941-1990)

Source: Modified From UDWR (1993), flow numbers do not represent current conditions

Figure 3-12 is a schematic of the current Virgin River inflows and diversions between the Quail Creek Diversion and the Washington Fields Diversion. There is an instream flow requirement set by the US Fish and Wildlife Service as a stipulation of the Quail Creek Project for protection of endangered species. The requirement is based on the Washington Fields diversion water right of 86 cfs, and requires that this amount of water, or the natural flow of the river if less than 86 cfs, be available in the stream at the diversion point. WCWCD can divert a substantial amount of water without violating the instream flow requirement because of the various tributaries and return flows that occur between the Quail Creek diversion point and the Washington Fields diversion. A minimum flow of 3 cfs is maintained downstream of the Quail Creek diversion point.

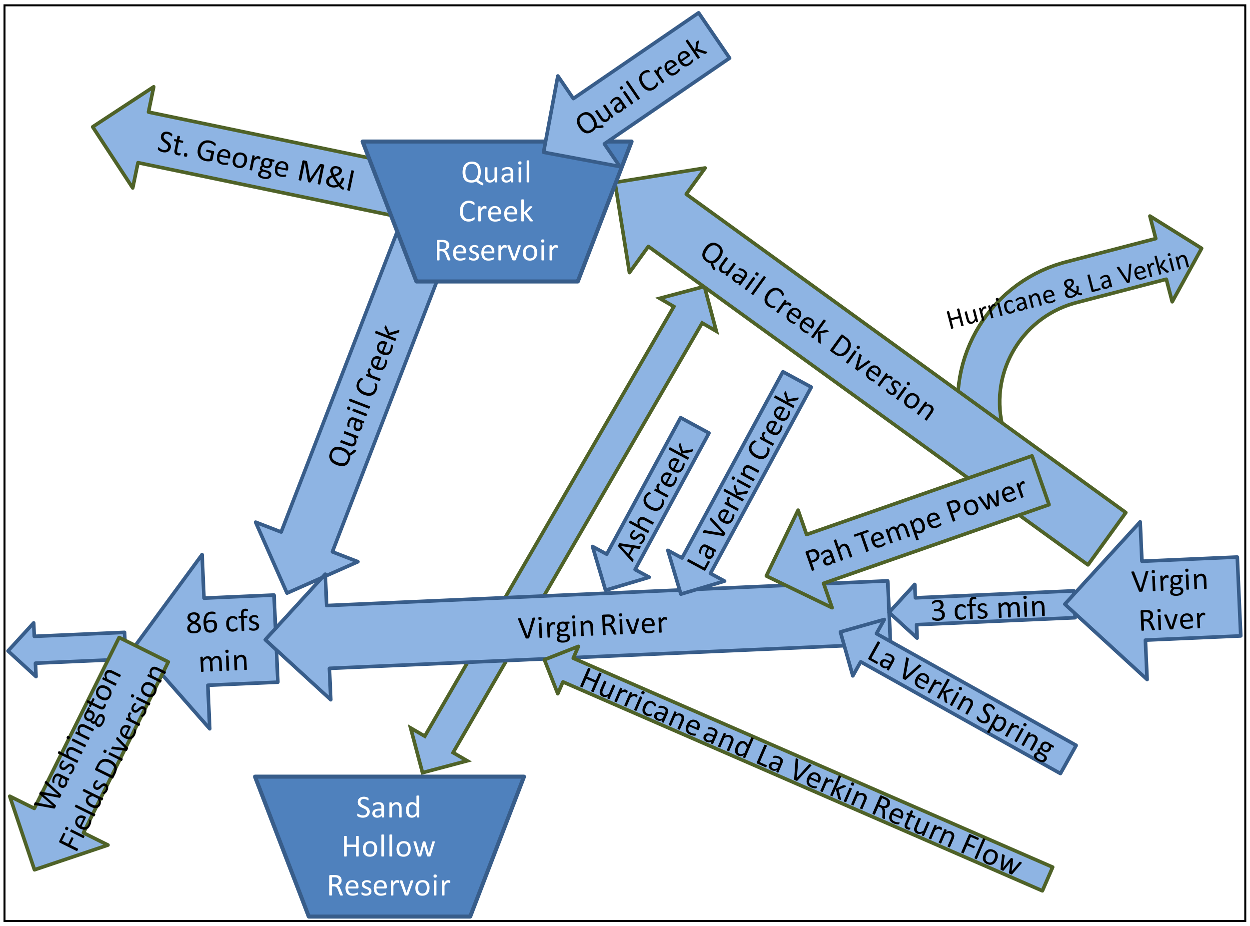


Figure 3-12
Schematic of Quail Creek Diversion to Washington Fields Diversion With Instream Flows

Historical streamflows are summarized at the following locations in the Virgin River Basin:

- Virgin River at Virgin, UT
- Virgin River at St. George, UT
- Virgin River at Littlefield, AZ
- Santa Clara River at St. George

Figure 3-13 demonstrates the Virgin River is typically a gaining stream from Virgin, UT to Littlefield, AZ in fall and early winter months. From January through August, flows decrease through St. George and increase again downstream of the state line.

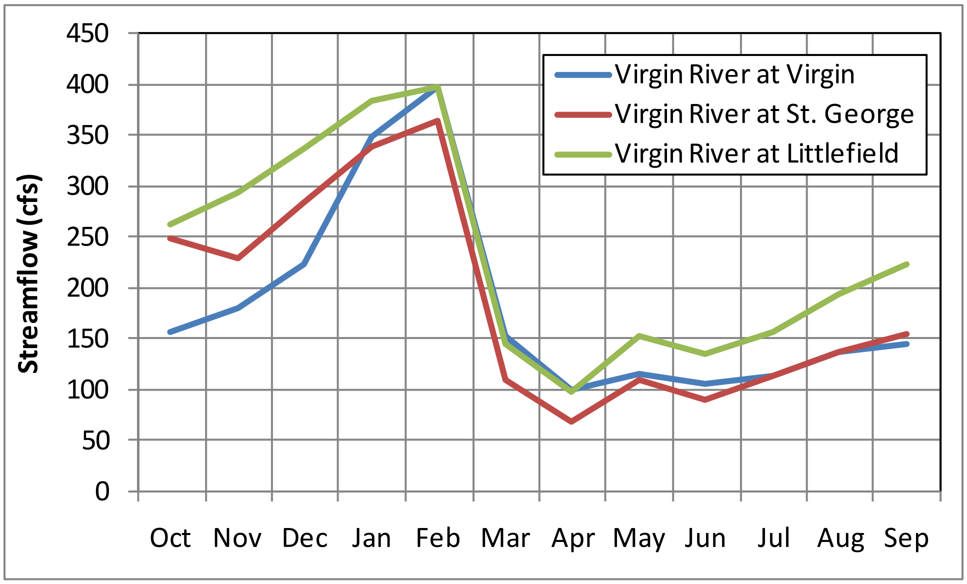


Figure 3-13
Monthly Streamflows in the Virgin River from Virgin, UT to Littlefield, AZ

The Virgin River has an instream flow requirement tied to the operation of Quail Creek Reservoir. It requires the lesser of 86 cfs or the natural flow in the river between the Quail Creek Reservoir Diversion and the Washington Fields Diversion (UDWR 1993).

3.2.2.1 Virgin River at Virgin, UT

This gage location is upstream of any major diversions and upstream of areas that would receive LPP water. Therefore, it is upstream from the potential impacts of return flows under the Proposed Action. Figure 3-14 depicts the historical daily flows for the Virgin River. Figure 3-15 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-16 shows the flow exceedance curve for the gage. The 90 percent exceedance value is 68 cfs (i.e. 90 percent of flows exceed 68 cfs), while the 10 percent exceedance value is 320 cfs. The median flow, which corresponds to the 50 percent exceedance level, is 122 cfs.

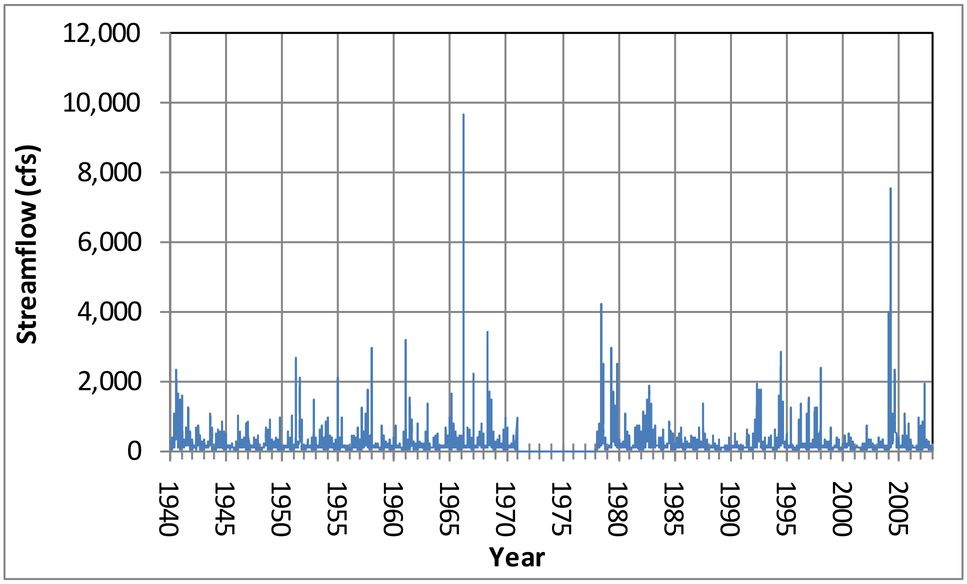


Figure 3-14
Virgin River at Virgin, Daily Flows

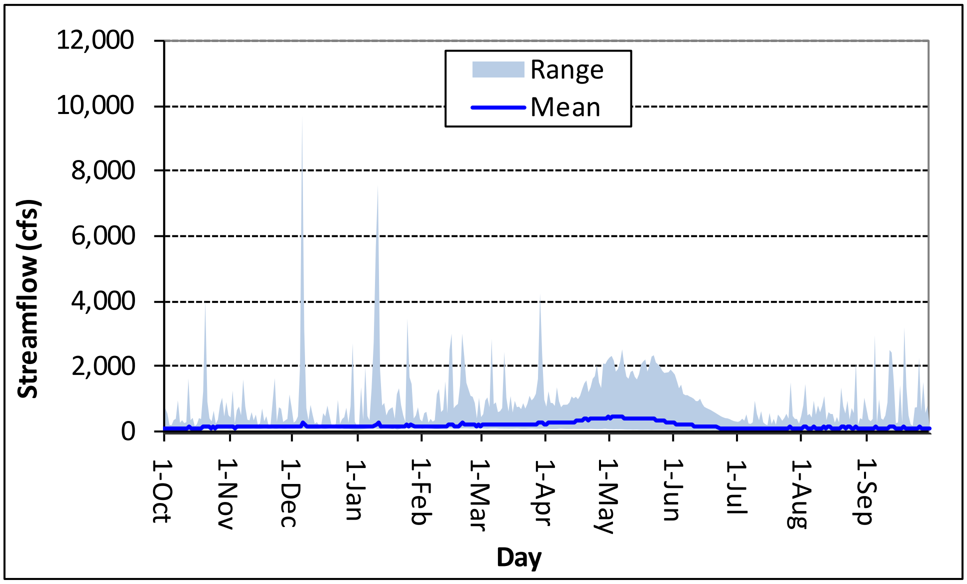


Figure 3-15
Virgin River at Virgin, Daily Mean and Range of Flow

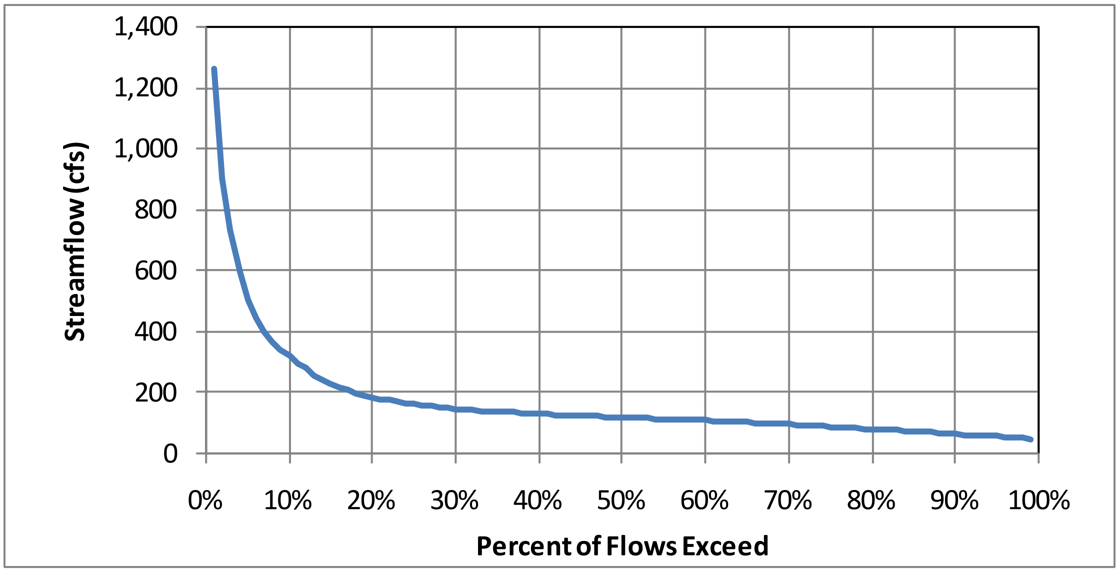


Figure 3-16
Virgin River at Virgin, Daily Flow Exceedance

Figure 3-17 shows monthly mean flows for the Virgin River. The flows show a distinct seasonal pattern with peak flows in May. Figure 3-18 shows the variation in streamflow from year to year. The long term mean annual streamflow is 182 cfs. Annual streamflow is usually greater than 100 cfs and in high flow years can exceed 300 to 400 cfs. Figure 3-19 shows the stage discharge rating curve for the Virgin River at Virgin.

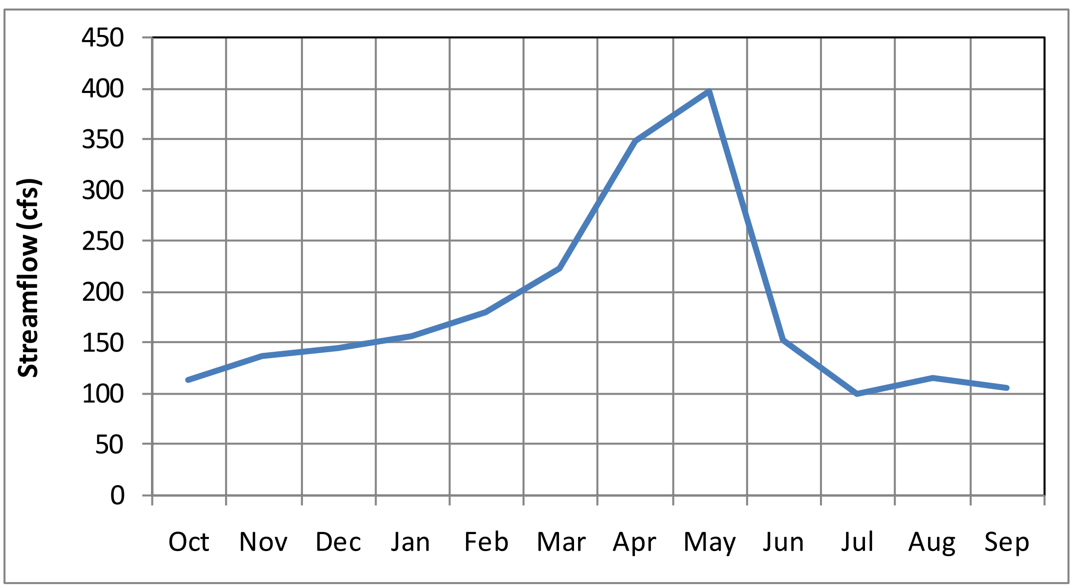


Figure 3-17
Virgin River at Virgin, Monthly Mean Flows

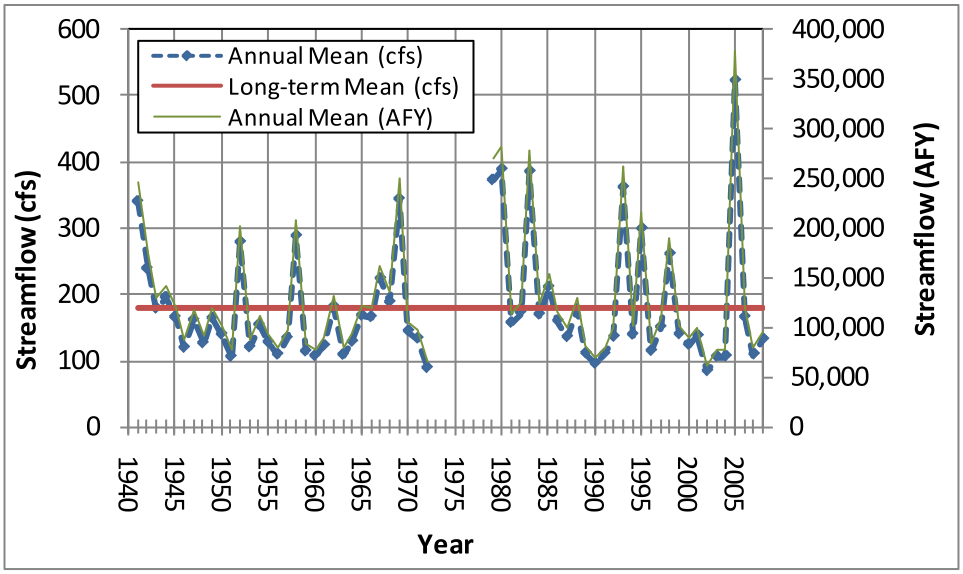


Figure 3-18
Virgin River at Virgin, Annual Mean Flows

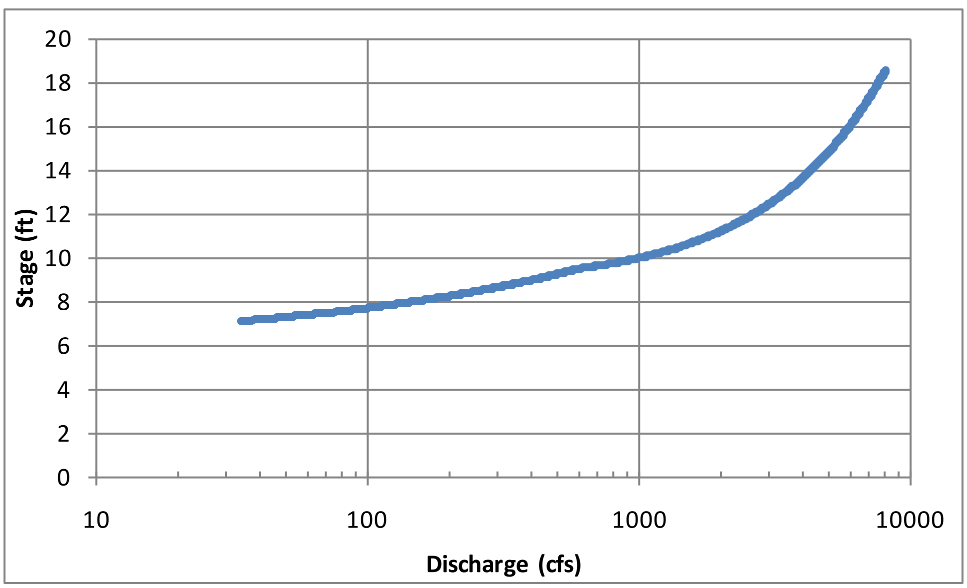


Figure 3-19
Virgin River at Virgin – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.2.2 Virgin River Near St. George, UT

The St. George gage is located downstream of town where the Virgin River enters a canyon section. Figure 3-20 is a USGS photograph of the gage location. There are several major inflows and diversions from the Virgin River between the Virgin and St. George gages including:

- Diversion to Quail Creek Reservoir, Hurricane and LaVerkin
- Diversion to St. George, Washington Fields
- Inflow from Santa Clara River, Ash Creek, LaVerkin Creek, LaVerkin Spring
- Return flows from Quail Creek Reservoir
- Return flows from St. George wastewater treatment facility

Figure 3-20
Virgin River Near St. George Gage Location

As shown in the daily streamflow chart in Figure 3-21, the period of record for this gage is relatively short. Figure 3-22 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-23 shows the flow exceedance curve for the Virgin River for the period of 1992 through 2008. The 90 percent exceedance value is 26 cfs, while the 10 percent exceedance value is 460 cfs. The median flow is 110 cfs.

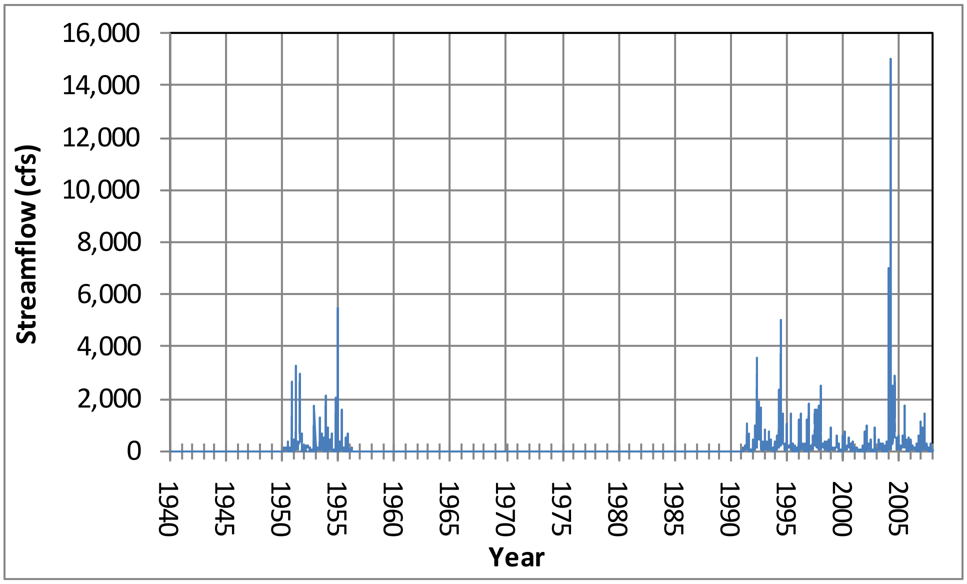


Figure 3-21
Virgin River Near St. George, Daily Flows

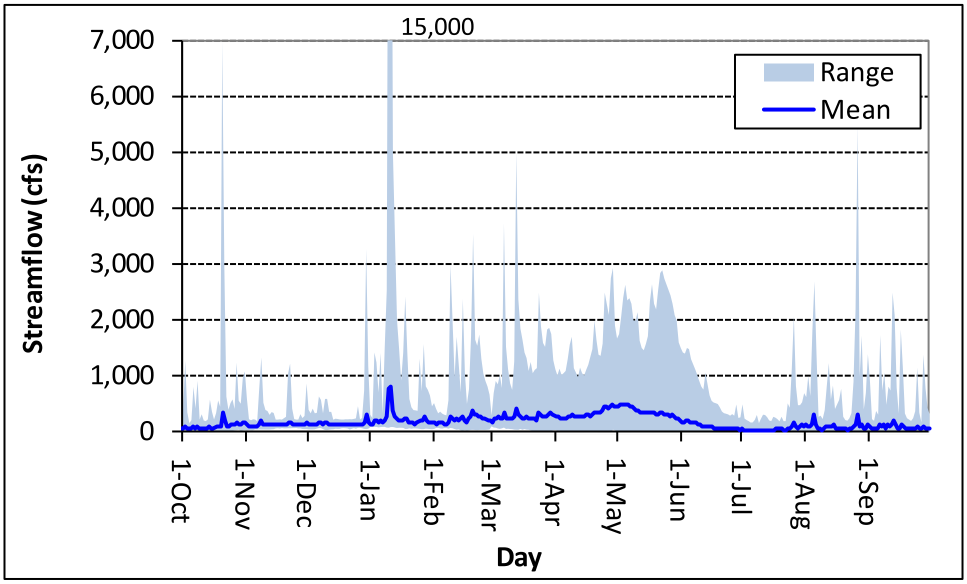


Figure 3-22
Virgin River Near St. George, Daily Mean and Range of Flow

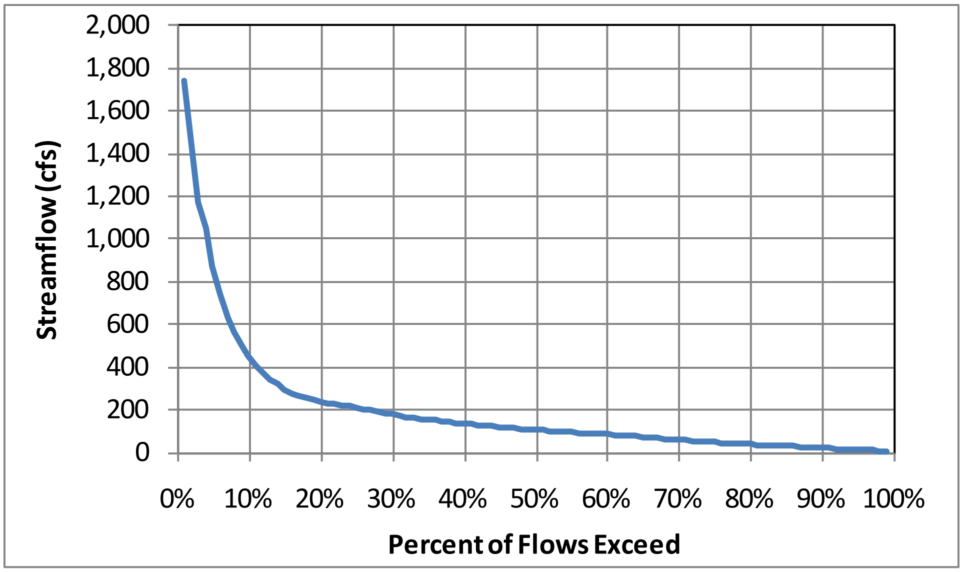


Figure 3-23
Virgin River Near St. George Flow Exceedance (1992 – 2006)

Figure 3-24 depicts monthly mean flows for the Virgin River for the period of 1992 through 2006. Compared to the upstream location, peak seasonal flows occur in late spring with low flows in summer. Figure 3-25 shows the historical annual mean flows in the Virgin River. The long term annual mean was not calculated due to the short period of record. Figure 3-26 depicts the stage-discharge curve for the gage.

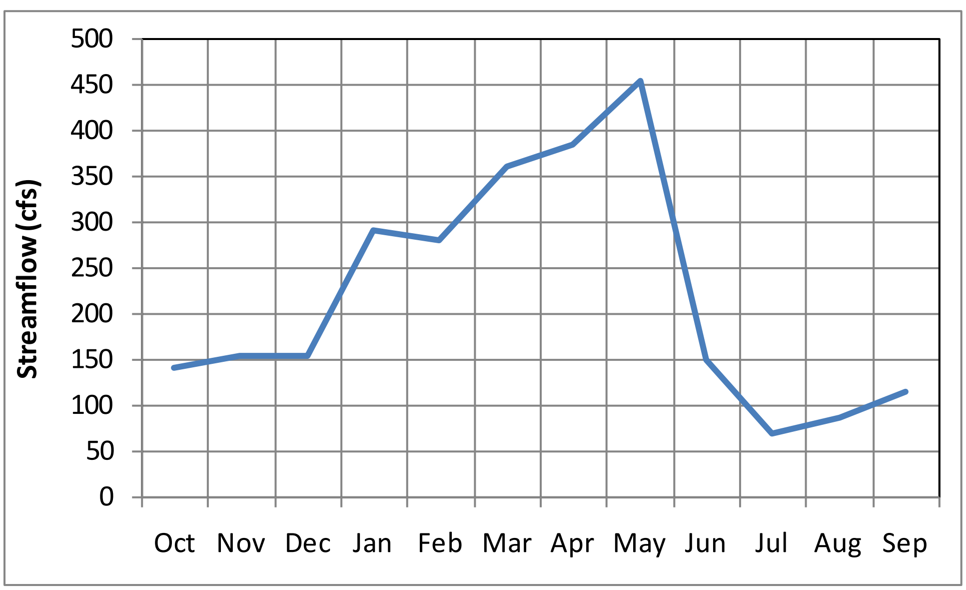


Figure 3-24
Virgin River Near St. George Monthly Mean Flows (1992 – 2006)

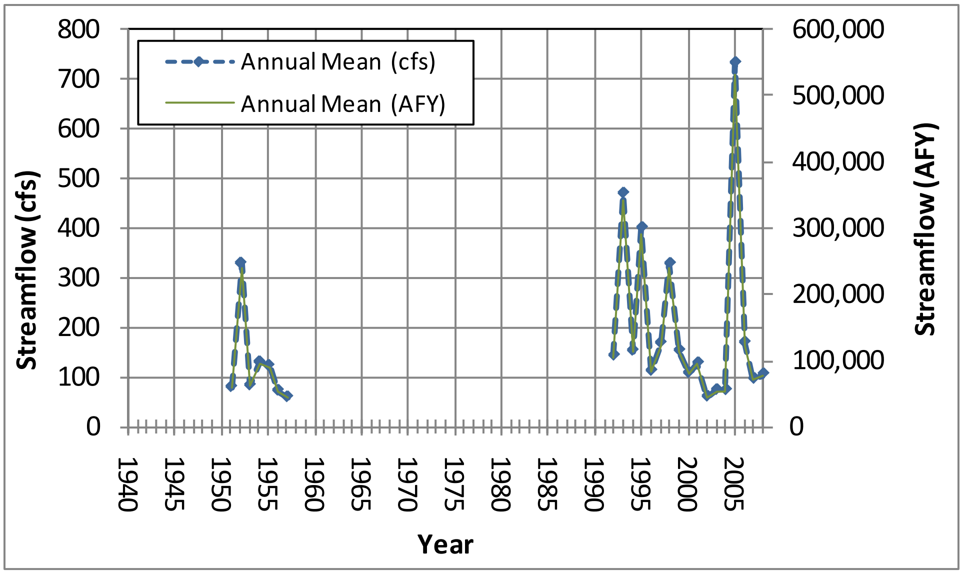


Figure 3-26
Virgin River Near St. George Annual Mean Flows

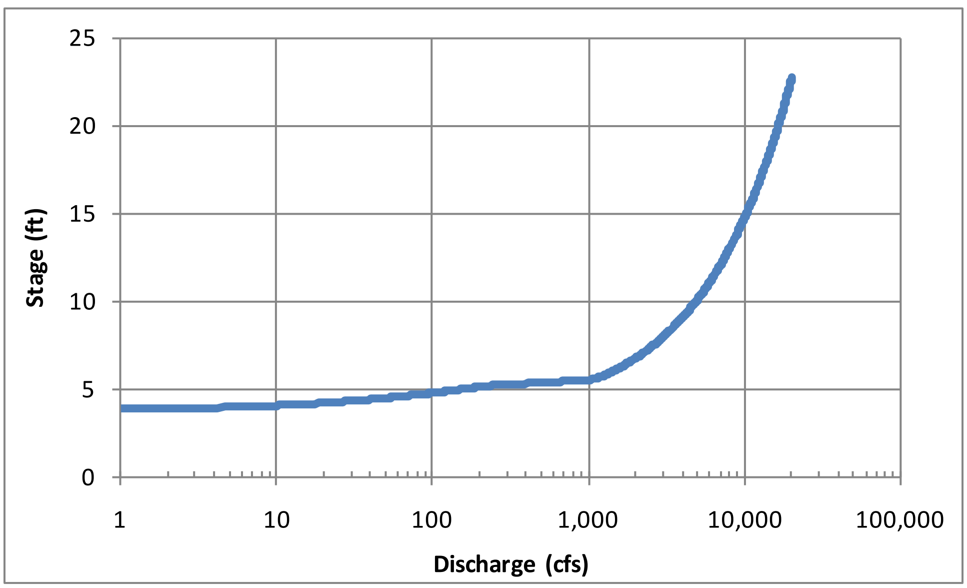


Figure 3-26
Virgin River Near St. George – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.2.3 Virgin River at Littlefield, AZ

The Virgin River at Littlefield, Arizona gage is located a few miles downstream of the state line. Figure 3-27 depicts historical daily flows. Figure 3-28 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-29 shows the flow exceedance curve. The 90 percent exceedance value is 62 cfs, while the 10 percent exceedance value is 401 cfs. The median flow is 145 cfs.

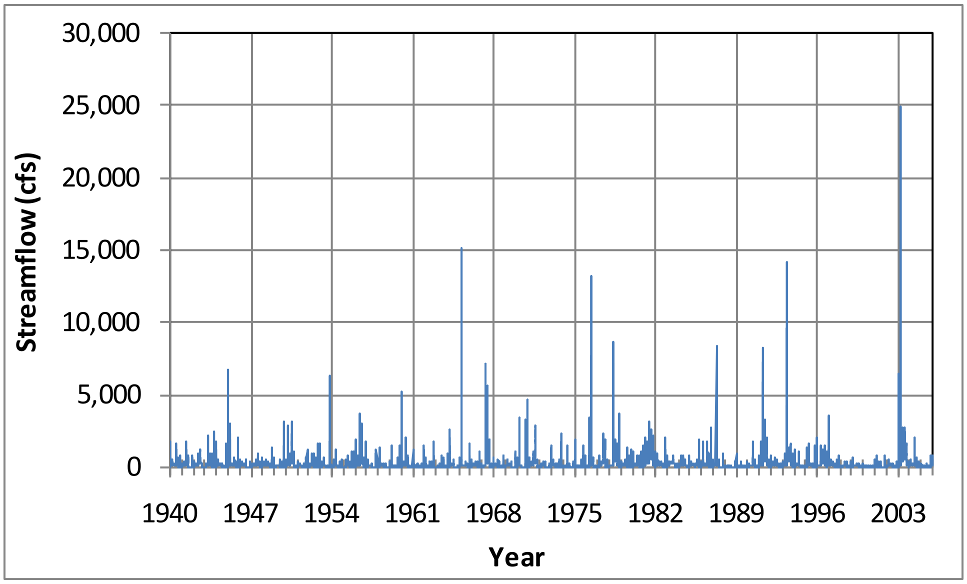


Figure 3-27
Virgin River at Littlefield, Daily Flows

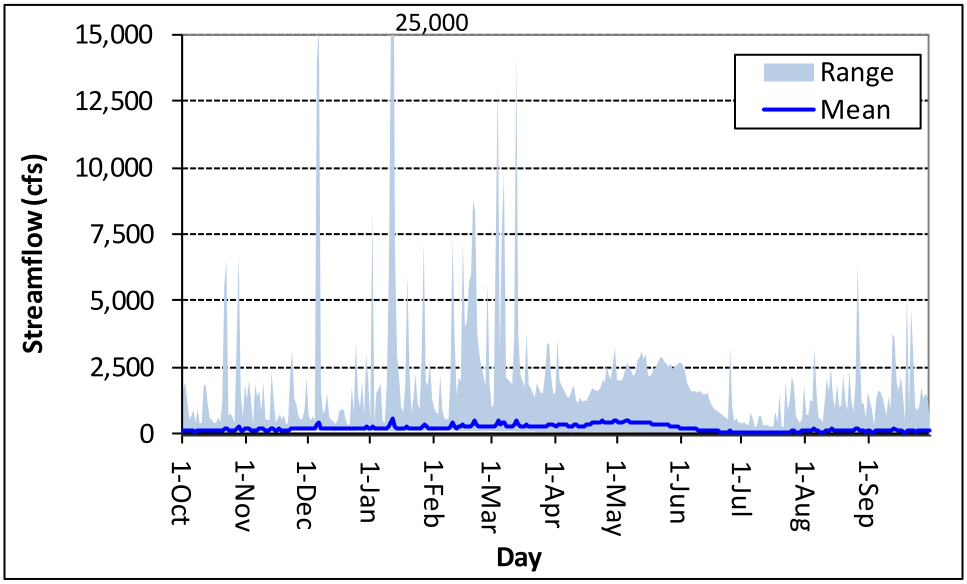


Figure 3-28
Virgin River at Littlefield, Daily Mean and Range of Flow

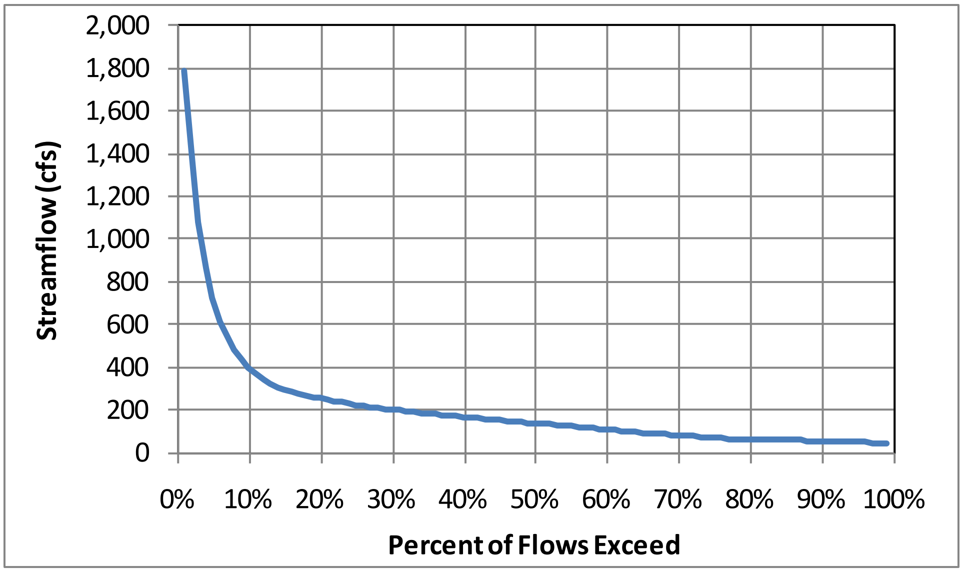


Figure 3-29
Virgin River at Littlefield, Flow Exceedance

Figure 3-30 shows monthly average flows for the Virgin River at Littlefield. Similar to the upstream locations, peak flows occur in late summer with low flows in the fall. Figure 3-31 depicts the historical annual mean flows. The long term mean is 235 cfs. Figure 3-32 depicts the stage-discharge curve for the gage.

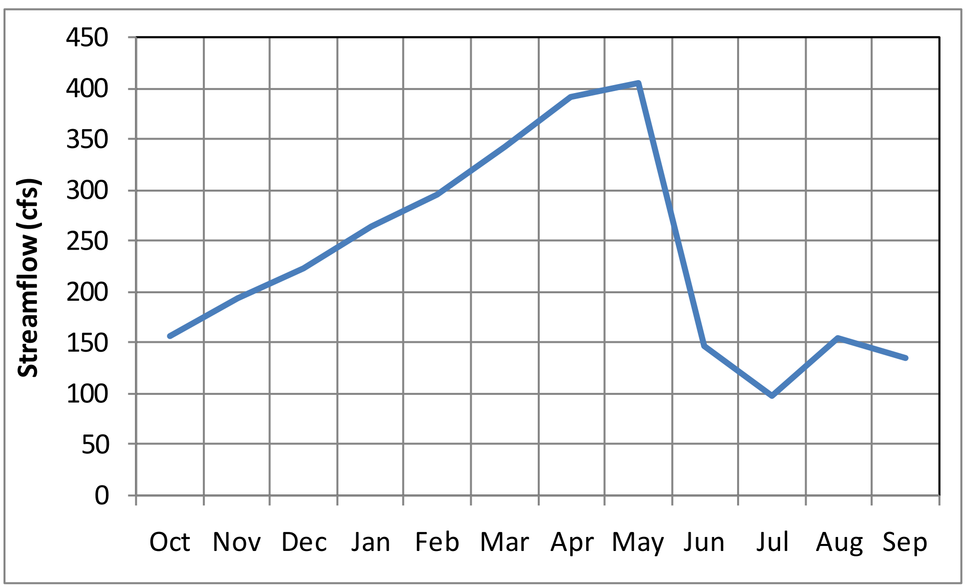


Figure 3-30
Virgin River at Littlefield, Monthly Mean Flows

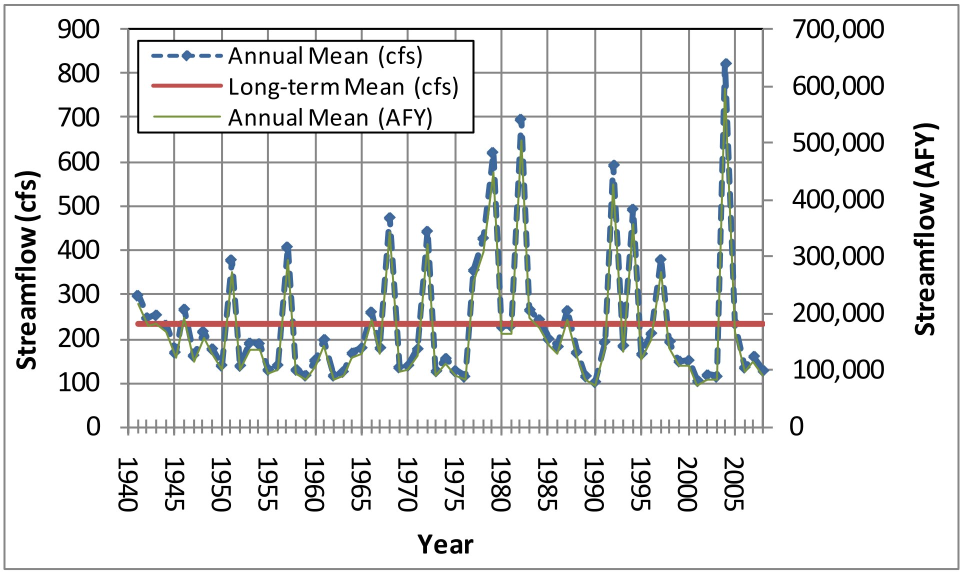


Figure 3-31
Virgin River at Littlefield, Annual Mean Flows

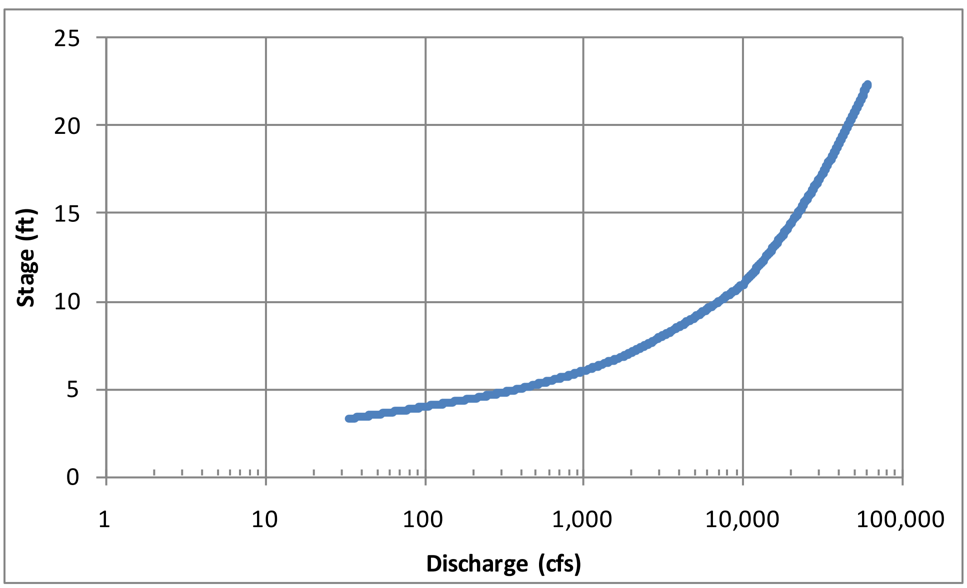


Figure 3-32
Virgin River at Littlefield – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.2.4 Santa Clara River at St. George

The Santa Clara River originates in the Pine Valley Mountain Wilderness north of St. George. This perennial stream flows though several communities including Ivins and Santa Clara before its confluence with the Virgin River south of St. George. The Santa Clara River at St. George gage is located about a mile upstream of the confluence with the Virgin River. The flow of the Santa Clara River is regulated by upstream reservoir and irrigation diversions. Flows in the Santa Clara River potentially could be affected by LPP return flows. Figure 3-33 shows the daily historical flows in the Santa Clara River. There is a gap in the streamflow record between 1956 and 1985. Figure 3-34 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-35 shows the flow exceedance curve. The 90 percent exceedance value is 1 cfs, while the 10 percent exceedance value is 27 cfs. The median flow is 4 cfs.

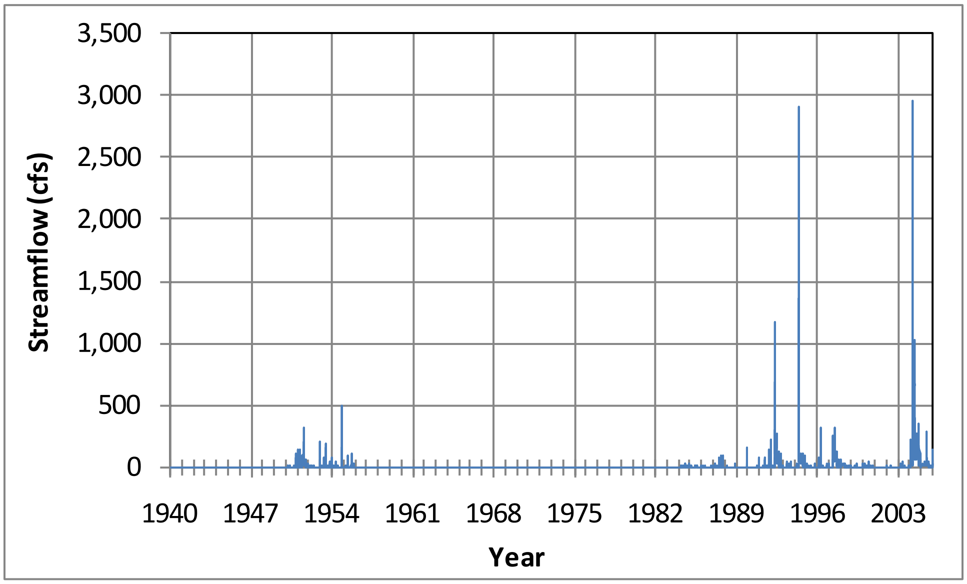


Figure 3-33
Santa Clara River at St. George Daily Flows

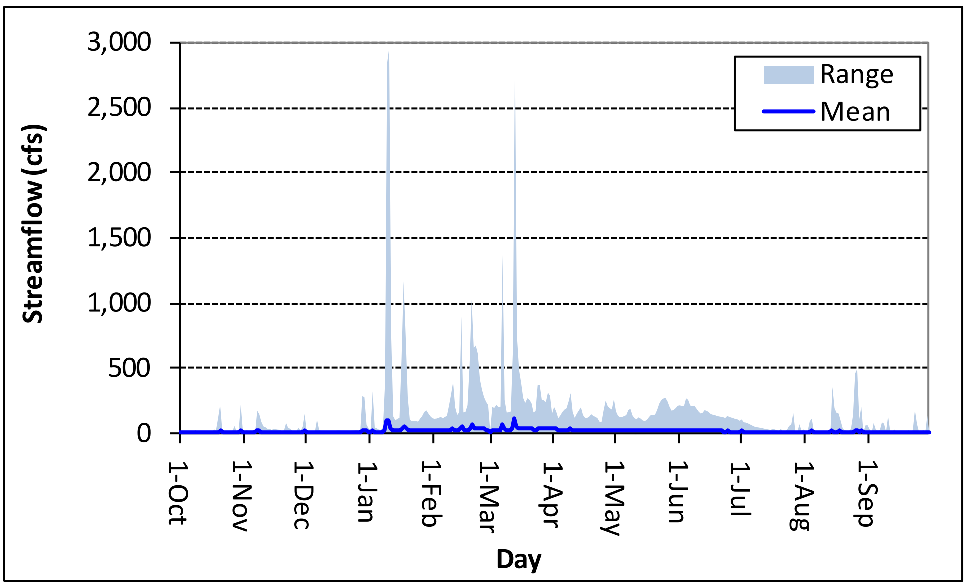


Figure 3-34
Santa Clara River at St. George Daily Mean and Range of Flow

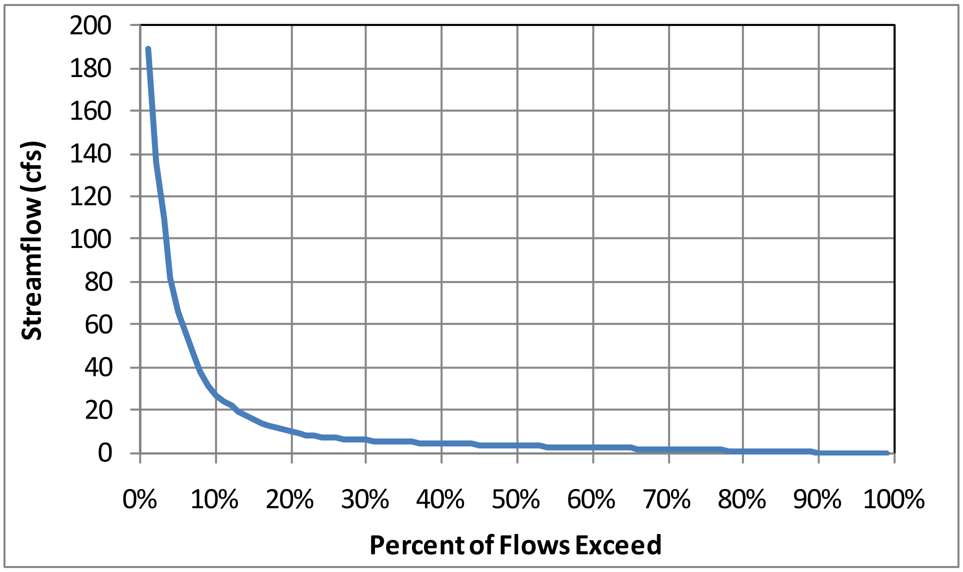


Figure 3-35
Santa Clara River at St. George Flow Exceedance

Figure 3-36 shows monthly mean flows for the Santa Clara River. Peak flows occur in spring with low flows occurring in late summer into fall. Figure 3-37 shows the historical annual mean streamflow; the long-term mean is not depicted due to the relatively short period of record. Figure 3-38 depicts the stage-discharge curve for the gage.

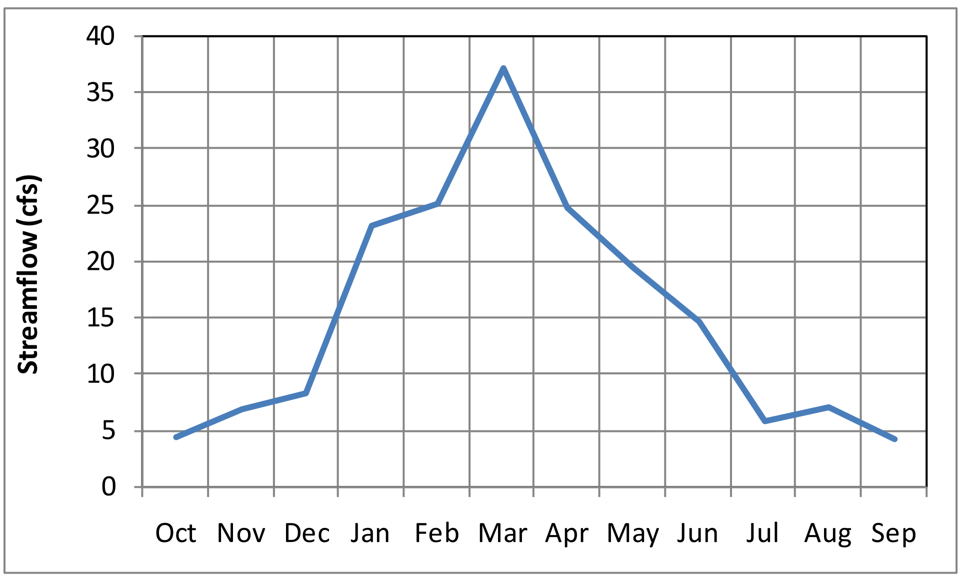


Figure 3-36
Santa Clara River at St. George Monthly Mean Flows

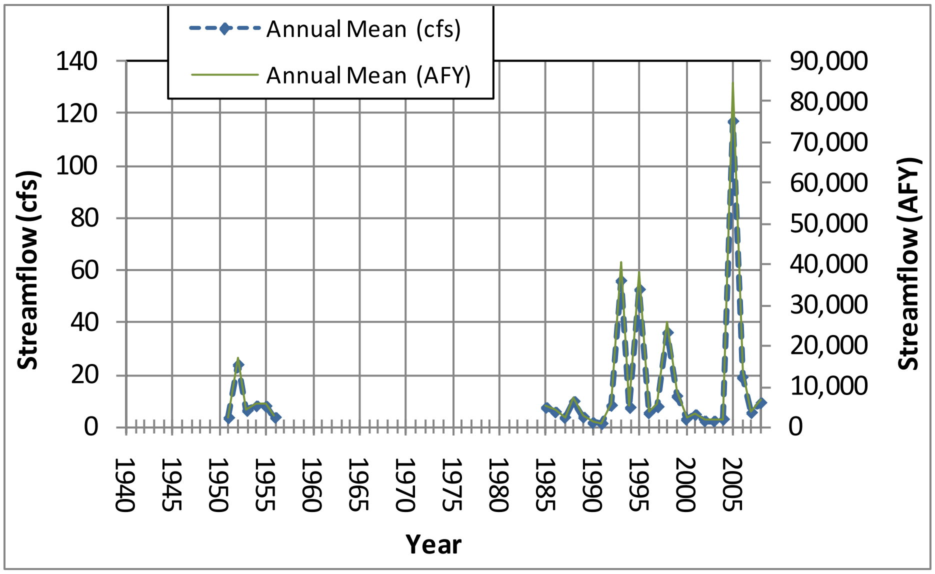


Figure 3-37
Santa Clara River at St. George Annual Mean Flows

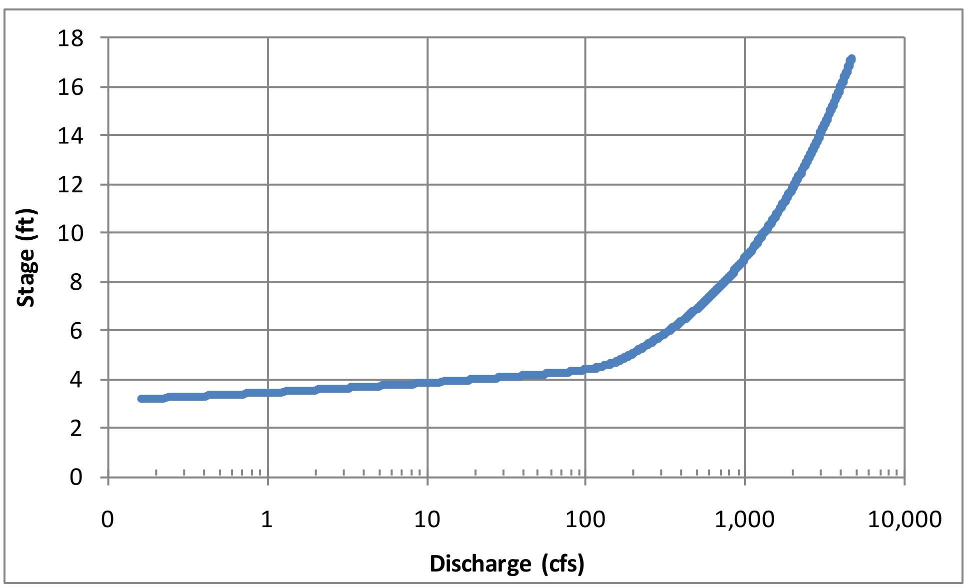


Figure 3-38
Santa Clara River at St. George – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.2.5 Ash Creek

The Ash Creek drainage originates in the Harmony Mountains west of the Cedar Valley and Kannara Creek east of the Cedar Valley. Ash Creek drains to the south along Interstate 15 and joins with the Virgin River near LaVerkin. Ash Creek does not have an active USGS stream gage. It has a drainage area of more than 200 square miles. There are several diversions from Ash Creek and its tributaries as well as an on-channel reservoir (Figure 3-10). Ash Creek is considered a perennial stream, although some reaches are dry except during extreme runoff events. The annual flow at the confluence with the Virgin River was estimated at 8,500 AFY for the period 1941 through 1990 (UDWR 1993).

3.2.2.6 LaVerkin Creek

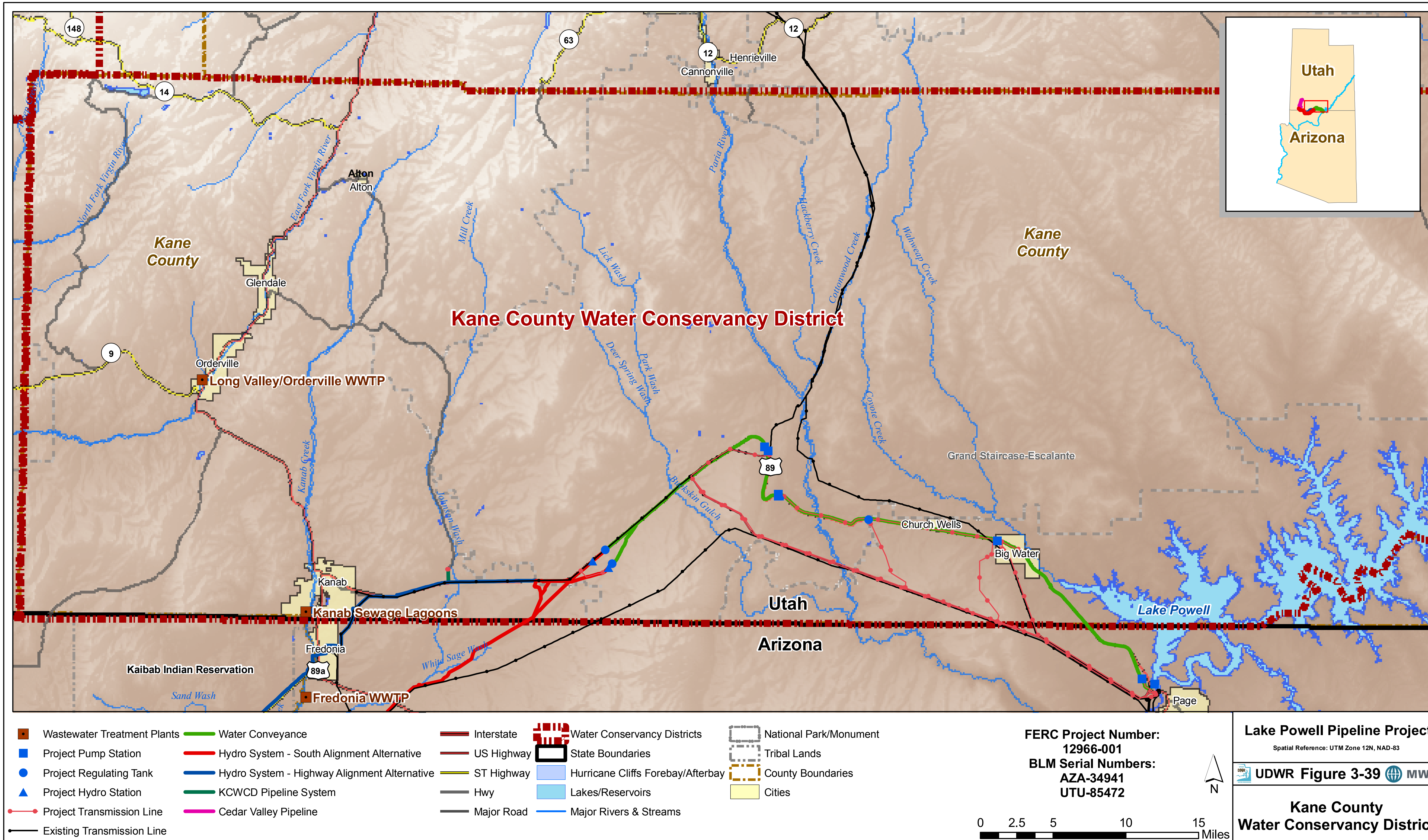
LaVerkin Creek has its headwaters at an elevation of over 9,000 feet on the Kolob Terrace. LaVerkin Creek flows through Zion National Park and east of the Hurricane Cliffs before joining with the Virgin River near LaVerkin. LaVerkin Creek does not have an active USGS stream gage. It has a drainage area of about 90 square miles, has no major diversions and an estimated annual flow for the years 1941 through 1990 of 8,850 AFY (UDWR 1993). Gage data collected between 1985 and 1991 showed mean monthly flows ranging from 2.6 cfs in July to 19 cfs in April.

3.2.2.7 Other Potentially Affected Streams

Gould Wash and Fort Pierce Wash could both be affected by non-sewered return flows. Neither stream has an active stream gage within the study area.

3.2.3 Kane, Mohave and Coconino County Drainages

Figure 3-39 shows the KCWCD service area and project facilities within the area. The additional water supply to KCWCD could potentially affect return flows in Kanab Creek in Utah and in Arizona. In addition, the pipeline would cross several washes in Kane, Mohave, and Coconino counties with the crossing locations dependent on which alignment is selected. With the exception of Kanab Creek and the Paria River, all of the crossings would be of intermittent streams, as listed in Table 2-1.



Kane County Water Conservancy District
Kane County
Kane County
Utah
Arizona
Henrieville
Cannonville
Alton
Glendale
Orderville
Long Valley/Orderville WWTP
Kanab
Kanab Sewage Lagoons
Fredonia
Fredonia WWTP
Kaibab Indian Reservation
Church Wells
Big Water
Page
Lake Powell
Grand Staircase-Escalante
North Fork Virgin River
East Fork Virgin River
Mill Creek
Lick Wash
Paria River
Hackberry Creek
Cottonwood Creek
Wahweap Creek
Deer Spring Wash
Park Wash
Coyote Creek
Buckskin Gulch
Kanab Creek
Johnson Wash
White Sage Wash
Sand Wash
148
14
63
12
12
9
89
89a
Wastewater Treatment Plants
Project Pump Station
Project Regulating Tank
Project Hydro Station
Project Transmission Line
Existing Transmission Line
Water Conveyance
Hydro System - South Alignment Alternative
Hydro System - Highway Alignment Alternative
KCWCD Pipeline System
Cedar Valley Pipeline
Interstate
US Highway
ST Highway
Hwy
Major Road
Water Conservancy Districts
State Boundaries
Hurricane Cliffs Forebay/Afterbay
Lakes/Reservoirs
Major Rivers & Streams
National Park/Monument
Tribal Lands
County Boundaries
Cities
FERC Project Number:
12966-001
BLM Serial Numbers:
AZA-34941
UTU-85472
N
0 2.5 5 10 15
Miles
Lake Powell Pipeline Project
Spatial Reference: UTM Zone 12N, NAD-83
UDWR Figure 3-39 MWH
Kane County
Water Conservancy District

3.2.3.1 Kanab Creek

In southern Utah, Kanab Creek drains a narrow valley from north to south with peak elevations of 9,000 feet in the Dixie National Forest. Most of the watershed upstream of Kanab is undeveloped. The Kanab Creek near Kanab gage is located 3.5 miles north of Kanab at an elevation of 5,060 feet. Downstream of the gage, Kanab Creek is generally completely diverted at Kanab City.

Figure 3-40 shows the historical daily flows in Kanab Creek upstream of the Kanab diversion. Figure 3-41 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-42 depicts the flow exceedance curve. The 90 percent exceedance value is 5 cfs, while the 10 percent exceedance value is 19 cfs. The median flow is 9 cfs.

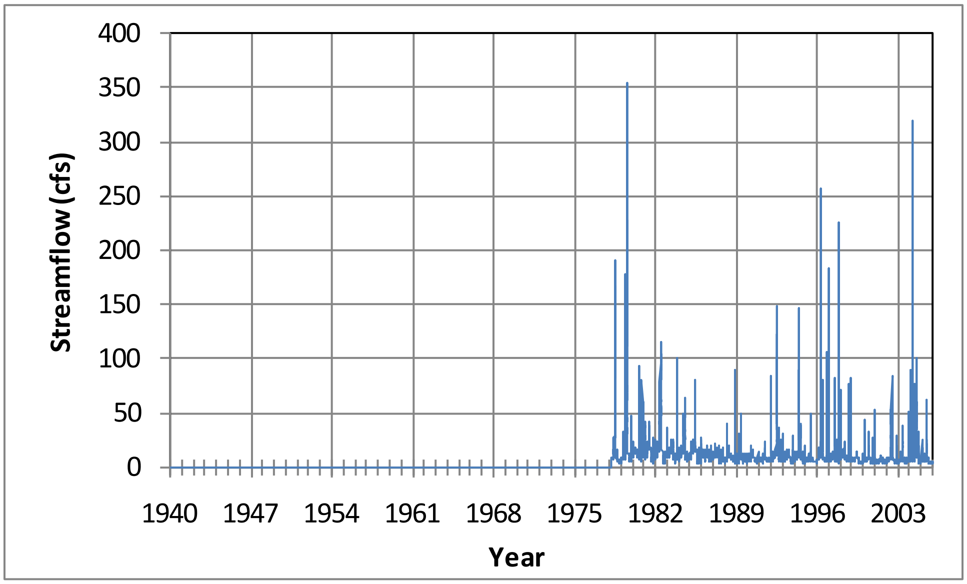


Figure 3-40
Kanab Creek Near Kanab, Daily Flows

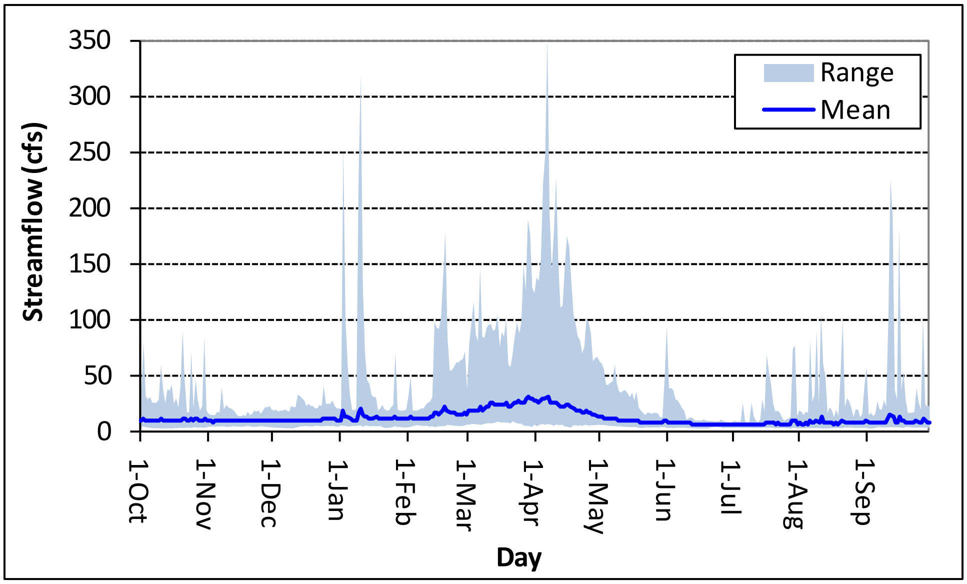


Figure 3-41
Kanab Creek Near Kanab, Daily Mean and Range of Flow

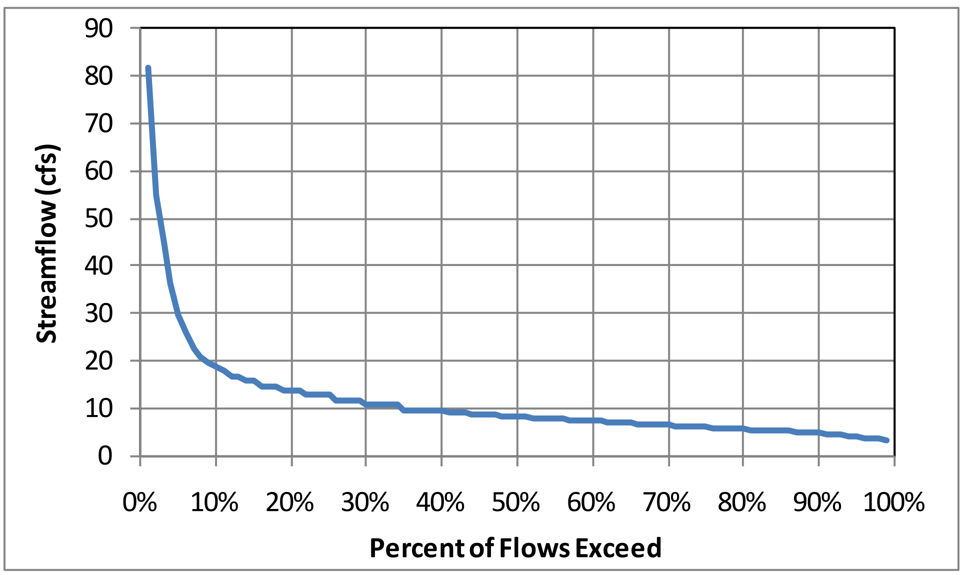


Figure 3-42
Kanab Creek Near Kanab, Flow Exceedance

Figure 3-43 shows the mean monthly flows for Kanab Creek. Peak flows occur in spring and low flows in summer. Figure 3-44 shows historical annual mean streamflows. The long-term mean annual streamflow is 12 cfs. Figure 3-45 depicts the stage-discharge curve for the gage.

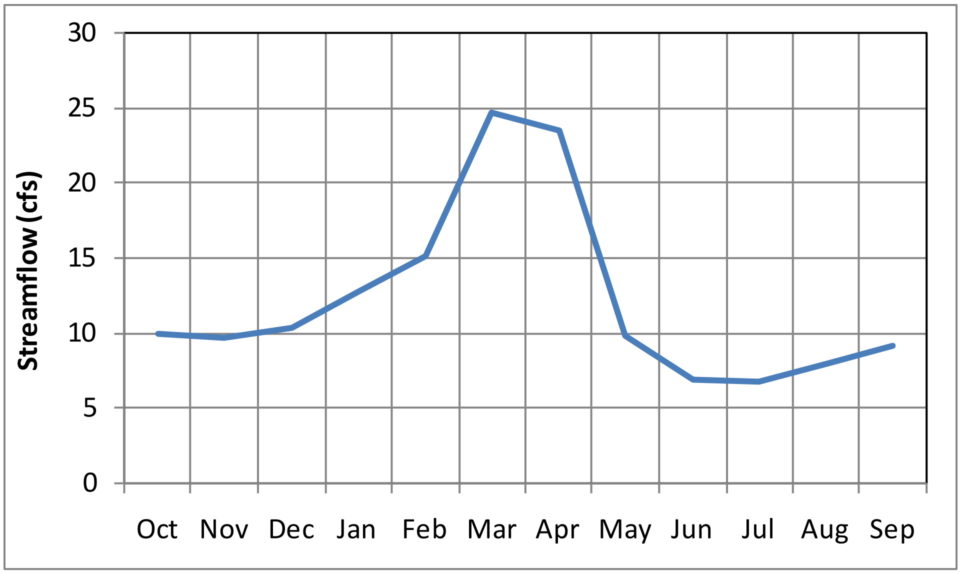


Figure 3-43
Kanab Creek Near Kanab, Monthly Mean Flows

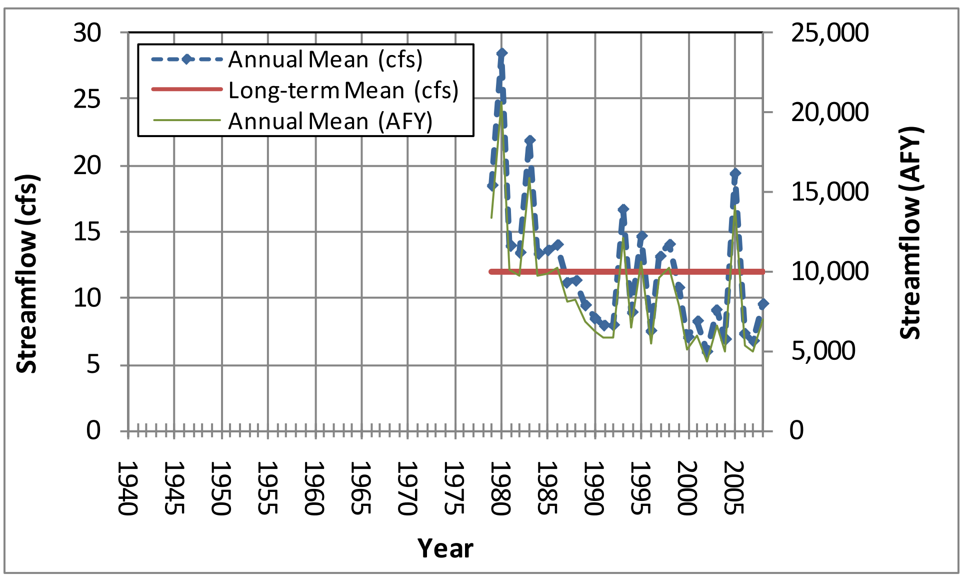


Figure 3-44
Kanab Creek Near Kanab Annual Mean Flows

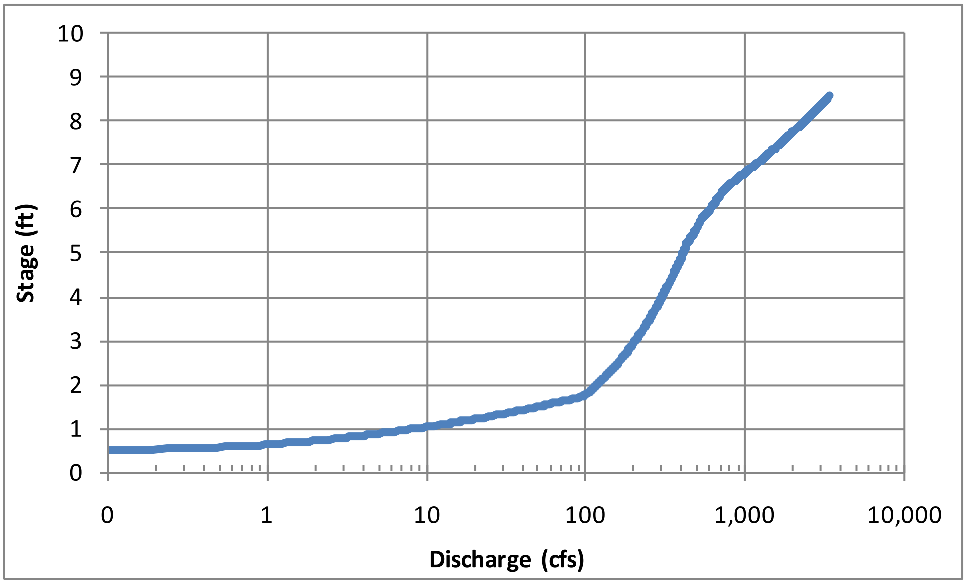


Figure 3-45
Kanab Creek Near Kanab – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.3.2 Paria River

The Paria River originates near Bryce Canyon National Park and drains to the south through Grand Staircase Escalante National Monument. The Paria River is eventually tributary to the Colorado River between Glen Canyon Dam and Lees Ferry.

The LPP would cross the Paria River at U.S. Highway 89, the same location as a relatively new stream gage site. At this point, the drainage area is 647 square miles. The Paria River near Kanab gage has a short period of record and the gage records are considered poor. Therefore, only a limited set of streamflow charts are presented. Figure 3-46 shows daily flows for the Paria River near Kanab period of record. Although flows are mostly less than 40 cfs, there are sporadic and short-term peak flow events. Figure 3-47 shows the daily mean and daily range of flows over the calendar year based on the six-year period of record. During this period, peak flows occurred from August through January. Figure 3-48 depicts the flow exceedance curve. The 90 percent exceedance value is 0 cfs, while the 10 percent exceedance value is 38 cfs. The median flow is 7 cfs. Figure 3-49 depicts the stage-discharge curve for the gage. Annual means for the period of record range from 10.9 cfs in 2003 to 42.1 cfs in 2005.

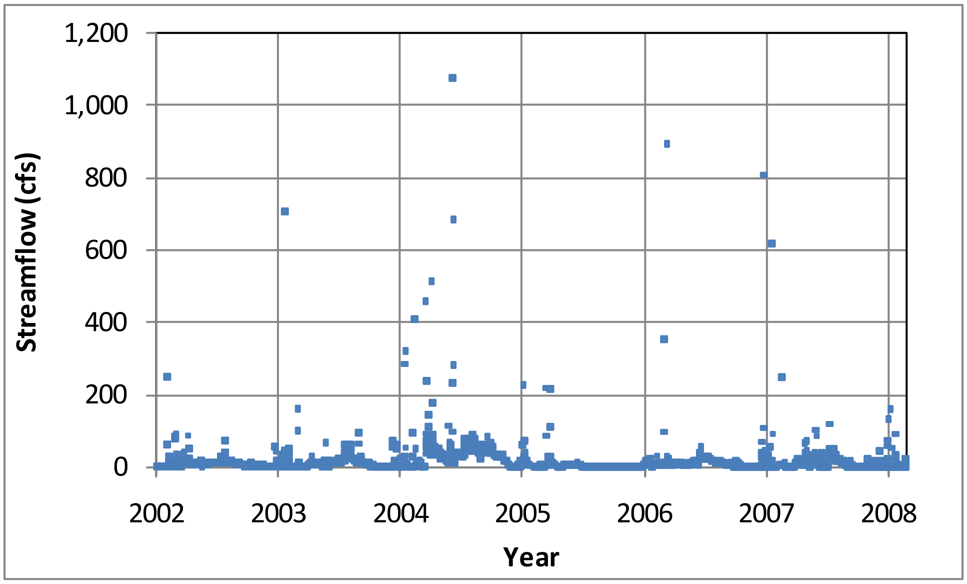


Figure 3-46
Paria River Near Kanab, Daily Flows

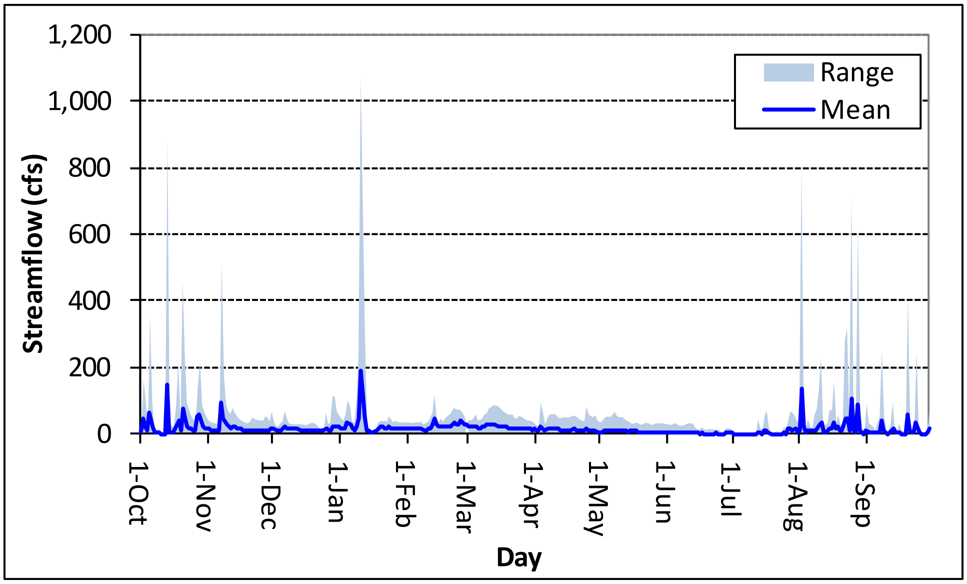


Figure 3-47
Paria River Near Kanab, Daily Mean and Range of Flow

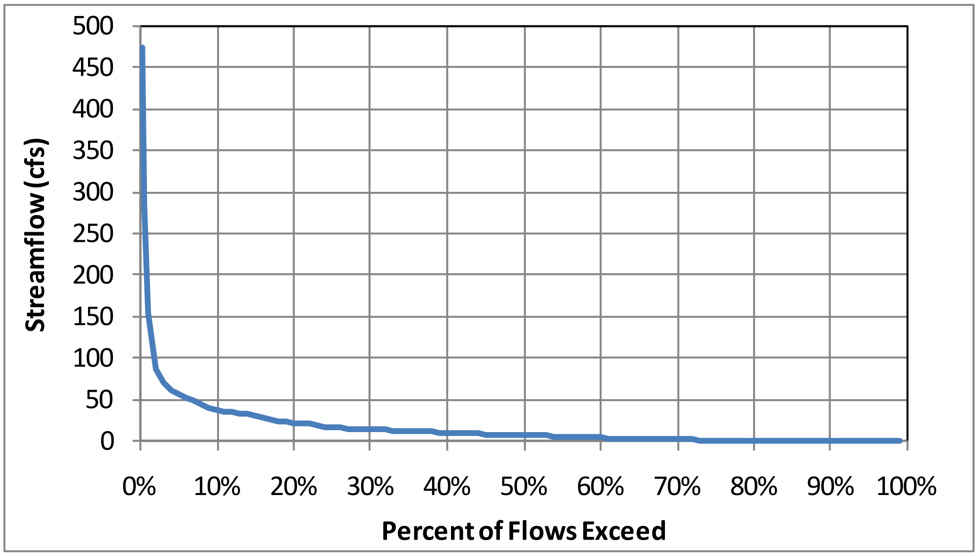


Figure 3-48
Paria River Near Kanab Flow Exceedance

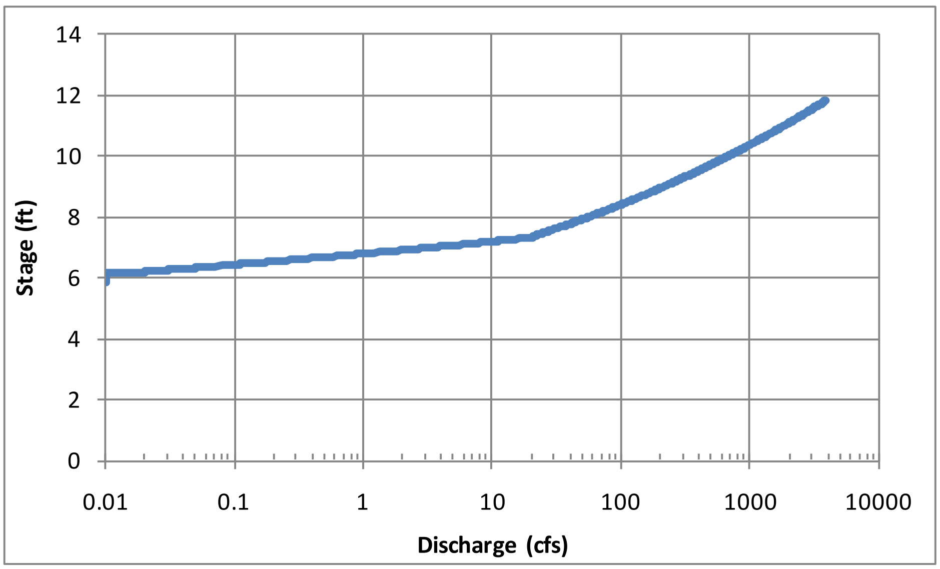
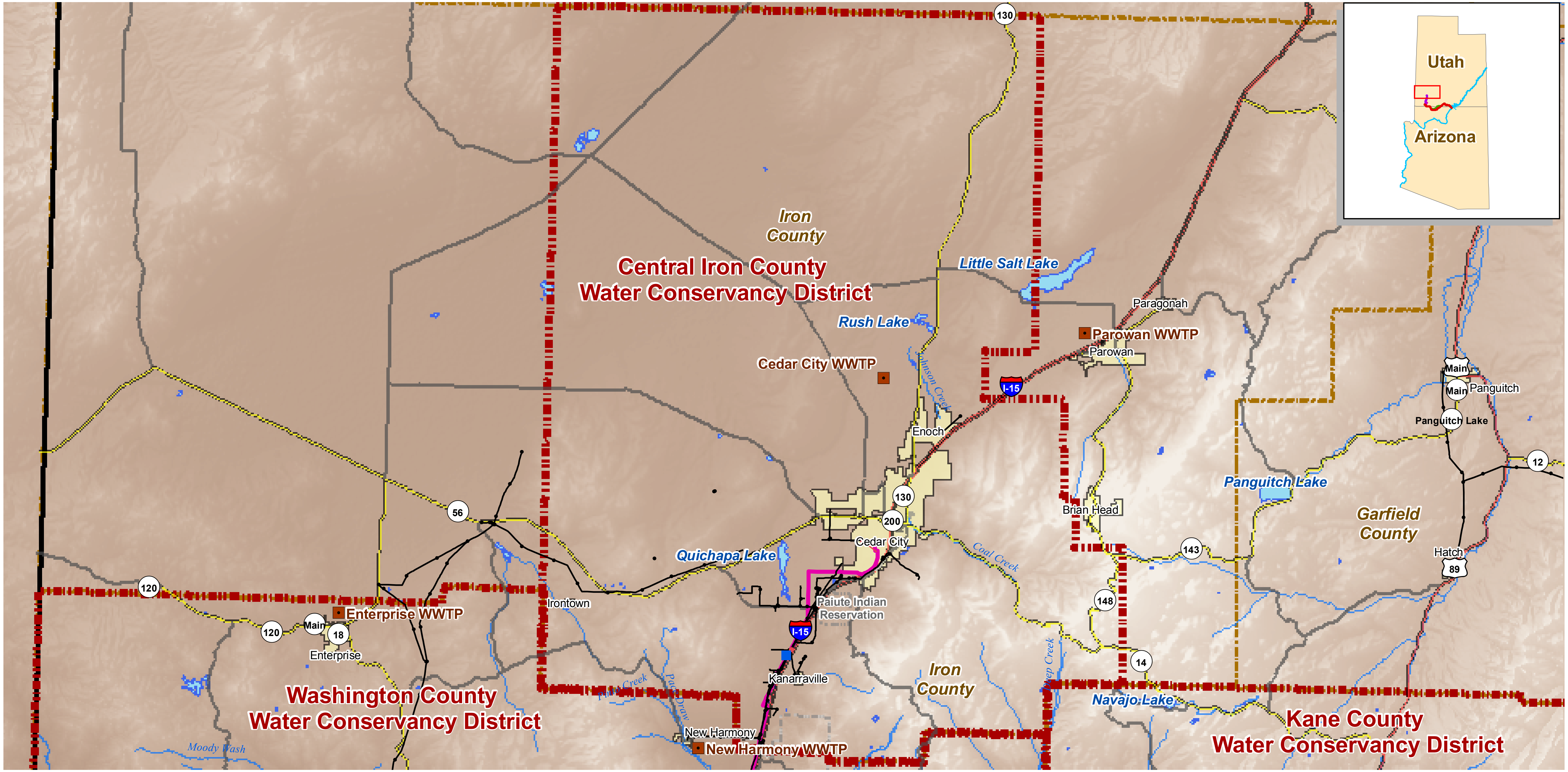


Figure 3-49
Paria River Near Kanab – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.2.4 Iron County Drainages

The Cedar City metropolitan area is located within a closed basin within Utah's Cedar Beaver basin. Several drainages originate in the Cedar Mountains east of Cedar City and either end with agricultural usage or in terminal reservoirs. Several intermittent streams south of Cedar City terminate in Quichapa Lake. Coal Creek flows through Cedar City and terminates in the agricultural area northwest of town. Several intermittent drainages north of town terminate at Rush Lake. The CICWCD and Cedar City would receive LPP water supply via the Cedar Valley Pipeline system. The CICWCD service area and LPP project facilities are depicted in Figure 3-50.



Wastewater Treatment Plants
Project Pump Station
Project Regulating Tank
Project Hydro Station
Project Transmission Line
Existing Transmission Line
Water Conveyance System
Hydro System - South Alignment Alternative
Hydro System - Highway Alignment Alternative
Kane County Pipeline System
Cedar Valley Pipeline System
Interstate
US Highway
ST Highway
Hwy
Major Road
Water Conservancy Districts
State Boundaries
Hurricane Cliffs Forebay/Afterbay
Lakes/Reservoirs
Major Rivers & Streams
National Park/Monument
Tribal Lands
County Boundaries
Cities

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

N

0 2 4 8 12 Miles

Lake Powell Pipeline Project

Spatial Reference: UTM Zone 12N, NAD-83

UDWR **Figure 3-50** MWH

Central Iron County Water Conservancy District

Coal Creek is the only stream in Iron County with a long-term stream gage operated by the USGS. Coal Creek originates in the Cedar Mountains southeast of Cedar City at elevations greater than 10,000 feet. Coal Creek drains to the northwest through Cedar City and into the agricultural lands of the Cedar Valley at about 5,500 feet. Most of the surface water in Coal Creek originates as snowfall. The flow generally dissipates in the valley through evaporation and infiltration. The Coal Creek gage is located one mile east of Cedar City.

3.2.4.1 Coal Creek Near Cedar City

Figure 3-51 depicts the historical daily flows in Coal Creek. Figure 3-52 shows the daily mean and daily range of flows over the calendar year based on the period of record. Figure 3-53 shows the flow exceedance curve for Coal Creek. The 90 percent exceedance value is 8 cfs, while the 10 percent exceedance value is 77 cfs. The median flow is 13 cfs.

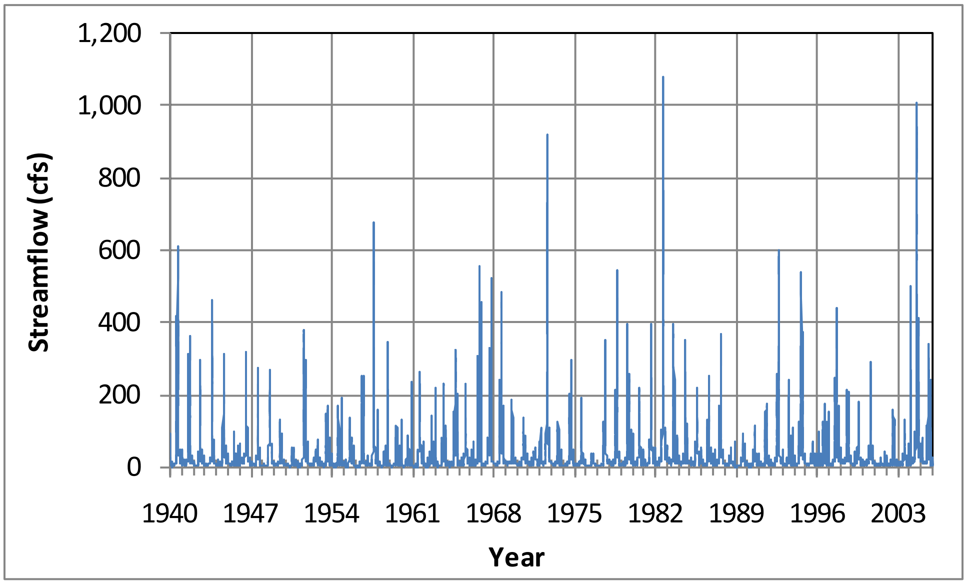


Figure 3-51
Coal Creek Near Cedar City, Daily Flows

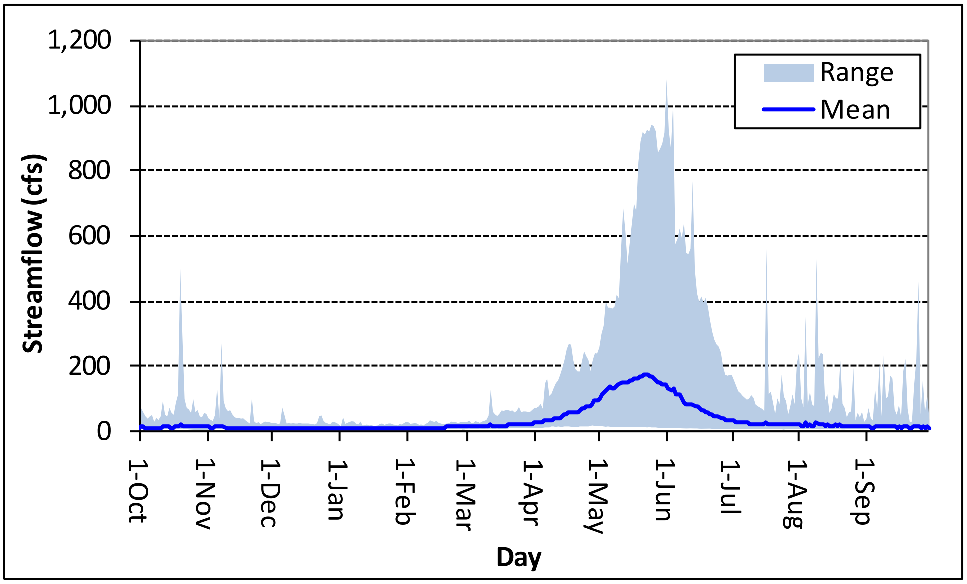


Figure 3-52
Coal Creek Near Cedar City, Daily Mean and Range of Flow

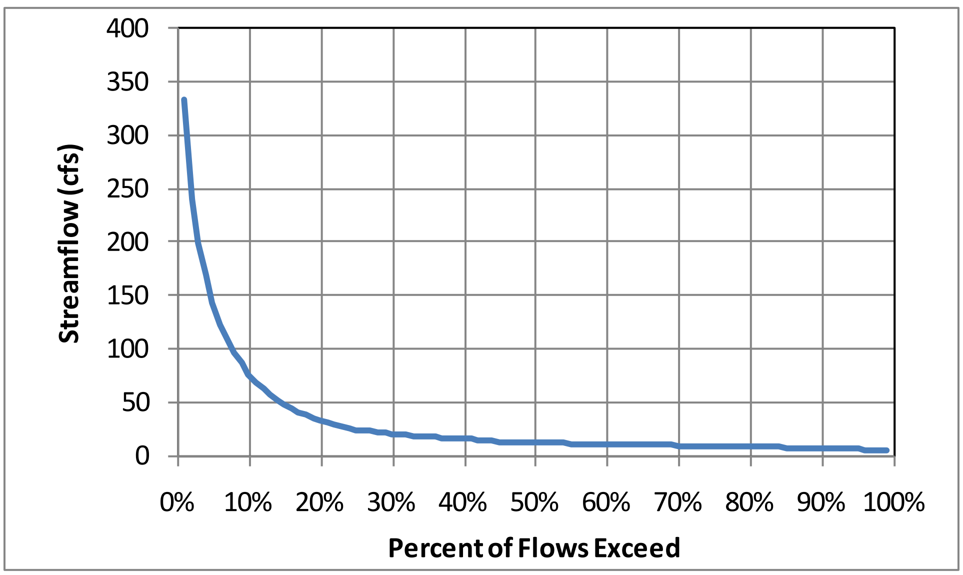


Figure 3-53
Coal Creek Near Cedar City, Exceedance

Figure 3-54 shows the monthly mean flows for Coal Creek. Peak spring flows are much greater than flows for most of the year. Figure 3-55 shows the historical annual mean streamflows. The long term mean streamflow is 34 cfs. Figure 3-56 depicts the stage-discharge curve for the gage.

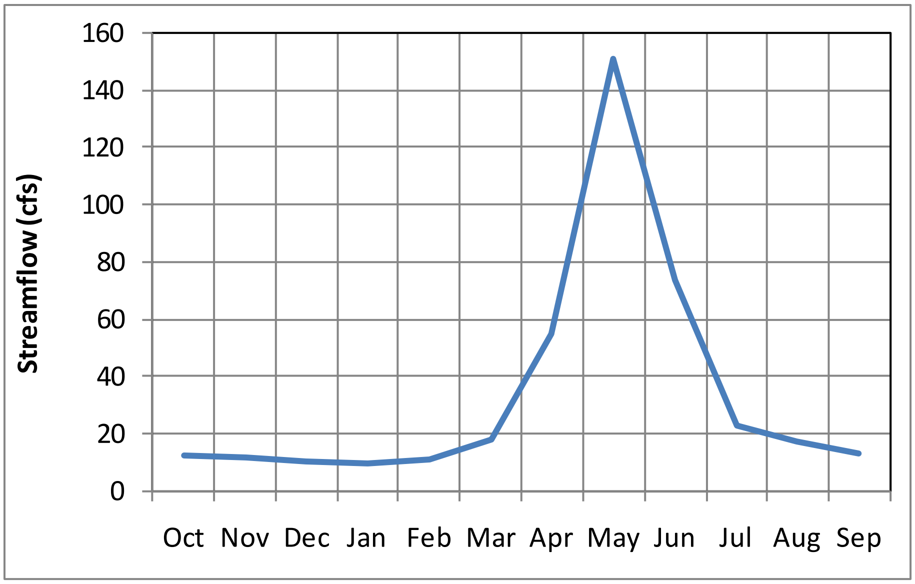


Figure 3-54
Coal Creek Near Cedar City, Monthly Mean Flows

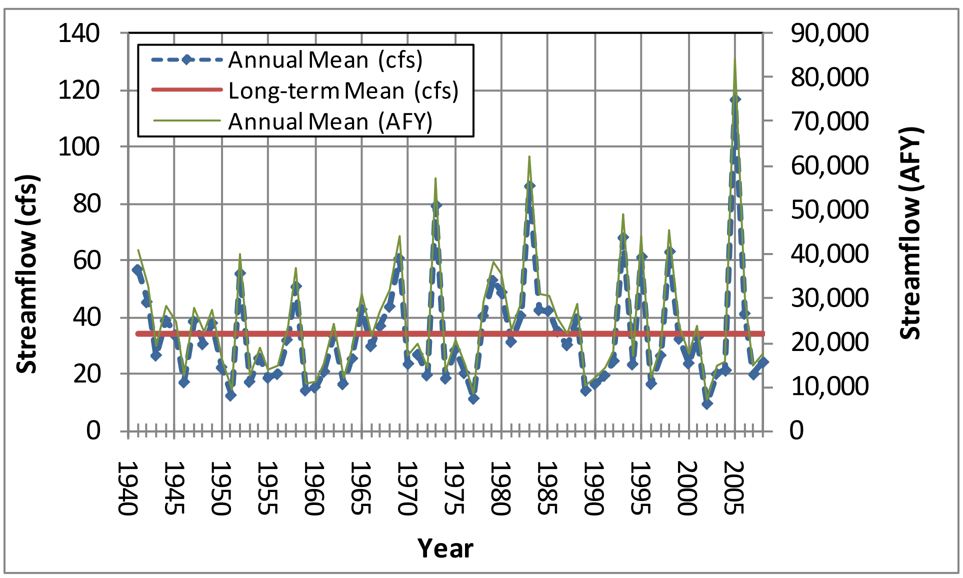


Figure 3-55
Coal Creek Near Cedar City, Annual Mean Flows

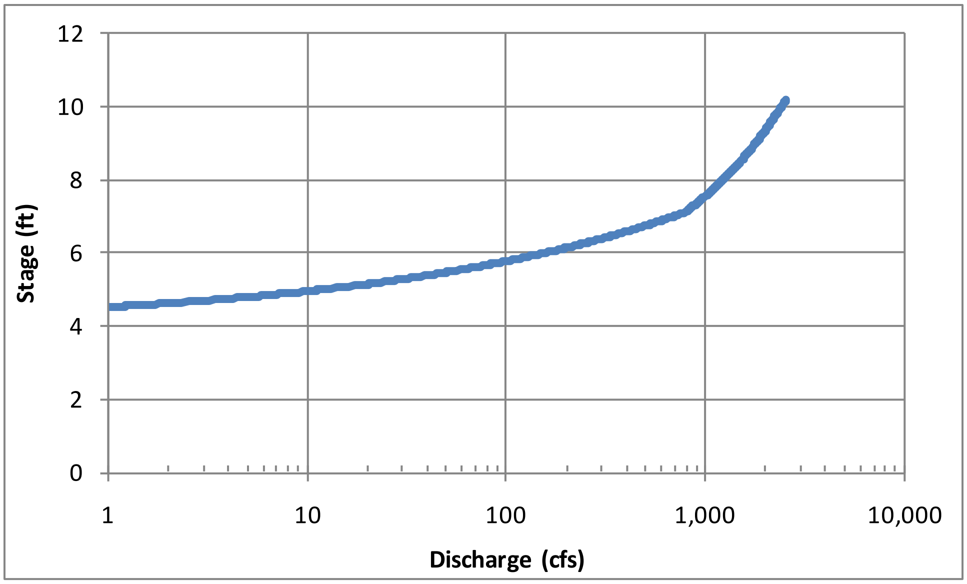


Figure 3-56
Coal Creek Near Cedar City – Stage Discharge Rating Curve
Note: Rating curves are subject to change over time

3.3 Return Flows

The St. George wastewater treatment plant serves the communities of St. George, Ivins, Santa Clara, and Washington. According to the 2005 M&I Water Supply and Use Report for the Kanab Creek/Virgin River Basin, for the communities served by the St. George WWTP, 43 percent of municipal and industrial (M&I) water use was indoor water use and 57 percent was outdoor water use. A total of 13,890 acre-feet returned to the wastewater treatment facility at St. George, 95 percent of the total indoor use. Most of the wastewater treatment plant flow, 98 percent, was considered sewered return flow and returned to the Virgin River. Of the 19,100 acre-feet of outdoor water use, UDWR assumed that 33 percent, returned to the Virgin River as non-sewered return flow (UDWR 2009). Table 3-3 summarizes water use and return flow estimates for 2005 for communities involved in the LPP.

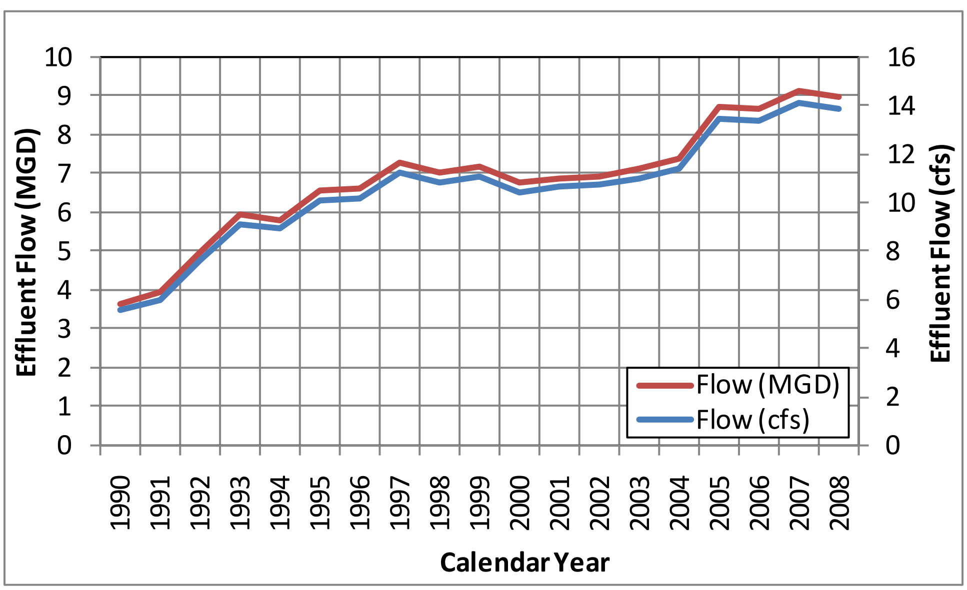
Table 3-3
2005 Water Use and Return Flow Summary for Major LPP Water Users (AF)
Page 1 of 2

Water Supplier	Total Water Use	Outdoor Water Use	Non-Sewered Return Flow	Indoor Water Use	Wastewater Treatment Inflow	Sewered Return Flow
Ivins	1,343	717	239	626	610	595
Santa Clara Municipal	1,482	927	309	555	541	531
St. George City	26,217	14,676	4,892	11,541	10,919	10,700
Washington Municipal	4,665	2,780	927	1,885	1,820	1,784
**Total St. George WWTP					13,890	13,610

Table 3-3
2005 Water Use and Return Flow Summary for Major LPP Water Users (AF)
Page 2 of 2

Water Supplier	Total Water Use	Outdoor Water Use	Non-Sewered Return Flow	Indoor Water Use	Wastewater Treatment Inflow	Sewered Return Flow
Toquerville	373	275	92	98	96	83
Hurricane	3,770	2,341	780	1,429	1,401	1,222
LaVerkin	850	414	145	436	401	340
**Total Ash Creek WWTP					1,898	1,645
Kanab	1,585	981	327	604	583	311
Cedar City	7,012	3,699	1,233	3,313	3,100	2,018
Enoch Municipal	1,056	545	182	511	403	280
**Total Cedar City WWTP					3,503	2,298
Source: UDWR (2007) and UDWR (2009)						

The St. George WWTP discharges to the Virgin River southwest of St. George (Figure 3-10). Figure 3-57 depicts historical flows through the wastewater treatment plant, which represent historical sewered return flows. Sewered return flows have increased at a steady rate since 1990. In 2008, wastewater effluent flows totaled 9 MGD, or about 14 cfs. St. George recently completed a wastewater reuse plant that takes water from the WWTP and treats it for use as secondary water. The plant is designed for 10 mgd capacity. The wastewater reuse plant only has one current large customer, a golf course, but has agreed to serve 2,000 AF per year to the Shivwits Band of the Paiute Tribe. The city has approved plans to store reuse water in a new 2,500 acre-foot reservoir and expand the system in the future. This expansion would reduce future sewered return flows to the Virgin River.



Source: Barnum (2008)

Figure 3-57
St. George Wastewater Plant Historical Effluent Flows

Wastewater for the towns of Toquerville, Hurricane, and LaVerkin is treated at the Ash Creek Special Service District wastewater treatment lagoons. For the communities served by the Ash Creek lagoons 39 percent of M&I water use was indoor water use and 61 percent was outdoor water use. A total of 1,898 acre-feet returned to the Ash Creek lagoons, 97 percent of the total indoor use. Water from the lagoons is land applied and does not have a surface return flow to the Virgin River. However, after accounting for evaporation, UDWR considered that 87 percent of the water delivered to the lagoons returned to the Virgin River. Of the 3,030 acre-feet of outdoor water use, UDWR assumed that 33 percent eventually returned to surface waters as non-sewered return flow (UDWR 2009).

The Cedar City wastewater treatment plant also treats flows from Enoch City and surrounding areas. According to the 2005 M&I Water Supply and Use Report for the Cedar/Beaver Basin, for the communities served by the Cedar WWTP, 47 percent of M&I water use was indoor water use and 53 percent was outdoor water use. A total of 3,503 acre-feet returned to the wastewater treatment facility, 92 percent of the total indoor use. The wastewater treatment facility is permitted to discharge to the Bulldog Irrigation Ditch (EPA 2009). The effluent is land applied east of the treatment facility. The closest stream is Johnson Creek, an intermittent creek that would discharge to Rush Lake, a terminal lake, under high flow conditions. UDWR considered that 66 percent of the wastewater flow was sewered return flow. Of the 2,122 acre-feet of outdoor water use, UDWR assumed that 33 percent returned as non-sewered return flow (UDWR 2007). Non-sewered return flows in this area would accrue to Coal Creek as well as various other intermittent streams that are not typically tributary to any larger drainage. Under high flow conditions some of the streams could discharge to terminal water bodies including Rush Lake and Quichapa Lake.

The City of Kanab uses a lagoon system for wastewater treatment. Water use data for 2005 showed that 38 percent of M&I water use was indoor water use and 62 percent was outdoor water use. A total of 583 acre-feet returned to the wastewater lagoons, 97 percent of the total indoor use. After accounting for evaporation, UDWR considered that 53 percent of the water delivered to the lagoons returned to Kanab Creek. Of the 981 acre-feet of outdoor water use, UDWR assumed that 33 percent eventually returned to surface waters as non-sewered return flow (UDWR 2009).

3.4 Reservoirs

The following describes storage information for potentially affected reservoirs and lakes in the study area.

3.4.1 Lake Powell

Lake Powell is the reservoir impounded by Glen Canyon Dam. It is the second largest reservoir on the Colorado River and has a total storage capacity of 24.32 maf. The reservoir is narrow, extending over 180 miles along the Colorado River and 80 miles up the San Juan River, and has a shoreline that is over 1,900 miles long. Lake Powell primarily provides water storage for use in meeting the delivery requirements to the Lower Colorado River consistent with the Law of the River. Releases are also timed for hydropower production. Lake Powell is an important regional resource for water-based recreation. Reclamation retains authority and discretion for the operation of Glen Canyon Dam and Lake Powell (Reclamation 2007).

The operating range of Lake Powell is between elevations 3,490 and 3,700 feet mean sea level. The elevation capacity curve for Lake Powell is shown in Figure 3-58. Pipeline intakes for LPP are proposed at three invert elevations: 3575, 3475, and 3375 feet above sea level.

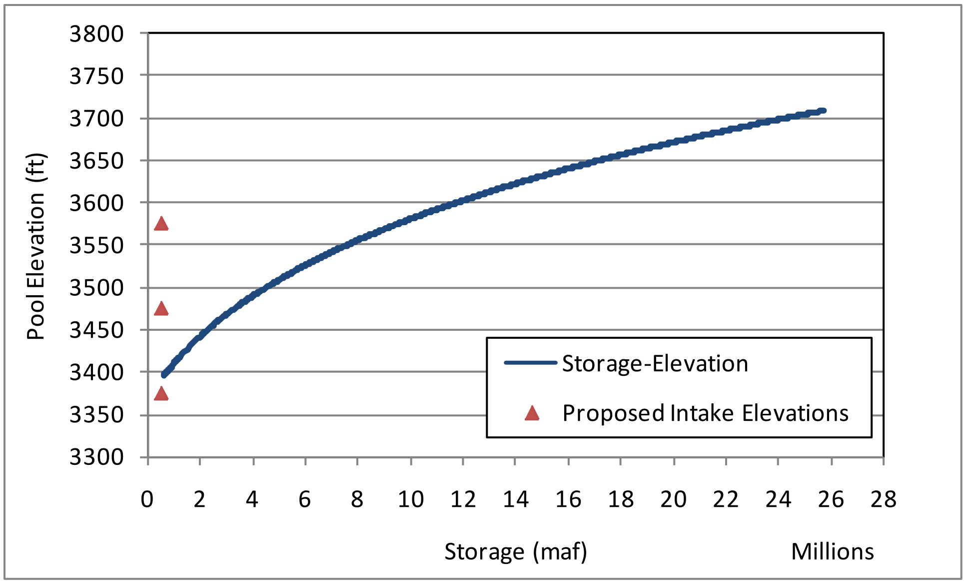
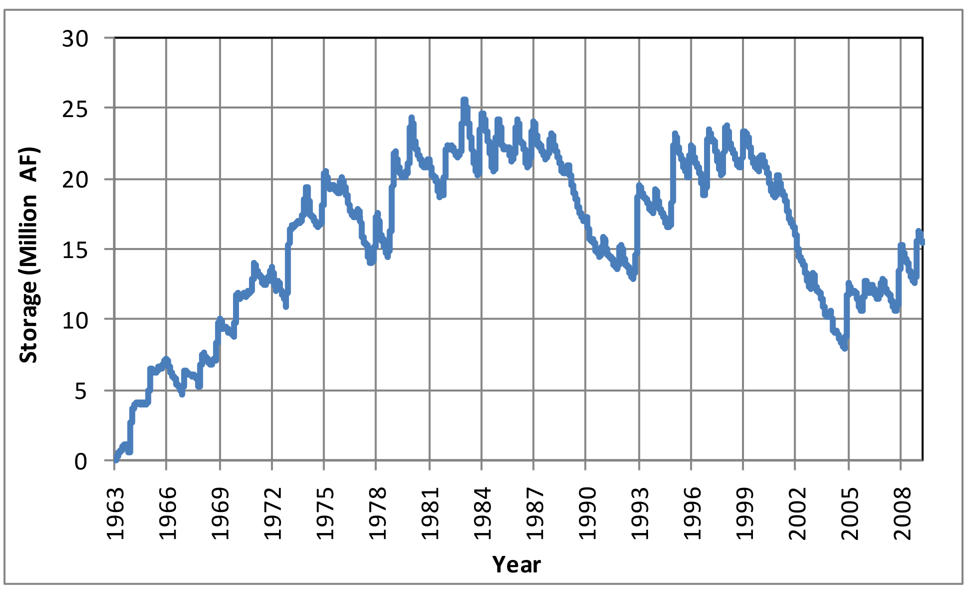


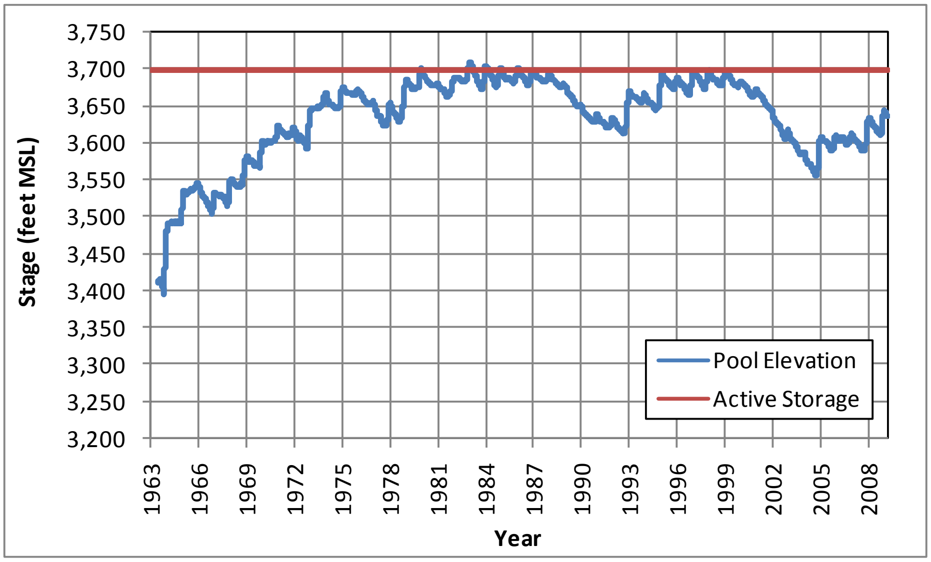
Figure 3-58
Lake Powell Elevation Capacity Curve

Historical storage data for Lake Powell is plotted in Figure 3-59, however, because of changes in the operational plans, historical data is not necessarily comparable to future conditions. The reservoir began filling in 1963. The fluctuations in elevations are primarily the result of highly variable hydrologic inflows into the Upper Colorado River Basin (Reclamation 2007). The substantial drawdown from 1999 through 2004 during the extended drought in the Upper Colorado River Basin is apparent. Figure 3-60 shows historical pool elevation, or stage, in Lake Powell. Emergency spills were made from the dam in 1983. Figure 3-61 depicts historical releases made from the dam.



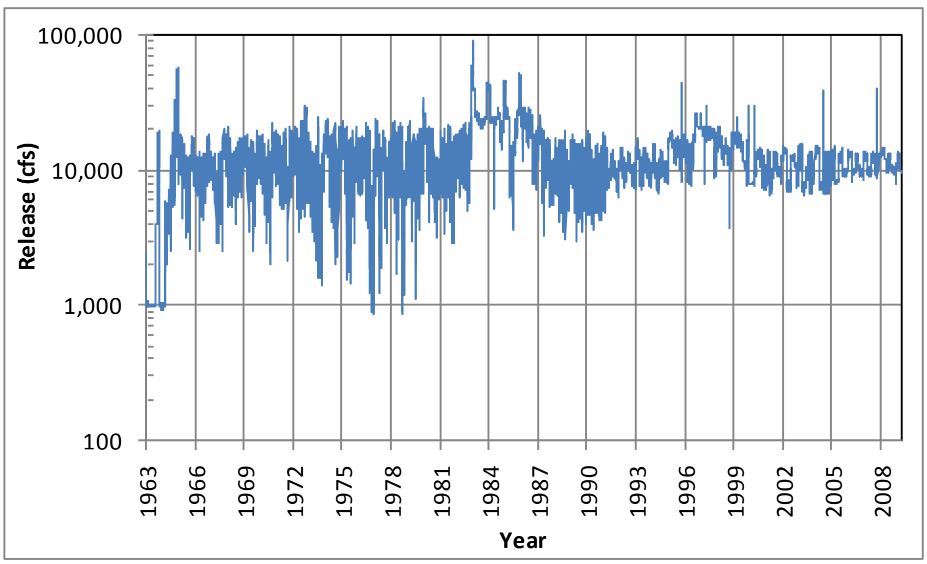
Source: Reclamation (2009)

Figure 3-59
Lake Powell Historical Storage



Source: Reclamation (2009)

Figure 3-60
Lake Powell Historical Stage



Source: Reclamation (2009)

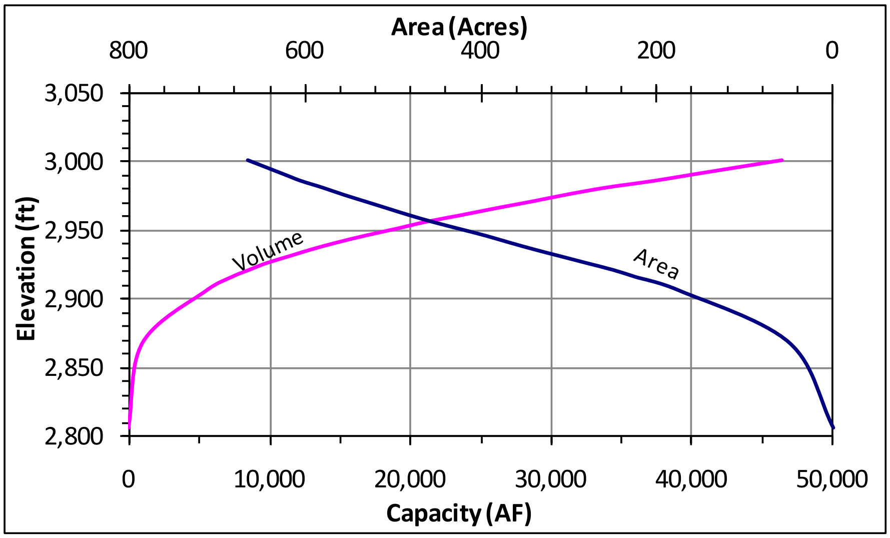
Figure 3-61
Lake Powell Historical Daily Releases

3.4.2 Quail Creek Reservoir

Located approximately 15 miles northeast of St. George, Quail Creek Reservoir is formed by two dams on Quail Creek, a minor tributary to the Virgin River. The reservoir was constructed by WCWCD and was completed in April 1985. Quail Creek Reservoir is owned and operated by WCWCD to meet regional culinary M&I water demands. The dam failed in January of 1989, and was then reconstructed. Water for storage in Quail Creek Reservoir originates in the Virgin River. It is diverted at the Quail Creek Diversion Dam, and is delivered to the reservoir in a pipeline. The diversion also supplies the towns of LaVerkin and Hurricane, the Pah Tempe Hydropower plant and Sand Hollow Reservoir before reaching Quail Creek Reservoir. Seepage from the reservoir returns to the Virgin River though Quail Creek.

WCWCD states that Quail Creek Reservoir has a reliable surface water yield of about 22,000 acre-feet per year of raw water for culinary uses (WCWCD 2006). Based on modeling performed by UDWR, the combined yield of Quail Creek and Sand Hollow reservoirs is 29,500 ac-ft per year (UDWR 2009). WCWCD operates a water treatment plant just below the reservoir for culinary distribution to WCWCD customers.

The reservoir has a storage capacity of 40,000 acre-feet and has a surface area of 620 acres. It has a minimum pool of 5,525 acre-feet. The area-elevation-capacity curve is included as Figure 3-62. Historical storage is plotted in Figure 3-63.



Kennard (2009)

Figure 3-62
Area-Elevation-Capacity for Quail Creek Reservoir

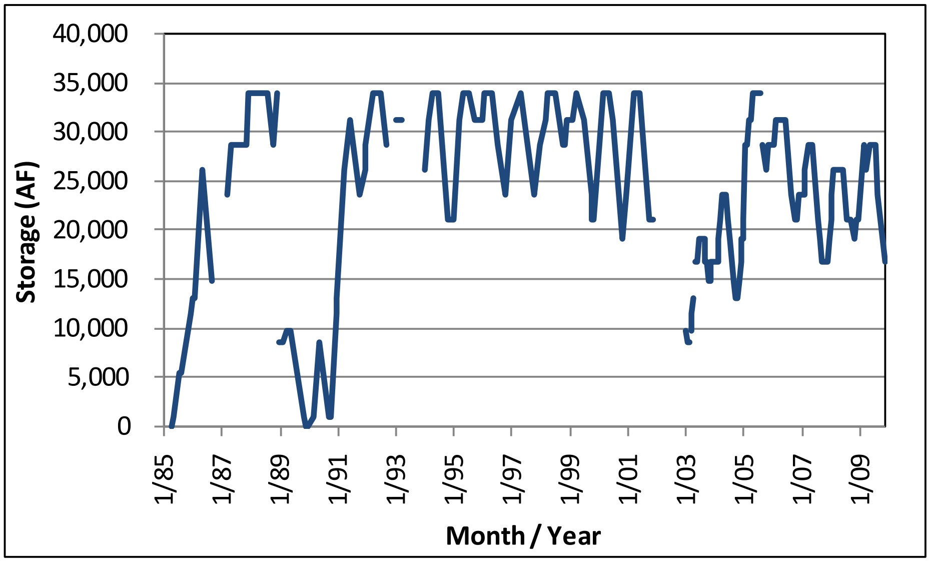


Figure 3-63
Quail Creek Reservoir Historical Storage
Source: Utah Division of Water Rights (2009) and Silva (2009)

3.4.3 Sand Hollow Reservoir

Sand Hollow Reservoir is a 50,000 ac-ft storage facility located about 5 miles southwest of Hurricane. The reservoir was constructed by WCWCD in 2002 and is used for culinary supply for WCWCD customers. Water to fill the Sand Hollow Reservoir is conveyed from the Virgin River in the same pipeline serving Quail Creek Reservoir. The reservoir has an active pool of about 30,000 acre-feet and a drought pool of 20,000 acre-feet that would provide water supplies in an extreme drought. Sand Hollow Reservoir also serves as a groundwater recharge facility for the Navajo Sandstone Aquifer. Figure 3-64 shows the area-elevation capacity curve for Sand Hollow Reservoir. Figure 3-65 shows historical reservoir storage in Sand Hollow Reservoir.

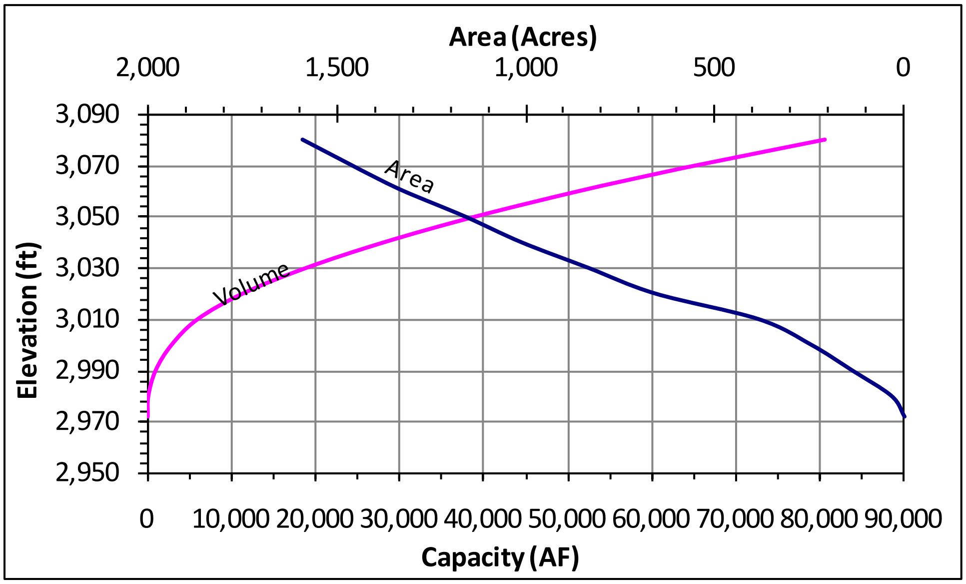


Figure 3-64
Area-Elevation-Capacity for Sand Hollow Reservoir
Data Source: Kennard (2009)

Figure 3-65
Historical Storage - Sand Hollow Reservoir
Data Source: Heilweil and Susong (2007) and UDWR (2009)

3.4.4 Rush Lake and Quichapa Lake

Rush Lake and Quichapa Lake are located in Iron County. Quichapa Lake is located southwest of Cedar City and west of the Cross Hollow Hills. Much of the area south and west of the Cedar City Airport naturally drains toward Quichapa Lake, which is the terminal lake in for a relatively small drainage area. Although under normal conditions, most of the surface water dissipates upstream of Quichapa Lake, under high flow conditions, runoff from this mostly rural area would reach Quichapa Lake. Rush Lake is located about 6 miles north of Enoch and is the terminal lake for another drainage area. Similar to Quichapa Lake, surface water usually dissipates before reaching Rush Lake, but under high flow conditions, Rush Lake would receive surface runoff from much of the area north of Cedar City.

3.5 Peak Flows

In the Kanab, Virgin River, and Cedar Beaver basins streams are prone to flash flooding from regional storm runoff or large snow runoff events from warm weather or rain on the snowpack. The unique rock formations in the study area convert nearly all precipitation to runoff. The sparse vegetation adds to the high flash flood potential of the region. The larger streams have potential for flooding caused by general storms originating in the Pacific Ocean (FEMA 2009).

Flood events can cause extreme erosion and sedimentation (DWRe 1993 and DWRe 1995). The 2005 flood in Washington County resulted in peak flows of 21,000 cfs at the Virgin River at Bloomington gage, close to the 100-year peak flow, and 6,200 cfs at the Santa Clara River at St. George gage, less than the 50-year peak flow. This flood resulted in an estimated $200 million in damage and a federal disaster declaration (FEMA 2009).

Table 3-4 summarizes estimated peak flows for various return intervals for streams in the study area. The peak flow data comes from the following various sources:

- Santa Clara River, Fort Pierce Wash, and Virgin Rivers – 2009 Flood Insurance Study for Washington County
- Coal Creek in Cedar City – Estimates using USGS regression equations because there is no recent Flood Insurance Study
- Kanab Creek – Estimates using USGS regression equations because there is no recent Flood Insurance Study

Table 3-4
Summary of Estimated Peak Flows

Flooding Source and Location	Drainage Area (Sq. Miles)	Peak Flow (cfs)		
		10-Year	50-Year	100-Year
Santa Clara River				
• From USGS gage near Santa Clara to Santa Clara City limit	424	NA	NA	8,200
• From Santa Clara City limits to confluence with Sand Hollow Wash	446	2,450	6,000	8,200
• From confluence with Sand Hollow Wash to Dixie Dr. Bridge	538	3,650	9,150	12,500
• From Dixie Dr. Bridge to Virgin River	540	3,750	9,500	13,000
Fort Pierce Wash				
• From Utah State line to confluence with Virgin River	1,680	NA	NA	22,000
Virgin River				
• From USGS gage near Hurricane to Washington City limits	1540	NA	NA	23,500
• From Washington City limit to confluence with Fort Pierce Wash	1,640	12,000	19,500	23,500
• From confluence with Fort Pierce Wash to St. George City limit	3,840	12,000	19,500	27,500
• From St. George City west limit to Utah/Arizona state line	4,000	NA	NA	27,500
Coal Creek				
• Near Cedar City	80.9	2,580	5,090	6,420
Kanab Creek				
• Near Kanab	194	2,390	3,870	4,570

Source: Santa Clara and Virgin - FEMA (2009), Coal and Kanab – USGS (2010)
NA = not available

3.6 Geomorphic Conditions

3.6.1 Colorado River

Construction of the Glen Canyon Dam modified the channel characteristics of the Colorado River downstream of Lake Powell. This is caused by sediment being trapped upstream of the dam and releases of clear water with the potential to erode the channel downstream of the dam.

A study of the 25 km downstream of the dam through Glen Canyon found that high releases that occurred in the 1960s and 1980s scoured substantial amounts of sediment from the channel bottom. The average size of bed material remaining in the channel is now 20 mm compared to 0.2 mm in 1956. Without peak flows, little change occurred to the channel bed between 1990 and 2004 (Grams et al 2004). The channel is now considered “armored” because the large size of channel material is resistant to movement from typical flows.

Several uses of Glen Canyon downstream of the dam and further downstream in the Grand Canyon are sensitive to geomorphology including:

- Archaeological sites
- Recreational uses such as sport fishing and associated day and overnight use on sand bars and alluvial terraces
- Spawning habitat for trout (gravel/cobble bed)
- Camping beaches

The Glen Canyon Adaptive Management Program allows scientists to test if high flows from the dam will:

- Remove or reduce predation of nonnative fish on endangered native fish
- Rejuvenate backwater habitats for native fish, especially the endangered humpback chub (Gila cypha)
- Re-deposit sand at higher elevations
- Preserve and restore camping beaches
- Reduce near-shore vegetation

High flow experiments from Glen Canyon Dam have been performed a few times since 1996. The most recent high flow release from Glen Canyon Dam was made in 2008 when adequate sediment in side-channels of the Grand Canyon was thought to be available for mobilization (Reclamation 2008). The complete synthesis of results from the 2008 experiment is not yet available. The experimental high flow events have not resulted in changes to the annual total amount of water released from Glen Canyon Dam.

3.6.2 Remaining Study Area Streams

The Virgin River and Santa Clara River have both been the subject of geomorphic studies. The conclusions of the studies indicate that channel and bank changes for these streams generally result from peak flow events. UDWR’s basin plans for the Kanab Creek, Virgin River, and Cedar/Beaver basins confirmed that much of the region is prone to flash flooding and associated erosion of stream banks and channels (UDWR 1993 and UDWR 1995). FEMA's most recent Flood Insurance Study for Washington County (2009) further supported the conclusion that local streams are erosion prone:

> *Streams are generally comprised of highly mobile sands, which can result in significant erosion and deposition during flood events. This situation is compounded by fast growing vegetation within the channels and floodplains in the project area, which restrict conveyance capacity and provide a potential source of debris during flood events.*

None of the studies reviewed described the effects, if any, of baseflow on channel stability. The Virgin River and Santa Clara River are discussed in further detail below.

3.6.2.1 Virgin River Stability

The hazard of bank erosion and lateral channel movement on the Virgin River is extreme. For the last 1,000 years, peak flow events have caused numerous shifts in the active channel location (Fuller 2007). Erosion and channel migration is generally attributed to high flow events, although even moderate flooding can cause stability problems on the Virgin River near St. George (Fuller 2005). Prior to the 2005 peak flow event, dense vegetation including tamarisk on both sides of the Virgin River low flow channel created a narrow corridor. The flood event of 2005 scoured away much of the vegetation and once again established a wider channel with steep unvegetated banks. As of 2007, the wider channel had not developed vegetation to stabilize the banks. In addition, wide point bars along much of the Virgin River indicated ongoing rapid lateral channel movement. With the vegetation lost since the 2005 flood, the Virgin River is now susceptible to greater channel and bank change during peak flow events (Fuller 2007).

Much of the Virgin River through St. George has been improved to reduce the likelihood of erosion and channel migration in future floods. However, those structures implemented by the NRCS in response to the 2005 flood were only designed for the peak discharge of 2005, substantially less than the 100-year flow. According to Fuller (2007), these structures would be susceptible to overtopping and other types of failures for flows exceeding the 2005 flood but less than the 100-year flood event.

3.6.2.2 Santa Clara River Stability

The Santa Clara River remained relatively stable from 1938 to 1984 even though several peak flow events occurred during that period. Since 1984, channel instability tended to occur in areas where humans disturbed the floodplain, channel, and vegetation. Fuller (2007) concluded that stream velocities are such that the Santa Clara River through Santa Clara and St. George will erode if not protected. Historically, vegetation provided adequate protection and areas where vegetation has been disturbed are subject to lateral erosion and degradation during high flow events. The 2005 flood that occurred on the Santa Clara River was equivalent to about a 25-year flood and it resulted in serious channel movement and flood damage. Floods of greater magnitude are likely on the Santa Clara River and could potentially result in additional channel change.

Chapter 4
Environmental Consequences

This chapter describes the expected direct and indirect impacts of all of the LPP pipeline alignment alternatives together. Other than differences in river crossing locations, the effects on surface waters for any of the different LPP Project alternative alignments are similar.

4.1 Significance Criteria

Significance criteria were not developed for surface water resources because the changes estimated in this analysis were used to evaluate the significance of the impacts that flow and water level changes would have on other affected resources. These resources include surface water quality, wetlands and riparian resources, aquatic resources, special status aquatic resources, and special status wildlife species.

One significance criterion is identified regarding peak flows and geomorphology:

- Effects on peak flows and/or geomorphology that could result in impacts to property such as damage to bridges or other structures would represent a significant impact.

4.2 Potential Impacts Eliminated from Further Analysis

There are no potential impacts identified that were eliminated from further analysis.

4.3 Streams and Return Flows

4.3.1 Colorado River

The LPP Project impacts on the Colorado River are based on the results of modeling performed by Reclamation. This section summarizes the simulated releases from Lake Powell, documented in further detail in Appendix B. The modeling methodology and scenarios are summarized in Section 2.2.2.2. More than 100 inflow hydrology datasets each are run for the DNF and NPC scenarios resulting in over 100 sets of model results for both inflow hydrology approaches. These time series results, or traces, are summarized by ranking the results at each timestep and determining the 10^{th}, 50^{th}, and 90^{th} percentiles at each time step. These percentiles are presented to summarize DNF and NPC results based on their probability of occurring. However, it is important to keep in mind that each percentile summary does not represent any one continuous trace, but rather a statistic that summarizes the results of all of the traces. Therefore, percentile results presented as a time series do not represent reservoir operations as they would occur sequentially under any particular inflow scenario. Figure 4-1 is an example from a previous Reclamation report of how selected traces and percentile statistics compare for simulated storage in Lake Mead.

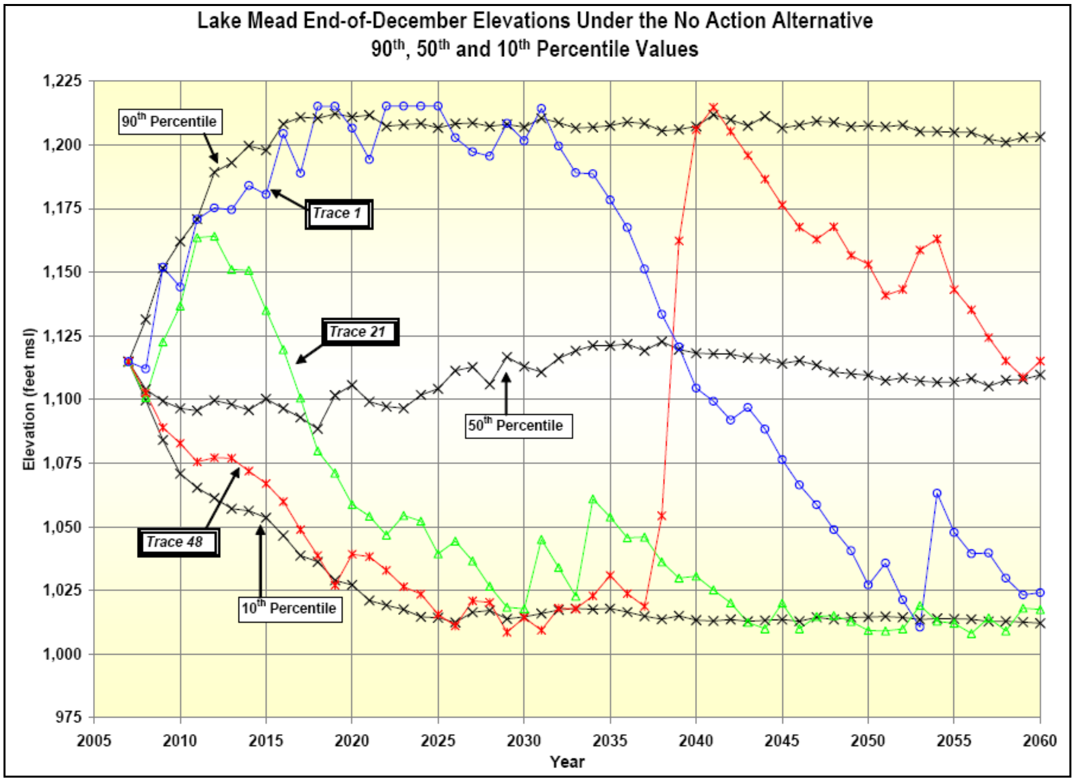


Figure 4-1
Example of Trace Results vs. Percentile Results
Source: Reclamation (2007)

The Final Planning Study results are summarized in Section 4.3.1.1, followed by the No Additional Depletions results in Section 4.3.1.2.

4.3.1.1 Final Planning Study (FPS)

For the Final Planning Study analysis, Reclamation's modeling of effects assumes that Utah's total annual depletions would remain the same for the Proposed Action and No Action scenarios and would match those in the Final EIS of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Shortage EIS). The spatial distribution of depletions for the State of Utah was modified for the Proposed Action scenarios to make the 86K withdrawals directly from Lake Powell rather than upstream of Lake Powell.

Figure 4-2 illustrates some of the differences between the NPC and DNF inflow simulations for the 86K pipeline scenario. Releases for the 50th percentile are plotted. The year 2027 is when reservoir operations in the simulation revert to the 2007 Shortage EIS No Action Alternative, a reduction in releases is apparent after that date. For the 50th percentile, there would be no difference in releases for the Proposed Action and No Action for the DNF inflow scenario and only minor differences for the NPC scenario. For the NPC inflow scenario, in 2 out of 52 simulated years, there would be differences in releases. Table 4-1 summarizes the differences in annual releases for the 10th, 50th, and 90th percentiles. The differences summarized all round to 0 percent when compared with the large volume of water released to the Colorado River. Figure 4-3 depicts the percent difference time series results for releases from Lake Powell. Simulated releases for each of the inflow simulations are discussed in the following sections.

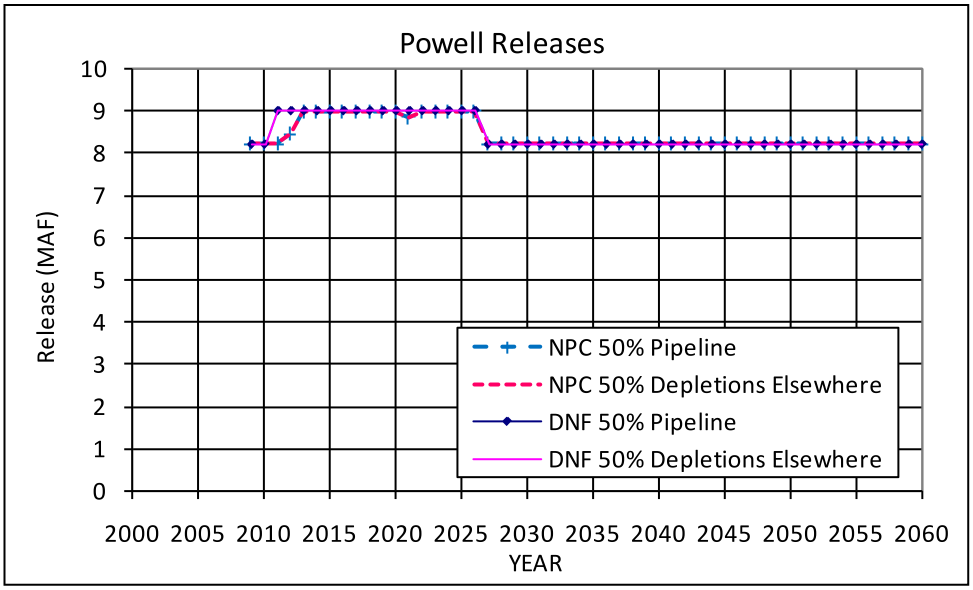


Figure 4-2
86K AF Simulations, 50th Percentile Lake Powell Releases Results (FPS)

Table 4-1
86K AF Simulations, Summary of Lake Powell Annual Release Differences (FPS)

	Acre-Feet per Year			Percent Difference		
Percentile	10th	50th	90th	10th	50th	90th
DNF Average Difference	0	0	3,164	0%	0%	0%
DNF Maximum Difference	0	0	-12,305	0%	0%	0%
NPC Average Difference	-497	-34	-3,503	0%	0%	0%
NPC Maximum Difference	-17,911	-1,589	-56,541	0%	0%	0%

Difference = Proposed Action – No Action; Percent Difference = Difference/No Action

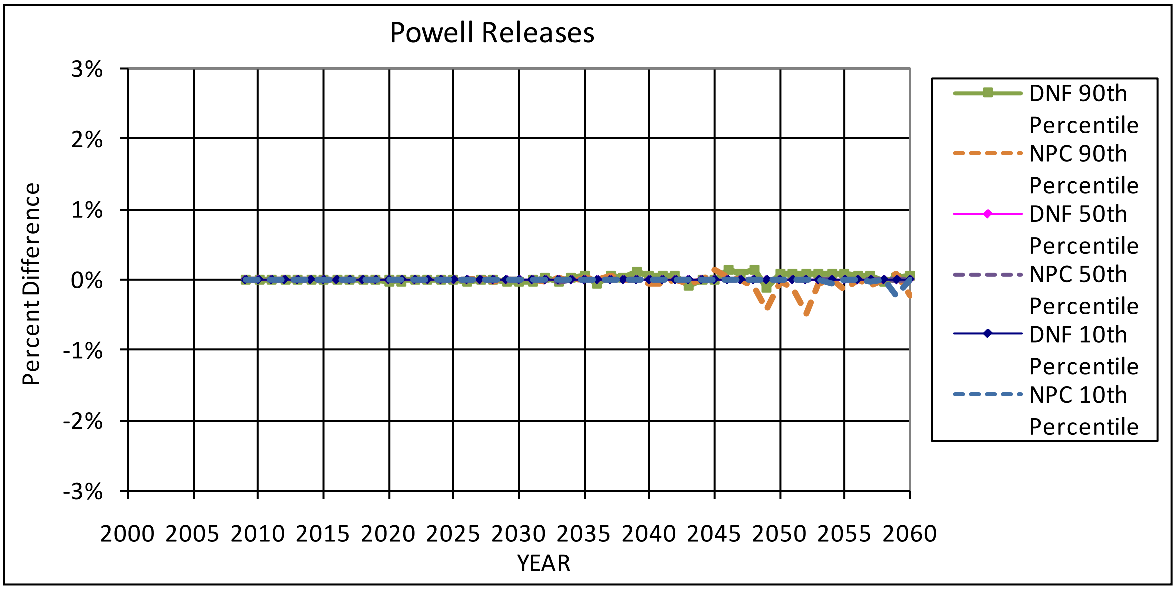


Figure 4-3
86K AF Simulations, Percent Difference in Lake Powell Releases (FPS)

4.3.1.1.1 Direct Natural Flow (DNF), ISM Results. DNF was the primary inflow dataset used for the 2007 Shortage EIS and therefore the results of this analysis are more comparable to those performed for that EIS. Under the 86K pipeline scenario, releases from Lake Powell (for the Proposed Action and No Action Alternative) are equal at the 10th and 50th percentiles and differ at the 90th percentile in some years. At the 90th percentile, releases for the Proposed Action are greater than the No Action Alternative more often. As summarized in Table 4-1, the 90th percentile average No Action Alternative releases are 3,164 AFY less than Proposed Action releases, a 0 percent difference. Figure 4-4 depicts the annual time series releases for the DNF scenario.

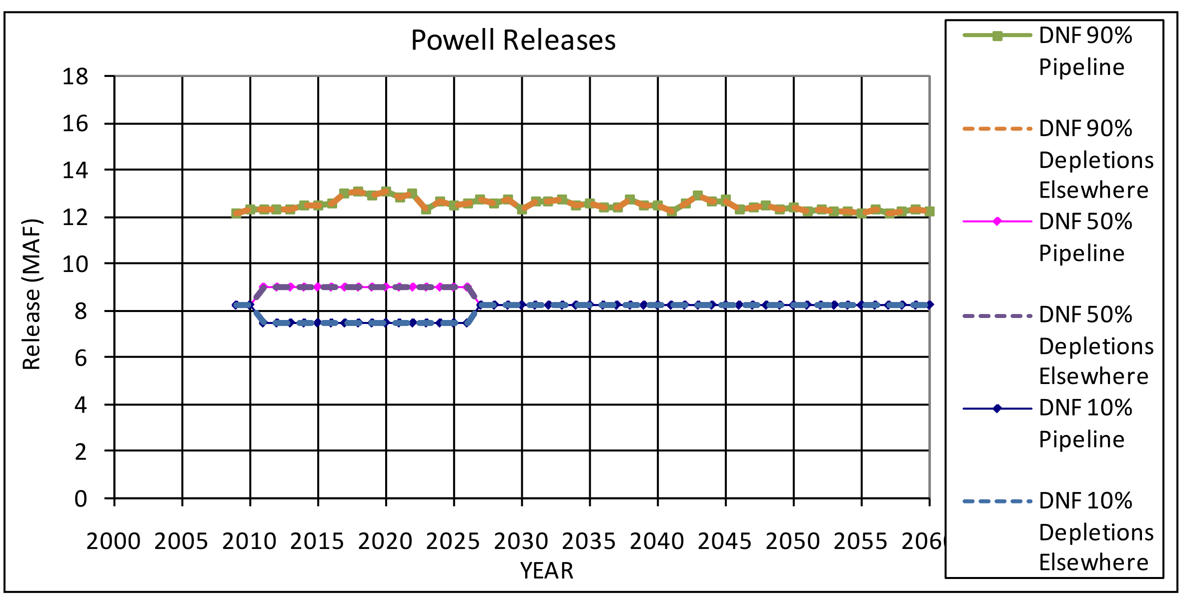


Figure 4-4
86K AF Simulations, DNF Lake Powell Releases Results (FPS)

4.3.1.1.2 Nonparametric Paleo-Conditioned (NPC) Results. Although the NPC and DNF simulations result in different water volumes released to the Colorado River, both showed minimal differences between the Proposed Action and No Action. As summarized in Table 4-1, at the 90th percentile, average No Action Alternative releases are 3,503 AFY more than Proposed Action releases, a 0 percent difference. Figure 4-5 depicts the annual time series releases for the NPC scenario.

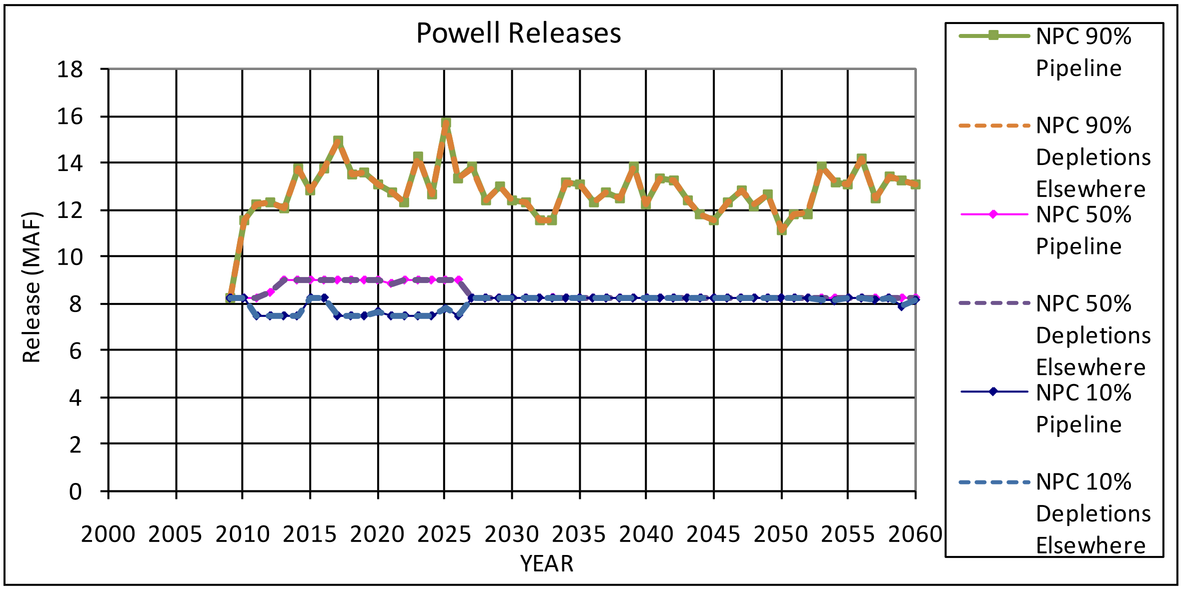


Figure 4-5
86K AF Simulations, NPC Lake Powell Releases Results (FPS)

4.3.1.2 No Additional Depletions

For the No Additional Depletions runs, water use was modeled the same as current levels plus those projects qualifying as reasonably foreseeable. The No Action scenario does not include a pipeline from Lake Powell.

Figure 4-6 illustrates some of the differences between the NPC and DNF inflow simulations under the 86K pipeline scenario. Releases at the 50th percentile are plotted. The year 2027 is when reservoir operations in the simulation revert to the 2007 Shortage EIS No Action Alternative, a reduction in releases is apparent after that date. At the 50th percentile, there would be no difference in releases for the Proposed Action and No Action Alternative under the DNF inflow scenario and only minor differences for the NPC scenario. For the NPC inflow scenario, in 5 out of 52 simulated years, there would be differences in releases. Table 4-2 summarizes the differences in annual releases at the 10th, 50th, and 90th percentiles. Differences are greatest for the 90th percentile and greater for NPC than DNF. Figure 4-7 depicts the percent difference time series results for releases from Lake Powell.

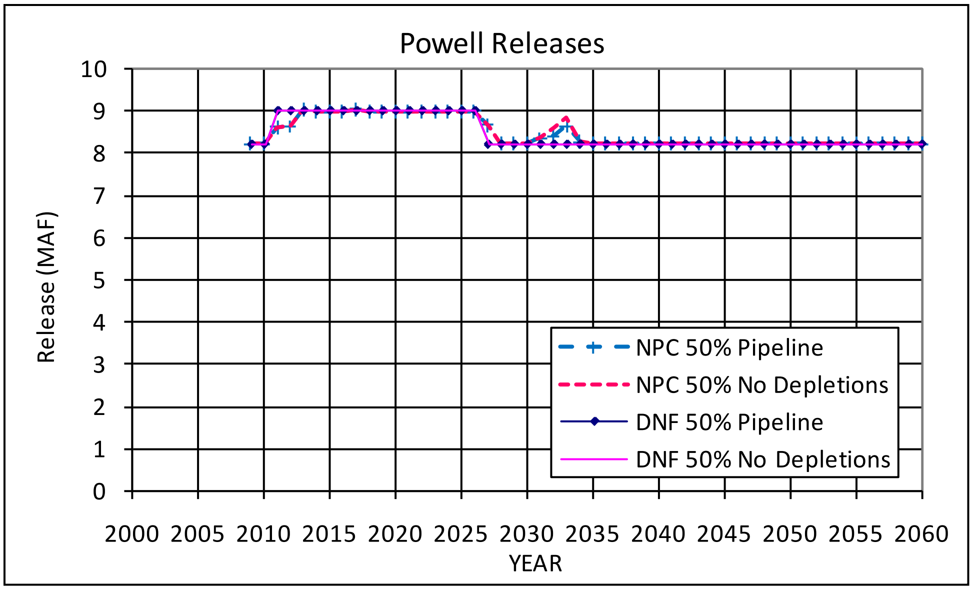


Figure 4-6
86K AF Simulations, 50th Percentile Lake Powell Releases Results (NAD)

Table 4-2
86K AF Simulations, Summary of Lake Powell Annual Release Differences (NAD)

	Acre-Feet per Year			**Percent Difference**		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
DNF Average Difference	0	0	-65,382	0%	0%	0%
DNF Maximum Difference	0	0	-335,557	0%	0%	-3%
NPC Average Difference	-19	-8,462	-90,150	0%	0%	-1%
NPC Maximum Difference	-967	-216,640	-502,347	0%	-2%	-4%
Difference = Proposed Action – No Action; Percent Difference = Difference/No Action						

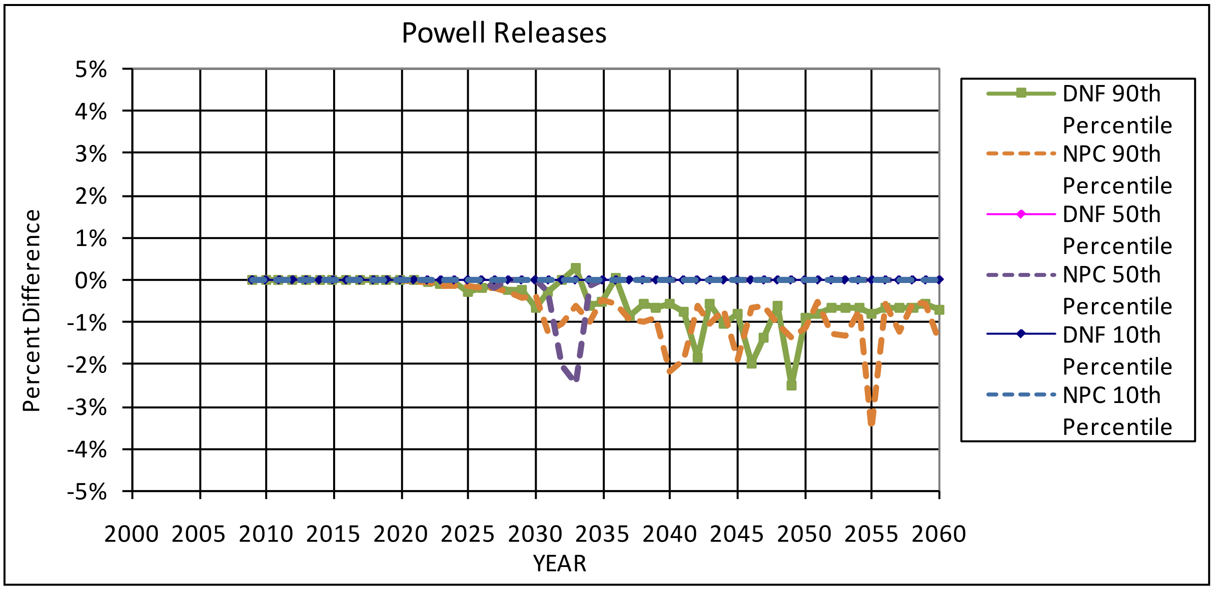


Figure 4-7
86K AF Simulations, Percent Difference in Lake Powell Releases (NAD)

4.3.1.2.1 Direct Natural Flow (DNF), ISM Results. Under the 86K pipeline scenario, releases from Lake Powell (for the Proposed Action and No Action Alternative) are equal at the 10^{th} and 50^{th} percentiles and differ by a small amount at the 90^{th} percentile in some years. At the 90^{th} percentile, releases under the No Action Alternative are greater than the Proposed Action more often. As summarized in Table 4-2, 90^{th} percentile average No Action Alternative releases are 65,382 AFY greater than Proposed Action, a 0 percent difference. Figure 4-8 depicts the annual time series releases for the DNF scenario.

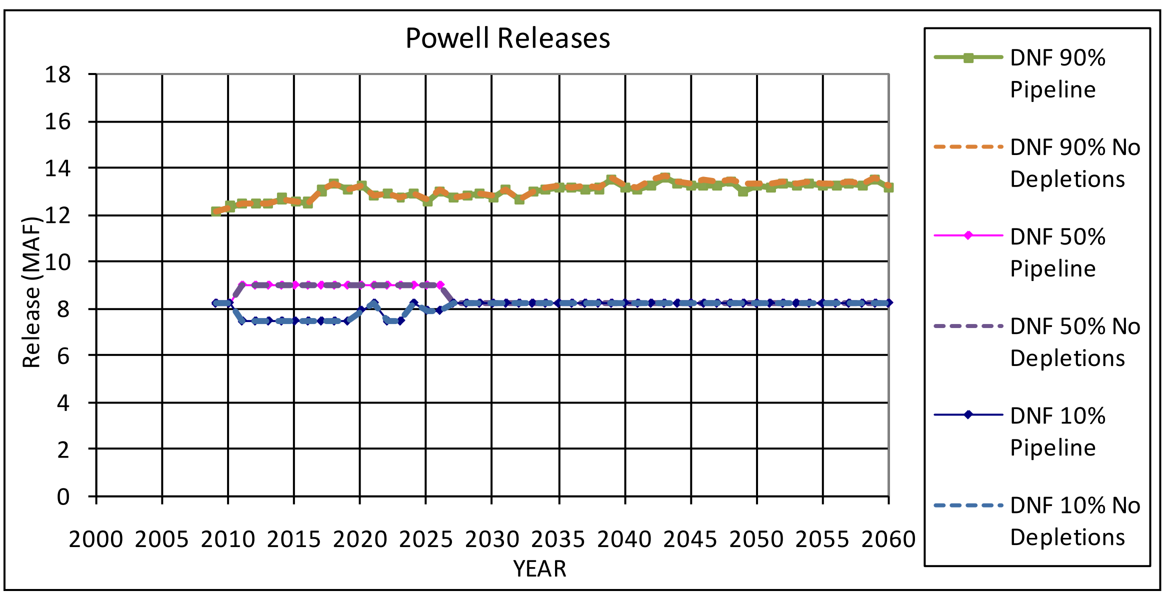


Figure 4-8
86K AF Simulations, DNF Lake Powell Releases Results (NAD)

4.3.1.2.2 Nonparametric Paleo-Conditioned (NPC) Results. Although the NPC and DNF simulations result in different water volumes released to the Colorado River, both showed minimal differences between the Proposed Action and No Action Alternative. Figure 4-9 depicts the annual time series releases for the NPC scenario. As summarized in Table 4-2, 90th percentile average No Action Alternative releases are 90,150 AFY greater than Proposed Action, a 1 percent difference.

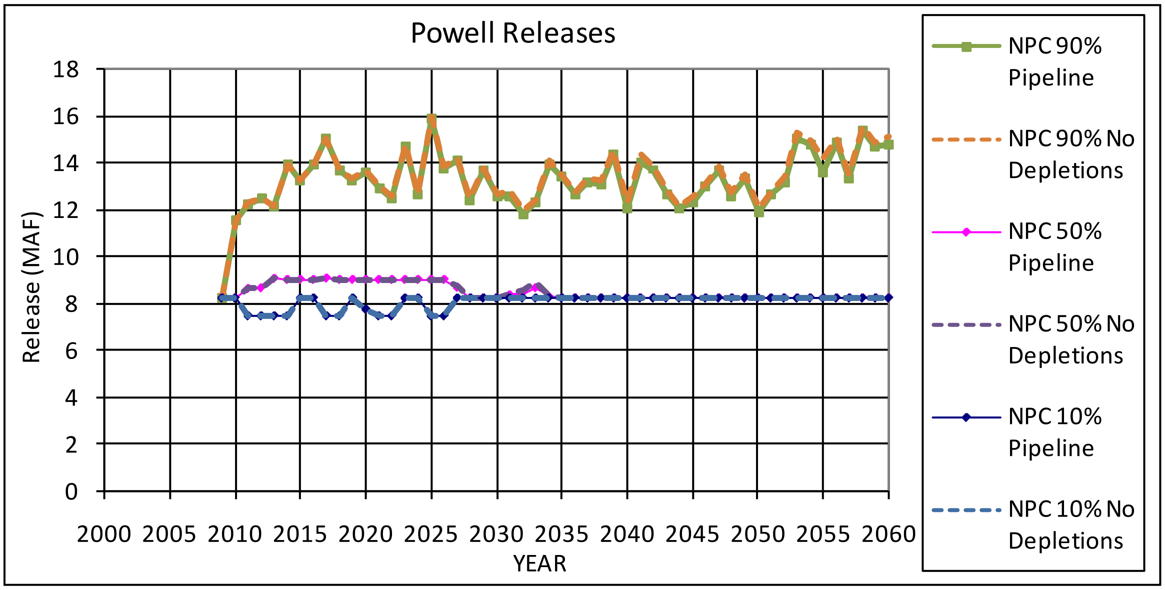


Figure 4-9
86K AF Simulations, NPC Lake Powell Releases Results (NAD)

4.3.2 Virgin River Drainages

The Virgin River Daily Simulation Model was used to evaluate hydrologic effects for three scenarios. Two simulations were performed with the model. Scenario 1 simulated the Base Case with full utilization of Virgin River water rights, without any additional storage or Lake Powell Pipeline deliveries. Scenario 2 represents the Proposed Action future conditions with the expanded secondary system utilizing 2,500 acre feet of re-regulating storage and 69,000 acre feet of annual Lake Powell Pipeline deliveries. The model simulates the maximum yield in the St. George Area with a specified maximum shortage in the worst year (10 percent in the Lake Powell Pipeline project simulations), while providing firm secondary water supplies to Hurricane, LaVerkin and Washington Fields.

The model includes five service areas. In the simulations, deliveries to the Hurricane, LaVerkin and Washington Fields service areas were unchanged between scenarios. Thus, return flows from these three service areas did not change between the simulations. Deliveries to service areas 4 and 5, representing the greater St. George area M&I demand and secondary use system were different between scenarios. Deliveries to these service areas are calculated by optimizing the resources in the model until a permitted shortage value is reached, in this case, 10 percent. Table 4-3 presents the deliveries made to each service area.

Table 4-3
Simulated Deliveries (acre-feet)

Service Area	Scenario 1-Base Case	Scenario 2-With Lake Powell Pipeline
1-LaVerkin	2,640	2,640
2-Hurricane	15,000	15,000
3-Washington Fields	62,214	62,224
4-St George Area M&I	22,587	80,212
5-Washington Fields Secondary	12,884	49,397
Total	**115,325**	**209,472**

The USGS Annual Water Data Report provides qualitative descriptions about the accuracy of the USGS stream gage measurements. For the two USGS gages representative of flow in the Virgin River below Quail Creek Reservoir (USGS 09408150 and USGS 09413500), accuracies are described as “good” and “fair”, respectively. A “good” rating means that measurements are within 10 percent of the actual flows and a “fair” rating represents daily discharge readings which are less accurate than “good” (USGS 2011). Differences in simulated streamflow along the Virgin River in the lower portion of the Washington County system were small, and within the degree of accuracy of the USGS stream gages in this area. Therefore, the differences between Virgin River flows under Scenario 1 (Base Case) and Scenario 2 (Proposed Action) would not be measurable. Table 4-4 shows the Virgin River Daily Simulation Model flow results with a comparison between the two scenarios and USGS gage error.

Table 4-4
Virgin River Daily Simulation Model Flow Results

USGS Gage No.	Gage Error	VRDSM Node	Scenario and Description	Water Year Months (cfs) Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
09408150	10%	QX21	1. Future w/ex. Fac.	98	97	108	114	131	191	302	364	130	94	101	105
			2. LPP+2500 AF St.	98	95	106	113	130	193	294	350	126	94	101	105
			Flow Difference	0	2	2	1	1	2	8	14	4	0	0	0
			Gage Error (flow)	10	10	11	11	13	19	29	35	13	9	10	11
09413200	10%	QX26	1. Future w/ex. Fac.	12	11	22	28	46	105	216	278	44	8	15	20
			2. LPP+2500 AF St.	12	10	20	27	45	107	208	264	40	8	15	19
			Flow Difference	0	1	2	1	1	2	8	14	4	0	0	1
			Gage Error (flow)	1	1	2	3	5	11	21	26	4	1	2	2
09413200	10%	QX27	1. Future w/ex. Fac.	41	47	67	80	100	155	259	312	73	34	40	46
			2. LPP+2500 AF St.	45	50	68	82	102	160	254	302	74	37	43	49
			Flow Difference	4	3	1	2	2	5	5	10	1	3	3	3
			Gage Error (flow)	4	5	7	8	10	16	25	30	7	3	4	5
09413200	10%	QX28	1. Future w/ex. Fac.	58	69	96	119	147	207	297	347	100	50	56	61
			2. LPP+2500 AF St.	63	74	98	122	150	214	294	339	102	55	61	67
			Flow Difference	5	5	2	3	3	7	3	8	2	5	5	6
			Gage Error (flow)	6	7	10	12	15	21	29	34	10	5	6	6
09413500	16%	QX29	1. Future w/ex. Fac.	60	76	103	123	151	210	297	347	100	50	56	62
			2. LPP+2500 AF St.	66	81	105	126	161	220	294	339	102	55	61	68
			Flow Difference	6	5	2	3	10	10	3	8	2	5	5	6
			Gage Error (flow)	10	12	16	20	24	34	47	54	16	8	9	10

Key: Flow difference exceeds USGS gage error
Flow difference is less than or equal to USGS gage error

Figure 4-10 shows simulated monthly average flows in the Virgin River below Quail Creek and Figure 4-11 shows the flow duration curves for the two scenarios. This location is downstream of return flows from Hurricane and LaVerkin, which do not change between simulations. It is also downstream of Quail Creek seepage and spill outflow to the Virgin River. This location is upstream of the Washington Fields Diversion, where the 86 cfs instream flow is measured.

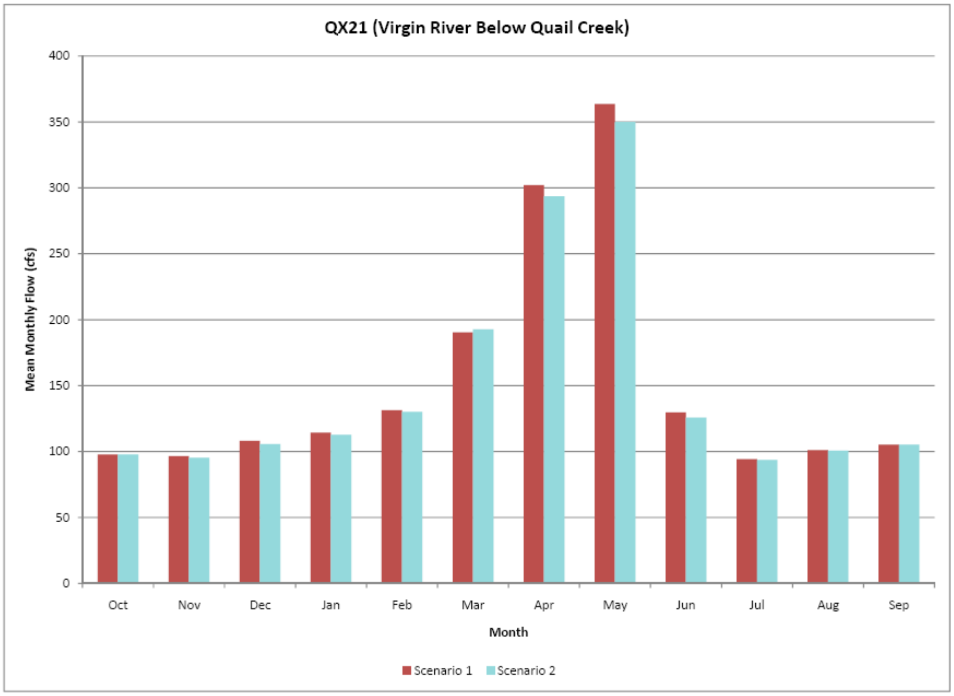


Figure 4-10
Virgin River Below Quail Creek – Simulated Monthly Flows

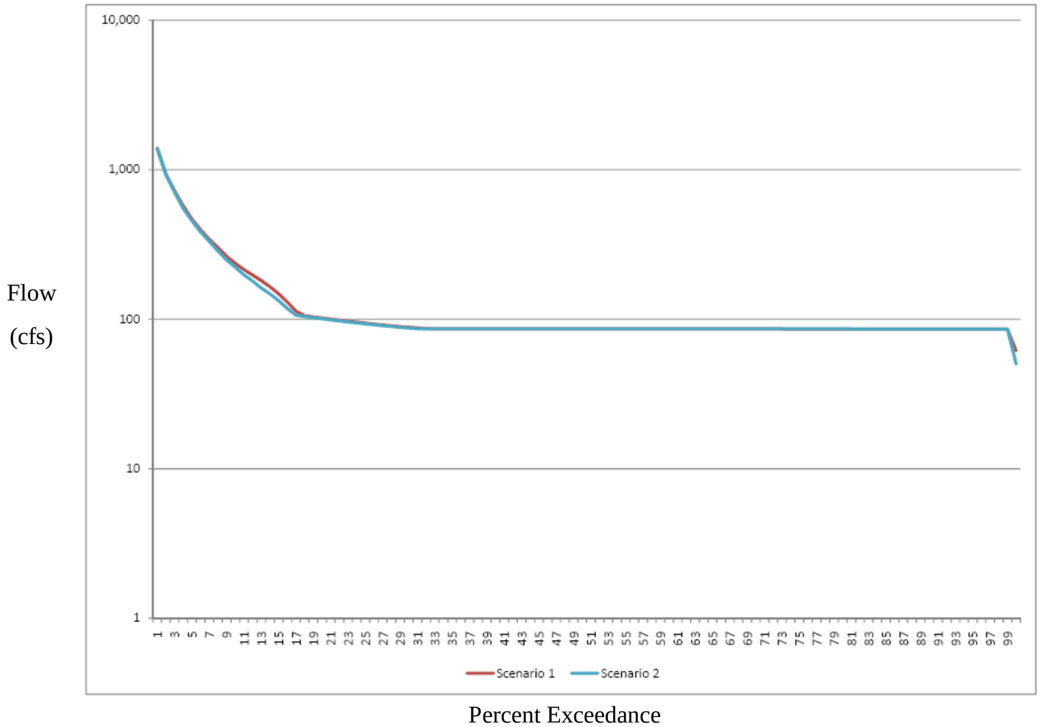


Figure 4-11
Virgin River Below Quail Creek – Simulated Flow Duration Curves

Figure 4-12 shows average monthly results for flow and Figure 4-13 shows flow duration curves for the Virgin River below the Washington Fields diversion. Although WCWCD may choose to leave some flow in the Virgin River at this point to prevent prolonged periods of zero flow, the simulation shows all of the water that can legally be diverted at this point. Both simulations resulted in low flows during the summer and fall months at this location as regulating storage is used and refilled in response outdoor secondary water demand throughout the summer.

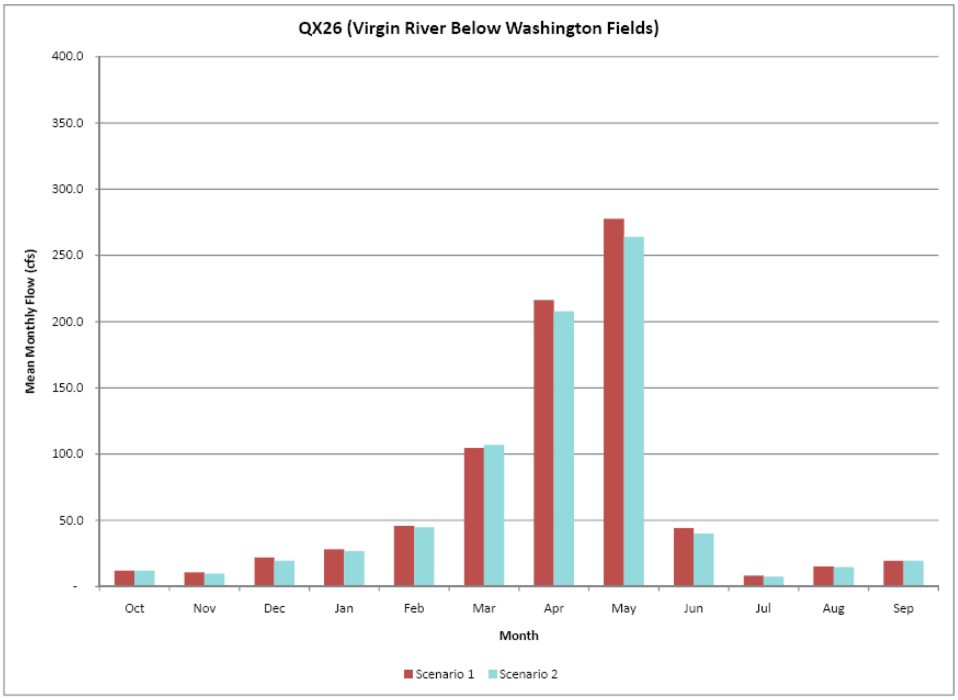
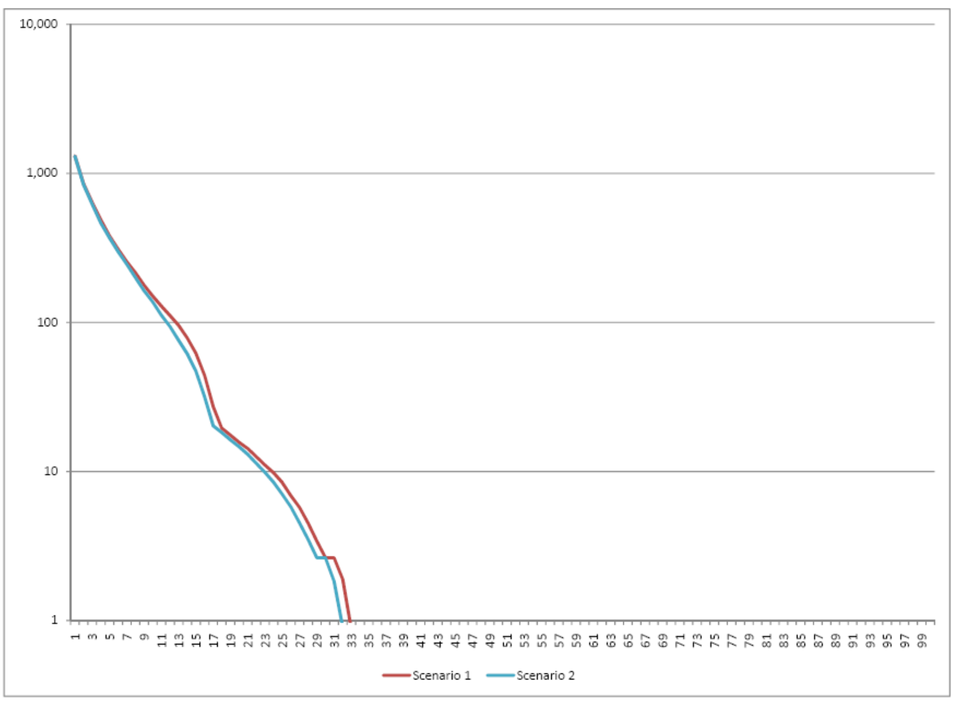


Figure 4-12
Virgin River Below Washington Fields Diversion – Simulated Monthly Flows

Flow (cfs)



Percent Exceedance

Figure 4-13
Virgin River Below Washington Fields Diversion – Simulated Flow Duration Curves

Figure 4-14 shows simulated monthly average flows in the Virgin River downstream of the Santa Clara River and immediately upstream of the St. George M&I land area return flow location. Figure 4-15 shows the simulated flow duration curves. Return flows from the Washington Fields land area are represented at this location.

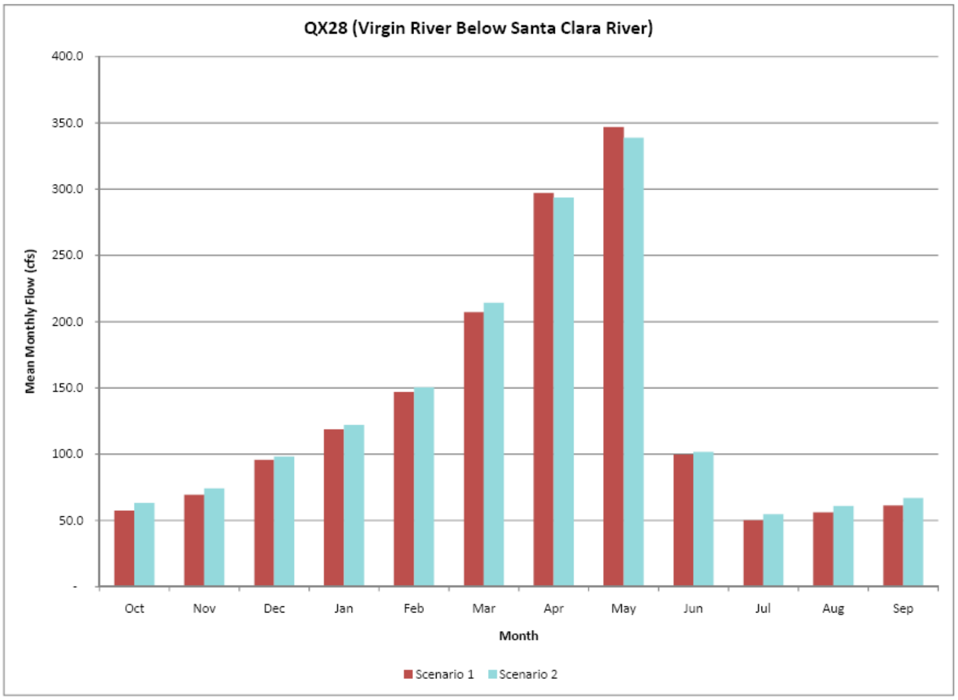
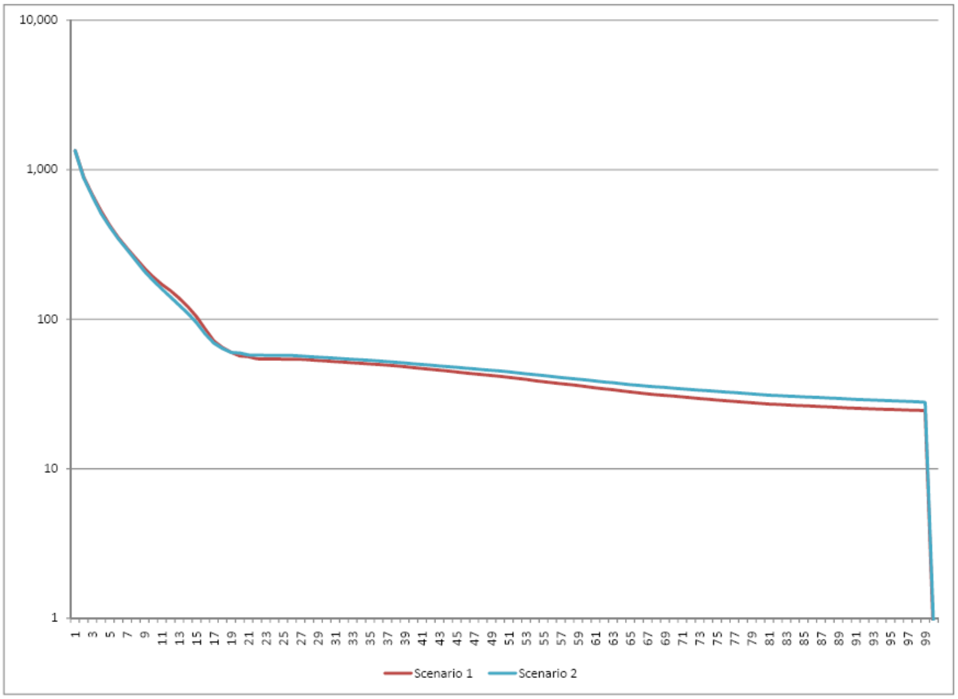


Figure 4-14
Virgin River Below Santa Clara River – Simulated Monthly Flows

Flow

(cfs)



Percent Exceedance

Figure 4-15
Virgin River Below Santa Clara River – Simulated Flow Duration Curves

Simulated monthly average flows for the Virgin River at the Utah-Arizona State line are shown in Figure 4-16 while simulated flow duration curves are shown in Figure 4-17. Flows at this location include return flows from the St. George M&I land area.

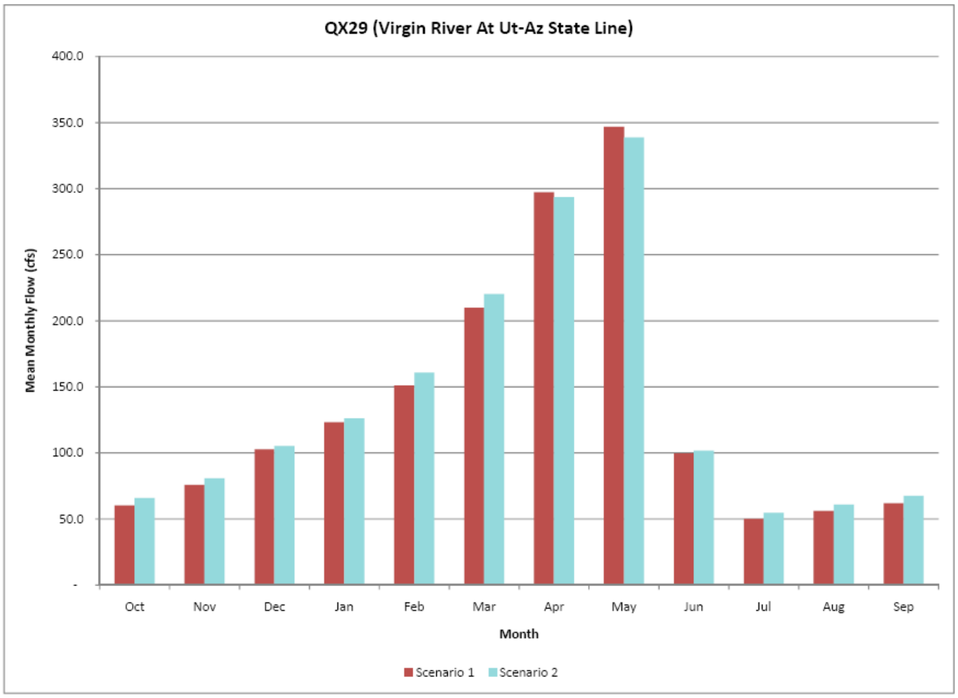
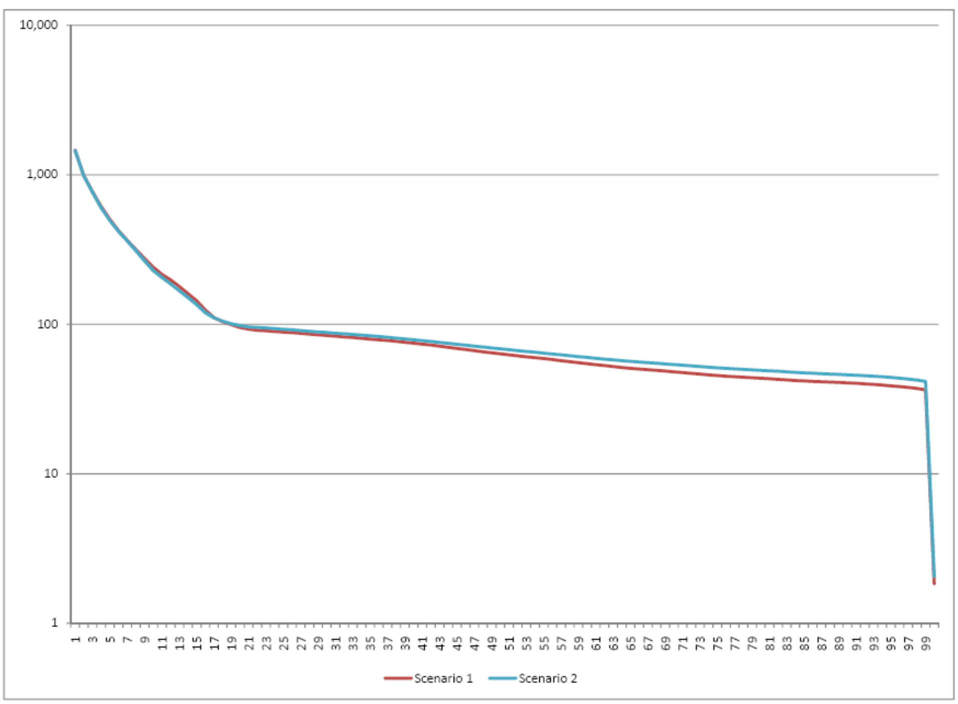


Figure 4-16
Virgin River at Utah-Arizona State Line – Simulated Monthly Flows

Flow (cfs)



Percent Exceedance

Figure 4-17
Virgin River at Utah-Arizona State Line – Simulated Flow Duration Curves

4.3.2.1 Stream Crossings

The only intermittent stream tributary to the Virgin River that would be crossed by the pipeline is Gould Wash, which would be crossed by the Cedar Valley Pipeline System south of Hurricane. For intermittent streams, the pipeline would be buried under the stream channel and construction activities would be planned to occur in the dry season when these channels typically would not be carrying water so that the LPP would not affect streamflows. Storms could cause flow in the channel or flash floods during the time of construction. The construction crew would have equipment on hand to divert flow around the construction area if this were to occur. This could have temporary and minor effects on natural streamflows, channel velocities and local erosion.

The Ash Creek crossing and Virgin River crossing at Sheep Bridge near Virgin would both be aerial crossings, which would not affect streams or streamflows.

The Proposed Action includes an open cut across LaVerkin Creek near Toquerville. Construction could be planned for summer when flows are typically at their lowest. The open cut would likely require construction in one half of the stream channel at a time using a water bladder dam and culvert pipes to direct flow to the other half of the stream. Water seeping into the construction area would be pumped out, likely into settling ponds, and disposed using land application. This would probably not affect the stream flow substantially, but could result in different flow velocities and erosion of bank and bed materials.

4.3.3 Kane, Mohave, and Coconino County Drainages

4.3.3.1 Return Flows

Kane County Water Conservancy District (KCWCD) has requested 10,000 AFY in LPP supply and was allocated 4,000 AFY by the State for this analysis. KCWCD does not require LPP water until after 2060 because additional groundwater and agricultural conversions could supply their needs during the planning horizon. According to the Water Needs Assessment, KCWCD may choose to take deliveries from the LPP prior to 2060 for several reasons, particularly because the pipeline will traverse Kane County (UDWR 2011).

Assuming that the City of Kanab uses the full 4,000 AFY according to their 2005 water use patterns (see Table 3-3) this would result in an additional 800 AFY of non-sewered return flow. More than 1,400 AFY of additional flow would be delivered to Kanab’s wastewater treatment facility, more than tripling the amount of water treated, and an additional 780 AFY of sewered return flow would accrue to Kanab Creek. The additional return flows would result in about 3 cfs of additional flow in Kanab Creek downstream of Kanab. If some of the 4,000 AFY allocated to KCWCD is used in the Johnson Canyon area or other parts of the KCWCD service area, return flows would attribute to local drainages proportional to the increase in water use and less return flow would accrue to Kanab Creek.

Figure 4-18 shows Kanab Creek downstream of Kanab, at the proposed location of the Existing Highway Alternative crossing. Based on field observations, the creek is frequently dry at this location and the channel is filled with vegetation. It is likely that additional return flows from LPP deliveries would result in more frequent flow in Kanab Creek downstream of Kanab.

Figure 4-18
Kanab Creek Near Arizona Route 389 in Fredonia - Facing Downstream

4.3.3.2 Stream Crossings

The pipeline would cross several intermittent streams in Kane, Mohave and Coconino counties as listed in Table 2-1 and shown in Figure 3-40. Field visits of the South Alignment Kanab Creek crossing and Highway Alignment crossing locations show that these sites are frequently dry. At intermittent streams, open cuts for pipeline construction could be scheduled for the dry season to avoid affecting streamflows or ephemeral aquatic habitat. The pipeline would be buried under each stream channel once construction is completed such that the streams or stream flow would not be affected by LPP operation.

There is typically a small amount of flow in the Paria River at the proposed crossing location at U.S. Highway 89. Figure 4-19 shows the highway bridge and USGS stream gage. As described for LaVerkin Creek in Section 4.3.2.1, the Proposed Action includes an open cut across this reach for pipeline construction. The open cut would likely require construction in one half of the stream channel at a time using water bladder dams and culvert pipes to direct flow to another part of the wide channel cross section. Streamflows would not be substantially affected, but the redirection of flow to part of the channel could result in different flow velocities and potential erosion of bank and bed materials.

Figure 4-19
Paria River Near Kanab USGS Gage and Highway 89
Source: USGS (2009)

4.3.4 Iron County Drainages

Return flows for KCWCD and CICWCD are not specifically modeled. CICWCD is assumed to receive up to 13,249 AFY of water from the LPP under the 86K alternative. Assuming the same water use and return flow ratios as described for existing conditions in Table 3-3, this would result in an additional 2,300 AFY of non-sewered return flow. Non-sewered return flow only affects surface water flows for part of the year because it is applied outdoors during the summer months and returns to the stream with a delay because of groundwater travel time. Drainage patterns through Cedar City are generally to the northwest, although water may either flow south of the airport and eventually toward Quichapa Lake or north of the airport and eventually to Rush Lake. Generally, surface flows are lost before they reach these terminal lakes. Under the Proposed Action, there may be additional flow in swales and ditches in the summer and fall because of additional outdoor water use.

More than 5,600 AFY of additional sewered return flow would be captured at Cedar City's wastewater treatment facility, more than doubling the amount of water treated. This would result in an additional 3,700 AFY of treated effluent that could either be: (1) land applied according to the current practice, with excess flows accumulating in the vicinity of Rush Lake; or (2) treated in a new wastewater reuse plant and distributed in Cedar Valley as secondary water.

The LPP would not cross any major streams in Iron County.

4.4 Reservoirs

4.4.1 Lake Powell

The effects on Lake Powell are based on the results of modeling completed by Reclamation. This section summarizes the findings of Reclamation's report, included in its entirety in Appendix B. The Final Planning Study results are summarized in Section 4.4.1.1, followed by the No Additional Depletions results in Section 4.4.1.2.

4.4.1.1 Final Planning Study (FPS)

Under the Final Planning Study analysis, Reclamation's modeling of effects assumes that Utah's total annual depletions would remain the same for the Proposed Action and No Action Alternative scenarios but the location of withdrawal would be different.

The Proposed Action traces result in slightly lower Lake Powell storage than the No Action Alternative. Figure 4-20 illustrates some of the differences between the NPC and DNF simulations at the 50th percentile. Although the different inflow hydrology scenarios result in different pool elevations, the differences between the Proposed Action and No Action runs are similar for the NPC and DNF inflow scenarios. For the 50th percentile results, reservoir storage would differ by less than 1 foot. Table 4-5 summarizes the average difference in simulated reservoir pool elevation at the 10th, 50th, and 90th percentiles over the model period and the maximum difference in pool elevation over the period.

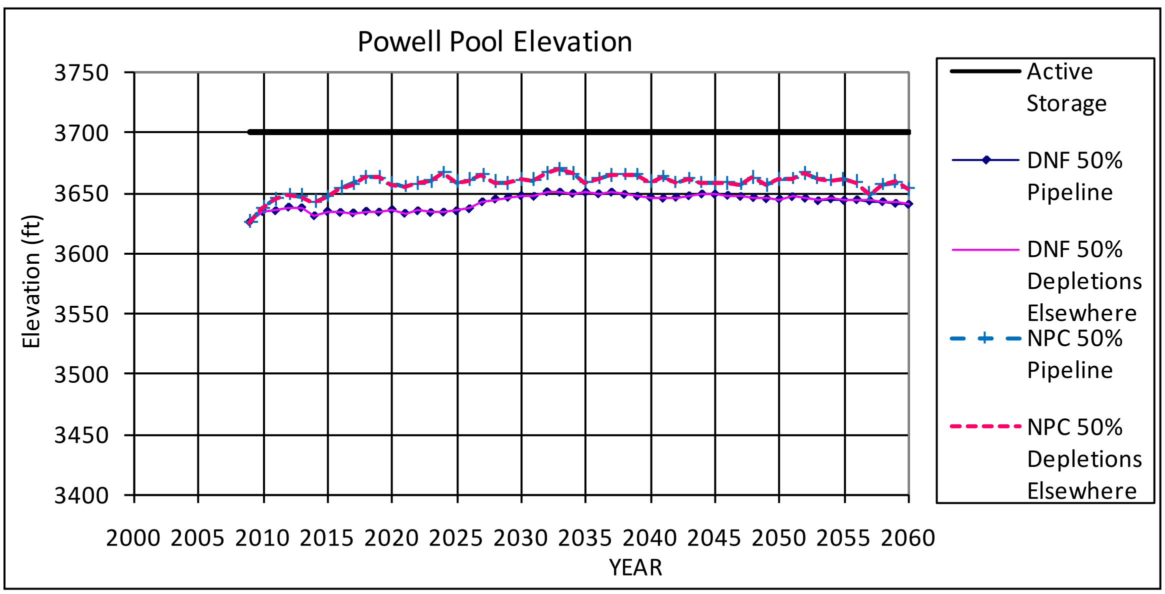


Figure 4-20
86K AF Simulations, 50th Percentile Lake Powell Stage Results (FPS)

Table 4-5 86K AF Simulations, Summary of Lake Powell Pool Stage Differences (Feet) (FPS)			
Percentile	**10th**	**50th**	**90th**
DNF Average Difference	-0.5	-0.2	0.0
DNF Maximum Difference	-1.8	-0.6	0.0
NPC Average Difference	-0.3	-0.1	0.0
NPC Maximum Difference	-1.7	-0.4	0.0
Difference = Proposed Action – No Action Percent Difference = Difference/No Action			

Figure 4-21 shows 50th percentile storage volumes for the two inflow scenarios. Table 4-6 summarizes the average and maximum differences in simulated reservoir storage at the 10th, 50th, and 90th percentiles over the model period. Only the 10th percentile shows any years with differences greater than 0 percent. Figure 4-22 depicts how the percent difference in storage volume varies over the model period for the three percentiles.

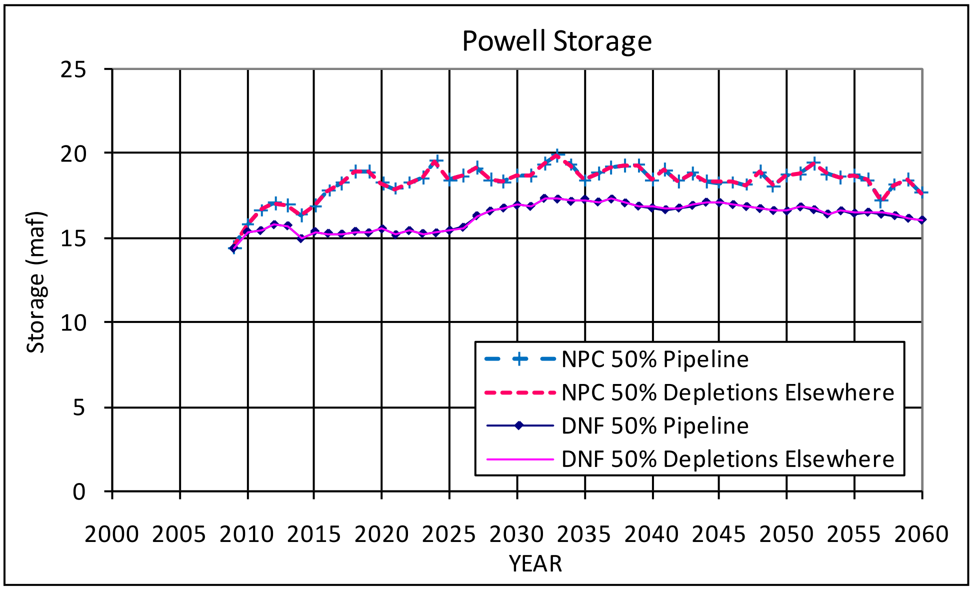


Figure 4-21
86K AF Simulations, 50th Percentile Lake Powell Storage Results (FPS)

Table 4-6 86K AF Simulations, Summary of Lake Powell Storage Differences (FPS)						
	Absolute Difference (AF)			Percent Difference		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
DNF Average Difference	-32,000	-25,000	-1,000	0%	0%	0%
DNF Maximum Difference	-128,000	-75,000	-3,000	-2%	0%	0%
NPC Average Difference	-17,000	-10,000	-2,000	0%	0%	0%
NPC Maximum Difference	-92,000	-47,000	-4,000	-2%	0%	0%
Difference = Proposed Action – No Action; Percent Difference = Difference/No Action						

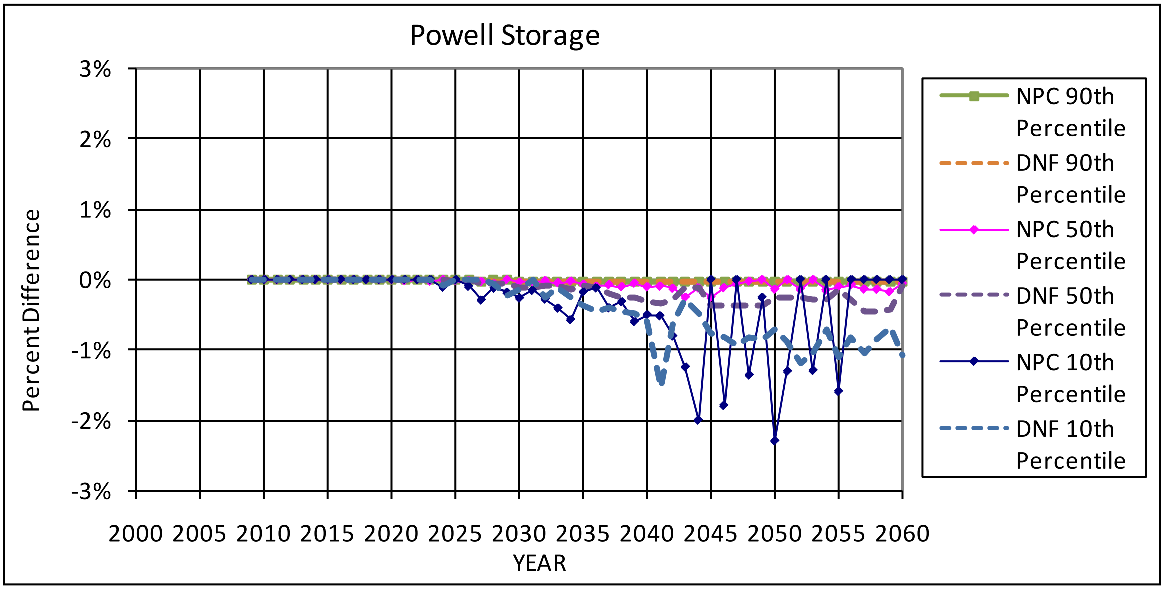


Figure 4-22
86K AF Simulations, Percent Difference in Lake Powell Storage Volume (FPS)

Additional details for the two inflow scenarios are included in the following sections.

4.4.1.1.1 DNF Results. Figure 4-23 shows the DNF scenario results at the 10th, 50th, and 90th percentiles. There is little difference in reservoir storage for any of the percentiles.

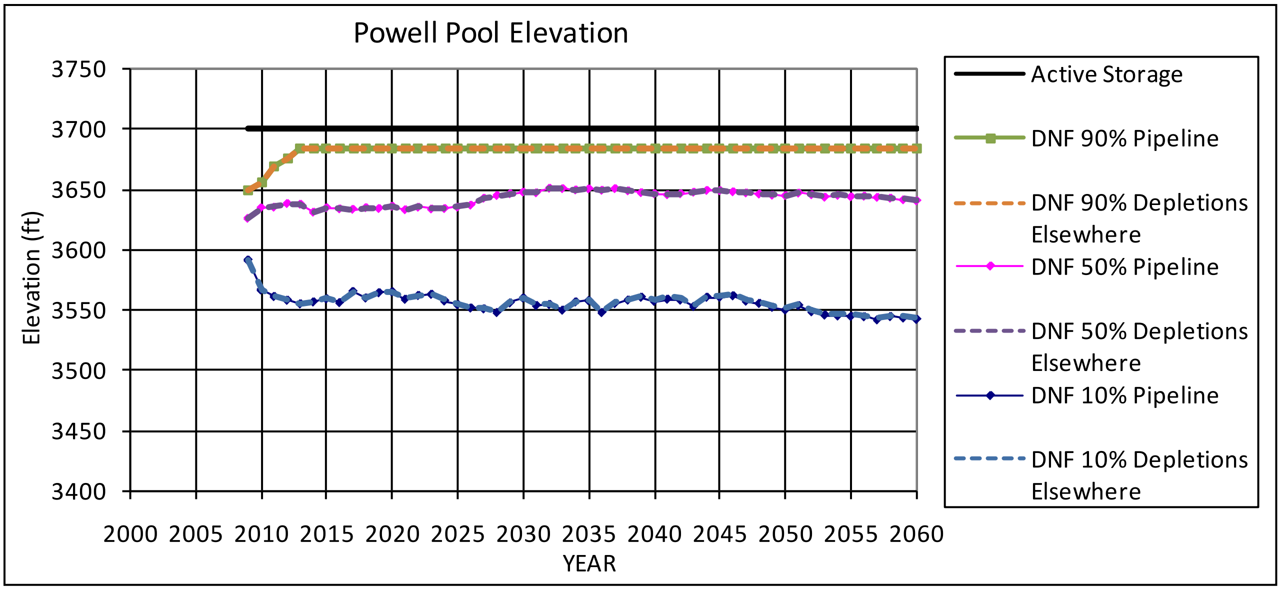


Figure 4-23
86K AF Simulations, DNF Lake Powell Stage Results (FPS)

4.4.1.1.2 NPC Results. Figure 4-24 shows the NPC scenario results at the 10th, 50th, and 90th percentiles. Although the simulated reservoir levels are particularly different from the DNF results for the 10th percentile, the differences between the Proposed Action and No Action storage levels are minimal and are similar to the DNF results.

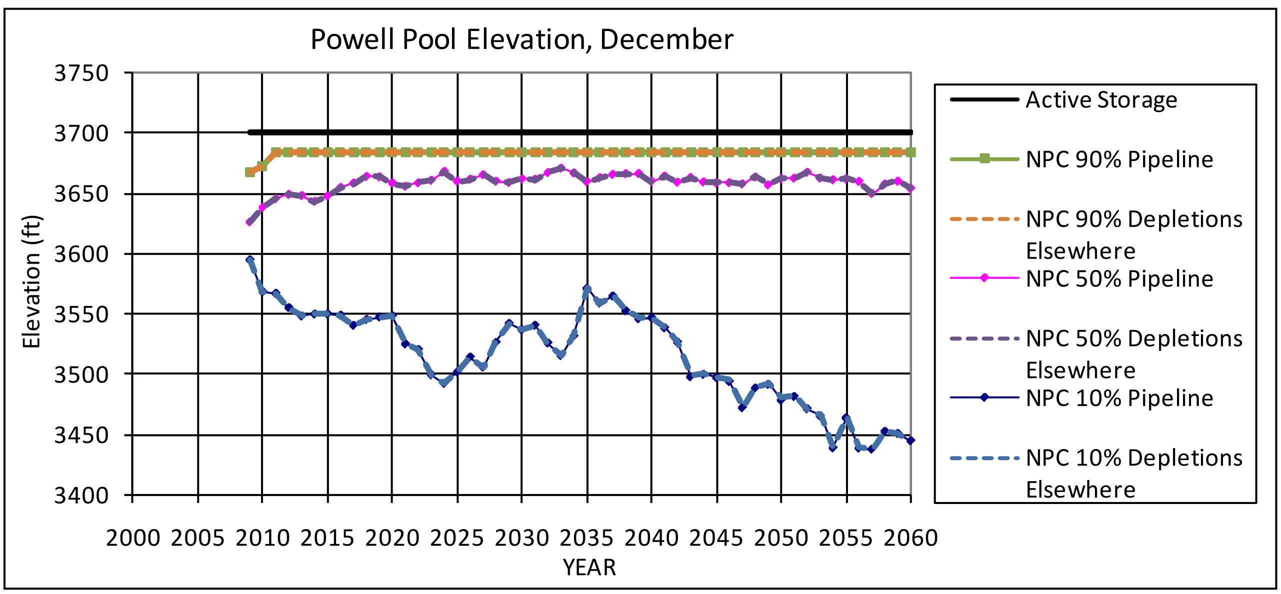


Figure 4-24
86K AF Simulations, NPC Lake Powell Stage Results (FPS)

4.4.1.2 No Additional Depletions (NAD)

For the No Additional Depletions runs, water use was the same as current levels plus those projects qualifying as reasonably foreseeable. The No Action Alternative scenario does not include a pipeline from Lake Powell or another location in the state.

The Proposed Action scenarios result in lower Lake Powell storage than the No Action. Figure 4-25 illustrates some of the differences between the NPC and DNF simulations for the 50th percentile. Pool elevation begins to differ between the No Action Alternative and Proposed Acton in the second half of the model period. For the 50th percentile results, reservoir storage would differ by about 6 feet or less under the DNF hydrology and 4 feet or less under the NPC hydrology. Table 4-7 summarizes the average difference in simulated reservoir pool elevation at the 10th, 50th, and 90th percentiles over the model period and the maximum difference in pool elevation over the period.

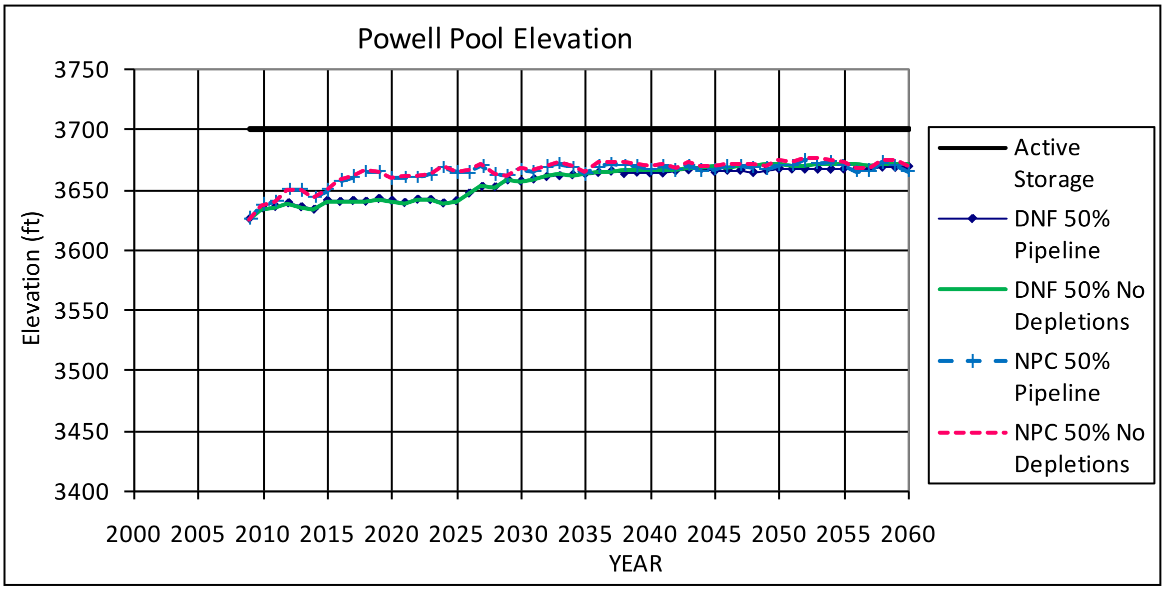


Figure 4-25
86K AF Simulations, 50th Percentile Lake Powell Stage Results (NAD)

Table 4-7
86K AF Simulations, Summary of Lake Powell Pool Stage Differences (Feet) (NAD)

Percentile	10th	50th	90th
DNF Average Difference	-3.6	-2.1	-0.1
DNF Maximum Difference	-11.3	-6.2	-0.4
NPC Average Difference	-4.7	-1.0	0.0
NPC Maximum Difference	-19.4	-4.0	-0.2
Difference = Proposed Action – No Action Percent Difference = Difference/No Action			

Figure 4-26 shows 50th percentile storage volumes for the two inflow scenarios. Table 4-8 summarizes the average and maximum differences in simulated reservoir storage at the 10th, 50th, and 90th percentiles over the model period. The 10th and 50th percentiles, when storage is low and median, show storage volume differences greater than 0 percent. Figure 4-27 depicts how the percent difference in storage volume varies over the model period for the three percentiles.

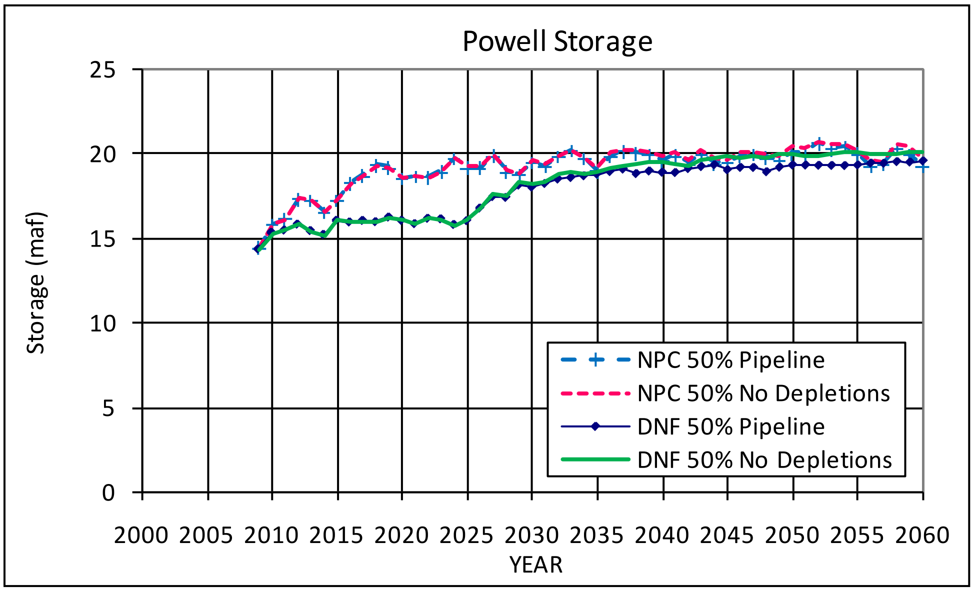


Figure 4-26
86K AF Simulations, 50th Percentile Lake Powell Storage Results (NAD)

Table 4-8
86K AF Simulations, Summary of Lake Powell Storage Differences (NAD)

	Absolute Difference (AF)			Percent Difference		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
DNF Average Difference	-334,000	-292,000	-12,000	-3%	-1%	0%
DNF Maximum Difference	-1,051,000	-839,000	-61,000	-9%	-4%	0%
NPC Average Difference	-313,000	-134,000	-6,000	-5%	-1%	0%
NPC Maximum Difference	-1,154,000	-554,000	-30,000	-24%	-3%	0%
Difference = Proposed Action – No Action; Percent Difference = Difference/No Action						

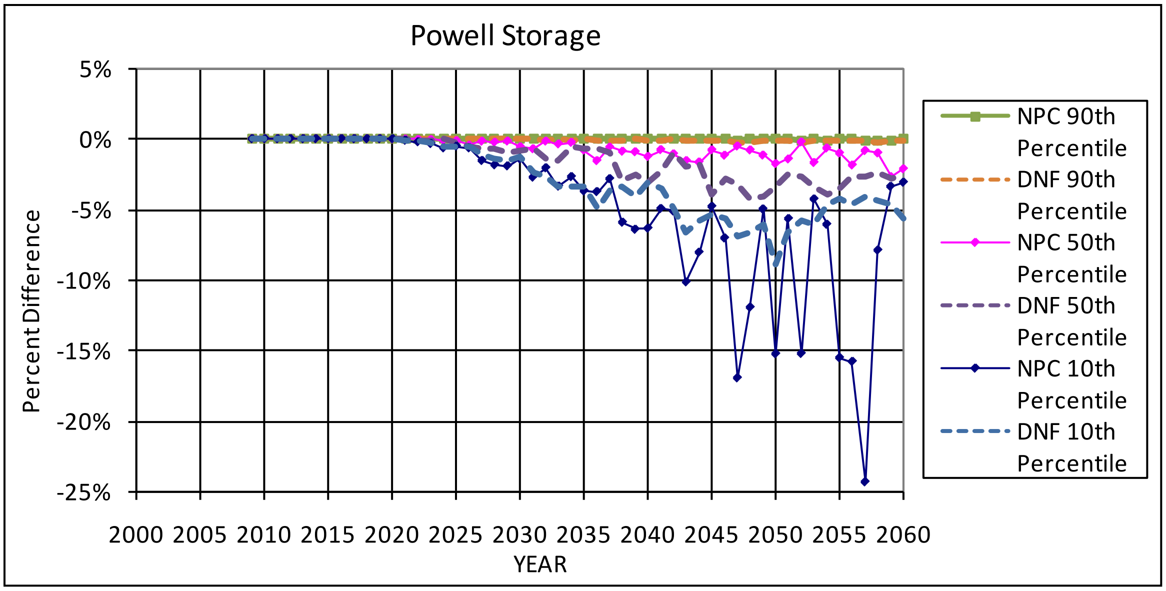


Figure 4-27
86K AF Simulations, Percent Difference in Lake Powell Storage Volume (NAD)

Additional details for the two inflow scenarios are included in the following sections.

4.4.1.2.1 DNF Results. Figure 4-28 shows the DNF scenario results at the 10th, 50th, and 90th percentiles. The greatest stage difference is 11 feet at the 10th percentile.

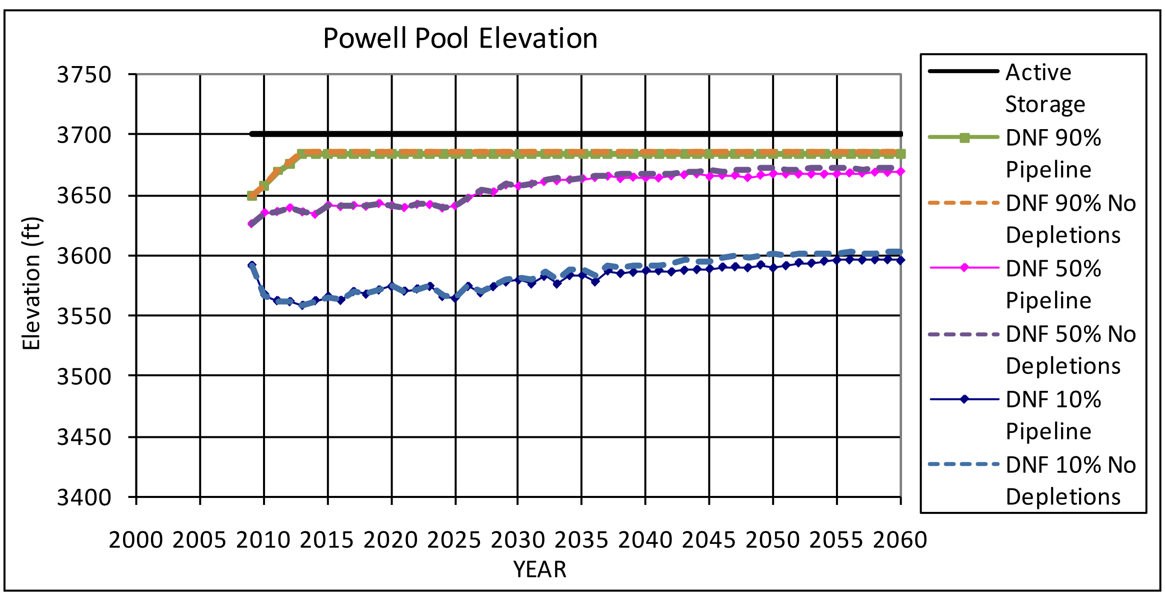


Figure 4-28
86K AF Simulations, DNF Lake Powell Stage Results (NAD)

4.4.1.2.2 NPC Results. Figure 4-29 shows the NPC scenario results at the 10th, 50th, and 90th percentiles. The simulated reservoir levels are particularly different from the DNF results at the 10th percentile, where water levels are about 100 feet lower. There is little difference between the alternatives for the 50th and 90th percentiles, and up to 19 feet of difference for the 10th percentile. Figure 4-30 shows the difference in water volume. The differences between the alternatives are up to 1 million acre-feet at the 10th percentile.

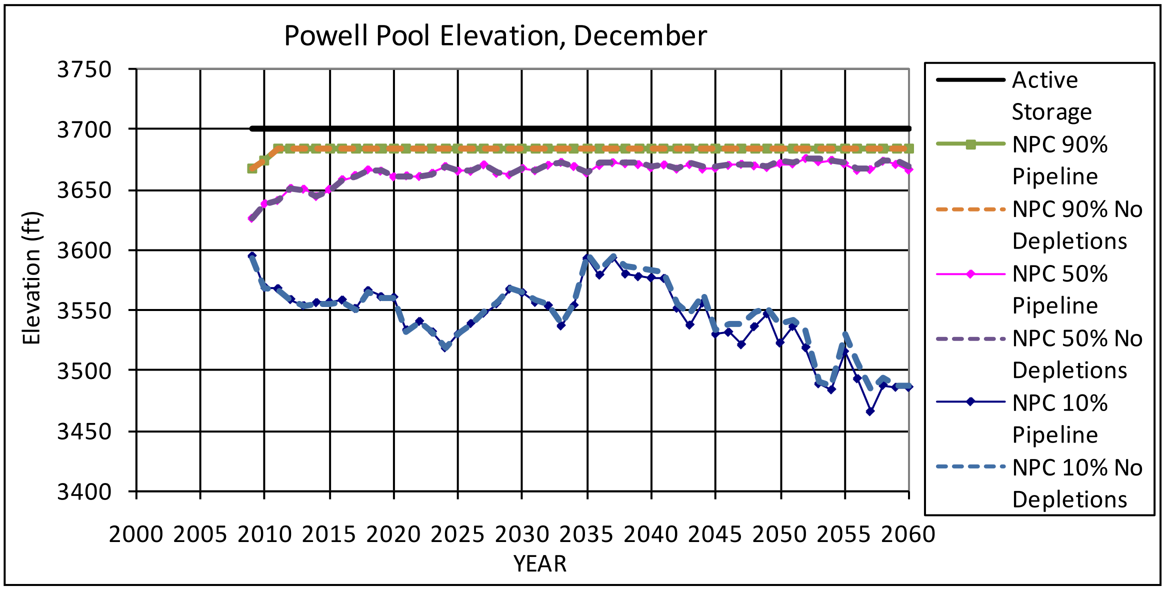


Figure 4-29
86K AF Simulations, NPC Lake Powell Stage Results (NAD)

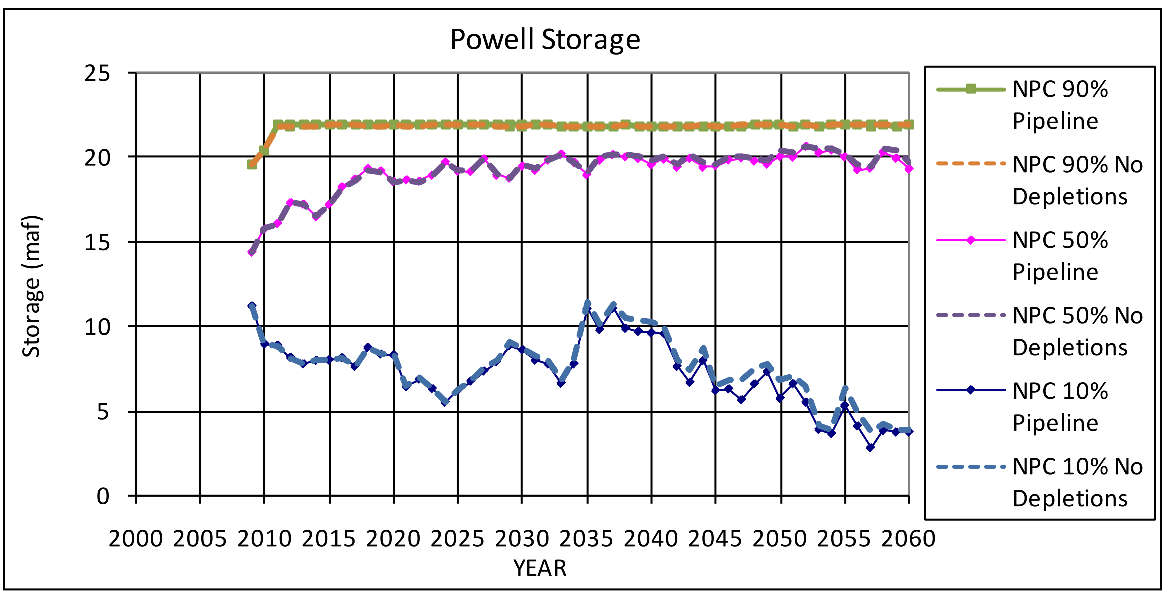


Figure 4-30
86K AF Simulations, NPC Lake Powell Storage Results (NAD)

4.5 Peak Flows

The impacts on peak flows would be minimal because the Proposed Action would not include the construction of any on-channel reservoirs. In cases of particularly erosive streams, the pipe may be protected by concrete encasement or a grade control structure that would be buried beneath the channel bed on the downstream side. If a grade control structure were to be uncovered during a high flow event, the structure could potentially affect peak flows and the geomorphology of the stream.

The Hurricane Cliffs Hydropower Forebay and Afterbay included in the Proposed Action could affect peak flows slightly by modifying the drainage area tributary to Fort Pierce Wash. However the facilities would have a relatively small storage volume available for intercepting storm runoff, and therefore would result in an unmeasurable decrease in flood peaks and volumes downstream.

4.6 Geomorphology

As described in Chapter 3, streams in the study area are highly susceptible to erosion from peak flow events. The LPP would have no measurable impact on peak flow rates in the study area, and therefore, would not result in changes to stream channel movement or sediment transport during peak events. As described above, concrete pipe encasements or buried grade control structures that become uncovered during peak flow events could affect the natural stream response to peak flows.

There could be temporary geomorphology effects during construction at any stream crossings where water is actively flowing. Water bladder dams used as diversion structures and coffer dams during construction in stream channels would minimize local geomorphologic changes.

For the Colorado River downstream of Lake Powell, there would be little to no effect on flows in the Colorado River and therefore no change in the sediment transport or channel forming flows. In addition, because there would be little or no effect on storage in Lake Powell, there would not be any effect on the ability to conduct high flow experimental releases from Lake Powell. These high flow experiments have been shown to affect geomorphology in the lower Colorado River and the Grand Canyon.

Chapter 5
Mitigation and Monitoring

5.1 Mitigation

The Best Management Practices (BMPs) described in Chapter 4 would be implemented as part of the LPP Project construction. Mitigation measures would not be necessary because the impacts on streams, reservoirs, lakes, peak flows and geomorphology would not be measurable.

5.2 Monitoring

Streamflows and reservoir levels in the southwest Utah study area are monitored on an ongoing basis by the local water conservancy districts and the USGS. Reservoir levels and streamflows on the Colorado River are monitored by Reclamation and the USGS. This monitoring is expected to continue into the foreseeable future.

Chapter 6
Unavoidable Adverse Impacts

Unavoidable adverse impacts are those environmental consequences of an action that cannot be avoided, either by changing the nature of the action or through mitigation if the action is undertaken.

All of alternatives would indirectly alter the hydrologic regime of certain reaches of the Virgin River, Santa Clara River, and other tributaries draining developed areas within Washington County. These hydrologic impacts would not be measurable at USGS gages in the Virgin River, based on the Virgin River Daily Simulation Model results comparing the Base Case, which includes full utilization of Virgin River rights, with the future under the Proposed Action with LPP water delivered into Sand Hollow Reservoir.

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.

Population growth would result in urban development and land use changes that would cause increased runoff from impermeable surfaces. Within WCWCD the population is expected to increase by more than 6 times the 2005 level of 127,090 to 860,378 by 2060. Increased runoff could affect peak flows and geomorphology in the urban centers in Kane, Iron, and Washington Counties. Impervious areas directly connected to channels and storm sewers can transport runoff more quickly than natural conveyances. The shortening of travel time quickens the rainfall-runoff response, causing flows in streams to peak faster and higher than under pre-developed site conditions.

As described in Chapter 3, channels within the southwest Utah study area, including the Virgin River and Santa Clara River, are prone to erosion and channel movement in peak flows. Although the Proposed Action would not directly affect peak flows, the additional urban development in 2060 could significantly increase peak flows. The increased peak flows have the potential to cause greater channel movement, structure, and property damage, if the channel and structures are not adequately engineered for these future conditions.

(The remainder of the cumulative impacts analysis is pending completion for identification of inter-related projects that would cause cumulative impacts with the LPP project.)

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Glossary

Culinary water – water suitable for drinking

Secondary water – water that has not been treated to drinking water standards but may be suitable for other uses such as irrigation or industrial processes

Baseflow – streamflow resulting from groundwater inflow to the stream; the flow that occurs during dry weather that is not the direct result of snowmelt or rainfall

Peak flow – the highest discharge in a stream, usually the result of large precipitation events or rapid snowmelt

Sewered return flows – the water supply that is not consumptively used and returns to surface waters via wastewater treatment facilities; generally the result of indoor water use

Non-sewered return flows - the water supply that is not consumptively used and returns to surface waters via storm drains and groundwater; generally the result of outdoor water use

Abbreviations and Acronyms

AFY - acre-feet per year

BLM – Bureau of Land Management

cfs – cubic feet per second

CICWCD - Central Iron County Water Conservancy District

CRSS - Colorado River Basin hydrology and operations model

DNF - Direct Natural Flow

DWRe - Utah Division of Water Resources

EIS – Environmental Impact Study

FEMA - Federal Emergency Management Agency

FERC - Federal Energy Regulatory Commission

FONSI - federal finding of no significant impact

FPS – Final Planning Study

GSENM - Grand Staircase-Escalante National Monument

KCWCD - Kane County Water Conservancy District

LPP – Lake Powell Pipeline

MAF – million acre-feet

MDG – million gallons per day

MSL – mean sea level

NAD – No Additional Depletions

NEPA - National Environmental Policy Act

NPC - Nonparametric Paleo-conditioned

ROD – Record of Decision

SITLA - Utah School and Institutional Trust Lands Administration

PCRC - Upper Colorado River Commission

USGS – United States Geological Survey

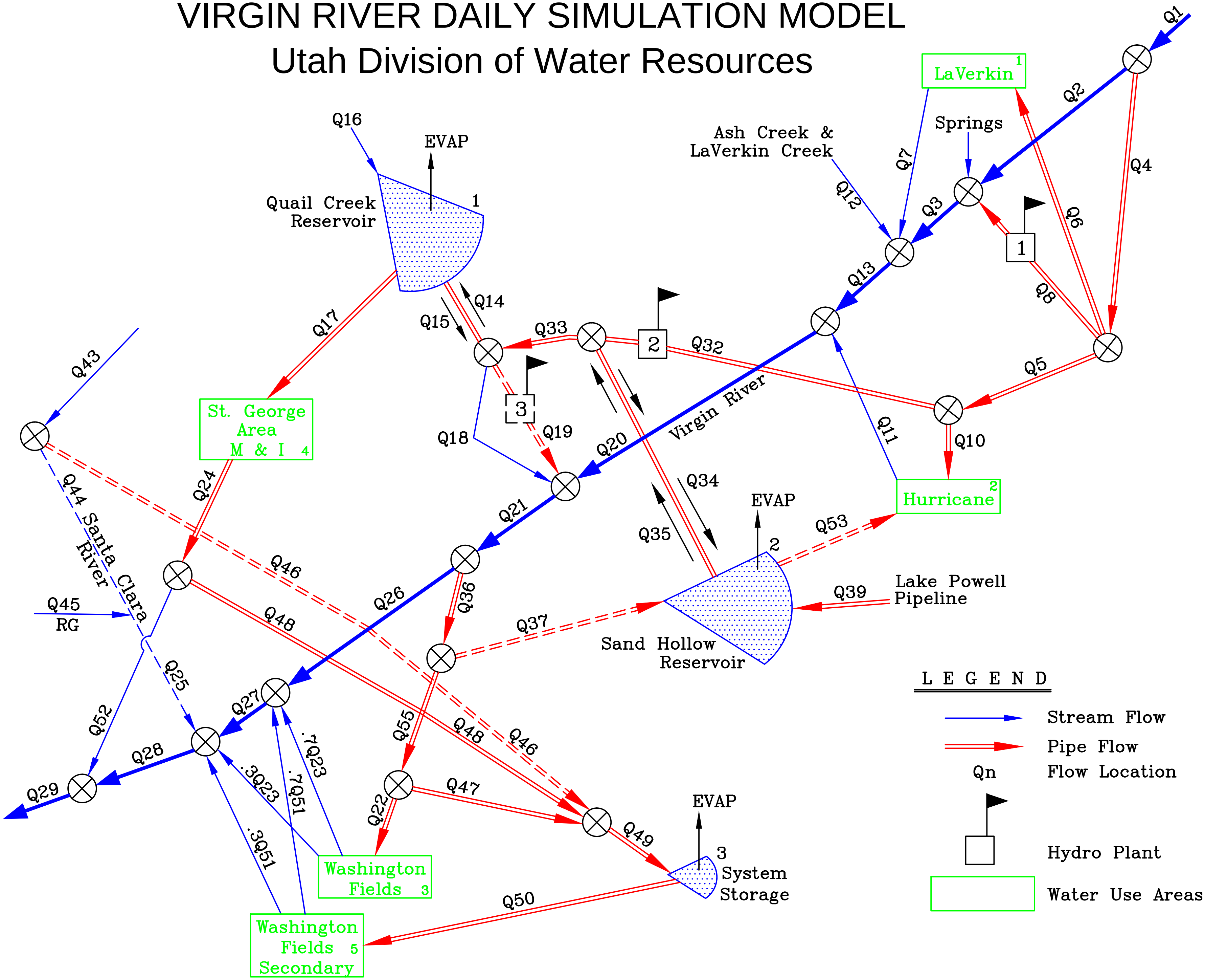
WCWCD – Washington County

List of Preparers

Name	Degree(s)	Role
MWH Consultant Team		
Lisa Fardal MWH, Inc.	M.S. - Civil Engineering B.A. - Biology B.A. – Environmental Studies	Surface Water Resources
Edwin Paulson MWH, Inc.	M.S. – Water Resources B.A. – Civil Engineering	Surface Water Resources
Brian Liming MWH, Inc.	M.S. – Civil and Environmental Engineering B.S. – Ecosystems Analysis	Report QA/QC Review
Diana Barnes MWH, Inc.	A.A. – Secretarial Science	Word Processing and Formatting

Appendix 1
Virgin River Daily Simulation Model and Description

VIRGIN RIVER DAILY SIMULATION MODEL
Utah Division of Water Resources



Lake Powell Pipeline
Virgin River Daily Simulation Model Flow Results
Comparison Between Scenario 1 and Scenario 2 With USGS Gage Error

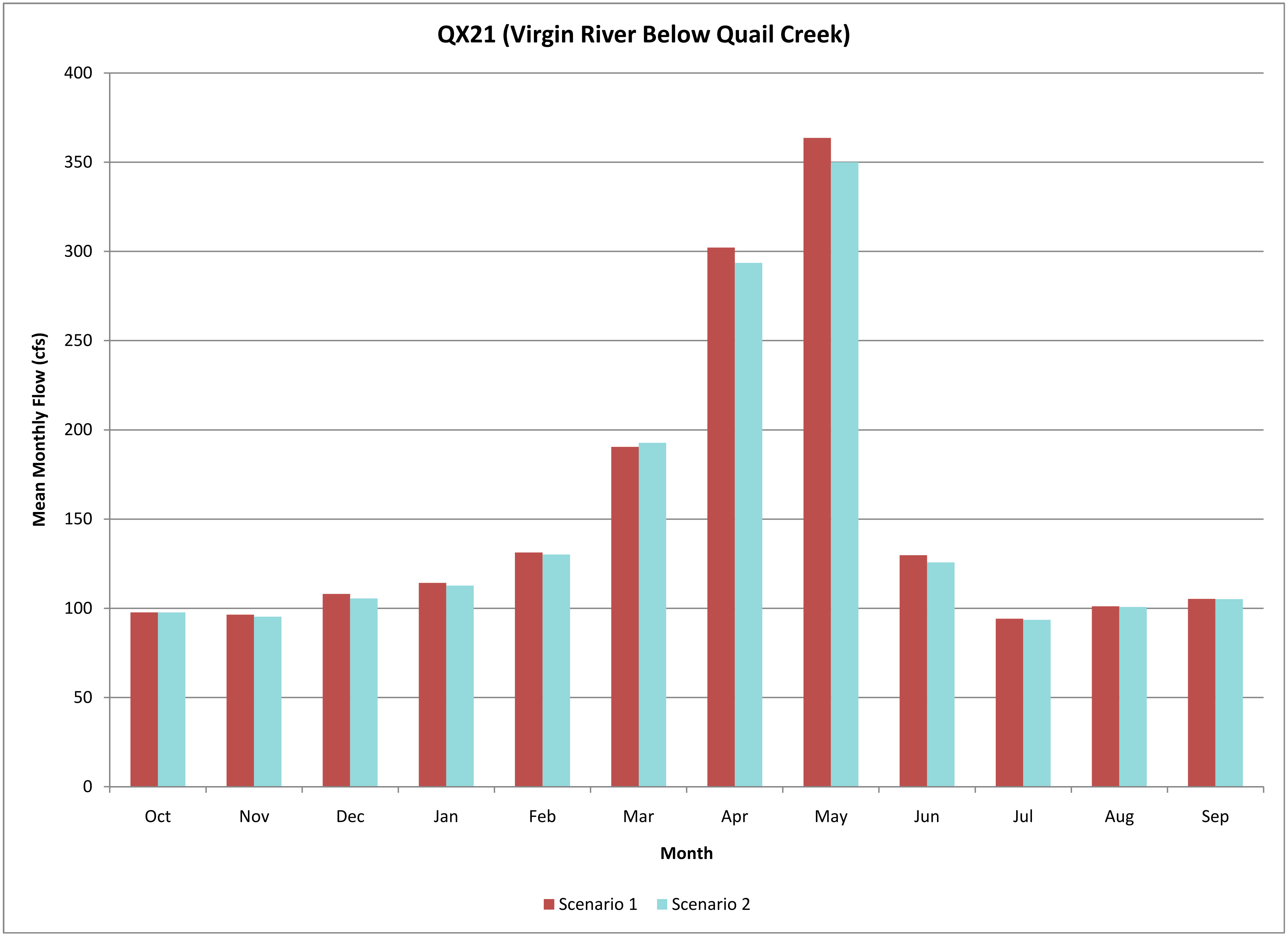
USGS Gage No.	**Gage Error**	**VRDSM Node**	**Scenario and Description**	Water Year Months (cfs)											
				Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
09408150	10%	QX21	1. Future w/ex. Fac.	98	97	108	114	131	191	302	364	130	94	101	105
			2. LPP+2500 AF St.	98	95	106	113	130	193	294	350	126	94	101	105
			Flow Difference	0	2	2	1	1	2	8	14	4	0	0	0
			Gage Error (flow)	10	10	11	11	13	19	29	35	13	9	10	11
09413200	10%	QX26	1. Future w/ex. Fac.	12	11	22	28	46	105	216	278	44	8	15	20
			2. LPP+2500 AF St.	12	10	20	27	45	107	208	264	40	8	15	19
			Flow Difference	0	1	2	1	1	2	8	14	4	0	0	1
			Gage Error (flow)	1	1	2	3	5	11	21	26	4	1	2	2
09413200	10%	QX27	1. Future w/ex. Fac.	41	47	67	80	100	155	259	312	73	34	40	46
			2. LPP+2500 AF St.	45	50	68	82	102	160	254	302	74	37	43	49
			Flow Difference	4	3	1	2	2	5	5	10	1	3	3	3
			Gage Error (flow)	4	5	7	8	10	16	25	30	7	3	4	5
09413200	10%	QX28	1. Future w/ex. Fac.	58	69	96	119	147	207	297	347	100	50	56	61
			2. LPP+2500 AF St.	63	74	98	122	150	214	294	339	102	55	61	67
			Flow Difference	5	5	2	3	3	7	3	8	2	5	5	6
			Gage Error (flow)	6	7	10	12	15	21	29	34	10	5	6	6
09413500	16%	QX29	1. Future w/ex. Fac.	60	76	103	123	151	210	297	347	100	50	56	62
			2. LPP+2500 AF St.	66	81	105	126	161	220	294	339	102	55	61	68
			Flow Difference	6	5	2	3	10	10	3	8	2	5	5	6
			Gage Error (flow)	10	12	16	20	24	34	47	54	16	8	9	10

Key: Flow difference exceeds USGS gage error
Flow difference is less than or equal to USGS gage error

Scenario 1	Sometimes called the 'Base Case', this scenario is represents the Virgin River System as it is currently developed under full utilization of water rights if it were to exist in its present state since 1941, the period of record. Demand in land areas 4 and 5 was iteratively adjusted such that the maximum shortage for both of the areas never exceeded ten percent.
Scenario 2	69,000 ac-ft imported by pipeline from Lake Powell. Also includes a re-regulating water storage facility with capacity of 2,500 ac-ft. Virgin River water is not used to satisfy demand in land area 5. (Washington Fields Sec)

	Demand for LA 5 (acft)	Thresh hold (cfs)	Reuse Capacity (cfs)	System Storage (ac-ft)	Total Deliveries (ac-ft)	St George	Washington Fields	Secondary With Converted Washington
Scenario 1	optimized	1,000	100	0	97,685	22,587	62,214	12,884
Scenario 2	optimized	1,000	200	2,500	191,832	80,212	62,224	49,397

Virgin River Daily	QX	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Scenario 1	21	97.7	96.5	108.0	114.2	131.3	190.5	302.2	363.6	129.8	94.2	101.1	105.3
Scenario 2	21	97.7	95.3	105.5	112.7	130.2	192.8	293.6	350.0	125.7	93.5	100.7	105.1
Scenario 1	26	11.9	10.7	22.0	28.2	45.8	104.5	216.4	277.5	44.0	8.2	15.0	19.5
Scenario 2	26	11.9	9.6	19.5	26.6	44.7	106.8	207.9	263.9	40.0	7.5	14.7	19.4
Scenario 1	27	40.8	46.8	67.3	80.1	99.8	154.5	258.6	312.2	73.4	34.0	39.9	45.6
Scenario 2	27	44.9	49.8	68.4	81.8	102.0	160.1	253.6	302.4	73.5	37.0	43.1	49.4
Scenario 1	28	57.5	69.4	95.7	118.8	146.8	207.2	297.1	346.8	99.7	50.0	56.0	61.3
Scenario 2	28	63.3	74.2	98.2	121.9	150.3	214.2	293.6	338.8	101.6	54.6	60.8	66.8
Scenario 1	29	60.2	75.9	102.7	123.3	151.0	209.9	297.2	346.8	99.7	50.0	56.0	62.0
Scenario 2	29	65.9	80.7	105.2	126.1	160.7	220.1	293.6	338.8	101.6	54.6	60.8	67.5


QX21 (Virgin River Below Quail Creek)
Mean Monthly Flow (cfs)
400
350
300
250
200
150
100
50
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Oct
Nov
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May
Jun
Jul
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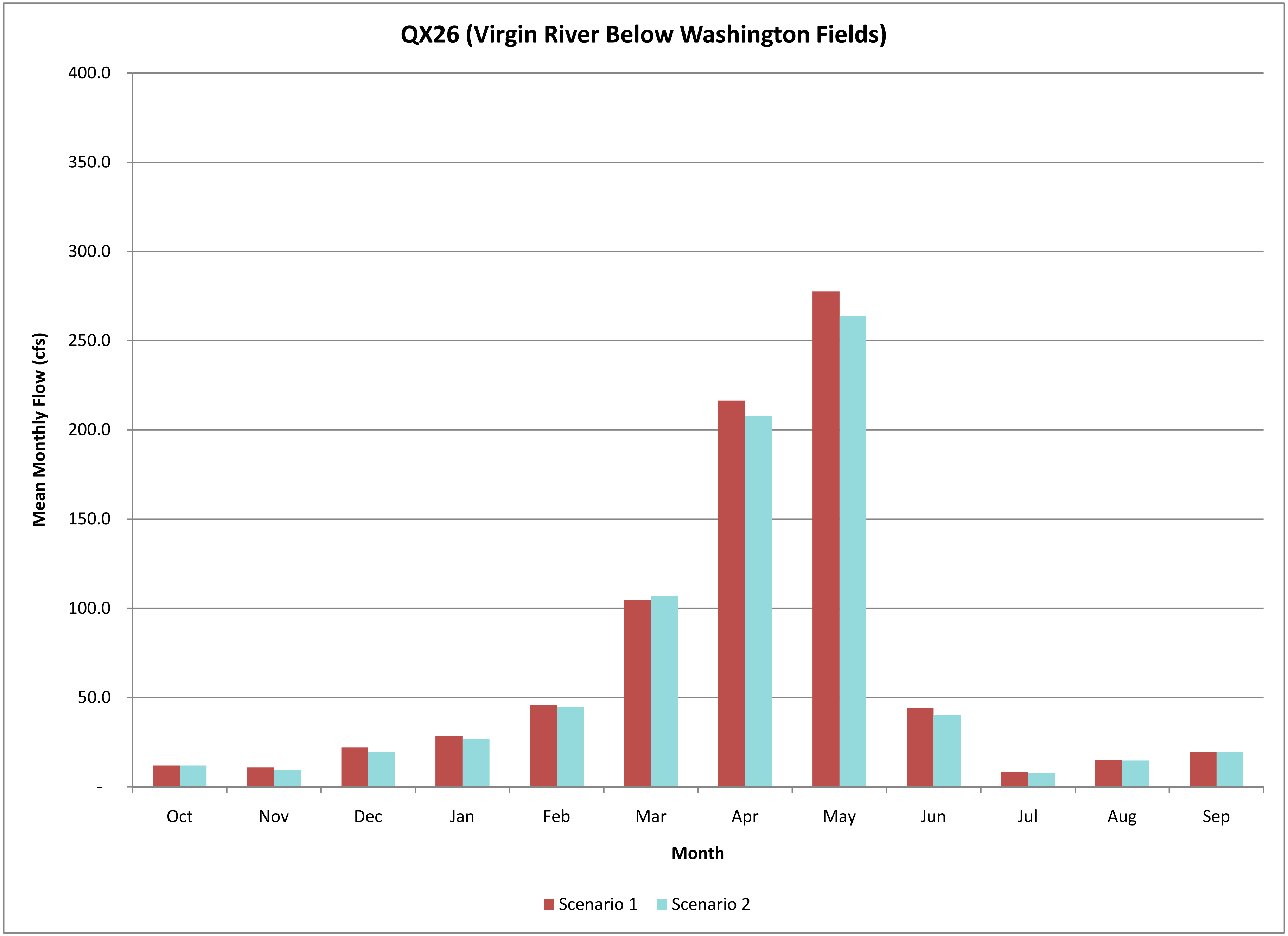
Month
Scenario 1
Scenario 2


QX26 (Virgin River Below Washington Fields)
Mean Monthly Flow (cfs)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
-
Oct
Nov
Dec
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Feb
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Apr
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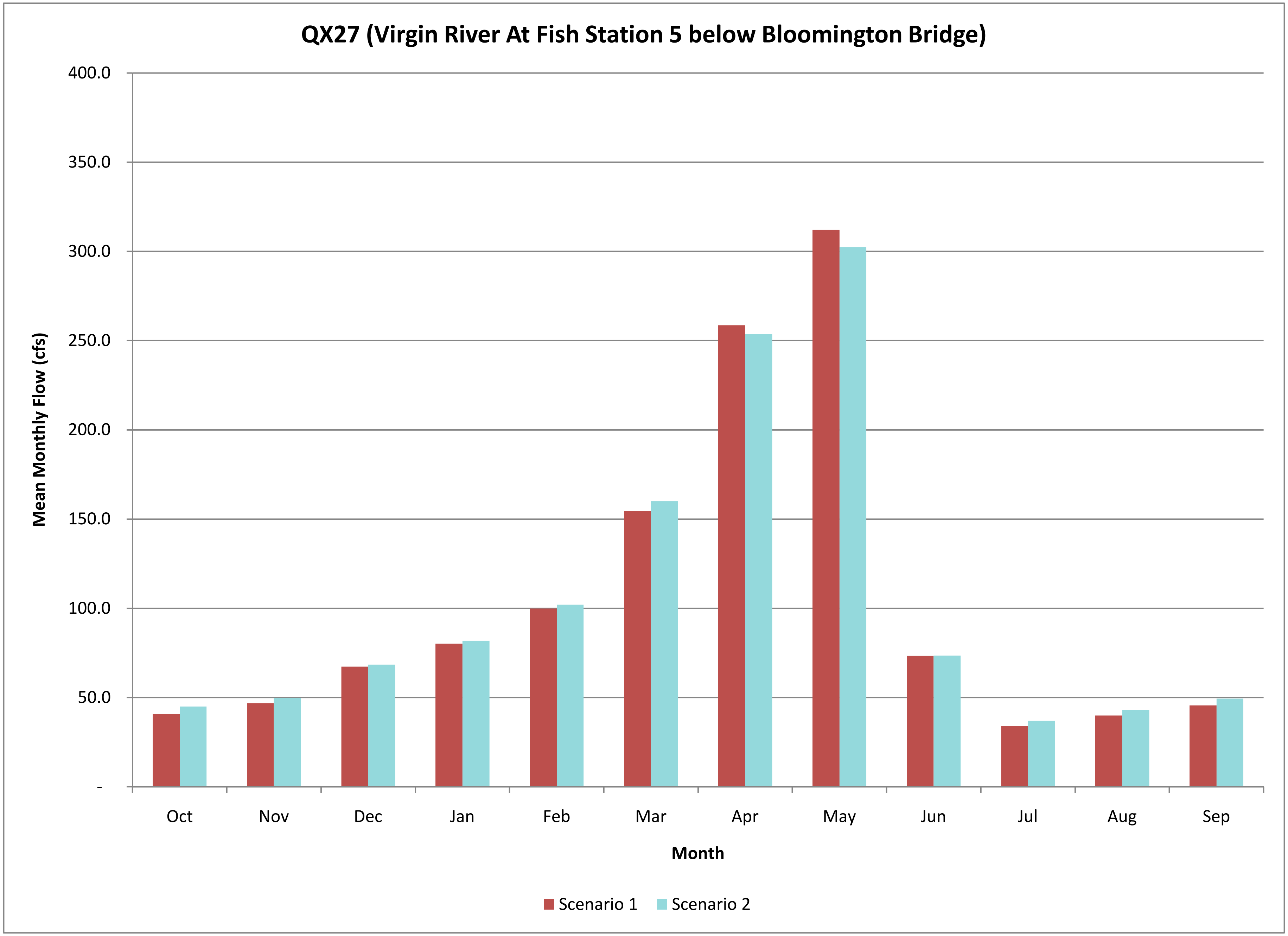
Month
Scenario 1
Scenario 2


QX27 (Virgin River At Fish Station 5 below Bloomington Bridge)
Mean Monthly Flow (cfs)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
-
Oct
Nov
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Aug
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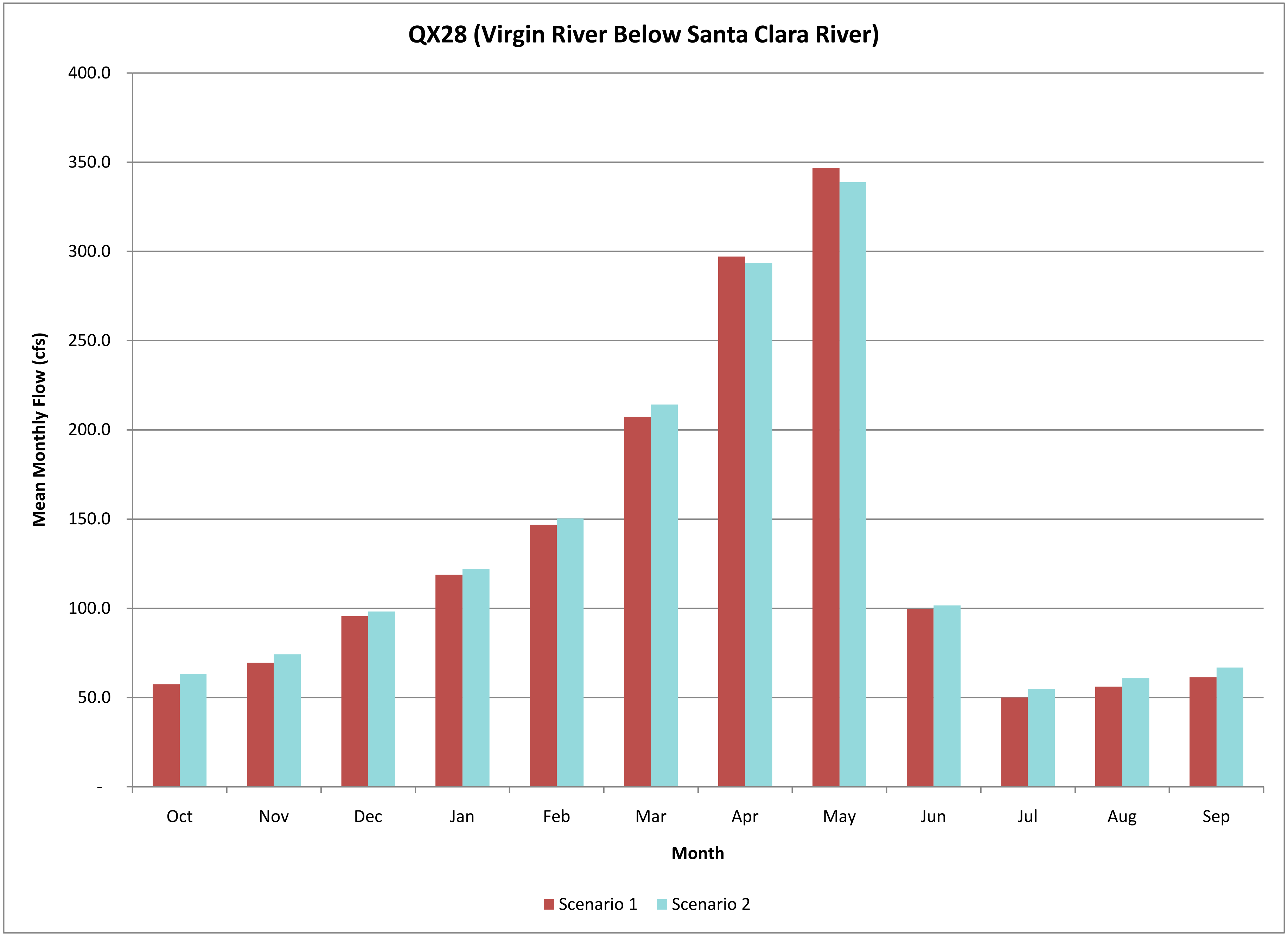
Month
Scenario 1
Scenario 2


QX28 (Virgin River Below Santa Clara River)
Mean Monthly Flow (cfs)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
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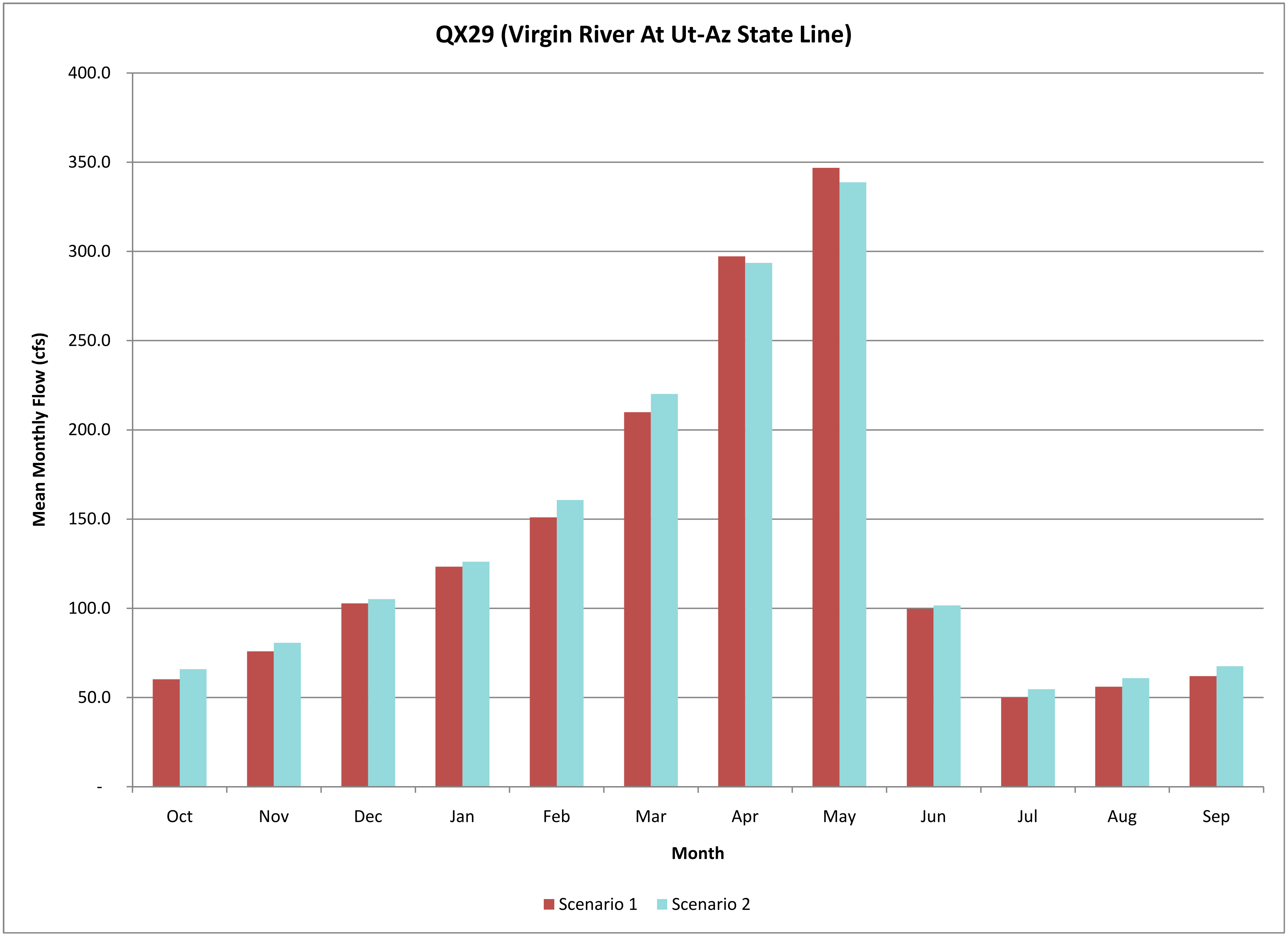
Month
Scenario 1
Scenario 2


QX29 (Virgin River At Ut-Az State Line)
Mean Monthly Flow (cfs)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
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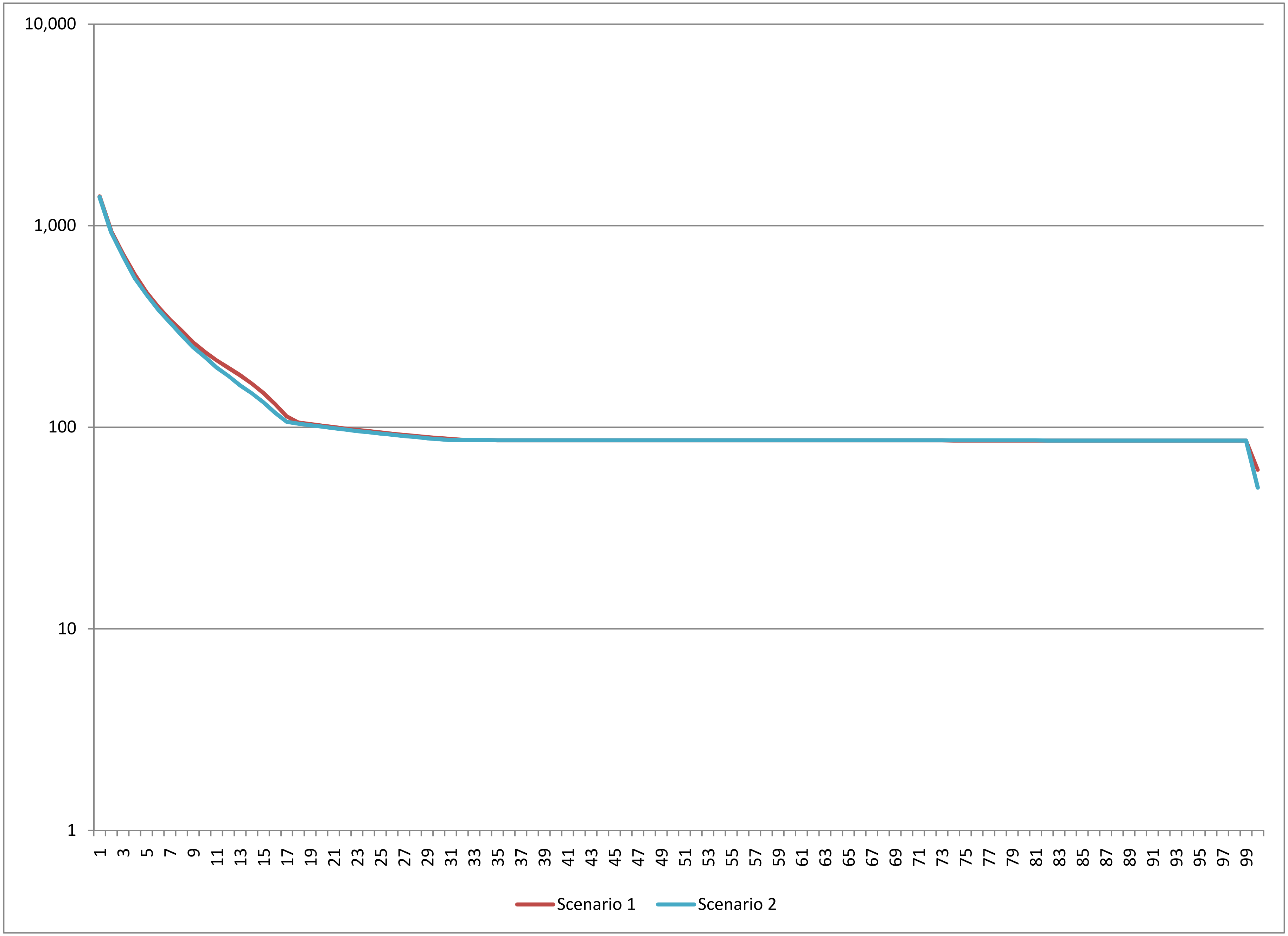
Scenario 1
Scenario 2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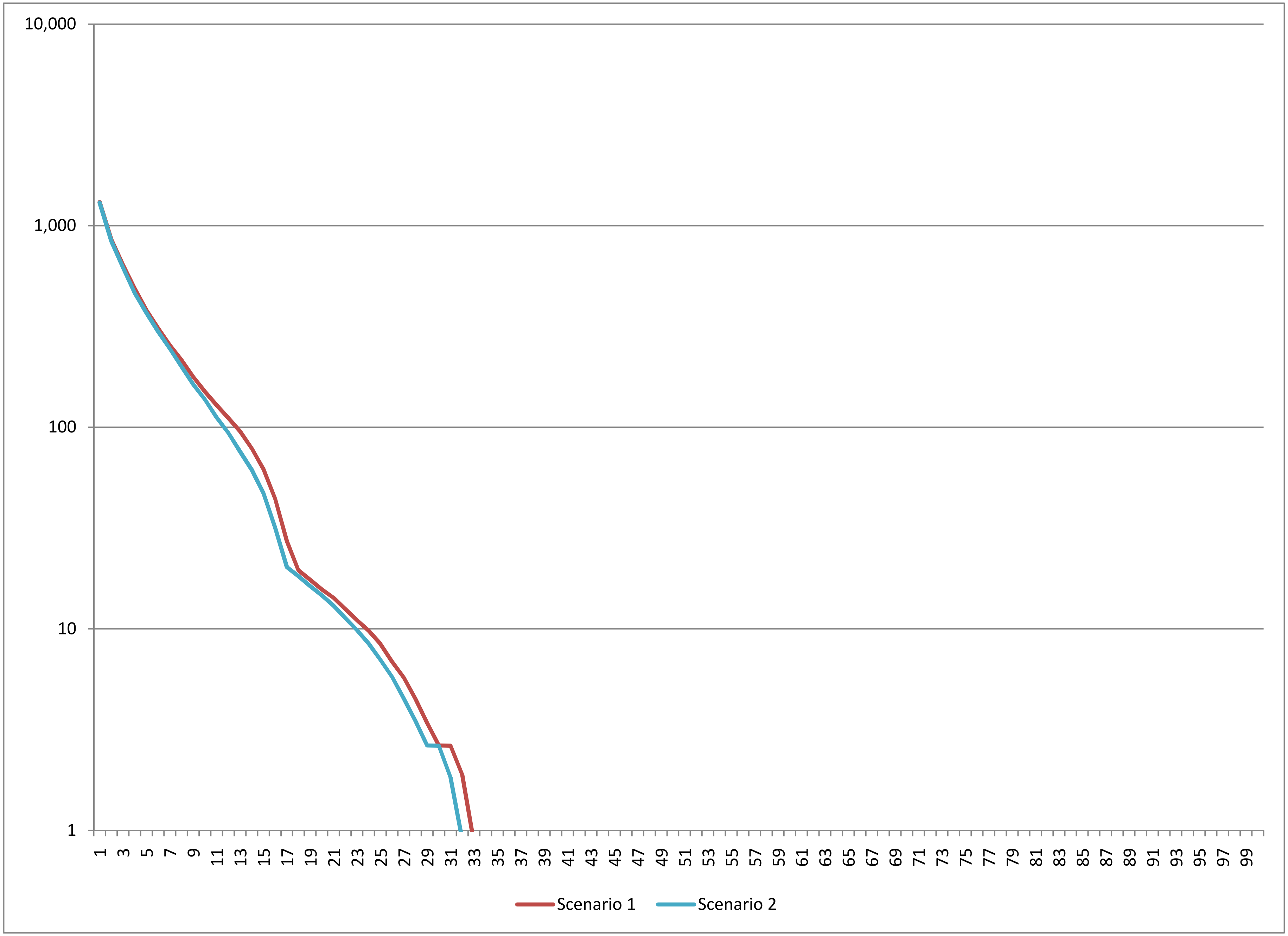
Scenario 1
Scenario 2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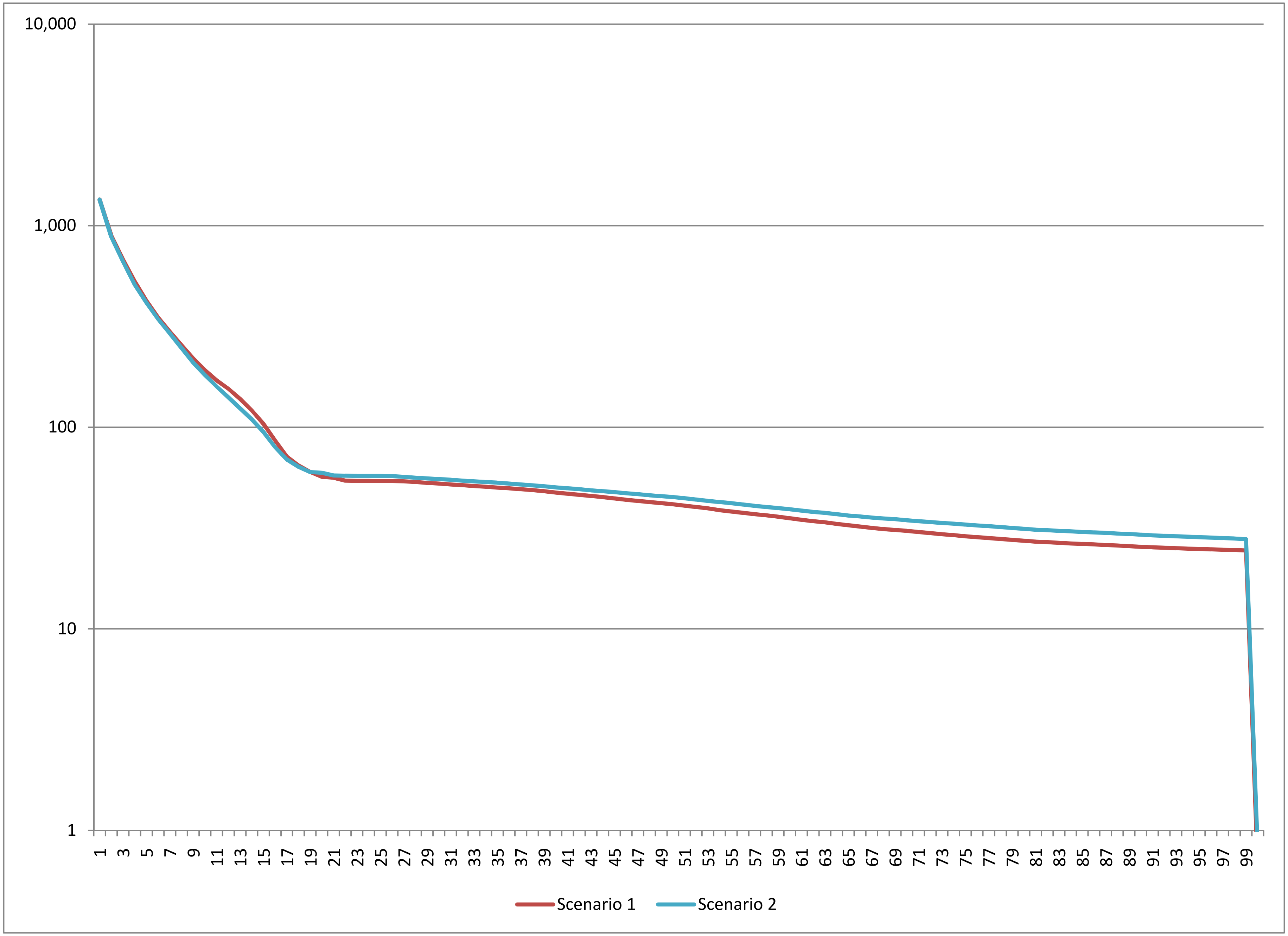
Scenario 1
Scenario 2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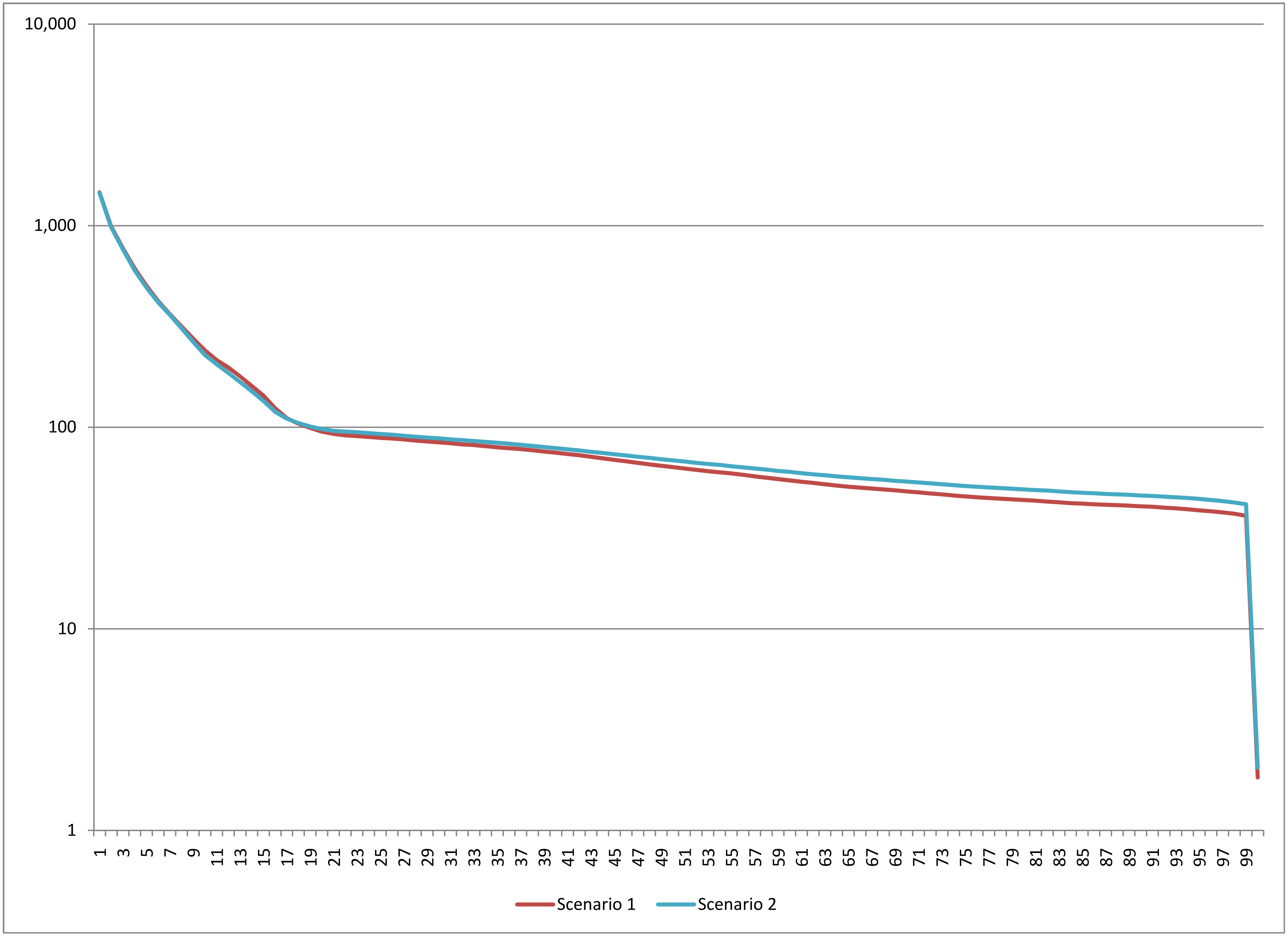
Scenario 1
Scenario 2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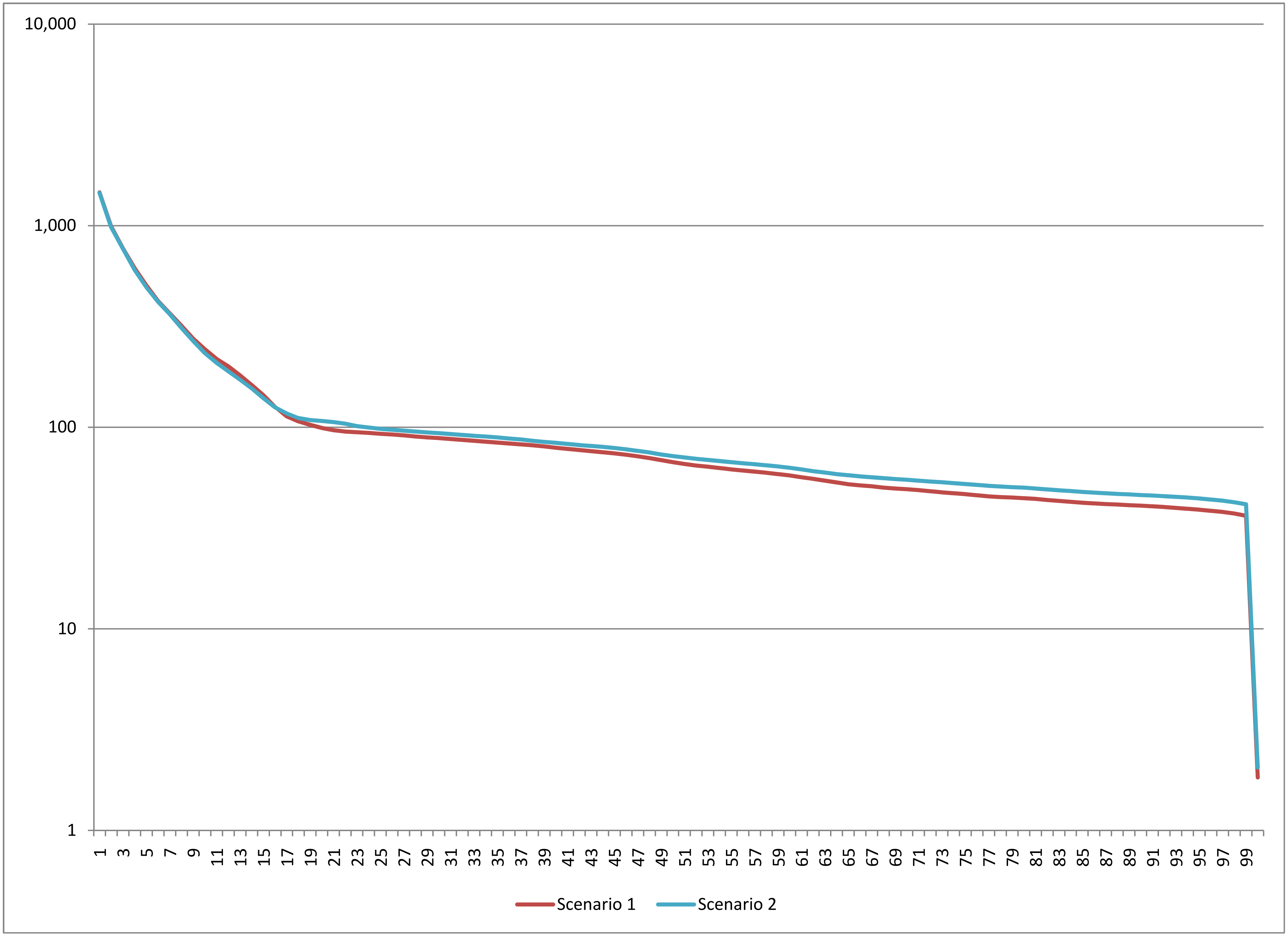
Scenario 1
Scenario 2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Scenario 1
Scenario 2

Pct	QX021	QX026	QX027	QX028	QX029
1	1396.1	1310.05	1345.29	1460.98	1460.98
2	936.67	850.82	891.71	987.98	987.98
3	724.9	638.9	679.73	769.58	769.88
4	572.91	486.86	528.75	611.07	613.21
5	466.25	380.43	423.15	503.75	505.05
6	395.29	309.46	350.97	422.62	423.24
7	341.66	255.82	297.62	363.69	366.49
8	300.94	214.9	255.01	316.53	317.95
9	263.63	177.64	219.04	274.32	274.95
10	236.05	150	192.22	241.07	243.56
11	214.36	128.44	170.55	215.11	218.03
12	196.99	111.03	154.96	197.51	200.06
13	181.14	95.31	138.34	178.78	181.28
14	164.48	78.43	121.13	159.9	161.75
15	147.83	61.92	103.85	143.36	144.02
16	129.98	44.08	85.85	124.13	125.85
17	113.07	27.21	71.47	110.91	113.2
18	105.48	19.5	64.77	104.02	106.85
19	103.49	17.53	60.03	99.15	102.76
20	101.64	15.7	56.73	95.22	99.13
21	100.17	14.24	56.14	92.64	96.53
22	98.53	12.55	54.37	91.09	95.15
23	96.96	11.01	54.16	90.3	94.43
24	95.7	9.8	54.13	89.51	93.63
25	94.31	8.43	54.09	88.62	92.73
26	92.81	6.88	54.04	87.79	91.97
27	91.58	5.73	53.93	86.97	91.04
28	90.41	4.49	53.45	85.95	89.92
29	89.35	3.41	52.96	84.91	89.02
30	88.27	2.64	52.49	84.15	88.25
31	87.32	2.63	52.01	83.26	87.32
32	86.44	1.89	51.54	82.29	86.44
33	86.31	0.87	51.08	81.51	85.58
34	86.3	0.3	50.69	80.44	84.69
35	86.08	0.29	50.22	79.57	83.84
36	86.07	0.27	49.75	78.74	83.01
37	86.07	0.25	49.32	77.85	82.27
38	86.07	0.24	48.73	76.83	81.33
39	86.06	0.24	48.15	75.78	80.27
40	86.06	0.16	47.42	74.7	79.18
41	86.06	0.15	46.81	73.62	78.06
42	86.06	0.15	46.21	72.56	77.03
43	86.06	0.15	45.64	71.36	76.1
44	86.06	0.15	45.05	70.08	75.16
45	86.05	0.14	44.31	68.9	74.14
46	86.05	0.14	43.68	67.77	73.05
47	86.05	0.13	43.11	66.6	71.78
48	86.05	0.02	42.54	65.44	70.23
49	86.05	0.02	41.98	64.42	68.73
50	86.05	0.01	41.42	63.36	67.14
51	86.05	0.01	40.8	62.35	65.76
52	86.05	0.01	40.16	61.39	64.59
53	86.05	0.01	39.54	60.56	63.64
54	86.05	0.01	38.83	59.75	62.7

Pct	QX021	QX026	QX027	QX028	QX029
55	86.05	0.01	38.18	58.91	61.77
56	86.05	0.01	37.58	58.02	60.96
57	86.05	0.01	37.04	57.09	60.19
58	86.05	0	36.56	56.17	59.45
59	86.05	0	35.95	55.34	58.59
60	86.05	0	35.31	54.53	57.59
61	86.05	0	34.72	53.69	56.46
62	86.05	0	34.23	52.89	55.38
63	86.05	0	33.71	52.14	54.29
64	86.05	0	33.12	51.38	53.18
65	86.05	0	32.67	50.73	52.17
66	86.05	0	32.13	50.14	51.52
67	86.05	0	31.65	49.6	50.89
68	86.04	0	31.28	49.1	50.22
69	86.04	0	30.92	48.57	49.69
70	86.04	0	30.57	48.03	49.23
71	86.03	0	30.18	47.48	48.73
72	86.02	0	29.83	46.95	48.18
73	86.01	0	29.48	46.4	47.56
74	85.97	0	29.14	45.85	47.03
75	85.97	0	28.8	45.35	46.5
76	85.97	0	28.5	44.93	45.94
77	85.96	0	28.21	44.55	45.42
78	85.96	0	27.91	44.19	45.05
79	85.96	0	27.61	43.85	44.76
80	85.96	0	27.33	43.49	44.46
81	85.95	0	27.07	43.16	44.09
82	85.95	0	26.88	42.8	43.52
83	85.95	0	26.69	42.43	43.07
84	85.95	0	26.53	42.04	42.6
85	85.93	0	26.36	41.76	42.17
86	85.93	0	26.22	41.49	41.86
87	85.93	0	26.03	41.28	41.57
88	85.92	0	25.9	41.03	41.31
89	85.92	0	25.72	40.81	41.04
90	85.92	0	25.53	40.56	40.8
91	85.92	0	25.37	40.26	40.5
92	85.79	0	25.22	39.92	40.17
93	85.78	0	25.1	39.55	39.84
94	85.78	0	24.99	39.15	39.42
95	85.78	0	24.89	38.73	38.97
96	85.78	0	24.77	38.27	38.5
97	85.78	0	24.66	37.75	37.97
98	85.78	0	24.58	37.19	37.3
99	85.78	0	24.46	36.36	36.38
100	61.48	0	0.63	1.83	1.83

Pct	QX021	QX026	QX027	QX028	QX029
1	1386.87	1301.09	1347.17	1452.73	1454.31
2	922.1	838.11	878.83	978.2	978.2
3	705.44	619.66	664.08	760.96	766.49
4	548.55	462.5	509.71	599.3	601.93
5	455.03	369.24	415.19	492.29	493.3
6	383.94	297.89	343.24	416.71	418.46
7	331.49	245.44	291.79	360.82	363.86
8	286.06	200.27	247.09	309.64	310.66
9	249.25	163.22	208.93	264.79	267.66
10	223.17	137.25	181.69	228.4	233.07
11	197.73	111.82	159.02	205.17	208.45
12	179.69	93.76	140.86	185.79	189.32
13	161.41	75.76	124.09	167.68	171.86
14	147.23	61.48	109.42	150.89	155.68
15	133.05	47.04	94.69	135.07	139.25
16	117.94	31.83	79.48	119.38	125.19
17	106.24	20.21	69.19	110.16	116.97
18	104.19	18.23	63.76	104.83	111.18
19	102.27	16.3	59.96	100.59	108.52
20	100.6	14.67	59.38	97.87	107.33
21	98.94	13.03	57.57	95.85	106.12
22	97.31	11.35	57.41	95.08	104.27
23	95.78	9.88	57.4	94.32	101.29
24	94.39	8.46	57.39	93.38	99.72
25	92.98	7.03	57.38	92.61	98.19
26	91.77	5.78	57.17	91.76	97.2
27	90.41	4.51	56.68	90.69	96.18
28	89.4	3.49	56.19	89.61	95.1
29	88.19	2.64	55.7	88.84	94.13
30	87.28	2.63	55.27	88.03	93.36
31	86.34	1.83	54.87	87.06	92.5
32	86.31	0.9	54.38	86.26	91.64
33	86.3	0.3	53.89	85.32	90.67
34	86.3	0.29	53.51	84.49	89.85
35	86.13	0.28	53.07	83.61	88.93
36	86.08	0.25	52.58	82.73	87.94
37	86.08	0.24	52.02	81.72	86.93
38	86.07	0.23	51.46	80.71	85.66
39	86.07	0.17	50.95	79.67	84.64
40	86.06	0.16	50.32	78.76	83.68
41	86.06	0.16	49.81	77.73	82.61
42	86.06	0.16	49.23	76.6	81.62
43	86.06	0.15	48.69	75.53	80.72
44	86.06	0.14	48.17	74.45	79.84
45	86.05	0.14	47.6	73.37	78.86
46	86.05	0.13	47.02	72.39	77.63
47	86.05	0.04	46.51	71.34	76.34
48	86.05	0.03	45.95	70.35	74.85
49	86.05	0.02	45.43	69.39	73.15
50	86.05	0.01	45.04	68.48	71.91
51	86.05	0.01	44.4	67.55	70.72
52	86.05	0.01	43.8	66.64	69.78
53	86.05	0.01	43.11	65.79	68.85
54	86.05	0.01	42.53	64.99	68.01

Pct	QX021	QX026	QX027	QX028	QX029
55	86.05	0.01	41.98	64.11	67.08
56	86.05	0.01	41.33	63.28	66.24
57	86.05	0.01	40.76	62.44	65.5
58	86.05	0	40.18	61.58	64.7
59	86.05	0	39.66	60.74	63.82
60	86.05	0	39.17	59.99	62.85
61	86.05	0	38.58	59.19	61.71
62	86.05	0	38	58.44	60.59
63	86.05	0	37.56	57.71	59.56
64	86.05	0	37.04	57	58.54
65	86.05	0	36.47	56.45	57.85
66	86.05	0	36.05	55.89	57.1
67	86.05	0	35.63	55.31	56.51
68	86.05	0	35.29	54.83	55.89
69	86.05	0	34.97	54.25	55.36
70	86.05	0	34.58	53.73	54.89
71	86.05	0	34.18	53.22	54.36
72	86.05	0	33.86	52.68	53.81
73	86.05	0	33.52	52.13	53.3
74	86.05	0	33.22	51.64	52.75
75	86.05	0	32.86	51.1	52.23
76	86.05	0	32.59	50.68	51.7
77	86.04	0	32.28	50.3	51.14
78	86.04	0	31.96	49.93	50.77
79	86.03	0	31.67	49.53	50.44
80	86.02	0	31.33	49.17	50.12
81	86.01	0	31.02	48.8	49.68
82	85.97	0	30.81	48.46	49.19
83	85.96	0	30.61	48.06	48.69
84	85.95	0	30.44	47.68	48.21
85	85.94	0	30.21	47.32	47.78
86	85.94	0	30.07	47.02	47.4
87	85.94	0	29.87	46.73	47.05
88	85.93	0	29.69	46.44	46.73
89	85.92	0	29.52	46.18	46.41
90	85.92	0	29.3	45.89	46.12
91	85.91	0	29.08	45.62	45.81
92	85.78	0	28.91	45.28	45.51
93	85.78	0	28.78	44.93	45.13
94	85.78	0	28.62	44.52	44.77
95	85.78	0	28.48	44.07	44.29
96	85.78	0	28.33	43.57	43.78
97	85.78	0	28.16	42.99	43.15
98	85.78	0	28.02	42.36	42.41
99	85.78	0	27.86	41.41	41.43
100	50.15	0	0.79	2.05	2.05

Appendix 2
Reclamation Colorado River Model Report

KGrantz UC-432

-DRAFT-

Lake Powell Pipeline Hydrologic Modeling

Executive Summary

March 8, 2010

Background

Through coordination with the State of Utah Division of Water Resources (State), the Bureau of Reclamation (Reclamation) conducted several hydrologic modeling runs using Reclamation's long-term planning model, Colorado River Simulation System (CRSS). The results of these model runs have been provided to the State for use in its planning studies for the Lake Powell Pipeline (LPP) project to determine potential impacts on the hydrology of the Colorado River System.

This report summarizes the results of two sets of hydrologic modeling runs, the Final Planning Study runs and the No Additional Depletions runs. Detailed reports on each of these sets of runs are also available.

Methodology

Hydrologic modeling of the Colorado River system for the period 2009 through 2060 was conducted to determine the potential hydrologic effects of the alternatives. Modeling provides projections of potential future Colorado River system conditions (i.e., reservoir elevations, reservoir releases, river flows) for comparison of those conditions under the No Action Alternative to conditions under each action alternative. These comparisons are typically expressed in terms of the relative differences in probabilities between the No Action Alternative and the action alternatives. Hydrologic modeling also provides the basis for the analysis of the potential effect of each alternative on other environmental resources such as water quality and hydropower. Due to the uncertainty with regard to future inflows into the system, multiple simulations were performed in order to quantify the uncertainties of future conditions and as such, the modeling results are expressed in probabilistic terms.

Analyses Performed

Two sets of hydrologic model runs are analyzed: the Final Planning Study analysis and the No Additional Depletions analysis. For each of these analyses multiple hydrologic model runs were conducted to evaluate all combinations of inflow scenarios and alternatives.

Final Planning Study Analysis

The Final Planning Study analysis assumes future water development in the Upper Colorado Riverbasin will occur according projections provided by the Upper Basin States to the Upper Colorado River Commission (UCRC). In this analysis to No Action alternative assumes that if Utah does not develop the Lake Powell Pipeline, that water will be developed somewhere else in the state. This analysis isolates the impact of the geographic location of the water use from the Colorado River system; Utah's total water use remains the same in the action and No Action alternatives.

No Additional Depletions Analysis
The No Additional Depletions analysis assumes water use in the Colorado Riverbasin will remain constant at current levels, except for reasonably foreseeable (pursuant to 43 CFR 46.30) future projects. Under the regulatory definition, a reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). In the No Additional Depletions analysis the No Action alternative assumes that if the Lake Powell Pipeline is not developed, that water will not be developed somewhere else in the state. This analysis isolates the effect of adding a new project (Lake Powell Pipeline) to the mix of existing and reasonably foreseeable depletions in the Colorado River system.

Alternatives Modeled

Three alternatives were modeled for each of the two analyses described above. These alternatives consist of a No Action Alternative and two action alternatives, Lake Powell Pipeline 86kaf Alternative and Lake Powell Pipeline 100kaf Alternative. The action alternatives reflect pipeline diversion schedules developed by the State and technical input from Reclamation staff regarding how to model the Lake Powell Pipeline in CRSS.

No Action Alternative
The No Action Alternative provides a baseline for comparison of each of the action alternatives. The No Action Alternative represents a projection of future conditions that could occur during the life of the proposed federal action without an action alternative being implemented. For the Final Planning Study analysis, this alternative assumes future water development in the Upper Colorado Riverbasin will occur according projections provided by the Upper Basin States to the Upper Colorado River Commission (UCRC). For the No Additional Depletions analysis, the No Action Alternative assumes all Upper Basin depletions except those deemed reasonably foreseeable are held constant at 2009 depletion levels for the entire model run

Lake Powell Pipeline 86kaf Alternative
The Lake Powell Pipeline 86kaf Alternative (86kaf Alternative) diverts water from the Colorado River system at Lake Powell. Diversions begin in 2020 with an annual volume of 1,975 acre-feet per year and increase each year through 2042 to 86,249 acre feet. Diversions are constant at 86,249 acre-feet per year from full build-out until the end of the model run (2042 through 2060).

Lake Powell Pipeline 100kaf Alternative
The Lake Powell Pipeline 100kaf Alternative (100kaf Alternative) diverts water from the Colorado River system at Lake Powell. Diversions begin in 2020 with an annual volume

of 1,899 acre-feet per year and increase each year through 2046 to 99,970 acre-feet. Diversions are constant at 99,970 acre-feet per year from full build-out until the end of the model run (2046 through 2060).

Inflow Hydrology Scenarios Modeled

Direct Natural Flow, Index Sequential Method Inflows

The future hydrology used as input to the model in this scenario consisted of samples taken from the historic record of natural flow in the river system over the 101-year period from 1906 through 2006. Natural flow is the observed flow adjusted for the effects of diversions and the operation of reservoirs upstream of the flow gage.

Nonparametric Paleo-conditioned Inflows

This inflow hydrology scenario uses paleo-hydrologic state information (i.e., wet or dry) to conditionally sample from the historic natural flow record. The paleo-hydrologic state information was derived from annual streamflow reconstructions from tree-ring chronologies of the years 762 to 2005 on the Colorado River at Lees Ferry. This technique generates flows with the same magnitudes as the historic record but with more variety in the sequencing of wet and dry spells.

Summary of Potential Hydrologic Impacts

General Observations

The assumptions of the two analyses, Final Planning Study analysis and No Additional Depletions analysis are significantly different, and as such, the results are also different. Overall, the Final Planning Study analysis shows very little or no hydrologic differences between the action and No Action alternatives. The No Additional Depletions analysis, indicate small hydrologic differences between the action and No Action alternatives at some percentile levels. For both analyses, the largest differences occur at lower reservoir elevations and at higher annual reservoir release volumes. Reservoir elevations and the percentage of higher volume reservoir releases are generally higher in the No Additional Depletions analysis compared to the Final Planning Study analysis. The choice of inflow scenario does not significantly affect the differences between the action and No Action alternatives. The differences between the two action alternatives are insignificant relative to their differences from the No Action Alternative.

Final Planning Study Analysis

Reservoir Storage

Under the No Action Alternative and the action alternatives, the elevations of Lake Powell are projected to fluctuate between full and lower levels during the period of analysis (2009 through 2060). The range of elevations projected using paleo-conditioned inflows is significantly larger, (up to approximately 100 feet lower in the 10^{th} percentile), than elevations projected using direct natural inflows. At the 90^{th} percentile level Lake Powell end-of-December elevation values, the action alternatives and the No Action Alternative are projected to be nearly the same over the period of analysis for both direct natural inflows and paleo-conditioned inflows. At higher elevations the proposed Lake

Powell Pipeline is expected to have very little or no effect on lake elevations. At the 50th and 10th percentiles, Lake Powell elevations under the action alternatives are approximately 0.2ft and approximately 0.4ft, respectively, lower than under the No Action Alternative, indicating relatively little impact to lake elevations at median and lower lake elevations. Though the projected elevations at the 10th and 50th percentiles are significantly lower for paleo-conditioned inflows than for direct natural inflows, differences between the No Action Alternative and action alternatives are nearly the same in both inflow scenarios.

The probability of Lake Powell elevations less than 3,490 feet msl (the approximate minimum elevation for operation of the Glen Canyon powerplant) is nearly the same for all alternatives. The probability is three percent or less assuming natural inflows and fifteen percent or less assuming paleo-conditioned inflows. Inflow scenario does not affect the differences between the action and No Action alternatives. This indicates the proposed pipeline would have little or no effect on the ability to generate power at Glen Canyon powerplant.

Reservoir Releases
Under the No Action Alternative and the action alternatives, the water year releases from Lake Powell are projected to fluctuate throughout the period of analysis. The range of releases projected using paleo-conditioned inflows is significantly larger, approximately one million acre feet higher in the 90th percentile, than water year releases projected using direct natural inflows. At the 10th and 50th percentile level Lake Powell water year release values, the action alternatives and the No Action Alternative are projected to be nearly the same over the period of analysis for both direct natural inflows and paleo-conditioned inflows, indicating little or no impact to reservoir releases at lower median water year release values. The 10th and 50th percentile releases reflect the minimum objective release of 8.23 maf or balancing releases. The 90th percentile releases reflect equalization or spill avoidance. At the 90th percentile, the water year release values under the action alternatives are approximately 3,000 acre feet (approximately 0.03 percent) less than the No Action Alternative. Though the projected releases at the 90th percentile are significantly higher for paleo-conditioned inflows than for direct natural inflows, differences between the No Action Alternative and action alternatives are nearly the same in both inflow scenarios at all percentile levels.

Releases of less than the annual minimum objective release of 8.23 maf occurred with essentially the same frequency (within 0.1 percent of the time) between the action and No Action alternatives. Releases above 8.23 maf also occurred with nearly the same frequency.

Releases from Flaming Gorge Reservoir are the same at the 50th and 90th percentile levels for the action and No Action alternatives for both inflow scenarios. At the 10th percentile level the differences are very small (less than 0.2 percent). This indicates that given the model assumptions, the Lake Powell Pipeline would have little impact on releases from Flaming Gorge.

No Additional Depletions Analysis

Reservoir Storage

Under the No Action Alternative and the action alternatives, the elevations of Lake Powell are projected to fluctuate but generally increase over time throughout the period of analysis (2009 through 2060). The range of elevations projected using paleo-conditioned inflows is significantly larger, (up to approximately 100 feet lower in the 10^{th} percentile), than elevations projected using direct natural inflows. At the 90^{th} percentile level Lake Powell end-of-December elevation values, the action alternatives and the No Action Alternative are projected to be nearly the same over the period of analysis for both direct natural inflows and paleo-conditioned inflows. At higher elevations the proposed Lake Powell Pipeline is expected to have very little or no effect on lake elevations. At the 50^{th} percentile, Lake Powell elevations under the action alternatives are approximately 2ft lower than under the No Action Alternative, assuming observed natural inflows (approximately 1ft assuming paleo-conditioned inflows). Results at the 10^{th} percentile level show approximately 4ft and 5ft average difference for observed natural and paleo-conditioned inflows, respectively, indicating a small potential impact to reservoir elevations at lower levels. To put this in perspective, Lake Powell has an operating range of over 200 feet and typically fluctuates 30 to 40 feet in a normal year.

The probability of Lake Powell elevations less than 3,490 feet msl (the approximate minimum elevation for operation of the Glen Canyon powerplant) is two percent or less assuming natural inflows and thirteen percent or less assuming paleo-conditioned inflows. Results are essentially the same for all alternatives assuming observed natural inflows. With paleo-conditioned inflows the probability of being below 3,490 feet msl is very slightly (two percent or less) higher in the action alternatives compared to the No Action alternative. This indicates the proposed pipeline could have very little impact on the ability to generate power at Glen Canyon powerplant.

Reservoir Releases

Under the No Action Alternative and the action alternatives, the water year releases from Lake Powell are projected to fluctuate throughout the period of analysis. The range of releases projected using paleo-conditioned inflows is significantly larger, approximately one million acre feet higher in the 90^{th} percentile, than water year releases projected using direct natural inflows. At the 10^{th} and 50^{th} percentile level Lake Powell water year release values, the action alternatives and the No Action Alternative are projected to be nearly the same over the period of analysis for both direct natural inflows and paleo-conditioned inflows. The 10^{th} and 50^{th} percentile releases reflect the minimum objective release of 8.23 maf or balancing releases. The 90^{th} percentile releases reflect equalization or spill avoidance. At the 90^{th} percentile, the water year release values under the action alternatives are approximately 80,000 acre-feet (or 0.6%) less than the No Action Alternative. Though the projected releases at the 90^{th} percentile are significantly higher for paleo-conditioned inflows than for direct natural inflows, differences between the No Action Alternative and action alternatives are nearly the same in both inflow scenarios at all percentile levels. These results show that the Lake Powell Pipeline would have little (less than one percent difference) or no impact on Lake Powell's annual release volumes.

Releases of less than the annual minimum objective release of 8.23 maf occurred with essentially the same frequency (within 0.3 percent of the time) between the action and No Action alternatives. Releases above 8.23 maf occurred approximately one percent less often under the action alternatives compared to the No Action Alternative. These results indicate the Lake Powell Pipeline would have little or no impact on Lake Powell's annual release tier.

Releases from Flaming Gorge Reservoir are the same at all percentile levels for the action and No Action alternatives for both inflow scenarios. This suggests that the Lake Powell Pipeline would have no impact on releases from Flaming Gorge.

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Lake Powell Pipeline Hydrologic Modeling

Final Planning Study Analysis

Overview

Through coordination with the State of Utah Division of Water Resources (State), the Bureau of Reclamation (Reclamation) conducted several hydrologic modeling runs using Reclamation's long-term planning model, Colorado River Simulation System (CRSS). The results of these model runs have been provided to the State for use in its planning studies for the Lake Powell Pipeline (LPP) project to determine potential impacts on the hydrology of the Colorado River System.

This report presents the results of one set of hydrologic modeling runs, the Final Planning Study analysis. A previous report for the Final Planning Study runs was provided to the State in December 2008. A modification to the pumping schedule and the rate at which the Lake Powell Pipeline depletions would come online necessitated re-running the model. This report presents the results from the reanalysis which incorporates the new pipeline depletion schedule.

Two alternatives were compared in the Final Planning Study runs: (1) a no action alternative that represents the current operations and planning on the Colorado River and is the preferred alternative of the 2007 Final Environmental Impact Statement of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Shortage EIS) and (2) an Action alternative that represents the Lake Powell Pipeline project as part of Utah's future development of Colorado River water.

The first section of this report presents an overview of the data. Next, the general methodology and technical assumptions of CRSS are reviewed, followed by the technical assumptions specific to this study and the Final Planning Study runs. The modeling results are then presented with an analysis of the differences between the action and no action alternatives. A discussion section concludes the report.

Data

Three future depletion scenarios, two potential Lake Powell Pipeline depletion schedules (86kaf and 100kaf) and one no pipeline depletion schedule, were modeled.

For each of the three depletion scenarios, two future inflow hydrology scenarios were modeled. One inflow scenario uses data from the observed streamflow record (1906-2006). The other inflow scenario uses hydrologic data derived from tree rings (762 - 2005) to represent climate variability in the Colorado Riverbasin over the past millennium. These methods are discussed in further detail below. Though the potential impacts of climate change have been studied in the Colorado Riverbasin, the data needed to quantitatively evaluate these potential impacts with CRSS was not yet available at the time of this study. Therefore, the paleo-hydrologic record was chosen as a means to evaluate the potential impacts from a wider range of dry and wet spells in the Colorado Riverbasin than is represented by the observed hydrologic record.

Future Depletion Scenarios

1. Lake Powell Pipeline (86kaf)

Pipeline depletion data for this scenario were provided by the State. The Lake Powell Pipeline maximum annual depletion is 86,249 acre-feet in the year 2042. Pipeline depletions are zero for the years 2009 through 2019. In 2020 pipeline depletions start at 1,975 acre-feet per year and increase each year through 2042 to 86,249 acre feet. The annual depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 86K. The annual volumes were disaggregated to monthly volumes based upon pump data that determined the number of pump days required each year. It was assumed that the pumps would operate at a constant flow rate from the first day of operation until the number of pump days was fulfilled each year. In addition, it was assumed that no pumping would occur the first 15 days of January each year to accommodate annual pipeline maintenance. The monthly depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 86K. Utah's total annual depletions remain the same as was modeled in the 2007 Shortage EIS. However, for this scenario the spatial distribution of Utah's depletions was modified from the 2007 Shortage EIS to specify a depletion occurring directly at Lake Powell. To keep Utah's total annual depletions constant, depletions from six nodes upstream of Lake Powell were decreased. The modified depletion schedules for these six nodes are provided in Attachment B: UtahDemandChanges.xls, worksheet 86K.

2. Lake Powell Pipeline (100kaf)

Pipeline depletion data for this scenario were provided by the State. The Lake Powell Pipeline maximum annual depletion is 100,000 acre-feet in the year 2046. Pipeline depletions are zero for the years 2009 through 2019. In 2020 pipeline depletions start at 1,975 acre-feet per year and they increase each year through 2046 to 100,000 acre feet. The annual depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 100KAF. The annual volumes were disaggregated to monthly volumes based upon pump data that determined the number of pump days required each year. It was assumed that the pumps would operate at a constant flow rate from the first day of operation until the number of pump days was fulfilled each year. In addition, it was assumed that the pumps would not be turned on until January 16th each year to accommodate 15 days for annual pipeline maintenance. The monthly depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 100KAF_monthly. Utah's total annual depletions remain the same as was modeled in the 2007 Shortage EIS. However, for this scenario the spatial distribution of Utah's depletions was modified from the 2007 Shortage EIS to specify a depletion occurring directly at Lake Powell. To keep Utah's total annual depletions constant, depletions from six nodes upstream of Lake

Powell were decreased. The modified depletion schedules for these six nodes are provided in Attachment B: UtahDemandChanges.xls, worksheet 100KAF.

3. No Action

Depletion data for this scenario were obtained from the 2007 Shortage EIS. Total Utah depletions, both annual and monthly, for years 2009 to 2060 are the same as those used in the 2007 Shortage EIS.

Future Inflow Hydrology Scenarios

1. Direct Natural Flow, Index Sequential Method

The future hydrology used as input to the model in this scenario consisted of samples taken from the historic record of natural flow in the river system over the 101-year period from 1906 through 2006 from 29 individual inflow points (or nodes) on the Colorado River System. Natural flow is the observed flow adjusted for the effects of diversions and the operation of reservoirs upstream of the flow gage. This natural flow record was developed by Reclamation and is used extensively in their hydrologic modeling and Environmental Impact Statements (EIS). In this inflow scenario, the existing historical record of natural flows was used to create a number of different future hydrologic sequences using a resampling technique known as the Indexed Sequential Method (ISM). The ISM provides the basis for quantification of the uncertainty and an assessment of the risk with respect to future inflows and is based upon the best available measured data. This inflow dataset and methodology was used as the primary inflow scenario in the 2007 Shortage EIS. Further details of Reclamation's natural flow dataset and the Index Sequential Method are available Attachment C: Chapter 4 of the 2007 Shortage EIS.

2. Nonparametric Paleo-conditioned (NPC) Inflows

This inflow hydrology scenario uses paleo-hydrologic state information (i.e., wet or dry) to conditionally sample from the historic natural flow record. The paleo-hydrologic state information was derived from annual streamflow reconstructions from tree-ring chronologies of the years 762 to 2005 on the Colorado River at Lees Ferry. The nonparametric paleo-conditioning technique first extracts the paleo-hydrologic state information from the streamflow reconstruction and then generates flow magnitudes by conditionally choosing from the historical record (i.e., from historical flows from a wet or dry sequence corresponding to the type of sequence derived from the paleo record). This technique generates flows with the same magnitudes as the historic record but with more variety in the sequencing of wet and dry spells. This inflow dataset and methodology was used for the sensitivity analysis in Appendix N of the 2007 Shortage EIS. Further details can be found in Attachment D: Appendix N of the 2007 Shortage EIS.

Methodology

Hydrologic modeling of the Colorado River system was conducted using Reclamation's long-term planning model, CRSS. The hydrologic modeling provides projections of potential future Colorado River system conditions (e.g., reservoir elevations, reservoir releases, river flows) under the no action alternative for comparison to conditions under each action of the two action alternatives. Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each alternative in order to quantify the uncertainties in future conditions, and the modeling results are typically expressed in probabilistic terms.

This document provides an overview of the hydrologic modeling and the framework within which the many simulations were undertaken. Further details regarding the model and modeling assumptions are also provided in Attachment E: Appendix A of the 2007 Shortage EIS.

Alternatives Modeled

Two action alternatives and a no action alternative were modeled. The action alternatives are the 86KAF and 100KAF depletion scenarios for the Lake Powell Pipeline described above. The no action alternative is the January 2009 official CRSS run and uses the same model assumptions as the 2007 Shortage EIS preferred alternative. Each action alternative includes specific assumptions with regard to the spatial distribution of Utah's projected future depletions (Attachment B).

Period of Analysis

Hydrologic modeling extends from 2009 through 2060.

Model Description

Future Colorado River system conditions under the no action alternative and the action alternatives were simulated using CRSS. The model framework of CRSS is a commercial river modeling software called RiverWare™; a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation and the Tennessee Valley Authority. CRSS was originally developed by Reclamation in the early 1970s and was implemented in RiverWare™ in 1996.

CRSS simulates the operation of the major reservoirs on the Colorado River on a monthly time-step and provides information regarding the projected future state of the system in terms of output variables including the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and the diversions to and return flows from the water users throughout the system. The simulation uses a mass balance (or water budget) approach to account for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, evaporation), and water moving through the system (i.e., either stored in reservoirs or flowing in river reaches). Further explanation of the model is provided in Attachment E. The model was used to project the future conditions of the Colorado River system on a monthly time-step for the period 2009 through 2060.

The input data for the model includes monthly future inflows (either DNF or NPC), various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions on January 1, 2009, and the future diversion and depletion schedules for entities in the Basin States and for Mexico. These future schedules were based on demand and depletion projections prepared and submitted by the Basin States.

Depletions (or water use) are defined here as diversions from the river less return flow credits, where applicable.

The rules of operation of the Colorado River mainstream reservoirs including Lake Powell are also provided as input to the model. These sets of operating rules describe how water is released and delivered under various hydrologic conditions.

General model assumptions:

- January 2009 initial conditions for all modeled reservoirs
  - Powell 3617.89 ft
- Run duration: 2009-2060
- Runs revert to the 2007 Shortage Final EIS No Action Alternative in 2027
- Index sequential method used for the Direct Natural Flow period of record (1906-2006): 101 simulations.
- Nonparametric paleo-conditioned inflows: 125 simulations

Modifications to CRSS

Several modifications were made to the official version of CRSS to model the Lake Powell Pipeline. The data for these changes were provided to Reclamation by the State to adjust the location of Utah's water use to account for the Lake Powell Pipeline. Specifically, a new diversion node, "Lake Powell Pipeline", was added to simulate water being pumped directly from Lake Powell. The spatial structure of previous versions of CRSS simulated a diversion to the "St. George Pipeline" at a location slightly upstream from Lake Powell. The old "St. George Pipeline" diversion node was removed from the model for this analysis. Utah's projected depletion schedules for the Lake Powell Pipeline were provided to Reclamation by the State.

Results

Each of the three alternatives was modeled using both the DNF and NPC future inflow scenarios, resulting in six model runs. For comparison purposes, each action alternative is compared to the no action alternative. The comparisons are made using both the DNF and NPC future inflow scenarios. At the request of the State, the following variables were evaluated:

- Powell pool elevation on Dec 31st (10th, 50th, 90th percentiles over time)
- Probability of Powell Dec 31st elevation < 3490 ft
- Powell water year release (10th, 50th, 90th percentiles over time)
- Powell water year release (flow duration curve throughout time)
- Powell monthly releases (12 months) (10th, 50th, 90th percentiles over time)
- Flaming Gorge annual release (10th, 50th, 90th percentiles over time)

Post-processing and Interpretation Procedures

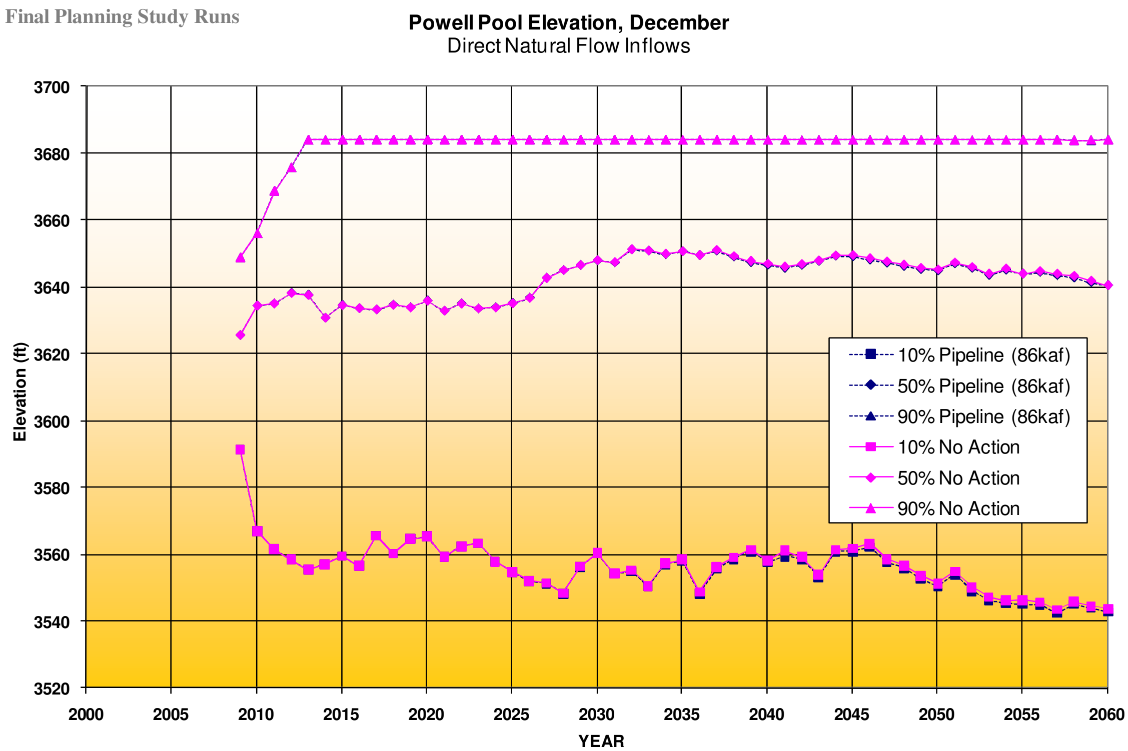
CRSS generates data on a monthly time-step for over 300 points (or nodes) on the Colorado River system. Furthermore, using ISM on the natural flow record, the model generated 101 possible outcomes for each node for each month of the model run. For the nonparametric paleo-conditioned inflow scenarios, 125 possible outcomes were generated for each node and month in the run period. These very large data sets generated for each alternative can be visualized as three-dimensional data “cubes” with the axes of time, space (or node) and trace (or outcome for each future hydrology). The data were aggregated to reduce the volume of data and to facilitate comparison of the alternatives.

For aggregation of data, simple techniques were employed. For example, Lake Powell pool elevations were evaluated on an annual basis (i.e., end of December) to show long-term lake elevation trends as opposed to short-term fluctuations. Standard statistical techniques were used to analyze the 101 or 125 possible outcomes for a fixed time or particular temporal span. Statistics that were generated included the 10^{th} 50^{th} and 90^{th} percentiles. Percentiles were determined by simply ranking the outcomes at each time-step (from highest to lowest) and determining the value at the specified percentile. This statistical method is used to view the results of all hydrologic sequences in a compact manner yet maintains the variability at high, medium, and low reservoir elevations that may be lost by averaging the results of all traces. Such a statistic provides information with regard to the probability (e.g., a 10 percent probability) of the variability of interest being at or below the 10^{th} percentile value in a specified year.

Direct Natural Flow, ISM Results

86K Pipeline Alternative

Figure 1 shows the differences in Lake Powell pool elevation in December between the 86K depletion alternative and the no action alternative at the 10^{th}, 50^{th}, and 90^{th} percentiles. Prior to the year 2020, there are no differences at any percentile level. Between 2020 and 2060, the differences range between 0 ft and 1.8 ft at the 10^{th} percentile, with Lake Powell elevation being lower in the 86kaf pipeline depletion alternative. In general, the differences are larger later in the later modeled years. Differences at the 50^{th} percentile level range from 0 ft to 0.6 ft, again with Lake Powell being lower in the 86kaf pipeline depletion alternative and with the larger of these differences generally occurring in the later years. Differences at the 90^{th} percentile level range from 0 ft to 0.03 ft.



Lake Powell Pool Elevation, December. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Figure 2 shows probability of Lake Powell pool elevation being below 3490 ft (minimum power pool) in March. March was chosen as this is the month the reservoir elevation is typically lowest. The probability of Lake Powell being below 3490 ft is the same in the action and no action alternatives, except in two years when the probability was approximately one and two percent higher in the action alternative.

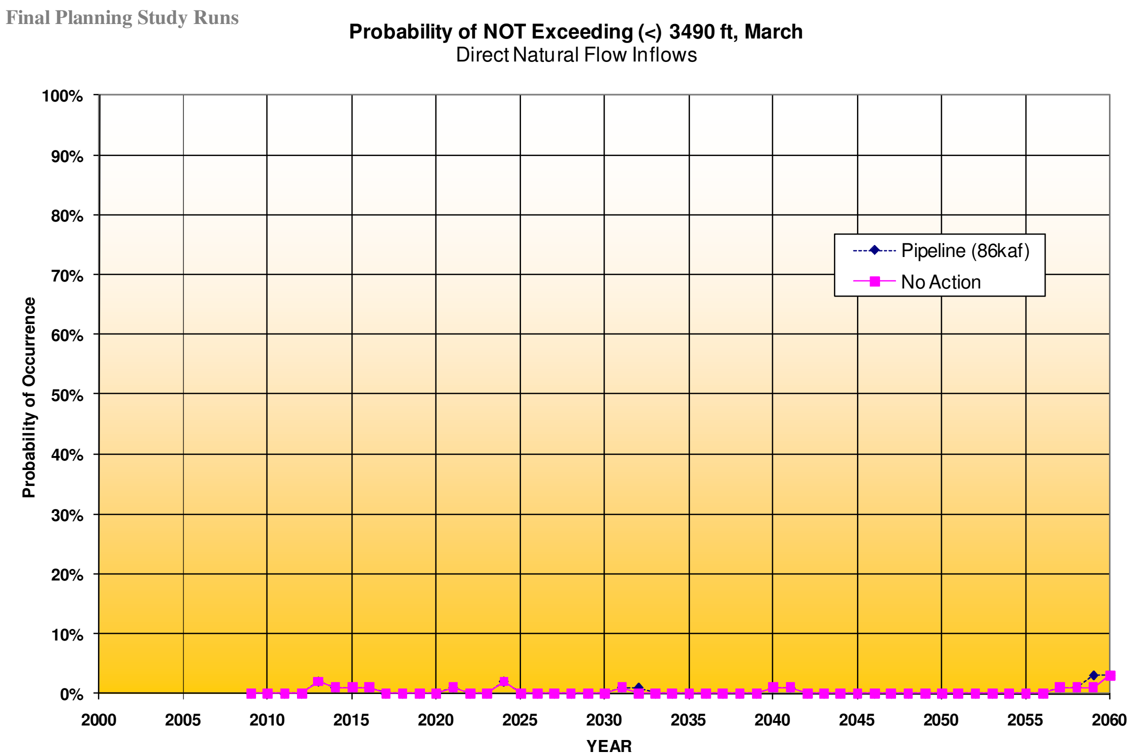
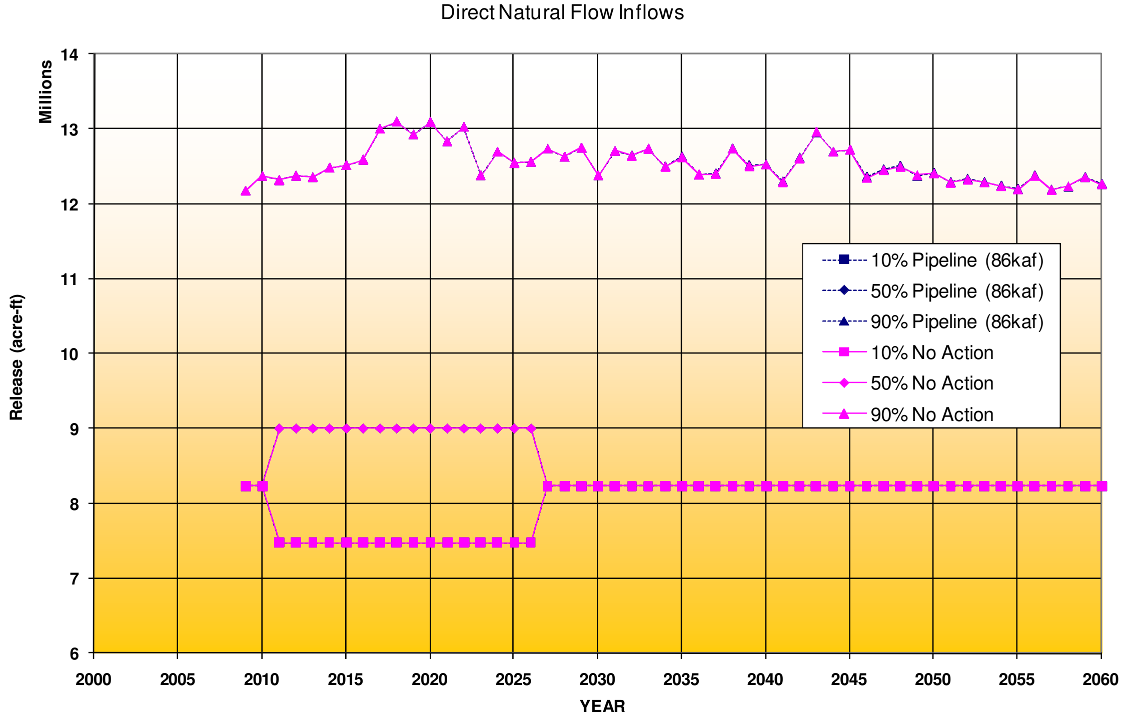


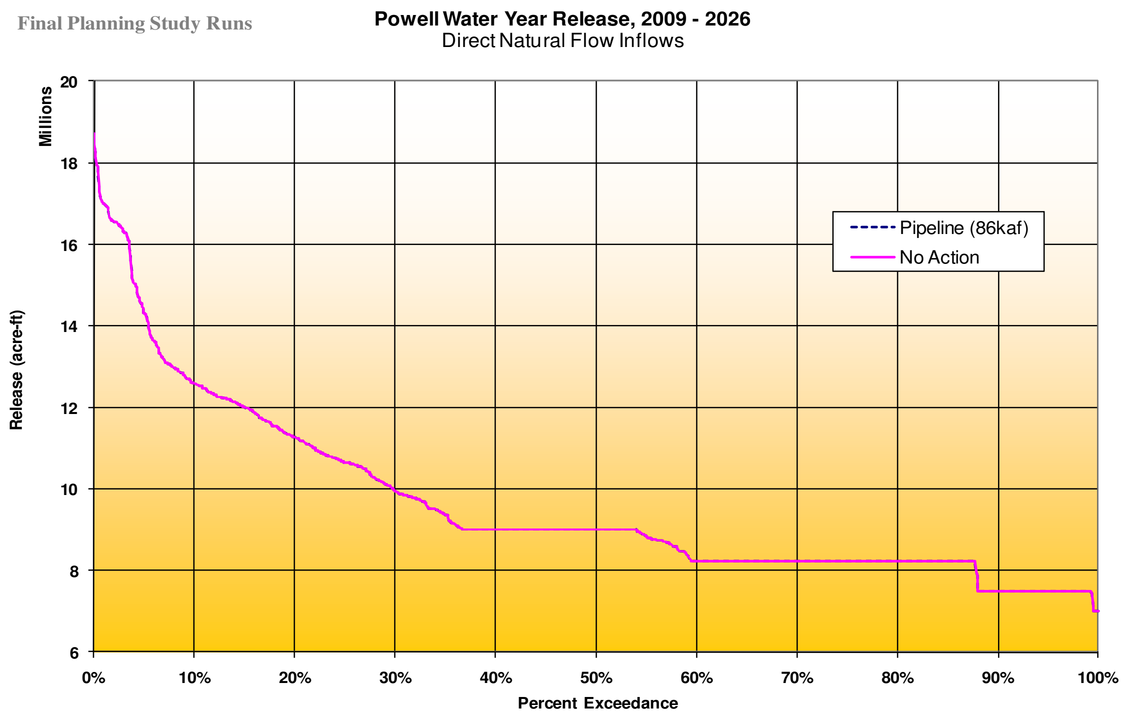
Figure 2. Probability of Lake Powell pool elevation being below 3490 ft in March. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Figure 3 presents Lake Powell's water year releases. For the 10th and 50th percentiles, there are no differences between the action and no action alternatives. For the 90th percentile, which reflects equalization releases from Lake Powell to Lake Mead or spill avoidance releases, the largest difference between the action and no action alternatives is approximately 18,000 acre-feet, or approximately 0.1% of the annual release, more being released in one year under the action alternative. See Attachment F for the differences in each year. Overall, the differences in annual releases between the action and no action alternative are very small. In general these differences are greater in the later simulated years than in the earlier years and the later years tend to result in the action alternative releasing more.

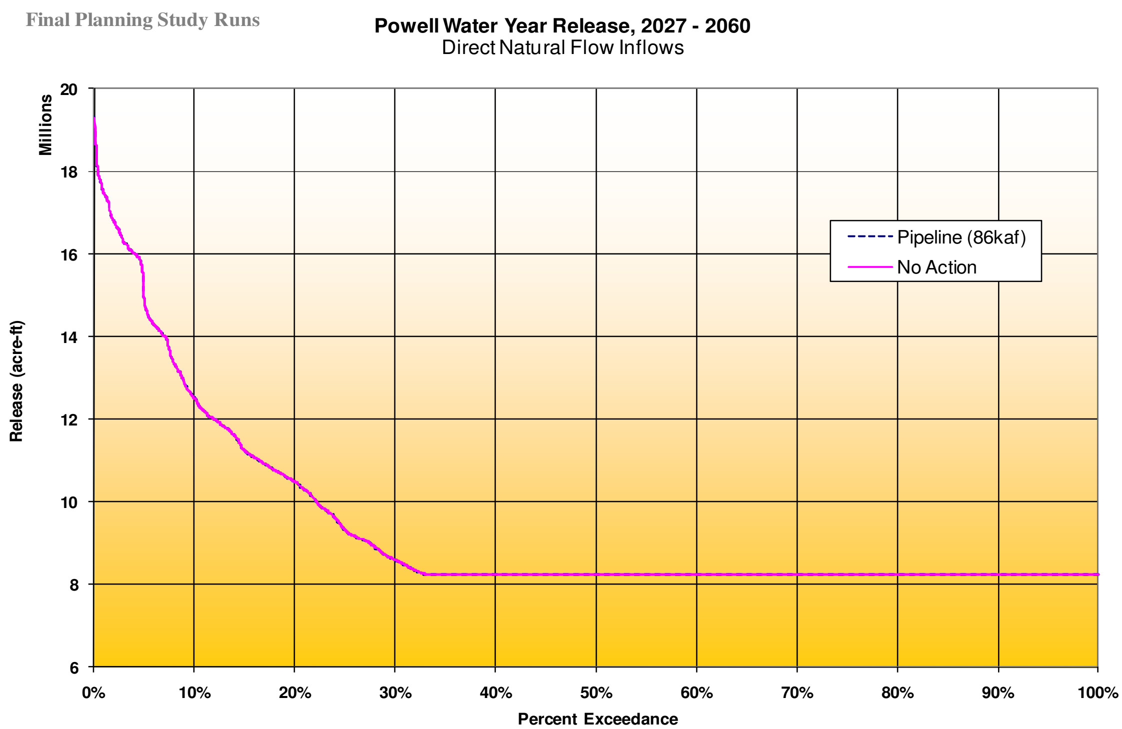


Lake Powell water year release. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

The flow duration curves of Lake Powell releases throughout the Interim Guidelines period (2009-2026) and throughout the post-Interim Guidelines period (2027-2060) are presented in Figure 4 (a) and (b), respectively. In this figure, Lake Powell releases at every exceedance percentile (from 0 to 100) are plotted, rather than the three percentile plots shown in Figure 3. The Interim Guidelines and post-Interim Guidelines periods are plotted separately because operations at Lake Powell differ significantly between these two time periods. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the action, however, the differences vary by both sign and magnitude throughout the curve. As evidenced in Figure 3, the greatest differences occur at the lower exceedance probabilities (higher percentiles), when Lake Powell is at higher elevation and making equalization releases to Lake Mead or releases for spill avoidance. The greatest difference of approximately 47,000 acre-feet, or 0.2%, per year more being released in the action alternative occurs at the 1 percent exceedance level (99th percentile). See Attachment F for the differences at each exceedance probability.



(a)



(b)

Figure 4. Lake Powell water year release, flow duration curve throughout time during the Interim Guidelines period (a) and during the post-Interim Guidelines period (b). Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Annual releases from Flaming Gorge are shown in Figure 5. Differences between the action and no action alternative are zero at the 50th and 90th percentiles and occur only at the later model run dates (2043-2050) for the 10th percentile. In these years releases from Flaming Gorge are lower with the action alternative; the greatest difference is 1,563 acre-feet per year, or approximately 0.2%, less being released.

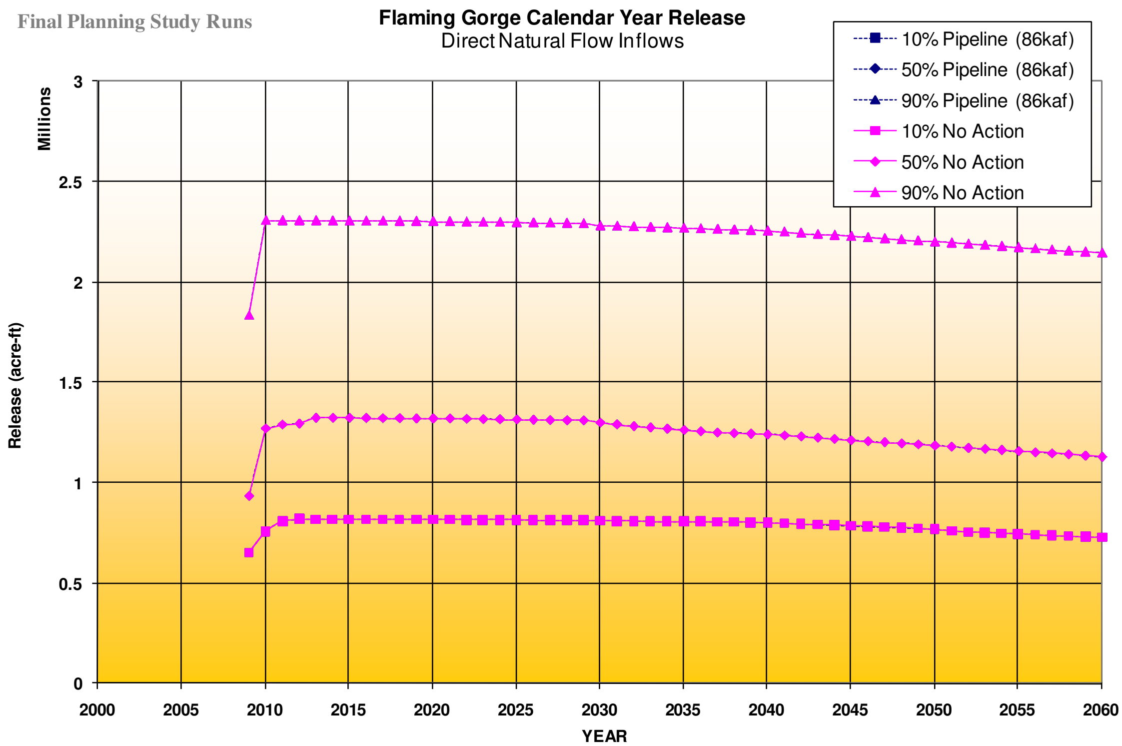
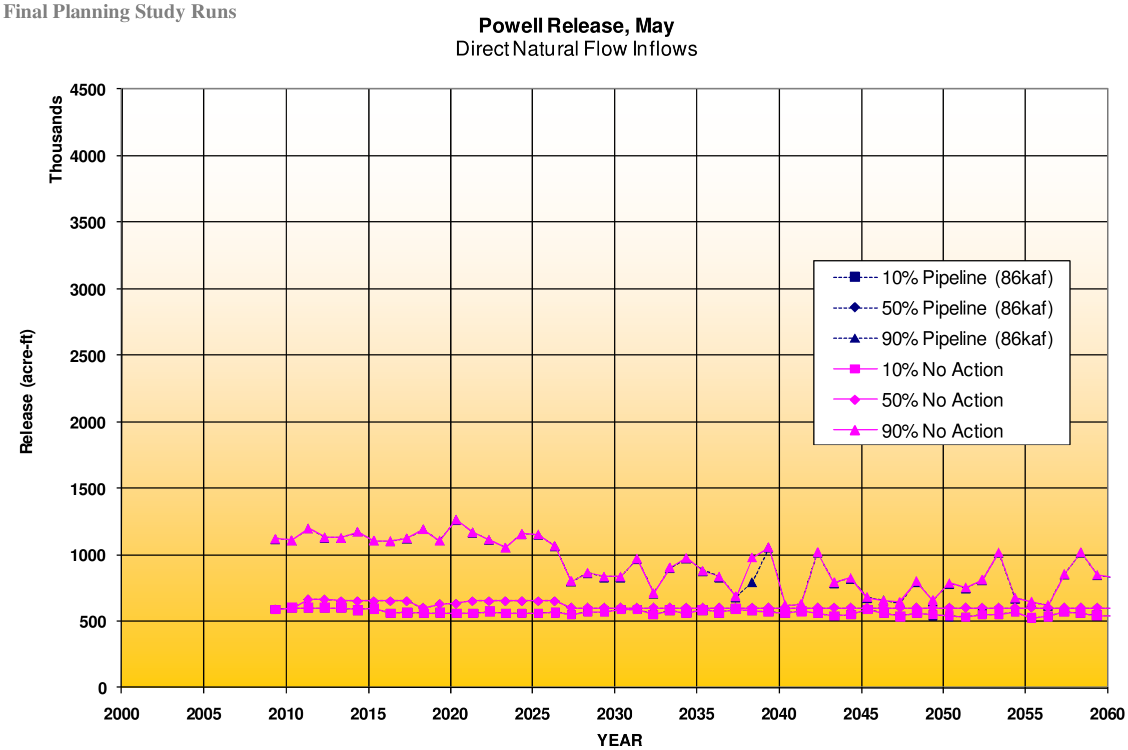


Figure 5. Flaming Gorge annual release. Direct natural flow inflows, 86kaf Lake Powell Pipeline max depletion.

The releases from Lake Powell in the monthly of May are shown in Figure 6. For results in every month, see Attachment F: FPS_DNF_86K_plots.xls. April and May are the months that show the greatest differences between the action and no action alternatives. For all months, the differences are greatest at the 90th percentile level (i.e., for higher releases including spill avoidance and equalization). Overall, releases from Lake Powell are generally lower for the months of October, November, January, February and March, ranging approximately from 500,000 acre-feet to 800,000 acre-feet for the 10th percentile and 500,000 to 1,000,000 acre-feet for the 90th percentile. Releases in the months of April through September and December are generally higher, ranging approximately from 500,000 acre-feet to 900,000 acre-feet for the 10th percentile and 600,000 to 2,000,000 acre-feet for the 90th percentile. Differences between the action and no action alternatives are greatest in the months in which there are higher releases and in which there is higher year to year variability.

Final Planning Study Runs



Lake Powell monthly release, May. Direct natural flow inflows, 86kaf Lake Powell Pipeline max depletion.

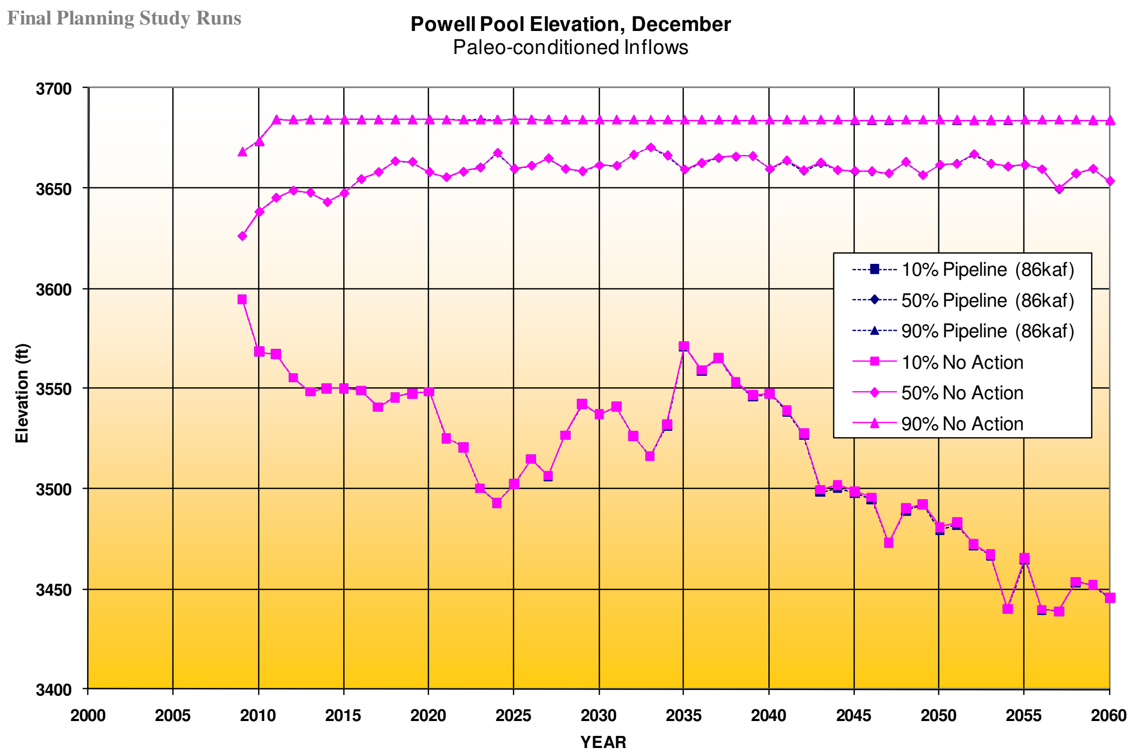
100K Pipeline Alternative

Results for the 100K pipeline alternative exhibit very similar trends to those shown in Figures 1 to 6. See Attachment G: FPS_DNF_100K_plots.xls for full set of figures and data. The range of differences of Lake Powell pool elevation is the same as those for the 86K pipeline scenario (Figure 1), to the nearest hundredth foot. Results for the probability of being below the minimum power pool are the same as presented in Figure 2. Results for Lake Powell water year release show differences within the same range and with the same trends as those exhibited in Figures 3 and 4. Results for Flaming Gorge annual release are within the same range as those for the 86K scenario (Figure 5). Lake Powell monthly release results are very similar to those for the 86K pipeline alternative (Figure 6).

Nonparametric Paleo-Conditioned Inflows Results

86K Pipeline Alternative

Figure 7 shows the differences in Lake Powell pool elevation in December between the 86K depletion alternative and the no action alternative at the 10^{th}, 50^{th}, and 90^{th} percentiles for NPC inflow scenario. The NPC inflow scenario produces a richer variety of wet and dry spells, resulting in different future elevations at Lake Powell when compared with the DNF inflow scenario. However, the differences between the action and no action alternatives are very similar to those for the DNF simulations. The greatest differences for Lake Powell elevation in the NPC inflow scenario occur in the 10th percentile (i.e., the lowest elevations), with a maximum simulated difference of 1.7 ft lower in the action scenario.



Lake Powell Pool Elevation, December. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline max depletion.

Overall, the probability of not exceeding Lake Powell's minimum power pool (3490 ft) in March is higher in the NPC inflow scenario compared to the DNF inflow scenario (Figure 8). However, the differences between the action and no action alternative for the NPC inflows are almost the same as those for the DNF inflows. With NPC inflows, the probability of Lake Powell being below 3490 ft is the same in the action and no action alternatives, except in three years when the probability was approximately one percent higher in the action alternative.

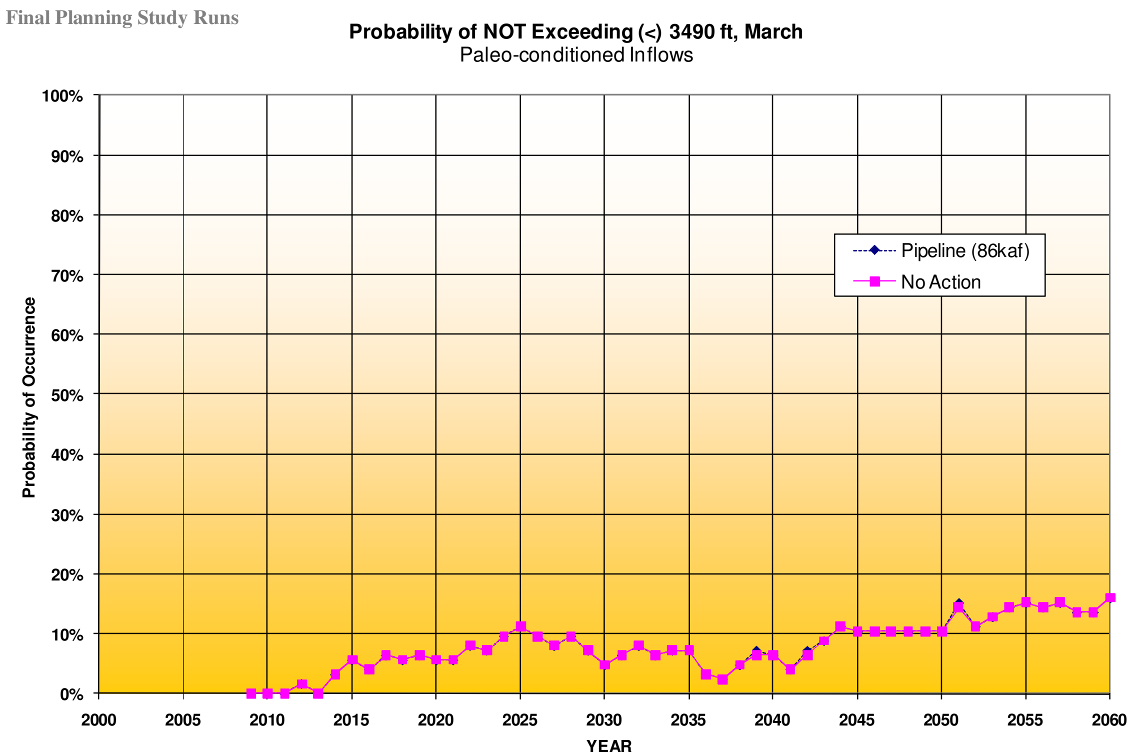
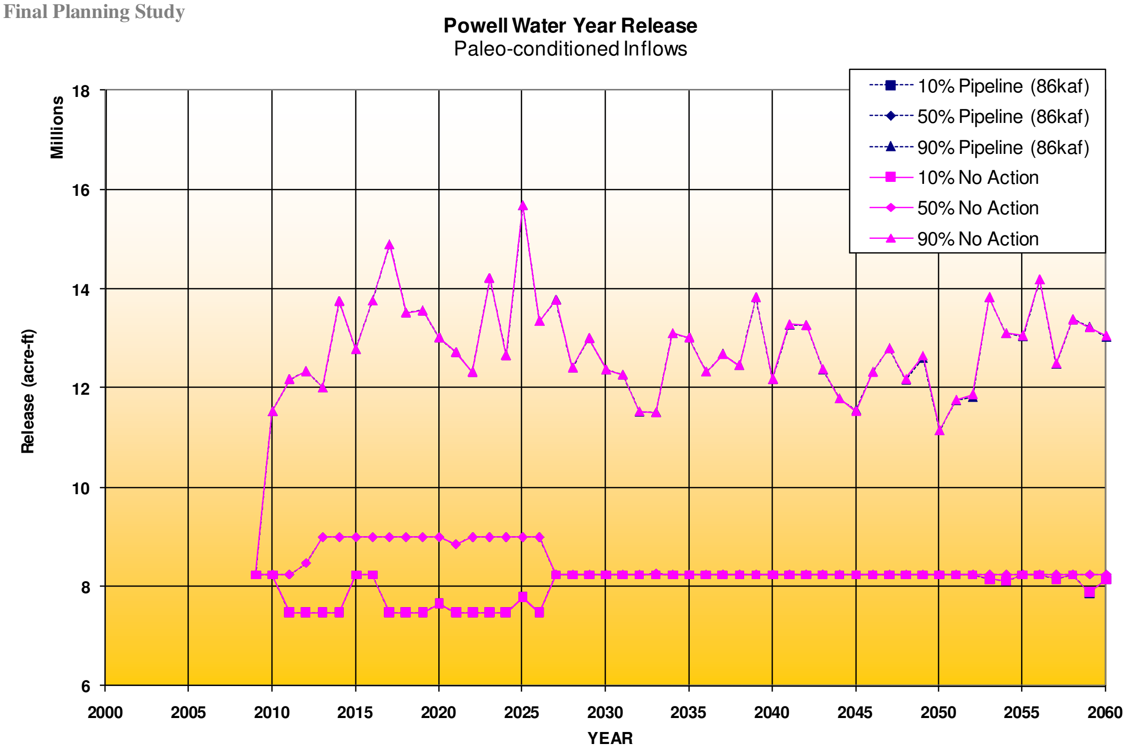


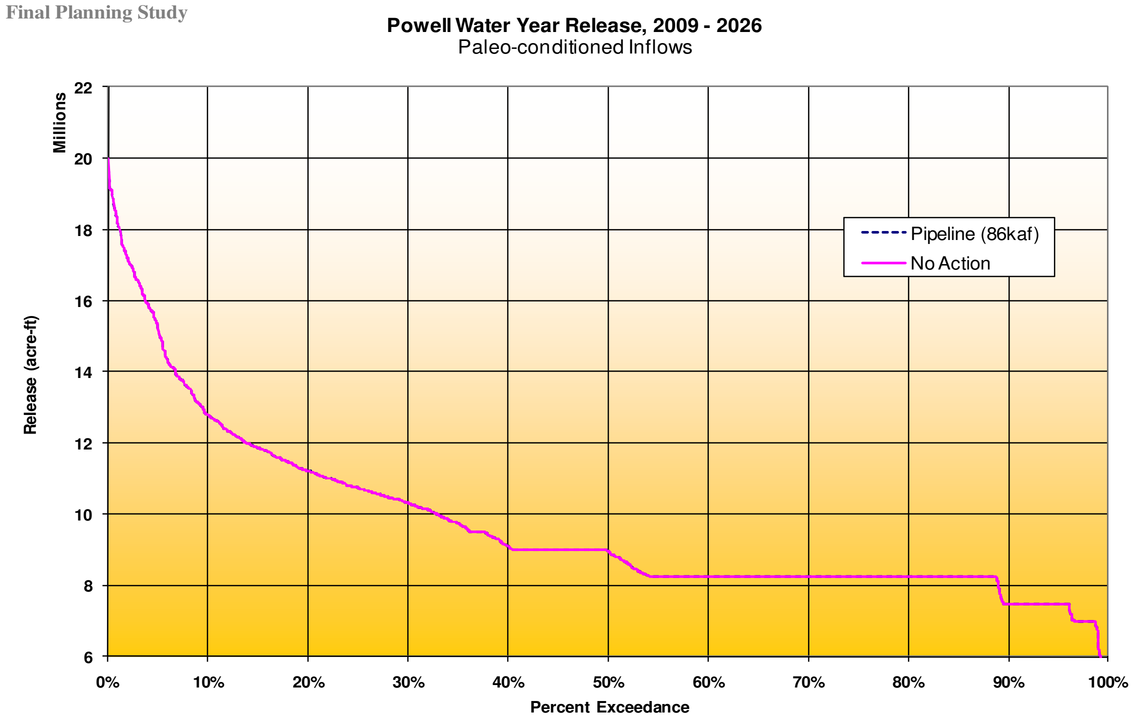
Figure 8. Probability of Lake Powell pool elevation being below 3490 ft in March. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline max depletion.

Results for NPC inflows and Lake Powell water year releases are shown in Figure 9. Though the overall release pattern varies from the DNF inflow scenarios, the differences between the action and no action alternatives are very similar to those for the DNF inflow scenario (Figure 3). The differences are greatest in the 90th percentile with a maximum difference of 56,500 acre-feet, or 0.5%, less begin released in the action alternative. In some years the action alternative results in greater releases from Lake Powell than the no action alternative, in other years the no action alternative results in greater releases from Lake Powell. See Attachment H for the differences in each year.

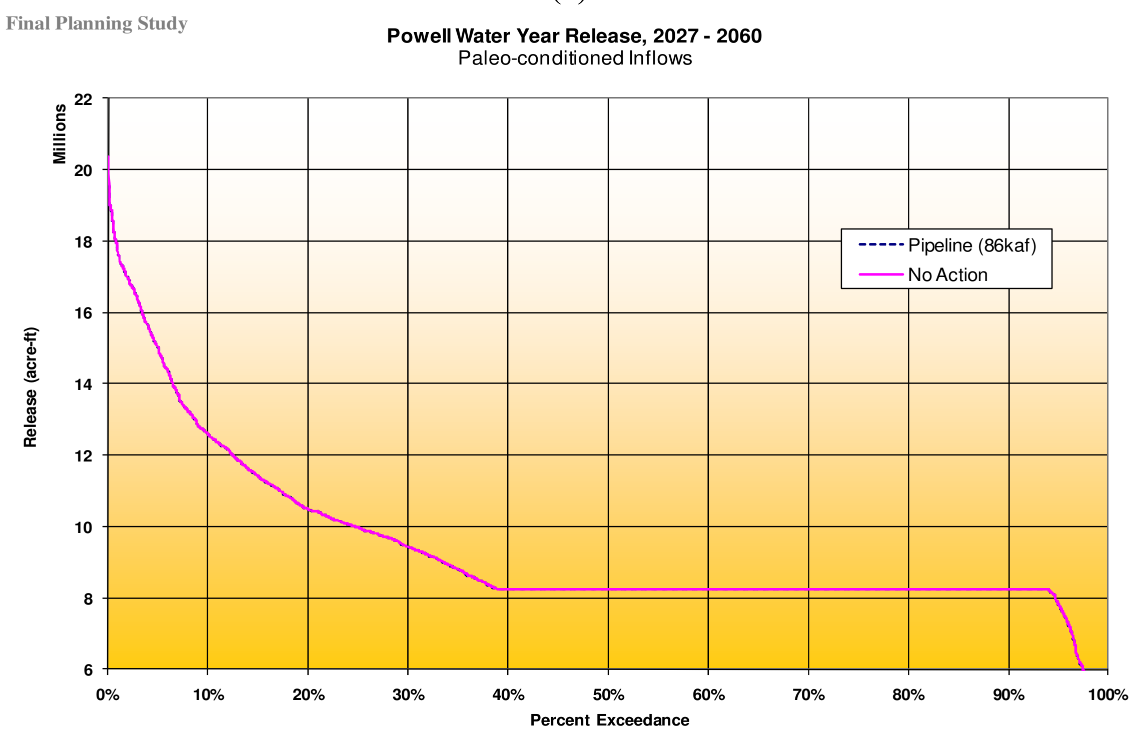


Lake Powell water year release. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline max depletion.

The flow duration curves of Lake Powell releases throughout the Interim Guidelines period (2009-2026) and throughout the post-Interim Guidelines period (2027-2060) are presented in Figure 10 (a) and (b), respectively. In this figure, Lake Powell releases at every exceedance percentile (from 0 to 100) are plotted, rather than the three percentile plots shown in Figure 9. The Interim Guidelines and post-Interim Guidelines periods are plotted separately because operations at Lake Powell differ significantly between these two time periods. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the pipeline, however, the differences vary by both sign and magnitude throughout the curve. As evidenced in Figure 9, the greatest differences occur at the lower exceedance probabilities (higher percentiles) when Lake Powell is making larger releases for equalization or spill avoidance. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the action, however, the differences vary by both sign and magnitude throughout the curve. The greatest difference of approximately 140,000 acre-feet, or 1%, per year more being released in the no action alternative occurs at the 1 percent exceedance level (99th percentile).



(a)



(b)

Figure 10. Lake Powell water year release, flow duration curve throughout time during the Interim Guidelines period (a) and during the post-Interim Guidelines period (b). Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

Annual releases from Flaming Gorge are shown in Figure 11. Differences between the action and no action alternative are zero in all years, except two. The greatest difference is 2,972 acre-feet, or 0.2%, per year less volume being released in the no action alternative.

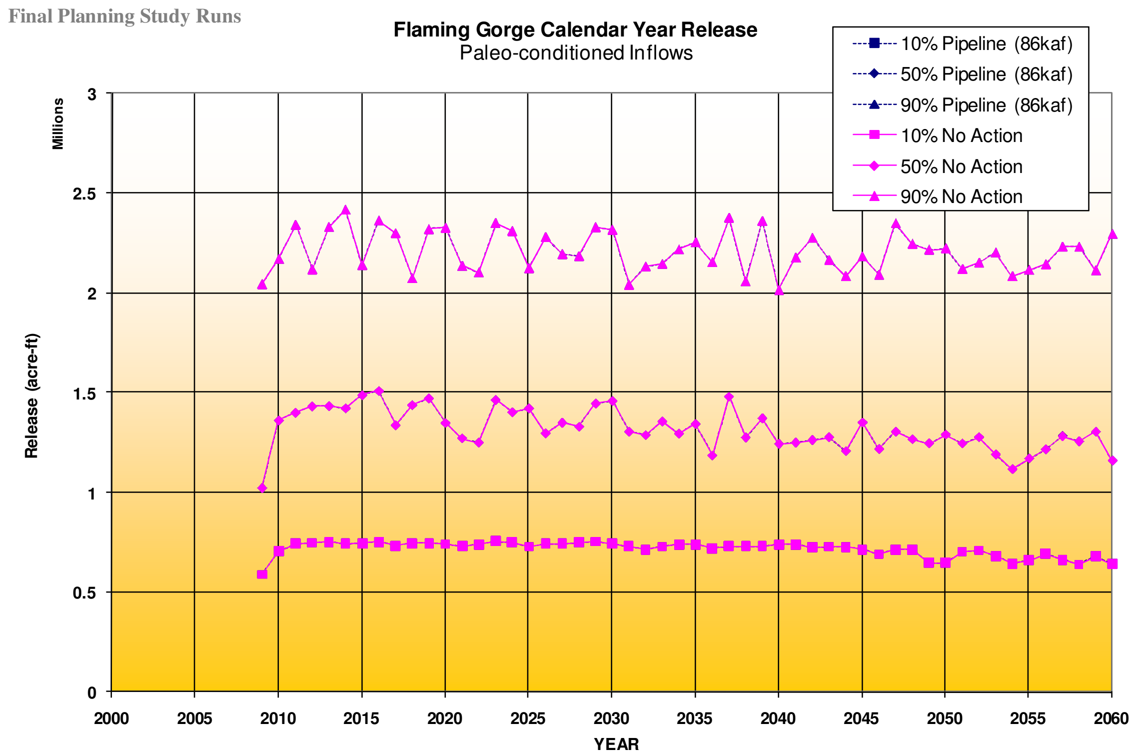
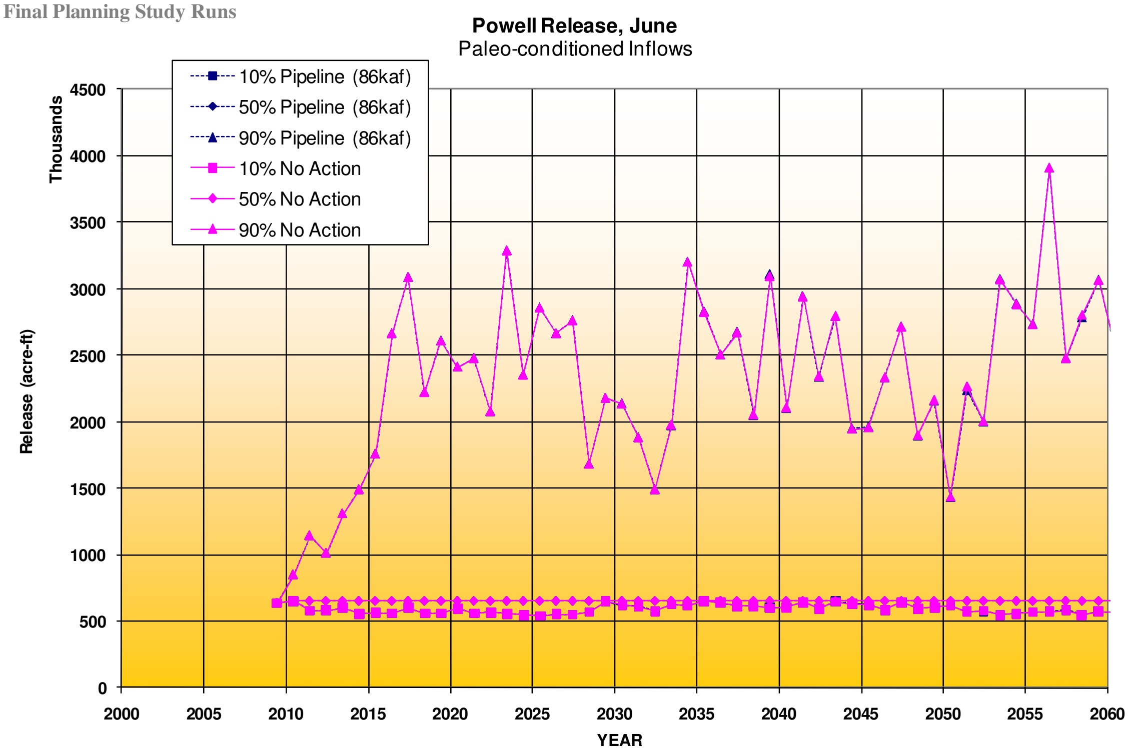


Figure 11. Flaming Gorge annual release. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline max depletion.

The releases from Lake Powell in the month of June for the NPC inflow scenario are shown in Figure 12. For results in every month, see Attachment H – FPS_NPC_86K_plots.xls. Across all months, the differences are similar to those in the DNF inflow scenario with the differences generally being greater at the 90th percentile level and with very few differences at the 50th percentile level. In June, the largest difference was 29,000 acre-ft, or 1%, less being released in the action alternative. For all months, in some years the action alternative released more water, in others, the no action alternative resulted in larger releases.

Final Planning Study Runs



Lake Powell monthly release, June. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

100K Pipeline Alternative

Results for the 100K pipeline alternative with the NPC inflow scenarios exhibit very similar trends to those shown in Figures 7 to 12. See Attachment I: FPS_NPC_100K_plots.xls for full set of figures and data. The range of differences of Lake Powell pool elevation is the same as those for the 86K pipeline scenario (Figure 7), to the nearest tenth foot; the greatest difference being 1.6 ft. Results for the probability of being below the minimum power pool are the same as presented in Figure 8, with differences of 1% in three years. Results for Lake Powell water year release show differences within the same range and with the same trends as those exhibited in Figures 9 and 10, with a maximum difference of 53,000 acre-feet, or 0.4% more being released in the no action alternative. Results for Flaming Gorge annual release are the same as those for the 86K scenario (Figure 11). Lake Powell monthly release results are very similar to those for the 86K pipeline alternative (Figure 12).

Discussion

The results from these hydrologic model runs should be interpreted with consideration to the model assumptions. Note that these model results do not represent what the actual reservoir elevations or releases will be in any particular year. Model results should be interpreted based on the relative differences between the action and no action alternatives.

These model runs implement the Interim Guidelines through 2026 and revert to the 2007 Shortage Final EIS No Action Alternative for model years 2027-2060. The modeled Lake Powell Pipeline begins depleting water in 2020 and is at full build out in 2042 (86K depletion alternative) and 2046 (100K depletion alternative). Thus, for this analysis the potential effects of the Lake Powell Pipeline project under the Interim Guidelines are evaluated for seven years, the first seven years of the pipeline when the project is just coming on line and depletions are lower. The effects of the pipeline at full build out are evaluated under post Interim Guidelines operational policies. It is currently unknown what the operational policies will be after 2026; thus the assumptions implemented in the 2007 shortage EIS were also implemented in this study (i.e. Interim Guidelines implemented through 2026.)

Attachments List

Attachment A: PipelineDepletions.xls
Attachment B: UtahDemandChanges.xls
Attachment C: 2007 Shortage EIS, Chapter 4
Attachment D: 2007 Shortage EIS, Appendix N
Attachment E: 2007 Shortage EIS, Appendix A
Attachment F: FPS_DNF_86K_plots.xls
Attachment G: FPS_DNF_100K_plots.xls
Attachment H: FPS_NPC_86K_plots.xls
Attachment I: FPS_NPC_100K_plots.xls

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Lake Powell Pipeline Hydrologic Modeling

No Additional Depletions Sensitivity Analysis

Overview

Through coordination with the State of Utah Division of Water Resources (State), the Bureau of Reclamation (Reclamation) conducted several hydrologic modeling runs using Reclamation's long-term planning model, Colorado River Simulation System (CRSS). The results of these model runs have been provided to the State for use in its planning studies for the Lake Powell Pipeline (LPP) project to determine potential impacts on the hydrology of the Colorado River System.

This report presents the results of one set of hydrologic modeling runs, the No Additional Depletions sensitivity analysis. A previous report for No Additional Depletions sensitivity runs was provided to the State in August 2009. A modification to the pumping schedule and the rate at which the Lake Powell Pipeline depletions would come online necessitated re-running the model. This report presents the results from the reanalysis which incorporates the new pipeline depletion schedule.

An analysis of the Final Planning Study runs, most recently updated in December 2009 with the new Lake Powell Pipeline depletion schedule, has also been provided to the State. The modeling runs described in this report are similar to the December 2009 Final Planning Study runs with two key differences. The first key difference is that in the No Additional Depletions runs all future Upper Basin depletions *except* for the Lake Powell Pipeline and other future depletions assumed to be reasonably foreseeable are modeled as constant at the 2009 depletion levels for the entire model run. In this context, a reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). See the Discussion section of this document for further discussion and Attachment B: ReasonablyForeseeable DepletionNodes.xls for specific CRSS model depletion nodes. In contrast, Final Planning Study runs projected future Upper Basin depletions to increase throughout the entire model run period. The second key difference is that in the Final Planning Study Runs it was assumed that if Utah did not take water at the Lake Powell Pipeline, it would be taken somewhere else in the state. This essentially isolates the impact of the geographic location of the depletion from the Colorado River system; Utah's total depletions remain the same in the action and No Action alternatives. In contrast, the No Additional Depletions sensitivity runs analyze the difference between taking water out of the Colorado River at Lake Powell Pipeline and not taking it out at all. In the No Additional Depletions sensitivity analysis, Utah's total depletions are *not* the same in the pipeline and no pipeline scenarios; they differ by volume going to the Lake Powell Pipeline. This essentially isolates the impact of whether Utah will take water for the Lake Powell Pipeline project.

Two alternatives were compared in the No Additional Depletions runs: (1) Upper Basin depletions held constant at 2009 levels *except* reasonably foreseeable depletions and (2) all Upper Basin depletions held constant at 2009 levels *except* reasonably foreseeable depletions *and* the Lake Powell Pipeline.

The first section of this report presents an overview of the data. Next, the general methodology and technical assumptions of CRSS are reviewed, followed by the technical assumptions specific to this study and the No Additional Depletions runs. The modeling results are then presented with an analysis of the differences between the action and no action alternatives. A discussion section concludes the report.

Data

In the No Additional Depletions runs, the same pipeline scenarios and inflow scenarios were modeled as in the Final Planning Study model runs. Three future depletion scenarios, two potential Lake Powell Pipeline depletion schedules (86kaf and 100kaf) and one no pipeline depletion schedule, were modeled.

For each of the three pipeline depletion scenarios, it was assumed that Upper Basin depletions without state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD).remained constant at the 2009 depletion levels currently in CRSS. Those depletions assumed reasonably foreseeable include Central Utah Project, Animas-La Plata, Dolores Project, Navajo-Gallup, Ute Indian Compact, and Navajo Indian Irrigation Project. See the discussion section for further details and Attachment B for CRSS model depletions nodes not held constant. Note that the 2009 depletions levels modeled are based upon the Upper Basin depletion schedules in CRSS and not the observed (or computed) depletions reported in the 2009 Consumptive Use and Loss (CU&L) Report prepared by Reclamation. This is because the 2009 CU&L report was not available at the time of the model runs or this report.

For each of the three depletion scenarios, two future inflow hydrology scenarios were modeled. One inflow scenario uses data from the observed streamflow record (1906-2006). The other inflow scenario uses hydrologic data derived from tree rings (762 - 2005) to represent climate variability in the Colorado Riverbasin over the past millennium. These methods are discussed in further detail below. Though the potential impacts of climate change have been studied in the Colorado Riverbasin, the data needed to quantitatively evaluate these potential impacts with CRSS was not yet available at the time of this study. Therefore, the paleo-hydrologic record was chosen as a means to evaluate the potential impacts from a wider range of dry and wet spells in the Colorado Riverbasin than is represented by the observed hydrologic record.

Future Depletion Scenarios

1. Lake Powell Pipeline (86kaf)

Pipeline depletion data for this scenario were provided by the State. The Lake Powell Pipeline maximum annual depletion is 86,249 acre-feet in the year 2042. Pipeline depletions are zero for the years 2009 through 2019. In 2020 pipeline depletions start at 1,975 acre-feet per year and increase each year through 2042 to 86,249 acre feet. The annual depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 86K. The annual volumes were disaggregated to monthly volumes based upon pump data that determined the number of pump days required each year. It was assumed that the pumps would operate at a constant flow rate from the first day of operation until the number of pump days was fulfilled each year. In addition, it was assumed that no pumping would occur the first 15 days of January each year to accommodate annual pipeline maintenance. The monthly depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 86K. For this scenario, Utah's (and all other Upper Basin States') total annual depletions are significantly lower than those modeled in the 2007 Final EIS of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Shortage EIS). This is because all depletions except the pipeline throughout the Upper Basin were held constant at 2009 depletion levels.

2. Lake Powell Pipeline (100kaf)

Depletion data for this scenario were provided by the State of Utah. The Lake Powell Pipeline maximum annual depletion is 99,970 acre-feet in the year 2060. Pipeline depletions are zero for the years 2009 through 2019. In 2020 pipeline depletions start at 1,899 acre-feet per year and they increase each year through 2060 to 99,970 acre feet. The annual depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 100KAF. The annual volumes were disaggregated to monthly volumes assuming a constant flow rate over all months, except in January for which the flow rate was assumed to be 0.0 cfs for 15 days during pipeline inspection and maintenance. The monthly depletion schedule is provided in Attachment A: PipelineDepletions.xls, worksheet 100KAF_monthly. For this scenario, Utah's (and all other Upper Basin States') total annual depletions are significantly lower than those modeled in the 2007 Final EIS of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Shortage EIS). This is because all depletions except the pipeline throughout the Upper Basin were held constant at 2009 depletion levels.

3. No Pipeline

Depletion data for this scenario were obtained from the official Upper Basin depletion schedule in CRSS. All Upper Basin depletions were held constant at 2009 levels for the years 2009 to 2060 *except* those assumed reasonably foreseeable. Lake Powell Pipeline depletions were assumed zero for the entire model run (2009-2060).

Future Inflow Hydrology Scenarios

1. Direct Natural Flow, Index Sequential Method

The future hydrology used as input to the model in this scenario consisted of samples taken from the historic record of natural flow in the river system over the 101-year period from 1906 through 2006 from 29 individual inflow points (or nodes) on the Colorado River System. Natural flow is the observed flow adjusted for the effects of diversions and the operation of reservoirs upstream of the flow gage. This natural flow record was developed by Reclamation and is used extensively in their hydrologic modeling and Environmental Impact Statements (EIS). In this inflow scenario, the existing historical record of natural flows was used to create a number of different future hydrologic sequences using a resampling technique known as the Index Sequential Method (ISM). The ISM provides the basis for quantification of the uncertainty and an assessment of the risk with respect to future inflows and is based upon the best available measured data. This inflow dataset and methodology was used as the primary inflow scenario in the 2007 Shortage EIS. Further details of Reclamation's natural flow dataset and the Index Sequential Method are available Attachment C: Chapter 4 of the 2007 Shortage EIS.

2. Nonparametric Paleo-conditioned (NPC) Inflows

This inflow hydrology scenario uses paleo-hydrologic state information (i.e., wet or dry) to conditionally sample from the historic natural flow record. The paleo-hydrologic state information was derived from annual streamflow reconstructions from tree-ring chronologies of the years 762 to 2005 on the Colorado River at Lees Ferry. The nonparametric paleo-conditioning technique first extracts the paleo-hydrologic state information from the streamflow reconstruction and then generates flow magnitudes by conditionally choosing from the historical record (i.e., from historical flows from a wet or dry sequence corresponding to the type of sequence derived from the paleo record). This technique generates flows with the same magnitudes as the historic record but with more variety in the sequencing of wet and dry spells. This inflow dataset and methodology was used for the sensitivity analysis in Appendix N of the 2007 Shortage EIS. Further details can be found in Attachment D: Appendix N of the 2007 Shortage EIS.

Methodology

Hydrologic modeling of the Colorado River system was conducted using Reclamation's long-term planning model, CRSS. The hydrologic modeling provides projections of potential future Colorado River system conditions (e.g., reservoir elevations, reservoir releases, river flows) under the No Pipeline scenario for comparison to conditions under each scenario of the two pipeline alternatives (86kaf and 100kaf). Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each alternative in order to quantify the uncertainties in future conditions, and the modeling results are typically expressed in probabilistic terms.

This document provides an overview of the hydrologic modeling and the framework within which the many simulations were undertaken. Further details regarding the model and modeling assumptions are also provided in Attachment E: Appendix A of the 2007 Shortage EIS.

Alternatives Modeled

Two action alternatives and a no action alternative were modeled. The action alternatives are the 86KAF and 100KAF depletion scenarios for the Lake Powell Pipeline described above. The no action alternative is the January 2009 official CRSS run and uses the same model assumptions as the 2007 Shortage EIS preferred alternative, with one exception: all Upper Basin depletions were held constant at 2009 levels *except* those assumed reasonably foreseeable.

Period of Analysis

Hydrologic modeling extends from 2009 through 2060.

Model Description

Future Colorado River system conditions under the action and no action alternatives were simulated using CRSS. The model framework of CRSS is a commercial river modeling software called RiverWare™; a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation and the Tennessee Valley Authority. CRSS was originally developed by Reclamation in the early 1970s and was implemented in RiverWare™ in 1996.

CRSS simulates the operation of the major reservoirs on the Colorado River on a monthly time-step and provides information regarding the projected future state of the system in terms of output variables including the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and the diversions to and return flows from the water users throughout the system. The simulation uses a mass balance (or water budget) approach to account for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, evaporation), and water moving through the system (i.e., either stored in reservoirs or flowing in river reaches). Further explanation of the model is provided in Attachment E. The model was used to project the future conditions of the Colorado River system on a monthly time-step for the period 2009 through 2060.

The input data for the model includes monthly future inflows (either DNF or NPC), various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions on January 1, 2009, and the future diversion and depletion schedules for entities in the Basin States and for Mexico. These future schedules were based on demand and depletion projections prepared and submitted by the Basin States, with one major exception. In the No Additional Depletions runs, except for reasonably foreseeable depletions, future Upper Basin depletions were assumed constant at 2009 levels; this assumption results in depletions significantly lower than the future depletion projections provided by the Upper Basin States which assume that Upper Basin depletions will grow through 2060. Depletions (or water use) are defined here as diversions from the river less return flow credits, where applicable.

The rules of operation of the Colorado River mainstream reservoirs including Lake Powell are also provided as input to the model. These sets of operating rules describe how water is released and delivered under various hydrologic conditions.

General model assumptions:

- January 2009 initial conditions for all modeled reservoirs
  - Powell 3617.89 ft
- Run duration: 2009-2060
- Runs revert to the 2007 Shortage Final EIS No Action Alternative in 2027
- Index sequential method used for the Direct Natural Flow period of record (1906-2006): 101 simulations.
- Nonparametric paleo-conditioned inflows: 125 simulations

Modifications to CRSS

Several modifications were made to the official version of CRSS to model the Lake Powell Pipeline. Data were provided to Reclamation by the State to adjust the location of Utah's water use to account for the Lake Powell Pipeline. Specifically, a new diversion node, "Lake Powell Pipeline", was added to simulate water being pumped directly from Lake Powell. The spatial structure of previous versions of CRSS simulated a diversion to the "St. George Pipeline" at a location slightly upstream from Lake Powell. The old "St. George Pipeline" diversion node was removed from the model for this analysis. Utah's projected depletion schedules for the Lake Powell Pipeline were provided to Reclamation by the State.

In addition, in the official version of the CRSS model, Upper Basin depletions increase over time based on demand and depletion projections prepared and submitted by the Upper Colorado River Commission (UCRC). In this version of CRSS, only those Upper Basin depletions assumed reasonably foreseeable increased according to the UCRC schedule. All other future depletions were held constant at the 2009 level.

Results

Each of the three alternatives was modeled using both the DNF and NPC future inflow scenarios, resulting in six model runs. For comparison purposes, each action alternative is compared to the no action alternative. The comparisons are made using both the DNF and NPC future inflow scenarios. At the request of the State, the following variables were evaluated:

- Powell pool elevation on Dec 31st (10th, 50th, 90th percentiles over time)
- Probability of Powell Dec 31st elevation < 3490 ft
- Powell water year release (10th, 50th, 90th percentiles over time)
- Powell water year release (flow duration curve throughout time)
- Powell monthly releases (12 months) (10th, 50th, 90th percentiles over time)
- Flaming Gorge annual release (10th, 50th, 90th percentiles over time)

Post-processing and Interpretation Procedures

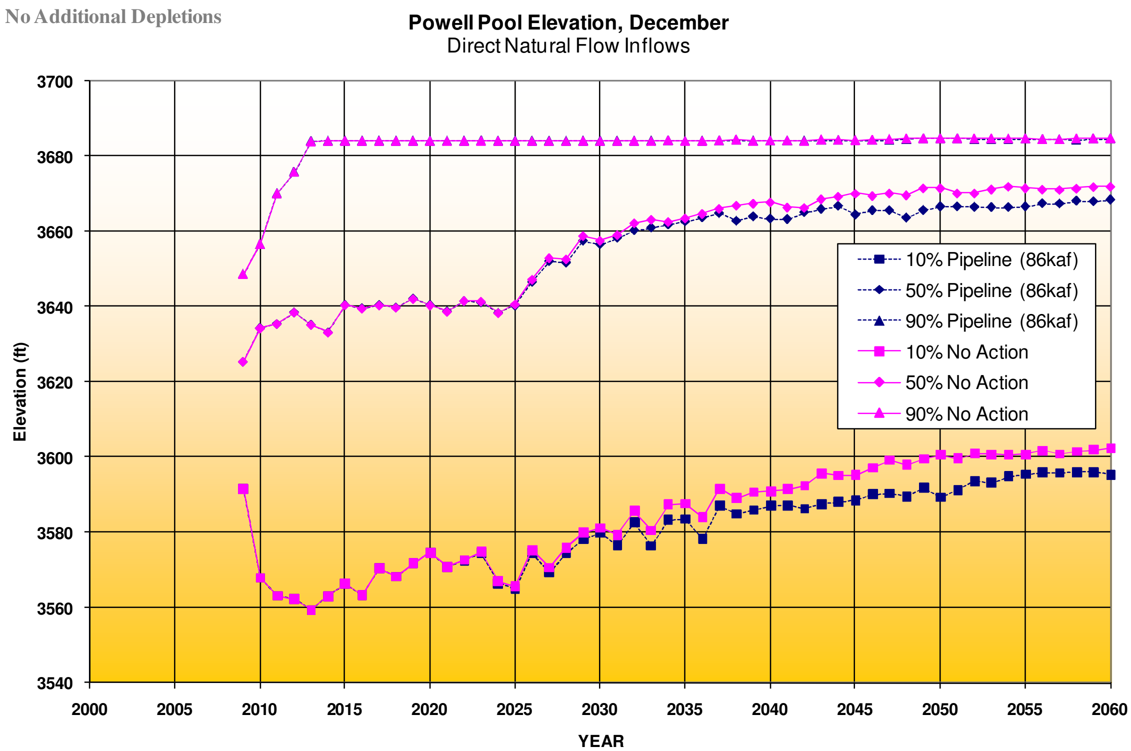
CRSS generates data on a monthly time-step for over 300 points (or nodes) on the Colorado River system. Furthermore, using the ISM on the natural flow record, the model generated 101 possible outcomes for each node for each month of the model run. For the nonparametric paleo-conditioned inflow scenarios, 125 possible outcomes were generated for each node and month in the run period. These very large data sets generated for each alternative can be visualized as three-dimensional data "cubes" with the axes of time, space (or node) and trace (or outcome for each future hydrology). The data were aggregated to reduce the volume of data and to facilitate comparison of the alternatives.

For aggregation of data, simple techniques were employed. For example, Lake Powell pool elevations were evaluated on an annual basis (i.e., end of December) to show long-term lake elevation trends as opposed to short-term fluctuations. Standard statistical techniques were used to analyze the 101 or 125 possible outcomes for a fixed time or particular temporal span. Statistics that were generated included the 10^{th}, 50^{th} and 90^{th} percentiles. Percentiles were determined by simply ranking the outcomes at each time-step (from highest to lowest) and determining the value at the specified percentile. This statistical method is used to view the results of all hydrologic sequences in a compact manner yet maintains the variability at high, medium, and low reservoir elevations that may be lost by averaging the results of all traces. Such a statistic provides information with regard to the probability (e.g., a 10 percent probability) of the variability of interest being at or below the 10^{th} percentile value in a specified year.

Direct Natural Flow, ISM Results

86K Pipeline Alternative

Figure 1 shows the differences in Lake Powell pool elevation in December between the 86K action alternative and the no action alternative at the 10^{th}, 50^{th}, and 90^{th} percentiles. Prior to the year 2020, there are no differences at any percentile level. Between 2020 and 2060, the differences range between 0 ft and 11.3 ft at the 10^{th} percentile, with Lake Powell elevation being lower in action alternative. In general, the pool elevation differences are larger later in the later modeled years. Differences at the 50^{th} percentile level range from 0 ft to 6.2 ft, again with Lake Powell elevation being lower in the action alternative and with the larger of these differences generally occurring in the later years. Differences at the 90^{th} percentile level range from 0 ft to 0.4 ft.



Lake Powell Pool Elevation, December. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Figure 2 shows probability of Lake Powell pool elevation being below 3490 ft (minimum power pool) in March. March was chosen as this is the month the reservoir elevation is typically lowest. There were no differences between the action and no action alternatives.

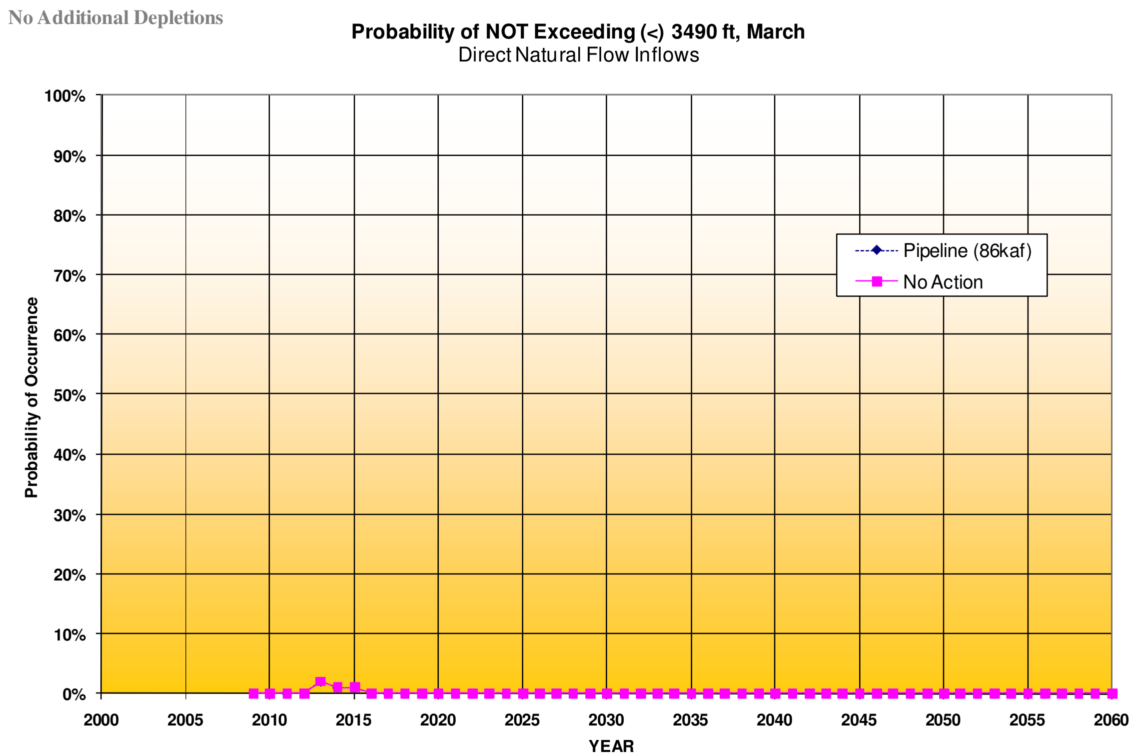
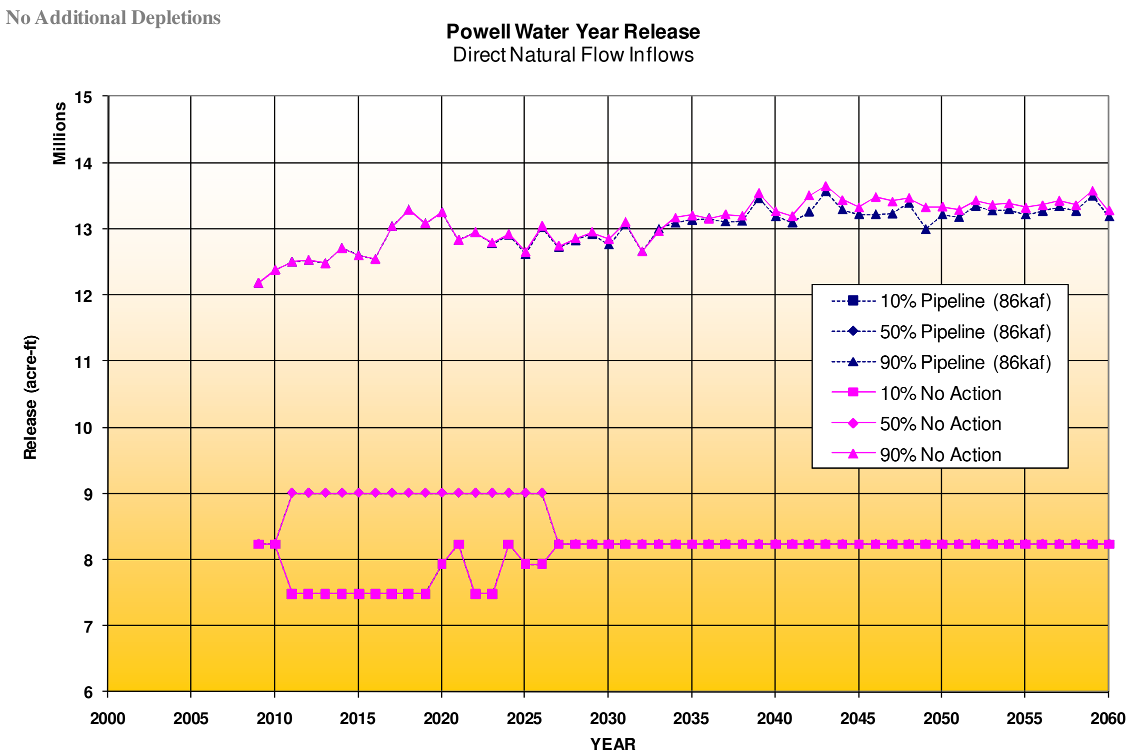


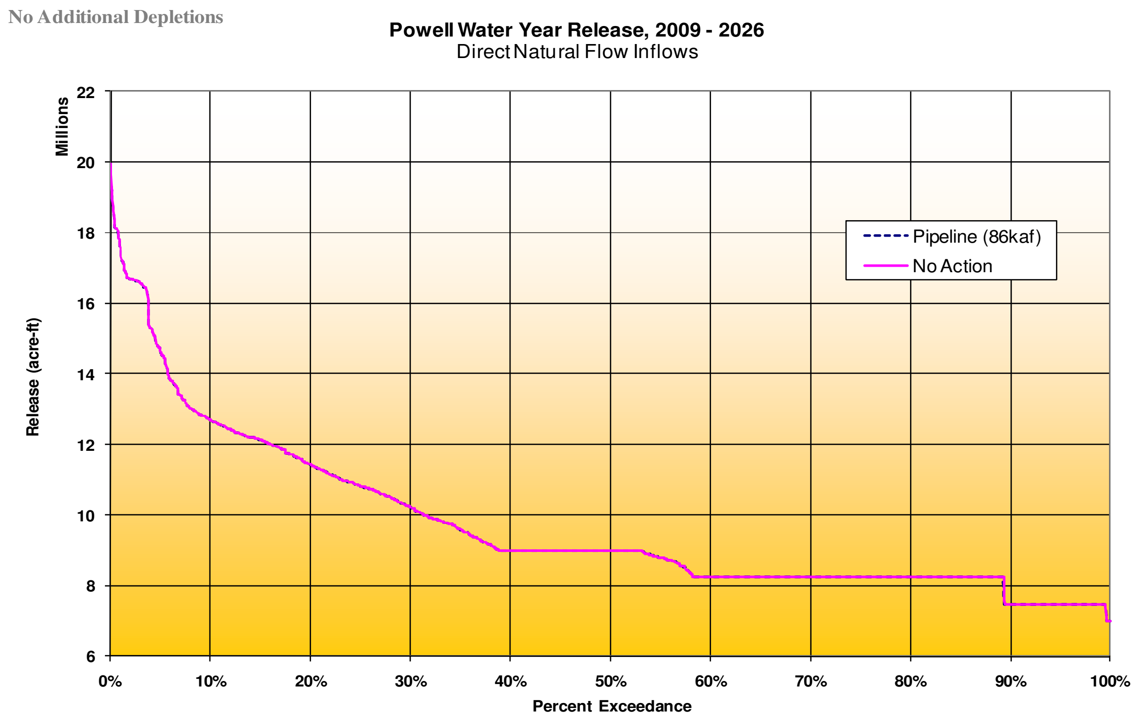
Figure 2. Probability of Lake Powell pool elevation being below 3490 ft in March. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Figure 3 presents Lake Powell water year releases. For the 10th and 50th percentiles, there are no differences between the action and no action alternatives. For the 90th percentile, which reflects equalization releases from Lake Powell to Lake Mead or spill avoidance releases, the largest difference between the action and no action alternatives is approximately 336,000 acre-feet, or approximately 2.6% of the annual release, more being released in one year under the no action alternative. See Attachment F for the differences in each year. In general the differences are greater in the later simulated years, after the pipeline is at full build out, and the later years result in the no action alternative releasing more. Note that with most Upper Basin depletions held constant at 2009 depletion levels, Lake Powell elevation increases over time thus resulting in more frequent and higher magnitude equalization and spill avoidance releases in both the action and no action alternatives.

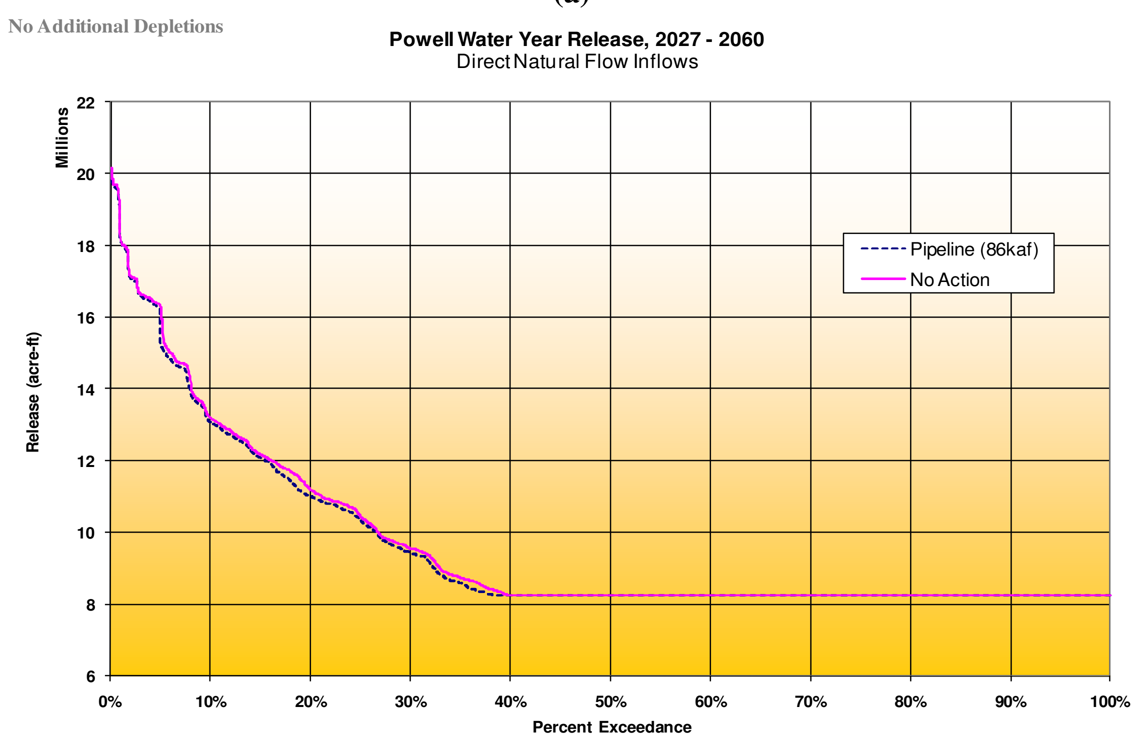


Lake Powell water year release. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

The flow duration curves of Lake Powell releases throughout the Interim Guidelines period (2009-2026) and throughout the post-Interim Guidelines period (2027-2060) are presented in Figures 4 (a) and (b), respectively. In this figure, Lake Powell releases at every exceedance percentile (from 0 to 100) are plotted, rather than the three percentile plots shown in Figure 3. The Interim Guidelines and post-Interim Guidelines periods are plotted separately because operations at Lake Powell differ significantly between these two time periods. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the action alternative, however, particularly during the Interim period, the differences vary by both sign and magnitude throughout the curve. As evidenced in Figure 3, the greatest differences occur at the lower exceedance probabilities (higher percentiles), when Lake Powell is at higher elevation and making equalization releases to Lake Mead or releases for spill avoidance. The greatest difference of approximately 1,064,000 acre-feet, or 6.9%, per year more being released in the no action alternative occurs at the 5 percent exceedance level (95th percentile). See Attachment F for the differences at each exceedance probability.



(a)



(b)

Figure 4. Lake Powell water year release, flow duration curve throughout time during the Interim Guidelines period (a) and during the post-Interim Guidelines period (b). Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

Annual releases from Flaming Gorge Reservoir are shown in Figure 5. At the 10th, 50th, and 90th percentiles, there are no differences between the action and no action alternatives.

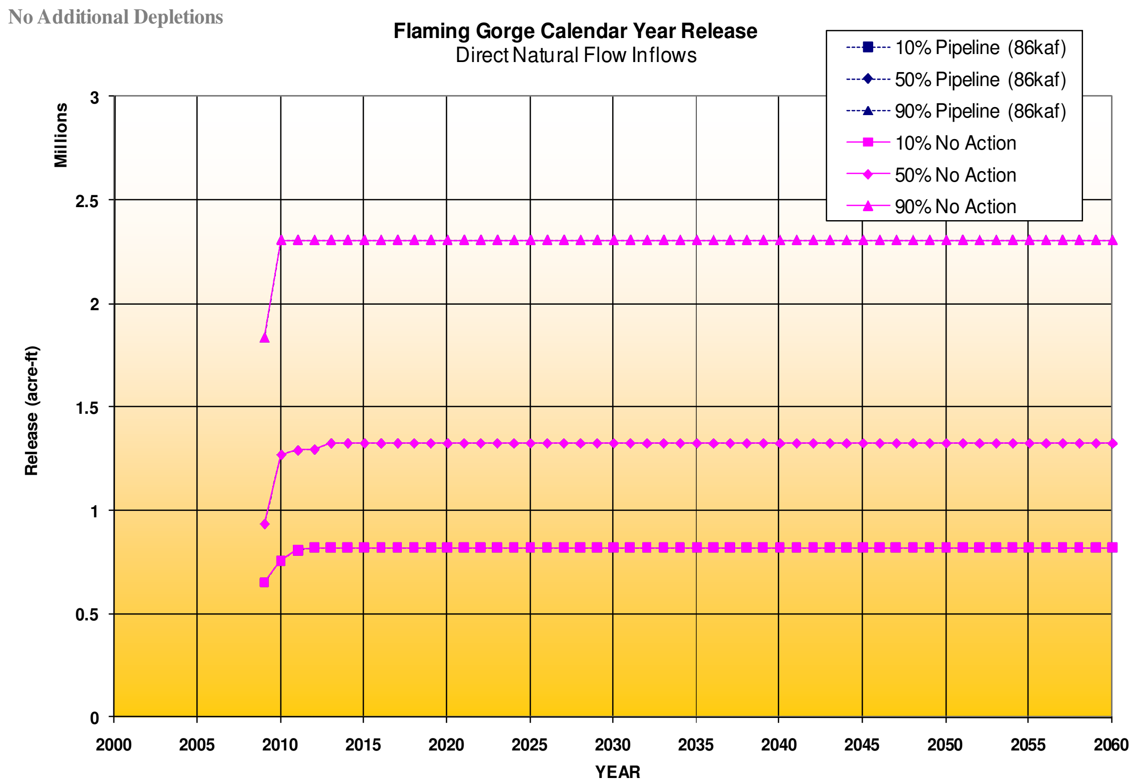
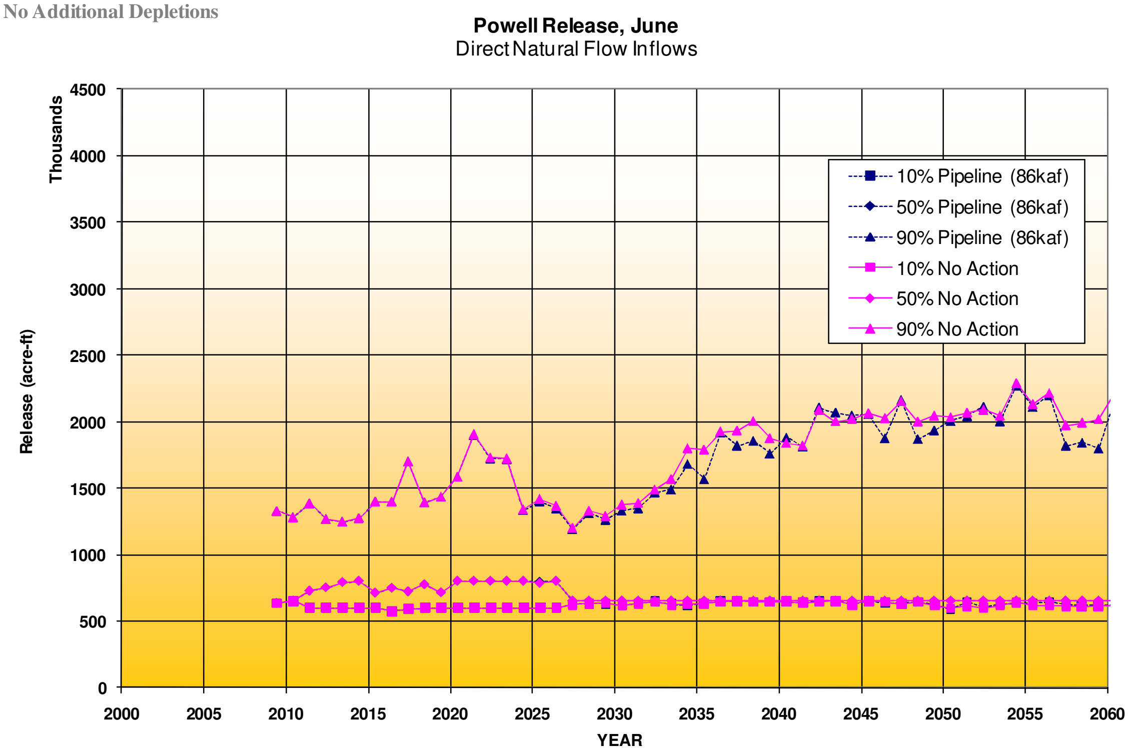


Figure 5. Flaming Gorge Reservoir annual release. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

The releases from Lake Powell in the month of June are shown in Figure 6. For results in every month, see Attachment F: NAD_DNF_86K_plots.xls. April through July are the months that show the greatest differences between the action and no action alternatives. For all months, the differences are generally greatest at the 90th percentile level (i.e., for higher releases including spill avoidance and equalization). Overall, releases from Lake Powell are generally lower for the months of October, November, January, February and March, ranging approximately from 500,000 acre-feet to 800,000 acre-feet for the 10th percentile and 600,000 to 1,100,000 acre-feet for the 90th percentile. Releases in the months of April through September and December are generally higher, ranging approximately from 500,000 acre-feet to 900,000 acre-feet for the 10th percentile and 600,000 to 2,200,000 acre-feet for the 90th percentile. Differences between the action and no action alternatives are greatest in the months in which there are higher releases and in which there is higher year to year variability.

No Additional Depletions



Lake Powell monthly release, May. Direct natural flow inflows, 86kaf Lake Powell Pipeline maximum depletion.

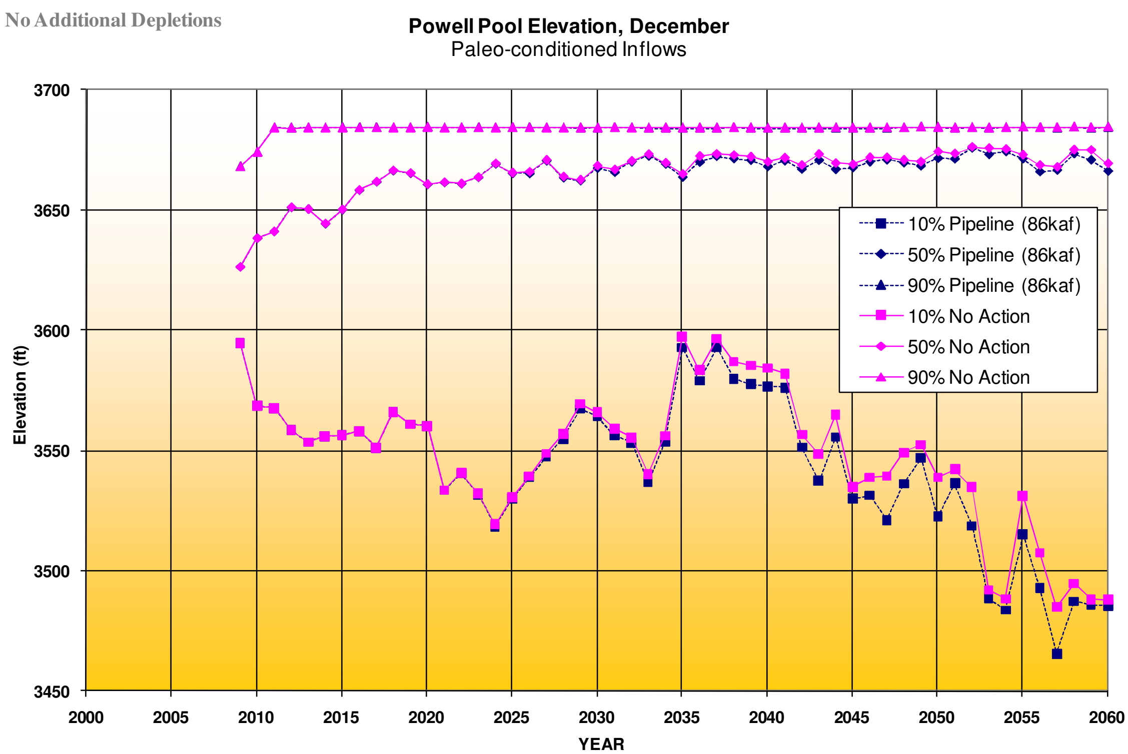
100K Pipeline Alternative

Results for the 100K action alternative exhibit very similar trends to those shown in Figures 1 to 6. See Attachment G: NAD_DNF_100K_plots.xls for full set of figures and data. The range of differences of Lake Powell pool elevation is the same as those for the 86K action alternative (Figure 1), to the nearest foot. Results for the probability of being below the minimum power pool are the same as presented in Figure 2, no differences between the action and no action alternatives. Results for Lake Powell water year release show differences within the same range and with the same trends as those exhibited in Figures 3 and 4, i.e., no differences at the 10th and 50th percentile and at the 90th percentile a maximum difference of 2.8% percent more being released in the no action alternative. Results for Flaming Gorge annual release are the same as the 86K action alternative (Figure 5), i.e. no differences at the 10th, 50th, or 90th percentile level. Lake Powell monthly release results are very similar to those for the 86K action alternative (Figure 6).

Nonparametric Paleo-Conditioned Inflows Results

86K Pipeline Alternative

Figure 7 shows the differences in Lake Powell pool elevation in December between the 86K action alternative and the no action alternative at the 10th, 50th, and 90th percentiles for NPC inflow scenario. The NPC inflow scenario produces a richer variety of wet and dry spells, resulting in different future elevations of Lake Powell when compared with the DNF inflow scenario. However, overall, the differences between the action and no action alternatives are similar to those for the DNF simulations. Prior to the year 2020, there are no differences at any percentile level and in general, pool elevation differences are larger later in the later modeled years. The greatest differences for Lake Powell elevation in the NPC inflow scenario occur in the 10th percentile (i.e., lowest elevations), with a maximum simulated difference of 19.4 ft lower in the action alternative.



Lake Powell Pool Elevation, December. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

Overall, the probability of not exceeding Lake Powell's minimum power pool (3490 ft) in March is higher in the NPC inflow scenario compared to the DNF inflow scenario (Figure 8). In addition, differences between the action and no action alternatives for the NPC inflows occur more frequently than did for the DNF inflows. The action alternative results in slightly higher probabilities (0.1% to 2% higher) of Lake Powell being below minimum power pool in 18 of the 52 years simulated.

No Additonal Depletions

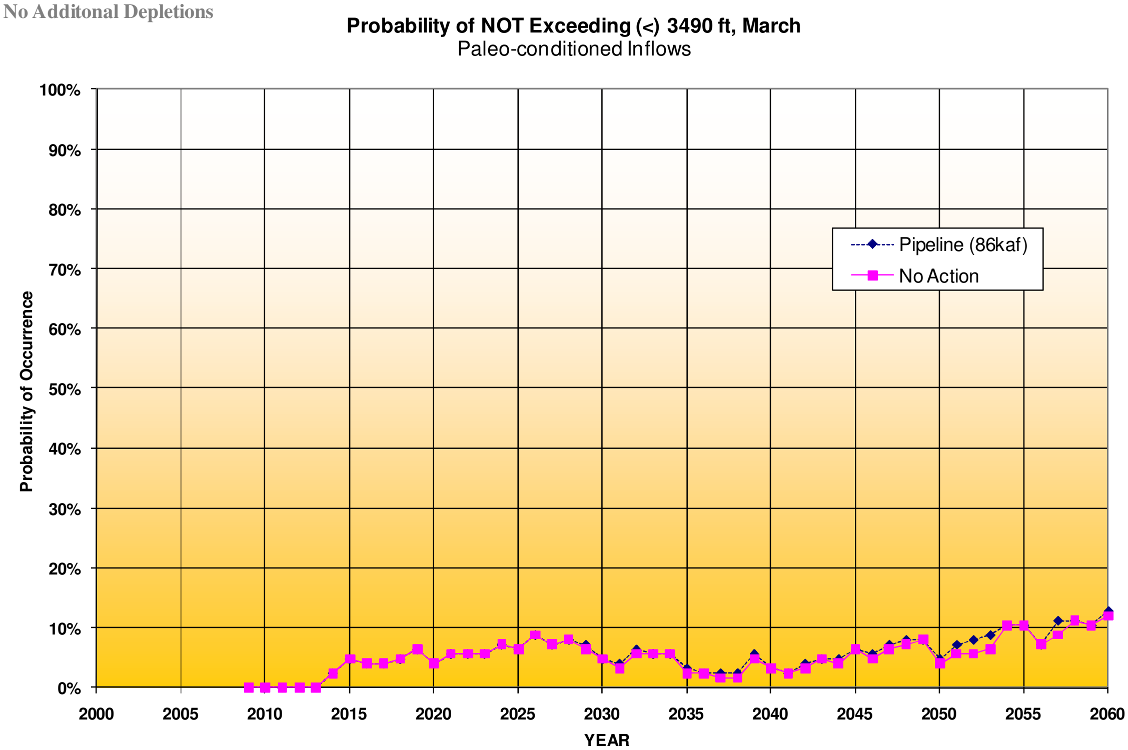
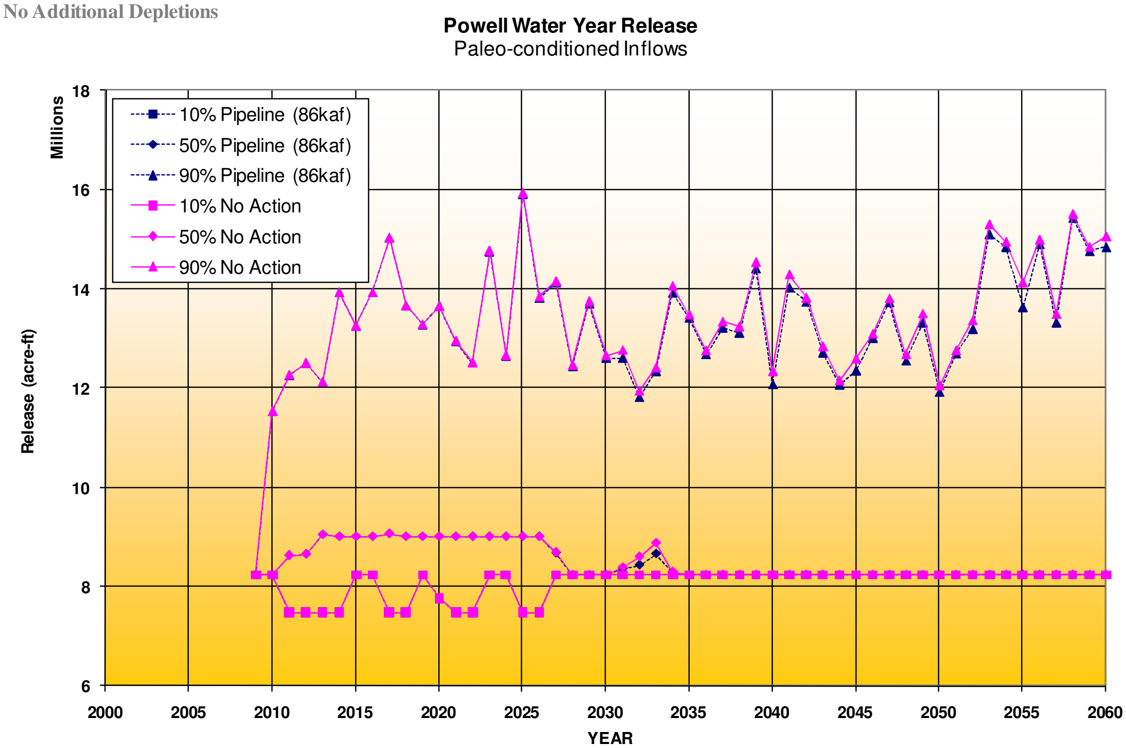


Figure 8. Probability of Lake Powell pool elevation being below 3490 ft in March. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

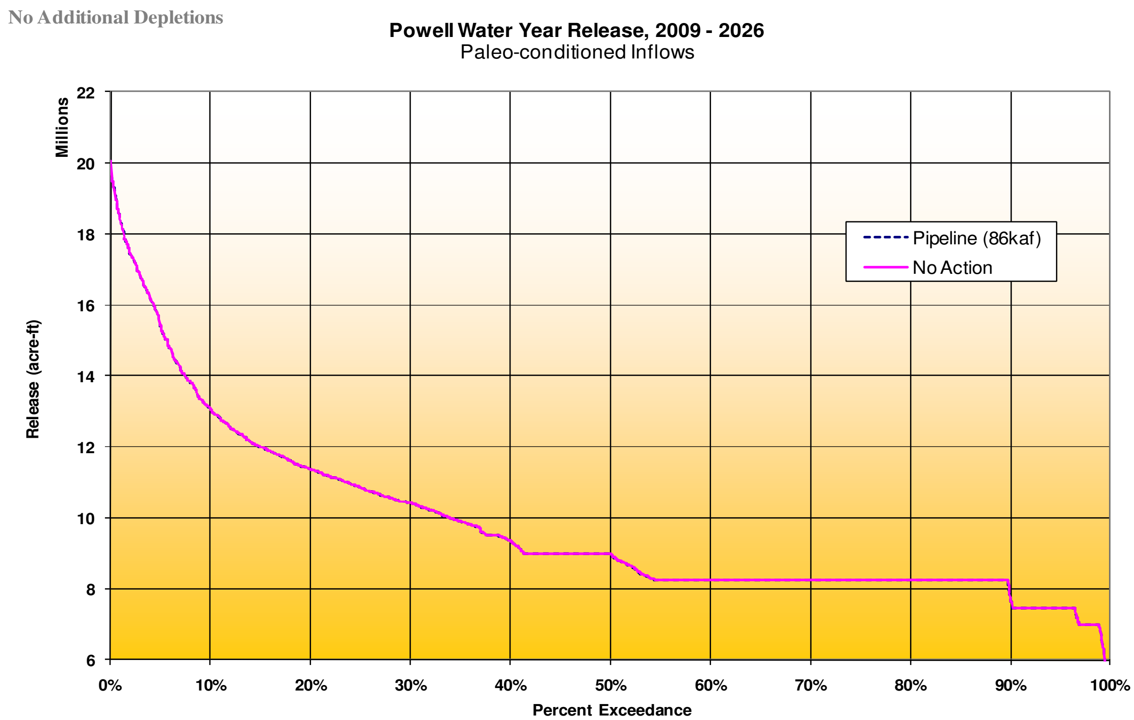
Results for NPC inflows and Lake Powell water year releases are shown in Figure 9. Though the overall release pattern varies from the DNF inflow scenarios, the differences between the action and no action alternatives are similar to those for the DNF inflow scenario (Figure 3). The differences are greatest in the 90th percentile with a maximum difference of 502,000 acre-feet, or 3.7%, less begin released in the action alternative. See Attachment H for the differences in each year.

No Additional Depletions

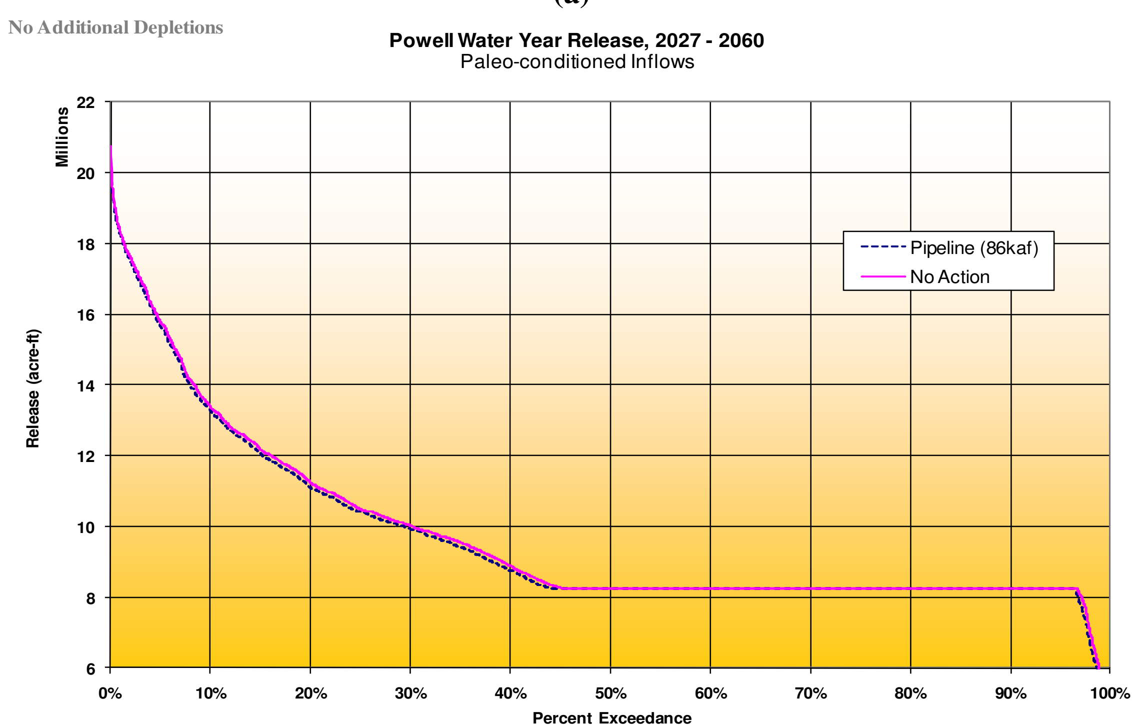


Lake Powell water year release. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

The flow duration curves of Lake Powell releases throughout the Interim Guidelines period (2009-2026) and throughout the post-Interim Guidelines period (2027-2060) are presented in Figure 10 (a) and (b), respectively. In this figure, Lake Powell releases at every exceedance percentile (from 0 to 100) are plotted, rather than the three percentile plots shown in Figure 9. The Interim Guidelines and post-Interim Guidelines periods are plotted separately because operations at Lake Powell differ significantly between these two time periods. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the action, however, the differences vary by both sign and magnitude throughout the curve. As evidenced in Figure 9, the greatest differences generally occur at the lower exceedance probabilities (higher percentiles) when Lake Powell is making larger releases for equalization or spill avoidance *or* at the highest exceedance probabilities (lower percentiles) when Lake Powell is making releases below the minimum objective release of 8.23 million acre-feet. For a given exceedance probability, the corresponding release volume is generally greater for the no action alternative than the action alternative, however, the differences vary by both sign and magnitude throughout the curve. The greatest difference of approximately 437,000 acre-feet, or 6%, per year more being released in the no action alternative occurs at the 98 percent exceedance level (2nd percentile).



(a)



(b)

Figure 10. Lake Powell water year release, flow duration curve throughout time during the Interim Guidelines period (a) and during the post-Interim Guidelines period (b). Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

Annual releases from Flaming Gorge Reservoir are shown in Figure 11. As with the DNF inflows, there are no differences between the action and no action alternatives.

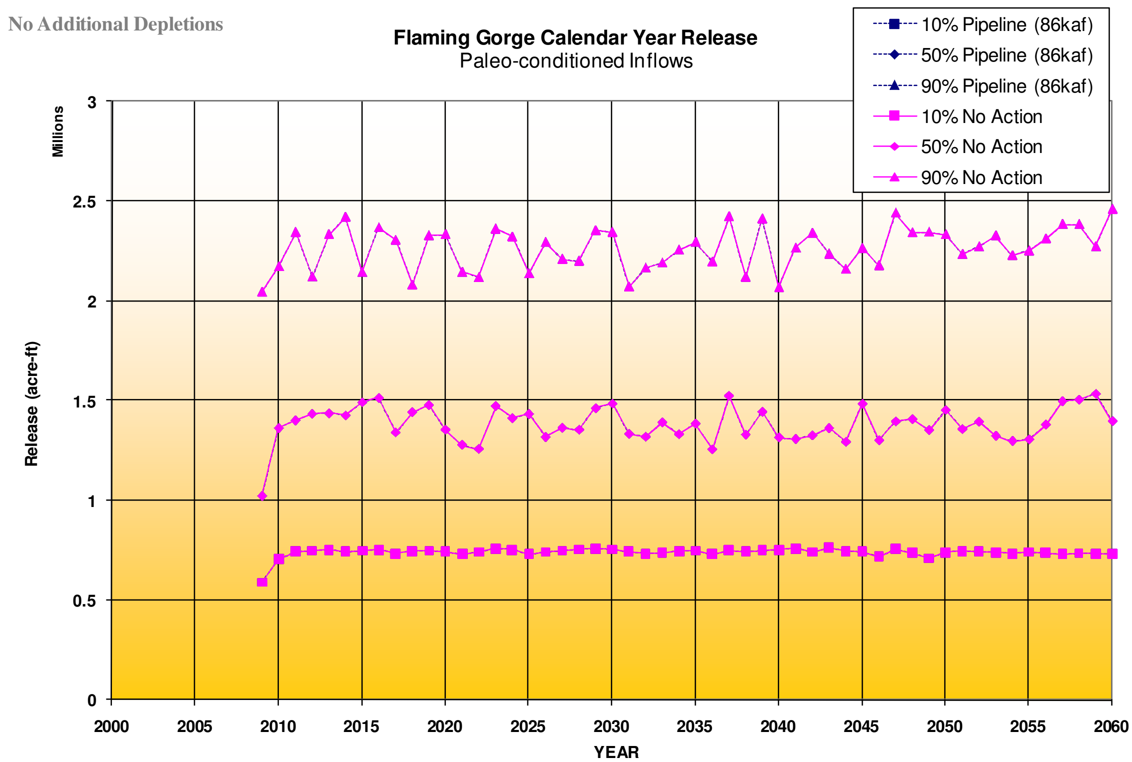
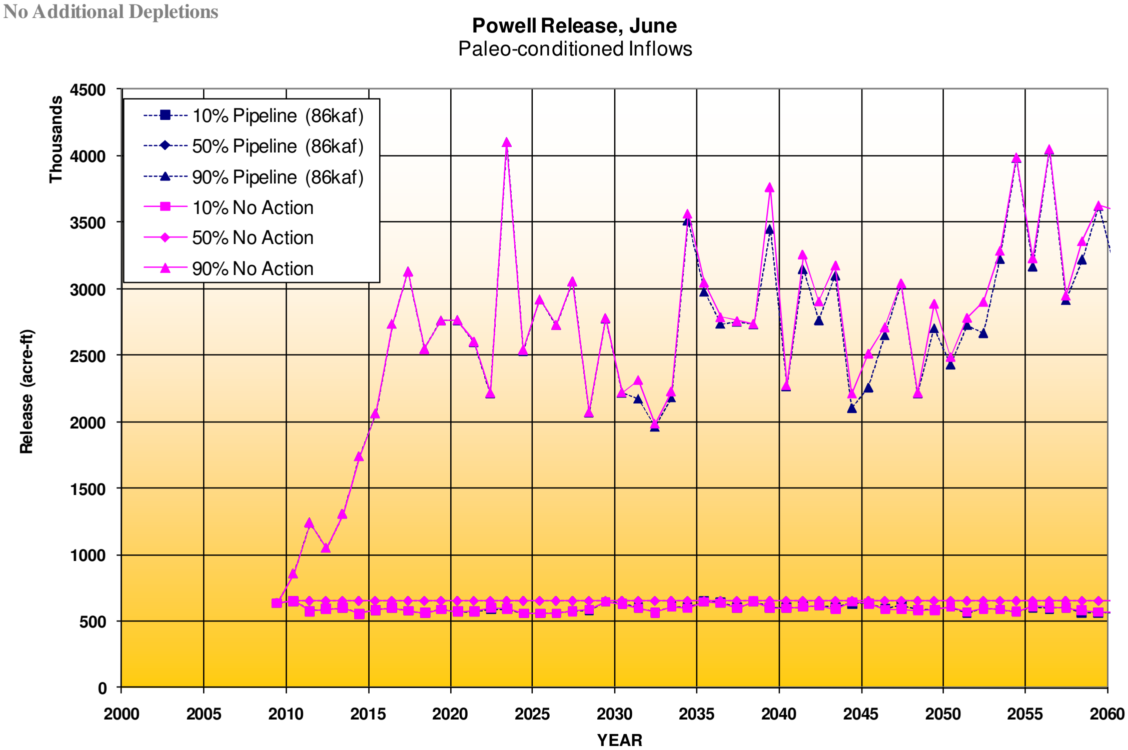


Figure 11. Flaming Gorge Reservoir annual release. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

The releases from Lake Powell in the month of June for the NPC inflow scenario are shown in Figure 12. For results in every month, see Attachment H – NAD_NPC_86K_plots.xls. Across all months, the differences are similar to those in the DNF inflow scenario with the differences generally being greater at the 90th percentile level and with very few differences at the 50th percentile level. In June, the largest difference was 461,600 acre-ft, or 15%, less being released in the action alternative. For all months, in some years the action alternative released more water, in others, the no action alternative resulted in larger releases.



Lake Powell monthly release, June. Paleo-conditioned inflows, 86kaf Lake Powell Pipeline maximum depletion.

100K Pipeline Alternative

Results for the 100K action alternative with the NPC inflow scenarios exhibit very similar trends to those shown in Figures 7 to 12. See Attachment I: NAD_NPC_100K_plots.xls for full set of figures and data. The pattern of differences of Lake Powell pool elevation is the same as those for the 86K action alternative (Figure 7), the greatest difference is Lake Powell elevation being 23.1 ft lower with the pipeline in the 10th percentile. Results for the probability of being below the minimum power pool are the similar to those presented in Figure 8, with the probability being 0.1% to 2% higher with the pipeline in 19 of the 52 simulated years. Results for Lake Powell water year release show differences similar than those exhibited in Figures 9 and 10, with the greatest difference at the 90th percentile being approximately 523,000 acre-feet, or 3.8% of the total release in that year. Results for Flaming Gorge Reservoir annual release are the same as those for the 86K action alternative (Figure 11); there are no differences between the action and no action alternatives in any year. Lake Powell monthly release results show very similar results, both in pattern and magnitude to those for the 86K action alternative (Figure 12).

Discussion

The results from these hydrologic model runs should be interpreted with consideration to the model assumptions. Unique to the No Additional Depletions analysis is the model assumption that no new projects or depletions will occur in the Upper Basin. This model assumption adopts a rigorous definition of what reasonably foreseeable future depletions are in the Upper Basin and is consistent with Reclamation's NEPA guidelines. Under this approach, a reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). These are the criteria of certainty that a future depletion would occur at a particular time and place. This is a conservative approach to modeling the alternatives and takes the strictest approach to defining what is included and excluded for the cumulative impact analysis required by the Council on Environmental Quality's regulations 40 CFR 1508.7.[1]

It is recognized that the Upper Basin States plan to develop their compact allocated Colorado River water and, as such, it is highly unlikely that depletions will remain at the 2009 level in the future.

It should also be noted that the modeling effect of holding most Upper Basin depletions constant at 2009 levels results in depletions significantly lower than the future depletion projections provided by the Upper Basin States which assume that Upper Basin depletions will grow through 2060. Lower depletions, in turn, result in Lake Powell's elevation increasing throughout the model run. Higher elevations at Lake Powell result in more frequent and higher magnitude equalization and spill avoidance releases in both the action and no action alternatives.

Note that these model results do not represent what the actual reservoir elevations or releases will be in any particular year. Model results should be interpreted based on the relative differences between the action and no action alternatives.

These model runs implement the Interim Guidelines through 2026 and revert to the 2007 Shortage Final EIS No Action Alternative for model years 2027-2060. The modeled Lake Powell Pipeline begins depleting water in 2020 and is at full build out in 2042 (86K action alternative) and 2046 (100K action alternative). Thus, for this analysis the potential effects of the Lake Powell Pipeline project under the Interim Guidelines are evaluated for seven years, the first seven years of the pipeline when the project is coming on line and depletions are lower. The effects of the pipeline at full build out are evaluated under post Interim Guidelines operational policies. It is currently unknown what the operational policies will be after 2026; thus the assumptions implemented in the 2007 shortage EIS were also implemented in this study (i.e. Interim Guidelines implemented through 2026.)

Attachments List

Attachment A: PipelineDepletions.xls
Attachment B: ReasonablyForeseeableDepletionNodes.xls

[1] Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

Attachment C: 2007 Shortage EIS, Chapter 4
Attachment D: 2007 Shortage EIS, Appendix N
Attachment E: 2007 Shortage EIS, Appendix A
Attachment F: NAD_DNF_86K_plots.xls
Attachment G: NAD _DNF_100K_plots.xls
Attachment H: NAD _NPC_86K_plots.xls
Attachment I: NAD _NPC_100K_plots.xls