RECLAMATION

Managing Water in the West

Interim Report

North Central Arizona Water Supply Feasibility Study

U.S. Department of the Interior
Bureau of Reclamation
Phoenix Area Office
Glendale, Arizona

September 2016

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Interim Report

North Central Arizona Water Supply Feasibility Study

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Acronyms

ADEQ	Arizona Department of Environmental Quality
ADOT	Arizona Department of Transportation
ADWR	Arizona Department of Water Resources
AEP	annual exceedance probability
AF	acre-feet
AFY	acre-feet per year
AMA	Active Management Area
amsl	above mean sea level
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
C Aquifer	Coconino Aquifer
CAP	Central Arizona Project
CCD	census county division
CFR	Comprehensive Facility Review
cfs	cubic feet per second
CLSM	controlled low strength material
CPTAC	Coconino Plateau Technical Advisory Committee
CPWAC	Coconino Plateau Water Advisory Council
DBE	Design Basis Earthquake
EA	Environmental Assessment
EIS	Environmental Impact Statement
GCNP	Grand Canyon National Park
GIS	Geographic Information Systems
GLCA	Glen Canyon National Recreation Area
GB	gigabyte
gpcd	gallons per capita per day
gpm	gallons per minute
HDD	horizontal directional drilling
HWNSS	Hopi Western Navajo Water Supply Study
IBC	International Building Code
IEEE	Institute of Electrical and Electronics Engineers
LCR	Little Colorado River
MAF	million acre-feet
MCE	Maximum Considered Earthquake
MGY	million gallons per year
N Aquifer	Navajo Aquifer

NCAP	North Central Arizona Pipeline
NCAWSS	North Central Arizona Water Supply Study
NCAWSFS	North Central Arizona Water Supply Feasibility Study
NED	National Economic Development
NEPA	National Environmental Policy Act
NGS	Navajo Generating Station
NPS	National Park Service
PHA	peak horizontal acceleration
PHSA	Probabilistic Seismic Hazard Analysis
P.L. 109-451	Rural Water Supply Act of 2006
PXAO	Reclamation's Phoenix Area Office
Reclamation	Bureau of Reclamation
ROF	2006 North Central Arizona Water Supply Study Report of Findings
ROW	right(s)-of-way
R-M Aquifer	Redwall-Muav Aquifer
RWSP	Rural Water Supply Program
SDWA	Safe Drinking Water Act
TSC	Reclamation's Technical Service Center (Denver, CO)
USGS	U.S. Geological Survey

Executive Summary

The purpose of the North Central Arizona Water Supply Feasibility Study (Study) is to evaluate the feasibility of alternative water supply components that could help meet demands of Study participants on the Coconino Plateau in Arizona. The Study partners include the Navajo Nation, Hopi Tribe, Arizona Department of Water Resources, Coconino County, Cities of Page and Flagstaff, and the Bureau of Reclamation (Reclamation). The largest portions of the land base in the Study Area are Indian reservations (including the Navajo Nation and the Hopi Tribe) and federal and state lands.

The primary source of water for the region is groundwater. Limited surface water supplies support habitat for listed and endangered species and are susceptible to drought, reducing reliability and limiting their use for domestic and municipal purposes.

Earlier studies identified an unmet municipal water demand of more than 28,100 acre-feet per year (AFY) in the region by the year 2050 for area communities and cities. The results of further analyses indicate that if water conservation reduces demand by 20 percent, there would still be an unmet water demand of more than 22,000 AFY by the year 2050. However, mandated conservation measures and lack of available water supplies already result in Coconino Plateau water users currently using water at the lowest per capita water use rate in the state of Arizona, with few opportunities for further conservation.

The area’s urgent and compelling need for water is based on the physical absence of available water and infrastructure; more than 50% of the Navajo Nation chapters and Hopi Tribe villages must haul water to meet basic needs. These water sources are often far from community members and do not meet safe drinking water standards. Tribal communities already have the lowest water use in the state, ranging from less than 10 gallons per capita per day (gpcd) for members who haul water to 89 gpcd. In comparison, water use in the City of Phoenix service area was about 185 gpcd in 2010.

Additionally, water development options are limited in the Study Area and continued groundwater pumping will impact long term groundwater conditions and lead to the decline of springs and seeps in critical areas such as the Grand Canyon, Verde River and Havasupai Reservation. Plus, groundwater and spring sites in the region frequently exceed arsenic standards and require costly treatment.

Thus, augmented water supplies are necessary to meet projected water demands for this region. The focus of this Study is the use of Lake Powell as an augmentation water supply source and a pipeline delivery system that would convey water from the mainstem Colorado River upstream of the Grand Canyon.

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River." This collection of documents apportions the water and regulates the use and management of the Colorado River among seven basin states and Mexico. Lee Ferry on the mainstem of the Colorado River is the boundary for the Upper and Lower Colorado River Basins as described in the Colorado River Compact of 1922; the Compact also apportioned 7.5 million acre-feet (MAF) of Colorado River water annually to each basin. The Boulder Canyon Project Act of 1928 apportioned the Lower Basin's 7.5 MAF among the states of Arizona, California, and Nevada, and authorized and directed the Secretary of the Interior to function as the sole contracting authority for Colorado River water use in the Lower Basin. The Upper Colorado River Basin Compact of 1948 apportions upper Colorado River water to Colorado, Utah, New Mexico, and Wyoming; the portion of Arizona that lies within the Upper Colorado Basin was also apportioned 50,000 acre-feet annually. Today, about 30,000 AFY of Arizona's Upper Basin apportionment is used at the Navajo Generating Station, which provides about 90 percent of the power used to pump water along the 336-mile-long Central Arizona Project aqueduct.

It should be noted that Lake Powell stores water for the Upper Basin, but the majority of North Central Arizona Water Supply Feasibility Study (NCAWSFS) users are located in the Lower Basin. According to the 2012 *Colorado River Basin Water Supply and Demand Study*, shortages in the Upper Basin are a reality today. Unlike the Lower Basin, which draws its supply from storage in Lake Mead, the Upper Basin is more dependent on annual streamflow to meet its needs. Thus, the Upper Basin must develop additional water supplies in order to realize full use of its Colorado River Compact apportionment. Additionally, Tribal water settlements in this area are outstanding and, when completed, may further refine current Colorado River water law. Although previous appraisal level analyses suggest that Lower Basin use of Upper Basin water is a viable augmentation alternative, issues related to Colorado River management and its associated "Law of the River" would have to be addressed.

Recognizing these regulatory challenges, this Study is being conducted as part of the Rural Water Supply Program (RWSP) authorized by the Rural Water Supply Act of 2006, Public Law 109-451, under which Reclamation awarded funding to non-federal sponsors of appraisal and feasibility studies in 2010, 2011, and 2012. On August 31, 2010, the NCAWSFS proposal was authorized to receive funding under P.L. 109-451 beginning in Fiscal Year 2011.

The NCAWSFS investigation began with data compilation and planning to encompass the furthest demand centers and all demands in between, and narrowed the scope of the project as partner participation warranted. As the Study proceeded, pipeline alignment alternatives were discussed with representatives of the communities that would benefit. The communities of Williams and Tusayan and Grand Canyon National Park require additional water supplies to meet future demands; however, due to immediate water infrastructure needs, small tax bases, and lack of funding for cost-share, these participants chose to not proceed with the NCAWSFS, and the alternatives to serve these communities were removed from further consideration.

In addition, with the collapse of a potential water settlement between the Navajo Nation and the Hopi Tribe and federal appropriations ceasing for the NCAWSFS after FY2012, the City of Flagstaff chose to not participate, but retained the option to reconsider if federal funding becomes available and settlement negotiations are initiated. Flagstaff will independently proceed with assessing the feasibility of a pipeline to convey groundwater pumped from the City's Red Gap Ranch to Flagstaff.

Thus, the alternatives pursued in the NCAWSFS include a mainstem pipeline from Lake Powell to Cameron, with spur lines to Keams Canyon and to Bitter Springs to meet tribal demands only.

The NCAWSFS is not complete. P.L. 109-451 did not authorize Reclamation to undertake or provide funding for project construction and, because the RWSP authority expires on September 30, 2016, all appraisal and feasibility studies authorized under Title I of the Act are scheduled to be completed by that date. As required under Title I Section 103 of the Reclamation Rural Water Supply Act of 2006, Final Rule Code of Federal Regulations (43 CFR Part 404) (Rule), Reclamation's Phoenix Area Office (PXAO) and the Technical Service Center (TSC) prepared this Study interim report to summarize NCAWSFS activities completed to date.

Reclamation originally intended to publish a complete feasibility study concluding report to support a recommendation to Congress regarding whether or not a proposed rural water supply project should be authorized for construction, and provide the reasons supporting the recommendation. However, given existing constraints on program resources, Reclamation is not recommending Congressional authorization or federal funding of any new appraisal or feasibility studies at this time, nor the implementation of any feasible projects. Instead, this interim report provides a summary of work completed to date.

The Coconino Plateau still requires safe, reliable water supplies to ensure the health and well-being of rural communities in the region. If eligible non-federal entities are interested in finalizing the NCAWSFS, a new study authority would be required.

1.0 Introduction

1.1 Purpose and Scope of Study

The primary purpose for the NCAWSFS is to evaluate the feasibility of alternative water supply components identified in the North Central Arizona Water Supply Study (NCAWSS) that could help meet demands of Study participants on the Coconino Plateau. The Study Area (Figure 1) is located within Coconino and Navajo Counties in Arizona, and includes six western Navajo Nation chapters, all Hopi Tribe villages, 12 non-tribal communities including the Cities of Flagstaff, Williams, Tusayan and the surrounding unincorporated communities, and Grand Canyon National Park.

The components of the proposed water supply system were initially identified as:

- Mainstem Pipeline from Page to Cameron (120 miles serving Coppermine, LeChee, Bodaway-Gap, Cameron, Tuba City, Moenkopi and Lower Moenkopi)
- Pipeline from Moenkopi to Kykotsmovi (50 miles serving the Hopi Mesas)
- Pipeline from Cameron to Flagstaff (53 miles serving Flagstaff, surrounding and dispersed communities)
- Pipeline from Flagstaff to Williams (32 miles serving Williams and dispersed communities)
- Pipeline from Cameron to Grand Canyon and Tusayan (59 miles serving Tusayan, Grand Canyon, and dispersed communities)
- C Aquifer Well Field at Red Gap Ranch and Pipeline to Flagstaff (41 miles serving Flagstaff)
- R Aquifer Wells at Williams (serving Williams)

Due to a lack of funds, dissolution of Tribal settlement negotiations, and pending expiration of RWSP authorization on September 30, 2016, Flagstaff, Williams, Tusayan and Grand Canyon National Park chose to not participate in the mainstem and lateral conveyance portion of the Study. The associated alternatives were removed from further investigation. Flagstaff chose to continue with an alternative to convey water from the City's Red Gap Ranch.

The scope of this Study is limited to the information and data that was collected within the available budget and timeframe in accordance with Reclamation's RWSP planning guidelines. The Study and associated cost estimating are not complete at this time. This interim report documents work accomplished to date and provides information that may be used by others to either complete the NCAWSFS or for other infrastructure projects that utilize the same corridors in northern Arizona.

While the results of the NCAWSFS would be useful during potential future Indian Settlement discussions, it is not the purpose of the Study. The purpose of the Study is simply to assess the feasibility of pipeline alternatives to meet future demands of Study participants.

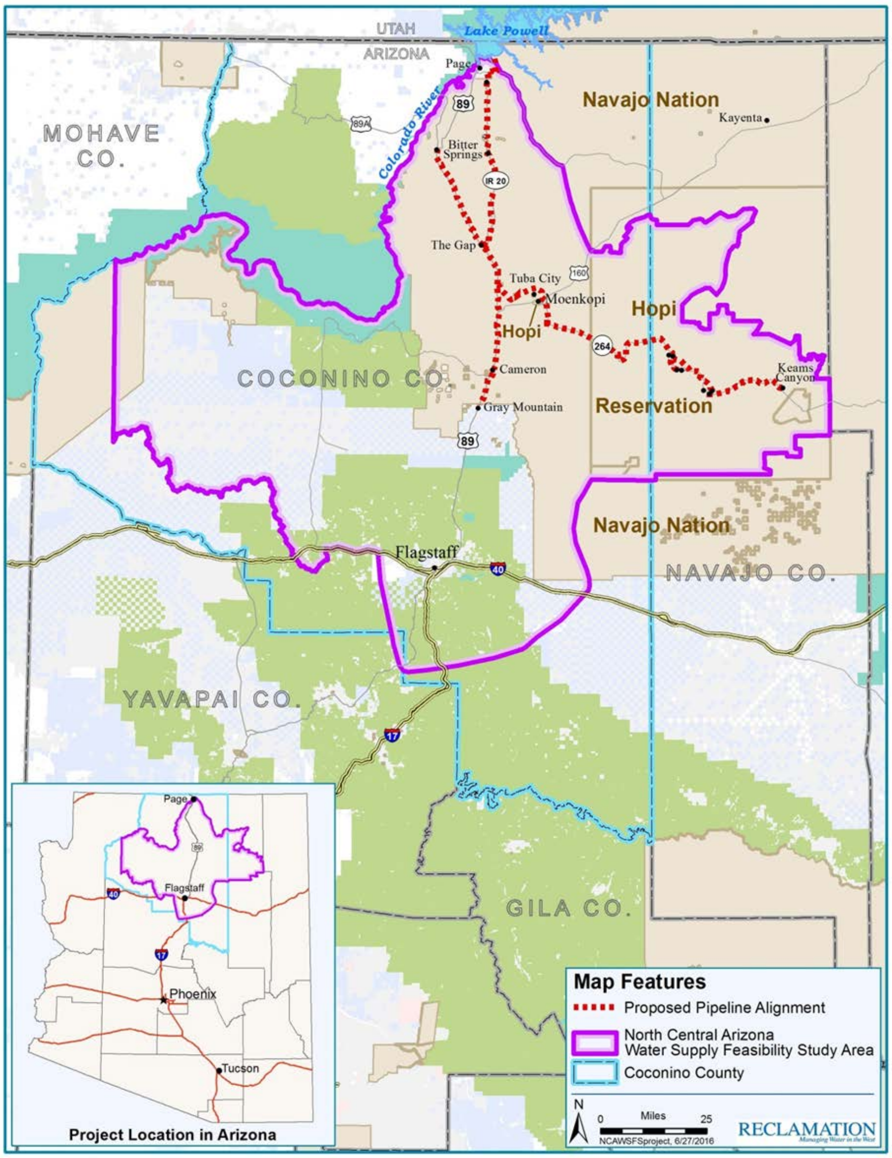

Figure 1: North Central Arizona Water Supply Feasibility Study Area

1.2 Study Authority

On August 31, 2010, the NCAWSFS proposal was authorized to receive funding under P.L. 109-451 beginning in Fiscal Year 2011. P.L. 109-451 does not authorize Reclamation to undertake or provide funding for project construction. Each construction project must be independently authorized.

1.3 Project Partners and Participants

The Study Area includes a relatively diverse group of communities and scattered rural populations with limited local water supply infrastructure. The Study Area encompasses tribal communities, highly dispersed non-tribal residential areas, small towns, and Flagstaff, a small city that is the dominant municipality. Many residents in the rural unincorporated areas of Coconino County rely on truck hauling and local water companies to access water.

1.3.1 Project Partners

Study partners include the Navajo Nation, Hopi Tribe, Arizona Department of Water Resources (ADWR), Coconino County, cities of Page and Flagstaff, and Reclamation.

1.3.2 Stakeholders

Stakeholders include the Coconino Plateau Water Advisory Council (CPWAC), Town of Tusayan, Grand Canyon National Park, Havasupai Tribe, cities of Sedona and Williams, the Sierra Club, Coconino and Kaibab National Forests, Wupatki National Monument, Sierra Club, ADWR, Arizona Department of Environmental Quality (ADEQ), Coconino County and others who attend the CPWAC and Coconino Plateau Technical Advisory Committee (See Section 1.3.8) meetings.

1.3.3 Federal

The U.S. Department of the Interior's Bureau of Reclamation is the lead agency for this federal action. Reclamation's TSC and PXAO prepared this interim report.

Reclamation also works cooperatively with regional stakeholders, the U.S. Geological Survey, U.S. Forest Service, U.S. Fish and Wildlife Service, and National Park Service to address environmental activities related to National Environmental Policy Act requirements associated with the Feasibility Study.

1.3.4 State

As a partner in this Study, ADWR originally requested Reclamation's participation in a rural water planning effort and provided funding prior to the 2007-2009 recession. Budget cuts and staff reductions resulted in reduced financial support, but ADWR, as well as ADEQ, remain involved in the effort, with representatives regularly attending CPWAC meetings.

1.3.5 Local

Non-tribal communities in the Study Area include the City of Flagstaff and its surrounding communities, such as Doney Park/Timberline and Fort Valley; Kachina Village and Mountainaire to the south along I-17; Parks and Williams to the west along I-40; Valle, Tusayan, and Grand Canyon Village in the western portion of the Study Area; and the City of Page at the northern edge of the Study Area.

1.3.6 Tribes

Located in northeastern Arizona, Hopi Reservation lands are surrounded by the Navajo Reservation. The lands are comprised of two noncontiguous parcels: lands within the Hopi Reservation and lands in and around the Moenkopi District, which consist of two villages (Upper Moenkopi and Lower Moenkopi) located 45 miles from the main Hopi Reservation.

The Navajo Nation encompasses most of the northeastern corner of Arizona, as well as portions of Utah and New Mexico. However, only the western portion of the reservation, including the populations in and around Cameron, Tuba City, Bodaway-Gap, Coppermine, and LeChee, is included within the Study Area.

1.3.7 Irrigation Districts

There is no representation by irrigation districts as there is minimal to no agriculture on the Coconino Plateau. Dry land farming is practiced by tribal communities.

1.3.8 Technical Advisory Committee

The Coconino Plateau Technical Advisory Committee (CPTAC), which supports the activities of the CPWAC and Coconino Plateau Watershed Partnership, is chaired by the Reclamation’s PXAO rural water study manager and comprised of engineers, scientists, program specialists, and administrators. Members participating in monthly meetings during the Feasibility Study process include:

- Reclamation
- CPWAC
- Navajo Nation
- Hopi Tribe
- City of Flagstaff
- City of Page
- Coconino County
- Northern Arizona University
- U.S. Fish and Wildlife Service
- U.S. Forest Service
- National Park Service
- Arizona Department of Water Resources
- Arizona Game and Fish Department
- City of Sedona

1.4 Public Involvement and Consultation and Coordination

Reclamation and ADWR executed a cost-share agreement to fund the NCAWSS appraisal study in 2000. As part of this effort, Reclamation organized the CPTAC, enlisting representatives from the demand areas, Grand Canyon Trust, U.S. Geological Survey (USGS), Northern Arizona University, Coconino County, Navajo Nation, Hopi Tribe, Havasupai Tribe, and interested local citizens.

In 2005, the CPWAC was formed, incorporating members of an earlier 1998 water advisory group, formalizing the role of regional stakeholders within the context of the ADWR Rural Water Program. The CPWAC is an organization consisting of 33 federal, state and local government entities, and tribes with land and water use management responsibilities, and public and private interests. The CPWAC was established to facilitate and implement sound water resource management and conservation strategies throughout the Coconino Plateau.

Pursuant to the Rural Water Supply Act, Coconino County, on behalf of the CPWAC, submitted a proposal to Reclamation's RWSP requesting authorization and funding to conduct a feasibility study of alternatives identified in the NCAWSS 2006 *Report of Findings*. The proposal received authorization in fiscal year 2010.

Coordination with partners is conducted through monthly meetings and strategic planning meetings of the CPWAC and the CPTAC. Meetings held at the USGS office in Flagstaff are well attended. NCAWSFS updates, requests for information and reviews and presentations are communicated via these meetings, email notification lists, and the CPWAC website.

Presentations have been provided throughout the region to partners and stakeholders to coordinate and provide study information and to discuss potential pipeline alignments and environmental and rights-of-way requirements.

1.5 Study Area Location and Description

The NCAWSFS Area is located in north-central Arizona south of the Colorado River. The Study Area includes parts of the Little Colorado River and numerous streams that flow into the Colorado River in Grand Canyon National Park to the north.

The primary source of water for the region is groundwater. What little surface water does exist provides habitat for numerous listed and endangered species and/or is highly susceptible to drought which reduces its reliability and limits its use for domestic and municipal purposes (Reclamation, 2006).

The Area includes specific communities that were the subject of a future water needs analysis that was completed during the NCAWSS appraisal study. The Study Area also encompasses locations with water resources that are either currently being used or have been identified as alternative sources to meet future water needs.

1.5.1 Geographic Location

The approximately 11,912 square-mile Study Area is located in the southern portion of the Colorado Plateau, a physiographic region that encompasses parts of four states in the southwestern United States (Colorado, Utah, New Mexico, and Arizona). The Area also includes the Coconino Plateau and Little Colorado River basin.

The Study Area is encompassed by Coconino County, but does not include all County lands; it also includes parts of Navajo County. Indian reservations comprise 38 percent of the County's land and are home to the Navajo, Hopi, Paiute, Havasupai, and Hualapai Tribes. The U.S. Forest Service, National Park Service (NPS), and Bureau of Land Management manage 40 percent of the land; the State of Arizona owns 9 percent; and the remaining 13 percent is owned by individuals or corporations (Reclamation, 2006). Flagstaff, Page and Williams are the major non-tribal population centers in the Study Area.

1.5.2 Climate

The climate of the Study Area is semiarid to arid. Large elevation changes across the region result in broad spatial and temporal temperature and precipitation variations. At higher altitudes, summers are moderate and winters severe. Average annual temperature ranges from 43° Fahrenheit (F) on the southwest side of the San Francisco Mountains to 68° F at the bottom of the Grand Canyon. Winter temperatures may dip to subzero in deep canyons and summer temperatures may exceed 100° F on the plateau (Bills, et al., 2007). The area is subject to drought and dry periods have been documented for hundreds of years. Average annual precipitation ranges from 5.5 inches at Cameron (Bills, et al., 2007) to 22.9 inches in Flagstaff (Staudenmaier, et al., 2009).

1.5.3 Vegetation

Primary vegetation types in the Study Area are ponderosa pine forest with piñon and juniper pines and aspen and oak interspersed with flat meadows with drought tolerant grasses and brush in the higher elevations. Lower elevations consist of grasses, brush and high desert species. Riparian ecosystems in the region have national significance as they are some of the few remaining riparian habitats in Arizona. These systems are fed by springs, seeps, and streams fed by springs and important to Native American culture. Further, these riparian habitats support a diverse biological habitat with species diversity that is about 100 to 500 times greater than non-riparian habitats. Sufficient data to interpret the variability and sustainability of the vast spring network of Grand Canyon National Park is lacking. It is uncertain how continued groundwater resource development and climate uncertainty will impact springs and the associated riparian habitats (Bills, et al., 2007).

Additionally, four national forests (Kaibab, Coconino, Apache-Sitgreaves and Tonto) are actively engaged in an initiative designed to restore fire-adapted ecosystems in the area. An ongoing collaboration with a diverse group of stakeholders, the Four Forest Restoration Initiative is carrying out landscape-scale restoration of the ponderosa pine forests in northern Arizona to reduce the potential for destructive wildfires, support sustainable forest industries and conserve natural resources. Stakeholders are conducting pre- and post-thinning monitoring as part of this effort to assess impacts of the restoration activities to local hydrologic conditions.

1.5.4 Topography

Most of the Study Area is 5,000 feet above mean sea level (amsl) and exhibits steep elevation changes due to geologic conditions and weathering. The highest elevation in the Study Area is in the San Francisco Peaks located in the south central portion, which include the highest peak in Arizona, Mt. Humphries at 12,633 ft amsl. The lowest point is 1,706 ft amsl on the Colorado River near Cove's Canyon in the Grand Canyon. The interior of the Study Area is comprised of flat-lying consolidated sediments that range from 5,000 feet at the northern end to about 8,000 feet thick at the southern end. Erosion of these sediments has resulted in low-relief hills and mesas, broad mature valleys and internal ephemeral drainages. The sedimentary rocks slope gently south-southwest and to the east and northeast. Many of the valleys have filled with gravel and erosional materials up to 100 feet thick or more with recent alluvium deposits. The predominance of ephemeral drainages and lack of free-flowing water at the land surface is attributed to rapid infiltration into permeable sedimentary and volcanic rocks. There are exceptions, and larger drainages exist that may have been more prominent during wetter periods and before the permeable volcanic rocks were deposited. Groundwater conditions and movement are controlled by internal drainage resulting from mineral dissolution within sedimentary deposits, recent tectonics, and breccia pipe development (Bills, et al., 2007).

1.6 Planning Scope

The NCAWSFS was initially based on demand projections for 2050 that were developed and provided in the 2006 NCAWSS *Report of Findings*. The water demand forecast was based on current and projected population and participant-identified water demands. Partners had opportunities to examine and revise water demands as part of this Study.

1.7 Relationship to Other Activities

The proposed NCAWSFS pipeline alignment is sited along a corridor that would be suitable for other large infrastructure projects in the region. The information compiled in this report can be used by other entities for siting rights-of-way corridors in the region.

One example of such an investigation that could benefit from this research is the analysis of potential energy alternatives that will be developed in association with an Environmental Impact Statement (EIS) for the Navajo Generating Station (NGS), a coal-fired powerplant in northeastern Arizona. The NGS presently provides power to portions of the southwestern United States and to the Central Arizona Project (CAP) to pump and deliver Colorado River water to users in southern Arizona. The alternatives would provide a reliable source of power that, Reclamation, would be continuously available to operate the CAP pumps, and provide a source of revenue through 2044.

Additionally, Reclamation completed the Southwest Navajo Rural Water Supply Program Appraisal Study for the Navajo Nation in March 2015. The study identifies problems, opportunities, and constraints associated with existing infrastructure and water management practices in the area.

Reclamation provided funds to Flagstaff to complete groundwater modeling to assess impacts of groundwater pumping at Red Gap Ranch on nearby surface water sources and a biological resource evaluation and a cultural resources inventory of Red Gap Ranch’s lands for proposed infrastructure on the property. The groundwater modeling report was completed in December 2015 and the cultural and biological resources reports were completed in February 2014.

1.8 Summary of Previous and Current Studies

Numerous water resource planning studies have been completed in north-central Arizona by federal, state, county, local and tribal governments and private parties to identify potential water sources available to meet future demands and to evaluate water rights claims in the Little Colorado River adjudication.

In 1998, ADWR organized a regional study to evaluate future municipal water demands for communities including the Navajo Nation; Cities of Flagstaff, Page, and Williams; the Town of Tusayan; and the Grand Canyon National Park. As part of the work, ADWR requested Reclamation’s technical assistance to evaluate the engineering hydraulics of a conceptual water conveyance infrastructure that had been identified in former studies. Reclamation interviewed water managers and stakeholder representatives who participated in the ADWR Rural Water Program planning process and contributed to the Phase I Report publication (ADWR, 1999). Reclamation then presented peer reviewed findings to a water advisory group organized by Coconino County, identifying uncertainties regarding the continued and future development of the groundwater aquifers on the Coconino Plateau and recommending that other water supply alternatives be considered (Reclamation, 1999).

In October 2000, Reclamation received funding to conduct an appraisal study of the region's water supply as authorized by the Reclamation Act (Act of June 17, 1902, ch. 1093, 32 Stat. 388), as amended, resulting in the NCAWSS. In October 2006, Reclamation's Phoenix Area Office and the Denver TSC completed the NCAWSS *Report of Findings* (Reclamation, 2006) documenting alternatives, population projections, water demands, and appraisal-level hydraulic engineering of alternatives that were recommended to be carried forward into a feasibility study.

In 2009, the Navajo Nation entered into a water service contract with the United States, acting through Reclamation, for 950 acre-feet per year (AFY) from Lake Powell (DOWL, 2016).

In 2014, Flagstaff completed *A Cultural Resources Inventory of 567.89 Acres for Water Infrastructure Development at Red Gap Ranch* and the *Red Gap Ranch Biological Resource Evaluation* (WestLand Resources, Inc., 2014 a and b). The City also completed the groundwater modeling report, *Red Gap Ranch – Leupp Water Resources Environmental Assessment Groundwater Flow Model*, in December 2015 to assess impacts of ranch pumping on nearby perennial streams (Southwest Ground-water Consultants, Inc. 2015).

A study was also commissioned by the Navajo Nation to assess potential intakes near Lake Powell. Results of this study are provided in the May 2016 *Water Facilities: Page-LeChee Raw Water Intake & Transmission Pipeline Preliminary Engineering Report* prepared for the Navajo Nation.

1.9 Feasibility Study Timeline

<u>October 28, 2009</u>
Feasibility study cost share timeframe begins.

<u>December 4, 2009</u>
ADWR and Reclamation partner to continue compiling water resource information as follow-up to the completion of the NCAWSS to support Reclamation's feasibility study.

<u>August 31, 2010</u>
2010 Rural Water Supply Program Funding Opportunity Announcement No. R10SF80458, Proposal Evaluations and Award Notifications, letter approves Plan of Study for North Central Arizona Water Supply Feasibility Study.

<u>September 30, 2011</u>
Agreement signed between Navajo Nation and Reclamation to conduct the NCAWSFS.

<u>November 30, 2011</u>
Agreement signed by Coconino County, Flagstaff, Page, ADWR and Reclamation to conduct the NCAWSFS.

<u>July 2012</u>
Collapse of the Navajo Nation–Hopi Tribe water settlement in which Navajo lawmakers rejected the agreement and the Hopi Tribal Council approved the settlement, but voted down enabling legislation submitted by Senator Kyl.

<u>September 24, 2012</u>
Assistance Agreement between Reclamation and Flagstaff granting $300,000 to Flagstaff for development of the Red Gap Ranch groundwater model. Model results will be used for National Environmental Policy Act (NEPA) requirements for the NCAWSFS.

<u>March 15, 2013</u>
Email correspondence from Williams informing Reclamation that the City Council had voted to not participate in the NCAWSFS.

<u>April 2013</u>
Letter from the Hopi Tribe, Cities of Flagstaff and Page, Town of Tusayan, Coconino County and CPWAC to Secretary of the Interior requesting federal funds for the Study.

<u>June 7, 2013</u>
Letter from the Navajo Nation to Senator McCain and Arizona congressional representatives requesting federal funds for NCAWSFS.

<u>July 2013</u>
Initiated development of an Interagency Agreement between Reclamation and the National Park Service at Grand Canyon National Park (GCNP) to assess the feasibility of including a lateral pipeline from the NCAWSFS mainstem to the GCNP.

<u>August 6, 2013</u>
Video conference meeting between CPWAC and Reclamation Commissioner requesting additional funding for the NCAWSFS.

<u>August 29, 2013</u>
Letter from GCNP to Reclamation regarding potential partnership. GCNP chose to proceed independently to assess and mitigate immediate water

infrastructure needs to delay long-term water augmentation alternative planning.

September 4, 2013
Agreement between the Hopi Tribe and Reclamation to conduct the NCAWSFS.

October 2, 2013
Agreement between Tusayan and Reclamation to conduct the NCAWSFS.

November 25, 2013
Letter from Tusayan describing conditional support based on GCNP participation. Tusayan will participate if GCNP participates. Neither continued participation.

January 9, 2014
Letter from GCNP to Reclamation officially stating that the NPS would not be participating in the NCAWSFS.

February 2014
Flagstaff completes a Cultural Resources Inventory and Biological Resource Evaluation for Red Gap Ranch.

August 5, 2014
Letter from Flagstaff informing Reclamation that Flagstaff City Council would not provide additional cost share to the NCAWSFS and may consider resuming cost share if federal funding returns.

September 30, 2015
Letter from Senator McCain to the Reclamation Commissioner requesting renewal of the Rural Water Supply Act authorization so that the NCAWSFS may continue.

December 2015
Flagstaff completes the *Red Gap Ranch – Leupp Water Resources Environmental Assessment Groundwater Flow Model* report.

October 2009 to September 2016
Continue monthly CPTAC and CPWAC meetings and/or conference calls and presentations to individual partners and stakeholders to disseminate information and coordinate efforts.

2.0 Challenges and Needs

2.1 Characterization of Conditions

The Study Area encompasses an area that includes more than 6 Navajo Nation chapters, all Hopi Tribe villages, several non-tribal communities, GCNP, Wupatki National Monument, and the Kaibab and Coconino National Forests. The primary source of water for the region is groundwater. Limited surface water supplies support habitat for listed and endangered species and are susceptible to drought, reducing reliability and limiting their use for domestic and municipal purposes.

The 2006 NCAWSS *Report of Findings* identified an unmet municipal water demand of more than 28,100 AFY in the region by the year 2050 for communities and cities included in the analysis. The results indicate that if water conservation reduces demand by 20 percent, there would still be an unmet water demand of more than 22,000 AFY by the year 2050. However, mandated conservation measures and lack of available water supplies result in Coconino Plateau water users currently using water at the lowest per capita water use rate in the state of Arizona, with few opportunities for further conservation.

The area's urgent and compelling need for water is based on the physical absence of available water and infrastructure; more than 50% of the Navajo Nation chapters and Hopi Tribe villages must haul water to meet basic needs. These water sources are often located far from community members and do not meet safe drinking water standards. Groundwater and spring sites in the region frequently exceed arsenic standards and require costly water treatment.

Groundwater pumping is not regulated by ADWR on the Coconino Plateau and groundwater continues to be developed throughout the region. Extensive conservation practices have been implemented by non-tribal communities in the region, and Flagstaff, for example, has decreased total potable water use despite population increases. Current water use in Flagstaff is 119 gallons per capita per day (gpcd) (Flagstaff, 2016). Tribal communities have the lowest water use in the state, ranging from less than 10 gpcd for members who haul water to 89 gpcd (Reclamation, 2006). In comparison, water use in the City of Phoenix service area was about 185 gpcd in 2010.

2.1.1 Augmenting Water Supplies from the Colorado River

The 2006 *Report of Findings* concluded that augmented water supplies are necessary to meet projected water demands in 2050 and recommended advancement of alternatives that use Lake Powell as an augmentation water supply source and a pipeline delivery system that would convey water from the mainstem Colorado River upstream of the Grand Canyon. However, a number of legal and regulatory conditions exist which make this alternative challenging to implement.

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River." This collection of documents apportions the water and regulates the use and management of the Colorado River among seven basin states and Mexico.

The cornerstone of the "Law of the River", the Colorado River Compact, was negotiated by the seven Colorado River Basin States and the federal government in 1922. It defined the relationship between the Upper Basin states, where most of the river's water supply originates, and the Lower Basin states, where most of the water demands were developing. The states could not agree on how the waters of the Colorado River Basin should be allocated among them, so the basin was divided into an upper and lower half, with each basin having the right to develop and use 7.5 million acre-feet (MAF) of river water annually. This approach reserved water for future Upper Basin development and allowed planning and development in the Lower Basin to proceed.

The Boulder Canyon Project Act of 1928 apportioned the Lower Basin's 7.5 MAF among the states of Arizona, California, and Nevada, and authorized and directed the Secretary of the Interior to function as the sole contracting authority for Colorado River water use in the Lower Basin. The Upper Colorado River Basin Compact of 1948 apportions upper Colorado River basin water to Colorado, Utah, New Mexico, and Wyoming; the portion of Arizona that lies within the Upper Colorado Basin was also apportioned 50,000 acre-feet annually. Today, about 30,000 AFY of Arizona's Upper Basin apportionment is used at the Navajo Generating Station, which provides about 90 percent of the power used to pump water along the 336-mile-long Central Arizona Project aqueduct.

The Lower and Upper Basin dividing point is at Lee Ferry downstream of Glen Canyon Dam. For this alternative, any diversion out of Lake Powell itself would be from the Upper Basin, while the vast majority of uses of this water would be in the Lower Basin. Upper Basin diversions are counted against the Upper Basin apportionment, thus use of this water would require negotiations between the Upper and Lower Basin states prior to final design.

Additionally, regional Tribal water settlements are outstanding and, when completed, may further refine current Colorado River water law.

Thus, although previous appraisal level analyses suggest that Lower Basin use of Upper Basin water is a viable augmentation alternative, issues related to Colorado River management and its associated "Law of the River" would have to be addressed as part of implementation.

2.2 Water Supply

2.2.1 Groundwater and Surface Water Supply Sources

The implementation of any rural water supply alternative on the Coconino Plateau must meet the projected water supply deficit and mitigate issues with federal, tribal, state, and regional laws associated with, but not limited to, the Safe Drinking Water Act, Endangered Species Act, and water management.

During the NCAWSS appraisal study, Reclamation identified the range of potential sources of water supply within the Study Area including:

- Surface water from the mainstem Colorado River above Grand Canyon
- Surface water from the mainstem Colorado River below Grand Canyon
- Surface water from the Little Colorado River (LCR) tributaries
- Groundwater from the alluvium of the LCR
- High-quality groundwater from the Coconino Aquifer (C Aquifer)
- Low-quality groundwater from the C Aquifer
- Groundwater from the Redwall-Muav (R-M) Aquifer
- Roaring Springs on the North Rim of the Grand Canyon

The NCAWSS assessed potential sources against demand centers in the Study Area to identify which sources could potentially supply future water demands. Preliminary costs were developed for conceptual infrastructure required to deliver water from potential water sources to each demand center. The 2006 *Report of Findings* found that the most viable option is to develop infrastructure to convey water from Lake Powell.

Geologic conditions are complex on the Coconino Plateau and groundwater supplies are in two primary aquifers: the C Aquifer and the R-M Aquifer, and also in perched groundwater zones interspersed throughout the region.

2.2.2 Approach to Water Supply Analysis

The Coconino Plateau is vast with complex geologic and hydrologic conditions. Perched aquifers are primarily dependent on precipitation and provide limited water supplies. Depth to groundwater ranges from several hundred feet to greater than 2,000 feet below land surface throughout the region.

The NCAWSS appraisal built on past investigations to assess potential water augmentation alternatives and recommend alternatives for feasibility. Prior investigations consisted of data collection and development of calibrated models to better understand groundwater and surface water conditions. The study results summarized here are from the 2006 *Report of Findings* and illustrate the availability and limitations of water supplies in the region.

- ADWR's analyses of tributary flows of the Little Colorado River concluded that, while flows in the LCR may be significant, the LCR is intermittent and carries a high sediment load, making it difficult to utilize (ADWR, 1989).

- The *Hopi Western Navajo Water Supply Study* (HWNSS) estimated that surface water in the Clear Creek and Chevelon Creek Basins, in addition to Jacks Canyon flow, could be collected to serve a range of demands (HDR, 2004).

- Hydrogeologic and groundwater flow modeling investigations for the *Tusayan Growth Environmental Impact Statement* (EIS) indicated that long-term pumping from the R-M Aquifer will result in decreased flows from Havasu Springs and smaller springs under the south rim of the Grand Canyon (Victor and Montgomery, 2000).

- The regional aquifer in the Flagstaff area is a complex system that has become an increasingly important water supply. Depth to water may be greater than 2,000 feet below land surface, making it difficult to drill exploration holes for testing to better understand complex geologic conditions. Based on limited information, the saturated thickness of the regional aquifer averages about 1,200 feet, and the amount of water in storage could be as much as 4.8 MAF, or about 10 percent of the total volume of the aquifer. The regional aquifer is heterogeneous and anisotrophic and has a complex groundwater flow system (Bills, et al., 2000).

- In 2002 groundwater was the major source of water supply in the Flagstaff area. Surface water resources in the area are unreliable, limited, and the associated surface water rights fully appropriated or under adjudication. Depth to groundwater in regional aquifers is deep and as a result high yield wells are installed to reduce drilling and completion costs. Flagstaff accounts for more than half of the region’s groundwater use (Bills and Flynn, 2002).

- Previous studies were reviewed to assess the availability of surface water supplies within and adjacent to the HWNSS and concluded that development of new surface water resources in the LCR basin are limited and that only two main sources of surface water are viable for M&I supplies: the Three Canyons watershed and the Colorado River supply. Significant upstream depletions leave no water for further practical development (HDR, 2004).

- Flow in ephemeral drainages was estimated to account for about 40 percent of the total flow in the LCR measured at Cameron. However, this average figure may be skewed by intense storm runoff. Streamflow is highly variable from day to day, month to month, and year to year; surface runoff carries a high sediment flow; and storm runoff in ephemeral washes has been used for irrigation (NRCE, 1995).

- Arizona's use of Colorado River water is subject to Article III of the 1948 Upper Colorado River Basin Compact which apportions Arizona the consumptive use of 50,000 AFY of Colorado River water from the Upper Colorado River System. Approximately 30,000 AFY of Arizona's Upper Basin apportionment is used at the Navajo Generating Station near Page, Arizona. The majority of the remaining Upper Basin apportionment to Arizona is used on the Navajo Reservation. The Boulder Canyon Project Act of 1928 apportioned to the State of Arizona the consumptive use of 2.8 MAF of Colorado River water from the Lower Colorado River System below Lee Ferry. Approximately 1.6 to 1.8 million acre-feet of Arizona's Lower Basin water apportionment is diverted into the Central Arizona Project from Lake Havasu. Arizona's remaining Lower Basin allocation is used by senior water right holders in southwestern Arizona. An assessment of diversion points, priority of water rights, and apportionment of shortages indicates that, while there is some uncertainty with acquisition of water contracts, Colorado River water supplies provide a viable, long-term reliable source of good quality water for use in a potential settlement between the Hopi Tribe and Navajo Nation. It must be noted that system shortages and/or prolonged droughts could negatively impact Colorado River water supplies and delivery of that water (HDR, 2004).

- Total water use in the Study Area in 2000 was estimated to be about 5.84 billion gallons, or 17,930 AF (RMI, 2002). This includes potable and non-potable use, but it does not include small communities for which data were not available.

- A USGS investigation describes physical conditions of the region including geology, topography, hydrology, climate, land use, vegetation, and occurrence of regional groundwater aquifers of the Coconino Plateau (Bills and Flynn, 2002).

- The regional C Aquifer underlying the Little Colorado River Basin has an aerial extent of more than 27,000 square miles with more than 1,000 well and spring sites identified in Arizona and New Mexico. The C Aquifer is the most productive aquifer in the LCR Basin. The LCR is the primary surface water feature in the area and is in direct hydraulic connection with the C Aquifer in some areas. Groundwater discharges as base flow from the C Aquifer to the LCR and as springs in Silver Creek and the lower reaches of Chevelon and Clear Creeks. R-M Aquifer springs that discharge in the lower 13 miles of the LCR maintain the base flow of this reach of the river and represent a regional drain for much of the north flowing groundwater in the LCR Basin (Hart, et al., 2002).

- Groundwater development in the C Aquifer has increased steadily since the 1940s. Groundwater pumpage from the C Aquifer during 1995 was about 140,000 AF. The system was assumed to be in a steady-state condition and the stability of discharge from major springs during the past several decades supported the steady-state assumption. C Aquifer discharge via downward leakage to the R-M Limestone Aquifer was estimated to be 319,000 AFY (Hart, et al., 2002).

- Three-dimensional groundwater modeling of the R-M Aquifer indicates that Havasu Springs captures the vast majority of the regional R-M flows and that smaller springs below the South Rim have smaller capture zones that are limited to the region near the South Rim (Kessler, 2002).

- In 2002, withdrawals from the C Aquifer exceeded 140,000 AFY and were growing at a rate of 3 to 4 percent per year. The C Aquifer is recharged along its southern flanks from Flagstaff to the White Mountains, on the eastern side of Arizona along the Defiance Uplift, and in western New Mexico along the Zuni Uplift (Ward, 2002). Groundwater diverges from these recharge zones, and most of it flows westward to discharge 200,000 to 300,000 AFY into the upper LCR and its tributaries; however, the largest discharge is at Blue Springs above the confluence with the Colorado River at more than 160,000 AFY.

- An assessment of Western Navajo and Hopi Reservations' water supply needs, alternatives, and impacts; existing conditions for the N Aquifer, the C Aquifer, and the Alluvial Aquifer along the LCR; potential growth within the Study Area; and water supplies available to support growth were evaluated to identify potential impacts of groundwater development on the aquifer systems. Previously developed and new groundwater models were used to evaluate potential alternatives to meet projected growth (HDR, 2004).

- Modeling conditions of increased pumping in the regional aquifer or decreased recharge due to climatic conditions suggested that these conditions may alter spring-fed ecosystems on the south rim of the Grand Canyon over short timespans (Kobor, 2004).

- A geochemical study of groundwater discharges along the South Rim of the Grand Canyon showed that the chemistry of each discharge site varied considerably, indicating spatial variability in the groundwater composition. Isotope analysis indicated that residence times for the groundwater discharges varied from 50 years to over 3,400 years. Assessments suggest that the water discharging from the R-M Aquifer follows multiple flow paths and has multiple recharge areas (Monroe, et al., 2004).

- Assessment of the geology, hydrology, and water quality of the C Aquifer for groundwater pumping near Leupp, Arizona (Hoffmann, et al., 2005).

- A numerical groundwater model was developed to evaluate the impacts of pumping from the C Aquifer at select reaches of Clear Creek, Chevelon Creek, and the LCR. The perennial flows in these three streams are maintained by discharges from the C Aquifer. The study evaluated the potential depletions in streamflows from withdrawals from the C Aquifer in the vicinity of Leupp, Arizona. Maximum withdrawals produced a maximum depletion of less than 0.6 cubic feet per second (cfs), or about 6 percent of the ultimate volume of water produced (Leake, et al., 2005).

- Development of groundwater flow model to evaluate pumping of a proposed well field south of Leupp, Arizona on Chevelon Creek, Clear Creek, and Blue Springs. Results indicate an adequate water supply for the proposed well field. The greatest impact on baseflow in the lower, perennial reaches of both Chevelon and Clear Creeks is due to future regional pumping. Water quality evaluation indicates adequate quality for public and industrial use.

2.2.3 Groundwater Availability

The 2006 NCAWSS *Report of Findings* information related to groundwater availability is summarized in this section.

Groundwater resources (Figure 2) in the Coconino Plateau region consist primarily of the N Aquifer, the C Aquifer and the R-M Aquifer. The N Aquifer is higher in the stratigraphic section than the C Aquifer or the R-M Aquifer and occurs east of the Study Area. Perched groundwater conditions exist in alluvial channels along the LCR and at other locations in the region.

2.2.3.1 Alluvial Aquifers and Other Perched Water-Bearing Zones

The alluvial channel aquifers in the Study Area are associated with perennial and intermittent streams in incised canyons. These aquifers have a limited extent and capacity and while they may be suitable for emergency or individual community systems, supplies from these aquifers would not be reliable.

Perched aquifers in the region are relatively small, discontinuous, dependent on precipitation, and have small yields. Water supplies from perched aquifers are variable from year to year. An exception is the Inner Basin Aquifer of San Francisco Mountain, a water-bearing zone with good well yields that has been developed by Flagstaff as one of its municipal water supplies.

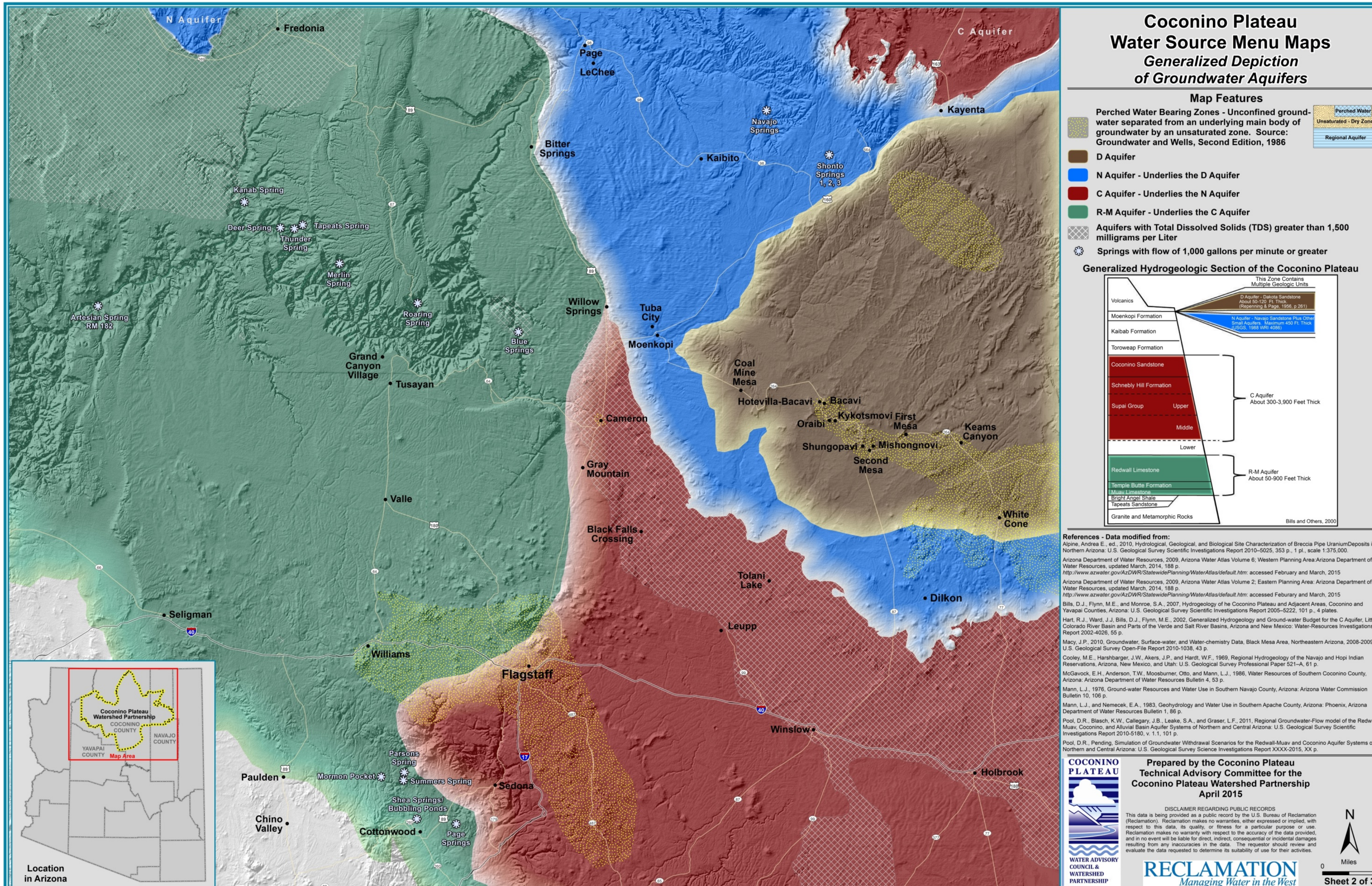

Figure 2: Groundwater Aquifers in the Study Area

The LCR Alluvial Aquifer Basin is a perched aquifer that parallels the river for about 25 river miles. Recharge is from precipitation, infiltration from surface flows in the river, and, possibly, from upward leakage from the C Aquifer. Model estimates indicate that the LCR Alluvial Aquifer could produce about 1,700 AF every two years (HDR, 2004).

2.2.3.2 Navajo Aquifer

The N Aquifer underlies the north and eastern portion of the Study Area and contains both confined regions and unconfined portions along its edges. It is characterized by deep saturated thickness and relatively high water quality, but little recharge. The N Aquifer underlies approximately 5,400 square miles of the LCR Basin, primarily beneath the Navajo and Hopi Reservations, but it does extend outside the LCR Basin to the north into Utah. The aquifer is thickest to the northwest and thins to extinction on the southern and southeastern boundaries. Yields from the N Aquifer are generally dependable, ranging from 10 to more than 1,000 gpm, and the water quality is good.

Groundwater modeling estimates indicate that N Aquifer recharge ranges from 2,500 to 13,000 AFY. Measured discharges from the N Aquifer are a minimum of 7,000 AFY; however, not all of the smaller springs were included in all of the measurements. Estimates of the volume of water stored in the N Aquifer vary from 180 to 400 MAF.

The N Aquifer is not a practical supply source for all of the NCAWSFS partners because the N Aquifer does not underlie the entire Study Area. The N Aquifer is the sole source of water for many Navajo and Hopi communities, and its springs have cultural and/or religious significance to the Tribes who believe groundwater withdrawal should remain within sustainable limits for use by future generations of tribal members.

2.2.3.3 Coconino Aquifer

The C Aquifer is comprised of several sedimentary units. The primary aquifer unit is the Coconino Sandstone, but the overlying Toroweap and Kaibab Formations and portions of the underlying Supai Group can be locally significant water-producing units. Although perched zones occur, the C Aquifer is largely drained of water west of Flagstaff and north of Cameron, coincident with the northeast-southwest trending Mesa Butte Fault.

Precipitation is the primary source of recharge for the C Aquifer. Recent trends in precipitation on the Colorado Plateau indicate that the region may become drier. Relying on the C Aquifer during drought conditions could substantially increase water demands in the region and possibly result in severe or catastrophic consequences if drought conditions persist (Hereford, et al., 2002).

Water quality in the upper and middle parts of the C Aquifer is reported as good to excellent. Evaporite deposits in the lower portions of the C Aquifer may yield poor quality, brackish water.

The C Aquifer has been extensively developed in localized areas and reported well yields range from a few gallons per minute (gpm) to as much as 1,000 gpm depending on well size, geologic formations, and primary and secondary permeabilities. C Aquifer hydraulic conductivity values range from 4 to 7 feet per day and may be greater depending on secondary permeability, such as fractures and faults (Cooley et al., 1969; Mann et al., 1986; and Bills et al., 2000).

The majority of the C Aquifer recharge occurs where it outcrops to the south along the Mogollon Rim and to the east on the slopes of the Defiance Uplift located near the Arizona/ New Mexico border. Estimates of total average annual recharge to the LCR Basin C Aquifer system range from 170,000 to 190,000 AFY (HDR, 2004; Hart et al., 2002). Current potable demand on the C Aquifer system is estimated to be in the range of 140,000 AFY.

Pumping from the C Aquifer to meet future participant demands within the Study Area requires consideration of the following issues:

- The C Aquifer is assumed to be in transient state, with aquifer conditions and springs changing over time based on pumping and recharge.
- C Aquifer pumping has impacted LCR base flows. Additional pumping from the C Aquifer will likely impact springs flows.
- The C Aquifer underlying the Study Area is mostly unsaturated.
- Deep groundwater wells, pumping and associated conveyance pipelines capital costs and long-term OM&R costs will be high.
- Not all C Aquifer recharge occurs near the Study Area.
- C Aquifer water quality degrades with distance from recharge areas and depth.
- The NCAWSFS area is located at the downstream end of the C Aquifer flow system, increases in upgradient pumping could affect water availability and quality in the Study Area.
- Unquantified water rights and unadjudicated claims in the LCR Basin may result in future water rights conflicts.

2.2.3.4 Redwall-Muav Aquifer

Few wells have been completed in the R-M Aquifer. A lack of hydrogeologic data makes aquifer yields uncertain. The hydrogeology of the R-M Aquifer and the degree of interconnectivity with other aquifers is not well understood. Water quality assessments are based on available well information and springs (Monroe et al., 2004) and show that water quality is generally good to poor.

Groundwater modeling indicates that regional flow in the R-M Aquifer is towards the Grand Canyon and Havasu Springs (Springer and Kessler, 2000; Kessler, 2002). Hydraulic conductivity data for the R-M Aquifer is not available. Transmissivity values estimated from modeling investigations range from 0.3 feet per day to 320 feet per day (Springer and Kessler, 2000) to 0.1 feet per day to 742 feet per day (Victor and Montgomery, 2000). These estimates vary because the thickness of the R-M Aquifer can vary from 50 to 900 feet. The R-M Aquifer does not outcrop within the Coconino Plateau. The main source of recharge may be downward leakage from the C Aquifer along fault zones.

2.2.4 Surface Water Availability

The information summarized here and in Figure 3 is from the 2006 *Report of Findings* which compiled and assessed prior surface water resource investigations.

A regional water resource assessment was conducted during the appraisal study which utilized results from previous regional surface water investigations. Based on available information, it was determined that opportunities to develop surface water resources in the LCR Basin are limited. The analysis identified two surface water sources that may provide a viable future M&I supply: the LCR Basin and importation of Colorado River supply. Potential surface water supply locations were identified as: the upper LCR Basin, the mainstem LCR and associated Three Canyons Watershed and Northern Washes Watershed; and the mainstem Colorado River (HDR, 2004).

The Upper LCR Basin is southwest of the Navajo Nation's southern boundary and is bound by the Mogollon Rim and the White Mountains of Arizona. Local runoff and storm water comprise flow in the mainstem LCR. Diversions and impoundments are primarily located near the headwaters and leave little water for development (HDR, 2004).

ADWR evaluated surface water resources in the region based on stream gage data from 1927 to 1987 and determined the median flow entering the southwestern portion of the Navajo Nation near Winslow, Arizona, was 162,900 AF annually. This is a significant volume of water; however, the LCR is predominantly an intermittent stream (ADWR, 1998).

Other contributions to LCR median flows include the lower mainstem LCR at 54,420 AFY and The Three Canyons watershed contribution of about 162,900 AFY and Clear Creek and Chevelon Creek Basins which contribute 4,000 to 20,000 AFY (ADWR, 1998). Flows from ephemeral washes may be 67,000 AFY (NRCE, 1995) although the volume is skewed by storm events. Baseflows, where they do exist in perennial stream reaches, are about 3,600 AFY or less. The streamflow may be variable, carries a high sediment load, and is used for local irrigation.

The NCAWSS Appraisal Study assessed regional water supplies based on the results of regional groundwater and surface water supply investigations previously conducted by others. The 2006 *Report of Findings* concluded that an evaluation of Colorado River water diversion points, priority of water rights, and shortage apportioning showed that, despite some uncertainty with the acquisition of long-term mainstem Colorado River water contracts, Colorado River supplies are viable and may provide a long-term reliable source of good quality water. It was noted that potential system shortages due to long-term drought could result in severe shortages and would have to be addressed (HDR, 2004). All states that share the river, and the federal government and Mexico participate in scenario planning to address potential Colorado River system shortages. Climate change was not evaluated in the 2006 *Report of Findings*, nor was it a part of the Plan of Study for the NCAWSFS, which assesses the feasibility of constructing a pipeline to deliver water supplies for participating partners who are responsible for assessing and acquiring Colorado River water supplies to meet their demands.

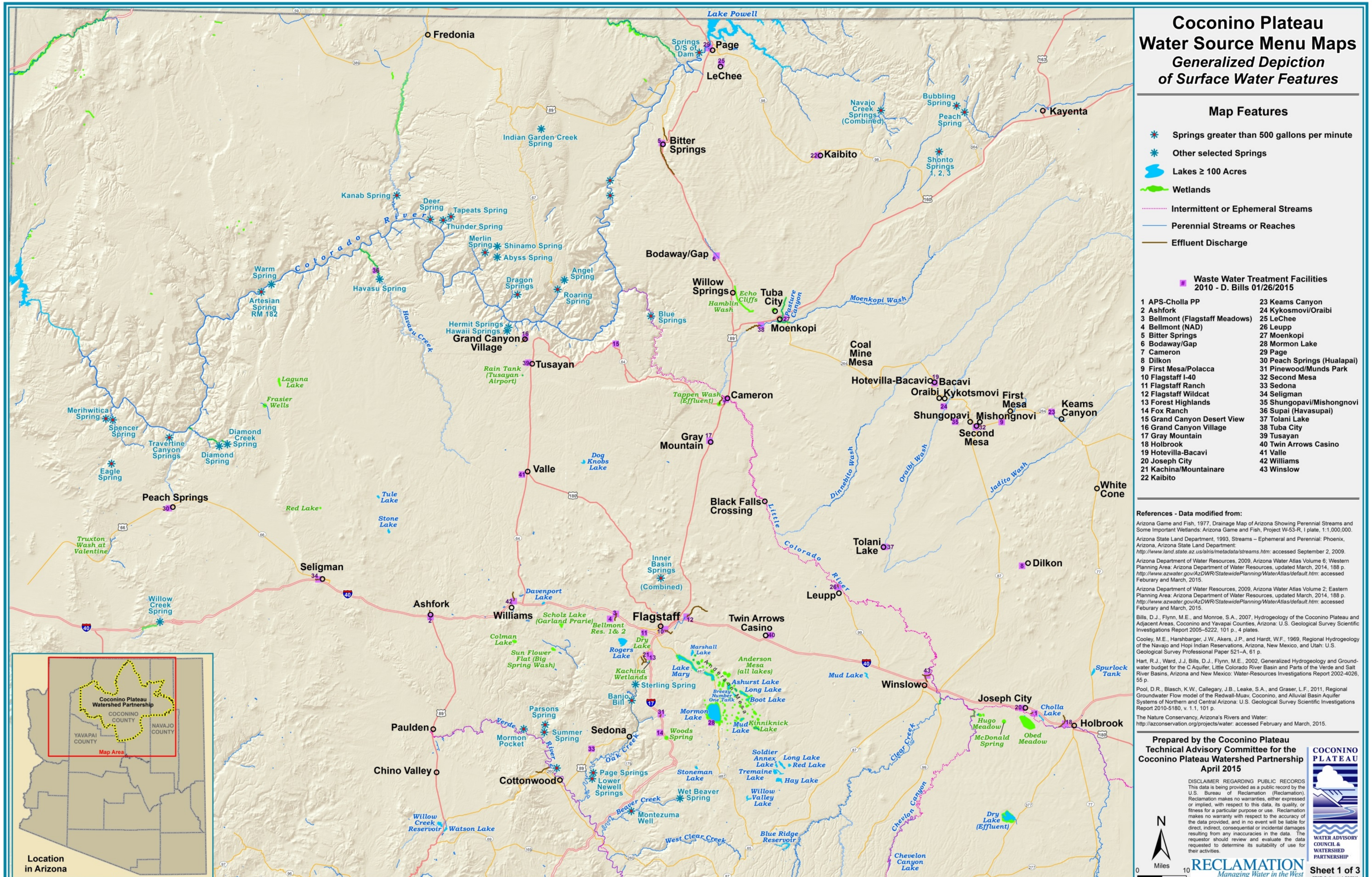

Figure 3: Surface Water Resources in the Study Area

2.2.5 Groundwater and Surface Water Legal Overview

Surface water and groundwater are managed distinctly in Arizona. Surface water use is governed under prior appropriation with the first priority right going to the earliest priority date. Surface water is not owned but may be diverted for beneficial use. During shortage, surface water is diverted based on the priority of the water right. In 1980, the Arizona Legislature passed the Groundwater Management Act which limits groundwater pumping within ADWR-designated Active Management Areas (AMAs) and allows unlimited pumping outside of an AMA with impact and reasonable use considerations.

The Groundwater Management Act established AMAs to manage groundwater pumping in areas with large populations. Within an AMA groundwater rights are grandfathered in, withdrawal permits are required, 100-year assured water supplies must be demonstrated for development, and conservation requirements must be met. There are five AMAs currently in existence in the State; none of them are located within the Study Area, where groundwater pumping is unlimited.

The water rights held by an Indian tribe are governed by federal law and first defined in the U.S. Supreme Court case of Winters v. United States, 207 U.S. 564 (1908). In Winters, the Supreme Court held that reservations will have water to fulfill the purposes of the reservation and that water is not subject to forfeiture or abandonment for nonuse or lack of beneficial use.

The Navajo Nation and the Hopi Tribe have the largest unsettled tribal water-rights case in Arizona. A water settlement between the Navajo Nation and the Hopi Tribe was underway in 2012. Senator Kyl submitted enabling legislation authorizing funding for water-delivery projects. Navajo lawmakers rejected the settlement and the Hopi Tribal Council approved the settlement but voted down the legislation, ending settlement negotiations. As a part of the proposed settlement, the Central Arizona Project offered 6,411 acre-feet of mainstem Colorado water in exchange for extended land and coal leases for the Navajo Generating Station (McKinnon, 2012).

2.2.5.1 Little Colorado River General Stream Adjudication

An ongoing general stream adjudication and judicial proceeding began in 1979 to establish the extent and priority of over 13,000 claims filed by nearly 5,000 parties including the Hopi Tribe, Navajo Nation, State of Arizona, the Salt River Project, Arizona Public Service, and the City of Flagstaff to settle water right claims in the LCR (In re: The General Adjudication of all Rights to Use Water in the Little Colorado River System and Source, Civil No. CV 6417 [Supreme Court, Apache County]).

A negotiated settlement would resolve tribal water rights and many other issues. Water sources of interest in the adjudication and/or the associated negotiations have included the C Aquifer, N Aquifer, the LCR and its major tributaries, and Colorado River water diverted from Lake Powell. Negotiations include the

Navajo Tribe assertion that the United States trust obligation to the Tribe was breached by the failure to consider Navajo rights to Colorado River water.

2.3 Water Demands

2.3.1 Description of Groundwater and Surface Water Demand

NCAWSFS water demands are based on an analysis of demands that was completed during the NCAWSS Appraisal Study and reported in detail in the 2006 *Report of Findings*. Those results are presented here and in Figure 3 and include any updates to the demand values that were used in the steady state hydraulic modeling that was completed for this Study (Appendix C).

In 2000, total water use in the Study Area was estimated to be about 5.84 billion gallons, or 17,930 AFY including potable and non-potable use (RMI, 2002). The figure does not include demands for small communities that haul water from standpipes or for communities where data were not available. Some of this estimated demand is met from surface water resources, particularly for the cities of Flagstaff and Williams, so the estimated demands on the C Aquifer would be reduced by the amount of demands that are met from surface water resources.

Estimates for the total demand on the C Aquifer in the year 2000 were on the order of 140,000 AFY and were growing by 3 to 4 percent per year (Hart, et al., 2002). Estimates performed as part of the HWNSS (HDR, 2004) indicated that demand projections in the year 2100 for the entire area underlain by the C Aquifer would be around 310,000 AFY, or roughly twice the average annual recharge to the C Aquifer, indicating that the C Aquifer would only be able to meet half of the area's demands, at best, without mining of the aquifer storage.

Modeling showed groundwater pumping results to have significant impacts on the C Aquifer east of the NCAWSS area and minimal impacts west from and in the vicinity of Cameron because the C Aquifer is unsaturated in this region. Relying on the C Aquifer to meet the needs of the NCAWSS Study Area would require well fields east of Flagstaff and south of Cameron and extensive distribution pipelines.

USGS estimates the storage capacity of the C Aquifer to be about 300 MAF (Hart et al., 2002). Other estimates range from 400 MAF (Cooley et al., 1969; Mann et al., 1986) to one billion AF (Ward, 2002). Although the estimates of the water in storage in the C Aquifer are large, groundwater overdraft of the C Aquifer would have significant impacts on stream baseflows and spring discharges.

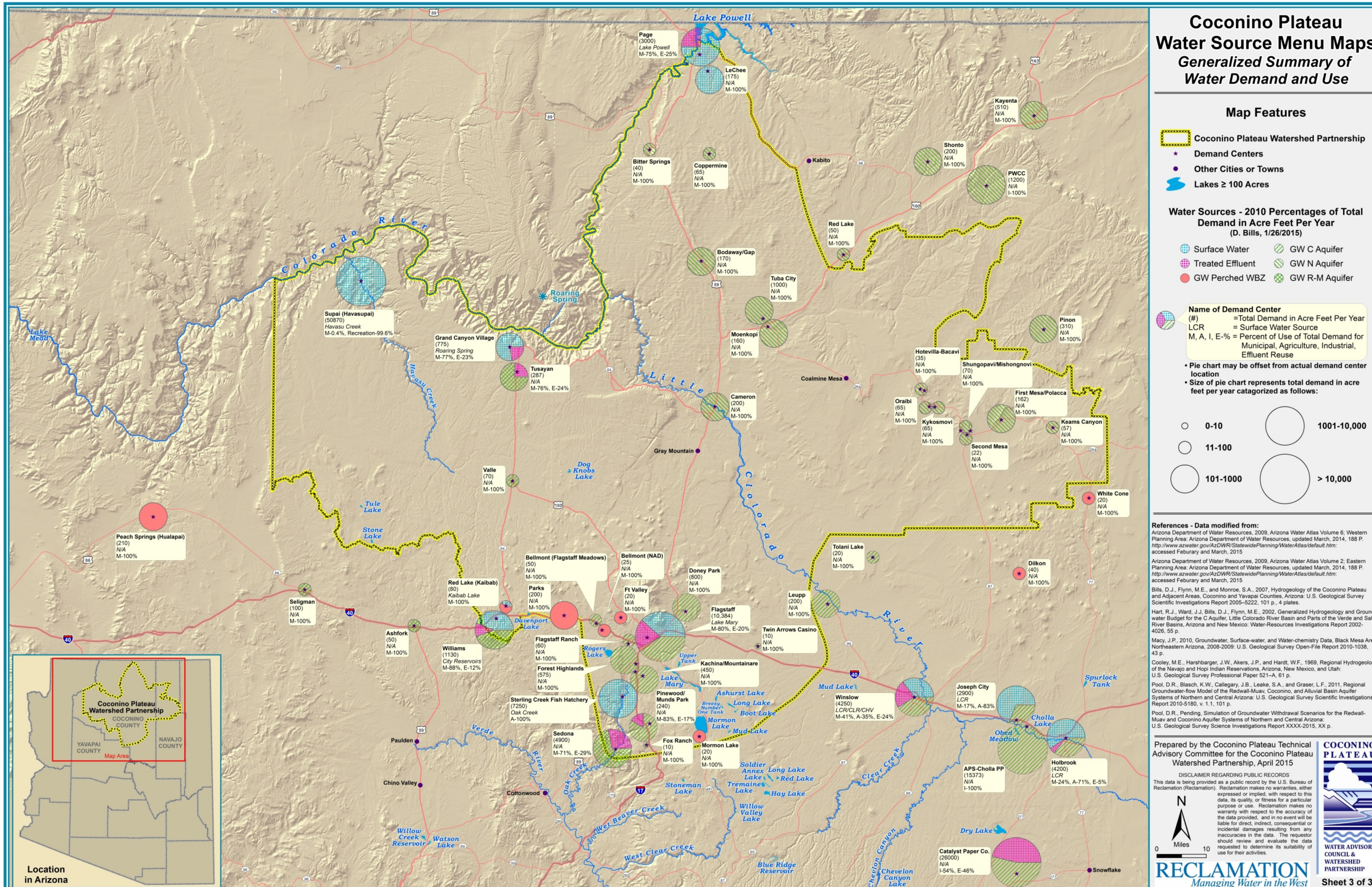

Figure 4: Demand and Use in the Study Area

Table 1 shows the estimated average annual water-budget components for the Coconino Plateau under steady state conditions assumed to be present before 1975, with the C Aquifer and the R-M Aquifer assumed to be in a state of dynamic equilibrium.

Table 1: Coconino Plateau water budget

Factor	Total in AFY
Total precipitation	8,700,000
Inflows - Natural recharge to the regional groundwater	300,000
Underflow from the east	7,000
Total inflow	307,000
Outflows - Groundwater discharge	300,000
Evapotranspiration from groundwater flow systems	7,000
Runoff from the watershed	200,000
Estimated evaporation from the watershed	8,200,000

Source: Reclamation, 2006

Several alternative alignments and water sources were presented in the 2006 *Report of Findings*. The North Central Arizona Pipeline (NCAP) described in this interim report is composed of one preferred alternative with one distinct, direct water source diversion site: Glen Canyon Dam reservoir (Lake Powell). An analysis of potential intake locations recommends an intake at the Navajo Generating Station, near Page, Arizona (DOWL, 2016). The project would serve the Navajo Chapters of LeChee, Coppermine, Bodaway-Gap, Tuba City, Cameron, Coalmine Canyon and the towns of Bitter Springs, Cedar Ridge and Gray Mountain; the Hopi communities of Moenkopi, Hotevilla, Bacavi, Old Oraibi, Kykotsmovi; and Hopi villages at First, Second, and Third Mesas.

2.3.2 Approach to Water Demand Analysis

A reliable supply of high quality potable water for north central Arizona has been the subject of previous studies. Studies of potential regional water systems have considered several water sources and/or intake locations. Therefore, so as not to lose sight of past study data related to projected populations, water demands and flows, and in order to anticipate readily adding or removing participant delivery points that would be accounted for in the hydraulic analysis of the pipeline system, results are summarized and presented here for entities identified in the NCAWSS *Report of Findings* and for others who considered becoming a NCAWSFS cost-share partner. These entities may not be part of the identified list of NCAP partners, as the number of NCAP partners changed over time due to the uncertainty of federal funding, the economic recession, a lack of cost-share funds, and looming short-term water supply issues.

As a result of budget constraints and sunset of the Rural Water Supply Program authorization on September 30, 2016, Reclamation is summarizing work-to-date in this interim report and will not proceed further with the Study. If partners choose to proceed with the Study and interest in NCAP expands, potential future participants would need to rerun the hydraulic analysis to include their water demands. The NCAP hydraulic analysis presented in this interim report only includes demands for the Navajo Nation, the Hopi Tribe, and the City of Page.

The conveyance system would be sized to deliver adequate volumes of water during periods of maximum use, and designed using estimated unmet maximum day demand based on NCAP participant delivery locations for a 2050 demand year. Flow values would need to be verified prior to final design based on confirmed NCAP participants.

The projected population and water demands from the *2006 North Central Arizona Water Supply Study Report of Findings* (ROF) (Reclamation, 2006) were initially used for this report. Table 2 provides a list of NCAP participants as of 2013.

Table 2: NCAP Participants in 2013

Tribal	Non-Tribal
Navajo Nation	Page
Coppermine	Grand Canyon National Park
LeChee	Tusayan
Bodaway-Gap*	Flagstaff
Tuba City	Doney Park/Timberline
Cameron**	Fort Valley
Coalmine Canyon	Kachina Village
	Mountainaire
Hopi Tribe	Parks
Moenkopi	
Howell Mesa	
Hotevilla	
Oraibi	
Kykotsmovi	
Shungopavi	
Sipaulovi	
Mishongnovi	
Polacca	
Keams Canyon	

*Includes Bitter Springs and Cedar Ridge.
**Includes Gray Mountain.
Source: Hopi Groundwater Project System Configuration, DOWL HKM, 2012

2.3.3 Tribal Population Projections

Tribal population data and projections from the 2006 ROF (Reclamation, 2006) were supplemented for additional tribal places using information from the *Western-Navajo Hopi Water Supply Needs, Alternatives, and Impacts Report*, Volume 2, Task 4.1 (HDR, 2004). Tribal population projections are shown below in Table 3. Population data and projections developed in the 2006 ROF that were adjusted for over/under counts were used in this report as this analysis contained a level of detail that was not readily available from 2010 Census Profile maps.

2.3.3.1 Navajo Nation

Population data and projections were obtained for the following Chapter locations in the Navajo Nation: Coppermine, LeChee, Bodaway-Gap (including the communities of Cedar Ridge and Bitter Springs), Tuba City, Cameron (including the community of Gray Mountain), and Coalmine Canyon (Reclamation 2006, HDR 2004).

2.3.3.2 Hopi Tribe

Population data and projections were obtained for the following Hopi Tribe locations: First Mesa - Polacca, First Mesa Village, and Keams Canyon - Hopi High School; Second Mesa - Shungopavi-Cultural Center, Second Mesa Upper Villages, and Second Mesa Lower Villages; Third Mesa - Kykotsmovi-Old Oraibi, Moenkopi, Lower Moenkopi, Bacavi, Hotevilla, Howell Mesa East/West; and other areas such as Side Rock Well, Turquoise (Tawaovi), Spider Mound, and South Oraibi (HDR, 2004).

2.3.3.3 Havasupai Tribe

Population data and projections were available in the 2006 ROF for the Havasupai location of Supai (Reclamation, 2006).

Table 3: Tribal Population Projections

Location	Population						
	2000 Census	2000 Adj. [1]	2010	2020	2030	2040	2050
Navajo Nation							
Coppermine Chapter	673	726	823	942	1,093	1,286	1,533
LeChee Chapter [2]							16,256
Bodaway-Gap Chapter [3]	1,837	1,982	2,246	2,569	2,982	3,509	4,183
Tuba City Chapter	8,736	9,426	11,155	14,552	18,892	24,436	31,520
Cameron Chapter [4]	1,231	1,328	1,577	2,076	2,713	3,528	4,568
Coalmine Canyon Chapter	374	404	457	523	607	714	852
Hopi Tribe [5]							
First Mesa							
Polacca, First Mesa Villages [6]		1,506	1,777	2,275	2,912	3,728	4,772
Keams Canyon - Hopi High School		547	637	816	1,044	1,337	1,711

Location	Population						
	2000 Census	2000 Adj. [1]	2010	2020	2030	2040	2050
Second Mesa							
Shungopavi-Cultural Center		1,349	1,533	1,735	1,965	2,225	2,519
Second Mesa Upper Villages [7]		720	811	919	1,040	1,178	1,333
Second Mesa Lower Villages [8]		345	385	436	494	559	633
Third Mesa							
Kykotsmovi-Old Oraibi		989	1,119	1,267	1,435	1,625	1,840
Moenkopi		749	889	1,195	1,606	2,158	2,901
Lower Moenkopi			*160*	*237*	*351*	*519*	*768*
Bacavi		300	347	444	568	727	930
Hotevilla		989	1,161	1,487	1,903	2,436	3,118
Howell Mesa East/West			*160*	*237*	*351*	*519*	*768*
Other Areas							
Side Rock Well			*160*	*237*	*351*	*519*	*768*
Turquoise (Tawaovi)			*160*	*237*	*351*	*519*	*768*
Spider Mound			*90*	*133*	*197*	*292*	*432*
South Oraibi			*90*	*133*	*197*	*292*	*432*
Havasupai Tribe							
Supai		650					2,900

[1] 2000 census population adjusted upward by 7.9% which is the average value of the 2000 Census undercount of Native American population in Arizona (Reclamation 2006, HDR 2004).
[2] LeChee Chapter changed to economic growth center per February 15, 2013, letter from Navajo Nation DWR; projected 2050 population revised.
[3] Includes Bitter Springs and Cedar Ridge.
[4] Includes Gray Mountain.
[5] Villages in italics are newer villages that are expected to grow in the future.
[6] Polacca-First Mesa Villages include Polacca, Walpi, Hano, and Sichomovi.
[7] Second Mesa Upper Villages include Mishongnovi, Sipaulovi, Toreva, and Sunlight Mission.
[8] Second Mesa Lower Villages include Lower Mishongnovi, Lower Sipaulovi, and Second Mesa School.

2.3.3.4 Non-Tribal Population

Nontribal population data and projections shown in Table 4 are from the ROF (Reclamation, 2006). As noted in the ROF, data for specific communities were included when such population data were available. Further, the populations of the rural area and smaller communities were not accounted for by incorporated towns and communities in the project area and was considered accounted for in the remainder of the Coconino County census county division (CCD) identified as "Total CCD remainder in study area."

Table 4: Non-Tribal Population Projections

Location	Population					
	2000	2010	2020	2030	2040	2050
Doney Park/Timberline	7,979	9,737	11,734	13,608	15,605	17,831
Fort Valley	660	754	863	964	1068	1,182
Grand Canyon Village	1,460	1,888	2,048	2,214	2,406	2,639
Kachina Village	2,664	2,683	3,120	3,522	3,941	4,397
Mountainaire	1,014	1,046	1,199	1,340	1,486	1,646
Page	9,570	11,128	13,057	14,841	16,714	18,770
Parks	1,137	1,335	1,604	1,898	2,256	2,701
Tusayan	562	819	890	996	1152	1,372
Valle	534	632	726	814	907	1,010
Williams	2,905	3,310	3,601	3,925	4,323	4,826
Flagstaff						
Low	63,107	71,981	81,972	91,529	101,907	113,684
High	59,158	67,024	78,299	91,471	106,859	124,840
Total CCD remainder in study area	4,051	6,026	7,760	9,242	10,674	12,099

Source: 2006 North Central Arizona Water Supply Study *Report of Findings* (Reclamation, 2006)

2.3.4 Projected Demands

2.3.4.1 Tribal Demands

Estimated tribal per capita water use projections are shown in Table 5 (Reclamation 2006, HDR 2004). Due to a lack of infrastructure and the need to haul water to meet present water demands, current tribal water use figures are lower than projected demands.

Table 5: Estimated Rates of Tribal Water Usage

Location	Estimated Rate of Water Use Gallons Per Capita Per Day (gpcd)						
	2000	2000 Adj. [1]	2010	2020	2030	2040	2050
Navajo Nation							
Coppermine Chapter	50	50	78	105	133	160	160
LeChee Chapter[2]							160
Bodaway-Gap Chapter[3]	50	50	78	105	133	160	160
Tuba City Chapter	100	100	130	160	160	160	160
Cameron Chapter[4]	100	100	130	160	160	160	160
Coalmine Canyon Chapter	50	50	78	105	133	160	160
Hopi Tribe[5]							
First Mesa							
Polacca, First Mesa Villages[6]	50	50	115	180	180	180	180
Keams Canyon - Hopi High School	50	50	105	160	160	160	160
Second Mesa							
Shungopavi-Cultural Center	50	50	95	140	140	140	140
Second Mesa Upper Villages[7]	50	50	95	140	140	140	140

Location	Estimated Rate of Water Use Gallons Per Capita Per Day (gpcd)						
	2000	2000 Adj. [1]	2010	2020	2030	2040	2050
Second Mesa Lower Villages[8]	50	50	95	140	140	140	140
Third Mesa							
Kykotsmovi-Old Oraibi	50	50	95	140	140	140	140
Moenkopi	50	50	105	160	160	160	160
Lower Moenkopi	*50*	*50*	*105*	*160*	*160*	*160*	*160*
Bacavi	50	50	105	160	160	160	160
Hotevilla	50	50	105	160	160	160	160
Howell Mesa East/West	*50*	*50*	*105*	*160*	*160*	*160*	*160*
Other Areas							
Side Rock Well	*50*	*50*	*105*	*160*	*160*	*160*	*160*
Turquoise (Tawaovi)	*50*	*50*	*105*	*160*	*160*	*160*	*160*
Spider Mound	*50*	*50*	*105*	*160*	*160*	*160*	*160*
South Oraibi	*50*	*50*	*105*	*160*	*160*	*160*	*160*
Havasupai Tribe							
Supai							160

[1] 2000 census population adjusted upward by 7.9% which is the average value of the 2000 Census undercount of Native American population in Arizona (Reclamation 2006, HDR 2004).
[2] LeChee Chapter changed to economic growth center per February 15, 2013, letter from Navajo Nation DWR; projected 2050 population revised.
[3] Includes Bitter Springs and Cedar Ridge.
[4] Includes Gray Mountain.
[5] Villages in italics are newer villages that are expected to grow in the future.
[6] Polacca-First Mesa Villages include Polacca, Walpi, Hano, and Sichomovi.
[7] Second Mesa Upper Villages include Mishongnovi, Sipaulovi, Toreva, and Sunlight Mission.
[8] Second Mesa Lower Villages include Lower Mishongnovi, Lower Sipaulovi, and Second Mesa School.

Estimated annual tribal water demands shown in Table 6 were calculated for each location by multiplying estimated projected population (Table 3) by estimated per capita use rate (Table 5). Estimated annual million gallons per year (MGY) was calculated as: (population) (estimated rate of water use (gpcd)) (365/1,000,000). The estimated AFY was calculated as: (MGY) (1,000,000) (0.134 cubic feet/gallon) (1 acre/43,560 square feet).

Table 6: Estimated Annual Tribal Water Demand

Location	Estimated Annual Water Demand							
	Unit	2000	2000 Adj. [1]	2010	2020	2030	2040	2050
Navajo Nation								
Coppermine Chapter	MGY	12	13	23	36	53	75	90
	AFY	38	41	72	111	163	231	275
LeChee Chapter[2]	MGY							
	AFY							2,920
Bodaway-Gap Chapter[3]	MGY	34	36	64	98	144	205	244
	AFY	103	111	195	303	444	630	751
Tuba City Chapter	MGY	319	344	529	850	1,103	1,427	1,841
	AFY	981	1,058	1,628	2,614	3,394	4,390	5,663

Location	Estimated Annual Water Demand							
	Unit	**2000**	**2000 Adj.** [1]	**2010**	**2020**	**2030**	**2040**	**2050**
Cameron Chapter[4]	MGY	45	48	75	121	158	206	267
	AFY	138	149	230	373	487	634	821
Coalmine Canyon Chapter	MGY	7	7	13	20	29	42	50
	AFY	21	23	40	62	90	128	153
Hopi Tribe[5]								
First Mesa								
Polacca, First Mesa Villages[6]	MGY		27	75	149	191	245	314
	AFY		85	230	460	589	753	965
Keams Canyon - Hopi High School	MGY		10	24	48	61	78	100
	AFY		31	75	147	188	240	307
Second Mesa								
Shungopavi-Cultural Center	MGY		25	53	89	100	114	129
	AFY		76	163	273	309	350	396
Second Mesa Upper Villages[7]	MGY		13	28	47	53	60	68
	AFY		40	87	144	163	185	210
Second Mesa Lower Villages[8]	MGY		6	13	22	25	29	32
	AFY		19	41	69	78	88	99
Third Mesa								
Kykotsmovi-Old Oraibi	MGY		18	39	65	73	83	94
	AFY		56	119	199	226	255	289
Moenkopi	MGY		14	34	70	94	126	169
	AFY		42	105	215	289	388	521
Lower Moenkopi	*MGY*			*6*	*14*	*20*	*30*	*45*
	AFY			*19*	*43*	*63*	*93*	*138*
Bacavi	MGY		5	13	26	33	42	54
	AFY		17	41	80	102	131	167
Hotevilla	MGY		18	45	87	111	142	182
	AFY		56	137	267	342	438	560
Howell Mesa East/West	*MGY*			*6*	*14*	*20*	*30*	*45*
	AFY			*19*	*43*	*63*	*93*	*138*
Other Areas								
Side Rock Well	*MGY*			*6*	*14*	*20*	*30*	*45*
	AFY			*19*	*43*	*63*	*93*	*138*
Turquoise (Tawaovi)	*MGY*			*6*	*14*	*20*	*30*	*45*
	AFY			*19*	*43*	*63*	*93*	*138*
Spider Mound	*MGY*			*3*	*8*	*12*	*17*	*25*
	AFY			*11*	*24*	*35*	*52*	*78*
South Oraibi	*MGY*			*3*	*8*	*12*	*17*	*25*
	AFY			*11*	*24*	*35*	*52*	*78*
Havasupai Tribe								
Supai	MGY							169
	AFY							521

[1] 2000 census population adjusted upward by 7.9% which is the average value of the 2000 Census undercount of Native American population in Arizona (Reclamation 2006, HDR 2004).
[2] LeChee Chapter changed to economic growth center per February 15, 2013, letter from Navajo Nation DWR; projected 2050 population revised.
[3] Includes Bitter Springs and Cedar Ridge.
[4] Includes Gray Mountain.
[5] Villages in italics are newer villages that are expected to grow in the future.
[6] Polacca-First Mesa Villages include Polacca, Walpi, Hano, and Sichomovi.
[7] Second Mesa Upper Villages include Mishongnovi, Sipaulovi, Toreva, and Sunlight Mission.
[8] Second Mesa Lower Villages include Lower Mishongnovi, Lower Sipaulovi, and Second Mesa School.

Estimated unmet tribal demand was the same as the estimated annual tribal demand for each of the out years since the current water supply sources (groundwater) are unsustainable (Reclamation, 2006). This analysis used a daily peaking factor of 2.0 for preliminary design purposes, the same as used in the 2006 ROF. The maximum day flow is typically 2.0 times greater than the average annual demand (peaking factor of 2). The peaking factor may be adjusted if the design is advanced and additional storage is included. Annual Unmet Peak Demand (AF) was calculated as (Annual Unmet Demand (AF)) (Daily Peaking Factor). Maximum Day Unmet Demand (mgd) was calculated as: (Annual Unmet Demand AFY) (43,560 cubic feet per AF)(7.48 gallons per cubic foot) / (365 days per year) / (million gal/1,000,000 gal) (2.0 peaking factor). Estimated tribal unmet annual, peak, and maximum day demands are provided in Table 7.

Table 7: Estimated Tribal Unmet Annual, Peak and Maximum Day Demand

Location	Estimated Annual Unmet Demand (AF)				Daily Peaking Factor	Estimated Annual Unmet Peak Demand (AF)	Estimated Unmet Maximum Day Demand (mgd)
	2020	2030	2040	2050	-	2050	2050
Navajo Nation							
Coppermine Chapter	111	163	231	275	2.0	551	0.492
LeChee Chapter[2]				2,920	2.0	5,841	5.214
Bodaway-Gap Chapter[3]	303	444	630	751	2.0	1,503	1.342
Tuba City Chapter	2,614	3,394	4,390	5,663	2.0	11,325	10.110
Cameron Chapter[4]	373	487	634	821	2.0	1,641	1.465
Coalmine Canyon Chapter	62	90	128	153	2.0	306	0.273
Hopi Tribe[5]							
First Mesa							
Polacca, First Mesa Villages[6]	460	589	753	965	2.0	1,929	1.722
Keams Canyon - Hopi High School	147	188	240	307	2.0	615	0.549
Second Mesa							
Shungopavi-Cultural Center	273	309	350	396	2.0	792	0.707
Second Mesa Upper Villages[7]	144	163	185	210	2.0	419	0.374
Second Mesa Lower Villages[8]	69	78	88	99	2.0	199	0.178
Third Mesa							

Location	Estimated Annual Unmet Demand (AF)				Daily Peaking Factor	Estimated Annual Unmet Peak Demand (AF)	Estimated Unmet Maximum Day Demand (mgd)
	2020	2030	2040	2050	-	2050	2050
Kykotsmovi-Old Oraibi	199	226	255	289	2.0	578	0.516
Moenkopi	215	289	388	521	2.0	1,042	0.930
Lower Moenkopi	*43*	*63*	*93*	*138*	*2.0*	*276*	*0.246*
Bacavi	80	102	131	167	2.0	334	0.298
Hotevilla	267	342	438	560	2.0	1,120	1.000
Howell Mesa East/West	*43*	*63*	*93*	*138*	*2.0*	*276*	*0.246*
Other Areas							
Side Rock Well	*43*	*63*	*93*	*138*	*2.0*	*276*	*0.246*
Turquoise (Tawaovi)	*43*	*63*	*93*	*138*	*2.0*	*276*	*0.246*
Spider Mound	*24*	*35*	*52*	*78*	*2.0*	*155*	*0.139*
South Oraibi	*24*	*35*	*52*	*78*	*2.0*	*155*	*0.139*
Havasupai Tribe							
Supai				521	2.0	1,042	0.930

[1] 2000 census population adjusted upward by 7.9% which is the average value of the 2000 Census undercount of Native American population in Arizona (Reclamation 2006, HDR 2004).
[2] LeChee Chapter changed to economic growth center per February 15, 2013, letter from Navajo Nation DWR; projected 2050 population revised.
[3] Includes Bitter Springs and Cedar Ridge.
[4] Includes Gray Mountain.
[5] Villages in italics are newer villages that are expected to grow in the future.
[6] Polacca-First Mesa Villages include Polacca, Walpi, Hano, and Sichomovi.
[7] Second Mesa Upper Villages include Mishongnovi, Sipaulovi, Toreva, and Sunlight Mission.
[8] Second Mesa Lower Villages include Lower Mishongnovi, Lower Sipaulovi, and Second Mesa School.

The Hopi Tribe provided revised annual demand figures based on the Hopi Groundwater Project System Configuration map prepared by DOWL HKM in 2012. The revised demand figures (Table 8) replace those in the 2006 ROF.

Table 8: Hopi Tribe 2050 Annual Demand

Location	Demand (AF)	Demand (mgd)[1]
Moenkopi	1,178	1.57
Hotevilla/Bacavi	654	0.87
Kykotsmovi	693	0.93
Second Mesa	921	1.23
First Mesa	923	1.23
Keams Canyon	215	0.29
Howell Mesa	123	0.16

[1/] Peaking factor 1.5
Source: Hopi Groundwater Project System Configuration, DOWL HKM, 2012

2.3.4.2 Non-Tribal Demands

Nontribal per capita water use projections for this analysis are from the ROF (Reclamation, 2006) and shown in Table 9. According to the ROF, 132 gpcd was Flagstaff use rate in 2002 while 120 gpcd was estimated for 2005; thus, two rates are shown in Table 9 for Flagstaff.

Table 9: Estimated Rates of Non-Tribal Water Usage

Location	Estimated Rate of Water Use Gallons Per Capita Per Day (gpcd)					
	2000	2010	2020	2030	2040	2050
Doney Park/Timberline	88	88	88	88	88	88
Fort Valley	162	162	162	162	162	162
Grand Canyon Village	366					
Kachina Village	81	81	81	81	81	81
Mountainaire	73	73	73	73	73	73
Page	351					326
Parks	162	162	162	162	162	162
Tusayan	276	276	276	276	276	276
Valle	162	162	162	162	162	162
Williams	198	198	198	198	198	198
Flagstaff						
2002	132	132	132	132	132	132
2005	120	120	120	120	120	120
Total CCD remainder in study area	50					120

Source: 2006 North Central Arizona Water Supply Study *Report of Findings* (Reclamation, 2006)

Estimated annual nontribal water demands shown in Table 10 were calculated for each location by multiplying estimated projected population (Table 4) by estimated per capita use rate (Table 9). Estimated annual million gallons per year (MGY) was calculated as: (population) (estimated rate of water use (gpcd)) (365/1,000,000). The estimated AFY was calculated as: (MGY) (1,000,000) (0.134 cubic feet/gallon) (1 acre/43,560 square feet). As in the 2006 ROF, the estimated demand for “Total CCD remainder in study area” was distributed across three areas as follows: communities surrounding Flagstaff - 25 percent; Flagstaff to Williams - 25 percent; and Williams to Tusayan - 50 percent.

Table 10: Estimated Annual Non-Tribal Water Demands

Location	Annual Water Demand						
	Unit	2000	2010	2020	2030	2040	2050
Doney Park/Timberline	MGY	256	313	377	437	501	573
	AFY	787	960	1,157	1,342	1,539	1,758

Location	Annual Water Demand						
	Unit	2000	2010	2020	2030	2040	2050
Fort Valley	MGY	39	45	51	57	63	70
	AFY	120	137	157	175	194	215
Grand Canyon Village	MGY	195					256
	AFY	599					786
Kachina Village	MGY	79	79	92	104	117	130
	AFY	242	244	283	320	358	399
Mountainaire	MGY	27	28	32	36	40	44
	AFY	83	86	98	110	122	135
Page	MGY	1,226					2,233
	AFY	3,764					6,857
Parks	MGY	67	79	95	112	133	160
	AFY	206	242	291	345	410	490
Tusayan	MGY	57	83	90	100	116	138
	AFY	174	253	275	308	356	424
Valle	MGY	32	37	43	48	54	60
	AFY	97	115	132	148	165	183
Williams	MGY	210	239	260	284	312	349
	AFY	645	734	799	871	959	1,071
Flagstaff							
Population Projection-Low-132 gpcd	MGY	3,040	3,468	3,949	4,410	4,910	5,477
	AFY	9,334	10,647	12,125	13,538	15,073	16,815
Population Projection-Low-120 gpcd	MGY	2,764	3,153	3,590	4,009	4,464	4,979
	AFY	8,486	9,679	11,022	12,308	13,703	15,287
Population Projection-High-132 gpcd	MGY	2,850	3,229	3,772	4,407	5,148	6,015
	AFY	8,750	9,914	11,581	13,530	15,806	18,465
Population Projection-High-120 gpcd	MGY	2,591	2,936	3,429	4,006	4,680	5,468
	AFY	7,955	9,012	10,529	12,300	14,369	16,787
Total CCD remainder in study area	MGY	74					530
	AFY	227					1,627
Surrounding Flagstaff (25%)	MGY	18					132
	AFY	57					407
Flagstaff to Williams (25%)	MGY	18					132
	AFY	57					407
Williams to Tusayan (50%)	MGY	37					265
	AFY	113					813

As in the 2006 ROF, this analysis estimated nontribal unmet demand was the incremental difference between 2000 demand and demand for each of the out years, excepted as noted here and shown in Table 11 for Flagstaff, Grand Canyon

Village, and Tusayan. For the 2006 ROF, the City of Flagstaff determined the appropriate unmet demand should be 8,027 AFY. For this analysis, the City of Flagstaff, in a letter dated March 15, 2013, stated that, "Flagstaff would require 12,000 acre-feet annually from the Western Navajo Pipeline 7 months of the year (April through October), or a maximum of 1,714 AF per month (12,928 gpm maximum flow for a 30-day month)." Unmet demands were specified in the 2006 ROF for Grand Canyon Village and Tusayan as 790 AFY and 425 AFY, respectively, because of suspected adverse impacts associated with pumping of the Tusayan R-M Aquifer wells on Grand Canyon springs and maintenance problems with the water supply system for the south rim of the Grand Canyon.

It should be noted that the Flagstaff City Council voted on July 8, 2014 to not fund the NCAWSFS until additional federal funds became available. Flagstaff continued to be involved with the Study as they proceeded with their own work on the proposed Red Gap Ranch well field. Coconino County was ambivalent about their partnership, but continued to participate in the NCAWSFS. As a result of Flagstaff's decision to no longer cost-share in the NCAWSFS, Reclamation excluded the area from Gray Mountain to the City of Flagstaff from the NCAP planning. Additionally, in a letter from the National Park Service dated January 9, 2014, Reclamation was officially informed that GCNP would not be participating in the NCAWSFS. Since GCNP was not participating, and as confirmed in a letter dated November 25, 2013, the Town of Tusayan informed Reclamation that that community would not be able to participate. Similarly, since GCNP was not participating, the Havasupai Tribe, which had not entered into or was pursuing a cost-share agreement, also chose not to participate in the NCAWSFS. Nevertheless, data for these locations was made available in case they wanted to be NCAWSFS participants in the future.

This demand analysis used a daily peaking factor of 2.0, the same as used in the 2006 ROF. Annual Unmet Peak Demand (AF) was calculated as (Annual Unmet Demand (AF)) (Daily Peaking Factor). Maximum Day Unmet Demand (mgd) was calculated as: (Annual Unmet Demand AFY) (43,560 cubic feet per AF) (7.48 gallons per cubic foot) / (365 days per year) / (1 million gal/1,000,000 gal) (2.0 peaking factor). However, since the demand for Flagstaff was for 7 months, the Maximum Day Unmet Demand (mgd) was calculated as: (Annual Unmet Demand AFY) (43,560 cubic feet per AF) (7.48 gallons per cubic foot) / (124 days per year) / (1 million gal/1,000,000 gal) (2.0 peaking factor). Estimated unmet nontribal annual, peak, and maximum day demands are in Table 11.

Table 11: Estimated Non-Tribal Unmet Annual, Peak and Maximum Day Demand

Location	Estimated Annual Unmet Demand (AF)				Daily Peaking Factor	Estimated Annual Unmet Peak Demand (AF)	Estimated Maximum Day Unmet Demand (mgd)
	2020	2030	2040	2050	-	2050	2050
Doney Park/Timberline	370	555	752	971	2.0	1,943	3.139
Fort Valley	37	55	74	95	2.0	190	0.383
Grand Canyon Village				790	2.0	1,580	1.403
Kachina Village	41	78	116	157	2.0	315	0.713
Mountainaire	15	27	39	52	2.0	103	0.240
Page				3,093	2.0	6,185	12.242
Parks	85	138	203	284	2.0	568	0.875
Tusayan	101	134	182	425	2.0	850	0.758
Valle	35	51	68	86	2.0	173	0.327
Williams	154	226	315	426	2.0	852	1.912
Flagstaff							
Population Projection-Low-132 gpcd				8,027	2.0	16,054	30.021
Population Projection-Low-120 gpcd				8,027	2.0	16,054	27.292
Population Projection-High-132 gpcd				8,027	2.0	16,054	32.967
Population Projection-High-120 gpcd				8,027	2.0	16,054	29.970
Demand from Flagstaff 2013 Letter				12,000	2.0	24,000	21.424
Total CCD remainder in study area				1,400	2.0	2,800	2.905
Surrounding Flagstaff (25%)				350	2.0	700	0.726
Flagstaff to Williams (25%)				350	2.0	700	0.726
Williams to Tusayan (50%)				700	2.0	1,400	1.452

2.3.5 NCAWSFS Participant Demands

Participant demands, with peaking factors, for each turnout are shown in Table 12.

Table 12: NCAWSFS Participant Demands

	TURNOUTS				EXISTING TANKS [2]			DEMAND AT TURNOUT [3]	DEMAND AT TURNOUT	
	AZ STATE PLANE		GRD		AZ STATE PLANE		GRD	(AFY)	(cfs)	
NAME	NORTHERN	EASTERN	ELEV	STATION [1]	NORTHERN	EASTERN	ELEV	(with Peaking Factor)	(with Peaking Factor)	REMARKS
MAIN TRUNK - INTAKE TO LECHEE - EAST ALTERNATIVE										
Page (east)	2145313.99	838929.94	4273	363+00	2150295.33	835615.56	4388	6,185	8.54	
LeChee (east)	2131271.17	838221.00	4752	513+50	2131038.40	839009.68	4810	5,841	8.07	
MAIN TRUNK - INTAKE TO LECHEE -WEST ALTERNATIVE										
Page (west)	2150541.81	827211.74	4076	148+27.9650	2150295.33	835615.56	4388	6,185	8.54	
LeChee (west)	2131001.82	837965.27	4750	394+00	2131038.40	839009.68	4810	5,841	8.07	
MAIN TRUNK - LECHEE TO BODAWAY/GAP										
Copper Mine	2019444.00	849944.45	5942	2156+00	2020712.44	853384.06	6130	551	0.76	
Bodaway/Gap	1929796.60	839809.58	5485	3076+00	1929183.97	840326.77	5473	1,003	1.39	The demand for Bodaway/Gap shown in Table 3-6 is 1,503 AFY which includes Bitter Springs. To calculate a demand for Bodaway/Gap independently, the 500 AFY demand for Bitter Springs presented in the DOWL HKM report dated 10/20/2008 was subtracted.
MAIN TRUNK - BODAWAY/ GAP TO GRAY MOUNTAIN										
Cameron	1764029.24	843846.55	4447	4937+00	1765077.42	841457.55	4531	1,590	2.20	The demand for Cameron shown in Table 3-6 is 1,641 AFY which includes Gray Mountain. The demand for Gray Mountain was calculated and then subtracted from the combined demand.
Gray Mountain	1731249.09	833192.39	4940	5288+19.13	1735100.97	824554.84	4929	51	0.07	The demand was calculated by multiplying the population of Gray Mountain in 2010 (41 people) by a population growth factor of 3.44 (same used for Cameron) to calculate an estimated 2050 population for Gray Mountain of 141. The estimated annual million gallons per year (MGY) was calculated as: (population: 141) (est. rate of water use: 160 gpcd) (365/1,000,000) = 8.23 MGY. The estimated acre feet per year was calculated as: (8.23 MGY) (1,000,000) (0.134 cubic feet/gallon) (1 acre/43,560 square feet) = 25.3 AFY. 25.3 AFY multiplied by a Peaking Factor of 2 = 50.6 AFY. This area has been proposed as a growth area so for the purposes of the hydraulic analysis, the demand was increased to 78 AFY.
BITTER SPRINGS SPUR - BODAWAY/ GAP TO BITTER SPRINGS										
Cedar Ridge	1961789.02	815677.13	5923	388+00	1963434.14	818504.24	6058	220	0.30	Demand calculated from pipe diameter shown in DOWL HKM report.
Bitter Springs	2051096.94	778521.58	5134	1398+68.17	2050888.76	781992.28	5270	500	0.69	Demand data from DOWL HKM dated 10/20/2008.
TUBA CITY SEGMENT - US 89/MOENAVE TO TUBA CITY										
Tuba City	1877077.75	902499.47	5132	625+07.4584	1875283.28	901344.14	5120	11,325	15.64	
HOPI SEGMENT - TUBA CITY TO KEAMS CANYON										
Moenkopi	1864993.27	909810.36	4839	170+00	1862859.68	905196.87	4917	1,318	1.82	Demand includes Moenkopi and Lower Moenkopi shown in Table 3-6.
Coal Mine	1818783.75	964425.46	5910	1019+00	1818232.30	964125.99	5970	306	0.42	
Howell Mesa	1812220.62	1039997.36	5727	2076+00	1812269.52	1039986.92	5727	276	0.38	
Hotevilla	1791191.91	1071368.08	6350	2558+00	1790145.09	1070108.49	6430	1,454	2.01	Includes demands for Hotevilla and Bacavi.
Oraibi Spur	1791190.55	1071369.55	6350	2558+02	1776538.95	1078062.15	6062	78	0.11	Table 3-6 shows a combined demand for Kykotsmovi and Old Oraibi, but there will be turnouts for each community. The demands shown were apportioned from the combined demand of 578.
Kykotsmovi	1781562.45	1089529.11	5660	2783+00	1776907.08	1083646.03	5775	500	0.69	
Shungopavi	1764453.81	1111644.92	6305	3116+00	1756206.33	1110305.52	6352	792	1.09	
Sipaulovi Top	1752849.91	1121403.12	6187	3274+00	1752489.51	1121066.60	6295	369	0.51	Table 3-6 indicates that the demand of 419 AFY includes Mishongnovi, Sipaulovi, Toreva, and Sunlight Mission. Demand was apportioned between Sipaulovi Top (369 AFY) and Mishongnovi (Ned L.) (50 AFY) turnouts.
Mishongnovi (Ned L).	1750863.68	1121450.03	5977	3312+25	1750778.16	1121494.05	5978	50	0.07	
Sipaulovi Lower	1747096.63	1120897.25	5737	3387+00	1748042.79	1121130.61	5793	199	0.27	
Polacca West	1755783.95	1150051.00	5623	3699+00	1759883.16	1147298.27	5825	729	1.01	Two turnouts are designated for the First Mesa area, but only one demand is shown in Table 3-6. The demand of 1,929 AFY was split between Polacca East and Polacca West turnouts.
Polacca East	1760477.94	1154943.06	5671	3770+00	1765786.33	1154610.25	5986	1,200	1.66	
Keams Canyon	1755208.01	1211913.77	6408	4426+96.70	1755208.01	1211913.77	6408	615	0.85	

[1] Stationing shown is based on stationing along each segment.

[2] Tank locations given for Howell Mesa and Oraibi are assumed. There are presently no existing tanks at those locations.

[3] Demands were taken from Table 3-6 of the North Central Arizona Water Supply Feasibility Study (NCAWSFS) Design Report-Draft dated 1/15/14 unless otherwise noted.

3.0 Infrastructure Components and Engineering Activities

3.1 General Engineering Activities

This interim report provides the results of engineering activities that were completed during this Feasibility Study. The following is a summary of completed components and associated appendices:

- Analysis and selection of most cost effective pipeline alignment.
- Development of survey control throughout the Study Area.
- Aerial mapping of the pipeline alignment to produce 2-foot contour intervals for plan-and-profile drawings (Appendix A). (Moenkopi to Keams Canyon remains to be mapped.)
- Plan-and-profile drawings for all mapped sections (Appendix B).
- Demand flow and turnout locations.
- Steady state hydraulics and pump analysis (Appendix C).
- Hydraulic modeling (Appendix D).
- Value Planning study (Appendix E).
- Scour study at cross-drainages for the main trunk from Page to Flagstaff, including The Gap to Bitter Springs spur and the U.S. Highway 89 Tee to Tuba City spur (Appendix F).
- Initial geologic mapping and field investigations (Appendix G).
- Location of pumping plants.
- Ground confirmation of pipeline alignment and pumping plant locations for conflicting field conditions.
- Survey of all road and driveway locations along the main trunk from Page to Gray Mountain, including The Gap to Bitter Springs spur and the U.S. Highway 89 Tee to Tuba City spur.

The following principal study components have not been completed:

- Transient pressure analysis
- Feasibility level geologic investigations
- Pumping plant design
- Pipeline vertical alignment
- Pipeline appurtenances
- Lake Powell intake design
- Water treatment facilities
- Water tanks design: in-line regulating, pumping plant forebay and delivery

- Cathodic protection
- Cost estimating for all study components
- Environmental Impact Statement

3.2 Facility Descriptions

Several alternative alignments and water sources were presented in the 2006 NCAWSS *Report of Findings.* The North Central Arizona Pipeline (NCAP) presented in this Feasibility Study is composed of one preferred alternative with one distinct, direct water source diversion site: Glen Canyon Dam reservoir (Lake Powell) (Reclamation, 2006).

The NCAP project proposed in the NCAWSFS includes features between Lake Powell, south to Gray Mountain, Arizona, including spurs to Bitter Springs, Tuba City, and Keams Canyon to convey filtered surface water to participants (see Figures 5 and 6). It includes the construction of a new pipeline and various appurtenant features such as a reservoir-side pumping plant, booster/re-lift plants, forebay tanks, water storage tanks, air chambers, regulating tanks, pressure reducing valves, valve vaults, and participant delivery vaults within the Study Area in north-central Arizona. Pipeline diameters would range from approximately 54 inches to 4 inches.

The project would serve the towns of Bitter Springs, Cedar Ridge and Gray Mountain, Navajo Nation Indian Reservation Chapters (LeChee, Coppermine, Bodaway-Gap, Tuba City, Cameron and Coalmine Canyon), and Hopi Indian Reservation communities (Moenkopi, Hotevilla, Bacavi, Old Oraibi, Kykotsmovi, Keams Canyon and Hopi villages at First, Second, and Third Mesas). The project would allow participating communities to fully use their water allocations and plan for drought concerns within the Study Area.

This subsection presents a summary of the major facilities for the preferred NCAP alignment that will be examined as part of the process required by NEPA. Potential options for the project were brainstormed, screened against the purpose and need developed during the NEPA public scoping process. Those that did not meet the purpose and need were eliminated from further consideration.

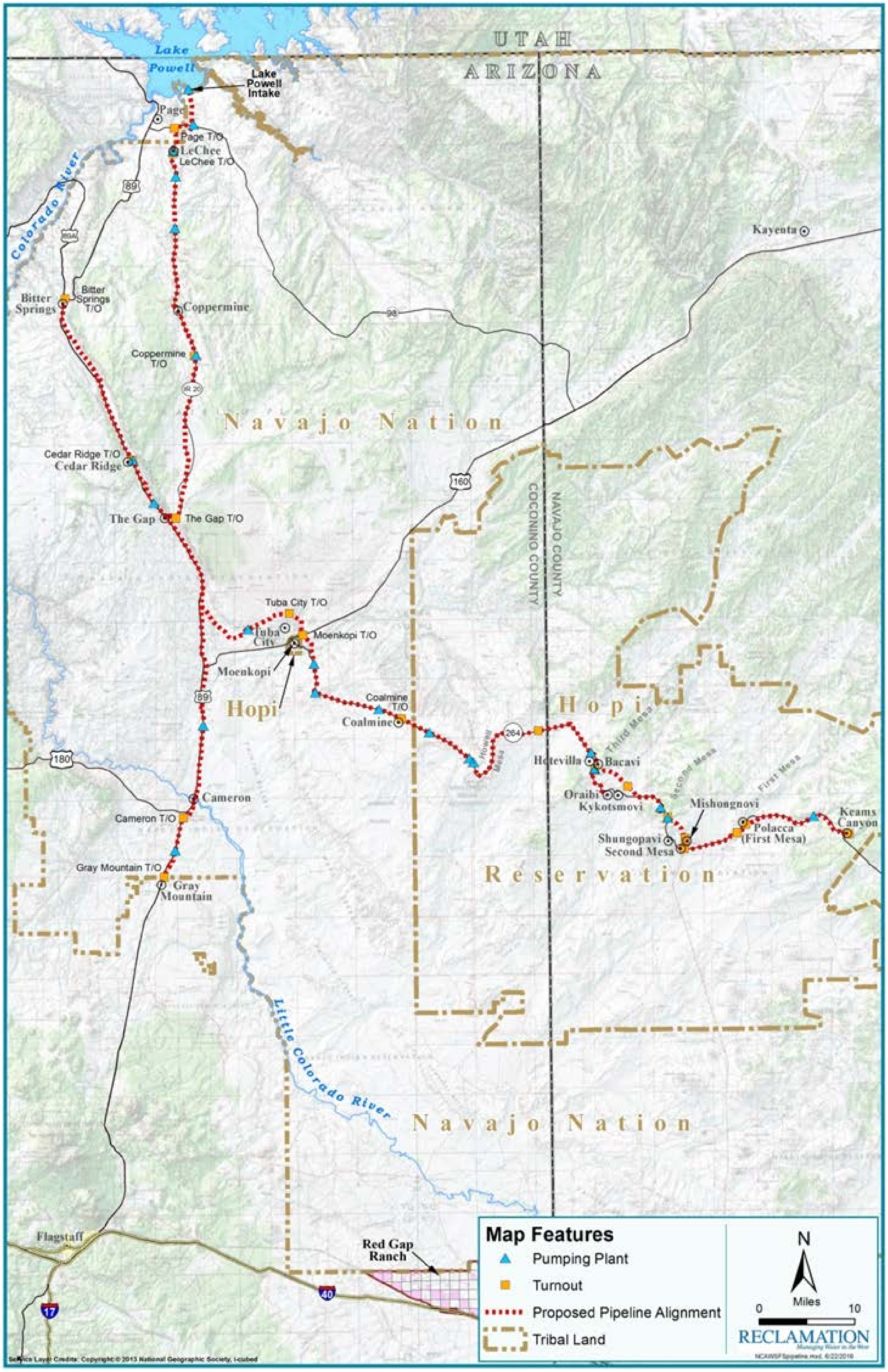

Figure 5: Proposed North Central Arizona Pipeline (NCAP) Features and Alignment

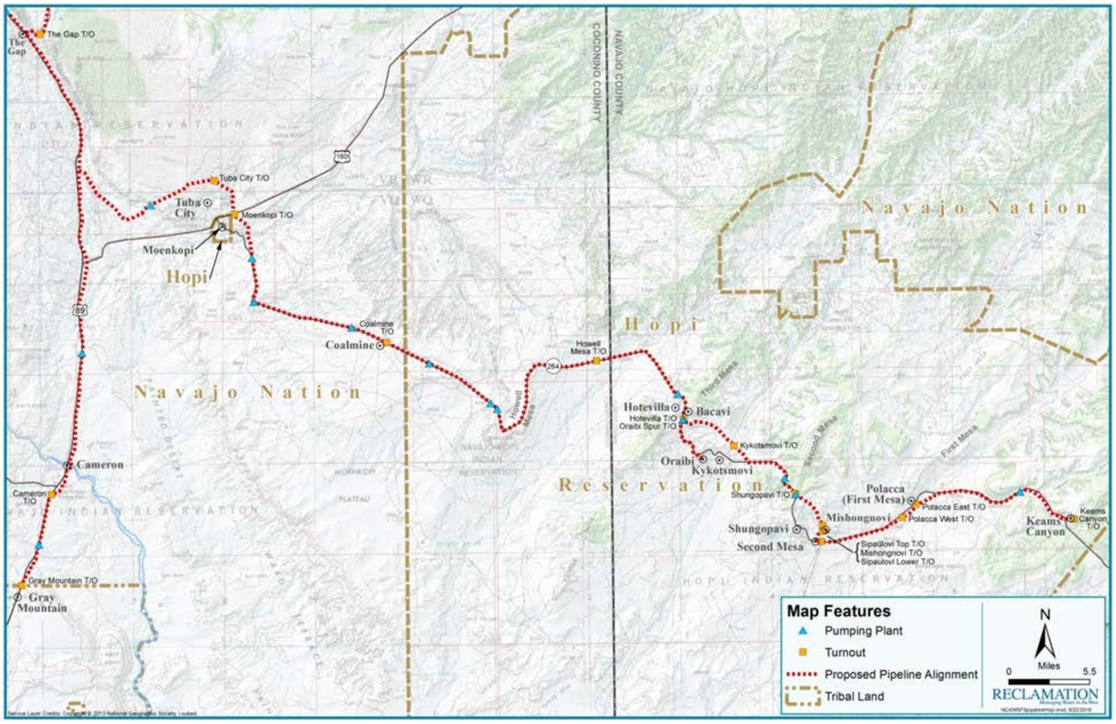

Figure 6: Detail of NCAP Alignment Serving Navajo and Hopi Communities

3.2.1 Regulating Storage

Regulating storage is the location(s) where the project source water and non-project water are stored prior to conveyance to the participants. The water is currently, and will continue to be, stored in Glen Canyon Reservoir.

3.2.2 Conduit Intake

The intake is the location on Lake Powell where source water would enter the NCAP conduit. The intake options are:

- East Intake located west of the Navajo Generating Station pumping plant
- Antelope Creek Intake located west of the mouth of Antelope Creek
- West Intake located in the Chains Area of Glen Canyon National Recreation Area

With a dam crest at elevation 3715, the maximum water surface in Glen Canyon Dam Reservoir (top of active conservation pool) is elevation 3700, the top of inactive pool is at elevation 3490, and the top of dead pool is elevation 3370. The structural height of the dam is 710 feet and the hydraulic height is 583 feet. The ground elevation downstream of the dam at the right abutment near the site of the proposed reservoir-side pumping plant is approximately elevation 3737.

Per the *Glen Canyon Dam Comprehensive Facility (CFR) Review* (Reclamation, 2010), the reservoir level fluctuates based on water supply conditions in the Upper Basin states and on current downstream demand; the addition of the NCAWSFS water demands would affect these existing conditions. As reported in the CFR, the reservoir was filled in 1983, and generally remained within approximately 25 feet of the top of active conservation pool, until declining from 1989 through 1993, and again from 2000 to 2005. The reservoir has been increasing in elevation since 2005 and was at elevation 3620 during the CFR examination in 2010. Additionally, per the CFR, the mean annual temperature for the dam site is 62.5° F, with monthly averages ranging from 35° F in January to 88° F in July.

3.2.3 Conveyance

Conveyance would be required to transport the water from the intake to delivery points, and would include the main conduit and the spurs to NCAP participants. Conveyance would also include any pumping and on-line operational storage, but these are described separately.

3.2.4 Pumping Plants

Pumping plant and booster plants would include forebay tanks, air chambers, and regulating tanks. Air chambers would be located within the plant yards, and regulating tanks would be located within the pipeline alignment. Booster pumping plants are located directly within the pipeline to increase pressure.

Table 13: Location of Pumping Plants

Label	Elev	AZ State Plane	
		Easting	Northing
PMP-1 East Intake	3658	846,559.2	2,166,845.9
PMP-2	4180	849,497.2	2,147,202.4
PMP-3	4709	838,349.2	2,132,636.5
PMP-4	5217	839,637.6	2,118,508.7
PMP-5	5749	839,213.2	2,089,983.0
PMP-6	4353	854,867.6	1,815,040.2
PMP-7	4559	839,290.2	1,745,902.6
PMP-Bitter Springs	5445	827,614.7	1,938,072.6
PMP-Cedar Ridge Turnout Booster	5913	815,838.5	1,961,841.3
PMP-Coppermine Turnout Booster	5944	850,898.3	2,019,751.6
PMP-Hopi 1	5076	879,510.9	1,868,272.4
PMP-Hopi 2	5053	916,046.9	1,849,224.0
PMP-Hopi 3	5484	916,836.2	1,833,328.4
PMP-Hopi 4	5780	951,948.6	1,824,102.1
PMP-Hopi 5	6064	979,855.9	1,811,219.8
PMP-Hopi 6	6106	1,001,957.5	1,796,854.7
PMP-Hopi 7	6233	1,004,296.6	1,794,826.3
PMP-Hopi 8	6004	1,069,266.5	1,800,153.9
PMP-Hopi 9	6036	1,107,745.7	1,769,873.5
PMP-Hopi 10	5964	1,192,364.5	1,765,050.7

Label	Elev	AZ State Plane	
		Easting	Northing
PMP-Hotevilla Booster	6372	1,071,065.5	1,790,868.9
PMP-Oraibi Spur Booster	6364	1,071,251.6	1,791,062.7
PMP-Shungopavi Booster	6308	1,111,744.5	1,764,072.0

3.2.5 On-Line Water Storage Tanks

Water storage tanks would serve three primary purposes: end of pipe delivery tanks, pumping plant forebay tanks, and in-line regulating tanks. The end of pipe delivery tanks have not yet been sized to fully account for demand reliability, fire flow, and holding and cycle times with respect to water quality.

The delivery tanks will be located to provide the desired delivery pressure during maximum day demand. Final delivery pressures have not been determined. When this information is available, tank heights and pipe diameters (directly affecting final costs) may require some design changes to accommodate demand requirements. The type and appearance (e.g., fluted, lattice) of the tanks would need to be coordinated further with the local communities and operating agencies.

The preliminary proposed locations of storage tanks used in this Study are described below in Table 14.

Table 14: Proposed Storage Tank Locations

	Label	Tank Base Elevation (ft)	Maximum Tank Water Elevation (ft)	HGL at Turnout Tee (ft)	X (ft)	Y (ft)	Pumped or Gravity Fed?
End of Pipe (Delivery) Tanks	T-Existing Bitter Springs	5,264.8	5,287.6	5,340.2	781,882.4	2,050,905.6	Gravity
	T-Existing Bodaway Gap	5,473.1	5,492.7	5,602.5	840,347.6	1,929,095.6	Gravity
	T-Existing Cameron	4,531.0	4,551.0	4,584.6	841,457.6	1,765,077.4	Gravity
	T-Existing Cedar Ridge	6,051.5	6,075.1	5,948.7	818,439.4	1,963,387.7	Pumped
	T-Existing Coal Mine	5,969.8	5,998.3	6,156.7	964,106.9	1,818,113.8	Gravity
	T-Existing Copper Mine	6,127.3	6,143.5	6,059.4	853,458.5	2,020,723.0	Pumped
	T-Existing Gray Mountain	4,929.0	4,949.0	N/A end of line	824,554.8	1,735,101.0	Pumped
	T-Existing Hotevilla	6,433.7	6,467.2	6,377.6	1,070,108.5	1,790,145.1	Pumped
	T-Existing Keams Canyon	6,408.0	6,428.0	N/A end of line	1,211,913.8	1,755,208.1	Pumped
	T-Existing Kykotsmovi	5,755.4	5,770.0	6,204.4	1,083,646.0	1,776,907.1	Gravity
	T-Existing LeChee	4,807.8	4,833.5	5,272.9	839,097.0	2,131,005.3	Gravity
	T-Existing Mishongnovi	5,978.1	5,985.3	6,304.7	1,121,494.1	1,750,778.2	Gravity
	T-Existing Moenkopi	4,917.0	4,937.0	5,156.3	905,196.9	1,862,859.7	Gravity
	T-Existing Page	4,377.6	4,419.9	4,743.1	835,702.1	2,150,281.1	Gravity
	T-Existing Polacca East	5,984.5	6,008.2	6,084.7	1,154,610.3	1,765,786.3	Gravity
	T-Existing Polacca West	5,831.6	5,870.3	6,106.0	1,147,298.3	1,759,883.2	Gravity
	T-Existing Shungopavi Water Tower	6,465.3	6,489.0	6,358.0	1,110,305.5	1,756,206.3	Pumped
	T-Existing Sipaulovi Lower	5,788.9	5,812.5	6,281.5	1,121,130.6	1,748,042.8	Gravity
	T-Existing Sipaulovi Top	6,293.3	6,310.8	6,317.4	1,121,066.6	1,752,489.5	Gravity
	T-Existing Tuba City	5,036.3	5,074.1	5,222.5	904,523.9	1,868,810.7	Gravity
	T-Proposed Howell Mesa	5,727.0	5,747.0	6,176.7	1,039,986.9	1,812,269.5	Gravity
	T-Proposed Oraibi	6,062.0	6,082.0	6,377.6	1,078,062.2	1,776,539.0	Gravity
Pump Plant Forebay Tanks	T-Forebay Bitter Springs PmP	5,440.5	5,460.0	N/A, in line	827,722.2	1,937,896.4	Pumped
	T-Forebay Hopi PmP-1	5,077.0	5,101.0	N/A, in line	879,467.6	1,868,244.3	Pumped
	T-Forebay Hopi PmP-2	5,047.4	5,062.0	N/A, in line	916,029.5	1,849,326.9	Gravity
	T-Forebay Hopi PmP-3	5,484.0	5,502.0	N/A, in line	916,818.7	1,833,334.3	Pumped
	T-Forebay Hopi PmP-4	5,776.8	5,798.0	N/A, in line	951,524.6	1,824,151.1	Pumped
	T-Forebay Hopi PmP-5	6,062.7	6,077.0	N/A, in line	979,816.6	1,811,238.2	Pumped
	T-Forebay Hopi PmP-6	6,097.4	6,109.0	N/A, in line	1,001,877.0	1,796,922.3	Pumped
	T-Forebay Hopi PmP-7	6,229.3	6,244.0	N/A, in line	1,004,255.7	1,794,886.0	Pumped
	T-Forebay Hopi PmP-8	6,005.0	6,022.0	N/A, in line	1,069,163.3	1,800,190.2	Gravity
	T-Forebay Hopi PmP-9	6,032.3	6,049.0	N/A, in line	1,107,804.9	1,769,930.2	Gravity
	T-Forebay Hopi PmP-10	5,964.1	5,979.1	N/A, in line	1,192,231.3	1,764,983.4	Gravity
	T-Forebay PmP-2	4,180.0	4,195.0	N/A, in line	849,439.3	2,147,327.0	Pumped
	T-Forebay PmP-3	4,710.0	4,725.0	N/A, in line	838,334.7	2,132,920.4	Pumped
	T-Forebay PmP-4	5,222.0	5,241.0	N/A, in line	839,647.4	2,118,666.5	Pumped
	T-Forebay PmP-5	5,769.9	5,788.0	N/A, in line	839,209.4	2,089,905.6	Pumped
	T-Forebay PmP-6	4,392.6	4,412.0	N/A, in line	855,289.4	1,818,182.0	Gravity
	T-Forebay PmP-7	4,564.0	4,582.0	N/A, in line	839,407.0	1,746,378.9	Pumped
In-Line Regulating Tanks	T-Hopi Reg Tank 1	5,218.0	5,258.0	N/A, in line	890,705.1	1,873,761.4	Pumped
	T-Hopi Reg Tank 2	5,214.9	5,232.0	N/A, in line	897,791.0	1,876,728.0	Gravity
	T-Hopi Reg Tank 3	6,155.0	6,170.0	N/A, in line	990,942.4	1,805,671.7	Pumped
	T-Hopi Reg Tank 4	6,320.0	6,350.0	N/A, in line	1,007,896.2	1,787,598.1	Pumped
	T-Hopi Reg Tank 5	6,307.0	6,335.0	N/A, in line	1,014,721.0	1,798,175.9	Gravity
	T-Hopi Reg Tank 6	6,358.0	6,378.0	N/A, in line	1,071,288.2	1,791,264.8	Pumped
	T-Hopi Reg Tank 7	6,333.0	6,353.0	N/A, in line	1,112,420.1	1,763,757.1	Pumped
	T-Hopi Reg Tank 8	6,317.4	6,329.0	N/A, in line	1,119,875.7	1,755,148.1	Gravity
	T-Reg Tank 1 Bitter Springs Spur	5,925.0	5,950.0	N/A, in line	815,714.3	1,961,696.2	Pumped
	T-Reg Tank 2 Bitter Springs Spur	5,508.0	5,538.0	N/A, in line	792,331.6	2,014,688.7	Gravity
	T-Reg Tank 1	6,109.3	6,135.0	N/A, in line	838,684.4	2,048,067.0	Pumped
	T-Reg Tank 2	5,943.0	5,973.0	N/A, in line	850,544.8	2,014,011.2	Gravity
	T-Reg Tank 3	5,493.0	5,523.0	N/A, in line	839,679.3	1,929,675.1	Gravity
	T-Reg Tank 4	5,153.0	5,178.0	N/A, in line	844,672.8	1,914,947.8	Gravity
	T-Reg Tank 5	4,616.0	4,636.0	N/A, in line	854,620.4	1,864,820.2	Gravity

3.3 Project Alignment

3.3.1 Conduit Route

The conduit routes and facility locations are illustrated on Figures 5 and 6 in Section 3.2 of this report. The maps include the NCAP proposed alignment, pumping plants and turnouts. The precise locations of conduit within the route and locations of the facilities were established during this Study. These features may shift by several hundred feet or more during final design level development and during the land acquisition process. Such shifts frequently occur during project design.

For cost estimating purposes and to easily identify alternative route options, the NCAP was divided into several reaches that extend between major hydraulic features along the route (Table 15).

Table 15: NCAP Reaches

Alignment Stations	Beginning Point	Ending Point
Sta. 10+00 to Sta. 518+62.66	Lake Powell Intake	LeChee
Sta. 10+02 to Sta. 3142+10.58	LeChee	The Gap
Sta. 3142+10.58 to Sta. 5288+19.13	The Gap	Gray Mountain
Sta. 10+00 to Sta. 1398.68.17	The Gap	Bitter Springs
Sta. 10+00 to Sta. 625+07.46	U.S. Hwy 89 Tee	Tuba City
Sta. 10+00 to Sta. 4426+96.70	Tuba City	Keams Canyon

3.3.2 Reach and Spur Descriptions

The easting and northing coordinates of all tanks and pump stations in Arizona State Plane Coordinates are included Appendix C, *Feasibility Design Steady State Hydraulics and Pump Selection Technical Memorandum*, in its appendices. Since the completion of this model, PXAO has ground-truthed the pump site locations and found that 11 of the pump stations and three of the tanks need to be relocated up or downstream slightly in order to accommodate existing utilities, steep slopes, or significant washes. TSC has not evaluated the movement of these pumping plants as part of this Study.

3.4 Aerial Mapping

Photogrammetry is an aerial mapping technology that utilizes multiple overlapping photographs taken of the ground from an aircraft. The photos are processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view) and used with specialized software to create a digital elevation model (DEM). The benefit of aerial photogrammetry is the ability to delineate manmade structures from the natural terrain.

Airborne LiDAR (Light Detection and Ranging) is also an aerial mapping technology, but it uses light in the form of a pulsed laser to measure the distance to the earth's surface. These light pulses, combined with other data collected during the flight, generate a three-dimensional point cloud model of the ground surface.

In order to create topographic contours for use in the plan and profile drawings and the steady state hydraulic analysis, Reclamation contracted for aerial photogrammetry and LiDAR point cloud models of the alignment corridors. Six contracts were awarded from 2011 to 2014 which covered the areas from Page to Flagstaff, Gap to Bitter Springs and Highway 89 to Tuba City. LiDAR data was also obtained from the Bureau of Indian Affairs for a segment of Coppermine Road that was collected using terrestrial LiDAR methods in anticipation of road widening. The alignment from Tuba City to Keams Canyon was not flown and neither aerial photogrammetry nor LiDAR data is available for that portion of the alignment. Table 16 shows the portions of the alignment that have been flown and have aerial data available. Index maps showing the location of the LiDAR point cloud data and aerial photographs are in Appendix A – *Mapping*. All data received from the aerial photogrammetry and LiDAR contracts will be stored at Reclamation's Phoenix Area Office and will be available to partners or other authorized entities.

Table 16: Aerial Photogrammetry and LiDAR Data Available for the NCAWSFS

Alignment Segment	Type of Data	Size (GB)
Lake Powell Intake to LeChee	Aerial photography (4 band, color, ortho-rectified), LiDAR points, Reports, Indexes, Control	478.0
LeChee to The Gap	Aerial photography (1 band, black & white, uncontrolled), LiDAR points, Reports, Indexes, Control from LeChee to north of Coppermine. BIA Terrestrial LiDAR and Topography north of Coppermine to The Gap	43.2
The Gap to Gray Mountain	Aerial photographs (4 band, color, uncontrolled), LiDAR points, Breaklines, Planimetric Features, Reports, Control	683.0
Gray Mountain to Flagstaff	Aerial Photographs (1 band, black & white, controlled and 4 band, color, uncontrolled), LiDAR points, Reports, Control, Breaklines	80.1
The Gap to Bitter Springs	Aerial photography (1 band, black & white, uncontrolled), LiDAR points, Reports, Indexes, Control	29.7
U.S. Hwy 89 Tee to Tuba City	Aerial photographs (3 band, color, uncontrolled), LiDAR points, Reports, Control, Planimetric Features	64.5
	TOTAL	**1,378.5**

3.5 Design Criteria

Plan and Profile drawings have been created for the main trunk of the NCAP alignment from Page to Gray Mountain and for The Gap to Bitter Springs spur and the Highway 89 Tee to Tuba City spur. Those portions of the alignment were flown and mapped using aerial LiDAR (Light Detection and Ranging) and photogrammetry methods. The portion of the NCAP alignment from Tuba City to Keams Canyon has not been flown or mapped. Appendix B, *Plan and Profile Drawings*, contains all the drawings prepared under this Study to be used in preliminary design. Appendix C, *Feasibility Design Steady State Hydraulics and Pump Selection*, contains pipeline and pumping design criteria.

3.5.1 Pipeline Appurtenances

The pipeline would need appurtenances including isolating valves, air/vacuum valves, blowoff valves, pressure sensing devices, cathodic protection, and, potentially, chlorination/cleaning points. Pressure reducing/altitude valves would be installed upstream of each on-line storage tank to prevent overflow and to maintain pressure in the pipeline upstream of the tanks. The NCAP would be designed for the water to pass through the water storage tanks at Coppermine, The Gap, and Cameron so that, in the unlikely circumstance that the upstream pressure reducing station malfunctions, the water would overflow the tank and safeguard the pipeline from excessive pressure. The upstream pipeline would be designed for the maximum static pressure and maximum surge pressure conditions.

3.5.2 Pipeline Transients

Surge pressures in pipelines result from changes in flow velocity. These velocity changes may originate from pumps starting/stopping or from valves closing/opening. The transient analysis has not yet been performed.

3.5.3 Electrical

The NCAP Study did not produce any design data for an electrical power system. Energy supply for pumping plants, booster plants, and other appurtenances will require a power study to determine electrical demand and possible sources.

3.5.4 Supervisory Control and Data Acquisition

The NCAP Study did not produce any design data for a supervisory control and data acquisition (SCADA) system.

3.5.5 Water Treatment

The project would deliver to the NCAWSFS participants either unfiltered (non-potable) water or filtered and disinfected (potable) water which would be treated at a centralized project facility. Filtered water meets all requirements of the Surface Water Treatment Rules (SWTR), except that a disinfectant residual is not provided. Disinfected water receives the same treatment as filtered water, but a disinfectant residual is also provided. If residual disinfection with free-chlorine is provided in a long pipeline, disinfection byproduct standards may be exceeded. Therefore, the treatment components of several action alternatives would provide filtered water without a disinfection residual (nonpotable) for conveyance through the NCAP to participant turnouts.

A final decision has not been made as to what degree the water will be treated prior to transmission from the first pumping station. Two types of treatment are certain to occur: first, mussel mitigation must be done so that there is no infestation and fouling of the transmission pipeline and pumping stations; and second, grit and sand must be removed prior to pumping to minimize wear on pumps. Additional treatment has not been decided at this point.

If the water is to be used for consumption it must be made potable at some point and comply with applicable regulations. Lake Powell is a surface water source and there are several rules pertaining to the Safe Drinking Water Act (SDWA) that apply. Once the water is conveyed from transmission lines to distribution systems, there are additional SDWA rules that local authorities must comply with. Most states and parts of the Navajo Nation implement and enforce the SDWA. If all of the treated water will be consumed in the Navajo Nation, the Nation will be the primary regulator.

If the NCAP is to supply potable water through the transmission line, the Value Planning Study (see Section 3.7 and Appendix E) agreed that from a purely economic perspective, that centralized treatment would be the best option. That would change in the event that either open channels are chosen as part of the transmission and conveyance, or if local communities desired to have more local control over the level of treatment.

Regardless of where it occurs, treatment will have to include compliance with the SWTR. The SWTR requires 3-log removal of Cryptosporidium and Giardia as well as 4-log removal of viruses (i.e., 99.9% and 99.99%, respectively). Typical processes to accomplish this are granular or membrane filtration accompanied with chemical and UV disinfection.

If an option is pursued to use open channels in the conveyance, then the water is considered raw surface water at that point, regardless of prior treatment. In that event, or in the event of the choice of local treatment, the complete requirements of the SWTR will have to be met prior to distribution.

The Value Planning Study also suggested that filtration for mussels should be combined with filtration for the SWTR. The same process that removes veligers (pelagic microscopic larvae) in the sub-200 micron range can remove other microorganisms and solids in the water. Another option that could take advantage of the dual-function filtration at the beginning of the conveyance is partial treatment. This option would provide initial filtration and pre-treatment near Lake Powell and provide further treatment such as Granular Activated Carbon for removal of natural organic material and final disinfection at turnouts to end users.

By not allowing many days of contact with chlorine disinfectant, treatment at the turnouts could preserve water quality and allow for a more economical solution.

3.5.6 Mussel Mitigation

The Colorado River (via Lake Powell) is the water supply source for the NCAP. Lake Powell has general water quality that is considered conducive to growth and propagation of mussels. Infestation has not yet occurred, but is considered "highly possible to likely." Regardless of the status of the mussel population, Reclamation designs facilities for at least a 50-year lifecycle and the probability of a mussel infestation is high over that time period. Table 16 illustrates what are generally considered optimal growth conditions in the Southwest and a comparison with Lake Powell water quality. Station LPCR0024 is a sampling point 2.4 km upstream of the Glen Canyon Dam. It is representative of the water quality that would likely be obtained by the project. The data was collected from 1946 through 2008 throughout the year and also at various depths in Lake Powell. The values in the last column are averages of up to 2,700 data points for each parameter.

Table 17: Quagga Mussel Optimal Growth Conditions

Parameter mg/L	No Potential	Little Potential	Moderate Potential	High Potential	Station LPCR0024
Calcium	<10	10-12	12-30	30-120	103
pH	<7.0, >9.5	7.0-7.8, 9.0-9.5	7.8-8.2, 8.8-9.0	8.2-8.8	8
Alkalinity	<35	35-42	42-100	100-420	140
Phosphorus	<.005, >.05	.005-.01, .035-.05	.01-.025	.025-.035	0.014
Nitrogen	<.075, >.75	.075-.150, .525-.750	.150-.375	.375-.525	0.63
TDS	<20	20-40	40-70	>70	773
TSS	>96	28-96	8-28	<8	1.9

TDS denotes Total Dissolved Solids
TSS denotes Total Suspended Solids

The water from Lake Powell will be obtained through a surface diversion of intake and pipeline transmission. If mussels are present in Lake Powell, they will be present in any surface diversion. Mussels are mobile in the water column in their juvenile life-stage at sizes ranging from 40 – 200 microns. Any intake from Lake Powell would potentially entrain and capture juvenile mussels, known as veligers. When the veligers find a suitable location to settle and grow into adults, they adhere to a surface and begin occluding hydraulic equipment.

Zebra and quagga mussels have infested the Lower Colorado River from Lake Mead to Lake Havasu. They have attached to every surface encountered including, trash racks, intake pipes, slide gates, anchor ropes, boat hulls and even trash and debris. The only surfaces that have resisted attachment are solid copper and specialized foul-resistant coatings.

Water management agencies have come to the conclusion that there is no easy solution to the mussel problem once they have gained entry into hydraulic equipment and that the best strategy is to prevent entrance into any equipment.

Careful design will be required to mitigate the impact of mussels on the intake. Intake screens could be made of copper, or coated with foul-resistant material to deter attachment. Once water passes the initial screens, some means of filtering out the veligers must be employed. Self-cleaning ballast filters have proven successful in smaller applications, and may be effective here if they can be scaled up to the full flow. Ballast filters will prevent any veligers over 40 microns from impacting downstream equipment.

Along with design intended to prevent mussel infestation of hydraulic equipment, an intensive monitoring and inspection program should be implemented from the initiation of service. Cleaning procedures should be in place from startup as well.

3.6 Scour Study of Stream Crossings

Due to NCAWSFS participation involvement, timing, and funding, the project area was broken into three Scour Study parts: Part I - City of Page to Flagstaff including The Gap to Bitter Springs spur and the U.S. Highway 89 Tee to Tuba City spur; Part II – Tuba City to Keams Canyon spur; and Part III - Tusayan and GCNP spur. Reclamation’s TSC completed Part I of the Scour Study with funding from the Rural Water Program during the summer of 2013 (see Appendix F).

3.7 Value Planning Study

A Value Study Team met for a five-day Value Planning study of the NCAP Project in April 2013. Costs were not developed during this Study because of limited time and the large-scale changes proposed. Therefore, costs/savings/additions for the Proposals were not included in the report (see Appendix E). The Team developed nine proposals which are summarized below.

Dependent Proposals: Proposals 2A and 2B are closely related. Acceptance of one proposal would preclude full rejection of the other. The same applies to Proposals 7A and 7B.

Combination: Proposal 3 can be combined with Proposals 2A or 2B.

Proposal 1: Mussel Mitigation
Mussels are present in Lake Powell and the project must plan for mitigation.

Proposal 2A: Centralized Water Treatment
Consider centralization of treatment facilities at the beginning of the pipeline to provide a cost comparison with Proposal 2B.

Proposal 2B: Water Treatment at Delivery Points
Consider treatment at tribal delivery points to provide a cost comparison with Proposal 2A.

Proposal 3: Utilize Slow Sand Filtration in Lieu of Rapid Sand Filtration
Consider a slow sand filtration process instead of rapid sand filtration process to reduce cost.

Proposal 4: Utilize Canals in Lieu of Piped Conveyance
Consider lined canals in appropriate reaches to convey flow instead of a pressurized pipeline to reduce cost.

Proposal 5: Phased Construction of Project
Consider optimizing pumping equipment, water treatment, storage tanks, and conveyance pipe size in conjunction with phased build-out to meet final demands and reduce operation, maintenance, and replacement (OM&R) costs.

Proposal 6: Reduce Number of Pumping Plants by Increasing Total Dynamic Head
This proposal is to consider increasing the pump total dynamic head (lift) from 400 feet (typical Reclamation practice) to 530 feet. Increasing pump lift will result in increased pipeline pressure class and cost as well as some increased mechanical and electrical equipment pumping plant costs, but will reduce the number of pumping plants.

Proposal 7A: Inclined Intake
Consider an inclined constant angle intake system to access a select depth of Lake Powell in conjunction with a reservoir-side pumping plant feature. This proposal needs to be compared to Proposal 7B.

Proposal 7B: Vertical Shaft(s) with Horizontal Lake Tap Intake(s)
Consider constructing a vertical shaft with horizontal lake tap lateral intake system to access select depth(s) of Lake Powell. This proposal needs to be compared to Proposal 7A.

4.0 Project Constructability

The Study quantified and assessed the constructability issues that would influence the construction of the NCAP and its related facilities at an appraisal level. Issues to be addressed include:

- Construction equipment
- Traffic disruptions
- Facility and site access
- Excavation and backfill considerations
- Roadway, railroad, river, and stream crossings
- Surface restoration
- Above and below ground utilities
- Summary and other constructability issues

This evaluation was based on the alternative NCAP corridors, pumping plant and booster plant, and on-line storage and pump regulating tank locations as described earlier in this report. The NCAP alignment would cross areas that would present two distinct types of construction considerations:

- The urban segments of the reaches and spurs would include urban areas with relatively dense residential and commercial/industrial developments. The southern and eastern edge of the Town of Page would be included. There are a few other minor urban areas along the route at Chapter delivery points.

- The rural segments of the reaches and spurs would extend south of the Town of Page to Gray Mountain, west to Bitter Springs and east to Keams Canyon and include significant stretches that cross a variety of potentially sensitive landscapes within the Navajo Nation and Hopi Reservation borders.

The urban segments of the NCAP would be in dense residential areas with high traffic roads, limited corridor widths, and/or limited areas available for construction staging. Therefore, consideration would be given to the hours of construction, noise, dust, traffic control, and related issues for its entire length. Rural segments may encounter areas of potential fossil remains, cultural and wildlife considerations. The possibility of using existing utility corridors and rights of way (ROW) could reduce the construction effects, but may increase construction issues due to restricted corridor widths.

4.1 Construction Equipment

Typical heavy construction equipment is expected to be used to complete the project. This equipment may include excavators, backhoes, bulldozers, loaders, tunneling and boring equipment, compactors, pavers, water trucks, front-end loaders, dump trucks, drill rigs, cement pump trucks, cranes, pickup trucks, and other miscellaneous equipment.

Pipeline construction activities would involve, but not be limited to, demolition of existing roadways as required, clearing, grubbing, excavation, pipe laying, backfill, and compaction. Controlled blasting may be required for rock excavation in some of the pipe reaches.

Clearing and grubbing would be accomplished using ground-skidding equipment. Pipeline construction would typically include a Cat 345 excavator, Cat 966 front end wheel loader, and 433E padfoot vibratory compactor or similar equipment. A Cat 330 excavator may be used for the pipeline spurs.

Pavers, smooth drum compactors, and pipe boring or tunneling equipment may be required to install pipeline adjacent to and beneath roadways in the urban areas. Horizontal Directional Drilling (HDD), micro-tunneling, or piping boring equipment would likely be required for the major roadway, streams and rivers, and railroad crossings.

In addition to the equipment stated above, cranes, cement trucks, forklifts, aerial lifts, portable generators, and drill rigs may be used for construction of the pumping plant, booster plants, air chambers, forebay tanks, regulating tanks, and water storage tanks. Equipment for shoring and unwatering or dewatering may be needed to divert or control surface water. Hydromulch equipment may be used to reseed disturbed areas.

4.2 Traffic Disruptions

Traffic disruptions associated with the NCAP project would generally be temporary and localized. Disruptions would be related directly to the construction within a specific area for a relatively short time period (usually no more than 30 days). The disruptions could be caused by material deliveries, equipment mobilization, or actual road closures for construction of the facilities. Short-term disruptions could also result from an increase in vehicular traffic resulting from the influx of construction workers.

- **General.** Identifying key alternate or detour routes, whenever available, could mitigate traffic disruptions, as could working within the shoulder and one lane of a multilane roadway or highway, and allowing passing capabilities on smaller roadways that are less traveled. Safety and hazard barriers, as well as lighting, should be used to bring awareness to the open trench hazards on either side of the backfilled roadway. All construction signage, flagmen, and detour signage should comply with the latest edition of the Arizona adopted version of the *Manual on Uniform Traffic Control Devices* (Federal Highway Administration, 2009).

- **Urban Segments**. Within urban areas, the construction contractor would need to coordinate with multiple agencies and entities with regard to traffic control and mitigation of traffic impacts. There would be additional concerns related to maintaining access for private roadways and driveways, and road closures, especially during peak traffic times. Mitigation may include such measures as night time/weekend construction that could be performed without affecting nearby residences, boring under larger and busier roadways such as highways and major collector streets, or construction within existing rights-of-way or easements that are part of or adjacent to roadways. The construction should be limited in the length of detours that are permitted during construction. No more than two city blocks should be unavailable for general traffic at any time. The contractor should be required to provide for residential/business access and emergency vehicles at all times. Trenches should not be permitted to remain open and uncovered overnight.

- **Rural Segments.** In general, rural construction of the NCAWSFS would be less likely to disrupt traffic. Key roadways may be important to keep open, however, due to the lack of alternative routing available. One mitigation technique would be to require continuous backfilling over the pipeline to keep key access roads and roadways open to the maximum practical extent, minimizing down time. Backfill over the off-road portions of the line could then be handled on a separate schedule, but the unexposed pipe length should be limited to 300 feet unless the contractor’s means and methods of construction warranted special consideration and approval by the engineer.

- **Pumping Plants, Booster Plants, and Tanks.** Sites for these facilities would be on properties generally isolated from the traveling public. With the exception of a needed construction and/or permanent access road, traffic disruption and effects should be minimal.

4.3 Facilities and Site Access

The primary facilities that would be included in the overall project include a reservoir-side intake, pumping plants, booster plants, and tanks. Appurtenant facilities, such as disinfection facilities, SCADA-related tower facilities, and pipeline structures (air valves, blowoffs, buried manholes, isolation valves) would also be needed, but their site access requirements would be small relative to the primary facilities.

The majority of the pipeline would be installed along, or directly adjacent to, existing easements. A study of existing easements would be conducted to determine if construction of the new pipeline is allowed. Existing easements may not be wide enough to allow for the construction and maintenance of the new pipeline and may require additional negotiations to widen. Obtaining new easements through urban areas may be difficult due to the number of landowners involved. Other municipal and industrial pipelines projects that run through urban areas have sometimes resulted in Reclamation relocating the pipelines and replacing sections of pipe to handle new surface vehicle loading. Easements through urban areas would need to be wide enough to make future repairs.

Typically, smaller equipment would need to be used in urban areas. Large equipment can nearly always access most rural sites.

Site access issues for NCAP primary facilities include:

- **Reservoir-side Intake, Pumping Plants and Booster Plants.** Due to the remoteness of some of the NCAP delivery points, these facilities may not be able to be constructed adjacent to existing facility sites. Minimizing the length of new road construction for site access is one of several factors in the final site selection process. A paved access road may be required to provide the site with all-weather access for trucks, personnel, and emergency equipment. The relative location of the site to electric power and transportation is also an important factor. The more remote the site is from existing utilities and roadways, the more expensive site development becomes, and the more costly the initial construction would be.

- **Tank Sites.** Tank sites (i.e., water storage and regulating) spread along the NCAP corridor have been considered for balancing demand, pumping plant regulations, and providing emergency water supply. Generally, the tank sites would be located on high ground or be elevated for hydraulic efficiency. Adequate site access could be a gravel roadway, one or two lanes wide, depending on length. Steep grades are not recommended because winter access and heavy equipment access may be required. Since telemetry equipment is anticipated to support system-wide control and monitoring, close proximity to a power supply is desirable.

- **Main Trunk and Spur Pipelines.** A majority of the NCAP would be installed along existing roadways or other established ROWs or easements. This would provide all-weather access to the pipeline for routine OM&R. For lengths that would not be adjacent to a ROW, a permanent easement 100 feet wide was proposed. However, widths would vary depending on site-specific conditions such as the need to avoid existing facilities or to conform to property boundaries. The easement width may be reduced for areas with constraints, depending on the diameter of the pipeline. Temporary construction easement width of an additional 40 to 60 feet would provide room for construction. Access to easements would be required via a gravel surfaced road from an existing roadway. Reaches across cultivated agricultural land would not require a permanent access road but those across grazing and open prairie lands may include location marker posts to identify the location of pipe alignments. By the completion of construction, the wheel paths for vehicular access should be established within the permanent easement and between marker posts. The wheel paths would be seeded as part of the final restoration; however, it would not be essential to establish a gravel surface across dry open lands. For pipelines that traverse existing canals or farm roads, the contractor should restore the roadways or motorized trails to the original preconstruction condition. Any fence line crossings should be secured by a lockable gate.

- **Site Security.** Securing facility sites is essential for ensuring public health and preventing theft. These facilities would require protection by means of a security fence and a lockable gate. Increased security measures may be warranted if the site is remote or not generally in plain view of the public. Any above or below ground controls or vaults should be secured with padlocks or have keyed entries. All facilities should be limited to access by authorized personnel only.

4.4 Difficulty of Excavation

Considering the length of the pipeline and the variation in terrain, a wide variation in soil conditions should be expected. In 2008, Reclamation performed seismic refraction surveys in conjunction with 17 test pits excavated in rock to determine the excavatability of portions of the alignment. From 2012 to 2016 Reclamation performed test pit investigations for the purpose of evaluating the required excavation effort. Results of those investigations and more detailed information on excavation requirements are presented Sections 5.1.1.2 and 5.1.5 of this report.

4.5 Backfill Requirements

Reclamation would identify suitable borrow and spoil sites and/or existing commercial sources as required. Limited spoil would be allowed within the construction corridors when it would not interfere with land use. Ability to use local materials for backfill/embedment and re-contouring versus need to import and export materials would affect constructability, cost, and the area of construction easement required.

4.5.1 Road Crossings

Generally, it is expected that NCAP construction within the urban segments would be along other utility easements or within existing street and road rights-of-way, while construction in the rural segment would be in or adjacent to available road rights-of-way whenever practical.

4.5.2 Urban Segments

The pipeline would be constructed under the pavements of city streets when street ROW is not sufficient for pipe installation outside of the paved area. This would also be true when necessary to avoid conflicts or realignment of other existing utilities and structures. State highways and major city streets are expected to require pipe installation via trenchless technology methods to avoid disruption of vehicular and pedestrian traffic in highly congested areas.

The crossing under state highways would be a major construction issue, and selection of the crossing site would be an important engineering and construction undertaking. Other sites would require trenchless technology methods, for which the primary crossing site selection parameters are crossing length and soil conditions. Such undertakings would be subject to rules and regulations of ADOT.

4.5.3 Rural Segments

State highways would require that pipe crossings be installed by tunneling or boring and jacking methods to minimize disruption of vehicle traffic. The crossings on U.S. Highway 89 would cause the greatest concern. Major county roads may require tunneling or boring and jacking methods, but the requirements for each road crossing may require negotiation with the local authorities. Open cut installation for crossings of unpaved county roads is usually the preferred option.

In rural communities, the same policy as currently exists for the Town of Page for working in city streets would be applied. The pipeline would be installed under pavement unless adequate ROWs existed and there were no other utilities present. Working inside the corporate limits of rural communities would be avoided to the greatest extent practicable.

4.6 Railroad Crossings

The proposed NCAP alignment does not cross any railroads. Active railroad crossings can only be constructed by tunneling, boring and jacking, HDD, or micro-tunneling methods. Construction is usually not permitted to encroach on railroad ROW, so entry and exit pits must remain off of the railroad property. Alternative pipe alignments would be selected to minimize the number of tracks at any required crossing, thereby reducing the length of the crossing. The Burlington-Northern-Santa Fe, and Black Mesa and Lake Powell (owned by the Salt River Project) railroad companies could be involved in the proposed crossings. Discussions with these entities should begin early.

The use of an abandoned railroad ROW with an existing easement for a pipeline would have advantages. This would be a unique opportunity to take advantage of a pre-graded length of ROW that would both facilitate construction and provide a no-cost stabilized roadbed for access. However, care must be used when using old railroad ROWs due to potential contamination and hazardous materials. Also, current ownership would need to be verified.

4.7 River/Stream Crossings

The Little Colorado River poses the greatest challenge to the project, in terms of river crossings. Three critical constructability considerations for the river crossings are to:

- Facilitate construction by avoiding steep, vertical, sandy banks that impair construction and would be difficult to re-stabilize.
- Avoid environmentally sensitive areas, including any wetlands or substantial tree and vegetation growth.
- Select crossing locations where the width of the river is minimal (as compared to the average width of the river).

Methods to address such crossings are described below:

4.7.1 Cofferdam/Dewater/Open Trench

This is the conventional method of pipe installation in a stream channel. It consists of diverting the stream flow to one side, removing water from the soil and work space, and installing the pipe into an excavated trench. Then, the process is repeated for the other side of the crossing. The stream channel is then reestablished after pipe installation.

4.7.2 Horizontal Directional Drilling

HDD is a trenchless construction method used to install pipelines of various sizes and materials below the ground surface. HDD is often used where open cut installations are not feasible, such as road and river crossings. Using directional drilling techniques, one guides a drill string along a bore path under obstacles such as rivers, lakes, railway crossings, or highways. As the hole is bored, a steel drill string is extended behind a cutting head. Drilling mud is used to cool the cutter, to flush excavated soil from the borehole, and to lubricate the borehole. The cutting head is removed, and a backreamer is attached. The pipe string is attached to the backreamer through a weak-link device. As the drill string is withdrawn to the drilling rig, the backreamer enlarges the borehole and the pipe string is drawn in.

4.8 Surface Restoration

All areas disturbed by construction that do not require special surface treatment, such as pavement replacement, would be seeded and mulched after construction or, if agricultural land, would have loam topsoil replaced. Temporary seeding may be required when disturbed areas remain untouched for more than 30 days. A turf seed mix would be required for established lawns. A native seed mix would be required for all other vegetated areas. Cultivated agricultural areas would not require reseeding. Sod may be required for limited areas within public areas or ROW. Requirements for erosion and sediment control would be established during final project design.

All areas with existing landscape cover or mulch would be replaced with similar size and type of cover materials. Pavements, sidewalks, and other hardscaped areas would be replaced with an equal or better surface as provided for in the final project specifications and plans.

Disturbed portions of the banks and beds of rivers, streams, and other waterways would be protected by rock riprap of adequate size and type to minimize erosion and scour. Any slopes greater than 3:1 should be protected with erosion control blankets after seeding. Some water conveyances may require additional protective measures if site-specific conditions dictate.

Irrigated cropland would require special consideration and attention during construction. Not only would it be critical to restore cropland with topsoil to the depth that exists, but also the quality of the topsoil, the relative density, and the original surface grading must be restored. Restoration of the existing surface grades is critical to farmers who rely on gravity irrigation of the crop rows. The quality of the topsoil and its depth would impact the yield that farmers expect from the croplands. Soil density must be adequate to support tractors and equipment but not dense enough to prevent water infiltration. Each negotiation for ROWs across cropland must include the specific requirements of the property owner with regard to these factors. While the cropland owners can be compensated for crop damages and losses during the construction period, the potential for post-construction litigation could be higher if these factors were not considered.

4.9 Above and Below Ground Utilities

Above and below ground utilities could exist over much of the NCAP alignment. Whenever possible, final design should minimize crossing under overhead utilities; this would be subject to the preferred alternative route selected. Horizontal clearances would be established and maintained during design and construction to minimize possible disruption of services and potential safety hazards during construction.

To minimize conflicts between highway and utility facilities along the U.S. Highway 89 and State Road 264 corridors and to be consistent with state-wide regulations for accommodating utilities within the State Highway ROW, coordination efforts with ADOT would be required per the process and regulations outlined in the State's *Guideline for Accommodating Utilities on Highway Rights-of-Way* (ADOT, 2015).

The utility design data collection activity would include the use of American Society of Civil Engineers *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data* (ASCE, 2002) recommendations for the quality of location.

4.10 Other Constructability Issues

Considerations for constructability in the urban segments, include:

- Extensive traffic control, impact planning, and public notifications/communications.
- Consideration of alternative hours of construction.
- More detailed routing considerations to avoid conflicts.
- Ability to negotiate and use existing easements.
- Greater number and complexity of pipeline crossings of roads, drainages, other utility impacts, etc.
- More expensive construction techniques such as extensive use of trenching/shoring techniques, bores, HDD, etc., will be required.
- Potential need to work within very restricted ROW.
- More repaving, replacing, and upgrading of impacted areas including roads, driveways, parking lots, drainages, landscaped areas, other utilities, etc.
- Need to carefully plan for adequate staging areas.
- More extensive signage and hazard warnings within the construction zone.
- Coordination of access with emergency services such as police and fire during limited access times.

Considerations for constructability in the rural segment include:

- Routing pipelines adjacent to private land that is adjacent or parallel to roadways to provide ease of construction and maintenance access, while remaining off the road to minimize impacts and utility conflicts.

- Routing along less used roadways, where convenient, to avoid other structures, facilities, and utilities.

- Avoiding disturbances to sensitive habitat such as undisturbed grassland and desert habitat, riparian zones, wetlands, and migratory and raptor nesting areas.

- Considering waterway (channel, stream, river, and canal) crossings by either open cut or bore or directional drill. Open cutting of a natural surface drainage should be accomplished during dry times of the year to minimize diversion and dewatering needs. Directional drilling should be used when open cutting is not practical or to reduce environmental impacts. Open cutting ditches and canals should be scheduled during the non-irrigation season.

- Avoiding wetlands, cemeteries, cultural resources, and historical areas whenever practical.

- Adjusting pipeline corridor widths as needed for construction and for permanent easements.

- Considering local soils, export of unusable excavated materials, and import of bedding/embedment and backfill materials when determining the pipeline construction width and trench design details. Acknowledging other pipeline features, such as valve stations, blowoff stations, etc., that will typically necessitate more convenient access, possibly greater easement requirements, and the potential need for a convenient drainage channel for discharging large volumes of water.

- Acquiring multiple staging areas, which may be the responsibility of the general contractor to acquire and manage.

- Backfilling roadway and driveways immediately after pipe placement when they provide the only option for access to homes, farms, and businesses.

- Potentially expanding the pipeline construction width when dealing with stockpiling surface soils for revegetation, exporting unusable materials, importing bedding/embedment materials, dealing with wet areas, and around channel, roadway, stream, railroad, or other pipeline/utility crossings. These potential issues would need to be analyzed and handled on a case-by-case basis during final design.

- Acquiring water for construction purposes

Issues related to a particular site being considered for pumping plants would include:

- Soils and geotechnical features
- Topography—more vertical sites generally require more land area
- Location with respect to residential development
- Zoning and nearby land uses
- Buffer zone availability
- Roadway access
- Proximity to pipeline alignment
- Ability to secure site from unwanted visitors
- Nearness to three-phase electric power service
- Provision of onsite backup power facilities
- Sewer facilities
- Adequate offsite drainage facilities to route onsite drainage

General considerations for tank and SCADA site development would include:

- Soils and geotechnical features
- Topography/elevation
- Roadway access
- Location to power service for telemetry, supply monitoring, and security systems
- Good access to roadways, but probably 100 feet from a roadway in more rural areas, to discourage casual visitation by unauthorized individuals
- Proximity to pipeline alignment
- Enough area for the tank and a valve/metering/control house, as well as about 50 feet of width around the facilities for access and maintenance
- Ability to secure from unwanted visitors
- Electrical emergency backup power or hookup for trailer mounted generator (if required)
- Specific land requirements will be determined as tank designs and SCADA system needs are further investigated

5.0 Regional Site Conditions

5.1 Geology

5.1.1 Geologic Explorations for Feasibility

Geologic characterizations described in this section were developed from available information within the NCAWSFS area and from limited geologic mapping and investigations conducted from 2012 through 2016.

This section presents a general discussion of engineering geologic considerations that relate to the site geology that may be encountered along the NCAP main trunk and spur alignments.

It is recommended that future work include continued development of site-specific geologic design data collection based on the final alignment. Future reports should include detailed station to-station geology based on smaller scale geologic surface maps and Natural Resources Conservation Service soils data. Geotechnical investigations of proposed structure locations have not been conducted and are recommended. No geologic investigations have been conducted at the East Intake site located on Lake Powell.

5.1.1.1 Preliminary Investigation Estimate

Surface and subsurface geologic explorations are normally required for each phase of a project to adequately characterize the geologic site conditions and reduce construction costs at unfavorable locations identified by those investigations. Geologic investigations conducted at each phase also assist engineers in selecting the best engineering design options and alignments for the particular site conditions.

In September 2007, a general field exploration program was estimated based on the following assumptions:

- One hollow stem auger exploration hole at each pumping plant, pressure reducing station and storage tank site
- One test pit for each ½ mile of pipeline
- One soil resistivity survey conducted every 5 miles
- One inclined core drill hole at the cliff-side intake pumping plant

The total length of the pipeline was estimated to be about 254 miles, including the Gray Mountain to Flagstaff segment which was removed from consideration in August of 2014. Using these general assumptions, about 27 hollow stem auger holes, 182 test pits and a minimum of 51 resistivity surveys were estimated to be required along a single preferred alignment. The number of soil samples to be collected and analyzed for physical properties was estimated to be about 209 (one per test pit and one per borehole). The estimate of one test pit at every one-half mile along the alignment was modified by 40 percent under the assumption that excavation along the alignment was estimated to be 60 percent rock and 40 percent common based on regional maps and other information available. The estimated number of test pits per mile was adjusted down assuming that only 40 percent of the alignment would be conducive to test pit excavation.

Additional geologic investigations along the preferred alignment were anticipated to allow for a more refined and accurate characterization of foundation conditions. Further effort would be performed during the preparation of the field exploration request that would be prepared by Reclamation's TSC engineering team in conjunction with the project geologist for coordinating and implementing the design data collection effort.

5.1.1.2 Previous Investigations

Lake Powell Reservoir-Side Pumping Plant Site

An appraisal study for the construction of a water intake and pumping plant for the City of Page was conducted by Reclamation in June 2004. The intake shafts were proposed to be situated within a cliff adjacent to Lake Powell and approximately 1,350 feet upstream of Glen Canyon Dam within the boundary of the Glen Canyon National Recreation Area (GLCA) Chains Area. The City of Page requested a right-of-way across the GLCA to construct the intake. The National Park Service (NPS) requested that the City of Page prepare an environmental assessment (EA) including a design study to analyze the geologic stability of the proposed site to support the project.

In November 2005, drill hole DH05-1, located about 670 feet upstream of the east spillway of Glen Canyon Dam, was drilled by a Reclamation crew at the request of the City of Page to a depth of 415 feet. The City of Page then contracted Reclamation to prepare a brief summary of the field work completed, including a geologic log, core photographs, and a visual inspection of the site for surface expressions of rock jointing. No geologist had been on site during the drilling. The hole was logged by a Reclamation geologist a month later and a report was prepared titled *Drill Hole DH05-1 Geologic Log, Core Photographs & Surface Joint Identification* in December 2005.

The NPS determined that the EA study was insufficient for their purposes, requiring more details to determine whether the site would be suitable from the standpoint of stability to support the facility. In response to a request by the Navajo Nation to keep the project moving, Reclamation performed a limited geotechnical evaluation of the pumping plant site located on the shore of Lake Powell titled *Lake Powell Reservoir-Side Pumping Plant Site - Geology Report* dated November 2007. A number of surface fractures were described and the local topography mapped to determine if the orientation of the existing joint sets formed a removable block or blocks that could potentially lead to slope instability. It was determined that no combination of surface discontinuities mapped at the site showed evidence of sufficient continuity and/or persistence to form a removable block which would compromise the canyon rim.

Seismic Refraction Surveys

Reclamation, in conjunction with the Navajo Nation, performed eighty-nine seismic refraction surveys along portions of the proposed Western Navajo-Hopi Pipeline, as it was previously known, in order to determine the rippability of the material that may be encountered during construction. The surveys were performed June 30 through July 17, 2008.

Photograph 1: Seismic refraction surveys were conducted to determine the rippability of materials along the proposed pipeline alignment. Date: July 17, 2008

In order to calibrate the seismic refraction surveys with actual excavation conditions, 17 test pits were excavated in specified areas that had already been surveyed. The proposed pipeline alignment was geologically mapped at a scale of 1 inch equals 10,000 feet. Rock types and their engineering characteristics were recorded at each seismic refraction survey site and at selected outcrops along the alignment.

In general, colluvium and bedrock having low seismic wave velocities (below about 2,000 ft/sec) were classified as common excavation. Common excavation implies that the material can be excavated with an excavator. Based on the test pit and test trench results, much of the bedrock classified as rippable can also be excavated by an excavator, especially near the ground surface. Table 18 shows the rippability classification of the materials along the pipeline alignment by length and percent total.

Table 18: Excavation Classification of Western Navajo-Hopi Pipeline

Excavation Classification	Pipeline Length (ft)	Percent
Common	366,140	40
Rippable	399,469	43
Marginally Rippable	120,578	13
Non-Rippable	34,085	4
Total	923,416	100

The report is titled *Proposed Western Navajo-Hopi Pipeline - Rippability of Materials Based on Seismic Wave Velocities - August 14, 2008*. Drawings in the report give an indication of the rippability of the foundation materials based on the measured wave velocities and geologic mapping.

Reports from previous investigations can be found in Appendix G1 – *Geology: Geologic Investigations*.

5.1.1.3 Current Investigations

Test Pit Excavations

A total of 112 test pits have been excavated along portions of the proposed pipeline in order to determine the depth to bedrock and to obtain soil samples for materials testing. The pits were approximately 20 feet long by 6 feet wide and 12 to 15 feet deep unless the backhoe met refusal. The pits were visually classified by a Reclamation geologist and representative samples taken and laboratory tested for gradation sieve analysis, moisture content, Atterberg limits and Proctor compaction. Selected soil samples were tested for shrink/swell potential (expansion index), pH, resistivity, and sulfate, sulfide and chloride content. In-place densities were measured using a sand cone apparatus in selected test pits at depths ranging from 3 to 5 feet.

Sixty-four (64) test pits were excavated in June of 2012, along U.S. Highway 89 north of Cameron to Bitter Springs and along Coppermine Road from The Gap to Coppermine Chapter. The test pits were spaced about one mile apart along the alignment in surficial deposits or in bedrock that was thought to be excavatable to some degree. Test pits TP-1 through TP-48 were excavated along U.S. Highway 89 or along the old U.S. Highway 89, which generally runs parallel to U.S. Highway 89. Test pit TP-17 was not excavated since bedrock was found to be at the surface nearby. Test pits TP-49 through TP-68 were excavated along Tribal Route 20 (Coppermine Road) from The Gap to about 6 miles north of Coppermine Chapter. Test pits TP-64, TP-65 and TP-66 were omitted because bedrock was observed at or near the surface.

Photograph 2: View of test pit TP-28 excavation located along The Gap to Gray Mountain portion of the alignment. Date: June 13, 2012.

Thirteen (13) test pits along a 7-mile-long alignment extending from the U.S. Highway 89 Tee to Tuba City, Arizona, were excavated in May 2013. The test pits are numbered TP-69 through TP-81 and were excavated in mostly wind deposited sand and ranged in depth from 2.4 to 13.0 feet deep.

Twenty-one (21) test pits were excavated in October 2015 along State Route 264 from Coalmine Canyon Chapter to Hotevilla, Arizona. The test pits are numbered TP-216 through TP-237 and were excavated to a depth of 13 feet or to refusal. TP-223 was not excavated due to its proximity to sandstone outcrops. The pits were located along State Road 264 within the Arizona Department of Transportation's right-of-way and were generally offset from the pipeline alignment by 60 to 100 feet.

Fourteen (14) test pits were excavated in April of 2016. The test pits are numbered TP-201 through TP-215 and were excavated to a depth of 12 to 14 feet or to refusal. TP-214 was not excavated due to access issues and its close proximity to shale outcrops. The pits were located along State Road 264 within the ADOT ROW and were generally offset from the pipeline alignment by 60 to 100 feet.

Test pit logs and soil test results can be found in Appendix G2 – *Geology: Test Pit Logs* and G3 – *Test Pit Laboratory Results*, respectively. Individual reports for each of the test pit investigations can be found in Appendix G1 – *Geology: Geologic Investigations*.

5.1.1.4 Geologic Mapping
Surface geologic mapping was performed along portions of the NCAP alignment at a scale of 1 inch equals 2,000 feet and is shown on Figures G-1 through G-9 in Appendix G4 – *Geology: Geologic Mapping*. Surface geologic mapping has not been transferred to plan and profile drawings at this time.

Standard Descriptors and Descriptive Criteria for Discontinuities and Standard Descriptors and Descriptive Criteria for Rocks are shown on Figures G-10 and G-11, respectively. The General Geologic Legend, Explanation and Notes drawing is shown on Figure G-12.

5.1.1.5 Future Investigations
Additional explorations may be necessary where the pipeline alignment crosses natural features such as washes and streams and any existing infrastructure and may include detailed geologic mapping, borings, supplementary test pit excavations, standard penetration testing and cone penetration testing. Geophysics (seismic refraction) have been used to investigate the excavatability of materials and the depths to bedrock along sections of the alignment. Other geophysical methods may be useful to investigate the conductivity and corrosion potential of soils and bedrock. Borrow investigations may be required to identify suitable materials for elevated portions of the alignment and where replacement of unsuitable material is required. Site-specific geologic investigations may be required at locations that are deemed to have adverse foundation conditions.

5.1.2 Regional Geology
The proposed alignment of the NCAP begins at Lake Powell on the Navajo Nation in north- central Arizona and extends south to Gray Mountain with spurs extending from The Gap to Bitter Springs and from U.S. Highway 89 to Tuba City, continuing to Keams Canyon on the Hopi Reservation (Figures 5 and 6 in Section 3.2). The NCAP ranges in elevation from 3,770 feet at Lake Powell to about 6,400 feet at Keams Canyon and is located within the Colorado Plateau Physiographic Province of the southwestern United States, a crustal block of relatively undeformed rocks surrounded by the highly deformed Rocky Mountains to the north and east and the Basin and Range Province to the south and west.

The Colorado Plateau extends across northern Arizona, southeastern Utah, northwestern New Mexico and western Colorado covering a land area of about 140,000 square miles (Figure 7). The mostly flat-lying sedimentary rock units that make up the Colorado Plateau are ringed by highlands and smaller plateaus that are between 3,000 feet to over 11,000 feet above sea level. The west coast Sierra Nevada Mountains prevent moisture laden air from reaching the southwestern states, resulting in a rain shadow effect. Annual precipitation on the Colorado Plateau is low, averaging about 10 inches per year. The combination high relief and low rainfall has resulted in limited plant cover.

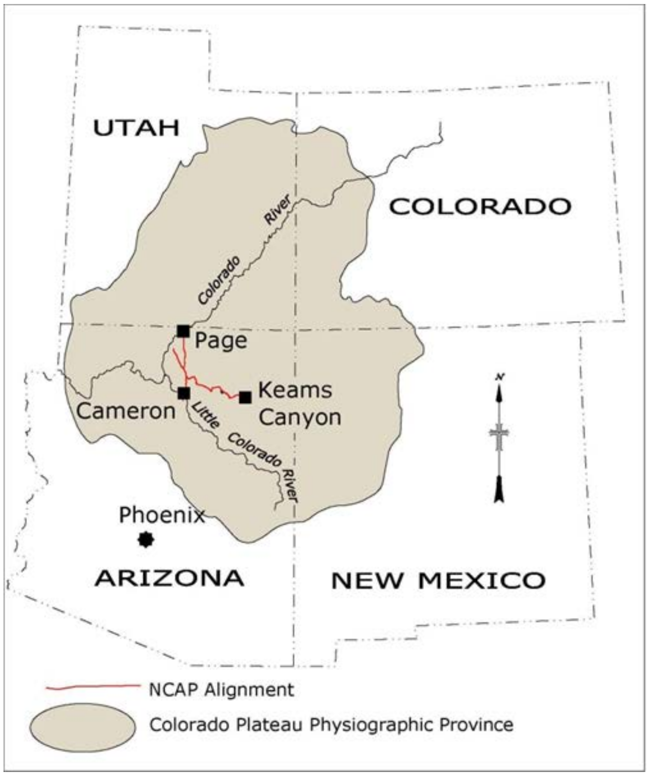

Figure 7: Location of the Colorado Plateau Physiographic Province

The metamorphic rocks that form the foundation of the Colorado Plateau are the result of large-scale tectonic plate collisions that formed the nucleus of the North American continent over a billion years ago. The basement rocks were later uplifted and eroded, resulting in a relatively smooth surface upon which the sedimentary rocks of the Paleozoic Era were deposited.

Throughout the Paleozoic Era (542-252 million years ago), the region was periodically inundated by shallow seas that laid down thick layers of sandstone, siltstone, shale and limestone. During times of sea regression, stream sediments and dune sands were deposited in some areas while other areas were eroded. Sediments accumulated in thick layers over a period of 300 million years.

Deep-seated basement faults were reactivated in the Late Paleozoic to Early Mesozoic resulting in the uplift of the ancestral Rocky Mountains and the formation of a series of northwest trending uplifts and sedimentary basins. The Kaibab Uplift was elevated at this time.

The Mesozoic Era (252-66 million years ago) saw the formation of the supercontinent Pangea and deposits of marine sediment generally waned on the Colorado Plateau while terrestrial deposits increased. Great accumulations of dune sand lithified to form broad expanses of cross-bedded sandstones. Volcanic eruptions to the west buried extensive regions beneath thick layers of ash. Toward the end of the Mesozoic Era, the Laramide Orogeny, initiated by the subduction of the Farrallon Plate beneath the western edge of the North American Plate, uplifted the Colorado Plateau and much of the American West. The Rocky Mountains were thrust up to the north and east of the Colorado Plateau. Crustal stretching caused the Basin and Range Province to break up into a series of down-dropped valleys and elongated mountains, while the thicker crust of the Colorado Plateau remained as a structurally intact block.

About 5 million years ago, the Colorado Plateau was uplifted an additional 4,000 to 6,000 feet initiating erosional down-cutting of major drainages such as the Colorado River and forming the Grand Canyon.

5.1.2.1 Structure

The major structures of the Colorado Plateau include broad folds, monoclines, vertical faults and igneous laccoliths and volcanic intrusions. Rather than the tight folds seen in orogenic belts such as the Rocky Mountains, folds within the Colorado Plateau are long, broad, nearly parallel anticlinal domes, synclinal basins, and monoclines that trend northwesterly (Figure 8). In general, the anticlines are asymmetrical and dip steeper on their eastern flanks.

Figure 8: Major geologic structures near the NCAWSFS pipeline

The East Kaibab and Echo Cliffs monoclines form the west and east boundaries, respectively, of the north-northwest trending Echo Cliffs uplift or anticline. The Echo Cliffs Monocline is dramatically visible as it trends along the Echo Cliffs in the western portion of the Study Area. The monocline, or one-sided fold, formed where sedimentary layers were draped over pre-existing faults in the Precambrian basement rock. Numerous northerly to northeasterly trending high angle normal faults and small grabens cross the uplift in the central and southern parts.

The Black Mesa basin, located in the eastern portion of the Study Area, is a nearly circular down warp bounded on several sides by monoclines. The deepest part of the basin is formed by the Black Mesa syncline which trends northwest across the middle of the basin. Faults of any consequence are rare.

Faults in the Colorado Plateau Province are mainly steep or near vertical. Displacement is on the range of a few feet to more than 1,500 feet. Faulting is thought to have taken place during the Laramide Orogeny with additional displacement occurring in Cenozoic time.

5.1.2.2 Drainage

The surface water within the Study Area flows through a series of tributaries into the Colorado River located to the west. Tanner Wash flows northward, generally along the strike of the rocks of the Chinle Formation from the vicinity north of Cedar Ridge into the Colorado River about 6 miles northwest of Bitter Springs. Hamblin Wash flows southward from Cedar Ridge and joins Moenkopi Wash about 3.5 miles south of U.S. Highway 160.

Moenkopi Wash flows southwestward past Tuba City, turns south near the U.S. Highway 89/ U.S. Highway 160 junction, and empties into the Little Colorado River a few miles northwest of Cameron. Dinnebito Wash, Oraibi Wash and Polacca Wash on the Hopi Reservation, flow southwestward from Black Mesa, crossing the NCAP alignment and draining into the Little Colorado River upstream and downstream of Leupp, Arizona.

The Little Colorado River located in the southern portion of the Study Area, flows northwestward, crossing the NCAP alignment at Cameron, Arizona and continuing to the Colorado River.

With the exception of the Colorado River, streams in the Study Area are intermittent in character, flowing only in response to rainfall.

5.1.3 Site Geology

Subsurface conditions along the alignment are not fully characterized at this time. Additional geotechnical field exploration programs should to be conducted along the proposed main trunk pipeline and lateral spur alignments to further characterize subsurface conditions in order to complete the feasibility and final design phases. Additional field exploration programs are needed to gather geotechnical and geologic information for structure foundations such as pumping plants and other structures and at locations near road crossings, rivers, streams, or other sensitive areas or where specialized construction techniques may be used.

5.1.3.1 Stratigraphy

For the most part, stratigraphic units used in the NCAWSFS conform to published data. Units that are within the regional stratigraphic column, but are not present in the Study Area have been excluded from this discussion. Figure 9 represents a generalized stratigraphic section of the formations and rock units in the Study Area. Selected units have been combined or are described as "undivided" due to the difficulty of distinguishing contacts between units that are locally similar in geologic makeup and have similar engineering characteristics. The geologic units that the proposed NCAP would cross are listed below. The map unit designation is shown in parenthesis at the left.

Surficial Units

(Fill) - Fill. Fill consists of various materials that have been placed or dumped by human activities and includes road construction.

(Qal) - Alluvium. Alluvium consists of clay, silt, sand, gravel, cobbles and boulders that have been deposited by streams and intermittent washes. Alluvium is shown on surface geology maps if it was estimated to be greater than 5 feet thick.

(Qe) - Eolian deposits. Eolian deposits consist primarily of silt and fine sand laid down by wind. Eolian deposits form a mantle of variable thickness over most of the landscape with the exception of river channels and active washes. Eolian deposits are shown on surface geology maps if it was estimated to be greater than 5 feet thick. Some test pit logs refer to eolian deposits as eluvium.

(Qcol) - Colluvium. Colluvium consists of unconsolidated accumulations of generally unsorted clay- to boulder-size material deposited by rainwash, sheetwash or downslope creep on or at the base of gentle slopes. Colluvium may include bedrock that has disaggregated or weathered in place. Colluvium is shown on surface geology maps if it was estimated to be greater than 5 feet thick.

Bedrock Units

(Tsy) - Basin Deposits (Pliocene - Middle Miocene). Sandstone and conglomerate deposited in shallow basins during and after late Tertiary faulting. Basin deposits commonly form rounded hills and ridges in modern basins. Exposures mapped in the Study Area were deposited on the erosional surface of the Mancos Shale Formation.

Sandstone consists of fine to coarse, subrounded sand with occasional rounded gravels that are variably cemented with calcium carbonate. Sandstone exposures are usually intensely weathered and soft, fragments crumble with manual pressure; becoming slightly harder with depth. Color is grayish orange.

Conglomerate consists of variable amounts of subrounded sand, gravel and cobbles moderately to strongly cemented with calcium carbonate. Color is variable due to clast color, but the matrix is usually light gray.

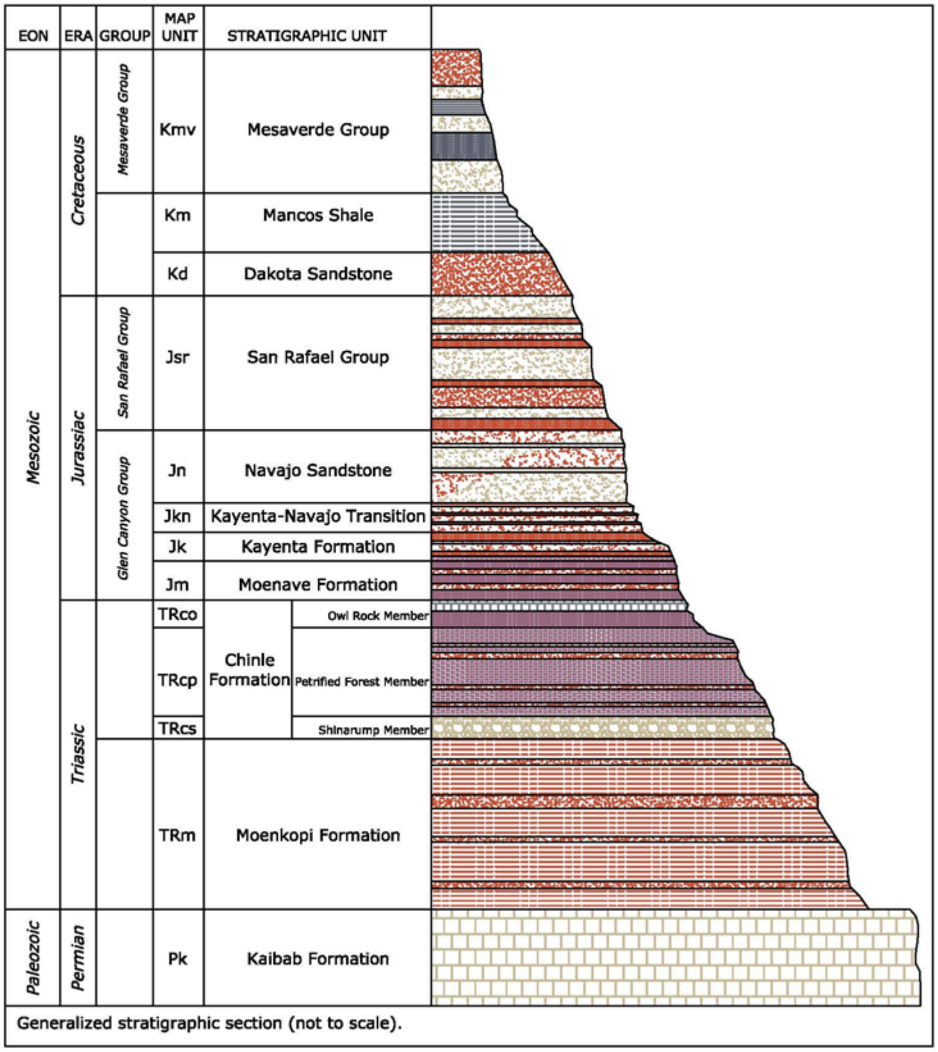

Figure 9: Stratigraphic column showing geologic units encountered in the Study Area (not to scale).

(Kmv) Mesaverde Group-Toreva Formation (Upper Cretaceous). The Toreva Formation is made up of three members, the Upper Sandstone Member, Middle Carbonaceous Member and the Lower Sandstone Member. Due to the thinness of the units and the mapping scale, the Toreva Formation is not broken out into members units on the plan maps, but when possible, member units are identified on test pit logs.

- The Upper Sandstone Member consists of light gray, fine- to coarse-grained, generally conglomeratic sandstone with interbedded soft, greenish gray shale.

- The Middle Carbonaceous Member consists of dark gray to brown, moderately soft shale, coal and yellowish gray, fine- to coarse-grained, moderately hard sandstone.

- The Lower Sandstone Member consists of light brown, fine- to medium-grained, moderately hard cliff forming sandstone.

(Km) Mancos Shale (Late Cretaceous). The Mancos Shale consists of soft to moderately soft shale interbedded with thin layers of fine-grained siltstone and sandstone. Color is medium to dark gray.

(Kd) Dakota Formation (Early Cretaceous). The Dakota Sandstone is subdivided into three units, in descending order; the Upper Sandstone Member, Middle Carbonaceous Member, and the Lower Sandstone Member. Contacts between the member units are gradational. Due to the thinness of the units and the mapping scale, the Dakota Formation is not broken out into member units on the plan maps, but when possible member units are identified on test pit logs.

- The Upper Sandstone Member consists of fine-grained sandstone and siltstone forming a series of thin to thick sandstone ledges and intercalated shaly beds. The unit is locally crossbedded at a low angle.

- The Middle Carbonaceous Member consists of carbonaceous siltstone and coal in flat, very thin beds. The siltstone is composed of silt, clay and fine-grained quartz grains. Gypsum crystals and stringers are present throughout the unit and weather out on the surface. The unit erodes into slopes capped by the Upper Sandstone Member.

- The Lower Sandstone Member consists of very pale orange, fine- to medium-grained, sub-rounded sandstone containing iron rich concretions. The sandstone is irregularly bedded and lenticular, containing crossbedded low angle sets. Conglomerate is locally present at the base of the unit in eroded channels. The sandstone is well cemented and forms blocky, vertical cliffs.

(Jsc) San Rafael Group (Late Jurassic). In the Study Area, the San Rafael Group is represented solely by the Carmel Formation. The Carmel Formation consists of a series of resistant ledge-forming sandstone beds separated by slope-forming siltstone and shale. The sandstone is composed of fine-grained, subangular quartz with minor amounts of mica cemented with calcium carbonate. Sandstone beds are about 1 to 3 feet thick, but some, especially in the upper part of the formation, are as much as 20 feet thick. The sandstone is moderately soft to moderately hard, forming either ledges or long dip slopes and is white to light greenish gray and weathers to pale yellowish brown. In most places outcrops are stained dark red by debris from the overlying siltstone units. The shale is very fine-grained, fissile, weakly cemented with calcium carbonate and flat bedded; beds are up to 20 feet thick, but generally less than 5 feet thick and weather to form slopes. The color is dark reddish brown, micaceous, and at places silty and sandy. The siltstone is grayish red and weathers to pale reddish brown.

At Coal Mine Canyon, located north of the Tuba City to Keams Canyon segment of the alignment, the Carmel and Entrada are considered inseparable and the entire San Rafael sequence consists of friable, white crossbedded and flat-bedded sandstone banded by a few thin, conspicuous beds of rust-colored siltstone.

Photograph 3: Sandstone from the San Rafael Group, Carmel Formation located along the LeChee to The Gap alignment Sta. 1095+00. The sandstone is soft, becoming moderately hard a few inches from the surface. Thin shale layers are apparent where the sandstone ledges are undercut. Date: August 27, 2013

(Jn, Jkn, Jk, Jm) Glen Canyon Group (Jurassic). During the Jurassic period, large portions of northeastern Arizona were covered by vast dune fields which were subsequently buried and lithified forming a series of sedimentary rocks dominated by cross-bedded sandstones. Thin lenses of limestone exposed within the series are thought to have originated in small interdune lakes.

The Glen Canyon Group usually consists of four formations. From youngest to oldest, these are the Navajo Sandstone, Kayenta Formation, Moenave Formation and Wingate Sandstone. The Wingate is not present in the Study Area and is not described here. Within the Study Area, the rocks of the Glen Canyon Group form the Echo Cliffs from Bitter Springs to Moenave, Arizona. The Navajo Sandstone forms the cap rock of the Kaibito Plateau from Page to The Gap.

- **(Jn) Navajo Sandstone**. The Navajo Sandstone is composed of medium- to fine-grained, subrounded quartz grains cemented with calcium carbonate, silica and iron oxides. Crossbedding is characteristic of the unit and bedding ranges from less than 1 to 10 inches apart. The sandstone is moderately soft to moderately hard depending on the degree of weathering and cementation and weathers into rounded hills and domes in which the crossbedding is etched out by erosion. For the most part, the Navajo Sandstone has two contrasting colors; reddish brown in the lower portion and light gray in the upper, but considerable variation occurs within those colors ranging from white to very pale orange to pale reddish brown.

The unit contains lenticular beds of cherty limestone one to two feet thick which are resistant to erosion and typically form ledges or flat-topped ridges.

The Navajo Sandstone intertongues with the underlying Kayenta formation. Several springs and seeps are associated with the base of the Navajo Sandstone along the Echo Cliffs and near Moenave.

Photograph 4: Navajo Sandstone along the Lake Powell Intake to LeChee alignment near Sta. 307+50. Note the characteristic cross bedding. Date: September 2, 2015

- **(Jkn) Kayenta-Navajo Transition Zone**. The Kayenta-Navajo Transition Zone represents the intertonguing of the Kayenta Formation and the overlying Navajo Sandstone and is characterized by a sequence of sandstone cliffs with siltstone and mudstone slopes. The cliffs are formed by layers of reddish brown and white, crossbedded sandstone (Navajo Sandstone) intertongued with slopes formed by purplish-red and reddish brown mudstone, siltstone and sandstone layers of the Kayenta Formation.

  The sandstone is fine-grained, soft to moderately hard and intensely to moderately weathered. The sandstone is typically cemented with calcium carbonate. Color ranges from reddish brown and medium dark purple to light gray. Layers of very hard chert up to 0.5-foot thick are present as discontinuous, intensely fractured lenses, usually within or in association with sandstone.

  The mudstone consists of approximately 60 percent clay and/or silt and 40 percent very fine sand. The mudstone is weakly indurated, nonfissile, moderately hard and moderately weathered. Color is medium purplish gray with light gray bands.

The siltstone is very fine-grained, moderately hard to hard and moderately weathered. Bedding ranges from 1/8 inch to 1.5 feet thick. Color is reddish brown to pale red.

- **(Jk) Kayenta Formation.** The Kayenta Formation typically consists of fluvial siltstone and sandstone. In the vicinity of Tuba City, the Kayenta formation is dissimilar in appearance to the type locality formation and is referred to as the silty facies of the Kayenta.

  The silty facies of the Kayenta Formation consists of fine-grained sandstone and interbedded mudstone. The bedding is lenticular, and crossbedding is common in the sandy units. The unit weathers into irregular badlands. Outcrops form rounded hills and earth pillars (hoodoos) having resistant cap rocks.

  The sandstone is fine-grained and locally silty with thin interbeds of purplish red, soft shale. The sandstone is moderately hard and moderately weathered. Bedding is spaced ½ inch to 1.5 feet apart. Color is pale red. The mudstone occurs as weakly indurated, nonfissile to fissile, thinly- to very thinly-bedded layers consisting of approximately 70 percent clay, and 30 percent fine sand.

  The mudstone is moderately weathered and moderately soft to moderately hard; fragments break with manual pressure, thicker portion requires moderate hammer blow to break. Color is medium reddish brown. Locally, thin limestone ledges occur in the upper part of the formation. The entire unit is banded pale red and grayish red.

- **(Jm) Moenave Formation.** The Moenave Formation in the Study Area consists entirely of the Dinosaur Canyon Member which is a succession of reddish-orange to light-brown sandstones, siltstones and mudstones of mainly fluvial and eolian origin. Exposures of the Moenave Formation form rounded hills, short cliffs, and hoodoos along the Echo Cliffs and on Ward Terrace. The contact with the underlying Owl Rock Member is unconformable and marked by a sharp contrast in lithology and color change from the reddish-orange fluvial sandstone of the Moenave to the gray mudstone, siltstone, and limestone of the Owl Rock.

  The sandstone is predominantly fine- to coarse-grained, moderately hard and moderately weathered. Bedding ranges from 0.1 to 6.0 feet thick and is locally crossbedded.

  The siltstone is very fine-grained, moderately hard to hard and moderately weathered. Bedding ranges from 1/8 inch to 1.5 feet thick.

Mudstone is very fine-grained (clay and silt-size particles), weakly indurated and moderately soft to moderately hard.

(TRco, TRcp, TRcs) Chinle Formation (Triassic). The Chinle Formation consists primarily of mudstone with layers of sandstone, conglomerate and limestone that were deposited by a large river system. The topography has since eroded into badlands with the mudstone weathering to clays that are prone to shrinking and swelling forming a popcorn-like texture. In the Study Area, the Chinle Formation is exposed along U.S. Highway 89 from Bitter Springs to Cameron, Arizona.

The Chinle Formation has been subdivided into three units, in descending order: the Owl Rock Member, the Petrified Forest Member, and the basal Shinarump Member. The Shinarump Member forms cliffs along the Little Colorado River and ledges that parallel U.S. Highway 89 and dip east. The resistant beds of the Owl Rock Member cap Ward Terrace. Between the river and Ward Terrace, the Petrified Forest Member is exposed forming an expanse of multicolored badlands commonly referred to as the “Painted Desert”.

- **(TRco) Owl Rock Member.** The Owl Rock Member consists of pale red to yellowish gray siltstone and shale interbedded with gray lenses of limestone. The siltstone is fine-grained, moderately hard and moderately weathered. Bedding is spaced 0.1 to 1.2 feet apart and the thickness of the layers range from a few inches to 4 feet. The shale is soft to moderately soft, moderately weathered and fissile. Shale layers range from a few inches to 5 feet thick. The limestone is hard, slightly weathered and moderately fractured; fractures and bedding are typically spaced 0.3 to 1 foot apart. Limestone layers range from 0.5 to 3 feet thick.

  The contact with the underlying Petrified Forest Member is generally marked a few feet below the lowest gray limestone bed of the Owl Rock Member.

- **(TRcp) Petrified Forest Member.** The Petrified Forest Member is typically subdivided into three units based on slight changes in lithology and color, but because the gradational changes are so variable and the engineering characteristics are similar, the units are not broken out in this Study. The unit is characterized by bentonitic mudstone interbedded with siltstone, sandstone and limestone. The Petrified Forest Member forms rounded hills and gentle slopes with random ledges of 0.5- to 2-foot-thick sandstone or limestone.

  The mudstone is a weakly indurated, nonfissile, conchoidally fracturing sedimentary rock consisting mostly of clay, but may contain up to 40% fine sand and a trace of lenticular gravel up to 10 mm in size. The mudstone is moderately soft to moderately hard, hand-size fragments break with manual pressure; thicker portion requires moderate hammer blow to break. Mudstone is variably cemented with calcium carbonate and has no to strong reaction with HCl. Color ranges from grayish red purple, medium to dark gray, with localized white and grayish red mottling and/or light greenish gray spots. Bedding is not discernible in test pit excavations, but when observed, bedding is spaced 1 to 4 inches apart in outcrops.

Photograph 5: Mudstone of the Chinle Formation, Petrified Forest Member forms soft, rounded mounds typical of badlands morphology. Date: September 2, 2015

Much of the mudstone consists of clays containing large amounts of bentonite, which formed in shallow waters into which a significant amount of volcanic ash fell. The silicate ash combined with various chemicals to form platelet-shaped crystals which impart its characteristic property of swelling to as much as 15 to 18 times its size when wetted by water.

The sandstone beds are composed predominately of fine- to medium-grained, subrounded to subangular sand variably cemented with calcium carbonate and/or silica. The sandstone is moderately soft and locally friable, breaks with manual pressure near the surface, but generally becomes harder with depth requiring a moderate hammer blow to break. Sandstone is slightly to moderately weathered; contains rust colored grains. Bedding ranges from less than 1 to 3 inches thick. Color is very light gray to brownish gray.

Contact with underlying Shinarump Member is gradational in most areas.

- **(TRcs) Shinarump Member.** The Shinarump Member is the basal unit of the Chinle Formation and consists of sandstone, conglomerate and lenses of mudstone and shale. It is resistant to erosion and forms continuous ledges and cliffs where exposed.

  The sandstone is comprised of subangular to subrounded, fine to predominantly medium and coarse grains of mostly quartz and feldspar.

Most of the sandstone units contain less argillaceous material as compared to the conglomerate. Calcium carbonate is the most common cementing agent, but silica and some ferruginous cement may be present. The sandstone is predominantly crossbedded, bedding is generally thinly to moderately bedded (spaced 0.1 to 1 feet apart), but can be massively bedded (greater than 10 feet) in some areas near the Little Colorado River. The sandstone is moderately hard to hard (can be scratched with a sharp pick with moderate pressure, requires heavy hammer blow to break), slightly to moderately weathered (oxidation limited to surfaces, some ferro-magnesium minerals are "rusty") and moderately fractured (fractures spaced 0.3 to 1 foot apart) mostly due to the presence of bedding joints.

Conglomerate consists of hard, subrounded, predominantly pebble to coarse gravel and cobble-size fragments in a matrix of sand and calcareous cement. Most of the gravel is composed of chert, quartz and/or quartzite. Conglomerate is moderately hard to very hard (can be scratched with a sharp pick with moderate pressure, requires repeated heavy hammer blow to break), slightly to moderately weathered (oxidation limited to surfaces, some ferro-magnesium minerals are "rusty") and generally moderately to slightly fractured (fractures spaced 0.5 to 3 feet apart).

Mudstone consists of weakly indurated, nonfissile, conchoidally fracturing sedimentary rock consisting of approximately 70 percent clay, and 30 percent fine sand cemented with calcium carbonate. The mudstone is slightly weathered and moderately soft to moderately hard (fragments break with manual pressure, thicker fragments requires moderate hammer blow to break). The shale interbeds are similar to the mudstone, but are fissile and bedding is laminated.

The lower contact with the Moenkopi Formation is unconformable.

Photograph 6: Shinarump Member (pebble conglomerate) outcrop along The Gap to Gray Mountain alignment near Sta. 5122+35. Date: August 29, 2011

- **(TRm) Moenkopi Formation (Early Triassic).** The Moenkopi Formation consists of reddish brown, interbedded shale, siltstone and sandstone interpreted to represent alluvial floodplain deposits and shallow tidal flats associated with a meandering river system. The Moenkopi Formation is typically subdivided into three units, in descending order, the Holbrook Member, Shnabkaib Member, and the Wupatki Member. The member units have similar engineering characteristic and were therefore combined as the Moenkopi undivided.

  The Moenkopi is composed mostly of reddish brown, argillaceous shale with interbedded lenses of siltstone, sandstone and infrequent limestone that form a slope and ledge topography. The shale is very fine-grained, fissile and moderately soft. Bedding is very thinly bedded to laminated (bedding spaced 3/8 inch to less than 1/8 inch). The siltstone is fine-grained, moderately hard and typically intensely to moderately fractured depending on the spacing of bedding planes. Bedding ranges from 0.1 to 1.3 feet apart. Sandstone is predominantly fine- to coarse-grained, moderately hard and moderately fractured. Bedding ranges from 0.1 to 4 feet apart. Limestone layers are 0.5 to 2 feet thick, hard and laminated to moderately bedded (bedding ranges from 1/8 to 4 inches thick).

  A dark reddish brown, cliff-forming sandstone layer referred to as the "lower massive sandstone" in the literature is exposed in the Little Colorado River Gorge at Cameron where it is about 40 to 50 feet thick.

Photograph 7: Shale and siltstone of the Moenkopi Formation (reddish brown hill in background) overlying the sandy limestone of the Kaibab Limestone (foreground) along The Gap to Bitter Springs alignment. Date: August 29, 2011

- **(Pk) Kaibab Limestone (Permian).** The Kaibab Limestone is primarily a sandy limestone or calcareous sandstone that contains mollusk fossils.

The unit is often weathered or stained dark gray or black by manganese oxide and forms a ledge-and-slope profile or broad flat plains in open areas.

The limestone is aphanic to fine-grained, strongly cemented with calcium carbonate and moderately hard in hand specimen (breaks with moderate hammer blow), but hard to very hard in outcrop (requires repeated heavy blow to break). The limestone is slightly weathered and moderately bedded; bedding planes are spaced 1 inch to 1 foot apart. Outcrops are moderately to slightly fractured, with fractures spaced 0.4 to 2 feet apart. Color is very light gray to very pale orange.

The sandstone is fine- to coarse-grained, calcareous, hard to very hard and slightly weathered. Bedding is spaced 1/2 to 8 inches apart and locally crossbedded. Color is light gray to yellowish gray.

5.1.3.2 Paleontological Resources

Fossils are the remains, imprints and traces of once-living organisms preserved in the Earth's crust. They may be bones and teeth, shells, leaf impressions, footprints, or burrows. Fossils are nonrenewable and relatively rare resources with significant scientific, educational, commercial, and recreational values. Paleontology is the science that uses fossils to study life in past geologic times.

The Chinle Formation, exposed along the NCAP alignment from The Gap to Cameron and from The Gap to Bitter Springs is famous for its petrified wood, but it also contains fossils of both amphibious and terrestrial reptiles and some of the early dinosaurs. The fauna of the Glen Canyon Group, which is exposed from Page to the Gap and around Tuba City, includes mollusks, crustaceans, fish, reptiles and dinosaurs. Reptile and dinosaur tracks are locally common.

The Paleontological Resources Preservation Act requires the Secretaries of the Interior and Agriculture to manage and protect paleontological resources on federal land. The law applies only to federal lands and includes criminal and civil penalties for fossil theft and vandalism while providing authority for issuing permits for collecting paleontological resources. Federal agencies are in the process of developing and implementing regulations.

Additional investigations may be necessary to delineate areas along the alignment which may contain fossils so that they can be monitored during construction activities.

5.1.4 General Geotechnical Considerations

Construction of the NCAP alignment will require typical construction techniques and may include directional drilled and installed pipeline sections, cofferdams, and infrastructure (e.g., pumping plants, meter vaults). Areas with potential adverse geologic site conditions will require site-specific exploration and laboratory testing. Possible adverse site conditions anticipated within the NCAP project area are discussed below. Features must also be constructed to minimize impacts to infrastructure in urban areas.

Most soil and rock foundations are assumed to provide adequate bearing capacity for pipelines and required infrastructure. Areas of loose and unconsolidated alluvium, colluvium and eolian deposits may require site-specific investigation, laboratory testing, design, and construction methods. Ground improvement, modification, or over-excavation may be required at heavy structures or elements under hydraulic stress (pumping plants, storage tanks, etc.) and/or areas possessing adverse foundation conditions as discussed below.

5.1.4.1 Expansive (Shrink/Swell) Soils

The shrink/swell potential of a soil or rock is the relative volume change that can be expected with changes in moisture content. When water is added, the clay minerals expand both vertically and horizontally. As the soils dry, the water loss causes shrinkage that can create surface cracks. This shrink/swell process disturbs the surface giving exposures a characteristic “popcorn” texture. This texture is readily seen on outcrops of the mudstones of the Chinle Formation, Petrified Forest Member.

Expansive soils and rock units are common along U.S. Highway 89 from Cedar Ridge to Cameron. Soils derived from the mudstone and shales of the Chinle Formation may have high to very high shrink-swell potential and may be moderately to highly corrosive to uncoated steel and concrete. Identification, delineation, and lab characteristics of these materials would be necessary to complete the design of the required NCAP features. Table 19 shows the Expansion Index measured in mudstone samples taken from six test pits excavated along U.S. Highway 89 in the Chinle Formation, Petrified Forest Member.

Table 19: Expansion Index Measured in Test Pits Excavated in the Chinle Formation, Petrified Forest Member

Test Pit	Depth (ft)	Material	Expansion Index	Potential Expansion
TP-18	2.5 - 9.0	Mudstone (Lean Clay)	49	Low
TP-30	2.0 -14.0	Mudstone (Lean Clay with Sand)	129	High
TP-40	0.0 - 5.0	Mudstone (Lean Clay with Sand)	137	Very High
TP-41	3.0 - 8.0	Mudstone (Fat Clay)	117	High
TP-46	0.0 - 8.0	Mudstone (Sandy Silt with Gravel)	40	Low
TP-48	1.8 - 7.5	Mudstone (Sandy Lean Clay)	20	Very Low

Swelling and shrinking of soils can cause damage to the pipeline and building foundations. A high shrink/swell potential indicates a hazard to maintenance of structures built in, on, or with material having this rating. Moderate and low ratings lessen the hazard accordingly.

Photograph 8: Mudstone of the Chinle Formation, Petrified Forest Member. The surface of the mudstone exhibits the characteristic "popcorn" texture indicative of materials with high shrink/swell potential. Date: August 29, 2011

5.1.4.2 Corrosion Potential

The potential for a soil or rock to react with construction materials such as concrete and ferrous metals is indicated by a number of parameters including resistivity, pH, sulfate, chloride, redox potential, and sulfide. Rapid and severe concrete deterioration can occur when concrete is improperly proportioned and comes in contact with soil or groundwater with abnormal levels of sulfates or chlorides, or water with a low pH. Strength loss of concrete and significant corrosion of reinforcing steel can occur in these conditions.

Selected test pit soil samples were measured for electrical resistivity, pH, and sulfate, sulfide and chloride content. Test results are shown on Table G-3 – *North Central Arizona Pipeline - Corrosion Potential* located in Appendix G3 – *Geology: Test Pit Laboratory Results*. Reclamation defines "highly corrosive soils" as any soil with a soil resistivity of 2,000 ohm-cm or less. Of the 70 samples measured, 56 percent rated as highly corrosive based on that definition. Cathodic protection may be required for sections of the proposed pipeline and related infrastructure that traverse the Chinle Formation and in alluvial materials found along the Gap to Bitter Springs alignment.

It should be noted that resistivity testing has only been conducted on test pit soil samples. No resistivity field surveys have been conducted for corrosion potential at this time.

5.1.4.3 Erosion Protection

Erosion protection may be required where the NCAP alignment intersects stream channels, intermittent stream channels and storm water runoff channels that have the potential for scour. Additional site-specific exploration and evaluation may be required for areas susceptible to high rates of scour and erosion.

A scour study, conducted in April 2013, assessed 132 sites along the proposed alignment from Page to Flagstaff and from The Gap to Bitter Springs and the U.S. Highway 89 Tee to Tuba City. Results of the scour study are contained in Appendix F. The alignment from Tuba City to Keams Canyon was not evaluated at that time. Future scour studies will be necessary for that segment of the NCAP alignment.

5.1.4.4 Foundation Strength

The strength of foundation materials is anticipated to be variable in alluvial deposits with some zones of loose, low density materials. Low strength foundation conditions are anticipated in clean, coarse-grained (poorly graded sand and poorly graded gravel) zones that have no cohesion and very high relative permeabilities. Relative permeabilities are anticipated to be high in all soil deposits, except clayey deposits. The occurrence and percentage of cobble- and boulder-size clasts is anticipated to be high along portions of the alignment that lie at the foot of steep cliffs or abrupt changes in elevations, such as The Gap to Bitter Springs alignment near the Echo Cliffs. Temporary slopes are anticipated to be stable at 1:1 or flatter in most dry (or dewatered) cut slopes excavated in alluvium.

Eolian deposits (Qe) were grouped separately from alluvial units. Qe is comprised of windblown deposits of fine sand and silt. This unit is anticipated to be loose and unconsolidated. Excavation through Qe materials would generally require flatter side slopes than excavations in alluvial units. Additional engineering and design may be necessary to accommodate changes in sand dune shape and configuration to maintain access to NCAP features. Eolian deposits are common on the Kaibito Plateau from Page to The Gap and along the alignment from west of Tuba City to Keams Canyon.

Eolian deposits are anticipated to have low foundation strength and would likely require compaction efforts or additional design to achieve adequate bearing capacity for pumping plant foundations. The soil is anticipated to be loose with low densities and no to low cohesion. Although most eolian deposits are anticipated to be dry, the unit has high relative permeabilities. Temporary slopes are anticipated to be stable at 2:1 or flatter in most dry (or dewatered) cut slopes excavated in eolian deposits.

Although not discussed at this level of study, more refined geologic characterization may be necessary to delineate possible clay deposits in pumping plant foundations. Clay foundations may require treatment or may need to be over excavated and replaced with select materials to construct NCAP features. Clay foundations may be susceptible to expansion, shrinkage, and other issues that cause constructability concerns.

All rock units are anticipated to have moderate to high foundation strengths and to provide adequate bearing capacity. Rock units would likely vary from low to high rates of permeability and secondary permeability. If permeability becomes an issue, site-specific analysis would likely be required. Temporary slopes are anticipated to be stable at near vertical to 1:1 slopes in moderately weathered to fresh rock units. Decomposed and intensely weathered rock units may require 1.5:1 or flatter temporary slopes.

5.1.5 Excavation Requirements

The majority of the excavation along the proposed alignment of the NCAP will require common excavation methods through alluvial, eolian and colluvial soil deposits, and soft rock units. Table G-1, titled *North Central Arizona Pipeline – Station to Station Geologic Surface Mapping*, located in Appendix G4 – *Geology: Geologic Mapping* describes the surface geology that has been mapped from station to station along the proposed alignment. The table includes the anticipated method of excavation based on limited test pit information and field mapping. Alluvium, colluvium and eolian deposits are all considered common excavation. Much of the sandstone, mudstone and shale encountered during test pit excavations that was classified as soft to moderately soft is assumed to be common excavation, even though the bedrock resisted excavation with a Deere 310K backhoe. It is assumed that a larger piece of equipment would be capable of excavating to the required excavation depth and the material was therefore classified as common excavation.

Although most soft rock units are anticipated to be excavatable using common excavation methods, some rock units or portions of rock units may require rock excavation, or it may be more economical to use rock excavation techniques. Site-specific analysis would be required to better define excavation requirements.

The NCAP alignment crosses a range of geological formations. Rock excavation techniques, like blasting or hydraulic hoe ramming, may be required in some of these areas to allow for excavation of the pipeline trench and other appurtenant feature foundations. Blasting may be needed if hard rocks are encountered near the surface.

Intersections with existing infrastructure (including roadways, railroad tracks, above and below ground utilities, etc.) may require horizontal directional drilling (HDD) methods. Site specific exploration and design will be required at each potential location.

5.1.6 Dewatering

The alignment of the pipeline is generally above the groundwater table. Exceptions are in areas where the alignment follows along or crosses washes or in areas where clay or low permeability materials produce perched groundwater conditions. Shallow groundwater can be expected in those areas with considerable seasonal fluctuations.

Evidence of groundwater near the surface can be seen along The Gap to Bitter Springs alignment from about station 3480+50 to 3489+25. Salts have accumulated at the surface as groundwater evaporates, leaving a mineral crust behind. Test pit TP-27 located at about station 3482+72 encountered groundwater at 4.5 feet below ground surface.

Trenching and excavations for NCAP feature foundations in wet conditions would need to be addressed in future planning and design phases. Dewatering and/or unwatering techniques would be required to construct portions of the NCAP project that intersect areas with high groundwater levels.

5.1.7 Slope Stability

Recommendations for cut slopes in surficial deposits were based on material type and texture. All cut slopes would need to be constructed in accordance with *Bureau of Reclamation Safety and Health Standards* (Reclamation, 2009) and pertinent Occupational Safety and Health Administration standards. Materials with excessive moisture may require further flattening for stability.

Cut slopes in bedrock would depend on the rock type and degree of weathering. Cut slopes in decomposed to intensely weathered, very soft to soft bedrock may require benching or cut slopes similar to those in soils, depending on the composition of the rock. Moderately weathered to fresh, moderately soft to hard bedrock could have vertical slopes if all requirements of the *Reclamation Safety and Health Standards* are met.

5.1.8 Geologic Hazards and Considerations

5.1.8.1 Liquefiable Soils

Although there may be loose and potentially liquefiable soils along the alignment, seismic risk is low within the project area. NCAP pipeline and appurtenant structures would generally be light and would not intersect any known active faults. Additional geologic investigations may be necessary to identify potentially liquefiable foundation materials.

5.1.8.2 Uranium Deposits

Within the Study Area, uranium ores occur naturally stratigraphically from the Moenkopi Formation to the Kayenta Formation with commercial mining concentrated in the lower portion of the Chinle Formation, Petrified Forest and Shinarump Members. Uranium ores may be encountered during excavation in geologic units that possess the conditions needed for ore deposition. Most of the ore bodies to date have been found in ancient stream channels that were eroded into shales and mudstones and filled with coarse-grained sediments and carbonaceous (organic) material interbedded with impermeable shale and mudstone. Uranium-rich fluids are generally mobile under oxidizing conditions, but will precipitate in the presence of a reducing environment. The carbonaceous material appears to have acted as the precipitating agent for the uranium minerals while the shale and mudstone layers formed an impermeable barrier that aided in ore deposition and retention.

Several abandoned uranium mines are located along or near the NCAP alignment north of Cameron, Arizona. The Jack Daniels No. 1 mine and the adjacent Jack Daniels No. 2, No. 4 and No. 5 mines are located about 2 miles north of the Little Colorado River. The proposed Gap to Gray Mountain pipeline alignment from station 4668+00 to 4680+00 runs along the western edge of the area disturbed by mining operations. The Jack Daniels No. 1 open pit mine has been filled in leaving an oval-shaped depression about 250 feet long, 160 feet wide and 1 to 4 feet deep. The depression fills with surface runoff during rain events.

The Jack Daniels No. 1 mine was named for a discarded whiskey bottle observed near radioactive drill cuttings left at the base of a powerline pole, which led to the discovery of the ore body. The mine was operated from 1956 to 1961 and, with a total production of 39,440 tons of ore, was the largest uranium mine in the area. The open pit was 500 feet long, 250 feet wide with a maximum depth of 26 feet. Three feet of overburden was removed to expose the ore body.

The Jack Daniels No. 1 ore body developed in a lens of fine- to medium-grained sandstone, clay-pellet sandstone, and clay-pellet conglomerate that contained carbonaceous matter, including carbonaceous fossil logs. The sandstones were deposited in irregular depressions cut into the mudstone near the base of the Chinle Petrified Forest Member and represent ancient fluvial channel fills. The sandstone at the Jack Daniels No. 1 ranged in thickness from 2 to 18 feet.

While doing clean-up mining in the Jack Daniels No. 1 open pit in 1960, it was determined that the ore body in the southwest corner of the pit extended to the west under U.S. Highway 89. After the highway was relocated in 1961, the southwest wall of the No. 1 pit was extended to the west forming an open pit 240 feet long, 100 feet wide and 10 feet deep that was named Jack Daniels No. 5. The proposed pipeline alignment crosses the No. 5 pit from about station 4674+00 to 4676+00.

The Charles Huskon No. 19 mine is located about 1,700 feet northeast of the Jack Daniels No. 1 mine, about 850 feet east of the pipeline alignment at station 4662+00. Although the alignment does not intersect the mine, there may be residual radiation associated with it.

No geologic investigations have been conducted to determine if uranium ores will be encountered during excavation of the proposed pipeline and appurtenant features. Future explorations may be necessary to test for potential radioactive hazards.

5.1.8.3 Landslides

The gentle slopes over most of the alignment make the potential for landslide hazards remote except in areas where the NCAP alignment traverses steep changes in elevation and rock type. An example of this condition is along cliff faces where hard sandstone overlies soft shale. Blocks of the sandstone can become detached and slide down the shale slope. These conditions can be found along the alignment from Tuba City to Keams Canyon near stations 1482+75, 2509+90, 2594+20 and 3026+40.

Existing landslides of this nature are also located on the Tuba City to Keams Canyon segment of the alignment from about station 3300+00 to 3350+00 where the alignment drops down from Second Mesa. Large (500- to 2,000-foot-long) blocks of layered sandstone of the Mesaverde Group, Toreva Formation have slid down the slope formed by the underlying softer shale of the Mancos Shale Formation. As the blocks slid, they rotated in a backward motion forming backward dipping steps leading down the slope. This type of rotational landslide is known as Toreva block, named for the type locality in the vicinity of Toreva, the small town located nearby. The depths of the failure surfaces are unknown.

A more detailed, site specific review of existing and potential landslides may be warranted during subsequent studies.

5.2 Seismic

Glen Canyon Dam is located in the interior of the Colorado Plateau Physiographic Province, approximately 4 miles from the proposed intake pumping plant, and is the nearest Reclamation facility. As discussed in the *Glen Canyon Dam Comprehensive Facility (CFR) Review* (Reclamation, 2010), the seismic loadings presented in the summary were taken from the reports by O’Connell (Reclamation, 2005) and Wong and others (Reclamation, 2000c). No new field investigations were conducted, nor were aerial photos reviewed as part of this report. This represents a fundamental limitation to the conclusions presented in the CFR summary, in part because no detailed seismic hazard studies have been done since an initial study by Klinger (Reclamation, 1991).

Two types of seismic sources contribute to the hazard at Glen Canyon Dam: faults and background seismicity. The closest fault with suspected Quaternary activity is the Eminence fault zone (~34 km from the dam), but estimated slip rates for this fault are very low (<0.2 mm/yr). Thus, the seismic hazard is dominated by background seismicity (Reclamation, 2000c).

Reclamation dam safety related features, such as Glen Canyon Dam, are reviewed using probabilistic loadings considering approximate return periods of 10,000 years and 50,000 years, while building type structures such as plants considered in the NCAWSFS would be evaluated for a return period of 2,500 years.

The peak horizontal acceleration (PHA) curve for Glen Canyon Dam is provided in the 2010 CFR. For annual exceedance probabilities (AEP) of $4x10^{-4}$ (equivalent to a return period of 2,500 years), the mean ground acceleration is calculated to be

0.09g; for an AEP of $1x10^{-4}$ (equivalent to a return period of 10,000 years), the mean ground acceleration is calculated to be 0.17g; and for an AEP of $2x10^{-5}$ (50,000 year return period), the mean ground acceleration is 0.30g. At Glen Canyon Dam, background seismicity controls the hazard.

The 1.0 second spectral acceleration curves for Glen Canyon Dam are provided in the 2010 CFR. For a return period of 2,500 years, the mean 1.0 second spectral acceleration is calculated to be 0.10g; for a return period of 10,000 years, it is calculated to be 0.16g; and for an AEP of $2x10^{-5}$ (50,000 year return period), the mean 1.0 second spectral acceleration is 0.25g.

The 0.2-second spectral acceleration curves for Glen Canyon Dam were not prepared nor provided in the 2010 CFR.

Ground movement seismic activity is anticipated to be minimal and should not adversely affect proposed NCAWSFS features.

5.2.1 Seismic Design Criteria for New Building and Other Structures

Local ground motions in regions with well-defined earthquake sources, known as deterministic motions, are used to develop Maximum Considered Earthquake (MCE) maps. The MCE is a term introduced by the Building Seismic Safety Council, which is an expert panel established by the National Institute of Building Sciences to develop national earthquake design standards. Current practice for the seismic analysis and design of new buildings establishes the Design Basis Earthquake (DBE) as a fraction of the MCE. In most of the Nation, the MCE is defined as a probabilistic ground motion having a 2-percent probability of being exceeded in 50 years, or in other words, it has an approximate return period of 2,500 years. In regions near faults, deterministic values establish the MCE, which remains equal to or less than the 2,500-year event. The Building Seismic Safety Council acknowledges that stronger shaking than the MCE could occur; however, it is judged economically impractical to design for such very rare ground motions, and selection of the 2,500-year event as the MCE ground motion would result in acceptable levels of seismic safety for the Nation. The Building Seismic Safety Council further substantiates its selection of the MCE by two aspects: (1) the seismic margin (i.e., built-in conservatism) in actual current design provisions is estimated to be at least a factor of 1.5, and (2) the positive response of newly designed buildings in coastal California during recent earthquakes. Based on the above discussion, the MCE selected for most facilities that would be constructed as part of the NCAP (such as pumping plants, and other building type structures) should be the 2,500-year event.

Following current standards for building design, the DBE for buildings should be considered as two-thirds of the MCE. This reduction is based largely on the estimated seismic margin believed to be embedded in current design standards. This seismic margin is based on several factors including the inherent conservatism in the analysis procedure, ratio of actual-to-specific material strength, and most importantly, prescriptive ductile detailing.

As mentioned above, the second aspect of a performance-based seismic evaluation is the expected performance level of the facility at the selected evaluation event. For most Bureau of Reclamation buildings, the minimum performance level to be satisfied is that which provides life-safety for the occupants and visitors. In some instances, however, given the economic value of the building, its content, or its operation, it is desirable to satisfy a higher performance level, which allows for minimal damage in the structure and the equipment.

Given the small tolerances necessary for functional operation of hydraulic equipment, many pumping plant substructures should remain elastic under the DBE. This performance condition would be the standard applied to that portion of the structure that is below ground or supports critical hydraulic equipment. For those portions of the structure that are above grade, the seismic design provisions in the *International Building Code* (IBC) (International Building Code Council, Inc., 2009) and the ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2005) are intended to be followed in their entirety because the reductions applied to the seismic loads are coupled with specific detailing requirements described in those provisions. To reduce the seismic loads, the superstructure must absorb the earthquake energy through nonlinear deformations, which could only be realized if proper detailing is provided. It should also be understood that the lower the acceptable level of risk of damage for the building, the lower the reduction factors should be.

It should be noted that the DBE ground motion level specified could result in both structural and nonstructural damage when evaluated for a life-safety performance level. For essential facilities, it is expected that the damage from the DBE ground motion would not be severe enough to preclude continued occupancy and function of the facility.

Current practice is to characterize the seismic demand at a site with a design response spectrum, which comprises a relationship of the maximum response ordinate (commonly spectral response acceleration) over the entire response-history record of a single-degree-of-freedom oscillator and the period or frequency of the oscillator, for a specified level of damping. Modern design standards such as ASCE/SEI 7 contain prescriptive provisions for developing a site design response spectrum using values of spectral response accelerations for short and long periods. These spectral accelerations are often obtained from ground shaking hazard maps for the MCE and are adjusted for specific site classification or may be developed based on site-specific seismic hazard characterization.

5.2.2 Site-Specific Determination of the MCE and DBE

In some cases, a site-specific seismic hazard study will be required. In general, a Probabilistic Seismic Hazard Analysis (PSHA) based on seismic sources and ground motion attenuation relationships with corresponding return periods of (but not limited to) 5,000, 10,000, and 50,000 years may be available because it is the preferred procedure used in dam analysis.

Current code requirements noted in ASCE/SEI 7 require that site-specific ground motion spectra of the DBE and the MCE be developed if:

- The structure is located on a Site Class F
- The structure is located at a site with the 1-second spectral response acceleration parameter (S1) greater than or equal to 0.60

If a site-specific PSHA is performed, the value of the PHA for the 2,500-year recurrence period (2-percent probability of exceedance within a 50-year period) would be extracted from the mean hazard curve developed in the site-specific study. This value for PHA would be considered the PHA for the MCE ground motion. The design spectral response acceleration at any period should be determined as two-thirds of the MCE spectral response acceleration. Many Bureau of Reclamation facilities, particularly dam sites, have existing and recently developed data from site-specific seismic hazard analysis. The availability of recently developed data for Glen Canyon Dam should be investigated and considered for evaluation of existing buildings or development of designs for new buildings at or near a dam site.

5.2.3 Prescriptive Determination of the MCE and DBE

In most cases, a site-specific PSHA would not be performed for pumping plant designs. A more common approach to determine the DBE demand would be to develop the site design response spectra curve using values of spectral accelerations obtained from national maps for the MCE and modified based on site classification. National maps depicting spectral accelerations for the MCE are available on the USGS website at: earthquake.usgs.gov/hazards/designmaps/buildings.php

5.2.4 Seismic Analysis Procedures for Superstructures

Current seismic analysis for superstructures (portion of facility or building above grade) uses one of three analytical procedures in accordance with ASCE/SEI 7. These procedures are known as:

- Equivalent Lateral Force Analysis
- Modal Response Spectrum Analysis
- Seismic Response History Analysis

It should be noted that the Equivalent Lateral Force Analysis may not be suitable for the seismic analysis and design of many new Bureau of Reclamation pumping plants. The required occupancy categories and the seismic design categories for many Reclamation facilities may eliminate this method from consideration.

The definitions for irregular structures in ASCE/SEI 7 can be difficult to correlate directly to Bureau of Reclamation plants. Current Reclamation practice considers a plant with an overhead crane to have a mass irregularity and a plant with stepped columns to be a vertical irregularity. Many of these plants are located in seismic areas with foundation conditions and occupancy categories that produce a seismic design category of D or E. These conditions result in a requirement to use the Modal Response Spectrum Analysis or Seismic Response History Procedure.

Nevertheless, it is not anticipated that NCAWSFS plants would have overhead cranes; they would be designed with removable hatch covers to allow the use of mobile cranes for performing OM&R activities on pumps and related equipment.

The Seismic Response History Analysis requires extensive ground motion data, as well as time for preparing the mathematical model and processing the analysis and results. Based on current computer modeling methods and techniques, the preparation and processing costs, in terms of time and money, and the benefits obtained from this method do not justify its use for most Reclamation plants and facilities.

The use of Modal Response Spectrum Analysis is well suited for structures supported above ground, in which the structure undergoes various modes of vibration, having different periods in response to the ground excitation. The structural response results in an amplification of the input ground acceleration. The total response of the structure is determined by combining the responses in the various modes of vibrations.

Common practice within Reclamation is to characterize the seismic demand at a site with a design response spectrum, which comprises a relationship of the maximum response ordinate (commonly spectral response acceleration) over the entire response-history record of a single-degree-of-freedom oscillator and the period or frequency of the oscillator, for a specified level of damping. Modern design standards such as ASCE/SEI 7 contain prescriptive provisions for constructing a site design response spectrum using values of spectral response accelerations for short periods (Ss, 0.2 second) and long periods (S_1, 1 second), which are often obtained from national maps for the MCE and are adjusted for specific site classification or may be developed based on site-specific seismic hazard characterization.

5.2.5 Seismic Analysis Procedure for Structures Below Ground

For underground structures, such as substructures for pumping plants, the dynamic response is different. It is reasonable to assume that these portions of the plant structure are restrained against free vibration, and hence, they only experience the ground excitation. Accordingly, the DBE demand for plant substructures will typically be represented by two-thirds of the PHA for the 2,500-year event. It should be understood, however, that systems and components within the plant structure may experience spectral accelerations higher than the PHA, depending on their dynamic characteristics (i.e., stiffness and mass).

If the substructure for the plant is not cast against rock, but is buried by placing backfill or embankment against the substructure, then the lateral earth pressures against the substructure are calculated similarly to the lateral earth pressures against retaining walls. Common Reclamation practice computes a total active fill force, P_{AE}, during a seismic event by adding a dynamic force component, $\Delta P_{AE,}$ to the active static lateral earth pressure force. Refer to *Design Criteria for Concrete Retaining Walls* (Reclamation, 1977) for a detailed description of this method.

The design value for the PHA used for analysis and design of structures below ground is obtained by extracting the acceleration at period T = 0 seconds from the response spectrum curve. For values of the PHA at T = 0 seconds that are greater than approximately 0.5g, methods other than that described in *Design Criteria for Concrete Retaining Walls* would be required.

The procedure described above for computing lateral earth pressures is based on Rankine's theory and the Mononobe-Okabe method for calculating lateral earth pressure. Also, the *Design Criteria for Concrete Retaining Walls* is limited to specific values of the effective angle of internal friction for the backfill material and to values of PHA less than approximately 0.5g. Other methods are available and have been developed since that method was initially adopted within Bureau of Reclamation in 1971, including advanced computer modeling methods for soil/structure interaction in both the static and dynamic conditions. Other methods may be appropriate and/or required for computing lateral earth pressures for seismic loading, particularly for large ground accelerations and/or unique soil conditions.

5.2.6 General Design Requirements

Selection of categories, design factors, and load factors required to perform designs in accordance with the IBC and ASCE/SEI 7 will be the responsibility of the design engineers. The following paragraphs briefly discuss the basis and recommendations for selecting values for parameters commonly required when the Bureau of Reclamation designs plants and other building type structures. Selection of values for these parameters is based on Reclamation's interpretation and application of the seismic design requirements found in the IBC and ASCE/SEI 7. Although the values for these parameters are assigned to each building on an individual basis, the paragraphs that follow present what is considered common practice within the Bureau of Reclamation.

Per ASCE/SEI 7, Reclamation typically assigns an occupancy category of III to major and minor pumping plants, and it can be extended to water treatment plants. Occupancy category III is selected for pumping plants if the loss of these facilities would have substantial economic impacts and/or cause a mass disruption of day-to-day civilian life in the event of failure.

The importance factor originated with the seismic base shear equation in the *Uniform Building Code* (International Conference of Building Officials, 1976). The concept and purpose of the importance factor at that time was to increase the design seismic forces in order to provide additional seismic resistance and prevent catastrophic collapse. Current practice within Bureau of Reclamation is to use ASCE/SEI 7 to assign occupancy importance factor of 1.25 to buildings in occupancy category III. The importance factors greater than 1.0 have the effect of reducing the potential for damage.

Based on current IBC and ASCE/SEI 7 provisions, structures designed to comply with the requirements of occupancy category III are expected to meet the life safety structural performance level.

In accordance with ASCE/SEI 7, depending on plant superstructure model building type(s), a Response Modification Coefficient, R, would need to be determined. The coefficient depends on the plant superstructure lateral-force resisting system(s) and accounts for facility ductility and requires appropriate structural member and connection detailing. The coefficient would reduce site spectral response acceleration parameters.

Site soil classifications would need to be made along the NCAWSFS pipeline route and should be based on a geological investigation that is conducted during the design data collection phase of the project. Site class type should be assigned in accordance with ASCE/SEI 7.

As seen in Table 20, spectral response acceleration parameters were determined, using ASCE/SEI 7 mapped MCE ground motion parameters, for several sites along the NCAWSFS alternative routes for a range of soil classifications. The Glen Canyon Dam site is founded on the Navajo Formation, moderately cemented sandstone (Class B). Depending on the soil classification and occupancy category, the NCAWSFS project area most likely would fall within a seismic design category of B or C and have a low to moderate level of seismicity and, thus, a low level of seismic hazard.

Design and installation of electrical equipment such as power transformers, breakers, unit substations, electrical cabinets, engine generators, etc., shall be in accordance with Institute of Electrical and Electronics Engineers (IEEE) *Standard 693, Recommended Practice for Seismic Design of Substations* (IEEE, 2005).

Other nonstructural components such as miscellaneous building structural subsystems, architectural elements, mechanical, and electrical equipment (not covered in *IEEE Standard 693*) shall be permanently attached to structures in accordance with design criteria provided in Chapter 13 of ASCE/SEI 7: Minimum Design Loads for Buildings and Other Structures, entitled *Seismic Design Requirements for Nonstructural Components* (ASCE, 2005).

Table 20: Summary of Multiple Site Spectral Response Acceleration Parameters

Location	Latitude (degrees)	Longitude (degrees)	S_s 0.2 sec (g)	S_1 1.0 sec (g)	Soil Class	F_a	F_v	$S_{MS} = F_aS_s$ (g)	$S_{M1} = F_aS_1$ (g)	S_{DS} = 2/3 S_{MS} (g)	S_{D1} = 2/3 S_{M1} (g)	PHA 0.4 S_{DS} (g)
Glen Canyon Dam	36.94N	111.48W			A	0.8	0.8	0.254	0.078	0.170	0.052	0.07
			0.318	0.098	B	1.0	1.0	0.318	0.098	0.212	0.065	0.08
					C	1.2	1.7	0.382	0.167	0.254	0.111	0.10
					D	1.6	2.4	0.509	0.235	0.339	0.157	0.14
					E	2.5	3.5	0.795	0.343	0.530	0.229	0.21
Page	36.90N	111.45W			A	0.8	0.8	0.254	0.078	0.170	0.052	0.07
			0.317	0.098	B	1.0	1.0	0.318	0.098	0.212	0.065	0.08
					C	1.2	1.7	0.382	0.167	0.254	0.111	0.10
					D	1.6	2.4	0.509	0.235	0.339	0.157	0.14
					E	2.5	3.5	0.795	0.343	0.530	0.229	0.21
LeChee	36.87N	111.47W			A	0.8	0.8	0.254	0.078	0.170	0.052	0.07
			0.318	0.098	B	1.0	1.0	0.318	0.098	0.212	0.065	0.08
					C	1.2	1.7	0.382	0.167	0.254	0.111	0.10
					D	1.6	2.4	0.509	0.235	0.339	0.157	0.14
					E	2.5	3.5	0.795	0.343	0.530	0.229	0.21
Coppermine	36.63N	111.45W			A	0.8	0.8	0.269	0.082	0.179	0.054	0.07
			0.336	0.102	B	1.0	1.0	0.336	0.102	0.224	0.068	0.09
					C	1.2	1.7	0.403	0.173	0.269	0.116	0.11
					D	1.6	2.4	0.538	0.245	0.358	0.163	0.14
					E	2.5	3.5	0.840	0.357	0.560	0.238	0.22

Location	Latitude (degrees)	Longitude (degrees)	S_s 0.2 sec (g)	S_1 1.0 sec (g)	Soil Class	F_a	F_v	$S_{MS} = F_aS_s$ (g)	$S_{M1} = F_aS_1$ (g)	$S_{DS} =$ 2/3 S_{MS} (g)	$S_{D1} =$ 2/3 S_{M1} (g)	PHA 0.4 S_{DS} (g)
Bodaway Gap	36.30N	111.46W			A	0.8	0.8	0.318	0.092	0.212	0.061	0.08
			0.398	0.115	B	1.0	1.0	0.398	0.115	0.265	0.077	0.11
					C	1.2	1.7	0.478	0.196	0.318	0.130	0.13
					D	1.6	2.4	0.637	0.276	0.425	0.184	0.17
					E	2.5	3.5	0.995	0.403	0.663	0.268	0.27
Bitter Springs	36.64N	111.66W			A	0.8	0.8	0.282	0.086	0.188	0.058	0.08
			0.352	0.108	B	1.0	1.0	0.352	0.108	0.235	0.072	0.09
					C	1.2	1.7	0.422	0.184	0.282	0.122	0.11
					D	1.6	2.4	0.563	0.259	0.375	0.173	0.15
					E	2.5	3.5	0.880	0.378	0.587	0.252	0.23
Tuba City	36.14N	111.24W			A	0.8	0.8	0.284	0.082	0.189	0.055	0.08
			0.355	0.103	B	1.0	1.0	0.355	0.103	0.237	0.069	0.09
					C	1.2	1.7	0.426	0.175	0.284	0.117	0.11
					D	1.6	2.4	0.568	0.247	0.379	0.165	0.15
					E	2.5	3.5	0.888	0.361	0.592	0.240	0.24
Cameron	35.87N	111.41W			A	0.8	0.8	0.352	0.099	0.235	0.066	0.09
			0.440	0.124	B	1.0	1.0	0.440	0.124	0.293	0.083	0.12
					C	1.2	1.7	0.528	0.211	0.352	0.141	0.14
					D	1.6	2.4	0.704	0.298	0.469	0.198	0.19
					E	2.5	3.5	1.100	0.434	0.733	0.289	0.29

Location	Latitude (degrees)	Longitude (degrees)	S_s 0.2 sec (g)	S_1 1.0 sec (g)	Soil Class	F_a	F_v	$S_{MS} = F_aS_s$ (g)	$S_{M1} = F_aS_1$ (g)	S_{DS} = 2/3 S_{MS} (g)	S_{D1} = 2/3 S_{M1} (g)	PHA 0.4 S_{DS} (g)
Gray Mtn.	35.75N	111.47W			A	0.8	0.8	0.366	0.103	0.244	0.069	0.10
			0.458	0.129	B	1.0	1.0	0.458	0.129	0.305	0.086	0.12
					C	1.2	1.7	0.550	0.219	0.366	0.146	0.15
					D	1.6	2.4	0.733	0.310	0.489	0.206	0.20
					E	2.5	3.5	1.145	0.452	0.763	0.301	0.31
Flagstaff	35.23N	111.66W			A	0.8	0.8	0.324	0.094	0.216	0.062	0.09
			0.405	0.117	B	1.0	1.0	0.405	0.117	0.270	0.078	0.11
					C	1.2	1.7	0.486	0.199	0.324	0.133	0.13
					D	1.6	2.4	0.648	0.281	0.432	0.187	0.17
					E	2.5	3.5	1.013	0.410	0.675	0.273	0.27

S_s = Mapped MCE, 5-percent damped, spectral response acceleration parameter at short period.

S_1 = Mapped MCE, 5-percent damped, spectral response acceleration parameter at period of 1 second.

F_a = Short period site coefficient (at a period of 0.2 second).

F_v = Long period site coefficient (at a period of 1.0 second).

S_{MS} = The MCE, 5-percent damped, spectral response acceleration at short periods adjusted for site class effects.

S_{M1} = The MCE, 5-percent damped, spectral response acceleration at a period of 1 second adjusted for site class effects.

S_{DS} = Design, 5-percent damped, spectral response acceleration at short periods.

S_{D1} = Design, 5-percent damped, spectral response acceleration at a period of 1 second.

PHA = Peak horizontal ground acceleration at T = 0 seconds

6.0 Conclusion

This NCAWSFS interim report describes work accomplished to date and concludes the study under the Rural Water Supply Program authority. No further work will be completed for the Study under the RWSP. The Study lacked federal and non-federal funding to complete all work identified in the Plan of Study prior to pending expiration of the RWSP authority on September 30, 2016.

It is important to note that P.L. 109-451 does not authorize Reclamation to undertake or provide funding for project construction. Each proposed construction project must be independently authorized.

The RWSP authority expires on September 30, 2016 and Reclamation work on all remaining appraisal and feasibility studies will end by that date. Given existing constraints on program resources, Reclamation is not recommending Congressional authorization or federal funding of any new appraisal or feasibility studies at this time.

The need for additional water resources to meet future projected demands remains. Prior studies have shown that there are limited local resources available and that a pipeline would help meet regional future water needs. Partners may choose to proceed with the Study without federal assistance, and complete the pipeline design on their own. If partners seek federal assistance to complete the Study, a new authority would be required.

The NCAWSFS is a collaborative partnership between Reclamation and the communities and Tribes of north-central Arizona to explore long-term water supply opportunities based on projected climate conditions and population changes. The Study explores enhancements to the existing water supply infrastructure and identifies potential opportunities to develop the NCAP that could help address the region’s Tribal water needs. Through the NCAWSFS, the communities in the area have made headway towards developing a strategy aimed at developing reliable water supplies in the region. The progress of this Study demonstrates significant steps forward towards accomplishing this goal.

7.0 Disclaimer

The North Central Arizona Water Supply Feasibility Study was funded jointly by the Bureau of Reclamation and Navajo Nation, Hopi Tribe, Arizona Department of Water Resources, Coconino County, and the Cities of Page and Flagstaff. It is a collaborative product of the Study participants identified in the Introduction of this report. The purpose of the Study is to assess current and future water supply and demand in the Study Area, and to identify a range of possible concepts to address any projected imbalances. The Study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the partners. The Study Interim Report does not propose or address the feasibility of any specific project, program or plan. Nothing in the Study is intended, nor shall the Study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the Study represents a commitment for provision of federal funds. Work accomplished to date is summarized in this interim report, so a concluding report will not be prepared.

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9.0 Appendices (on disc)

Appendix A - Mapping
Appendix B - Plan and Profile Drawings
Appendix C - Technical Memorandum: Steady State Hydraulics and Pump Selection
Appendix D - Steady State Hydraulic Modeling
Appendix E - Value Planning Report
Appendix F - Scour Study
Appendix G - Geology