Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

Electronically Filed
Nov 08 2022 04:38 p.m.
Elizabeth A. Brown
Clerk of Supreme Court

ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, et al.

Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

JOINT APPENDIX

VOLUME 11 OF 49

WARM SPRINGS NATURAL AREA

Stewardship Plan

SE ROA 12122

JA_4884

SE ROA 12123


WARM
SPRINGS
NATURAL
AREA
SOUTHERN NEVADA WATER AUTHORITY
LUCCHESI GALATI
people process place
SE ROA 12124

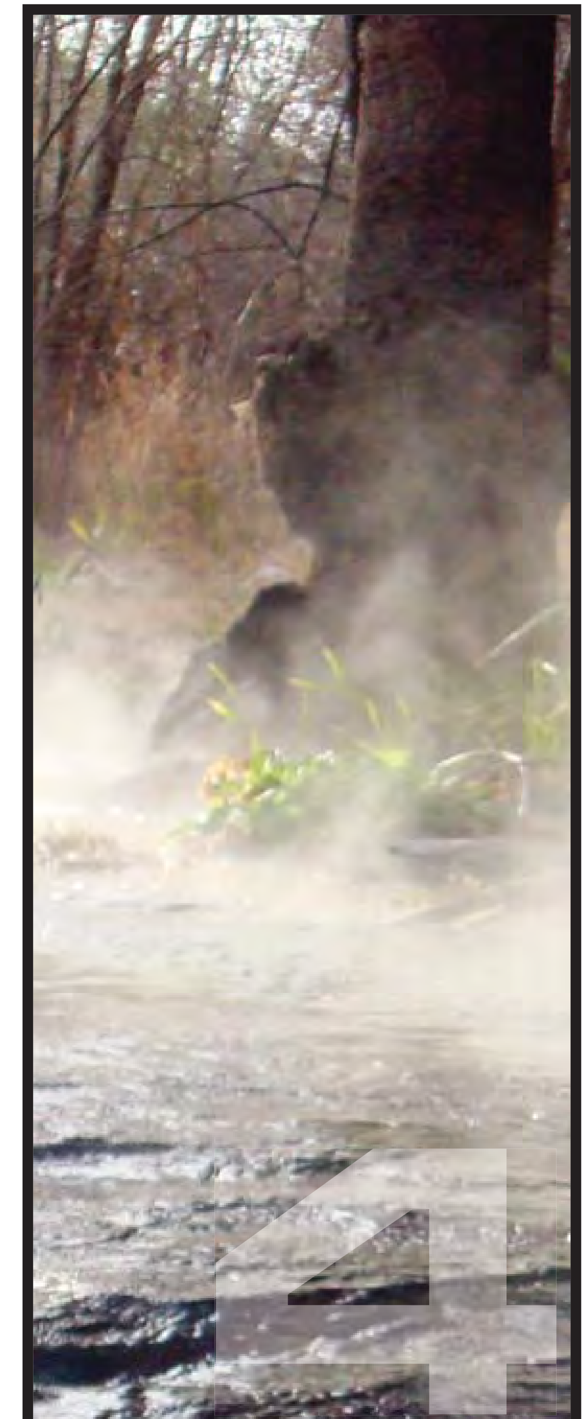
TABLE OF CONTENTS

SE ROA 12125


1


2


3


4


5

CONTRIBUTORS 2007-2010

CORE TEAM

Tanya Anderson, The Nature Conservancy
Janet Bair, US Fish and Wildlife Service
Robert Johnson, SNWA
Cynthia Martinez, US Fish and Wildlife Service
Janet Monaco, SNWA
Jon Sjöberg, Nevada Department of Wildlife

TECHNICAL ADVISORS

Elisabeth Ammon, Great Basin Bird Observatory
Mauricia Baca, Outside Las Vegas Foundation
Amy LaVoie, US Fish and Wildlife Service
Heidi Roberts, HRA Inc., Conservation Archaeology
Amy Sprunger, US Fish and Wildlife Service
Cris Tomlinson, Nevada Department of Wildlife

SNWA STAFF

William Rinne, Director, Surface Water Resources Department
Janet Monaco, Manager, Muddy and Virgin Rivers Division
Robert Johnson, Manager, Warm Springs Natural Area
Cathryn Cherry, Environmental Planner
David Syzdek, Environmental Biologist
Crystal Shanley, Biologist

2011

Disclaimer

The following document is intended to be a guidance document for Warm Springs Natural Area as described under “Plan Purpose” on page 15 and is not intended to require implementation of any specific management action recommendation. Implementation of such actions is left to the discretion of the SNWA Board of Directors.

June 2011

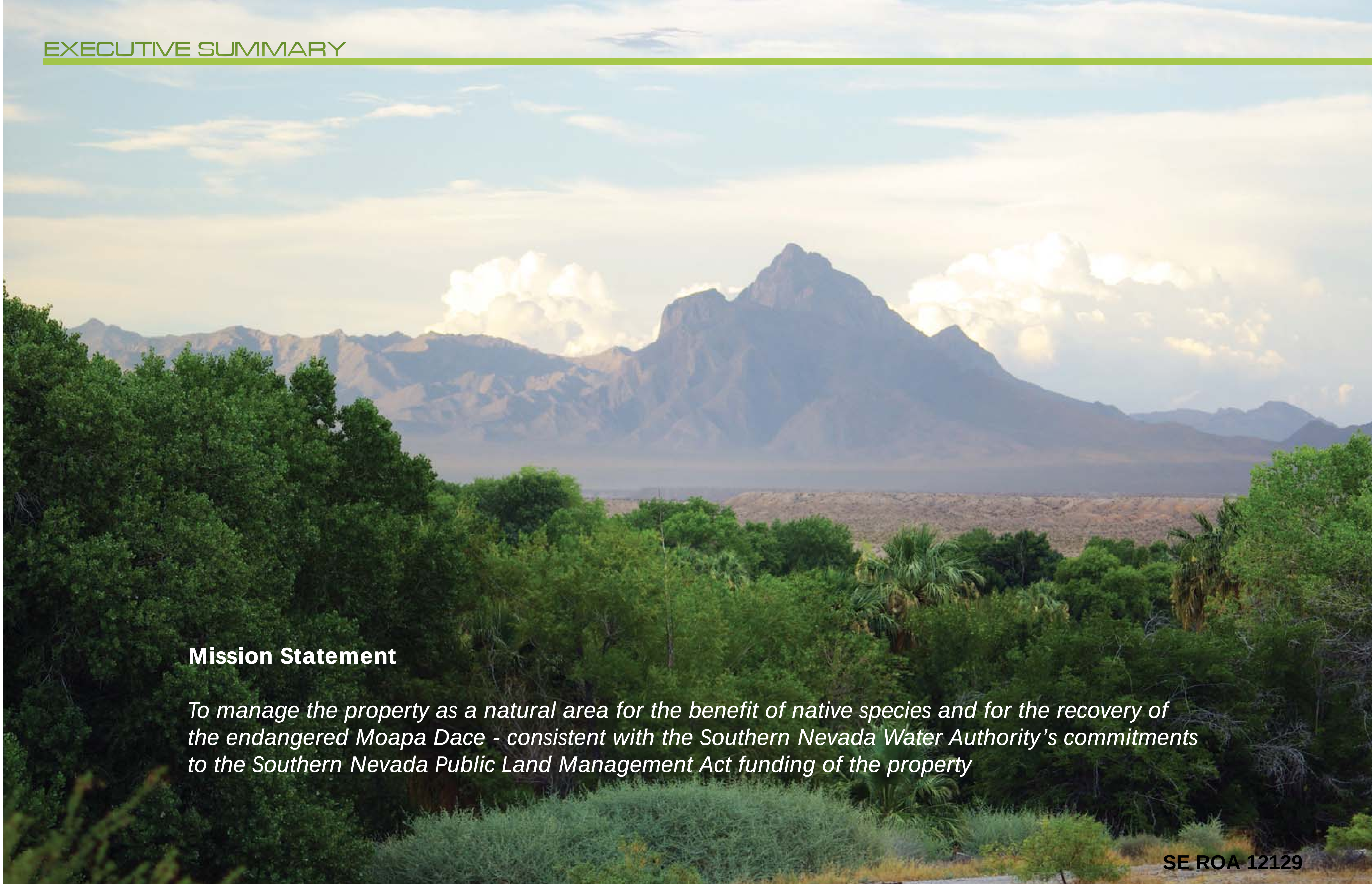
SNWA BOARD OF DIRECTORS

Shari Buck	Chair, City of North Las Vegas
Steven Kirk	Vice Chair, City of Henderson
Susan Brager	Las Vegas Valley Water District
Tom Collins	Clark County Water Reclamation District
Duncan McCoy	City of Boulder City
Steve Sisolak	Big Bend Water District
Lois Tarkanian	City of Las Vegas

SNWA MANAGEMENT

Patricia Mulroy	General Manager
Richard B. Holmes	DGM, Engineering/Operations
Philip D. Speight	DGM, Administration
John J. Entsminger	AGM, Strategic Initiatives

SOUTHERN NEVADA WATER AUTHORITY



Mission Statement

To manage the property as a natural area for the benefit of native species and for the recovery of the endangered Moapa Dace - consistent with the Southern Nevada Water Authority's commitments to the Southern Nevada Public Land Management Act funding of the property

EXECUTIVE SUMMARY

The Warm Springs Natural Area

Like a gemstone stashed away in the upper Moapa Valley, the Warm Springs Natural Area holds the secret to the headwaters of the Muddy River. Here, five major thermal spring complexes gush from the deep carbonate aquifer and converge in tributaries before flowing into the Muddy River and on to Lake Mead. Through time, the Warm Springs Natural Area has sustained many unique species that occur here and nowhere else in the world. This area has a long history of use by humankind. Native Americans, prehistoric peoples, outlaws, and early settlers were sustained by the abundant natural resources in the area. Howard Hughes considered the property worthy of his ownership. Showgirls came from Las Vegas to sun themselves under palm-thatched cabanas, and today the Warm Springs area attracts birders, naturalists, and wildlife enthusiasts.

When the property became available in 2005, the Southern Nevada Water Authority (SNWA) recognized the important conservation value and moved to acquire the 1,220-acre parcel formerly known as the "Warm Springs Ranch" – the largest tract of private property along the Muddy River. This unique environment is home to the Moapa dace – a small, endemic fish living on the Warm Springs Natural Area and Moapa Valley National Wildlife Refuge and nowhere else in the world. The Moapa dace is a key species to management of SNWA's water resources in the Muddy River and Coyote Spring Valley due to its ties to the deep carbonate aquifer and its limited distribution. The Secretary of the Department of the Interior approved Southern Nevada Public Land Management Act (SNPLMA) funding for acquisition of the Warm Springs Ranch. Upon acquisition in September of 2007, SNWA became the steward for managing this significant property to preserve its important ecological integrity. Once SNWA became the new landowner, it renamed the property the "Warm Springs Natural Area."

Stewardship Plan

SNWA committed to join with stakeholders to develop a long-term stewardship plan for the property. The purpose of this document is to establish the framework and direction for management of the Warm Springs Natural Area. It is SNWA's intention that the Stewardship Plan will lay a foundation for the property that will foster relations between SNWA and the property neighbors (the US Fish and Wildlife Service, Moapa Band of Paiutes, Coyote Springs Investment, LLC., Moapa Valley Water District, Clark County, Moapa Town Advisory Board, and others) while preserving the important ecological integrity of the property.

Management Direction

The Stewardship Plan is intended to establish a framework for appropriate land uses for the property that preserve the integrity of the natural resources and allow for management of water resources of the valley. This framework clarifies SNWA's responsibilities and management direction as they pertain to conservation of the Warm Springs Natural Area and ensures consistency with SNWA's commitments in the SNPLMA Nomination and the Muddy River Recovery Implementation Program. The Stewardship Plan establishes direction and clarifies SNWA's intentions for property management.

SNPLMA OBJECTIVE

"The property will be acquired as a Parks, Trails, and Natural Area acquisition with the objective to develop a natural area. The natural area will provide controlled public access to enjoy the abundant natural resources, will include interpretation of the resources and Threatened and Endangered species located on the site, and will include measures to preserve and protect those resources. Natural Resources on the Property include, aquatic habitat for the Virgin River Roundtail Chub, the endemic Moapa Dace, the Southwestern Willow Flycatcher, and the Yellow-Billed Cuckoo. The property includes Nevada's largest breeding population of Vermilion Flycatcher. Within this section of the Muddy River reside pockets of native Mesquite Bosque and Cottonwood-Willow riparian habitat."
(*SNPLMA Financial Assistance Agreement*)

PLAN GOALS AND OBJECTIVES

Provide a clear statement for future management

Clarify SNWA's intentions and direction for property management

Give neighbors, visitors, governmental and non-governmental organizations an understanding of SNWA's management actions on and around the property

Ensure management actions consistent with the SNPLMA Nomination Package and Financial Assistance Agreement

Ensure management actions consistent with the Muddy River Recovery Implementation Program

Provide a basis for the development of staffing plans, budget needs, maintenance operations, and capital improvements

1

SE ROA 12132

WARM SPRINGS NATURAL AREA FACTS

- 1,220 acres of Mojave Desert riparian ecosystem
- 28 Sensitive Species
- Annual Rainfall 5.4 in.
- Elevation: 1,689 - 1,923 feet above mean sea level
- Five major spring complexes form the headwaters of the Muddy River
- Water emanates from 90° F thermal springs

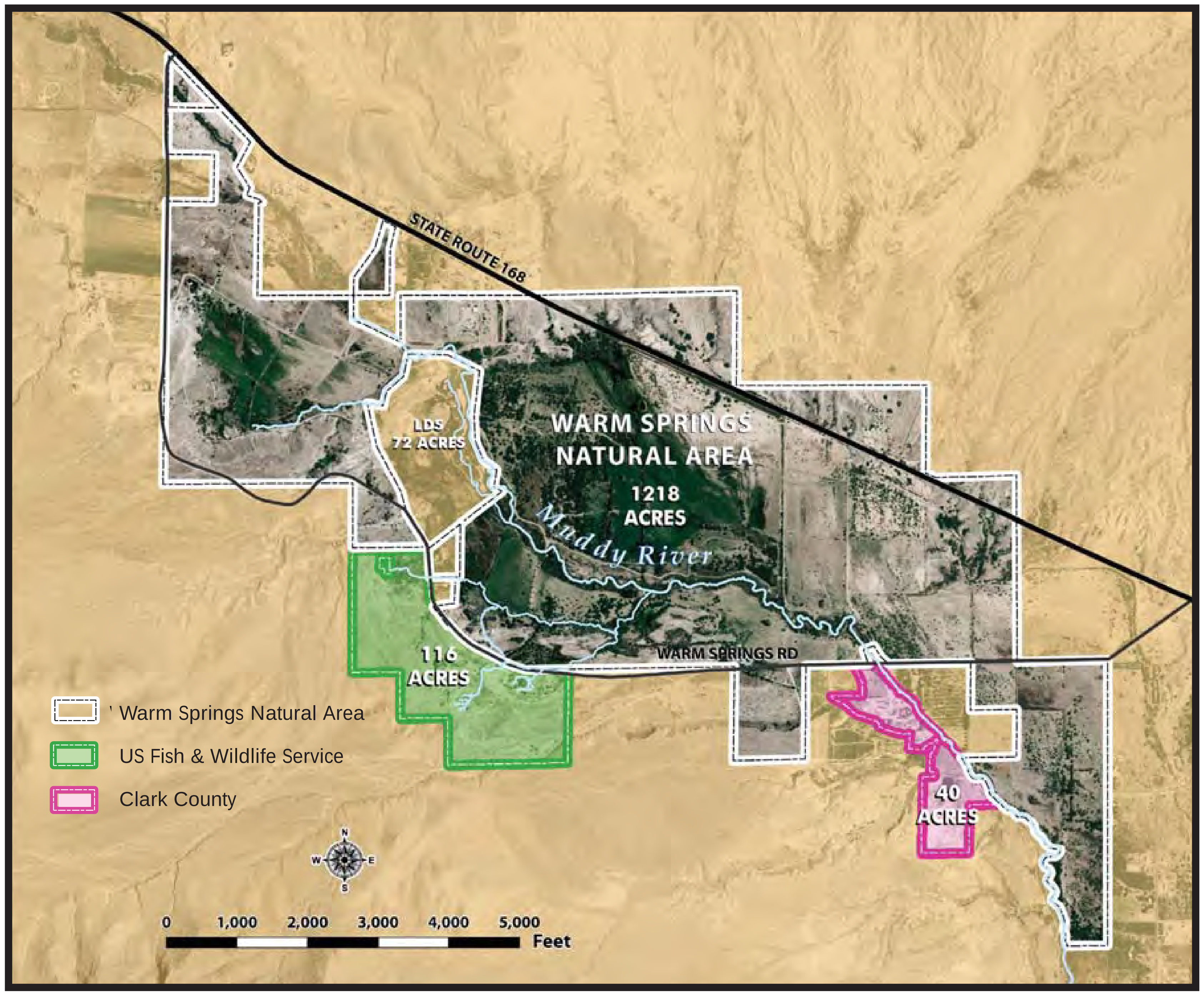
1.01 SITE OVERVIEW

Moapa Valley

The Warm Springs Natural Area is located approximately seven miles northwest of the Town of Moapa and 60 miles northeast of Las Vegas, in Clark County, Nevada. The Natural Area is in upper Moapa Valley, a valley about 40 miles long running roughly northwest to southeast. The towns of Moapa, Glendale, Logandale and Overton are located in the Moapa Valley. Logandale is about 12 miles southeast of Moapa and Glendale. Overton is another five miles southeast of Logandale. Population numbers in the Moapa Valley from the 2000 US Census (which did not include the Town of Moapa) were 5,784. In the 2000 US Census, the Town of Moapa had a population of 928. The population of the Moapa Valley was estimated to be 7,200 in 2008 and 7,471 in 2009 which does not include the Moapa Indian Reservation. The Reservation's population was estimated to be 1,292 in 2009.

Headwaters of the Muddy River

Like a gemstone stashed away in the upper Moapa Valley, the Warm Springs Natural Area holds the secret to the headwaters of the Muddy River. Here, five major thermal spring complexes gush from the deep carbonate aquifer on three properties - the Moapa Valley National Wildlife Refuge, the Warm Springs Natural Area and the LDS Church property. They converge on the Warm Springs Natural Area in tributaries which flow into the Muddy River and on to Lake Mead.



Warm Springs Natural Area

The Warm Springs Natural Area is generally bordered by State Route 168 to the north, Warm Springs Road to the south and the Arrow Canyon Range to the west. The Moapa Valley National Wildlife Refuge and Clark County lands border the Natural Area to south. About 3.8 miles of the Muddy River flow through the Natural Area. The landscape is a mixture of desert, riparian, and fallowed agricultural fields. Here, seasonally flooded pastures are lined with mature Fremont cottonwoods. Goodding's willows and velvet ash trees occur throughout the property. Skirting the fields are numerous groves of established mesquite trees, in which the Vermilion flycatcher nests occur. The adjoining pastures have abundant insects such as large fleshy grasshoppers, which are a staple of the flycatcher's diet. The largest nesting population of Vermilion flycatchers in Nevada were observed here in 2000. The Warm Springs Natural Area has long been used by Native Americans, outlaws and early settlers. Today, the property continues to attract the attention of birders, naturalists, and wildlife enthusiasts.

PROPERTY PURPOSES

Protect the endangered Moapa dace and its habitat

Establish conservation projects that provide mitigation benefits for future water development

Manage the property as a natural area for the benefit of native species

Restore and manage the area as an ecological reserve including implementation of recovery actions identified in the Muddy River Recovery Implementation Program

Create opportunities for low-impact public use

Develop public education opportunities which include ecological processes and endangered species recovery

Provide the opportunity for a program of national scientific research on aquatic and terrestrial systems in the Mojave Desert

SE ROA 12134

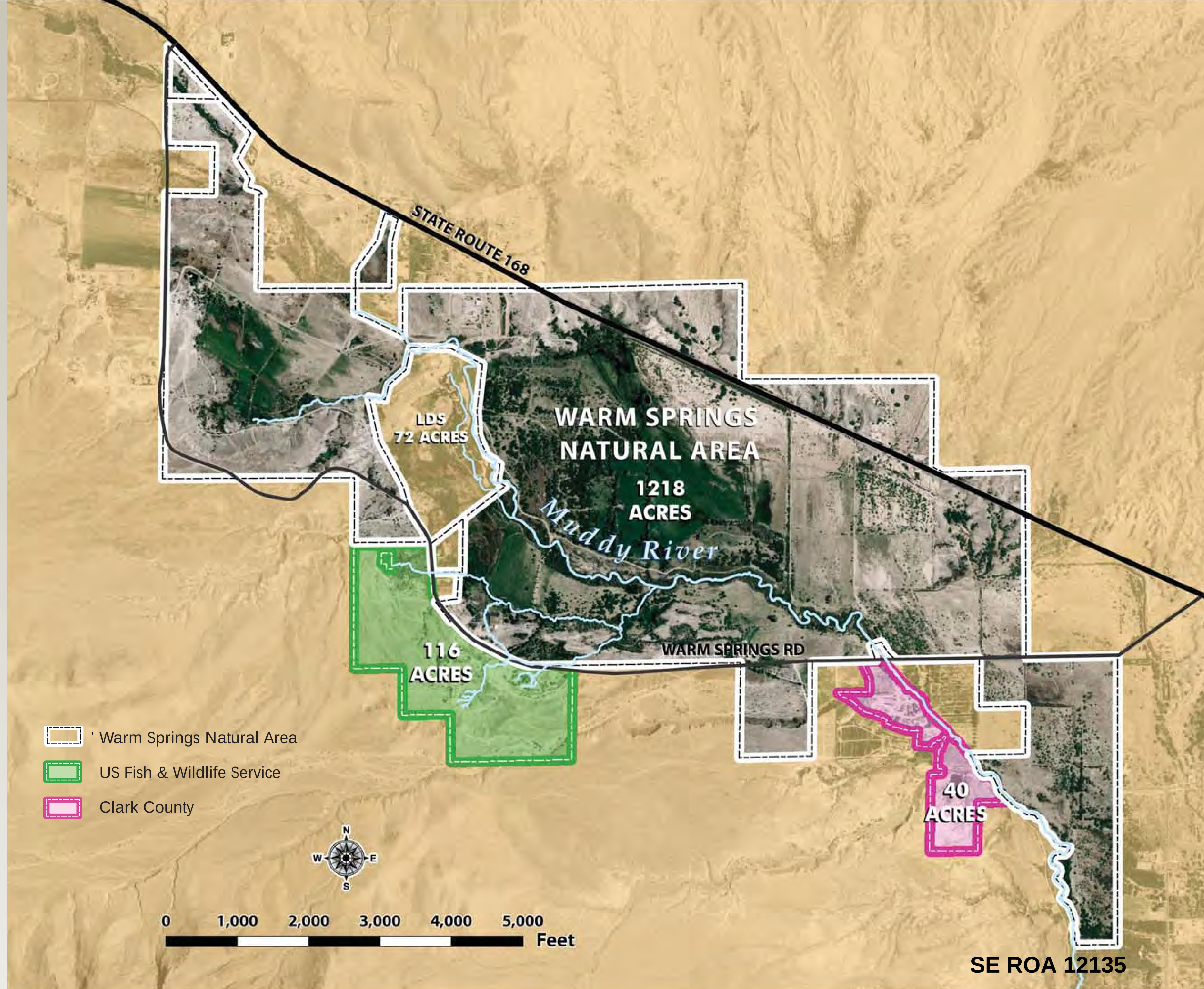
MUDDY RIVER RECOVERY IMPLEMENTATION PROGRAM EXECUTIVE COMMITTEE AND STAKEHOLDERS

SOUTHERN NEVADA WATER AUTHORITY

COYOTE SPRINGS LAND

The Nature Conservancy

Protecting nature. Preserving life.™



1.02 STAKEHOLDER PROCESS

Muddy River Recovery Implementation Program

Development of the Muddy River Recovery Implementation Program (RIP) was identified in the 2006 *Muddy River Memorandum of Agreement (MOA) and the Intra-Service Programmatic Biological Opinion for the Proposed MOA Regarding the Groundwater Withdrawal of 16,100 Acre-Feet per Year from the Regional Carbonate Aquifer in Coyote Spring Valley and California Wash Basins, and Establish Conservation Measures for the Moapa Dace, Clark County, Nevada*.

The Executive Committee of the RIP is comprised of the signatories to the MOA which include SNWA, the US Fish and Wildlife Service, the Moapa Valley Water District, the Moapa Band of Paiutes, and Coyote Springs Investment, LLC. The RIP has a technical subcommittee, the Biological Advisory Committee. The Hydrologic Review Team was formed by the MOA and serves as a technical advisory committee to the RIP. Nevada Department of Wildlife was added as an *ad hoc* member to the Executive Committee.

The goal of the RIP is to implement a series of species recovery actions necessary to promote recovery and conservation of aquatic species in the Muddy River ecosystem, while at the same time, providing for mitigation and minimization of potential effects associated with the development and use of water supplies and other activities that may affect the aquatic ecosystem.

Stakeholder Process/Core Team

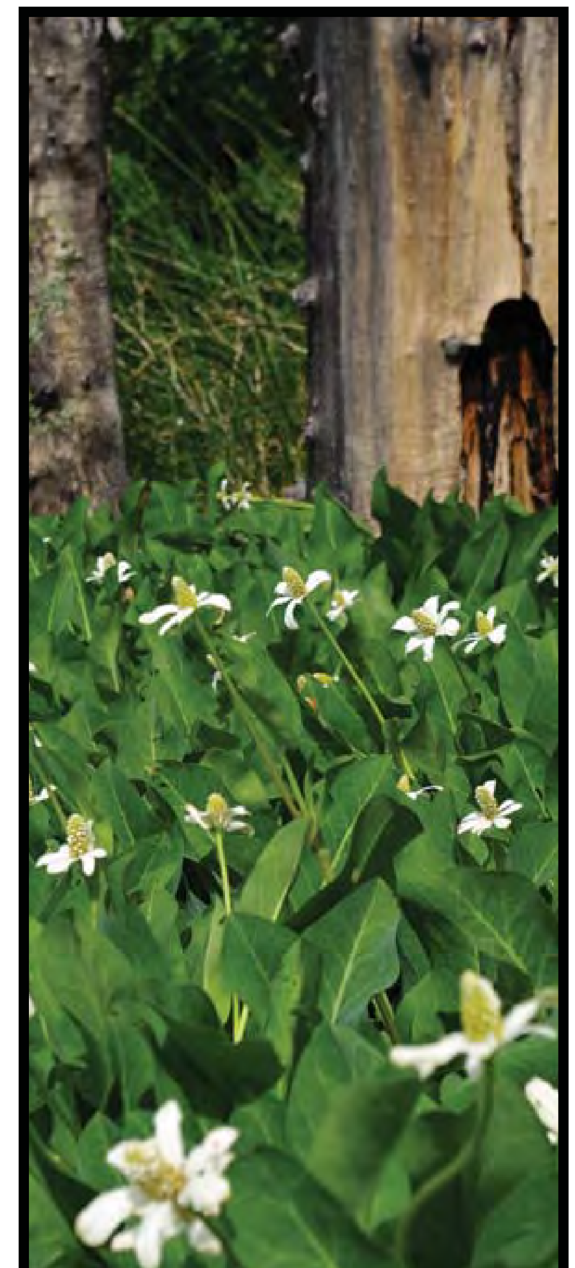
SNWA committed in its Southern Nevada Public Land Management Act (SNPLMA) Nomination package to the Secretary of the Department of Interior to enlist the involvement of specific stakeholders to develop the Stewardship Plan. To that end, the RIP Biological Advisory Committee agreed to join SNWA in the shared vision of developing a plan that satisfies the property stakeholders and directs management actions that benefit the natural resources on site and the water resource entities involved. The RIP Biological Advisory Committee identified a process to develop the Warm Springs Natural Area Stewardship Plan. The process entailed the Core Team developing the Stewardship Plan and other stakeholders providing review.

Core Team

The Core Team consists of representatives from SNWA, the US Fish and Wildlife Service, the Nevada Department of Wildlife and The Nature Conservancy. Individuals on the Core Team are named in the "Contributor" list on page 4. The Core Team met 2007 through 2010 and came together for workshops to discuss shared concepts and a vision for the Warm Springs Natural Area. The Core Team developed the Mission Statement - "*To manage the property as a natural area for the benefit of native species and for the recovery of the endangered Moapa dace – consistent with the Southern Nevada Water Authority's commitments to the Southern Nevada Public Land Management Act funding of the property*" - which establishes prioritization of management goals and serves to frame future decisions. Their recommendations have been reflected in this Stewardship Plan.

Core Team Members

- Southern Nevada Water Authority
- US Fish and Wildlife Service
- The Nature Conservancy
- Nevada Department of Wildlife



MUDDY RIVER RECOVERY IMPLEMENTATION PROGRAM

Executive Committee
- Southern Nevada Water Authority
- US Fish & Wildlife Service
- Moapa Valley Water District
- Coyote Springs Investment
- Moapa Band of Paiutes
- Nevada Dept. of Wildlife (*ad hoc* member)

Biological Advisory Committee
- US Fish & Wildlife Service
- Nevada Dept. of Wildlife
- US Geological Survey
- Bureau of Land Management
- Southern Nevada Water Authority
- Moapa Valley Water District
- Coyote Springs Investment
- Moapa Band of Paiutes
- The Nature Conservancy
- Clark County

Other Stakeholders
- Moapa Town Advisory Board
- Moapa Valley Town Advisory Board
- Property neighbors

SE ROA 12136

1.03 COMMITMENTS FOR MANAGING THE PROPERTY

SNWA Commitments

Commitments for the Warm Springs Natural Area were established prior to the acquisition of the property in the Southern Nevada Public Land Management Act (SNPLMA) Financial Assistance Agreement signed on May 16, 2007. In the Financial Assistance Agreement, SNWA agreed to:

Accomplish the OBJECTIVE as approved by the Secretary of the Department of the Interior
Furnish qualified personnel for the coordination, oversight, and performance of the objective for the project
Provide supervision for the project to include responsibility for all technical aspects, development, implementation, scheduling, safety, coordination, and other project needs
Make certain necessary permits or environmental clearances are obtained
Own and maintain in perpetuity any land, buildings, trails, facilities, or other features improved or constructed.

SNPLMA Nomination

As part of the 2005 SNPLMA Nomination to the Secretary of the Department of Interior, SNWA identified it would conduct a number of actions on the property. The Secretary of the Department of Interior approved SNPLMA funding for acquisition of the Warm Springs Natural Area on February 7, 2006. In the 2005 SNPLMA Nomination, SNWA pledged it would carry out:

Development of educational and recreational areas/trails emphasizing the natural resources for public use consistent with the Moapa Valley National Wildlife Refuge and other adjacent lands
Invasive plant management
Invasive fish and invertebrate management
Bank and channel stabilization activities
Construction and/or enhancement of wetlands
Restoration and/or enhancement of riparian and upland habitat
Spring pool restoration/enhancement

SNPLMA OBJECTIVE

"The property will be acquired as a Parks, Trails, and Natural Area acquisition with the objective to develop a natural area. The natural area will provide controlled public access to enjoy the abundant natural resources, will include interpretation of the resources and Threatened and Endangered species located on the site, and will include measures to preserve and protect those resources. Natural Resources on the Property include, aquatic habitat for the Virgin River Roundtail Chub, the endemic Moapa Dace, the Southwestern Willow Flycatcher, and the Yellow-Billed Cuckoo. The property includes Nevada's largest breeding population of Vermilion Flycatcher. Within this section of the Muddy River reside pockets of native Mesquite Bosque and Cottonwood-Willow riparian habitat."
(*SNPLMA Financial Assistance Agreement*)

Property Purposes

Purposes for the Warm Springs Natural Area were established by SNPLMA directives and agreed to early on by the Core Team. Purposes include:

Protect the endangered Moapa Dace and its habitat

Establish conservation projects that provide mitigation benefits for future water development

Manage the property as a natural area for the benefit of native species

Restore and manage the area as an ecological reserve including implementation of recovery actions identified in the Muddy River Recovery Implementation Program

Create opportunities for low-impact public use

Develop public education opportunities which include ecological processes and endangered species recovery

Provide the opportunity for a program of national scientific research on aquatic and terrestrial systems in the Mojave Desert

1.04 PURPOSE OF THE STEWARDSHIP PLAN

Plan Purpose

The purpose of the Warm Springs Natural Area Stewardship Plan is to establish a long-term management direction for the Warm Springs Natural Area that will foster relations between SNWA and the property neighbors (the US Fish and Wildlife Service, Moapa Band of Paiutes, Coyote Springs Investment, LLC., Moapa Valley Water District, Clark County, Moapa Town Advisory Board, and others) while preserving the important ecological integrity of the property. The Stewardship Plan establishes a framework for appropriate land uses that preserves the integrity of the natural resources and is consistent with SNWA's management of the water resources. It clarifies SNWA's responsibilities and management direction as they pertain to the Warm Springs Natural Area and ensures consistency with SNWA's commitments in the SNPLMA Nomination and the Muddy River Recovery Implementation Program.

The development of the Stewardship Plan for the natural resources and facilities has involved soliciting stakeholder input, developing the mission statement to guide the process, and establishing the goals and objectives for the management of the property.

The purpose of the Stewardship Plan is also to identify public uses considered compatible with the intent of the SNPLMA application to "develop educational and recreational areas/ trails emphasizing natural resources for public use consistent with the Moapa Valley National Wildlife Refuge, The Nature Conservancy, and other adjacent lands."

While the Stewardship Plan is intended to provide guidance for SNWA management and future land uses and activities on the Warm Springs Natural Area, it is important to note that the Stewardship Plan is a conceptual document to begin dialogue and is not intended to require implementation of any specific management action recommendations. Implementation of such actions is left to the discretion of the SNWA Board of Directors through the annual budgeting process and through specific contract approvals as needed.

If funding is approved for a specific program or program element or if requests are made for the Warm Springs Natural Area for a specific use, the Stewardship Plan is intended to provide important guidance on how that program or program element is to be implemented.

Plan Goals and Objectives

The following goals and objectives were developed by the Core Team:

Provide a clear statement for future management

Clarify SNWA's intentions and direction for property management

Give neighbors, visitors, governmental and non-governmental organizations an understanding of SNWA's management actions on and around the Warm Springs Natural Area

Ensure management actions consistent with the Southern Nevada Public Land Management Act Nomination Package and Financial Assistance Agreement

Ensure management actions consistent with the Muddy River Recovery Implementation Program

Provide a basis for the development of staffing plans, budget needs, maintenance operations, and capital improvements

PROPERTY PURPOSES

Protect the endangered Moapa dace and its habitat

Establish conservation projects that provide mitigation benefits for future water development

Manage the property as a natural area for the benefit of native species

Restore and manage the area as an ecological reserve including implementation of recovery actions identified in the Muddy River Recovery Implementation Program

Create opportunities for low-impact public use

Develop public education opportunities which include ecological processes and endangered species recovery

Provide the opportunity for a program of national scientific research on aquatic and terrestrial systems in the Mojave Desert

SE ROA 12138

2

SE ROA 12140

2.01 SITE HISTORY

The known history of land use at WSNA begins with Native Americans during the Early Agricultural period (AD1-550). Though hunting and gathering certainly occurred during the Archaic period (5500 BC-AD 1), it was not until the early inhabitants began agriculture that land use took on new meaning. In the upper Muddy River, agriculture can trace its origins as far back as AD 20-220 from a radiocarbon dated corn cob. Cultivating maize, squash, and gourds was commonplace along the Muddy River and its tributaries during this period.

The Southern Paiutes continued to use and live around the WSNA when the Dominguez-Escalante Party charted the Spanish Trail.

The Spanish Trail passes about eight miles to the southeast (1776). The Coyote Spring Rockshelter on WSNA shows a period of use through the Early Historical (AD 1600-1830) and Settlement (1830-1900) periods where the shelter was possibly used by the Paiutes to escape Spanish slave raids that were common along the Spanish Trail.

Along with early American explorers, Mormon pioneers were among the first new arrivals to view the upper Muddy River area. Though the majority of settlements were established in the lower Muddy River drainage, the town of West Point (about five miles down river) was established in 1868 and persisted until the flood of 1870.

Around that time, the Muddy Springs band of Paiute Indians was led by Chief Rufus. Their home would have included Big Muddy Spring and the surrounding area of WSNA.

The first recorded settlement on the WSNA was by the Texas outlaw Alexander Dry. He built a stone cabin with an arrowweed thatched roof near a spring on WSNA in the late 1870s. He also ran a herd of cattle, the beginning of grazing and its cumulative impacts to the property.

Advent of maize farming in upper Muddy River (Basket maker II).
AD 100 - 300

1776
Spanish priests Garces, Dominguez, and Escalante encounter Southern Paiutes. Their route becomes the Old Spanish Trail.

Southern Paiutes - victims of Spanish slave trade.
1776 -1850s

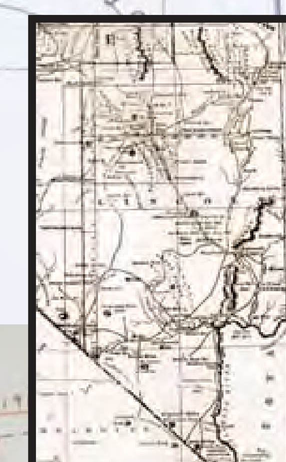
Mormon settlement along Muddy River.
1860s

1866
Chief Rufus of the Muddy Springs Band of Paiutes joins with other tribal chief and Mormon leaders to end hostilities.

Mormon settle West Point (closest settlement to Warm Springs).
1867

1870
Town of West Point abandoned following a flood and occupied by Paiutes.

Texan outlaw Alexander Dry (Dri) homesteaded on WSNA. He built and lived in a stone cabin next to a spring until he was shot by the outlaw Jack Longstreet in 1882.
Ca. 1870



The Home Ranch established.
Early 1900s

1905
Warm Springs schoolhouse along the Muddy River at WSNA.

School house moved to Big Muddy Spring.
1920

1950
Francis Taylor acquired Baldwin and Home Ranches and other smaller parcels and he named the 1,200 acres the "Warm Springs Ranch." He built the "Big House" otherwise known as the Taylor Mansion aside Big Muddy Spring and began extensive pasture improvements.

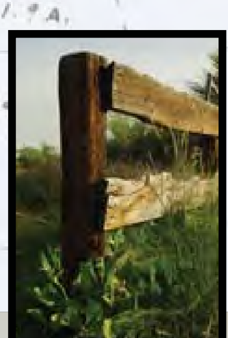
Howard Hughes purchases Warm Springs Ranch. Ranching and agricultural practices continue.
1971

SE ROA 12141

By 1906, at least three homes comprising the Home Ranch existed. The WSNA property was largely divided by the Home Ranch to the southeast, and the Baldwin Ranch to the northwest. At one point, a dairy existed on the Baldwin portion. The bulk of the property was under cultivation or irrigated pasture by the 1950s which endured through the 1970s. The properties comprising the WSNA passed several owners, but of note was the consolidation of property by Frank Taylor who purchased both ranches in 1950.

The property was then sold to Howard Hughes in 1971 and then to the Latter Day Saints Church in 1978. In 2001, most of the Warm Springs Ranch property was sold to South Fifteen LLC who sold it to SNWA in 2007. Though cultivation practices ended in the late 1970s after leasing the water used for irrigation, cessation of grazing only ended in 2008. As a natural area, the property will now be restored to native conditions for the benefit of wildlife.


Folies Bergère Cabana



1973

Warm Springs Ranch (acres: 150 alfalfa, 70 oats, 400 improved pastures, 250 native pastures, 323 rangeland, and 60 corrals/ buildings).

1978

Following death of Howard Hughes in 1976, Warm Springs Ranch sold to LDS church. Ranching and agricultural practices continue.

1980s

Water rights leased to Nevada Power. Irrigated agricultural fields abandoned.

2001

Property sold to South Fifteen, LLC. Approximately 72 acres surrounding the Big Muddy Springs were retained by the LDS Church.

October 2005

SNWA submitted an application under Round 6 of the Southern Nevada Public Land Management Act (SNPLMA) to acquire the Warm Springs Ranch.

February 2006

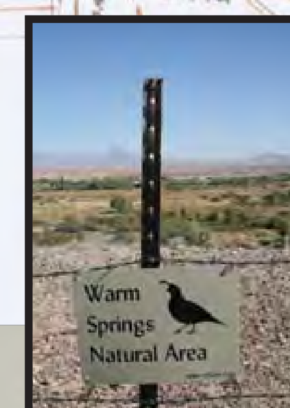
The Secretary of the Department of Interior approved SNWA's request for funding to acquire Warm Springs Ranch.

July 20/2006

SNWA Board of Directors approved an agreement between South Fifteen, LLC, Sunburst Properties, LLC, Pay Dace, LLC, and SNWA for the acquisition of the Warm Springs Ranch by SNWA and authorized the General Manager to negotiate and execute the agreement and documents necessary to effectuate the transfer.

May 16/2007

The Financial Assistance Agreement between SNWA and the United States Department of Interior Bureau of Land Management (BLM) was signed. SNWA was awarded funding to purchase the property and committed to manage it as a Natural Area.

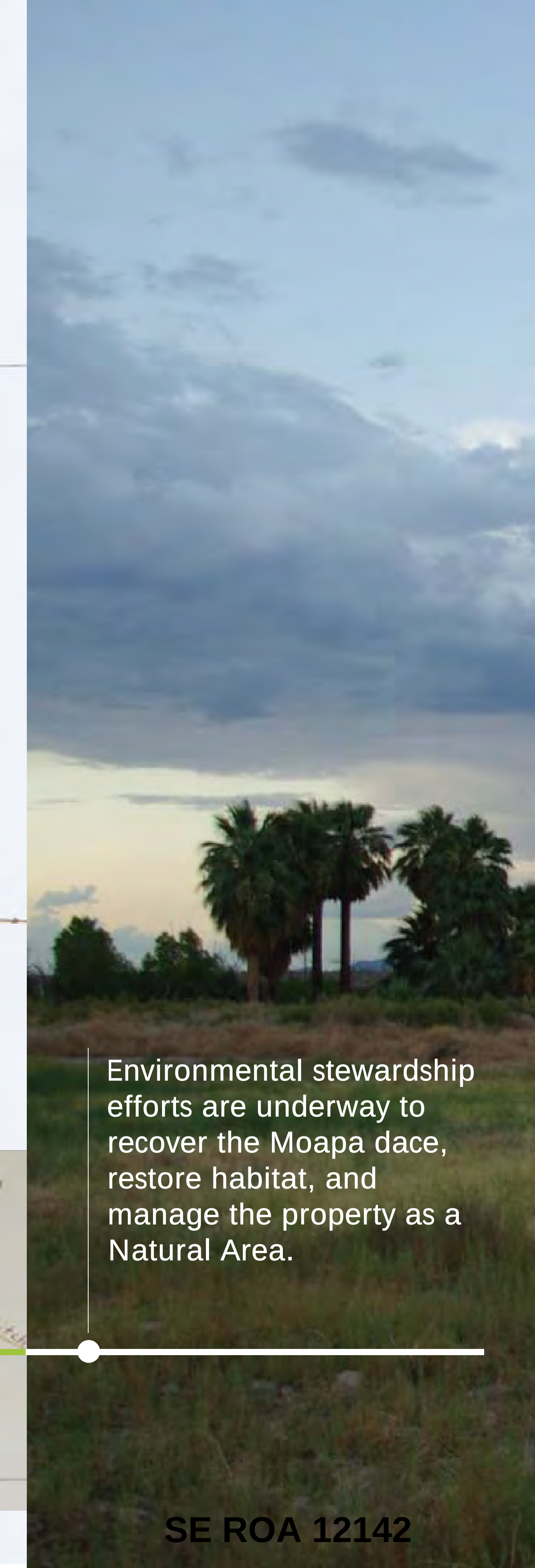


September 13/2007

Purchase of the Warm Springs Ranch was finalized and SNWA renamed the property "Warm Springs Natural Area".

2008

End of ranching.



Environmental stewardship efforts are underway to recover the Moapa dace, restore habitat, and manage the property as a Natural Area.


HOME RANCH et al
NEAR
MOAPA NEVADA
T. 14 S.R. 65 E. M.D.B.+M.
by
L. Tanner
Scale 400 Ft = One Inch
1918
S½ S½ Sec. 7
S½ S½ Sec 10
N½ N½ Sec. 21
N½ N½ Sec. 22
16
15
High Ground
Brush
Home
Ranch
Baldwin Ranch
Bledsoe Ranch
Salt Grass
Old Ditch
Spring Channel
Muddy River
O Flag
High Ground
Swamp
Alfalfa
Grain
Broken up 1916

2.02 CULTURAL RESOURCES

Imagine crossing Nevada's harsh desert on horseback or wagon in the heat of summer, with its miles and miles of barren soil and scrubby creosote. Then off in the distance you see a lush strip of green surrounding a flowing stream. Here, in what is today the Moapa Valley, tired settlers found water to quench their thirst, forage for their animals, shade from the heat, and warm pools to bathe tired feet. The area's flowing springs fed plants, animals, and people for thousands of years—both Native American and Euroamerican.

Rich cultural heritage is preserved in the numerous archaeological sites found throughout the Warm Springs Natural Area. The archaeological record tells us that Southern Paiute people and their ancestors lived in the Moapa Valley for thousands of years before the first American settlers arrived. The archaeological survey of the area identified prehistoric habitations, trails, artifact scatters and rock shelters located on the terraces above the floodplain. Archaeologists believe that pithouse villages, like those found elsewhere in the Southwestern United States, probably lie buried in the Valley's deep soils. Springs, fertile soils, lush vegetation, and plentiful wildlife created a unique desert oasis. The wild grasses and seeds that the first Euroamerican settlers fed to their livestock were the staple foods of the area's Southern Paiute occupants.

Before Native Americans began small-scale subsistence farming in the region 2,000 years ago, they collected and ate the plentiful edible foods. Thick stands of mesquite trees produced nutritious seed pods that were ground, made into cakes, and stored in caches. Grass seeds, wolf berries, cactus fruit, and Indian spinach (Prince's plume) are just a few of the numerous wild plants that the Native Americans collected to supplement their crops of corn, beans, and squash. Bighorn sheep and smaller animals such as quail, doves, rabbits, and mice were hunted with traps or bows and arrows. Occasionally, large family groups gathered to hunt jackrabbits by chasing them into large handmade nets that could be hundreds of yards in length. The Southern Paiute people and their ancestors developed cultural practices and traditions that enabled them to grow and prosper for thousands of years. Outlaws, like Alexander Dry, hid in the Warm Springs area and raised stolen cattle in the late 1800s.

The first Euroamericans to settle the region were members of the Church of Jesus Christ of the Latter Day Saints—the Mormons. Their descendants, including Ute Perkins and his large family, still occupy the Moapa Valley today. Historic corrals, irrigation canals, fences, and house foundations found throughout the WSNA are a reminder of the region's early ranching and farming families, like the Perkins, who struggled and fought to settle the American West. The Perkins family leased the Home Ranch, located in the WSNA for six years, between 1923 and 1929. The family raised cattle and hogs, cultivated hay and grain, and grew fruit trees on the ranch, and the only source of power was a water wheel until the 1930s. Although all of the buildings once occupied by the Perkins family on the Home Ranch burned in a 1987 fire, the oral histories, written stories, and photos provide abundant information about what early pioneer life was like in the area.


Moapa Paiute House


Las Vegas Paiute Encampment 1900


Water wheel

Warm Springs Ranch 1941 station wagon ("Woodie")

Cardy Lamb Springs
N. Fork Muddy
S. Fork Muddy
Baldwin Spring Complex
Big Muddy Springs Stream
Muddy River
Post Card
PLACE STAMP HERE
Stream Temperature
32°C / 90.3°F
31°C / 88.5°F
30°C / 85.7°F
29°C / 83.4°F
27°C / 81.8°F
22°C / 72.7°F
Temperature data courtesy of USGS and is an average of hourly temperature readings taken from 3/7/08 to 12/11/08. Temperatures between 17 sampling locations (not shown) are interpolated.
Jones Spring Complex
Apcar Stream
Pederson Str
Refuge Str
Pederson Spring Complex
Plummer Spring Complex

2.03 HYDROLOGY AND WATER DEVELOPMENT

More than any other feature of the landscape, the hydrology of the Warm Springs area is key to the landscape. The unique hydrology is the reason Native Americans, ranchers, and people with recreational interests were drawn to the property and also the reason the property supports an endangered fish. The hydrology ties together a unique natural environment with the rich cultural, historic, and socioeconomic uses of the Warm Springs Natural Area. All are juxtaposed through time due to the thermal waters which emanate from more than twenty regional springs, numerous seeps and wetlands in the area. The springs then form warm-water tributaries, which become the headwaters of the Muddy River. The thermal spring water wells up at about 90°F from a deep carbonate aquifer. As the water flows downstream it cools and becomes less favorable to the existence of the endangered Moapa dace and the other thermophilic species.

Hydrology

There are five major spring complexes in the area. Two of these are on the Warm Springs Natural Area: Cardy Lamb and Baldwin Springs. The largest spring, producing over 4.8 million gallons per day, is Big Muddy Spring located on the LDS Recreation Area. The remaining springs - Pederson and Plummer Springs - are located on the Moapa Valley National Wildlife Refuge. Two lesser spring complexes of note, are Twin Springs on the Warm Springs Natural Area and Jones Springs on the Moapa Valley National Wildlife Refuge. A number of other unnamed springs and seeps also occur in the area (Beck et al. 2006).

The Warm Springs area is located near the southern end of the White River regional groundwater flow system and is believed to be the largest and one of the most southerly outflows from this groundwater system. The aquifers in this area are generally composed of Paleozoic carbonate rocks and Tertiary sedimentary rocks. Recharge in this system is primarily from precipitation in the high mountain ranges of eastern Nevada (Eakin 1966).

The US Geological Survey, irrigation districts, the US Bureau of Reclamation, the State of Nevada, SNWA and others have collected water levels and stream gage data throughout the system as far back as 1913. Six continuous-record stream gaging stations and 11 partial-record stations in the area are cooperatively maintained by SNWA and the USGS (Beck et al. 2006).

History of Water Development

From European settlement in the late 1800s to about the 1950s, water use in the area consisted of a few ranches that derived their water from individual springs or wells. In the 1950s, the ranches eventually merged into one large ranch with an intricate system of irrigation ditches.

Water Companies

In 1954, the Moapa Valley Water Company and the Overton Water District entered into a joint agreement to divert water from the Warm Springs area to residences, businesses, and dairy establishments to the south. For this purpose, water was developed from the Baldwin Springs complex. In 1960, a pump house was also built on Jones Spring and the landowner, Francis Taylor, donated water rights and one acre of land to the Moapa Valley Water Company. Frederick Apcar soon bought the surrounding 45 acres for his own private recreational use, concreted one of the springs and built a large swimming pool on the site. A new pump house was constructed on the Jones Spring in 2004 by the Moapa Valley Water District (Beck et al. 2006).

Recreational Facilities

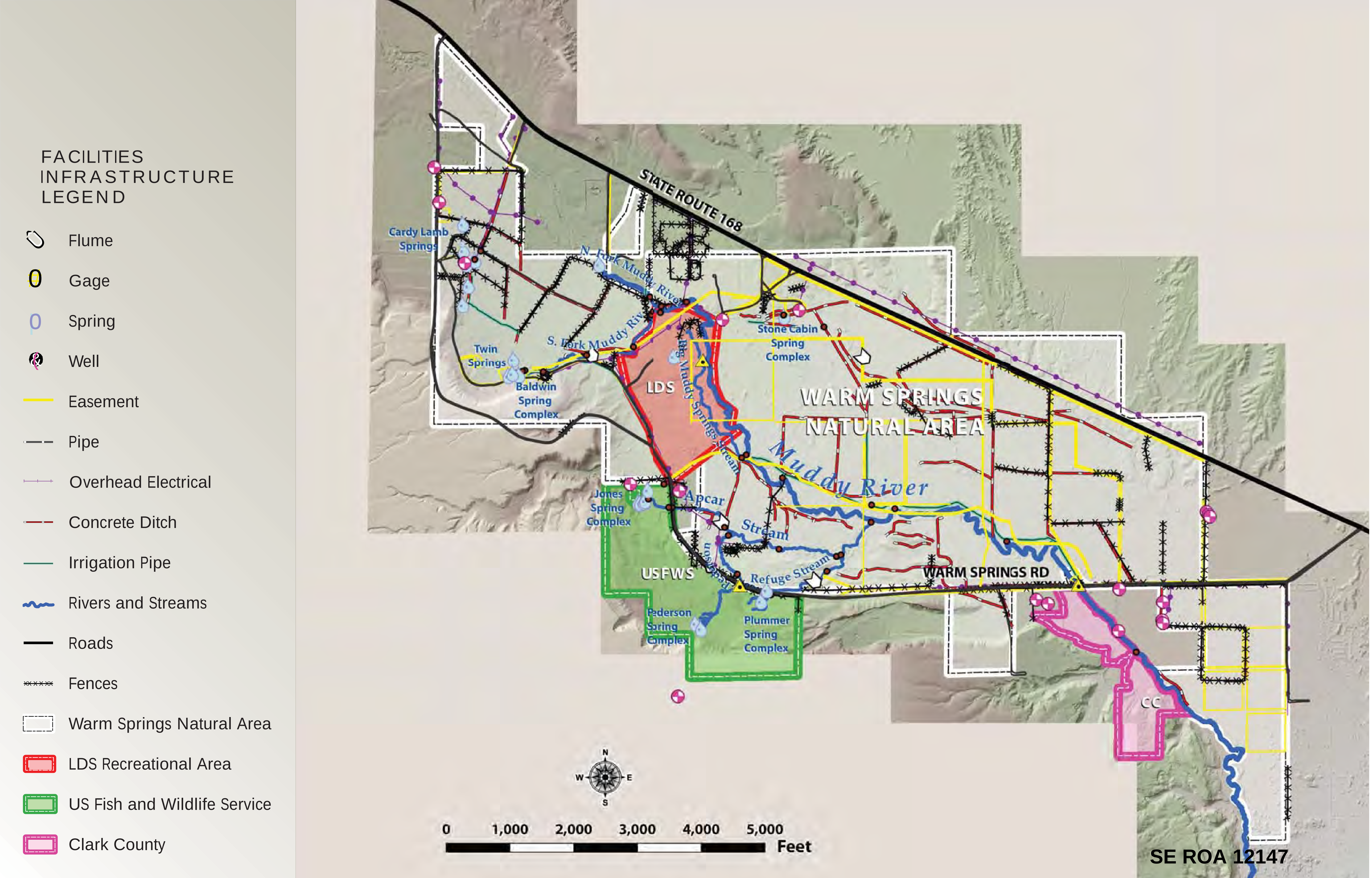
Other recreational facilities were built to take advantage of the 90°F water for swimming. At the Pederson Springs, the 7-12 Warm Springs Resort was built in the 1950s. This resort had two swimming pools, one of which was built directly over a spring and the other was fed with piped spring water. The Desert Oasis Warm Springs Resort had a swimming pool, ponds, spa and water slide all fed by the Plummer Springs. Other recreational swimming facilities included a large spring fed pond and swimming pool on the LDS property fed by Big Muddy Springs. In the early 1980s the LDS Church constructed a very large swimming pool at the Cardy Lamb Springs (Beck et al. 2006).

Power Plant

In the mid-1960s, the Reid Gardner coal-fired power plant was constructed about three miles downstream of the Warm Springs area. Initially, water for the plant was obtained from the Muddy River near the plant and from several wells in the Warm Springs area on the Lewis Property. By the early 1970s, Nevada Power (now NV Energy) constructed a diversion dam and a pumping station on the Muddy River just above Warm Springs Road. Water is pumped from the river and piped to power plant. In the 1980s, the power plant was expanded and Nevada Power purchased water rights from the LDS Church and other private landowners in the Warm Springs area. Currently, NV Energy seasonally operates about 12 alluvial wells in the Warm Springs area and the surface water diversion on the river. Generally, the surface water is used in the winter months and the wells are pumped in the summer months (Beck et al. 2006).

Moapa Valley National Wildlife Refuge

In 1979, the Moapa Valley National Wildlife Refuge was created from most of the 7-12 Warm Springs Resort and a small portion of the Desert Oasis Warm Springs Resort. By the late 1990s most of the swimming pools and other recreational infrastructure from the old 7-12 Warm Springs Resort had been removed and restored for the Moapa dace. The Desert Oasis Warm Springs Resort operated until 1994 when a fire closed the resort. After the fire, the resort remained closed until it was purchased by Del Webb and turned over to the Moapa Valley National Wildlife Refuge. In 2001, the US Fish and Wildlife Service (USFWS) expanded the Wildlife Refuge by purchasing 45 acres of land around Jones Spring (Apcar unit). The USFWS removed the swimming pool that Frederick Apcar had installed and begun restoring the stream below the pump house (Beck et al. 2006). In 2007, USFWS removed all the palm trees from the Apcar unit and restored the stream channel in Spring 2009.


FACILITIES INFRASTRUCTURE LEGEND
Flume
Gage
Spring
Well
Easement
Pipe
Overhead Electrical
Concrete Ditch
Irrigation Pipe
Rivers and Streams
Roads
Fences
Warm Springs Natural Area
LDS Recreational Area
US Fish and Wildlife Service
Clark County
STATE ROUTE 168
Cardy Lamb Springs
N. Fork Muddy River
S. Fork Muddy River
Twin Springs
Baldwin Spring Complex
LDS
Stone Cabin Spring Complex
WARM SPRINGS NATURAL AREA
Muddy River
Apcar Stream
Jones Spring Complex
USFWS
Refuge Stream
WARM SPRINGS RD
Pederson Spring Complex
Plummer Spring Complex
CC
N
W
E
S
0
1,000
2,000
3,000
4,000
5,000
Feet

2.04 FACILITIES MANAGEMENT


Water diversions


Irrigation ditches


Historic structures


Municipal water source/ water treatment plant


Historic recreation


County road

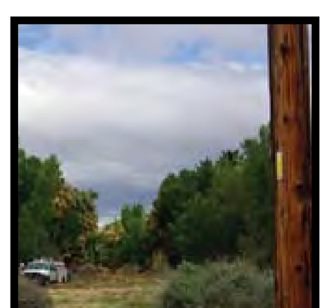

Existing fencing


Non-historic structures


Production wells


Easement maintenance


Historic agriculture


Overhead easements


Pipeline easements


Fence maintenance

Acquisition of the Warm Springs Natural Area by SNWA in 2007 included not only property assets but also a requirement to accommodate entities with easements on the property. Easements for water and power conveyance traverse the property servicing Moapa Valley Water District, NV Energy, and Overton Power Company. Gaging stations to monitor stream flows exist on several stream reaches and have monitoring requirements by federal and state agencies. County roads and State Highway 168 overlay a portion of the property. Because the property was previously used mainly for agriculture, irrigation ditches and fencing are ubiquitous features found throughout the Natural Area. To improve the aesthetics and decrease habitat segregation, much of the fencing and ditch works will be removed. Any features of historic significance will be preserved.

EXISTING PROPERTY USES

RIGHTS-OF-WAY

Moapa Valley Water District
Baldwin Spring box
Baldwin Spring treatment plant
Baldwin Spring pipeline
Jones Spring pipeline

NV Energy
LDS East (Stone Cabin Spring) Well
LDS Central (Willow Spring) Well
LDS West Well
Pipelines

Overton Power Lines

Roads
Clark County roads
State Highway 168

WATER RIGHTS/MONITORING

Water Monitoring Activities
Iverson Flume (USGS)
South Fork Flume (NV Energy)
Apcar Flume (NDWR)
Cardy Lamb Spring (NV Energy)

Water Rights
Twin Springs
Cardy Lamb Spring
Irrigation Company Water

3

Vermilion flycatcher

SE ROA 12150


Common buckeye on sunflower
(Junonia coenia on *Helianthus annuus)*


Cryptantha (*Cryptantha* sp.)


Tarantula *(Aphonopelma* spp.*)*

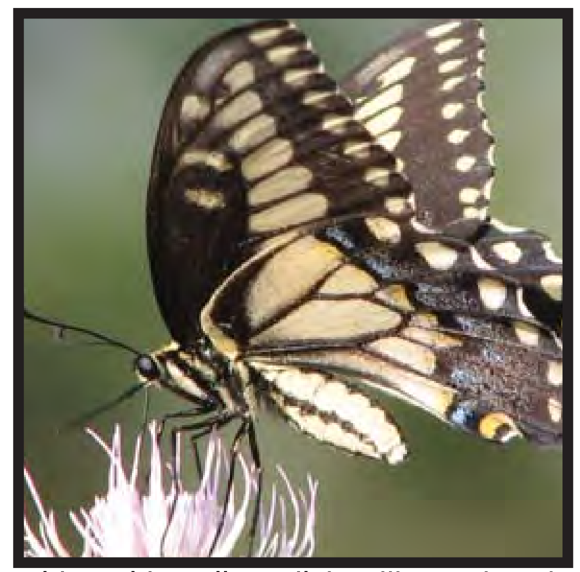
3.01 BIODIVERSITY

The upper Muddy River is considered one of the Mojave's most important areas of biodiversity and regionally important ecological but threatened riparian landscapes (Provencher et al. 2005). Not only does the Warm Springs Natural Area encompass the majority of Muddy River tributaries it is also the largest single tract of land in the upper Muddy River set aside for the benefit of native species in perpetuity.

The prominence of water in an otherwise barren Mojave landscape provides an oasis for regional wildlife. A high bird diversity is attributed to an abundance of riparian and floodplain trees and shrubs. Contributions to plant diversity come from the Mojave vegetation that occur on the toe slopes of the Arrow Canyon Range from the west and the plant species occupying the floodplain where they are supported by a high water table. Several marshes and wet meadows add to the diversity of plants and animals. The thermal springs and tributaries host an abundance of aquatic species, many of which are endemic. The WSNA provides a haven for the abundant wildlife that resides permanently or seasonally and provides a significant level of protection for imperiled species.


Coyote *(Canis latrans)*


Damselfly *(Enallagma sp.)*

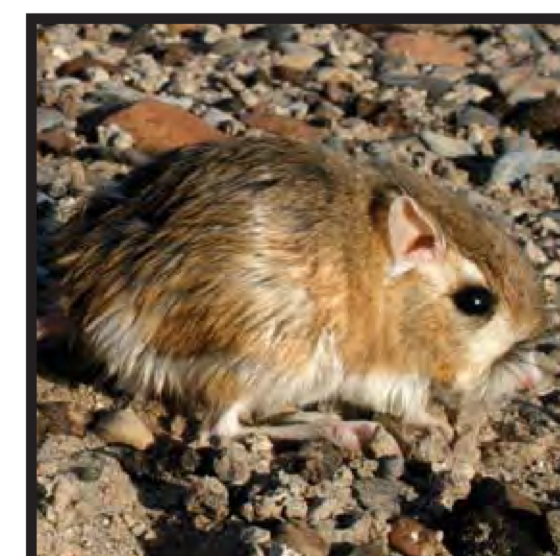

Old World swallowtail *(Papilio machaon)*


Desertsnow *(Linanthus demissus)*


Lobe-leaved Phacelia *(Phacelia crenulata)*


Beavertail cactus (*Opuntia basilaris*)


Pacific tree frog *(Pseudacris regilla)*


Merriam's kangaroo rat
(Dipodomys merriami)

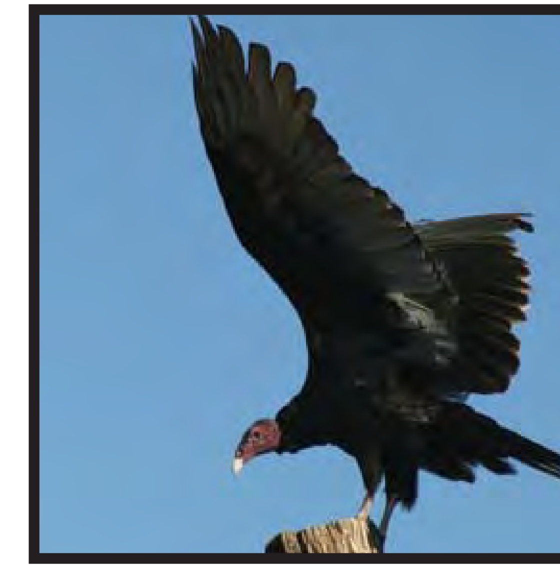
SE ROA 12151


Great horned owl *(Bubo virginianus)*


Desert banded gecko *(Coleonyx variegatus)*


Spinyhair blazingstar *(Mentzelia tricuspis)*


Bighorn sheep (*Ovis canadensis*)


Turkey vulture *(Cathartes aura)*

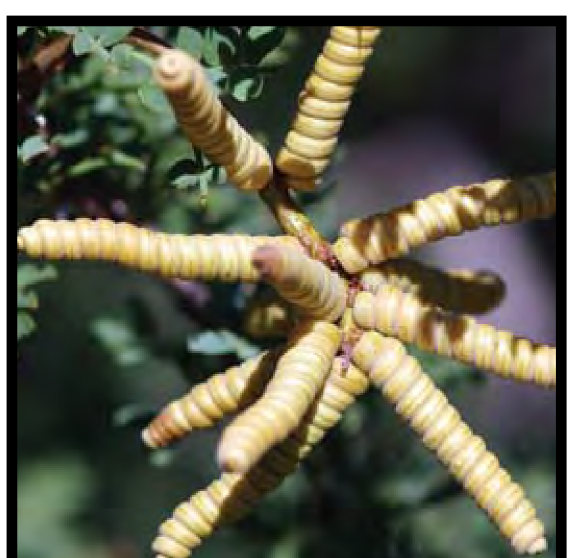

Master blister beetle *(Lytta magister)*


Brittlebush *(Encelia farinosa)*


California kingsnake
(Lampropeltis getula californiae)


California palm *(Washingtonia filifera)*
seeds


Desert horned lizard
(Phyrnosoma platyrhinos)

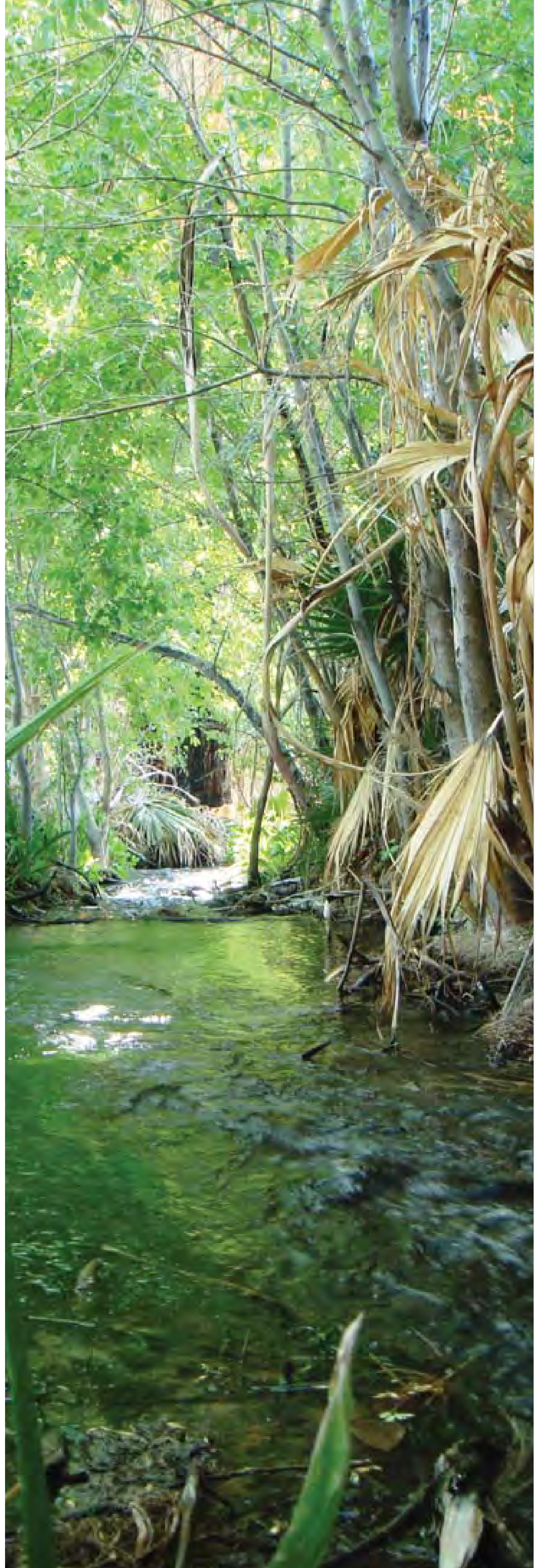

Screwbean mesquite *(Prosopis pubescens)*
pods


Mesquite mistletoe
(Phoradendron californicum) fruit


Honey mesquite *(Prosopis glandulosa)*
flowers


Desert Tortoise *(Gopherus agassizii)*


Catclaw acacia *(Acacia greggii)* seed pods



3.02 SENSITIVE SPECIES OF WSNA

Endemic Species

All organisms, their niches, and their interactions with each other comprise biological resources. Because of the plentiful spring water with its unique thermal properties, the Warm Springs Natural Area (WSNA) harbors an abundance of endemic species that occur nowhere else on earth. Of all the endemic species that occur on WSNA, the Moapa dace (*Moapa coriacea*) is the most imperiled and is federally protected as an endangered species. For this reason, the priority of management attention is focused on its protection and recovery. The Moapa dace's recovery is largely dependent upon restoring stream habitat and the removal of introduced, competitive fish species.

Thermal properties of the WSNA springs and tributaries are key to the existence of the endemic and rare species.

Ecological Isolate

The WSNA is considered a ecological isolate (or island) within the dry Mojave Desert, providing quality riparian and mesquite woodlands that attract an abundance of wildlife, especially birds. The endangered Southwestern willow flycatcher (*Empidonax traillii extimus*) has been documented as nesting on the property. Protecting the nesting habitat is an important management objective to help ensure long-term population viability for this endangered species. Plant communities and their floristic composition, structure, and condition all contribute to habitat quality and preferential use by wildlife. Soil disturbance and the introduction of invasive weeds have created a threat to habitat quality and increase the risk of catastrophic wildfires.

Species Conservation

In addition to species protected under the federal Endangered Species Act (ESA), numerous other species are considered at-risk because of their local endemism or limited distribution. A critical management component on the WSNA is not only identifying threatened and/or endangered species, but also managing at-risk or rare plants and animals. It is important to monitor at-risk species in order to assess population stability. It requires less effort to protect a species from becoming endangered than recovering one once it has become such.

There are several bird species on the WSNA identified under the Partners in Flight Species Conservation Priority list. These species will be provided appropriate conservation consideration.

Some species such as the Vermilion flycatcher (*Pyrocephalus rubinus*) and Phainopepla (*Phainopepla nitens*) are signature species at the WSNA. Due to abundant and predictable population levels, they are important for recreational viewing by the birding community. Protecting at-risk and other important species is primarily a function of protecting and enhancing their respective habitats. Much of their habitat requirements overlap where multiple species are benefited from the same management practices.

Because of the oasis effect, provided by lush riparian vegetation in an otherwise harsh Mojave Desert ecosystem, WSNA supports a large and diverse population of bats. At least 15 species of bats have been documented using various habitats of the Warm Springs Natural Area. Fields, mesquite woodlands, riparian habitats, marshes, and open water offer large insect populations and foraging opportunities for bats.

Sensitive Species

28 Sensitive Species on WSNA				
Common Name	Scientific Name	USFWS	NNHP State Status	Footnotes
Fish				
1 Moapa White River springfish	*Crenichthys baileyi moapae*		critically imperiled in state	4,6,8
2 Virgin River chub	*Gila seminuda (Muddy River Population)*		globally - critically imperiled	4,5,6,8
3 Moapa dace	*Moapa coriacea*	Endangered	critically imperiled in state	1,4,5,6,8
4 Moapa speckled dace	*Rhinichthys osculus moapae*		critically imperiled in state	4,5,6,8
Invertebrates				
5 Western naucorid	*Ambrysus mormon*			7
6 Warm Springs crawling water beetle	*Haliplus eremicus*		not ranked	4
7 MacNeill sooty wing skipper	*Hesperopsis gracielae*		critically imperiled in state	4,5,6
8 Moapa naucorid	*Limnocoris moapensis*		critically imperiled in state	4,7,8
9 Moapa riffle beetle	*Microcylloepus moapus*		critically imperiled in state	4,5,7
10 Pahranagat naucorid	*Pelocoris biimpressus shoshone*			4,7
11 Moapa pebblesnail	*Pyrgulopsis avernalis*	petitioned for listing	imperiled in state due to rarity	4,7,8
12 Moapa Valley pyrg	*Pyrgulopsis carinifera*	petitioned for listing	critically imperiled in state	4,7
13 Moapa skater	*Rhagovelia becki*			7
14 Moapa Warm Springs riffle beetle	*Stenelmis moapa*		critically imperiled in state	4,5,7,8
15 Grated tryonia	*Tryonia clathrata*	petitioned for listing	imperiled in state due to rarity	4,7,8
Birds				
16 Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	Candidate	globally - vulnerable to decline	3,4,5,6
17 Southwestern willow flycatcher	*Empidonax traillii extimus*	Endangered	critically imperiled in state	1,4,5,6
18 Phainopepla	*Phainopepla nitens*		imperiled in state due to rarity	4,5,6
19 Vermilion flycatcher	*Pyrocephalus rubinus*			6
20 Summer tanager	*Piranga rubra*			6
Bats				
21 Townsend's big-eared bat	*Corynorhinus townsendii*		imperiled in state due to rarity	4,5,6
22 Spotted bat	*Euderma maculatum*		imperiled in state due to rarity	4,5,6
23 Western red bat	*Lasiurus blossevillii*		critically imperiled in state	4,5
24 Western yellow bat	*Lasiurus xanthinus*		critically imperiled in state	4
25 California leaf-nosed bat	*Macrotus californicus*		imperiled in state due to rarity	4,5,6
26 Fringed myotis	*Myotis thysanodes*		imperiled in state due to rarity	4,5,6
27 Big free-tailed bat	*Nyctinomops macrotis*		imperiled in state due to rarity	4,5,6
Reptiles				
28 Desert tortoise	*Gopherus agassizii*	Threatened	vulnerable to decline	2,4,5,6

FOOTNOTES:
1 Listed as Endangered under the Endangered Species Act
2 Listed as Threatened under the Endangered Species Act
3 Candidate species under the Endangered Species Act
4 State of Nevada Department of Conservation & Natural Resources. 2009
5 Bureau of Land Management - Nevada Special Status Species
6 Clark County Multiple Species Habitat Conservation Plan (MSHCP). 2000
7 Muddy River Headwaters Macroinvertebrate Report - Albrecht et al. 2008
8 U.S. Department of the Interior Fish and Wildlife Service. 1996. Recovery plan for the rare aquatic species of the Muddy River ecosystem

28 SENSITIVE SPECIES

There are **28 at-risk** or rare species including some endangered or threatened species residing on the property. The 1996 *Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem* identifies current status, threats and recovery needs for the Moapa dace and seven other rare, aquatic species (three fish, two snails and two insects).

Other species are included from the Clark County Multiple Species Habitat Conservation Plan (2000), the Nevada Natural Heritage Program at-risk tracking list and/or watch list, and rare aquatic species at WSNA identified in a survey report by Albrecht et al. (2008).

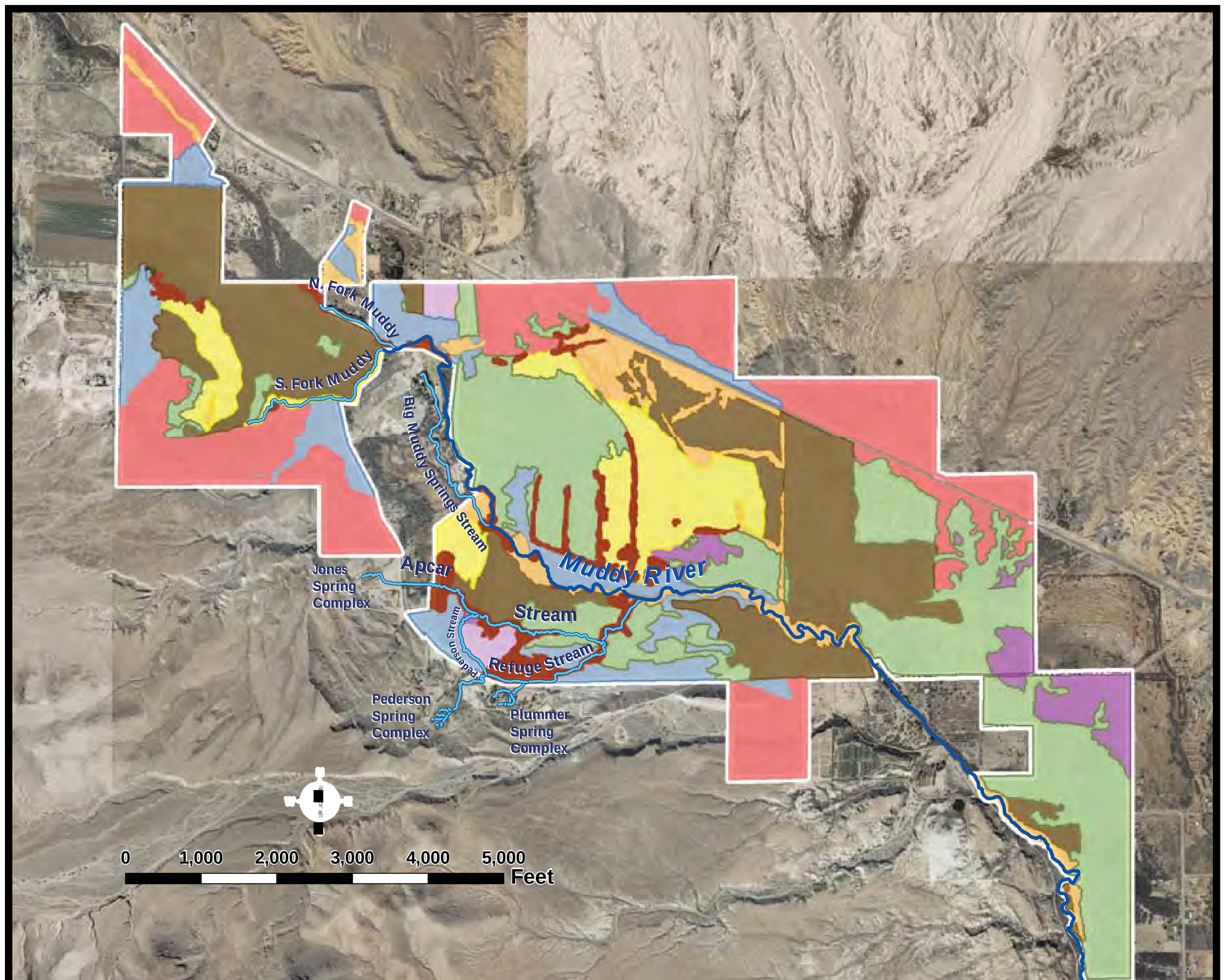
3.03 ECOLOGICAL SYSTEMS OF THE WSNA

ECOLOGICAL ASSEMBLAGES

- Muddy River Aquatic Assemblage
- Warm Springs Aquatic Assemblage
- Riparian Woodlands
- Riparian Shrubland
- Riparian Marsh/Meadow
- Mesquite Bosques

OTHER ECOLOGICAL GROUPS

- Creosote Bush Shrubland
- Saltbush Shrubland
- Alkali Meadow
- Abandoned Agricultural Fields
- Other



Six ecological systems were identified by Provencher and Andress (2004) as occurring in the upper Muddy River. Each system forms an ecologically functional assemblage that contains habitat features and a suite of organisms. All six assemblages are known to occur on the Warm Springs Natural Area and help characterize the existing ecological units that require management in order to protect wildlife, many of which are endemic or regionally rare. The Warm Springs Aquatic Assemblage and the Muddy River Aquatic Assemblage are of particular interest due to the endangered Moapa dace *(Moapa coriacea)* as well as several endemic invertebrates.

The other assemblages provide habitat for a variety of wildlife but especially for rare birds such as the Southwestern willow flycatcher *(Empidonax traillii extimus)*, Yellow-billed cuckoo *(Coccyzus americanus occidentalis)*, Vermilion flycatcher *(Pyrocephalus rubinus)*, Summer tanager *(Piranga rubra)*, and Phainopepla *(Phainopepla nitans)*. Each assemblage and its associated species that merits management consideration is discussed per assemblage. This approach emphasizes the need to manage functional systems and habitats in order to sustain and/or enhance identified recovery species. While the same species may occupy multiple ecological assemblages, each species is discussed in the assemblage where it reaches maximum prevalence.

SE ROA 12155

3.04 MUDDY RIVER AQUATIC ASSEMBLAGE

The Muddy River Aquatic Assemblage encompasses the Muddy River. It is characterized by shrubby vegetation composed primarily of tamarisk and honey mesquite growing along a highly incised streambank. Water temperatures range between 80°-90° F on the WSNA. Exotic fishes such as tilapia, mollies, and mosquito fish are ubiquitous. While many aquatic animal species occur throughout the aquatic assemblages, a few reach maximum prevalence within this assemblage. Two native fishes and two aquatic invertebrates of concern primarily occur in this assemblage.

SPECIES FOR MANAGEMENT CONSIDERATION

- Virgin River chub
  Gila seminuda - Muddy River Population*
- Moapa speckled dace
  *Rhinichthys osculus moapae**
- Warm Springs crawling water beetle
  Haliplus eremicus
- Moapa skater
  Rhagovelia becki

** Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem (USFWS 1996)*

Virgin River chub
(Gila seminuda)

The Muddy River population of Virgin River chub has a high potential for being listed as an endangered species. It has been declining throughout the Muddy River since the 1960s. Chub decline has been attributed to changes in water and substrate quality, channelization, introduced fishes, and parasites. Since its extirpation in the Warm Springs area in about 1997, this species has not been able to recolonize these streams due to a diversion dam near Warm Springs Road. The Virgin River chub averages 8-10 inches in length. It prefers deep streams with swift water. Dietary preferences of larval and juvenile chub consist primarily of aquatic insects. Adult chub feed on both insects and algae. Management of Virgin River chub on WSNA requires reestablishing connectivity with the core population that occur downstream, eliminating introduced fishes, and restoring floodplain vegetation.

Virgin River chub
(Gila seminuda)

Moapa speckled dace
(Rhinichthys osculus moapae)

Moapa speckled dace populations are known to fluctuate greatly. The Moapa speckled dace averages three inches in length and typically lives for three years. The speckled dace is a close relative of the Moapa dace and has similar habitat requirements but prefers the cooler water temperatures below the Warm Springs area. Because of this thermal barrier, the two species are non-competitive. Larval speckled dace are primarily plankton feeders, while the adults feed primarily on both aquatic insects and algae. Speckled dace prefer the lower horizon of shallow, cobble riffles. They likely face similar threats from deterioration in water quality, introduction of non-native fish, and parasites. The source population of speckled dace resides downstream of WSNA below a fish barrier. Restoring a population on the WSNA will require reestablishing connectivity.

Moapa speckled dace
(Rhinichthys osculus moapae)

Aquatic invertebrates

The only published collection of the Moapa skater *(Rhagovelia becki)* was by Polhemus (1973) who described the species and by Huillet (1998). Several surveys since have not recorded the species (Albrecht et al. 2008, Stevens Ecological Consulting 2004, Sada and Herbst 1999), but *R. choneutes* was commonly observed in the Warm Springs area, suggesting either local extirpation or misidentification of *R. becki* (Sada and Herbst 1999). The Warm Springs crawling water beetle *(Haliplus eremicus)* was collected originally on the LDS Recreational Property as well as from Arizona (Wells 1989) and subsequently from the Muddy River on the LDS property (Huillet 1998). Current collection records include California and Utah within its range (R. Baumann, personal communication, April 2009).

Warm Springs crawling water beetle
(Haliplus eremicus)

Surveys for Virgin River chub are currently conducted in the Muddy River in Spring and Fall.

Moapa dace population surveys are conducted each February and August.

3.05 WARM SPRINGS AQUATIC ASSEMBLAGE

The Warm Springs Aquatic Assemblage is considered irreplaceable and the most important assemblage in the upper Muddy River ecoregional portfolio (Provencher and Andress 2004). This assemblage includes the thermal springs and tributaries which constitute the headwaters of the Muddy River. The endangered Moapa dace *(Moapa coriacea)* and the Moapa White River springfish *(Crenichthys baileyi moapae)* are native thermophiles dependent upon the warm springs and streams for survival. The Moapa pebblesnail *(Pyrgulopsis avernalis)* is an endemic snail species found in the headwaters of the upper Muddy River. Additionally, three thermophilic aquatic insects are endemic to the Muddy River headwaters, namely, the Moapa naucorid *(Limnocoris moapensis)*, Moapa riffle beetle *(Microcylloepus moapus)*, and Moapa Warm Springs riffle beetle *(Stenelmis moapa)* (Parker et al. 1997). All seven species are identified by the Nevada Natural Heritage Program as at-risk. Other rare species within this assemblage that occur on the WSNA and other locations in Nevada include the Western naucorid *(Ambrysus mormon)*, Pahranagat naucorid *(Pelocoris biimpressus shoshone)* (Parker et al. 1997), and Moapa Valley pyrg *(Pyrgulopsis carinifera)* (Albrecht et al. 2008). The latter two species are also listed as "at-risk" by the Nevada Natural Heritage Program.

The overall condition of the Warm Springs Aquatic Assemblage is considered "poor" due to water withdrawals, entrenchment, and exotic species (Provencher et al. 2005). Past and ongoing stream restoration has improved conditions, but until the Moapa dace population has rebounded, restoration efforts will continue. On the WSNA, stream reaches and spring heads have been identified and prioritized by the Biological Advisory Committee for restoration. The Lower Pederson has been rechanneled, and the system is currently being improved for dace habitat by installing drift stations and augmenting natural revegetation. Of the nine upper Muddy Valley stream segments identified for restoration by Provencher et al. (2005), four reside almost exclusively on the WSNA, and one other is shared with the Moapa Valley National Wildlife Refuge. The remaining reach segments would not be considered part of the Warm Springs Aquatic Assemblage but rather the Muddy River Aquatic Assemblage.

SPECIES FOR MANAGEMENT CONSIDERATION

Endemics

Moapa dace *(Moapa coriacea)**
Moapa White River springfish *(Crenichthys baileyi moapae)**
Moapa naucorid *(Limnocoris moapensis)**
Moapa riffle beetle *(Microcylloepus moapus)*
Moapa pebblesnail *(Pyrgulopsis avernalis)**
Moapa Warm Springs riffle beetle *(Stenelmis moapa)**

Rare Non-Endemics

Grated tryonia *(Tryonia clathrata)**
Moapa Valley pyrg *(Pyrgulopsis carinifera)*
Western naucorid *(Ambrysus mormon)*
Pahranagat naucorid *(Pelocoris biimpressus shoshone)*

** Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem (USFWS 1996)*

MOAPA DACE

Moapa dace
(Moapa coriacea)

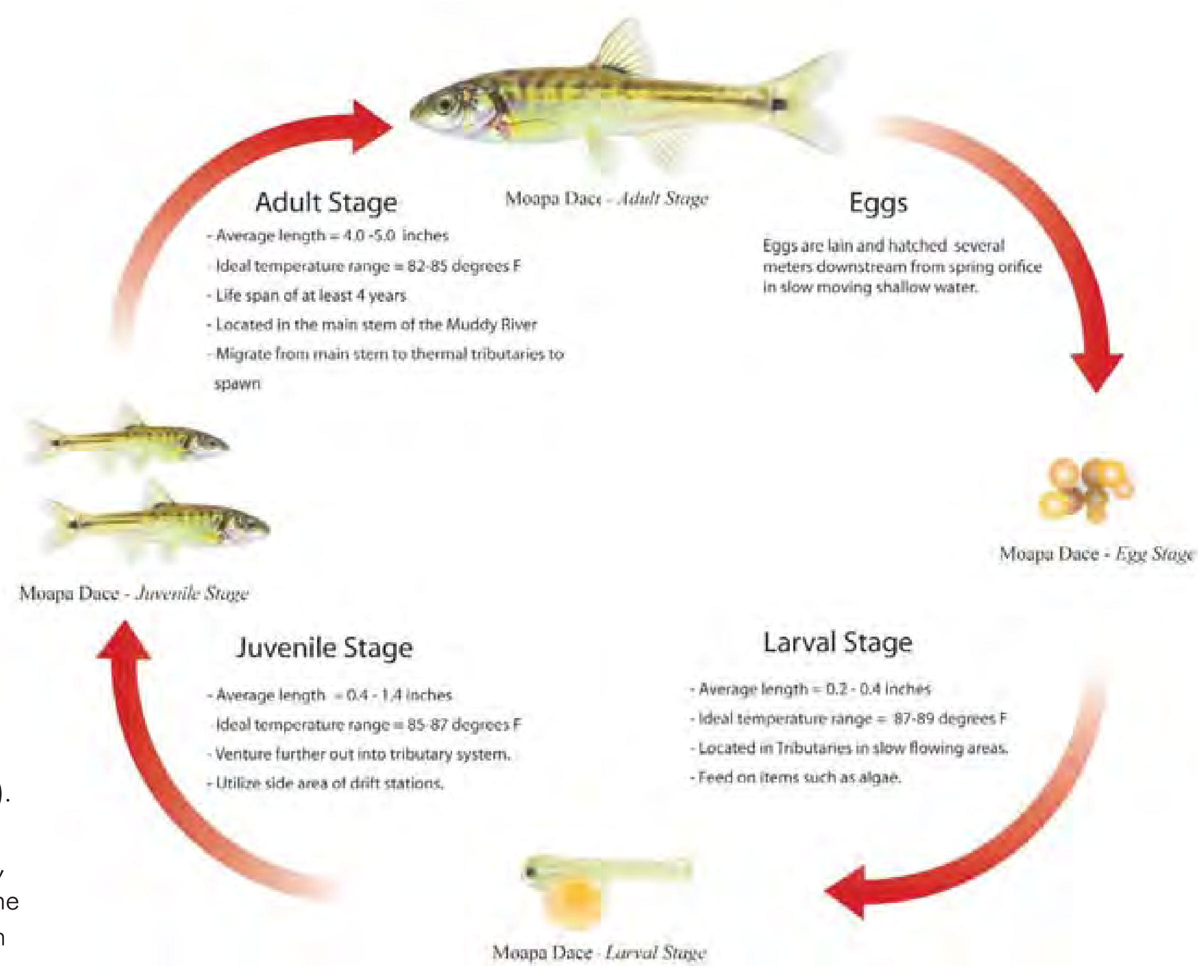
Of all the endemic species that occur on the WSNA, the Moapa dace is the most imperiled and is federally protected as an endangered species. For this reason, the highest priority management attention on the WSNA is focused on its protection and recovery. The recovery of the Moapa dace is largely dependent on restoring stream habitat quality and the removal of introduced fish species that compete with and predate upon the dace.

In 1967, the Moapa dace was listed as an endangered species under the Endangered Species Preservation Act of 1966. This fish only occurs in the warm springs, tributaries, and upper main stem of the Muddy River. Several critical springs for the dace occur on the neighboring Moapa Valley National Wildlife Refuge which feed the Refuge, Pederson, and the Apcar Streams. Those streams flow through the WSNA and provide important habitat for the dace. The WSNA also has an important spring that feeds the Refuge Stream and provides dace spawning habitat. Currently the Refuge Stream and springheads support the largest dace population, followed by the Pederson Stream. The Apcar Stream also has the potential to significantly contribute to dace recovery following the completion of restoration activities.

Life History

Adult Moapa dace are approximately four inches in length. A key identification characteristic is a large black spot near the end of the tail (Hubbs and Miller 1948). Fish typically live for four years, but can live up to approximately eight years in the main stem of the Muddy River. The Moapa dace is a warm water fish, and habitat type preferences vary with each life stage (larval, juvenile and adult). Larval Moapa dace begin their life in the warmer, slow-moving thermal spring outflows, and will venture out further and deeper into the water column of the tributaries and main stem of the river as they get larger. Adult Moapa dace return to the spring outflows from the river to reproduce. Reproduction takes place year round, but peak reproduction occurs in the spring when food sources, such as insects and plant material, are most readily available. All three habitat types (thermal springs, thermal tributaries, and the main stem river) are essential for Moapa dace reproduction and survival (Scoppettone et al. 1992).

Life Cycle of the Moapa Dace



RECOVERY GOALS FOR DELISTING

Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem (USFWS 1996)

- 6,000 adult Moapa dace present in 5 spring systems
- Restore 75% of historic habitat in 5 spring systems
- Eliminate adverse effects of non-native fish and parasites
- Protect habitat in 3 of the 5 spring systems through agreements, easements, or acquisition

STEPS TO ACHIEVE RECOVERY

Install fish barriers
Eradicate/control non-native species
Install drift stations
Restore/protect spring/stream flow dynamics
Restore riparian vegetation
Restore spring/stream connectivity

OTHER RARE AQUATIC SPECIES

Moapa White River springfish
(Crenichthys baileyi moapae)

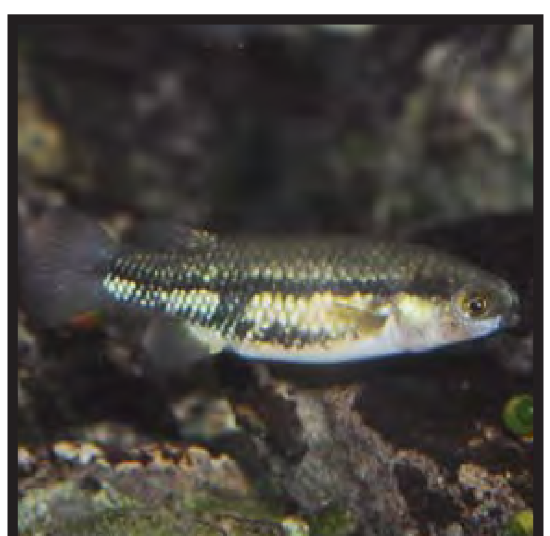
As the most abundant native fish on WSNA and the entire upper Muddy River, the Moapa White River springfish is the least threatened. The springfish is able to tolerate high water temperatures and low dissolved oxygen making the thermal springs and streams on WSNA ideal habitat. The upper Muddy River is the source population for those downstream. The Moapa White River springfish is commonly 1.5-2.0 inches in length and typically lives three years. Springfish reproduce year-round, with peak reproduction occurring in the spring when food sources, such as algae and aquatic insects are most readily available. Protecting existing thermal and flow qualities of the upper Muddy River springs and reaches, and controlling introduced fishes is important for this species.

Aquatic Invertebrates

Several aquatic invertebrates identified for management consideration are known to reach their maximum prevalence in the Warm Springs Aquatic Assemblage. The *Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem* (1996) recognizes two snails and two insects as species of concern. They are all endemic to the Muddy River and known to occur on WSNA. The Clark County Multiple Species Habitat Conservation Plan (2000) identifies one additional snail and two additional aquatic insects as high priority species for evaluation. An aquatic invertebrate survey performed on WSNA by Albrecht et al. (2008) identified three additional rare insect species. The Nevada Natural Heritage Program adds another aquatic insect purported as occurring on WSNA on their watch list.

The Amargosa naucorid *(Pelocoris shoshone amargosus)* may have mistakenly been thought as occurring in the Muddy River due to referenced use of the common name "Amargosa naucorid." Parker et al. (1997) lists *P. shoshone* as occurring in thermal springs of the upper Muddy River, but no mention is made of the subspecies. The *Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem* (USFWS 1996) identifies *Pelocoris shoshone shoshone* as a species of concern on their recovery list but applies the common name as Amargosa naucorid. Huillet (1998) did not sample *Pelocoris shoshone* but listed *Pelocoris biimpressus shoshone* indicating taxonomic confusion among literature citing *Pelocoris* in the Muddy River.

Pelocoris biimpressus shoshone was also encountered by Sada and Herbst (1999). Albrecht et al. (2008) listed a sampled naucorid as *Pelocoris biimpressus (?shoshone)* suggesting uncertainty as to the identification at the subspecies level. It is apparent that all variations are the same species – hereafter referred to as the Pahranagat naucorid *(Pelocoris biimpressus shoshone)*.



Moapa White River springfish
(Crenichthys baileyi moapae)

Moapa Warm Springs riffle beetle
(Stenelmis moapa)

Pahranagat naucorid
(Pelocoris biimpressus shoshone)

Moapa naucorid *(Limnocoris moapensis)*

Aquatic Invertebrate Recovery

The general belief is that restoring stream habitat for Moapa dace will be beneficial for all aquatic invertebrates. Competition theory suggests niche separation will occur across the breadth of existing niches. Single species management can easily favor one group of species over another. Due to the diversity of rare aquatic species in the upper Muddy River, aquatic invertebrate sampling will be implemented for all stream restoration projects. Restoration projects will also give due consideration to habitat heterogeneity in design and implementation.

Stream restoration efforts require provisions for the full suite of endemic and rare aquatic macroinvertebrates at WSNA. Because the different species prefer different flow velocities, water depths, substrates, vegetation, coarse particulate organic matter, and bank structure, it is imperative to maintain a diversity of aquatic habitat parameters throughout the stream reaches. Sada and Herbst (1999) recommend maximizing habitat diversity to benefit the entire community.

Focusing restoration work solely on fishes may negatively impact aquatic invertebrates. Community stability, resistance, and resilience are positively related to species diversity.

Moapa pebblesnail *(Pyrgulopsis avernalis)*

Aquatic Invertebrates - Percent Occurrence per 11 Reaches from Muddy River Headwaters to NV Energy Diversion	% Reach Occurrence
Grated tryonia *(Tryonia clathrata)*	100%
Moapa Warm Springs riffle beetle *(Stenelmis moapa)*	91%
Moapa riffle beetle *(Microcylloepus moapus)*	91%
Western naucorid *(Ambrysus mormon)*	82%
Moapa pebblesnail *(Pyrgulopsis avernalis)*	73%
Moapa naucorid *(Limnocoris moapensis)*	73%
Moapa Valley pyrg *(Pyrgulopsis carinifera)*	73%
Pahranagat naucorid *(Pelocoris biimpressus shoshone)*	27%

Albrecht et al. 2008

The occurrence of rare aquatic invertebrates throughout the headwaters of the Muddy River within the Warm Springs Aquatic Assemblage indicates broad distribution with the exception of the Pahranagat naucorid which was only sampled in 3 of 11 headwater reaches (Albrecht et al. 2008). It was located in the Apcar, South Fork, and middle main stem reaches. Previous sampling by Sada & Herbst (1999) did not encounter it in the South Fork but did locate it in the Plummer and Pederson streams. They noted a habitat preference for slow backwater with fine substrates and sparse vegetation. Huillet (1998) mentioned the naucorid as commonly collected. The distribution of this species appears greater than what was sampled by Albrecht et al. (2008) and is likely an artifact of sample methodology.

SE ROA 12160

Velvet ash woodland

3.06 DECIDUOUS RIPARIAN WOODLAND

SPECIES FOR MANAGEMENT CONSIDERATION

- Southwestern willow flycatcher
  Empidonax traillii extimus
- Western yellow-billed cuckoo
  Coccyzus americanus occidentalis
- Summer tanager
  Piranga rubra
- Townsend's big-eared bat
  Corynorhinus townsendii
- Western red bat
  Lasiurus blossevillii
- Western yellow bat
  Lasiurus xanthinus
- Fringed myotis
  Myotis thysanodes

The Deciduous Riparian Woodland along the Muddy River and its tributaries on WSNA have an abundance of velvet ash *(Fraxinus velutina)*, Fremont cottonwood *(Populus fremontii)*, Gooding's willow *(Salix gooddingii)*, and California fan palm *(Washingtonia filifera)*. The deciduous trees are especially important as nesting habitat for birds and as shade cover for native fish. The fan palms, while not desirable when they are impacting stream flow dynamics, do provide roosting habitat for the yellow bat and food for a variety of birds. Riparian woodlands have expanded along many irrigation ditches thereby extending the distribution of quality bird habitat. In many riparian areas, the trees alternate with or are replaced by the Riparian Shrubland Assemblage, forming an ecotone.

Management of riparian woodland entails protecting existing quality habitat from fire, exotic plant invasion, and age-related decadence, as well as restoring riparian woodland along denuded stream reaches. Velvet ash and Goodding's willow are particularly valuable riparian woodland species. Where recruitment of these species is not occurring naturally, site augmentation with propagated plants or transplants is recommended. The desired condition for this assemblage is a heterogeneous composition of age classes and tree densities throughout the riparian corridors.

Fremont cottonwood provides the largest structural component in this assemblage and is an important habitat species. It readily pioneers disturbed riparian areas and will likely not require significant restoration attention. In established groves along irrigation ditches, the trees continue to persist because their roots have reached groundwater, but recruitment of new trees is limited because of discontinued irrigation. In such areas, managed restoration may be desirable.

Because the California fan palm has invasive characteristics, develops undesirable fuel loads, and can negatively impact stream flow dynamics, it will not be purposefully planted as a component in riparian woodland restoration. In many woodland areas, the palms will be controlled in favor of more desirable native trees. Where fuel loads are not an issue, palms may be left intact. Where palm trees are removed, native tree species will be restored.

RIPARIAN SPECIES

Southwestern willow flycatcher
(Empidonax traillii extimus)

The southwestern willow flycatcher is a small, insect-eating bird that has been protected as an endangered species by the US Fish and Wildlife Service since 1995. There are estimated to be only 900 - 1,000 breeding pairs of the southwestern willow flycatcher. Southwestern willow flycatchers breed in sites that have very dense tree cover usually close to water and over saturated soil.

Resident southwestern willow flycatchers were noted on the Warm Springs Natural Area in 2004, 2005, 2007, 2008, 2009, and 2010. In 2008, nine southwestern willow flycatchers were located on WSNA north of the Apcar Stream (Braden et al. 2009). In 2009, four birds were found in dense patches of trees north of the Muddy River (Klinger & Conrad 2010). Of the four birds detected, two were a pair that fledged three young (McLeod et al. 2010).

Western yellow-billed cuckoo
(Coccyzus americanus occidentalis)

The Western yellow-billed cuckoo is a medium-sized, slender and inconspicuous bird that forages in dense, leafy trees and eats large insects such as grasshoppers and caterpillars. The Nevada Department of Wildlife has identified cuckoos in a few areas around the state in small numbers. These birds are nomadic and numbers fluctuate greatly from year to year. A significant portion of the cuckoos found in Nevada in the early 2000s were at the Warm Springs Natural Area but more recent surveys have only detected one bird each year from 2003 to 2006, zero in 2007, and three in 2008. Two detections were made in 2009 (Bruce Lund, personal communication, 2009). These birds have been observed in the large woodland north of the main stem of the Muddy River (Braden et al. 2009), but cuckoos can be found throughout the WSNA in appropriate habitats.

Summer tanager
(Piranga rubra)

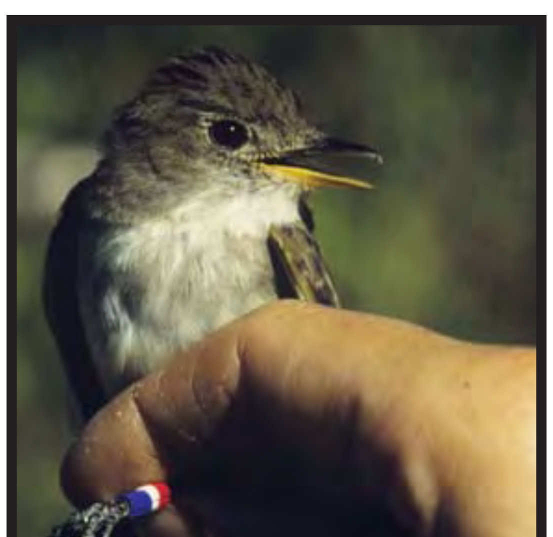
The summer tanager, a Clark County Multiple Species Habitat Conservation Plan Covered Species, is a medium-sized bird with a stout bill. Males are a brilliant red color and females are a buffy orange color. Males have small crests. Summer tanagers feed on bees and wasps that they catch in the air. They are confirmed breeders on the Warm Springs Natural Area according to Great Basin Bird Observatory (Appendix 4). Management for the summer tanager is similar to management for the southwestern willow flycatcher and includes preservation and establishment of dense riparian vegetation.

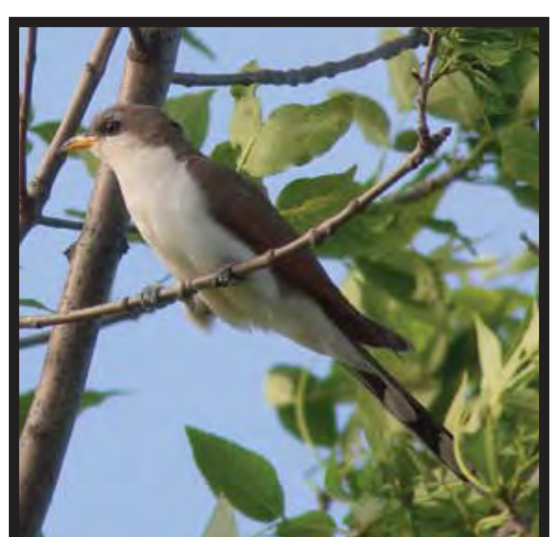
Western yellow bat
(Lasiurus xanthinus)

The Western yellow bat has been recorded roosting in the palm trees *(Washingtonia filifera)* of the Warm Springs Natural Area. This is the only population of yellow bats that has been located in Nevada, and this population is disjunct and more northerly than other populations of yellow bats (O'Farrell et al. 2004).

RIPARIAN WOODLAND BAT SPECIES

- Western yellow bat
  Lasiurus xanthinus
- Townsend's big-eared bat
  Corynorhinus townsendii
- Western red bat
  Lasiurus blossevillii
- Fringed myotis
  Myotis thysanodes


Southwestern willow flycatcher
(Empidonax traillii extimus)


Western yellow-billed cuckoo
(Coccyzus americanus occidentalis)


Summer tanager *(Piranga rubra)*


Western yellow bat
(Lasiurus xanthinus)

SE ROA 12162

JA_4924

3.07 RIPARIAN SHRUBLAND

The Riparian Shrubland at WSNA occurs along sections of the South Fork and Muddy River as well as along some irrigation ditches. Shrubs including Emory's baccharis *(Baccharis emoryi)*, arrowweed *(Pluchea sericea)*, coyote willow *(Salix exigua)* and other riparian non-obligates such as quailbush *(Atriplex lentiformis)* commonly occur in this assemblage. This riparian shrubland provides valuable habitat for birds, small mammals, and terrestrial invertebrates.

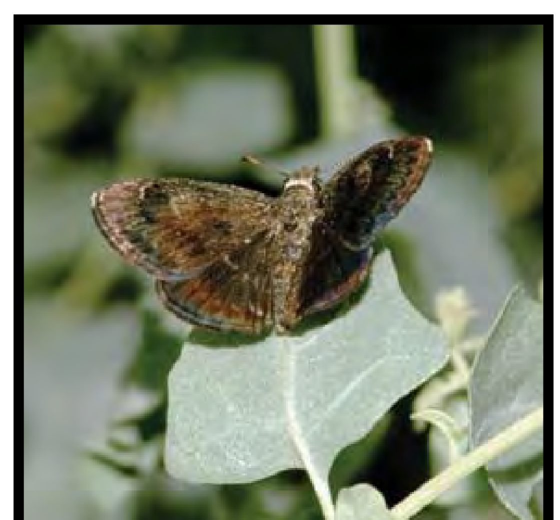
SPECIES FOR MANAGEMENT CONSIDERATION

- MacNeill sooty wing skipper
  Hesperopsis gracielae

MacNeill sooty wing skipper
(Hesperopsis gracielae)

Quailbush is a known host plant for the MacNeill sooty wing skipper. Larvae of this butterfly feed on the leaves whereas the adults forage for nectar on flowering plants. Quailbush occurs abundantly at WSNA and is not in danger of diminishing.

The MacNeill sooty wing skipper is considered common to abundant in Moapa Valley having been collected from Bowman Reservoir and Hidden Valley (Austin & Austin 1980). Hidden Valley is approximately five miles south of the WSNA and no fragmented host plant populations occur between recorded collections and the WSNA property. Adults have been recorded nectaring on tamarisk, salt heliotrope *(Heliotropium curassavicum)*, and alfalfa *(Medicago sativa)* (Austin & Austin 1980). However, Nelson (2009) did not record the MacNeill sooty-wing skipper at the WSNA during limited sampling in April and July 2009.



MacNeill sooty wing skipper
(Hesperopsis gracielae)

Quailbush
(Atriplex lentiformis)

SE ROA 12163

3.08 RIPARIAN MARSH/MEADOW

Marshes and seeps provide essential habitat for amphibians, birds, invertebrates, and small mammals. Because wetland habitat is so productive, it provides the food base to support higher trophic species such as predators. Due to its rarity and resource-rich quality within an otherwise resource-scarce Mojave desert ecosystem, riparian marshes and seeps attract and harbor an abundance of wildlife.

SPECIES FOR MANAGEMENT CONSIDERATION

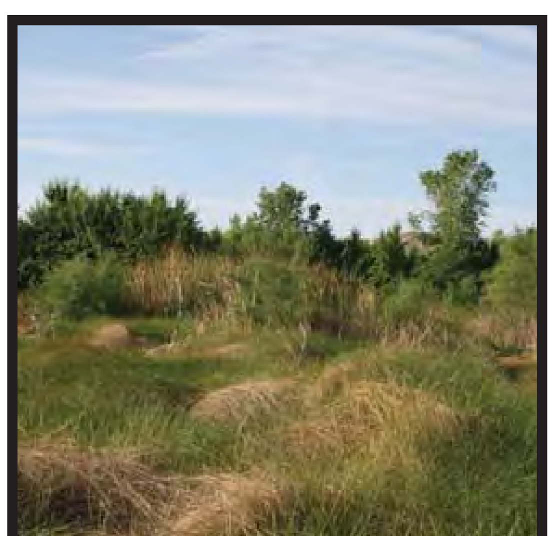
- Relict leopard frog
  Lithobates onca

Marshland on the Warm Springs Natural Area is primarily derived from spring outflow that may be either partially ponded or terminates in wet meadows. The amount of water varies seasonally with the greatest standing water most abundant during the winter months when the groundwater is particularly close to the surface. In some areas, riparian meadow vegetation can be found where surface water is entirely absent. Vegetation in such areas is supported by the high water table in the winter months. Riparian meadows form an important feeding ground for many of the bird species found on the natural area. Mowing in combination with periodic prescribed fire is useful to maintain the health and productivity of riparian meadows. The few marshes found on the Natural Area are largely overgrown with cattails and would benefit from the management practices that expose surface water for waterfowl and other wildlife.

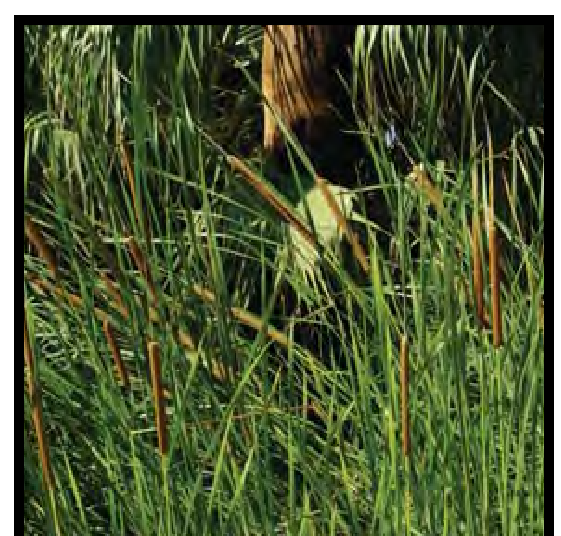
Introduction of the Relict leopard frog

The relict leopard frog *(Lithobates onca)* historically occurred in springs near the Colorado, Virgin, and Muddy Rivers including the springs at the headwaters of the Warm Springs Natural Area (Bradford et al. 2004). By 1950, this frog was believed to be extinct. However, in 1991 relict leopard frogs were rediscovered in several springs near Littlefield Arizona, near Lake Mead, and below Hoover dam. Conservation efforts include monitoring existing populations, enhancing spring habitats, captive rearing, and translocating frogs into historic and new locations.

Because Warm Springs Area is within the historic range of the relict leopard frog, frogs were relocated to adjacent lands owned by Clark County in 2010. Releasing relict leopard frogs on the Warm Springs Natural Area may be part of recovery efforts for this species.



Marsh



Cattails

Relict leopard frog *(Lithobates onca)*

Yerba ma

Honey mesquite pods

3.09 MESQUITE BOSQUE

Both honey mesquite *(Prosopis glandulosa)* and screwbean mesquite *(Prosopis pubescens)* comprise the mesquite woodland community type. Of the two, screwbean mesquite is regionally least common and perhaps therefore the most ecologically significant. On the WSNA screwbean mesquite forms a dense (near monotypic) woodland in some areas and provides important nesting and shelter habitat for many species of wildlife. The screwbean mesquite woodland at WSNA is the largest contiguous stand in Nevada. Both mesquite species host the parasitic mesquite mistletoe *(Phoradendron californicum)* which is an important food item for the Phainopepla. Aerial photographs of WSNA taken in 1950 reveal an absence of mesquite in the floodplain due to cultivated crops. Much of the land currently occupied by mesquite was still farmed as late as 1985. The abundance of mesquite at the present time reflects a discontinuation of farming and change to cattle grazing as the primary land use on the property since the late 1980s. While mature stands of mesquite provide positive habitat attributes, the total replacement of native grasslands by mesquite is not desirable. Ideally, a mosaic of mesquite woodland across the landscape representing different age-classes and densities is the preferred ecological state. At present, the woodland understory is dominated by non-native grasses and forbs, remnants of former pasture species. A long-term goal of restoring native understory species will only enhance the value of this vegetation type.

Phainopepla
(Phainopepla nitans)

The phainopepla is a medium-sized bird. Males are a silky black color and females are gray. Both sexes have crests. Phainopeplas feed on both berries and flying insects. The phainopepla is closely tied to the availability of the berries of mistletoe (*Phoradendron* spp.) which is a parasitic plant that grows on mesquite trees (*Prosopis* spp.). The phainopepla eats the mistletoe berries, digests them, and defecates the remaining sticky seeds on the branches of mesquite trees. The seeds sprout and the mistletoe becomes established on new mesquite trees. Management for phainopepla includes maintaining mesquite stands that are parasitized by mistletoe.

Phainopepla
(Phaninopepla nitans)

Vermilion flycatcher
(Pyrocephalus rubinus)

The Vermilion flycatcher is a small flycatcher found in the southwestern United States southward to Argentina. This species inhabits desert riparian areas but primarily nests in the screwbean woodland on the WSNA. The Warm Springs Natural Area is home to the largest breeding population of Vermilion flycatchers in Nevada. Males are a bright red color and females are gray with a peach belly. Vermilion flycatchers feed mostly on flying insects, such as bees and dragonflies that they catch on the wing. They often forage over water or meadows. Management for the Vermilion flycatcher includes keeping riparian and mesquite woodlands relatively open because they avoid densely wooded areas. These birds also occur in the riparian-agricultural interface especially near lightly cultivated or abandoned fields near open water.

Vermilion flycatcher
(Pyrocephalus rubinus)

Spotted bat
(Euderma maculatum)

The spotted bat is a large bat with extremely large ears and three large white spots on its back. This state-protected species is known to roost on cliffs and to forage in mesquite bosques in the Warm Springs Natural Area (O'Farrell et al. 2004 and Williams et al. 2006). The spotted bat eats a variety of insects but primarily feeds on moths. This species is rare and patchy in occurrence in a variety of habitats throughout the western United States. The spotted bat has one young per year in June or July. Little else is known about this elusive species. Management for the spotted bat includes protecting cliff roosting areas and maintaining insect and moth diversity by maintaining open mesquite bosque habitat.

SPECIES FOR MANAGEMENT CONSIDERATION

- Phainopepla
  Phainopepla nitans
- Vermilion flycatcher
  Pyrocephalus rubinus
- Spotted bat
  Euderma maculatum

3.10 OTHER ECOLOGICAL GROUPS

Several plant communities exist on WSNA that do not fall within TNC's six ecological "assemblages" (Provencher et al. 2005) but still harbor rare and protected animal species. Additional plant communities include the creosote bush shrubland, saltbush shrubland, and alkali meadows.

SPECIES FOR MANAGEMENT CONSIDERATION
(Creosote bush shrubland)

- Desert tortoise
  Gopherus agassizii
- California leaf-nosed bat
  Macrotus californicus
- Big free-tailed bat
  Nyctinomops macrotis

Creosote bush shrubland

Characteristic of the Mojave Desert, this shrubland provides habitat for the threatened desert tortoise and at least two species of bats, the California leaf-nosed bat and the big free-tailed bat. Creosote bush shrubland occupies the upland areas of WSNA above the floodplain. It is also the dominant vegetation type that surrounds WSNA. Much of the plant diversity documented on the WSNA occurs in this community. The Creosote bush shrubland at the WSNA has not been heavily impacted by past agricultural practices. This area is in good condition with expansive distribution outside the WSNA boundary. Management action will likely be limited to controlling some of the common non-native weeds that increase the risk and spread of wildfire such as red brome *(Bromus rubens)* and Sahara mustard *(Brassica tournefortii)*.

Saltbush shrubland

This vegetation community is found in more saline soils of the floodplain in the upper Muddy River. In the most saline soils where a high water table exists, iodinebush *(Allenrolfea occidentalis)* can be a dominant species. Other areas on the WSNA are dominated by quailbush *(Atriplex lentiformis)* and Mojave seablite *(Suaeda moquinii)*. This community often forms a gradient with alkali meadows.

Alkali meadow

Saltgrass *(Distichlis spicata)* is the most prevalent species found within this plant community followed by alkali sacaton *(Sporobolus airoides)*. Because of the past extensive cultivation at WSNA, remnant stands of alkali meadows are considered extremely important. Much of this community type has been replaced by Bermuda grass *(Cynodon dactylon)*. These meadows also serve as foraging grounds for wildlife, especially where they border mesquite woodland.


Creosote bush shrubland


Saltbush shrubland


Alkali meadow

4

SE ROA 12168

4.01 SPECIAL MANAGEMENT

Stewardship Plan

SNWA committed to join with stakeholders to develop a long-term plan for the property. The purpose of this document is to establish long-term management direction for the Warm Springs Natural Area. It is SNWA's intention that the Stewardship Plan will establish a framework for appropriate land uses for the property that preserve the integrity of natural resources and lay a foundation for the property that will foster stakeholder relationships. The Stewardship Plan is intended to clarify SNWA's responsibilities and management direction as they pertain to conservation on the Warm Springs Natural Area and ensure consistency with the SNWA's commitments in the SNPLMA Nomination and the Muddy River Recovery Implementation Program.

While the Stewardship Plan is intended to provide guidance for SNWA management and future land uses and activities on the Warm Springs Natural Area, it is important to note that the Stewardship Plan is a conceptual document to begin dialogue and is not intended to require implementation of any specific management action recommendations. Implementation of such actions is left to the discretion of the SNWA Board of Directors through the annual budgeting process and through specific contract approvals as needed.

Management Priorities

The prioritization process was formulated by the Core Team and experts in various fields. The Mission Statement developed by the Core Team establishes management priorities and serves to frame future decisions.

The following are management priorities for the property:

- Manage the property for the benefit and recovery of the Moapa dace. This includes restoring and protecting the thermal springs and their outflows.
- Manage the property for the benefit of federally-protected, state-protected, sensitive, and thermal endemic species.
- Manage the property as a Natural Area – which means encouraging native species and their ecological assemblages and removing invasive species.
- Reduce fuel loads and establish fire breaks on the Natural Area to protect neighbors and property.
- Carry out SNPLMA commitments for the property for controlled public access of the Natural Area.

Goals and Objectives

Goals and objectives guide implementation of future management actions toward activities that produce the desired outcome of a well-balanced Natural Area. The Core Team identified the following goals and objectives to direct future management for the Warm Springs Natural Area:

- Protect listed, sensitive, and thermal endemic species and their habitat when conducting management activities;
- Reduce fuels on site, focusing first on the portion of the property adjacent to neighbors and then property-wide fuels reduction to insure safety;
- Preserve cultural and historic resources on the property;
- Utilize local, native species when restoring the Natural Area;
- Reduce invasive species on site, where possible;
- Encourage public appreciation of the natural systems through education;
- Provide the opportunity for scientific research programs of the Warm Springs ecological system; and
- Consider the Warm Springs Natural Area as a component of the Muddy River ecosystem (migratory flyway, headwaters of the Muddy River, etc.) when implementing management decisions.

MANAGEMENT PRIORITIES

Manage the property for the benefit and recovery of the **Moapa dace**. This includes restoring and protecting the thermal springs and their outflows.

Manage the property for the benefit of **protected species**: federal, state, sensitive and thermal endemic species.

Manage the property as a **Natural Area** – which means promoting native species and their habitats and controlling invasive species.

Reduce fuel loads and establish fire breaks on the Natural Area to protect neighbors and property.

Carry out SNPLMA commitments for controlled **public access** of the Natural Area.

Illegal Dumping

Illegal dumping of trash has occurred at certain locations of the WSNA for many years. Lawn and garden refuse and household items are a few of the commonly encountered items once disposed of on the property. The most serious known dump site is an area adjacent to BLM land that has always been accessible just off Highway 168 on a gravel road. To prevent further dumping, it is necessary to adequately fence off open access areas and to properly sign the property. Existing trash will need to be removed and disposed of properly at an authorized landfill.

Beaver Management

Although beaver dams and ponds are well known for their important role in flood control and in the establishment of wetlands, meadows, and riverine forests, beaver dams and ponds can be detrimental to Moapa dace habitat. Dams cause the swift-flowing water to slow, pond, and cool, which reduces the length of stream with the warm water temperatures needed by the dace. This ultimately reduces the amount of adequate dace habitat. Non-native dace competitors and predators such as mollies and tilapia thrive in the slow moving water behind beaver dams. Due to the imperiled status of the Moapa dace, beavers and their dams should be removed from streams containing Moapa dace. Beaver and dam removal will improve habitat for the dace by increasing water temperatures, increasing appropriate swift water habitat, and will reduce habitat for non-native fish.

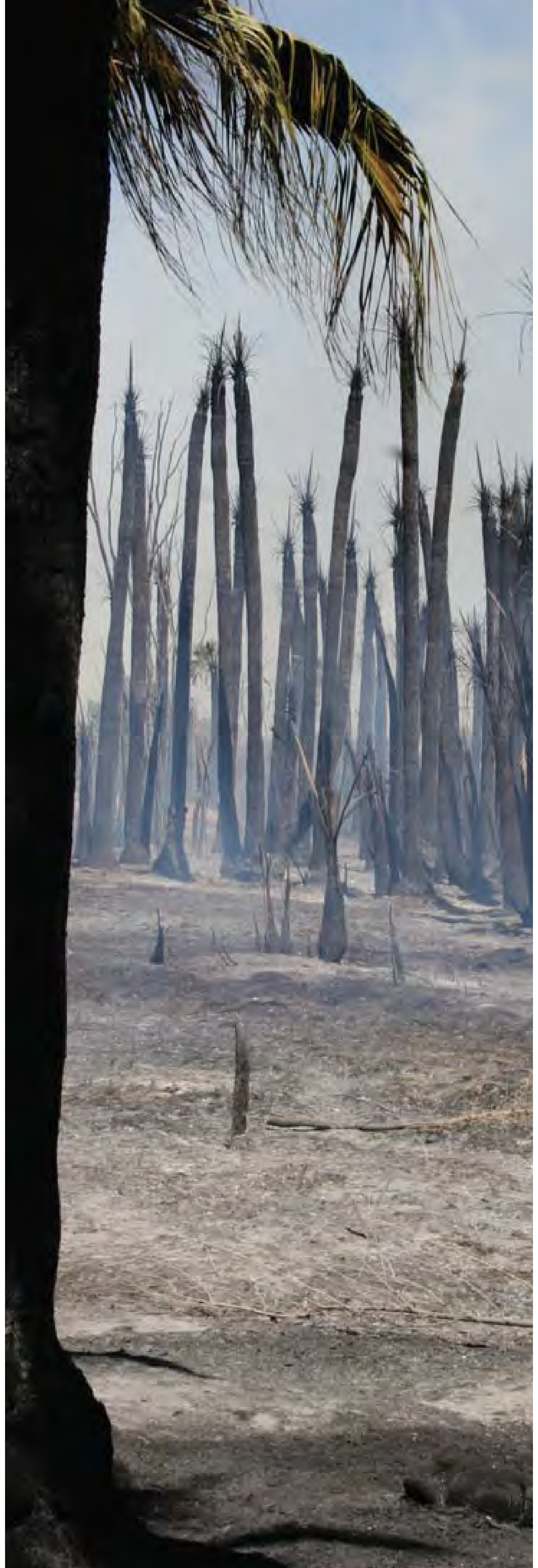
Grazing

The current ecological condition of WSNA (ranging from poor to good) is primarily due to the cumulative effect of crop cultivation and extensive grazing. While grazing pastured or grassland systems can have the visual effect of a pleasing pastoral scene, its persistent practice has more subtle but lasting negative effects on natural systems. Cattle preferentially forage on certain species, thereby encouraging the expansion of less preferred plants. On WSNA, alkali goldenbush *(Isocoma acradenia)* and honey mesquite *(Prosopis glandulosa)* have greatly increased due to grazing.

Grazing for the sake of livestock production is no longer a justifiable activity under managing the property as a natural area. The use of animals to accomplish certain management objectives may be considered in the event that other alternatives are not available or are less satisfactory.

Using grazing for the purpose of fuels reduction or biological weed control is worthy of consideration given other factors of habitat quality are preserved. Currently, preference for fuels reduction is being given to mechanical mowing and prescribed fire. For the purpose of weed control in biologically sensitive areas where chemical control is not appropriate, confined, intensive grazing may produce desirable outcomes.

Vegetation manipulation by grazing should only be considered in localized situations. Grazing can have the unwanted outcome of introducing or spreading noxious weeds. Overgrazing can negatively affect plant community composition. Serious problems persist from past grazing, impacting stream bank stability, water quality, and hydrological function, which has negatively altered Moapa dace habitat.



4.02 FIRE MANAGEMENT

Fire History

Warm Springs Natural Area has experienced many wildfires over the past half century. Large wildfires have occurred approximately every ten years. A large wildfire occurred in 1987 consuming several homes and barns at the old Home Ranch. Another catastrophic fire occurred in 1994 impacting property and Moapa dace habitat on the Moapa Valley National Wildlife Refuge. In 2004, a wildfire followed the palms up the North Fork and destroyed a home. In 2008 a lightning strike ignited a palm tree on the northern side of the property starting a 2.5 acre wildfire that was quickly quelled thanks to water trucks working nearby. A fire in 2010 burned 601 acres, destroying a residence, staffing quarters and the “Big House” on the LDS Church Recreational Area.

Fire can have positive effects on natural ecosystems. Many ecosystems require fire to maintain plant community health and productivity which can support a more abundant and diverse wildlife component. While wildfire can be beneficial, the threat of wildfire to private property has been and continues to be a relevant concern for property owners in the Warm Springs area. The impact of wildfire to the endangered Moapa dace is also of concern. Burning vegetation along streams can raise the water temperature. Ash deposition in streams can raise the pH and lower the dissolved oxygen.

The loss of desirable riparian and mesquite woodland due to wildfire can also have significant impacts on sensitive bird species. Wildfire results in the expansion of introduced weeds which in turn can increase frequency and extent of future wildfires. Much of WSNA is densely vegetated and entails a certain degree of risk for wildfire. Steps to reduce wildfire risk to property and habitat will be implemented as part of a fuels reduction program and outlined in a wildfire management plan.

Pre-suppression

Pre-suppression means taking preventative action to reduce the likelihood or extent of accidental or natural wildfires. Pre-suppression activities include surveying WSNA and prioritizing areas that would benefit from fuel reduction, fire breaks, and vegetative manipulation. Weed management is a related activity that contributes to the reduction of fine fuels. A survey of fuels around priority wildlife areas, structures, and neighboring properties will be required on a regular basis. Fuel loads may be reduced using a variety of methods including mechanical, chemical, and biological treatments. Because fuel biomass will continually accrue from one growing season to the next, fuels reduction will need to be an ongoing program requiring vigilant monitoring.

Palm trees contribute to the most serious build up of fuels at the WSNA. Dry palm fronds are highly flammable and are easily ignited by lightning strikes. Because so much biomass accumulates in the palm tree skirts, palm fires are intense and can carry in the tree canopies regardless of understory vegetation. Fire risk from palm trees can be partially remedied by regularly trimming palm skirts or complete removal of enough trees to disrupt fuel continuity. Given the thousands of palm trees on the property, palm frond trimming is not feasible for property wide application.

Grass contributes to the establishment of a fine fuel load through which fire can rapidly advance. There are several areas where perennial grasslands are extensive. Because these grasses are generally valuable habitat components, maintaining roads to function as fire breaks should be employed. Additional roads can be created to act as fire breaks against grassland fire. Periodic prescribed burns in grasslands can help minimize the buildup of fine fuels. Prescribed burning can also improve the overall quality of grass dominated systems.

Prescribed fire

Prescribed fire can be a valuable management tool and is a viable option for WSNA. Use of prescribed fire is however contingent upon the development of a site specific prescribed fire plan with a full complement of appropriate response personnel and equipment. Following prescribed burns, areas that lack the capacity to rejuvenate as native plant communities should be reseeded with native species. Encouraging native plant revegetation will help exclude the establishment of exotic weeds which can exacerbate future fire problems.

SE ROA 12171

Fire Breaks

Fire breaks can provide an effective safeguard against fire advance if their width is sufficient to prevent a breach. The appropriate width of a fire break is dependant upon adjacent fuel types. Higher, denser vegetation such as trees require wider fire breaks. Regardless of fire break design, high winds can carry embers far beyond any fire break. Fire breaks require regular maintenance to preserve their effectiveness. Fire break lines will need to be monitored regularly and treated as appropriate. Mechanical or chemical treatments can be effective though mechanical treatments can subsequently promote the growth of weedy species.

Besides defensive perimeters around neighboring property owners, fire breaks within the property are necessary to reduce the spread and severity of fire. Palm trees skirts form a near continuous fuel source for fire to travel riparian corridors. The heat generated from flame engulfed palm trees contributes to the rapid spread of fire into neighboring vegetation. Sections of palm trees along the waterways may be removed to eliminate a contiguous line of fuel load.

Palm Management

Fond memories of swimming amid the palms as a child at Warm Springs pervade the memory of many local citizens. The public has a strong emotional link to the past and palm trees appeal to people's sense of place. There is considerable debate regarding the palm trees' origin and the role California palms play in the riparian ecosystem. Palms on WSNA will be managed individually, depending upon an identified impact to hydrological function, stream ecology, or as a fire risk. Palms having no direct impact may be left for wildlife. The first management solution for palms considered as a fire risk may be to trim the palm skirt, otherwise they may be removed.

Fire Response

The Clark County Fire Department has fire suppression responsibilities outside incorporated areas within Clark County and therefore has command responsibility. The closest Clark County Fire Department station is the Moapa Volunteer Fire Department Station 72 located in Moapa. Federal agencies responded to the fire in July 2010, due to the proximity of WSNA to the Moapa Valley National Wildlife Refuge.

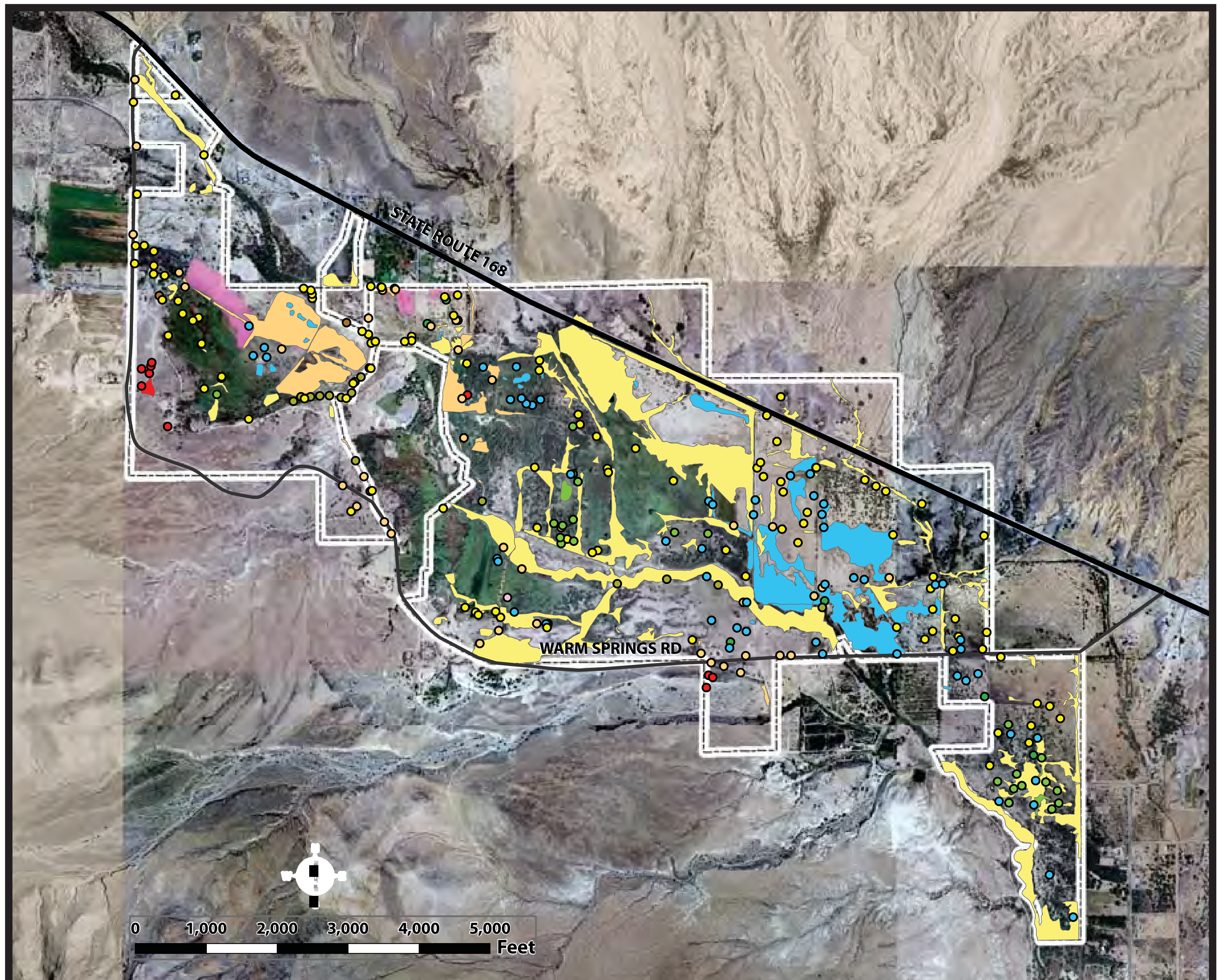
Post-fire Rehabilitation

Depending upon the severity and extent of habitat damage following a wildfire, natural recovery, augmented recovery, or intensive rehabilitation should be evaluated for treatment consideration. Post-fire weed control is usually necessary to prevent the spread of invasives. Post-fire monitoring using photo-points and vegetation analysis should be encouraged. Unlike federal agencies which have access to emergency fire funds to help rehabilitation efforts, WSNA rehabilitation will be contingent upon budgeted funding availability. For that reason, pre-suppression will be emphasized; however, a post-fire analysis can be conducted to develop a response plan that will document restoration needs and costs. Post-fire rehabilitation plans will be coordinated with the Biological Advisory Committee and the USFWS.

4.03 INVASIVE MANAGEMENT

2008 Weed Survey

- Malta Starthistle
- Perennial Pepperweed
- Russian Knapweed
- Sahara Mustard
- Saltcedar
- Morning Glory
- Hoary Cress
- Malta Starthistle
- Perennial Pepperweed
- Russian Knapweed
- Sahara Mustard
- Saltcedar
- Common Reed
- Giant Reed
- Morning Glory
- Warm Springs Natural Area



A 2008 weed survey at the WSNA identified seven noxious and two nuisance weed species (Tri-County Weed Control 2008). Three additional noxious weeds and five additional nuisance weeds were identified by WSNA staff. Prioritization of weed species, based on negative habitat effects, invasiveness, and risk for additional impacts at the WSNA, identified both noxious and nuisance weed species as targets for control.

Weed Management

Any undesired plant in a given location can be classified as a weed; however, not all weeds are equal. Some weeds are labeled "noxious" and require abatement action according to Nevada State law. In Nevada, noxious weeds are broken into one of three categories (A, B, or C). Category A noxious weeds require active control of all populations. Control of Category B noxious weeds is centered on reducing the risk of further contamination and the eradication of emerging populations. Category C noxious weeds are generally widespread, and abatement is at the discretion of the state quarantine officer. Other weeds are considered "nuisance" and have no legal requirement for eradication/control even if the nuisance weed may be ecologically more damaging than any given noxious weed.

Invasive Plants

While saltcedar is one of the most dominant weeds on the property, it is relatively stable when compared to Russian knapweed which is expanding and has the potential to dominate new areas on the WSNA. Similarly, Malta starthistle is highly invasive due to its mode of dispersal. It is commonly found along roads and trails where it is dispersed as a hitchhiker on people, animals, or vehicles. Russian thistle is problematic due to its potential risk for wildfire. Russian thistle can grow in dense stands and is extremely flammable when dry. Wind commonly piles Russian thistle along fence lines or hedgerows, creating an opportunity for rapid fire movement over long distances. Russian thistle can also roll across the landscape while on fire during windy conditions, further exacerbating fire spread.

Noxious Weeds	Acres Infested	Category	Management Priority
Russian knapweed *(Acroptilon repens)*	157.5	B	1
Malta starthistle *(Centaurea melitensis)*	47.9	A	2
Saltcedar *(Tamarisk spp.)*	35.4	C	3
Perennial pepperweed *(Lepidium latifolium)*	*	C	8
Sahara mustard *(Brassica tournefortii)*	1.5	B	9
Hoary cress *(Cardaria draba)*	*	C	10
Giant reed *(Arundo donax)*	*	A	12
White horse-nettle *(Solanum elaeagnifolium)*	*	B	**
Johnson grass *(Sorghum halepense)*	*	C	**
Puncture vine *(Tribulus terrestris)*	*	C	**

* Less than one acre
** Low management priority

Bermudagrass was originally planted as a pasture grass and dominates much of the grassland and mesquite understory.
Due to its competitive nature, it precludes many desirable native species especially herbaceous forbs which are distinctly lacking on the property. Eelgrass, an aquatic plant, is of particular importance to Moapa dace habitat, though it is already widespread and has likely reached its maximum distribution on the WSNA. The remaining species occupy small areas and/or comprise a minimal threat but will either be monitored or treated as time and resources permit.

The WSNA management strategy follows an Integrated Pest Management (IPM) approach to weed control and/or eradication. Mechanical, chemical, and biological control measures will be given due consideration as control treatments. Because of the contamination potential for chemical residues into surface waters supporting Moapa dace and other sensitive aquatic species, non-chemical control options will be given priority in areas where contamination is possible. Chemicals that can directly or indirectly affect fish will not be used within a generous buffer zone, in windy conditions, or during inclement weather. The use of any chemical within or bordering dace habitat will require coordination with the US Fish and Wildlife Service. In all instances, best management practices will apply. Use of any restricted chemical will require an on-site, licensed person for the duration of chemical application. Care will be taken to prevent the bioaccumulation of systemic chemicals in soils or systems caused by multiple applications or by using highly persistent chemicals. The development of an IPM Plan for the property would address the various issues associated with managing pest species at the WSNA.

Nuisance Weeds	Acres Infested	Management Priority
Prickly Russian thistle *(Salsola tragus)*	150.0	4
American eelgrass *(Vallisneria americana)*	*	5
Bermudagrass *(Cynodon dactylon)*	150.0+	6
Red brome *(Bromus rubens)*	*	7
Field bindweed *(Convolvulus arvensis)*	*	11
Common reed *(Phragmites australis)*	*	**
Russian olive *(Elaeagnus angustifolia)*	*	**


Malta starthistle


Tamarisk


Tamarisk

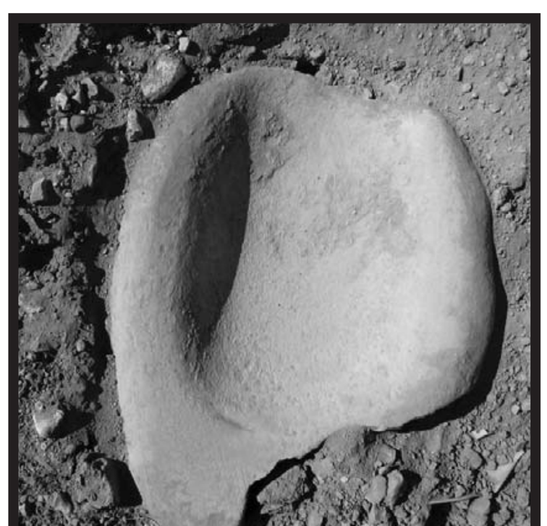
4.04 CULTURAL RESOURCE MANAGEMENT

Many of the important resources found on the WSNA property are cultural and historical. Historic property can include buildings, structures, objects, sites, and traditional cultural properties that are at least 50 years old. Protecting cultural resources on the WSNA is a management goal of SNWA. In 2008, an intensive archaeological survey was conducted to identify and document the archaeological resources on WSNA and evaluate the eligibility of these resources for nomination to the National Register of Historic Places (NRHP) (HRA 2008 and 2009). The survey identified three previously recorded sites and 16 previously unrecorded archaeological sites. Of these 19 sites, 16 are prehistoric habitations, trails, artifacts scatters, and rock shelters; and three are historic. The historic sites include the Home Ranch, irrigation ditches, and a recreational facility built by Xavier Cougat for Folies Bergère showgirls in the late 1950s.

HRA recommended that 12 of the 19 properties are eligible for nomination to the NRHP because they are likely to yield information important to prehistory or history. Most of the NRHP-eligible sites are prehistoric artifact scatters located on the upland terraces and hills. Only a few archaeological sites were identified in the low-lying floodplain where past agriculture would have been practiced.

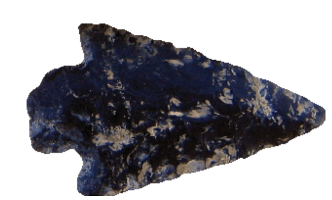
Management of known archaeological sites includes protection from public access and future development plans. Most of the area's archaeological resources are fragile and can be impacted in direct and indirect ways. Direct impacts occur when a site is affected by construction activities such as grading or digging, and indirect impacts are typically damages that are visual or result from visitors or daily operations. Impacts to the archaeological sites can be avoided by taking these resources into consideration during the early stages of planning. Areas containing known cultural resources should be avoided during future development projects. If avoidance is not possible, then a treatment plan to mitigate impacts to cultural resources should be developed in consultation with the State Historic Preservation Office. These treatment plans may include surface mapping, artifact collection and analysis, monitoring, and in some cases excavation.

Interpretive opportunities for public interest and education will be explored. Signs and other interpretive displays explaining the area's unique history may be incorporated into visitor facilities and trails.



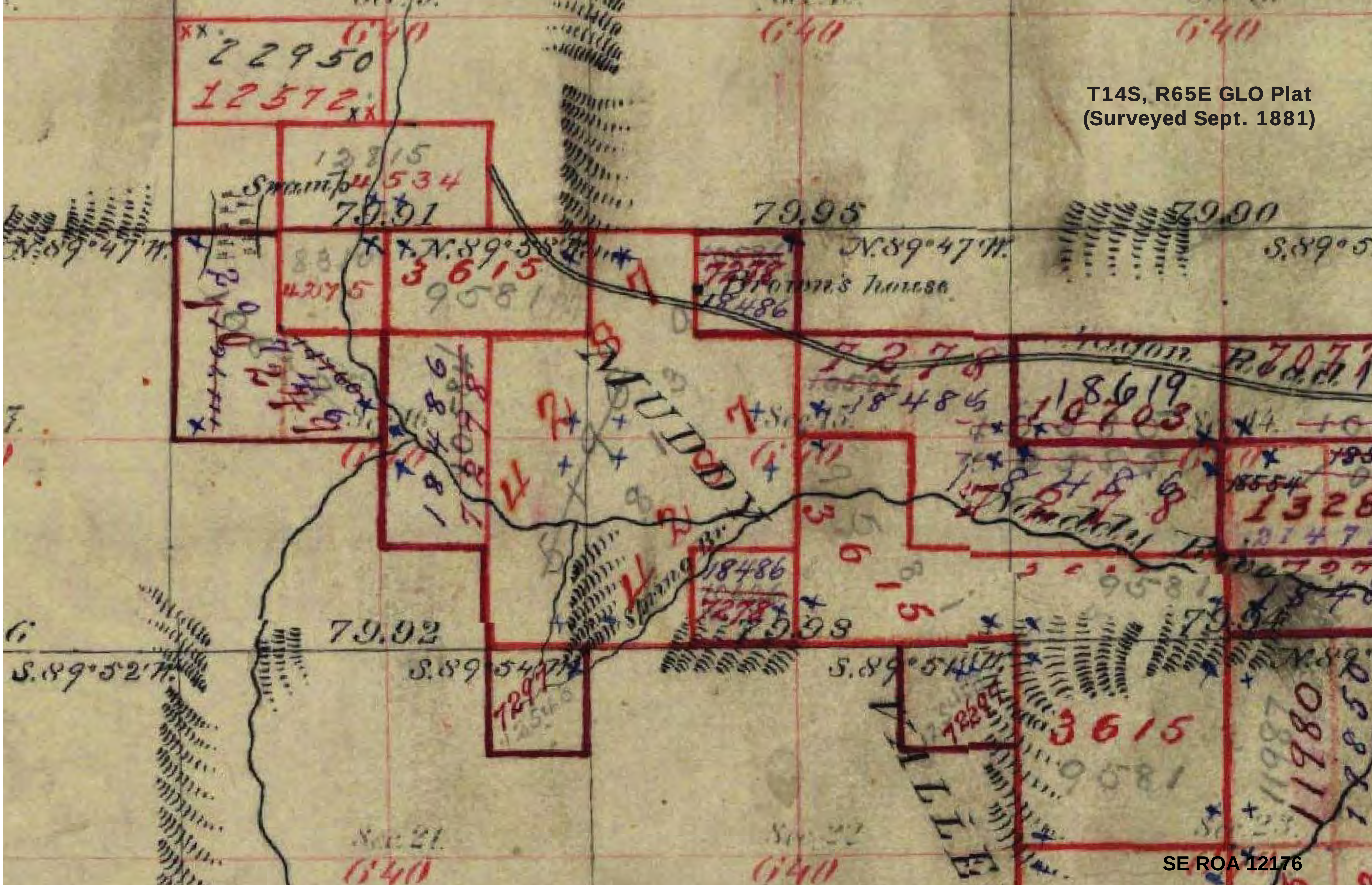
Great Basin metate

Eastgate expanding stem projectile point



Obsidian Rose Spring projectile point

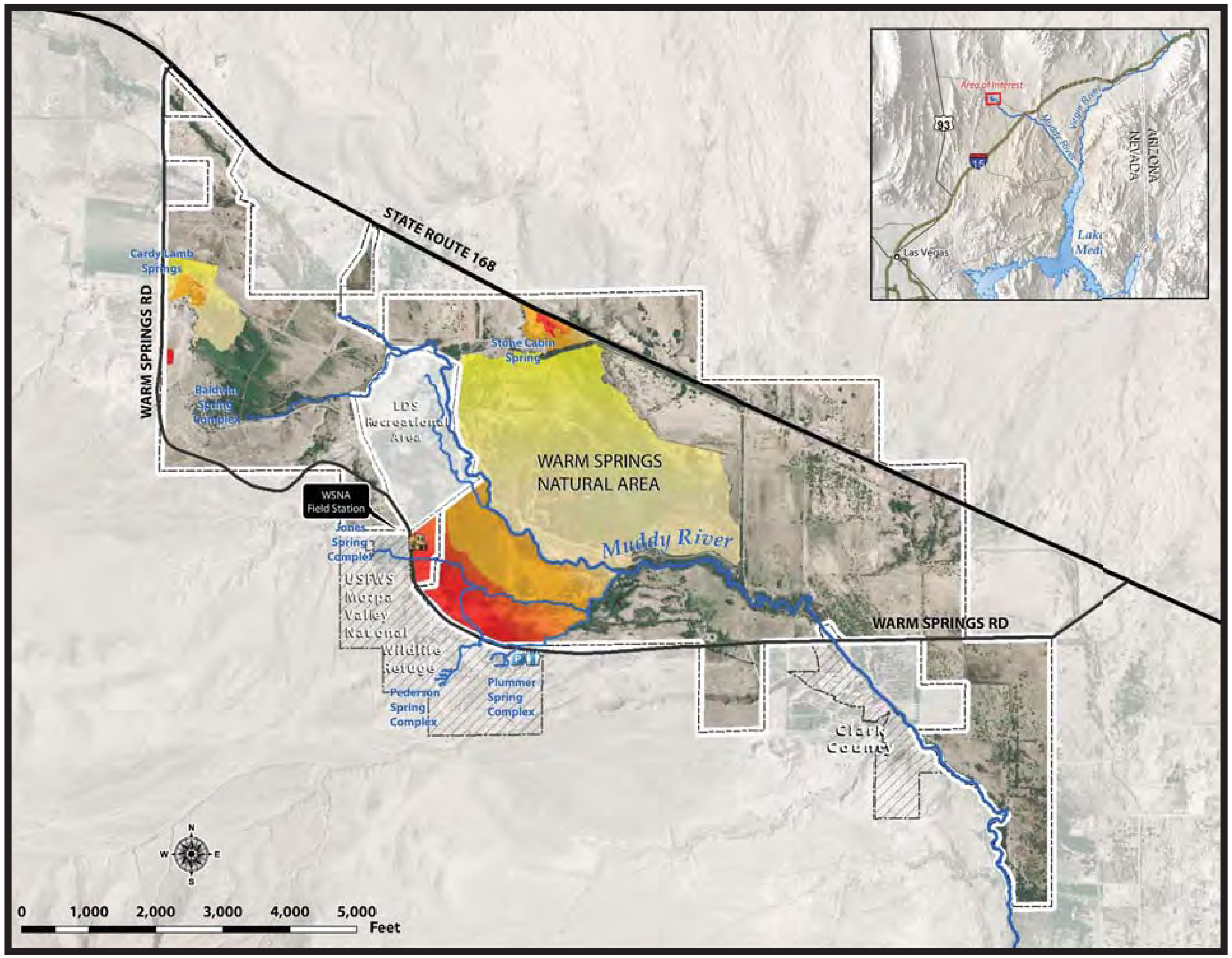
SE ROA 12175

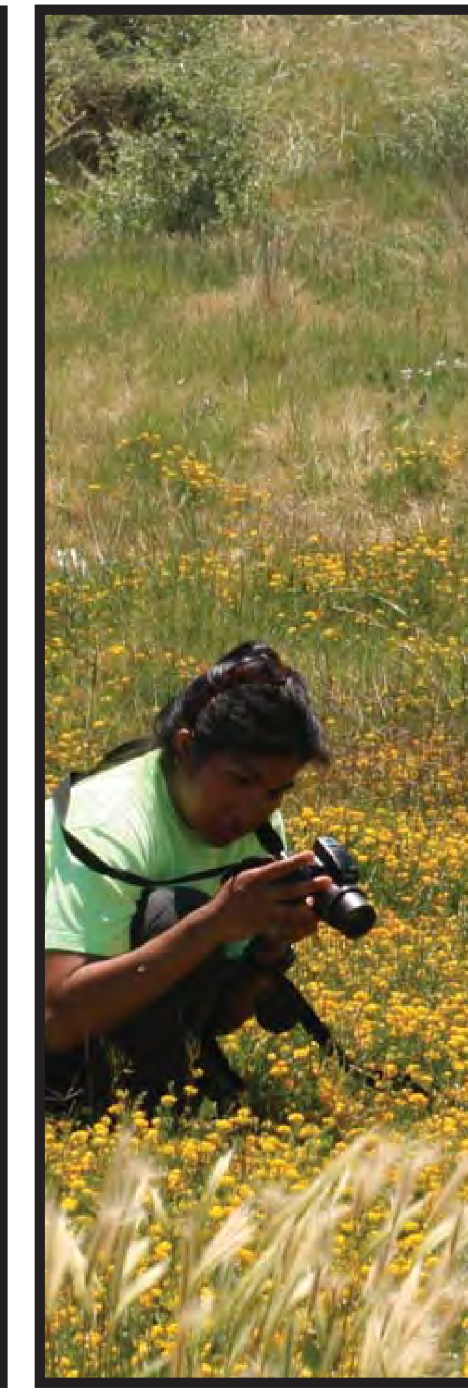

T14S, R65E GLO Plat
(Surveyed Sept. 1881)
22950
12572
Swamp
79.91
79.95
79.90
N.89°47'W.
N.89°47'W.
Brown's house
3615
9581
MUDDY
Spring Br.
79.92
S.89°52'W.
79.98
79.94
Sec. 21.
640
SE ROA 12176

5

5.01 PUBLIC USE

CONCEPTUAL PLAN





Public Sites

Type

WSNA Field Station

Parking Area

Restrooms

Interpretive Zones

Usage

High Interpretive Zone

Medium Interpretive Zone

Low Interpretive Zone

SE ROA 12179

Public Use

The Warm Springs Natural Area is an expansive and unique oasis resting in the Mojave Desert, yet the adjacent neighbors surrounding the property serve as a critical link to maintaining the important ecosystems on site. The biological and cultural diversity of this place is not limited or defined by the property boundaries, therefore the neighbors serve as important partners in the public use of the property. Since the establishment of the Moapa Valley National Wildlife Refuge (Refuge) in 1979, area residents have expressed a strong desire to see the area open for public use. Plans for the Refuge include a program of environmental education showcasing the uniqueness of the springs' fauna and ecology. Visitor access on the Warm Springs Natural Area would reflect the goals of the public use of the Refuge. The Refuge theme of protecting thermal springs and their associated endemic fish and invertebrate species would be expanded on Warm Springs Natural Area to include the ecology of the fingerling tributaries - formed from the spring outflows - as they traverse the Natural Area and form the headwaters of the Muddy River. In addition to the thermal dependent species on the property, a key theme to be interpreted for visitors to the Warm Springs Natural Area would include viewing the abundant and diverse variety of bird species inhabiting the riparian corridor, mesquite forests and retired pasture land.

A well-visited Natural Area devoted to environmental education will increase citizen awareness about the challenges of water management and land development, threats from invasive species, historic use of the Warm Springs Area to early Mormon agricultural practices, and the value of biodiversity in areas of regional spring complexes and desert riparian systems.

Adjacent access between the Warm Springs Natural Area and the Wildlife Refuge serves to manage public access cooperatively with the US Fish and Wildlife Service as identified in the "Park, Trails, and Natural Area" category of the Southern Nevada Public Land Management Act. It is also important to reconnect the local community with the resources and values of the Muddy River region. By creating opportunities for appropriate, low-impact public use, as well as the tremendous opportunities that would come from the potential to establish the property as a field research station, the education opportunities are endless.

The level of public use will be carefully evaluated by SNWA to assess the number of visitors, appropriate uses of the property, security issues, desired messaging, and minimization of long-term impacts to the property. To thoroughly evaluate these issues, it is anticipated that public use may be implemented in phases.

Nature Trail and Kiosk

The initial development of a public use component may involve a roadside kiosk, parking area, and primitive nature trail. Interpretation may include orientation to the property and the important ecology of the system, and SNWA's plans for the Natural Area. If the approach is implemented, visitors to the Natural Area and those driving the perimeter of the property would be able to view the kiosk with roadside interpretive signage of the Natural Area to illustrate interesting aspects of the property to folks out for a Sunday drive as well as roadside tourists pulling off the highway for a rest.

This initial phase may involve opening the property to a target audience to enjoy a nature trail or limited foot trail use of the property. Target audiences could include school groups and the birding community. To date, bird watchers have traveled from the Northwestern United States hoping to access the Warm Springs Natural Area to see the vermilion flycatcher. In this scenario, school groups and tours could be accompanied by interpretive biologists able to guide students and enhance the experience.

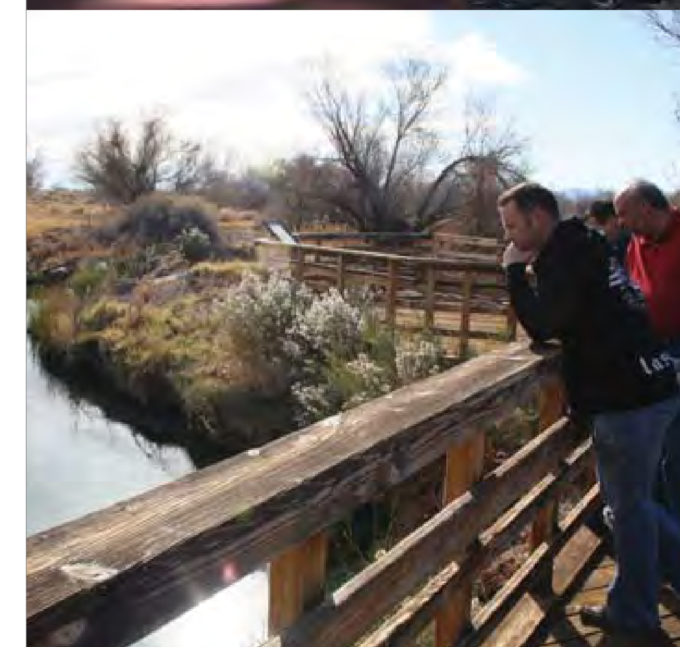
Interpretive Zones

Conceptual zones of interpretation have been proposed to encompass projected compatible public use interests. The high interpretive zone (see map) includes easy access along Warm Springs Road and is immediately adjacent the Moapa Valley National Wildlife Refuge. This zone has abundant wildlife viewing opportunities as well as a rich history of early settlement for historical interpretation. Zones of medium and low interpretation represent areas where visitors experience nature first-hand with minimal trailside interpretation. For lower-level interpretive zones, interpretation assistance may be provided in the form of pamphlets and trail guides obtained at trailhead kiosks. Trails in these areas will be more primitive and may be as simple as a rock lined trail or mowed path.

Future Plans

Depending on available resources, the next phase of the public use component could be implemented about five years after the initial phase. This may involve a loop trail for hiking and accessing the interior of the property. Interpretive storylines could be refined to target important interpretive elements. Themes may include the natural environment and ecology; current-day water resource use in the area; history of the property such as prehistoric use by early peoples and Native Americans, agricultural development by early settlers in the valley and historic uses of the property such as ownership by Howard Hughes.

> *The natural area will provide controlled public access to enjoy the abundant natural resources...*
> SNPLMA Objective



SE ROA 12180

5.02 MANAGEMENT PRIORITIES

Stewardship Plan

SNWA committed to join with stakeholders to develop a long-term plan for the property. The purpose of this document is to establish long-term management direction for the Warm Springs Natural Area. It is SNWA's intention that the Stewardship Plan will establish a framework for appropriate land uses that preserves the integrity of natural resources and lays a foundation for fostering stakeholder relationships. The Stewardship Plan is intended to clarify SNWA's responsibilities and management direction as they pertain to conservation on the Warm Springs Natural Area and ensures consistency with SNWA's commitments in the SNPLMA Nomination and the Muddy River Recovery Implementation Program.

While the Stewardship Plan is intended to provide guidance for SNWA management and future land uses and activities on the Warm Springs Natural Area, it is important to note that the Stewardship Plan is a conceptual document to begin dialogue and is not intended to require implementation of any specific management action. Implementation of such actions is left to the discretion of the SNWA Board of Directors through the annual budgeting process and through specific contract approvals as needed.

Prioritization Process

The prioritization process was formulated by the Core Team and technical experts in various fields. The Mission Statement developed by the Core Team - "To manage the property as a natural area for the benefit of native species and for the recovery of the endangered Moapa dace – consistent with the Southern Nevada Water Authority's commitments to the Southern Nevada Public Land Management Act funding of the property" – establishes prioritization of management goals and serves to frame future decision processes.

The Moapa dace has been designated as the highest management priority for consideration when restoring the property as a natural area and restoring the riparian ecosystem. This includes protecting the natural thermal springs on the property. The next highest priority is to manage for federal and state-protected species and thermal endemic species identified in the Muddy River RIP and, in general, prioritize restoration for management of the 28 sensitive species on the property. The next highest priority is to manage the property as a Natural Area – which means promoting native species and their habitats and controlling invasive species. Reducing fuel loads and establishing fire breaks to protect habitat and property is the next priority. Lastly, it is a priority to carry out SNPLMA commitments for the property for public use and scientific research.

Management Priorities

The following are management priorities for the property as determined by the interagency Core Team, biological experts, and SNPLMA commitments:

- Manage the property for the benefit and recovery of the Moapa dace. This includes restoring and protecting the thermal springs and their outflows.
- Manage the property for the benefit of federally-protected, state-protected, sensitive, and thermal endemic species.
- Manage the property as a Natural Area – which means promoting native species and their habitats and controlling invasive species.
- Reduce fuel loads and establish fire breaks on the Natural Area to protect neighbors and property.
- Carry out SNPLMA commitments for the property for controlled public access of the Natural Area.

Moapa Dace Recovery

The highest priority at WSNA is to protect and aid in the recovery of the Moapa dace. Moapa dace recovery is an important objective as a component for managing SNWA's water rights in Coyote Spring Valley and the Muddy River. Restoration activities are designed to substantially improve Moapa dace habitat in order to increase populations and contribute to recovery of the species.

Actions that protect existing Moapa dace habitat will likely protect other sensitive aquatic species. Moapa dace "restoration" actions, however, will need to consider impacts to all other affected sensitive species both aquatic and terrestrial. The BAC has prioritized dace restoration projects by reach. Some restoration projects identified by the BAC have already been completed or are in the beginning stages of execution. The main objectives of the BAC dace restoration projects by reach are to:

- Restore stream thermal properties
- Restore stream flow dynamics
- Eradicate tilapia
- Install dace habitat features
- Restore stream connectivity

It is expected that controlling invasive species whether of terrestrial or aquatic origin will directly or indirectly aid in the recovery and stability of sensitive species.

Protected Species Management

In addition to the endangered Moapa dace, other federally and state protected species live at WSNA. Managing for protected species is a priority as well as managing for rare or sensitive species (Appendix 2) which could receive protection status in the future due to habitat loss or population declines. Protected species include species protected under the Endangered Species Act of 1973, the Migratory Bird Treaty Act of 1918, the Bald Eagle Protection Act of 1940, and Nevada Revised Statutes Chapters 501 & 503 which include game species. Other species identified for management consideration include those species listed by the Nevada Natural Heritage Program, Nevada At-Risk Species Tracking List, and Nevada Plant and Animal Watch-List. Species under these categories are prime candidates for scientific research which can contribute in future status assessments.

Natural Area Management

Management of the Natural Area includes property management for all wildlife species and their habitats with an emphasis on restoring natural systems and processes. The Natural Area also consists of facilities, equipment, and support infrastructure used to carry out the management objectives for the property. Implementation of management objectives are slated to occur over several years.

Important components for managing the property as a natural area include:
1) resource protection, 2) habitat restoration, and 3) property maintenance.

Resource Protection: It is more cost-effective to protect existing quality habitat from degradation than to restore quality habitat after it has been lost. Noxious and nuisance weeds have the ability to stress ecosystem health and even displace native plant communities. Weeds also contribute to the buildup of fine fuels, which in combination with natural plant decadence can contribute to catastrophic wildfires. Wildfires can in turn impact Moapa dace habitat and alter plant community composition trajectories in favor of invasive species and novel plant communities. Implementation of proactive management strategies to accomplish weed control and fuels reduction is an imperative long-term management requirement at WSNA. Long-term natural resource monitoring is also an important management component for assessing biological trends and measuring progress. Cultural resources are also important property facets that require careful management consideration and protection.

Habitat Restoration: The goal in habitat restoration is to advance the recovery of native species by encouraging diversity in species, habitat structure, and ecological processes. The current condition in habitat quality varies across the property. Methods to enhance habitat need to be identified and evaluated based on individual site characteristics and available resources.

The property overall lacks a native herbaceous component across the alluvial floodplain. Floodplain soils were used for intensive crop production or in combination with grazing. Bermudagrass was widely planted as a forage species and still persists over much of the property. Restoring the native herbaceous cover will require a long-term commitment, entailing reintroduction of lost native forbs and a gradual replacement of bermudagrass with saltgrass *(Distichilis spicata)*, alkali sacaton *(Sporobolus airoides)*, and scratch grass *(Muhlenbergia asperifolia)*. To preserve the genetic integrity of local germplasm, revegetation material should be sourced from the property or from the same drainage system. A plant nursery may be utilized to grow native plant material and store transplant material for revegetation projects.

Property Maintenance: Capital assets such as the manager's residence, field station, sheds, equipment, etc., have ongoing maintenance needs with associated costs. Roads and fences traversing the property also require routine management attention. As with all properties owned by SNWA, property maintenance is an ongoing commitment and may be conducted by both internal staff and outside services. Maintaining property infrastructure is an important element for effective, sustainable management of the natural area over time.

Fire Management

Of highest priority is protection of neighbors, life, and property from wildfire. Protecting species requires protecting their habitat. Implementing a fire management program can be helpful in protecting neighbors and habitat from catastrophic wildfires. Fire management as addressed under special management (Section 4.02) will include a fuels reduction plan and the establishment of appropriate fuel breaks.

Public Use

Objectives identified in the SNPLMA Financial Assistance Agreement for public use are detailed in Section 5.01. Implementation of actions facilitating the controlled public access component identified in the SNPLMA Objective is projected to begin in about 2012. The extent of limited public use is in part dependent upon funding availability from grants and budgeting processes and may be implemented over time. Initially, primitive trails with nominal interpretive features may be installed. The public interpretive component of the Natural Area would focus on natural features with low impact on the natural environment. To that end, trail development features could emphasize trailhead entrances, trail quality, and interpretation, while maintaining a primitive look and feel. Trail maintenance will be a continuous management commitment.

MANAGEMENT PRIORITIES

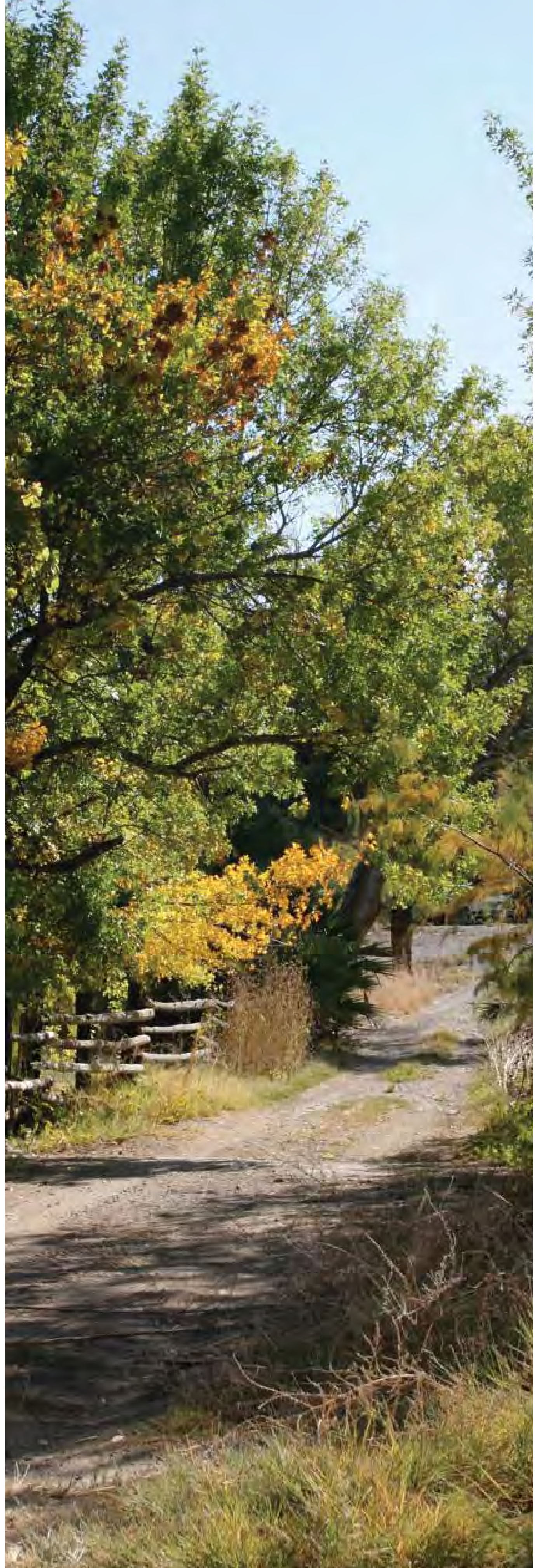
Manage the property for the benefit and recovery of the **Moapa dace**. This includes restoring and protecting the thermal springs and their outflows.

Manage the property for the benefit of **protected species**: federal, state, sensitive and thermal endemic species.

Manage the property as a **Natural Area** – which means promoting native species and their habitats and controlling invasive species.

Reduce fuel loads and establish fire breaks on the Natural Area to protect neighbors and property.

Carry out SNPLMA commitments for controlled **public access** of the Natural Area.



5.03 ACCOMPLISHMENTS AND NEXT STEPS

Accomplishments to Date

As a ranch for the last one hundred years, Warm Springs Natural Area underwent an identity change when SNWA took possession of it in Fall of 2007. Lands that had been watered via a spiderweb of irrigation ditches for growing crops and grazing over 800 head of roping steers in the winter, were committed to transition back to the native vegetation that once grew there. Years of buildup of weighty palm trees - knocked back only when wildfire fire ripped through the property - were slated to be trimmed or removed to reduce the fire hazard or to improve Moapa dace habitat.

Staff Assigned

SNWA sought important advice from neighbors and resource agencies and then set in motion some basic plans. With the new land responsibility, SNWA hired a caretaker to look after its acquisition. In 2008, SNWA hired a manager for the Warm Springs Natural Area to further protect the property, live on site, and interface with the citizens of the Moapa Valley. SNWA biologists and hydrologists were dedicated to the property and surrounding region.

Inventories Completed

SNWA also set out to inventory what it had acquired.

Boundary surveys as well as rights-of-way crisscrossing the property were defined before purchase. Resource inventories on site were lacking since the property had been previously held in private ownership. Access for Moapa dace surveys was now guaranteed. Next, SNWA contracted cultural surveys to identify archeological and historic sites (HRA, 2008, 2009).

Bird surveys were conducted by the Great Basin Bird Observatory, San Bernardino County Museum, and Nevada Department of Wildlife. As expected in a sensitive setting, abundant varieties of birds were found, including an endangered bird, a candidate bird, and other birds considered sensitive (Appendix 2).

Aquatic invertebrates were surveyed on the property (Albrecht et al., 2008). This was a valuable characterization of the other thermal dependent species inhabiting the spring outflows over this previously-ranched property. Four of these species are included in the 1996 *USFWS Recovery Plan for the Rare Aquatic Species of the Muddy River Ecosystem*.

Pollinators and their habitat affinities relative to habitat quality were studied in 2009 (Nelson, 2009).

A floral inventory was completed in 2010 by Dr. Robert L. Johnson, the Warm Springs Natural Area Manager (Appendix 5). Bat species on the property were described previously by Williams and O'Farrell (2004) and Williams, O'Farrell and Riddle (2006). In addition, the Warm Springs Area Hydrologic Monitoring Network is established for the area (Appendix 6).

All in all, the Warm Springs Natural Area was found to be home to 28 Sensitive Species (Appendix 2) and a host of other native species drawn to the warm springs oasis. At the time of acquisition, a number of the species were not known to occur on the property, but will be important to the development of regional resource management strategies for the Muddy River Recovery Implementation Program.

Maintenance Accomplished

Upon acquisition, SNWA began management of the property. Clean-up of trash, a dump site, and an abandoned building were undertaken. Weeds were mapped and treated by Tri-County Weed Control. Weed treatments are being continued to date to reduce persistent weed problems. The Muddy River Regional Environmental Impact Alleviation Committee (MRREIAC) treated tamarisk along the Sim Road property boundary in 2009. Palm trees were trimmed along Warm Springs Road and the Refuge Stream in 2009, and stimulus funding provided for fuels reduction in 2010. SNWA acquired equipment and tractors to maintain the property. Mowing weeds in abandoned agricultural fields is an ongoing job.

Stream Restoration Work

Upon the recommendations of the Muddy River Biological Advisory Committee, SNWA funded construction of the Lower Pederson Stream channel in 2008. This reconnected the thermal springs on the Refuge to the lower Apcar stream thereby providing contiguous Moapa dace habitat and allowing for movement upstream for spawning. The investment has proven profitable in dace numbers, as they have significantly climbed in the Lower Pederson Stream since the restoration.

MOA Accomplishments

A number of conservation actions required by the 2006 MOA were implemented and have contributed toward recovery of the Moapa dace. They include:

- Improvement and restoration of Moapa dace habitat on the Apcar Unit of the Moapa Valley National Wildlife Refuge.
- Development of the Muddy River Recovery Implementation Program.
- Funding for development of an Ecological Model for the Moapa dace by the USGS.
- Construction of a fish barrier in the South Fork of the Muddy River.
- Funding for eradication of non-native fish in the South Fork of the Muddy River.
- Formation of a technical committee, the Hydrological Review Team.

Next Steps

The Stewardship Plan is intended to be an overarching umbrella document to guide the future of Warm Springs Natural Area. It establishes property commitments, documents accomplishments, and sets a course for the future. By no means does it encompass the details of how all will be accomplished.

Step-down Plans

It is envisioned that there will be step-down plans to further formulate critical components and guide resource management. For example, step-down plans may include a Restoration Plan, a Public Use Plan, and a Fire Management Plan. A Restoration Plan provides the roadmap for a rich, viable Natural Area with local, native species replacing areas claimed by weeds. A Public Use Plan directs limited public uses which are compatible with the Refuge and with a Natural Area. The Fire Management Plan insures the property is managed for protection of neighbors' property and to insure safety. These plans would be implemented as directives from SNPLMA documents and as directed by the SNWA Board of Directors.

Process Forward

As a template for the Stewardship Plan process, it has been successful to enlist the help of property stakeholders to advise and provide important information and feedback. Management of the property will benefit with this kind of cooperative effort forward. It is envisioned that stakeholders would continue to include the US Fish and Wildlife Service, Nevada Department of Wildlife, The Nature Conservancy, the Executive Committee of the Muddy River Recovery Implementation Program, the Biological Advisory Committee, Clark County, the Moapa Town Advisory Board, the Moapa Valley Town Advisory Board, and technical experts, as needed.

Fuels Reduction

Reducing the fire hazard and build-up of fuels will be an on-going management responsibility. Progress has been made and will continue. SNWA is blading fire breaks adjacent to neighboring properties; reducing palm-tree fuel loads; cutting fire breaks between palm trees; eliminating tamarisk; and reducing other vegetation that is known to transmit fire across properties. These are continuing maintenance activities associated with the Warm Springs Natural Area. SNWA contracted a company with technical fire expertise to compile a fire management plan after the 2010 fire.

Restoration Forward

Progress has been made since 2002 when restoration for Moapa dace habitat was first initiated on the Moapa Valley National Wildlife Refuge. Much of the Refuge has been restored. And as discussed on the previous page, reaches have also been restored and reclaimed on the Warm Springs Natural Area. The Biological Advisory Committee identified a plan for stream reaches that still need to be restored as high priority reaches. SNWA is looking to restore additional reaches on the Warm Springs Natural Area as part of the Muddy River Recovery Implementation Program (RIP). Restoration of Moapa dace habitat for the major thermal spring systems identified in the 1996 *Recovery Plan for Rare Aquatic Species of the Muddy River Ecosystem* is feasible to be accomplished under the RIP. As new streams are restored on the Refuge and on the Warm Springs Natural Area, they will require maintenance, weeding aquatic invasive plants, and trapping and removal of invasive fish.

Natural Area restoration is a gradual and long-term process. It will continue to be accomplished and worked at over time. As habitats for sensitive species are restored, often grants are readily available to do so. Funding will be sought to augment native habitat replenishment and the Natural Area restoration through time.

Public Use

Careful planning is essential to shape the limited public use component of the property. It will be a delicate balance to provide an enjoyable experience for the public that respects the sensitive environment. SNPLMA funding is being sought to provide for a public use component that would potentially include a primitive nature trail, a shade structure or a bird-viewing platform. Providing meaningful interpretation for the public will also be important.

Management Components	
HABITAT RESTORATION	
	Hydrological data collection
	Stream restoration
	Stream maintenance
	Invasive aquatic control
	Terrestrial habitat restoration
	Restoration nursery
LIMITED PUBLIC USE	
	Public use planning
	Trail establishment
	Interpretive elements
RESOURCE PROTECTION	
	Noxious weed eradication
	Fuels reduction
	Biological monitoring
	Hydrological monitoring
	Cultural resource inventory
	Property access issues/security
	Perimeter fencing
	Property acquisition
PROPERTY MAINTENANCE	
	Equipment maintenance
	Maintenance shed
	Field station maintenance
	Facility maintenance
	Property interior fence removal
	Residence maintenance
	Road/trail maintenance

CONTRIBUTORS 2007-2010

CORE TEAM

Tanya Anderson, The Nature Conservancy
Janet Bair, US Fish and Wildlife Service
Robert Johnson, SNWA
Cynthia Martinez, US Fish and Wildlife Service
Janet Monaco, SNWA
Jon Sjöberg, Nevada Department of Wildlife

TECHNICAL ADVISORS

Elisabeth Ammon, Great Basin Bird Observatory
Mauricia Baca, Outside Las Vegas Foundation
Amy LaVoie, US Fish and Wildlife Service
Heidi Roberts, HRA Inc., Conservation Archaeology
Amy Sprunger, US Fish and Wildlife Service
Cris Tomlinson, Nevada Department of Wildlife

SNWA STAFF

William Rinne, Director, Surface Water Resources Department
Janet Monaco, Manager, Muddy and Virgin Rivers Division
Robert Johnson, Manager, Warm Springs Natural Area
Cathryn Cherry, Environmental Planner
David Syzdek, Environmental Biologist
Crystal Shanley, Biologist

PHOTO CREDITS

Page 3: Vermilion flycatcher, Pablo Lèautaud (shared under a Creative Commons license for non-commercial use at www.flickr.com/photos/pleautaud/913191344/in/set-72157603757048983/).

Pages 18 and 19: Background map is 1918 map drawn by L. Tanner. Southern Paiute basket weaver Mary Ann Pepo at Moapa in 1940 by Arthur Rothstein.

Page 20: Background map is 1918 map drawn by L. Tanner.

Page 21: Moapa Paiute House, William R. Palmer Collection, Special Collections, Southern Utah University. Las Vegas Paiute Encampment 1900 by Sadie Kiel George and in the private collection of Elizabeth v.T. Warren. Warm Springs Ranch 1941 station wagon "Woodie," donated by Ann W. Funk to the Nevada State Museum.

Page 27: Vermilion flycatcher, Pablo Lèautaud (shared under a Creative Commons license for non-commercial use at www.flickr.com/photos/pleautaud/913191344/in/set-72157603757048983/).

Page 28: From left to right. Common buckeye on sunflower, Bruce Lund. Old world swallowtail, Bruce Lund.

Page 33: Moapa dace illustrations by Joseph R. Tomelleri.

Page 38: Virgin River chub, Brandon Albrecht.

Page 40: Western yellow-billed cuckoo, US Bureau of Reclamation. Southwestern Willow Flycatcher, US Bureau of Reclamation. Summer tanager, Jerry Oldenettel (shared under a Creative Commons license for non-commercial use at www.flickr.com/photos/jroldenettel/2146321428/). Western yellow bat, Allen Calvert.

Page 43: Yuma clapper rail, Joe Kahl. Red-winged blackbirds, Bruce Lund.

Page 44: Vermilion flycatcher, Doug Greenberg (shared under a Creative Commons license for non-commercial use at www.flickr.com/photos/dagberg/2020944801/).

Page 51: Beaver, Laszlo Ilyes (shared under a Creative Commons license for non-commercial use at www.flickr.com/photos/laszlo-photo/152839527/).

Page 54: Metate, HRA, Inc. Conservation Archeology Staff. Arrowheads, HRA, Inc. Conservation Archeology Staff.

Page 51: GLO Plat, Government Land Office Plat surveyed September 1881.

All other photos by SNWA staff and Lucchesi Galati.

CITATIONS

Albrecht, B., E. de la Hoz, and E. Oborny. 2008. Distribution and relative abundance of aquatic macroinvertebrates in the headwater tributaries of the Muddy River, Clark County, Nevada. Final Report PR-1128-3-1. Bio-West, Inc.: Logan, Utah. 39 pp.

Austin, G.T. and A.T. Austin. 1980. Butterflies of Clark County, Nevada. Journal of Research on the Lepidoptera 19:1-63.

Baumann, R. 2009. Professor Emeritus, Department of Biology, Brigham Young University. pers. comm.

Beck, D.A., R. Ryan, R.J. Veley, D.P. Harper, and D.J. Tanko. 2006. Water-surface elevations, discharge, and water-quality data for selected sites in the Warm Springs area near Moapa, Nevada. U.S. Geological Survey Open-File Report 1311. 230 pp.

Braden, G.T., M. Rathbun, T. Hoggan, A. Davenport, and K. Carter. 2009. The status of yuma clapper rail and yellow-billed cuckoo along portions of the Virgin River and Muddy River in southern Nevada, with incidental observations of the southwestern willow flycatcher: 2008 Final. Biological Sciences Division, San Bernardino County Museum, Redlands, California. Final Report to the Southern Nevada Water Authority. 58 pp.

Bradford, D.F., J.R. Jaeger, and R.D. Jennings. 2004. Population status and distribution of a decimated amphibian, the relict leopard frog (Rana onca). The Southwestern Naturalist, 49(2):218-228

Clark County Multiple Species Habitat Conservation Plan (MSHCP). 2000. Clark County DCP. Retrieved from: http://www.accessclarkcounty.com/depts/daqem/epd/dcp/pages/dcp_guidingdocs.aspx.

Eakin, T.E. 1966. A regional interbasin groundwater system in the White River area, southeastern Nevada. Water Resources Research 2:251–271.

HRA, Inc. Conservation Archaeology. 2008. An archaeological survey of approximately 1,200 acres in the Warm Springs Ranch project area, Clark County, Nevada. Final Report No. 08-01. 106 pp.

HRA, Inc. Conservation Archaeology. 2009. The Home Ranch: an early 20th century ranch in the Warm Springs project area, Clark County, Nevada. Addendum to Final Report No. 08-01. 59 pp.

Hubbs, C.L. and R.R. Miller. 1948. Two new relict genera of cyprinid fishes from Nevada. University of Michigan Museum of Zoology Occasional Papers 507: 1-30.

Huillet, A. 1998. Aquatic insects of the Muddy River drainage with emphasis on Moapa Warm Springs, Nevada: including notes on *Limnocoris moapensis* (Naucoridae). Master's Thesis, Brigham Young University.

Klinger, C., and B. Conrad. 2010. Southwestern Willow Flycatcher and Yellow-Billed Cuckoo Survey and Monitoring at Select Sites in Southern Nevada, 2009 Annual Report. Nevada Dept. of Wildlife. Las Vegas, NV. 68 pp.

Lund, B. 2009. Moapa, Nevada, pers. comm.

McLeod, M.A., and T.J. Koronkiewicz. 2010. Southwestern Willow Flycatcher surveys, demography, and ecology along the lower Colorado River and tributaries, 2009. Annual report submitted to Bureau of Reclamation, Boulder City, NV, by SWCA Environmental Consultants, Flagstaff, AZ. 165 pp.

Nelson, M. S. 2009. Associations of Terrestrial Invertebrate Groups with Environments at the Warm Springs Natural Area, Nevada. Technical Memorandum No. 86-68220-10-02. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado. 38 pp.

Nevada Department of Conservation & Natural Resources. 2009. Nevada National Heritage website. Retrieved from: http://heritage.nv.gov/.

Nevada State Engineer. 2002. State engineer order number 1169. State Engineer of the State of Nevada, Carson City, Nevada.

O'Farrell, M.J., J.A. Williams, and B. Lund. 2004. The western yellow bat *(Lasiurus xanthinus)* in southern Nevada. The Southwestern Naturalist, 49:514-518.

Parker, M.S., G.G. Scoppettone, and M.B. Nielsen. 1997. Distribution and relative abundance of benthic macroinvertebrates along the Muddy River, Nevada. National Biological Service, California Science Center, Reno Field Station unpublished report.

Polhemus, J.T. 1973. Notes on aquatic and semiaquatic Hemiptera from the southwestern United States (Insecta: Hemiptera). The Great Basin Naturalist, 33(2):113-119.

Provencher, L. and R. Andress. 2004. Integrated science assessment for the upper Muddy River, Clark County, Nevada. Annual report to the Clark County MSHCP, Nevada. TNC: Reno, NV.

Provencher, L., S. Wainscott, and R. Andress. 2005. Integrated science assessment for the upper Muddy River, Clark County, Nevada. Final report to the Clark County MSHCP. TNC: Reno, NV.

Sada, D.W., and D.B. Herbst. 1999. Habitat use by rare aquatic macroinvertebrates in spring brooks of the upper Muddy River, Clark County, Nevada.

Scoppettone, G.G., H.L. Burge, and P.L. Tuttle. 1992. Life history, abundance, and distribution of Moapa dace *(Moapa coriacea)*. Great Basin Naturalist 52(3): 216-225.

Scoppettone, G.G. 1993. Interactions between native and nonnative fishes of the upper Muddy River, Nevada. Transactions of the American Fisheries Society 122: 599-608.

Scoppettone, G.G., J.A. Salgada, and M.B. Nielsen. 2005. Blue tilapia *(Oreochromis aureus)* predation on fishes in the Muddy River system, Clark County, Nevada. Western North American Naturalist 65(3): 410-414.

Stevens Ecological Consulting, LLC. 2004. An ecological survey of the upper Muddy River, Clark County, Nevada. Final Report.

Tri-County Weed Control. 2008. Report and recommendations for Warm Springs Natural Area project. Ely, Nevada. April 2008. 2 pp.

U.S. Dept. of the Interior Bureau of Land Management. 2006. Financial assistance cooperative agreement no. FAA060138. Priority #6-5; Project #WA03. Warm Springs Ranch Acquisition for Development of a Natural Area. SNPLMA Parks, Trails and Natural Areas – Southern Nevada Water Authority. 14 pp.

U.S. Dept. of the Interior Bureau of Land Management. 2006. Implementation agreement. Southern Nevada Public Land Management Act of 1998 Public Law 105-263 (as amended) and Federal Land Transaction Facilitation Act of 2000 Public Law 106-248. 158 pp.

U.S. Dept. of the Interior Fish and Wildlife Service. 1995. Virgin River fishes recovery plan. Salt Lake City, Utah. 45 pp.

U.S. Dept. of the Interior Fish and Wildlife Service. 1996. Recovery plan for the rare aquatic species of the Muddy River ecosystem. Portland, Oregon. 60 pp.

U.S. Dept. of the Interior Fish and Wildlife Service. 2006. Intra-service programmatic biological opinion. File No. 1-5-05-FW-536. Muddy River memorandum of agreement regarding the groundwater withdrawal of 16,100 acre-feet per year from the regional carbonate aquifer in Coyote Spring valley and California Wash basins, and establish conservation measures for the Moapa dace, Clark County, Nevada. April 20, 2006. 23 pp.

U.S. Dept. of the Interior Fish and Wildlife Service. 2009. Moapa valley national wildlife refuge website. Retrieved from: http://www.fws.gov/desertcomplex/moapavalley/.

Wells, S.A. 1989. A new species of *Haliplus* from Warm Springs, Nevada (Coleoptera: Haliplidae). Great Basin Naturalist 49:89-91.

Williams, J.A., M.J. O'Farrell, and B.R. Riddle. 2006. Habitat use by bats in a riparian corridor of the Mojave Desert in southern Nevada. Journal of Mammalogy 87:1145-1153.

SE ROA 12186

A

THE PROCESS

The Secretary of the Department of Interior approved funding to acquire the Warm Springs Natural Area under Round 6 of the SNPLMA “Park, Trails and Natural Area” category.

- October 2005 – SNWA submitted an application under Round 6 of the Southern Nevada Public Land Management Act (SNPLMA) to acquire the Warm Springs Ranch under the “Park, Trails and Natural Area” category.
- February 7, 2006 - the Secretary of the Department of Interior approved SNWA’s request for funding to acquire Warm Springs Ranch.
- July 20, 2006 - SNWA Board of Directors approved an agreement between South Fifteen, LLC, Sunburst Properties, LLC, Pay Dace, LLC, and SNWA for the acquisition of the Warm Springs Ranch by SNWA and authorized the General Manager to negotiate and execute the agreement and documents necessary to effectuate the transfer.
- May 16, 2007 - The Financial Assistance Agreement between SNWA and the United States Department of Interior Bureau of Land Management (BLM) was signed. SNWA was awarded funding to purchase the property and committed to manage it as a Natural Area.
- September 13, 2007 – Purchase of the Warm Springs Ranch was finalized and SNWA renamed the property “Warm Springs Natural Area”.

A.01 SNPLMA NOMINATION

Financial Assistance Agreement

SNWA signed the Southern Nevada Public Land Management Act (SNPLMA) Financial Assistance Agreement (FAA) with the United States Department of Interior Bureau of Land Management on May 16, 2007 to purchase the property under the “Parks, Trails and Natural Area” category. The following are key excerpts from the FAA:

Section I. “Statement of Joint Objectives”

A. PURPOSE
This Agreement is made and entered into by the Department of the Interior, Bureau of Land Management (BLM), Nevada State Office for the Las Vegas Field Office, and the Southern Nevada Water Authority, through implementation of the Southern Nevada Public Land Management Act, for the purpose of developing parks, trails, and natural areas in Clark and Lincoln County, Nevada.

B. OBJECTIVE
Cooperation between BLM and Clark County in order to facilitate the construction of the Warm Springs Ranch Acquisition for Development of a Natural Area. The property will be acquired as a Parks, Trails, and Natural Area (PTNA) acquisition with the objective to develop a natural area under the PTNA category in a future round. Totaling approximately 1179 acres this property is located in the upper Muddy River Valley approximately 7 miles northwest of the Town of Moapa and borders the Moapa Valley National Wildlife Refuge.

There is approximately 3.8 miles of Muddy River and tributary frontage and substantial wetland and riparian habitat. The natural area will provide controlled public access to enjoy the abundant natural resources, will include interpretation of the resources and T&E species located on the site, and will include measures to preserve and protect those resources. Natural Resources on the Property include, aquatic habitat for the Virgin River Roundtail Chub, the endemic Moapa Dace (listed), the Southwestern Willow Flycatcher, and the Yellow-Billed Cuckoo. The property includes Nevada’s largest breeding population of Vermilion Flycatcher. Within this section of the Muddy River reside pockets of native Mesquite Bosque and Cottonwood-Willow riparian habitat.

Section II. “Definitions”

Section III. “Project Management”

A. THE RECIPIENT (SNWA) AGREES TO:

1. *Accomplish the stated Objective of the Project as approved by the Secretary of the Interior or as otherwise modified.*
2. *Adhere to the policies and procedures identified in the IA.*
3. *Furnish qualified personnel for the coordination, oversight, and performance of the objective for the Project.*
4. *Provide supervision for the Project to include responsibility for all technical aspects, development, implementation, scheduling, safety, coordination, and other Project needs.*
5. *Make certain necessary permits or environmental clearances are obtained.*
6. *Own and maintain in perpetuity any land, buildings, trails, facilities, or other features improved or constructed, unless a shorter period is specifically stated in a separate project nomination authorized through the approval by the Secretary of the Interior.*

B. THE BLM AGREES TO:

1. *Provide coordination and assistance during all phases of Project development, including, but not limited to providing guidance regarding SNPLMA policies and procedures.*
2. *Conduct Project inspections and meet with Project staff to confirm project progress and assist in achieving objectives for this Project*
3. *Facilitate and coordinate the processing of funding, to include amendments to this Agreement.*
4. *Adhere to the policies and procedures identified in the IA.*
5. *Recipient’s submitted documents are incorporated by reference: Project Proposal entitled Warm Springs Ranch Acquisition for Development of a Natural Area, as approved by the Secretary of the Interior on February 7, 2006, SF 424, Application for Federal Assistance, SF 424A, Budget Information - Non-Construction Programs, SF 424B, Assurances – Non-Construction Programs, SF424B, Assurances - Non-Construction Programs, DI-2010 and Appendix B-6 Estimated Necessary Expenses & Key Milestone Dates.*

Nomination by the Secretary of the Interior

The following are excerpts from the SNPLMA Special Account Nomination Round 6 to the Secretary of the Department of Interior for the purchase of the Warm Springs Ranch (Warm Springs Natural Area).

Project: Warm Springs Ranch Acquisition

A. The Southern Nevada Water Authority (SNWA) proposes to acquire and manage 1,179 acres of privately held property along the upper Muddy River, also referred to as the Warm Springs Ranch as a natural area under the PTNA category. This property is the single most ecologically significant privately held property along the Muddy River. The property is approximately seven miles northwest of the Town of Moapa in Clark County, Nevada. The property is bordered by State Route 168 to the north, Warm Springs Loop Road to the south and the Moapa National Wildlife Refuge to south and west (see attached map). The property is bisected by approximately 3.8 miles of the Muddy River. The acquisition will address the potential need to acquire water rights for sustainability of the natural area. It will also address acquisition of mineral and mining rights, including any that may be held by third parties, to ensure that the resources within the natural area will not be subject to damage or destruction from mining operations.

Upon acquisition of the Warm Springs Ranch property, the SNWA will work cooperatively with stakeholders to implement a series of management and conservation actions. Principle among these may include:

- *Development of educational and recreational area/trails emphasizing the natural resources for public use consistent with the Moapa National Wildlife Refuge and other adjacent lands*
- *Invasive plant management*
- *Invasive fish and invertebrate management*
- *Bank and channel stabilization activities*
- *Construction and/or enhancement of wetlands*
- *Restoration and/or enhancement of riparian and upland habitat*
- *Spring pool restoration/enhancement*

B. The SNWA will be responsible for the operation, maintenance and management of the property over the long-term as a natural area under the PTNA category. However it is anticipated that this will be accomplished cooperatively with other stakeholders.

C.1. The acquisition of this property will place in public ownership one of the most biologically and culturally significant properties in Southern Nevada. In addition to the significant benefits to species and habitat that would accrue from acquisition and restoration of the property, the Warm Springs Ranch also provides an opportunity to reconnect the local community with the resources and values of the Muddy River region. By creating opportunities for appropriate, low-impact public access, as well as the tremendous opportunities that would come from the potential to establish the property as a field research station, the educational opportunities are endless.

C.2. Acquisition of the property by the SNWA would place the property in public trust in perpetuity.

C.3. Once acquired, the SNWA has committed to working with all relevant stakeholders (including, but not limited to, The Nature Conservancy, Clark County, U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, Nevada Division of Wildlife, Town of Moapa, etc.) to determine how the property should be improved and managed for the long-term benefit of the species and habitat within the context of a natural area under the PTNA category.

C.4. Acquisition of the property will increase the opportunity to acquire funding and engage in collaborative joint management of the property.

Acquisition of this property is considered as one of the highest priority action items for conservation in southern Nevada by Clark County, U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, Red Rock Audubon Society and The Nature Conservancy.

Property Deed

The Deed for the Warm Springs Natural Area was signed on August 31, 2007 and recorded on September 13, 2007. In it, the Warm Springs Ranch and 16 other parcels were conveyed to the Southern Nevada Water Authority (Grantee) from the following Grantors: South Fifteen, LLC; Sunburst Properties LLC; Dace 2 Fish, LLC; Moapa Express, LLC; Pay Dace, LLC; and TNES, LLC. The following is an excerpt from the Property Deed:

THE GRANT & CONVEYANCE HEREUNDER IS EXPRESSLY SUBJECT TO A RESTRICTION & COVENANT RUNNING WITH THE LAND:

IT IS EXPRESSLY UNDERSTOOD AND AGREED that the conveyance of the Land described herein to the GRANTEE, SOUTHERN NEVADA WATER AUTHORITY, a political subdivision of the State of Nevada, is made for the benefit of the people of the State of Nevada for the exclusive use as a public park, trail, or natural area under Section 4(e)(3)(A)(iv) of the federal Southern Nevada Public Land Management Act of 1998, Public Law 105-263, 112 Stat. 2343, as amended. If the Land described herein is not used or ceases to be used as a public park, trail, or natural area within ninety-nine (99) years from the date of this conveyance, any person or entity may enforce the terms of this use restriction in a court of competent jurisdiction.

A.02 SENSITIVE SPECIES TABLE

28 Sensitive Species on WSNA				
Common Name	**Scientific Name**	**USFWS**	**NNHP State Status**	**Footnotes**
Fish				
1 Moapa White River springfish	*Crenichthys baileyi moapae*		critically imperiled in state	4,6,8
2 Virgin River chub	*Gila seminuda (Muddy River Population)*		globally - critically imperiled	4,5,6,8
3 Moapa dace	*Moapa coriacea*	Endangered	critically imperiled in state	1,4,5,6,8
4 Moapa speckled dace	*Rhinichthys osculus moapae*		critically imperiled in state	4,5,6,8
Invertebrates				
5 Western naucorid	*Ambrysus mormon*			7
6 Warm Springs crawling water beetle	*Haliplus eremicus*		not ranked	4
7 MacNeill sooty wing skipper	*Hesperopsis gracielae*		critically imperiled in state	4,5,6
8 Moapa naucorid	*Limnocoris moapensis*		critically imperiled in state	4,7,8
9 Moapa riffle beetle	*Microcylloepus moapus*		critically imperiled in state	4,5,7
10 Pahranagat naucorid	*Pelocoris biimpressus shoshone*			4,7
11 Moapa pebblesnail	*Pyrgulopsis avernalis*	petitioned for listing	imperiled in state due to rarity	4,7,8
12 Moapa Valley pyrg	*Pyrgulopsis carinifera*	petitioned for listing	critically imperiled in state	4,7
13 Moapa skater	*Rhagovelia becki*			7
14 Moapa Warm Springs riffle beetle	*Stenelmis moapa*		critically imperiled in state	4,5,7,8
15 Grated tryonia	*Tryonia clathrata*	petitioned for listing	imperiled in state due to rarity	4,7,8
Birds				
16 Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	Candidate	globally - vulnerable to decline	3,4,5,6
17 Southwestern willow flycatcher	*Empidonax traillii extimus*	Endangered	critically imperiled in state	1,4,5,6
18 Phainopepla	*Phainopepla nitens*		imperiled in state due to rarity	4,5,6
19 Vermilion flycatcher	*Pyrocephalus rubinus*			6
20 Summer tanager	*Piranga rubra*			6
Bats				
21 Townsend's big-eared bat	*Corynorhinus townsendii*		imperiled in state due to rarity	4,5,6
22 Spotted bat	*Euderma maculatum*		imperiled in state due to rarity	4,5,6
23 Western red bat	*Lasiurus blossevillii*		critically imperiled in state	4,5
24 Western yellow bat	*Lasiurus xanthinus*		critically imperiled in state	4
25 California leaf-nosed bat	*Macrotus californicus*		imperiled in state due to rarity	4,5,6
26 Fringed myotis	*Myotis thysanodes*		imperiled in state due to rarity	4,5,6
27 Big free-tailed bat	*Nyctinomops macrotis*		imperiled in state due to rarity	4,5,6
Reptiles				
28 Desert tortoise	*Gopherus agassizii*	Threatened	vulnerable to decline	2,4,5,6

FOOTNOTES:

1 Listed as Endangered under the Endangered Species Act
2 Listed as Threatened under the Endangered Species Act
3 Candidate species under the Endangered Species Act
4 State of Nevada Department of Conservation & Natural Resources. 2009
5 Bureau of Land Management - Nevada Special Status Species
6 Clark County Multiple Species Habitat Conservation Plan (MSHCP). 2000
7 Muddy River Headwaters Macroinvertebrate Report - Albrecht et al. 2008
8 U.S. Department of the Interior Fish and Wildlife Service. 1996. Recovery plan for the rare aquatic species of the Muddy River ecosystem

A.03 RESOURCE INVENTORIES

Resource Inventories for WSNA				
Data	Completed	Survey Frequency	Source	Data Collection Methodology
Property Ownership				
ALTA survey	yes	once	SNWA	ALTA survey standard
Site Geography				
Aerial photo coverage	yes	biannual	SNWA	Aerial photography
LiDAR elevation	yes	once	SNWA	Laser altimetry
Soil survey	yes	once	NRCS	
Hydrological features	ongoing	progressive	SNWA	Multiple methods
Cultural Resources				
Class I archeological survey	yes	once	HRA Inc.	Literature search
Class III archeological survey	yes	once	HRA Inc.	30 m. transects, total cover-age
Biological Resources				
Moapa dace survey	yes	biannual	SNWA, USGS, NDOW, USFWS	Snorkel survey - reach
Aquatic invertebrate survey	yes	5 years	Bio-West Inc.	D-frame kick net - reach seg-ment
Small mammal survey	partial	5 years	SNWA	Sherman live trap - transect
Floral inventory	yes	10 years	SNWA	Observation
Lepidoptera	yes	5 years	BOR	Observation, netting
Hymenoptera survey	partial	10 years	BOR	observation, pan trapping
Bird survey	yes	annually	SNWA, GBBO, NDOW	GBBO transect, intensive area surveys, breeding bird census; Christmas bird count
Herpetological survey	no	5 years	SNWA	Observation, pitfall arrays

PRELIMINARY CHECKLIST OF MONTHLY RELATIVE ABUNDANCE OF BIRDS ON THE WARM SPRINGS NATURAL AREA

Relative Abundance

High **Low**

SPECIES*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Grebes												
Pied-billed Grebe												
Cormorants												
Double-crested Cormorant												
Pelicans												
American White Pelican												
Ducks, Swans, Geese												
Ruddy Duck												
Canada Goose												
Wood Duck												
American Wigeon												
Green-winged Teal												
Mallard												
Northern Pintail												
Blue-winged Teal												
Cinnamon Teal												
Northern Shoveler												
Canvasback												
Ring-necked Duck												
Bufflehead												
Herons, Egrets, Bitterns												
Snowy Egret												
Great Blue Heron												
Great Egret												
Cattle Egret												
Green Heron												
Black-crowned Night-Heron												
American Bittern												
Ibis and Spoonbills												
White-faced Ibis												
New World Vultures												
Turkey Vulture												
Ospreys												
Osprey												
Hawks, Eagles, Kites												
Mississippi Kite												
Northern Harrier												
Sharp-shinned Hawk												
Cooper's Hawk												
Common Black-Hawk												
Red-shouldered Hawk												
Broad-winged Hawk												
Swainson's Hawk												
Red-tailed Hawk												
Ferruginous Hawk												
Rough-legged Hawk												
Golden Eagle												
Falcons, Caracaras												
American Kestrel												
Merlin												
Prairie Falcon												
Peregrine Falcon												
Pheasants, Grouse, Quail, Turkeys												
Chukar												
Ring-necked Pheasant												
Wild Turkey												
Gambel's Quail												
Rails and Coots												
Virginia Rail												
Sora												
American Coot												
Cranes												
Sandhill Crane												
Sandpipers												
Wilson's Snipe												
Long-billed Curlew												
Greater Yellowlegs												

SPECIES*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lesser Yellowlegs												
Solitary Sandpiper												
Spotted Sandpiper												
Willet												
Long-billed Dowitcher												
Least Sandpiper												
Avocets and Stilts												
Black-necked Stilt												
Plovers and Lapwings												
Killdeer												
Gulls and Terns												
Ring-billed Gull												
Bonaparte's Gull												
Pigeons and Doves												
Rock Pigeon												
Band-tailed Pigeon												
Eurasian Collared-Dove#												
Mourning Dove												
White-winged Dove												
Inca Dove												
Cuckoos and Allies												
Yellow-billed Cuckoo												
Greater Roadrunner												
Owls												
Barn Owl												
Great Horned Owl												
Burrowing Owl												
Long-eared Owl												
Northern Saw-whet Owl												
Nightjars												
Lesser Nighthawk												
Common Nighthawk												
Common Poorwill												
Swifts												
White-throated Swift												
Hummingbirds												
Black-chinned Hummingbird												
Costa's Hummingbird												
Broad-tailed Hummingbird												
Rufous Hummingbird												
Kingfishers												
Belted Kingfisher												
Woodpeckers												
Lewis's Woodpecker												
Red-naped Sapsucker												
Ladder-backed Woodpecker												
Northern Flicker												
Tyrant Flycatchers												
Olive-sided Flycatcher												
Western Wood-Pewee												
Willow Flycatcher												
Gray Flycatcher												
Dusky Flycatcher												
Cordilleran Flycatcher												
Say's Phoebe												
Black Phoebe												
Vermilion Flycatcher												
Ash-throated Flycatcher												
Brown-crested Flycatcher												
Cassin's Kingbird												
Western Kingbird												
Crows and Jays												
Western Scrub-Jay												
American Crow												
Common Raven												
Vireos and Allies												
Bell's Vireo												
Plumbeous Vireo												

SE ROA 12193

PRELIMINARY CHECKLIST OF MONTHLY RELATIVE ABUNDANCE OF BIRDS ON THE WARM SPRINGS NATURAL AREA

Relative Abundance

High — **Low**

SPECIES*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cassin's Vireo												
Red-eyed Vireo												
Warbling Vireo												
Shrikes												
Loggerhead Shrike												
Northern Shrike												
Waxwings and Silky-Flycatchers												
Phainopepla												
Cedar Waxwing												
Thrushes												
Varied Thrush												
Western Bluebird												
Mountain Bluebird												
Townsend's Solitaire												
American Robin												
Mockingbirds and Thrashers												
Northern Mockingbird												
Sage Thrasher												
Crissal Thrasher												
Starlings												
European Starling												
Nuthatches and Creepers												
White-breasted Nuthatch												
Brown Creeper												
Wrens												
Cactus Wren												
Rock Wren												
Marsh Wren												
Bewick's Wren												
Winter Wren												
House Wren												
Gnatcatchers and Bushtits												
Verdin												
Blue-gray Gnatcatcher												
Black-tailed Gnatcatcher												
Bushtit												
Swallows												
Tree Swallow												
Violet-green Swallow												
Northern Rough-winged Swallow												
Barn Swallow												
Cliff Swallow												
Kinglets, Chickadees												
Ruby-crowned Kinglet												
Golden-crowned Kinglet												
Mountain Chickadee												
Larks												
Horned Lark												
Old World Sparrows												
House Sparrow												
Wagtails and Pipits												
American Pipit												
Siskins, Crossbills, and Allies												
Pine Siskin												
American Goldfinch												
Lesser Goldfinch												
Cassin's Finch												
House Finch												
Evening Grosbeak												
New World Warblers												
Orange-crowned Warbler												
Nashville Warbler												
Virginia's Warbler												
Lucy's Warbler												
Northern Parula												
Yellow Warbler												
Yellow-rumped Warbler												
Black-throated Gray Warbler												

SPECIES*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Townsend's Warbler												
Hermit Warbler												
Black-and-White Warbler												
American Redstart												
Worm-eating Warbler												
MacGillivray's Warbler												
Common Yellowthroat												
Wilson's Warbler												
Yellow-breasted Chat												
Buntings, Sparrows, Tanagers, Allies												
Song Sparrow												
Lincoln's Sparrow												
Swamp Sparrow												
White-crowned Sparrow												
Dark-eyed Junco												
Savannah Sparrow												
Baird's Sparrow												
Chipping Sparrow												
Brewer's Sparrow												
Vesper Sparrow												
Lark Sparrow												
Black-throated Sparrow												
Sage Sparrow												
Green-tailed Towhee												
Spotted Towhee												
Abert's Towhee												
Hepatic Tanager												
Summer Tanager												
Western Tanager												
Rose-breasted Grosbeak												
Black-headed Grosbeak												
Blue Grosbeak												
Lazuli Bunting												
Indigo Bunting												
Blackbirds, Grackles, and Orioles												
Hooded Oriole												
Bullock's Oriole												
Orchard Oriole												
Scott's Oriole												
Yellow-headed Blackbird												
Red-winged Blackbird												
Western Meadowlark												
Great-tailed Grackle												
Brewer's Blackbird												
Brown-headed Cowbird												

* This checklist was compiled by GBBO using the Nevada Bird Atlas, Nevada Bird Count point count transects, two area search plots, and grid inventory/rapid area searches (April through June, and September 2009), as well as a checklist provided by Bruce Lund, containing the results of his birding on the property between 1998 and 2007.

Based on limited data; the Eurasian Collared-Dove was not recorded during the 1998-2007 time period but has been prevalent 2008-2009; however, winter surveys have not yet been completed on the property.

Footnotes:

(1) Species names in **bold** indicate that they are confirmed or probable breeders. However, not all birds breeding on the property may be highlighted, since each year of surveys produces breeding evidence for new species.

(2) The relative abundance of a species in a particular month is indicated by the shading (white indicates no records, black indicates high relative abundance). There are not specific numbers or densities attached to these because much of the non-breeding data was from Lund's checklist which has uncertain effort/standardization for each month.

Floral Inventory: Warm Springs Natural Area

Prepared by: Robert L. Johnson PhD, Southern Nevada Water Authority, May 2011

Family	Scientific Name / Common Name	Author
Amaranthaceae	***Amaranthus retroflexus*** Redroot amaranth	L.
Amaranthaceae	***Tidestromia oblongifolia*** Arizona honeysweet	(S. Watson) Standl.
Apiaceae	***Apium graveolens*** Wild celery	L.
Apiaceae	***Berula erecta*** Cut-leaf water-parsnip	(Hudson) Cov
Apiaceae	***Cicuta maculata*** Water-hemlock	L.
Apiaceae	***Hydrocotyle verticillata*** Whorled marshpennywort	Thunb.
Apocynaceae	***Apocynum cannabinum*** Indianhemp	L.
Apocynaceae	***Nerium oleander*** Oleander	L.
Arecaceae	***Washingtonia filifera*** California fan palm	(Linden ex André) H. Wendl.
Asteraceae	***Acroptilon repens*** Hardheads, Russian knapweed	(L.) DC.
Asteraceae	***Ambrosia dumosa*** Burrobush	(A. Gray) Payne
Asteraceae	***Ambrosia eriocentra*** Woolly fruit bur ragweed	(A. Gray) Payne
Asteraceae	***Ambrosia salsola var. salsola*** Burrobrush	(Torrey & A. Gray) Strother & B. G. Baldwin
Asteraceae	***Amphipappus fremontii ssp. fremontii*** Fremont's chaffbush	Torr. & A. Gray ex A. Gray
Asteraceae	***Antheropeas lanosum*** White easterbonnets	(A. Gray) Rydb.
Asteraceae	***Atrichoseris platyphylla*** Parachute plant	(A. Gray) A. Gray
Asteraceae	***Baccharis emoryi*** Emory's baccharis	A. Gray
Asteraceae	***Baccharis salicifolia*** Mule-fat	(Ruiz & Pav.) Pers.
Asteraceae	***Baileya multiradiata*** Desert marigold	Harv. & A. Gray ex A. Gray
Asteraceae	***Bebbia juncea*** Sweetbush	(Benth.) Greene
Asteraceae	***Centaurea melitensis*** Maltese star-thistle	L.
Asteraceae	***Chaenactis carphoclinia*** Pebble pincushion	A. Gray
Asteraceae	***Chloracantha spinosa*** Spiny chloracantha	(Benth.) G.L. Nesom
Asteraceae	***Cirsium mohavense*** Mojave thistle	(Greene) Petr.

Family	Scientific Name / Common Name	Author
Asteraceae	***Conyza canadensis*** Canadian horseweed	(L.) Cronquist var. glabrata (A. Gray) Cronquist
Asteraceae	***Encelia farinosa*** Brittlebush	A. Gray ex Torr
Asteraceae	***Geraea canescens*** Hairy desertsunflower	Torr. & A. Gray
Asteraceae	***Geraea canescens*** Hairy desertsunflower	Torr. & A. Gray
Asteraceae	***Gutierrezia sarothrae*** Broom snakeweed	(Pursh) Britton & Rusby
Asteraceae	***Helianthus annuus*** Common sunflower	L.
Asteraceae	***Isocoma acradenia*** Alkali goldenbush	(Greene) Greene
Asteraceae	***Lactuca serriola*** Prickly lettuce	L.
Asteraceae	***Laennecia coulteri*** Coulter's horseweed	(A. Gray) G.L. Nesom
Asteraceae	***Palafoxia arida*** Desert palafox	B.L. Turner & Morris
Asteraceae	***Pluchea odorata*** Sweetcent	(L.) Cass.
Asteraceae	***Pluchea sericea*** Arrowweed	(Nutt.) Coville
Asteraceae	***Psathyrotes pilifera*** Hairybeast turtleback	A. Gray
Asteraceae	***Psathyrotes ramosissima*** Velvet turtleback	(Torr.) A. Gray
Asteraceae	***Psilostrophe cooperi*** Whitestem paperflower	(A. Gray) Greene
Asteraceae	***Rafinesquia neomexicana*** New Mexico plumeseed	A. Gray
Asteraceae	***Solidago spectabilis*** Nevada goldenrod	(D.C. Eaton) A. Gray var. confinis (A. Gray) Cronquist
Asteraceae	***Sonchus asper*** Spiny sowthistle	(L.) Hill
Asteraceae	***Sonchus oleraceus*** Common sowthistle	L.
Asteraceae	***Stephanomeria pauciflora*** Brownplume wirelettuce	(Torr.) A. Nelson
Asteraceae	***Stylocline micropoides*** Woollyhead neststraw	A. Gray
Asteraceae	***Symphyotrichum divaricatum*** Southern annual saltmarsh aster	(Nutt.) G.L. Nesom
Asteraceae	***Xanthium strumarium*** Rough cocklebur	L.
Asteraceae	***Xylorhiza tortifolia var. tortifolia*** Mojave woodyaster	(Torr. & A. Gray) Greene
Asteraceae	***Chaenactis carphoclinia var. carphoclinia*** Pebble pincushion	A. Gray
Boraginaceae	***Amsinckia menziesii var. intermedia*** Common fiddleneck	(Lehm.) A. Nelson & J.F. Macbr. var. (Fisch. & C.A. Mey.) Ganders

Family	*Scientific Name* Common Name	Author
Boraginaceae	***Amsinckia tessellata*** Bristly fiddleneck	A. Gray
Boraginaceae	***Cryptantha angustifolia*** Narrowleaf cryptantha	(Torr) Greene
Boraginaceae	***Cryptantha barbigera*** Bearded cryptantha	(A. Gray) Greene
Boraginaceae	***Cryptantha gracilis*** Narrowstem cryptantha	Osterh.
Boraginaceae	***Cryptantha nevadensis*** Nevada cryptantha	Nelson & Greene
Boraginaceae	***Cryptantha pterocarya var. cycloptera*** Wingnut cryptantha	(Torr.) Greene var. (Greene) J.F. Macbr.
Boraginaceae	***Cryptantha recurvata*** Recurved cryptantha	Cov
Boraginaceae	***Cryptantha utahensis*** Scented cryptantha	(A. Gray) Greene
Boraginaceae	***Heliotropium curassavicum*** Salt heliotrope	L.
Boraginaceae	***Pectocarya platycarpa*** Broadfruit combseed	Munz & I.M. Johnst.) Munz & I.M. Johnst.
Boraginaceae	***Pectocarya recurvata*** Curvenut combseed	I. M. Johnston
Boraginaceae	***Plagiobothrys jonesii*** Jone's popcornflower	A. Gray
Brassicaceae	***Brassica tournefortii*** Sahara mustard	Gouan
Brassicaceae	***Chorispora tenella*** Crossflower, Muskmustard	(Pall.) DC.
Brassicaceae	***Descurainia pinnata ssp. Glabra*** Western tansymustard	(Walter) Britton ssp. (Woot. & Standl.) Detling
Brassicaceae	***Guillenia lasiophylla*** California mustard	(Hook. & Arn.) Greene
Brassicaceae	***Lepidium fremontii*** Desert pepperweed	S. Watson
Brassicaceae	***Lepidium lasiocarpum var. lasiocarpum*** Shaggyfruit pepperweed	Nutt.
Brassicaceae	***Lepidium latifolium*** Broadleaved pepperweed	L.
Brassicaceae	***Malcolmia africana*** African mustard	R. Br.
Brassicaceae	***Physaria tenella*** Moapa bladderpod	(A. Nelson) O'Kane & Al-Shehbaz
Brassicaceae	***Rapistrum rugosum*** Annual bastardcabbage	(L.) All.
Brassicaceae	***Sisymbrium irio*** London rocket	L.
Brassicaceae	***Sisymbrium orientale*** Indian hedgemustard	L.
Brassicaceae	***Thelypodium integrifolium ssp. affine*** Entireleaved thelypody	(Nutt.) Endl. ex Walp ssp. (Greene) Al-Shehbaz
Cactaceae	***Cylindropuntia bigelovii*** Teddybear cholla	(Engelm.) F.M. Knuth

Family	*Scientific Name* Common Name	Author
Cactaceae	***Cylindropuntia echinocarpa*** Wiggins' cholla	(Engelm. & Bigelow) F.M. Knuth
Cactaceae	***Cylindropuntia ramosissima*** Branched pencil cholla	(Engelm.) F.M. Knuth
Cactaceae	***Echinocactus polycephalus*** Cottontop cactus	Engelm. & Bigelow
Cactaceae	***Echinocereus engelmannii*** Engelmann's hedgehog cactus	(Parry ex Engelm.) Lem.
Cactaceae	***Echinomastus johnsonii*** Johnson's fishhook cactus	(Parry ex Engelm.) E.M. Baxter
Cactaceae	***Ferocactus cylindraceus*** Leconte's barrel cactus	(Engelm.) Orcutt var. lecontei (Engelm.) H. Bravo
Cactaceae	***Mammillaria tetrancistra*** Common fishhook cactus	Engelm.
Cactaceae	***Opuntia basilaris*** Beavertail pricklypear	Engelm. & Bigelow
Cactaceae	***Opuntia polyacantha var. erinacea*** Grizzlybear pricklypear	Haw. var. (Engelm. & Bigelow ex Engelm.) Parfitt
Campanulaceae	***Nemacladus glanduliferus*** Glandular threadplant	Jeps.
Caryophyllaceae	***Spergularia salina*** Salt sandspurry	J. Presl & C. Presl
Chenopodiaceae	***Allenrolfea occidentalis*** Iodine bush	(S. Watson) Kuntze
Chenopodiaceae	***Atriplex confertifolia*** Shadscale saltbush	(Torr. & Frém.) S. Watson
Chenopodiaceae	***Atriplex elegans var. elegans*** Wheelscale	(Moq) D. Dietr
Chenopodiaceae	***Atriplex hymenelytra*** Desertholly	(Torr.) S. Watson
Chenopodiaceae	***Atriplex lentiformis*** Big saltbush, Quailbush	(Torr.) S. Watson
Chenopodiaceae	***Atriplex polycarpa*** Cattle saltbush	(Torr.) S. Watson
Chenopodiaceae	***Atriplex semibaccata*** Australian saltbrush	R. Br.
Chenopodiaceae	***Bassia hyssopifolia*** Fivehorn smotherweed	(Pall.) Kuntz
Chenopodiaceae	***Monolepis nuttalliana*** Nuttall's povertyweed	(Schult.) Greene
Chenopodiaceae	***Nitrophila occidentalis*** Boraxweed	(Moq.) S. Watson
Chenopodiaceae	***Salsola tragus*** Prickly Russion thistle	L.
Chenopodiaceae	***Suaeda calceoliformis*** Pursh seepweed	(Hook.) Moq.
Chenopodiaceae	***Suaeda moquinii*** Mojave seablite	(Torr.) Greene
Convolvulaceae	***Calystegia sepium*** Hedge false bindweed	(L.) R. Br.
Convolvulaceae	***Convolvulus arvensis*** Field bindweed	L.

Family	Scientific Name Common Name	Author
Cuscutaceae	***Cuscuta californica*** Chaparral dodder	Hook. & Arn.
Cuscutaceae	***Cuscuta indecora*** Bigseed alfalfa dodder	Choisy
Cuscutaceae	***Cuscuta pentagona*** Fiveangled dodder	Engelm.
Cuscutaceae	***Cuscuta salina var. major*** Goldenthread	Engelm. var. Yunck.
Cyperaceae	***Carex nebrascensis*** Nebraska sedge	Dewey
Cyperaceae	***Carex praegracilis*** Clustered field sedge	W. Boott
Cyperaceae	***Cladium californicum*** California sawgrass	(S. Watson) O'Neill
Cyperaceae	***Cyperus odoratus*** Fragrant sedge	L.
Cyperaceae	***Cyperus strigosus*** Strawcolored flatsedge	L.
Cyperaceae	***Eleocharis macrostachya*** Pale spikerush	Britton
Cyperaceae	***Eleocharis rostellata*** Beaked spikerush	(Torr.) Torr.
Cyperaceae	***Schoenoplectus americanus*** Chairmaker's bulrush	(Pers.) Volkart ex Schinz & R. Keller
Elaeagnaceae	***Elaeagnus angustifolia*** Russian olive	L.
Ephedraceae	***Ephedra fasciculata*** Arizona jointfir	A. Nelson
Euphorbiaceae	***Argythamnia neomexicana*** New Mexico silverbush	Müll. Arg.
Euphorbiaceae	***Chamaesyce albomarginata*** Whitemargin sandmat	(Torr. & A. Gray) Small
Euphorbiaceae	***Chamaesyce micromera*** Sonoran sandmat	(Boiss. ex Engelm.) Woot. & Standl.
Euphorbiaceae	***Chamaesyce setiloba*** Yuma sandmat	(Engelm. ex Torr.) J.B.S. Norton
Fabaceae	***Acacia greggii*** Catclaw acacia	A. Gray
Fabaceae	***Glycyrrhiza lepidota*** Wild licorice	Pursh
Fabaceae	***Lotus glaber*** Narrow-leaf bird's-foot trefoil	Mill.
Fabaceae	***Medicago sativa*** Alfalfa	L.
Fabaceae	***Melilotus indicus*** Annual yellow sweetclover	(L.) All.
Fabaceae	***Melilotus officinalis*** Yellow sweetclover	(L.) Lam.
Fabaceae	***Prosopis glandulosa var. torreyana*** Western honey mesquite	Torr. var. (L.D. Benson) M.C. Johnst.
Fabaceae	***Prosopis pubescens*** Screwbean mesquite	Benth.

Family	Scientific Name Common Name	Author
Fabaceae	***Psorothamnus fremontii*** Fremont's dalea	(Torr. ex A. Gray) Barneby
Fabaceae	***Trifolium fragiferum*** Strawberry clover	L.
Geraniaceae	***Erodium cicutarium*** Redstem stork's bill	(L.) L'Hér. ex Aiton
Geraniaceae	***Erodium texanum*** Texas stork's bill	A. Gray
Hydrocharitaceae	***Vallisneria americana*** American eelgrass	Michx.
Hydrophyllaceae	***Eucrypta micrantha*** Dainty desert hideseed	(Torr.) A. Heller
Hydrophyllaceae	***Nama pusillum*** Eggleaf fiddleleaf	A. Gray
Hydrophyllaceae	***Phacelia calthifolia*** Calthaleaf phacelia	Brand
Hydrophyllaceae	***Phacelia crenulata var. crenulata*** Cleftleaf wildheliotrope	Torr. ex S. Watson
Hydrophyllaceae	***Phacelia fremontii*** Fremont's phacelia	Torr.
Hydrophyllaceae	***Phacelia incana*** Hoary phacelia	Brand
Hydrophyllaceae	***Phacelia neglecta*** Alkali phacelia	M.E. Jones
Hydrophyllaceae	***Phacelia pulchella var. gooddingii*** Goodding's phacelia	A. Gray var. (Brand) J.T. Howell
Iridaceae	***Sisyrinchium sp.*** Blue-eyed grass	
Juncaceae	***Juncus cooperi*** Cooper's rush	Engelm.
Juncaceae	***Juncus mexicanus*** Mexican rush	Willd. ex Schult. & Schult. f.
Krameriaceae	***Krameria erecta*** Pima ratany	Schultes
Krameriaceae	***Krameria grayi*** White ratany	Rose & Painter
Lamiaceae	***Lycopus americanus*** Bugleweed	W.C. Barton
Lamiaceae	***Salazaria mexicana*** Mexican bladdersage	Torr.
Lemnaceae	***Lemna sp.*** Duckweed	
Lemnaceae	***Spirodela polyrrhiza*** Common duckmeat	(L.) Schleid.
Liliaceae	***Androstephium breviflorum*** Pink funnel lily	S. Watson
Liliaceae	***Calochortus flexuosus*** Winding mariposa lily	S. Watson
Loasaceae	***Mentzelia albicaulis*** Whitestem blazingstar	(Hook.) Torr. & A. Gray
Loasaceae	***Mentzelia oreophila*** Argus blazingstar	J. Darl.

Family	Scientific Name	Common Name	Author
Loasaceae	***Mentzelia tricuspis***	Spinyhair blazingstar	A. Gray
Lythraceae	***Lythrum californicum***	California loosestrife	Torr. & A. Gray
Malvaceae	***Eremalche rotundifolia***	Desert fivespot	(A. Gray) Greene
Malvaceae	***Malva neglecta***	Common mallow	Wallr.
Malvaceae	***Malvella leprosa***	Alkali mallow	(Ortega) Krapov.
Malvaceae	***Sphaeralcea ambigua***	Desert globemallow	A. Gray
Malvaceae	***Sphaeralcea angustifolia***	Copper globemallow	(Cav.) G. Don
Nyctaginaceae	***Allionia incarnata var. villosa***	Trailing windmills	L. var. (Standl.) B.L. Turner
Nyctaginaceae	***Boerhavia wrightii***	Largebract spiderling	A. Gray
Nyctaginaceae	***Mirabilis laevis var. retrorsa***	Wishbone-bush	(Benth.) Curran var. (A. Heller) Jeps.
Nyctaginaceae	***Selinocarpus nevadensis***	Desert moonpod	(Standl.) Fowler & Turner
Oleacea	***Fraxinus velutina***	Velvet ash	Torr.
Onagraceae	***Camissonia brevipes***	Sun cup	(A. Gray) Raven
Onagraceae	***Camissonia refracta***	Narrowleaf suncup	(S. Watson) P.H. Raven
Onagraceae	***Epilobium ciliatum***	Fringed willowherb	Raf.
Onagraceae	***Gaura coccinea***	Scarlet beeblossom	Nutt. ex Pursh
Papaveraceae	***Eschscholzia glyptosperma***	Desert poppy	Greene
Plantaginaceae	***Plantago lanceolata***	Narrowleaf plantain	L.
Plantaginaceae	***Plantago major***	Common plantain	L.
Plantaginaceae	***Plantago ovata***	Desert Indianwheat	Forskal
Poaceae	***Achnatherum hymenoides***	Indian ricegrass	(Roemer & Schultes) Barkworth
Poaceae	***Andropogon glomeratus***	Southwestern bushy bluestem	(Walter) Britton, Sterns, & Pogg
Poaceae	***Aristida purpurea. var. wrightii***	Wright's threeawn	Nutt. var. (Nash) Allred
Poaceae	***Avena fatua***	Wild oat	L.
Poaceae	***Bouteloua barbata***	Sixweeks grama	Lag.
Poaceae	***Bromus catharticus***	Rescuegrass	Vahl

Family	Scientific Name	Common Name	Author
Poaceae	***Bromus diandrus***	Ripgut brome	Roth
Poaceae	***Bromus rubens***	Red brome	L.
Poaceae	***Bromus tectorum***	Cheatgrass	L.
Poaceae	***Cynodon dactylon***	Bermudagrass	(L.) Pers.
Poaceae	***Dasyochloa pulchella***	Low woollygrass	(Kunth) Willd. ex Rydb.
Poaceae	***Distichilis spicata***	Saltgrass	(L.) Greene
Poaceae	***Echinochloa crus-galli***	Barnyardgrass	(L.) P. Beauv.
Poaceae	***Holcus mollis***	German velvetgrass	L.
Poaceae	***Hordeum brachyantherum***	Meadow barley	Nevski
Poaceae	***Hordeum marinum ssp. gussonianum***	Mediterranean barley	Huds. spp. (Parl.) Thell.
Poaceae	***Muhlenbergia asperifolia***	Scratchgrass	(Nees & Meyen ex Trin.) Parodi
Poaceae	***Paspalum dilatatum***	Dallisgrass	Poir.
Poaceae	***Phalaris minor***	Littleseed canarygrass	Retz.
Poaceae	***Phragmites australis***	Common reed	(Cav.) Trin. ex Steud.
Poaceae	***Pleuraphis rigida***	Big galleta	Thurb.
Poaceae	***Polypogon monspeliensis***	Annual rabbitsfoot grass	(L.) Desf
Poaceae	***Schedonorus arundinaceus***	Tall fescue	(Schreb.) Dumort.
Poaceae	***Schismus arabicus***	Arabian schismus	Nees
Poaceae	***Schismus barbatus***	Common Mediterranean grass	(Loefl. ex L.) Thell.
Poaceae	***Setaria sp.***	Bristlegrass	
Poaceae	***Sporobolus airoides***	Alkali sacaton	(Torr.) Torr
Polemoniaceae	***Aliciella hutchinsifolia***	Desert pale gilia	(Rydb.) J.M. Porter
Polemoniaceae	***Aliciella latifolia***	Broad-leaf gilia	(S. Watson) J.M. Porter
Polemoniaceae	***Gilia scopulorum***	Rock gilia	M.E. Jones
Polemoniaceae	***Gilia transmontana***	Transmontane gilia	(H. Mason & A.D. Grant) A.D. Grant & V.E. Grant
Polemoniaceae	***Ipomopsis polycladon***	Manybranched ipomopsis	(Torr.) V.E. Grant

Family	*Scientific Name* / Common Name	Author
Polemoniaceae	***Langloisia setosissima*** Great Basin langloisia	(Torr. & A. Gray ex Torr.) Greene
Polemoniaceae	***Linanthus arenicola*** Sanddune linanthus	(M.E. Jones) Jeps. & V. Bailey
Polemoniaceae	***Linanthus demissus*** Desert snow	(A. Gray) Greene
Polygonaceae	***Chorizanthe brevicornu*** Brittle spineflower	Torr.
Polygonaceae	***Chorizanthe rigida*** Devil's spineflower	(Torr.) Torr. & A. Gray
Polygonaceae	***Eriogonum brachypodum*** Parry's buckwheat	Torr. & A. Gray
Polygonaceae	***Eriogonum fasciculatum*** Eastern Moave buckwheat	Benth.
Polygonaceae	***Eriogonum inflatum*** Desert trumpet	Torr. & Frém
Polygonaceae	***Eriogonum thomasii*** Thomas' buckwheat	Torr.
Polygonaceae	***Eriogonum trichopes*** Little deserttrumpet	Torr.
Polygonaceae	***Polygonum punctatum*** Dotted smartweed	Elliot
Polygonaceae	***Rumex crispus*** Curly dock	L.
Polygonaceae	***Rumex hymenosepalus*** Canaigre dock	Torr.
Primulaceae	***Samolus valerandi. ssp. parviflorus*** Seaside brookweed	L. ssp. (Raf.) Hultén
Punicaceae	***Punica granatum*** Pomegranate	L.
Ranunculaceae	***Delphinium parishii ssp. parishii*** Desert larkspur	A. Gray
Resedaceae	***Oligomeris linifolia*** Lineleaf whitepuff	(Vahl) J.F. Macbr.
Resedaceae	***Oligomeris linifolia*** Lineleaf whitepuff	(Vahl) J.F. Macbr.
Rutaceae	***Thamnosma montana*** Turpentinebroom	Torr. & Frém.
Salicaceae	***Populus fremontii ssp. fremontii*** Fremont cottonwood	S. Watson
Salicaceae	***Salix exigua*** Narrowleaf willow	Nutt
Salicaceae	***Salix gooddingii*** Goodding's willow	C.R. Ball
Scrophulariaceae	***Mimulus guttatus*** Yellow monkeyflower	DC
Scrophulariaceae	***Mohavea breviflora*** Golden desert-snapdragon	Coville
Scrophulariaceae	***Neogaerrhinum filipes*** Yellow twining snapdragon	(A. Gray) Rothm.
Scrophulariaceae	***Veronica americana*** American brooklime	(Raf) Benth

Family	*Scientific Name* / Common Name	Author
Solanaceae	***Datura wrightii*** Sacred thorn-apple	Regel
Solanaceae	***Lycium andersonii*** Water jacket	A. Gray
Solanaceae	***Lycium cooperi*** Peach thorn	A. Gray
Solanaceae	***Lycium torreyi*** Torrey wolfberry	A. Gray
Solanaceae	***Nicotiana obtusifolia*** Desert tobacco	M. Martens & Galeotti
Solanaceae	***Physalis crassifolia*** Yellow nightshade groundcherry	Benth.
Solanaceae	***Solanum elaeagnifolium*** Silverleaf nightshade	Cav.
Suaruraceae	***Anemopsis californica*** Yerba mansa	(Nutt.) Hook. & Arn.
Tamaricaceae	***Tamarix aphylla*** Athel tamarisk	(L.) Karst
Tamaricaceae	***Tamarix ramosissima*** Saltcedar	Ledeb.
Typhaceae	***Typha domingensis*** Southern cattail	Pers.
Verbenaceae	***Phyla lanceolata*** Lanceleaf fogfruit	(Michx.) Greene
Viscaceae	***Phoradendron californicum*** Mesquite mistletoe	Nutt.
Vitaceae	***Vitis arizonica*** Canyon grape	Engelm.
Zygophyllaceae	***Larrea tridentata*** Creosote bush	(DC.) Coville
Zygophyllaceae	***Tribulus terrestris*** Puncture vine	L.

Total Species: 248

SE ROA 12199

A.06 HYDROLOGIC MONITORING TABLE

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	Hydrogeologic Unit	AGENCY	WL MEASUREMENT FREQUENCY	PRODUCTION/ FLOW DATA FREQUENCY	Remarks	UTM_X	UTM_Y
Groundwater Monitoring:												
219	ABBOTT	UM7		Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly			706442.8946	4065656.5879
219	ARROW_CANYON			Well	Production	Carbonate	MVWD	Continuous	Continuous		701103.7690	4067755.2460
219	ARROW CANYON 2			Well	Production	Carbonate	MVWD	Continuous	Continuous		701103.3700	4067768.3000
219	BEHMER-MW			Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly			706030.6983	4065280.1818
219	CSV-1	364601114514301		Well	Monitor	Valley Fill	SNWA	Monthly			691377.9927	4071630.4100
219	CSV-2	364650114432001		Well	Monitor	Carbonate	SNWA/USGS/NV Energy	Continuous		NVEnergy includes data	703217.0806	4072966.7777
219	EH-4			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous			703929.2650	4064736.4078
219	EH-5B			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous			701568.7861	4067619.1347
219	LDS CENTRAL	UM49		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Daily		704113.9580	4066543.6361
219	LDS EAST	UM50		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Daily		704478.9759	4066594.2407
219	LDS WEST	UM18		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Daily		702746.2777	4067083.3415
219	LEWIS 1 OLD	UM55		Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly			702076.8581	4068229.1435
219	LEWIS 2	UM74		Well	Production	Valley Fill	NPC (NVEnergy)	Continuous	Daily		702339.3990	4067921.3381
219	LEWIS NORTH	UM45		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous			701588.5926	4067871.6716
219	LEWIS SOUTH	UM43		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous			702737.1327	4067265.8985
219	MX-6	CE-DT-6	364604114471301	Well	Production	Carbonate	MVWD	Monthly	Continous		697482.4475	4071381.1641
219	PERKINS OLD	UM15		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous			705637.2978	4065223.3801
219	PERKINS PRODUCTION			Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Daily		705692.9601	4065206.0659
219	UMVM-1	DEADMAN WASH		Well	Monitor	Carbonate	SNWA	Continuous			694304.6450	4070247.5450
220	EH-3			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous			721085.0000	4063300.0000
220	EH-7			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous			720660.0000	4060990.0000
Surface Water Monitoring:												
219	BALDWIN SPRING BOX			Spring		Flow Meter	MVWD	Continuous	Continuous		703257.3243	4066270.2745
219	JONES SPRING BOX			Spring		Flow Meter	MVWD	Continuous	Continuous		703713.6616	4065660.8144
219	PEDERSON EAST SPRING GAGE	PLAYBOY POOL GAGE		Spring		Flume	SNWA/USGS	Continuous	Continuous		704034.2489	4065063.0421
219	PEDERSON SPRING GAGE			Spring		Weir	SNWA/USGS	Continuous	Continuous		704008.0508	4065088.5140
219	WARM SPRINGS WEST GAGE			Spring		Flume	SNWA/USGS	Continuous	Continuous		704210.7611	4065272.2446
219	IVERSON FLUME			Stream		Flume	SNWA/USGS	Continuous	Continuous		704569.9449	4065295.8619
219	MUDDY SPRING GAGE			Spring		Flume	SNWA/USGS	Continuous	Continuous		704018.1277	4066347.6635
219	MOAPA GAGE			Stream		Stream Gage	USGS	Continuous	Continuous		705823.3289	4065349.9049
220	GLENDALE GAGE			Stream		Stream Gage	USGS	Continuous	Continuous		719896.9331	4058057.4259
220	OVERTON GAGE			Stream		Stream Gage	SNWA/USGS	Continuous	Continuous		730091.3558	4046453.5134
215	BLUE POINT SPRING			Spring		Stream Gage	NPS	Continuous	Continuous		730352.7311	4030270.7397
215	ROGERS SPRING			Spring		Stream Gage	NPS	Continuous	Continuous		729419.7449	4028891.3629

Source: List of sites that will be monitored for the duration of the Order 1169 test, as requested by, and submited to, the Nevada Division of Water Resources

SE ROA 12201

Southern Nevada Water Authority
100 City Parkway, Suite 700
Las Vegas, NV 89106
t: (702) 862-3400
www.snwa.com

Lucchesi Galati
500 Pilot Road, Suite A
Las Vegas, NV 89119
t: (702) 263-7111
www.lgainc.com

SOUTHERN NEVADA WATER AUTHORITY

LUCCHESI GALATI | people process place

Development of a
Numerical Groundwater Flow Model of Selected Basins within the Colorado Regional Groundwater Flow System, Southeastern Nevada

Version 1.0

Prepared For:

National Park Service

U.S. Fish & Wildlife Service

Bureau of Land Management

Prepared by:

Tetra Tech, Inc.
363 Centennial Parkway, Suite 210
Louisville, Colorado 80027

September 28, 2012

SE ROA 12204

TABLE OF CONTENTS

TETRA TECH

LIST OF TABLES

LIST OF FIGURES

ATTACHMENTS

1.0 BACKGROUND

Continued population growth in southern Nevada is increasing the demand for water. Historically, the Colorado River and groundwater in Las Vegas Valley have met the water needs of the populace of much of southern Nevada. However, the volume of water available from these sources is limited, and groundwater resources outside of Las Vegas Valley are increasingly being targeted for development. A regional carbonate-rock aquifer has the potential for being a large and productive source of water. However, this is the regional aquifer that is the source of several large-volume warm springs that discharge on Federal lands and provide baseflow to streams. The properties that make it a productive aquifer also result in the effects of pumping the aquifer being transmitted over long distances, with eventual capture of the water that discharges from springs and thus depletion of their flow. Reduction or cessation of spring discharge on Federal lands would likely have an adverse effect on sensitive habitat and species. Development of a tool for predicting the future effects of pumping groundwater from the regional aquifer system is needed to help manage and protect the water-dependent resources on Federal lands.

Large-scale groundwater development of the regional aquifer is planned by Southern Nevada Water Authority (SNWA) and other water purveyors. The Nevada Division of Water Resources, the agency that regulates water rights within the State of Nevada, is also seeking information through studies that assist the agency in groundwater development decisions. In 2001, the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), and the U.S. Bureau of Land Management (BLM), collectively the DOI bureaus, participated in an administrative hearing held by the Nevada State Engineer concerning proposed development in Coyote Spring Valley, about 40 miles northeast of Las Vegas Valley. As part of their preparations for hearing, the DOI bureaus cooperated in the development of a preliminary numerical groundwater flow model, prepared by GeoTrans, Inc., to simulate groundwater flow in the area and to evaluate and demonstrate the potential effects of groundwater pumping on water levels in the aquifer and on nearby spring flows. This preliminary model was constructed in a short period of time based on geologic information compiled in the early 1990's for a much larger area.

In 2002, the Nevada State Engineer issued an order (Order 1169) holding all pending groundwater applications in Coyote Spring Valley and selected nearby hydrographic areas in abeyance for at least five years, until further evaluation of the effects of groundwater pumping under existing permits is completed. Since 2000, some or all of the DOI bureaus also have interacted and negotiated with parties seeking large quantities of groundwater rights in several hydrographic areas north and northeast of Las Vegas, including Coyote Spring Valley, California Wash, Garnet Valley, Black Mountains Area, Lower Meadow Valley Wash, Kane Springs Valley, Clover Valley, Virgin River Valley, and Tule Desert. In some cases, negotiated settlement agreements were reached. Additionally, Environmental Impact Statements (EIS's) or Environmental Assessments (EA's) were conducted by the BLM pursuant to the National

Environmental Policy Act (NEPA) in some of these valleys regarding right-of-ways for proposed groundwater conveyance structures (i.e., pipelines), and consideration was given to the effects on the environment of groundwater withdrawals to supply the conveyance structures. The negotiated settlement agreements, EIS's, and EA's all contain language that requires some cooperation among the parties to develop hydrogeologic information to facilitate future water-resource management decisions. Order 1169 required that at least half of all existing groundwater rights in Coyote Spring Valley must be pumped for at least two consecutive years, before the Nevada State Engineer would consider the applicants' pending applications for additional groundwater rights. Water-level and spring discharge monitoring during the two-year "test pumping" would provide additional information on the response of the groundwater system to pumping. During the Nevada State Engineer's abeyance period and as these agreements are implemented, the DOI bureaus have participated in several scientific investigations with the goal of producing information that will enable refinement of the numerical model and improve the model's accuracy in predicting the effects of groundwater development on nearby Federal water resources.

1.1 AREA OF INVESTIGATION

The area of investigation for the expanded, updated model comprises all or portions of 13 contiguous hydrographic areas within the regional aquifer system of eastern and southeastern Nevada known as the Colorado Regional Ground-Water Flow System (CRGWFS). The area of this investigation (Figures 1.1-1 and 1.1-2) is located in southeastern Nevada and small parts of northwestern Arizona and southwestern Utah, and includes the following hydrographic areas: Clover Valley (hydrographic area #204), Lower Meadow Valley Wash (#205), Kane Springs Valley (#206), Coyote Spring Valley (#210), Garnet Valley (#216), Hidden Valley (North) (#217), California Wash (#218), Muddy River Springs Area (#219), Lower Moapa Valley (#220), Tule Desert (#221), Virgin River Valley (#222), the part of Black Mountains Area (#215) that is north and east of the Las Vegas Valley Shear Zone, and the part of Las Vegas Valley (#212) that is north of the Las Vegas Valley Shear Zone and east of the crest of the Sheep Range (see Figure 1.1-2). Hereinafter, this area is referred to as the study area. The study area is bounded on the north by the Pahranagat Shear Zone and the Caliente Caldera Complex; on the east by the Beaver Dam Mountains, the Virgin Mountains, and the Overton Arm of Lake Mead; on the south by the Las Vegas Valley Shear Zone and Lake Mead; and on the west by the Sheep Range. The principal aquifers in the study area are the regional Paleozoic carbonate-rock aquifer and basin-fill aquifers.

The NPS, FWS, and BLM each have lands under their jurisdiction within the study area. The FWS's Moapa Valley National Wildlife Refuge (NWR) is located within the study area (see Figure 1.1-2). The Moapa Valley NWR comprises an area of several large-volume warm springs (referred to collectively as the Muddy River Springs) inhabited by the endangered Moapa dace, a small desert fish. These springs, and other nearby springs (collectively referred to as the Muddy

River Springs, form the headwaters of the perennial stretch of the Muddy River. In addition, the FWS has responsibility for threatened and endangered species at other locations within the study area, including the Virgin River. The NPS's Lake Mead National Recreation Area (NRA) also occupies a portion of the study area. The Virgin and Muddy Rivers discharge into Lake Mead within the Lake Mead NRA. An area of several warm springs exists in the Overton Arm area of Lake Mead NRA (Figure 1.1-2), including Rogers Spring and Blue Point Spring, which have a combined discharge of approximately 1,000 gallons per minute. The BLM manages most of the land within the study area and has resource concerns associated with the water-dependent riparian habitat and species along the Lower Meadow Valley Wash, and several smaller springs at various locations throughout the study area. The source of the Muddy River Springs is the regional carbonate-rock aquifer. The source of Rogers and Blue Point springs is not yet completely understood; however, the majority of their recharge probably is also from the regional aquifer system. The Muddy River is sustained by regional groundwater discharge at the Muddy River Springs located in the upper Moapa Valley. The Virgin River also probably interacts with groundwater from the regional aquifer system.

1.2 PREVIOUS DEPARTMENT OF INTERIOR AGENCY MODELS

A three-dimensional model of part of the study area was developed by GeoTrans, Inc. in 2001 using an available geologic model and hydrologic information. This model was used to develop preliminary estimates of the effects of pumping in Coyote Spring Valley on springs in the Muddy River Springs area. It was revised and recalibrated in 2003 (GeoTrans, 2003) to include the addition of head-dependent flux boundary conditions, updating of land surface elevations, modification of boundary condition parameters, minor modifications to the model grid, and incorporation of newly identified and updated pumping and water-level data. While this model was an improvement on the 2001 model, the results of this model indicated that additional refinement of the model was necessary to improve its predictive ability.

1.3 APPROACH

The current model expansion and refinement involved:

1. Adding the lower Virgin River Valley and Clover Valley hydrographic areas to the model domain;
2. Construction of a new 3-D geologic framework of the study area based on recent studies and reports;
3. Incorporation of the results from recent evapotranspiration (ET) studies conducted by the USGS providing spatial and temporal distributions of ET rates;
4. Inclusion of new geologic, hydrologic, and geochemical information gathered from the drilling, construction, and sampling of several new production and monitoring wells in the study area by the Southern Nevada Water Authority (SNWA), by Vidler Water Company, Inc. (VWC), a private water-development firm, and others; and

5. Calibration of the model developed using MODFLOW-2000 (Harbaugh, et al., 2000) to observed water levels, streamflow and spring discharge information, and responses to temporally varying evapotranspiration and pumping rates.

2.0 SOURCES OF INFORMATION

2.1 GEOLOGY

Model refinements included constructing a new 3-D geologic framework model of the study area based on recent: (1) geologic mapping conducted cooperatively by consultants for the SNWA and by the U.S. Geological Survey (USGS), in cooperation with the NPS, FWS, SNWA, and the Virgin Valley Water District(VVWD); (2) geologic cross sections constructed by the USGS in cooperation with the NPS (Page et al., 2011) and by Dixon and Katzer (2002) in the Virgin Valley basin; and (3) geophysical studies by the USGS of the 3-D extent of Tertiary-aged basins within the study area in cooperation with the NPS.

2.2 SPRING AND STREAM LOCATIONS AND FLOWS

Information concerning spring and stream discharge was obtained from several different sources. The USGS maintains the National Water Information System database which provided data on spring and stream discharge gaging sites maintained by the USGS. The Southern Nevada Water Authority performed an inventory of wells and springs (SNWA, 2003, 2005) which included information on springs in the Muddy River Springs area. The USGS, with support by the NPS, performed synoptic streamflow surveys on the Muddy River (Beck and Wilson, 2006) and Virgin River (Beck and Wilson, 2005) which provided streamflow measurements on these rivers at many locations at a given point in time.

Locations for small springs that did not have surveyed locations were determined from locating them with on topographic maps followed by observing their locations on Google Earth. The locations and elevations were determined from the Google Earth coordinates.

2.3 EVAPOTRANSPIRATION

The spatial and temporal distributions of evapotranspiration rates were determined during recent evapotranspiration (ET) studies conducted by the USGS and the U.S. Bureau of Reclamation (USBR). The National Park Service funded the United States Geological Survey to delineate the distribution of and to quantify the amount of annual discharge from ET for the study area (DeMeo et al., 2008). These estimates were based on a combination of satellite mapping of plant communities and measurement of evaporation rates at different locations in southern Nevada using energy-balance techniques. In addition, the energy-balance studies provided information on ET rates during the year, across the growing and non-growing seasons.

2.4 WELL CONSTRUCTION

Well-construction data have been assembled and entered into a database for the development of modeling datasets. These data include surveyed coordinates, surveyed top of casing, ground surface elevation, and well depth. Sources of these data include USGS National

Water Information System (NWIS, 2012) and SNWA websites, references listed in Table 3-1 below, personnel from USGS, NPS, FWS, and BLM, and the reports listed in the Water-Level Data section. Additional reports that contain well construction information include Hess (1986), Berger et al. (1988), SNWA and the Las Vegas Valley Water District (LVVWD) (2003), Lincoln County Water District (LCWD) and VWC (2005), SNWA and LVVWD (2005).

2.5 GROUNDWATER PRODUCTION

Data on groundwater production were obtained from the sources listed in Table 2-1.

Table 2-1. Sources of data on groundwater production

Source	Years	Wells
SNWA	1987-2007, 2010-2011	Behmer, Lewis, LDS, Arrow Canyon, Garnet (GV), LMVW, CSI, MX, Cogen, RW-1
Desert Research Institute (DRI)	1987-1995	Lewis, LDS, Behmer, LMVW
Moapa Valley Water District (MVWD)	1993-2007	Arrow Canyon, MX
Vidler Water Company (VWC)	2001-2007	MW1-10 and FF1 and 2B
Coyote Springs Investment (CSI)	2005-2007, 2011	CSI, MX
VVWD (from Nevada Department of Water Resources (NDWR))	1999-2011	VVWD, Bunkerville
Las Vegas Valley Water District (LVVWD)	1949-1986, 2008-2009	Behmer, Lewis, GV
NDWR	1999-2011	GV, Arrow Canyon, Behmer, CSI, CSV-RW2, LDS, Lewis, MX, Cogen, Paiutes, Perkins, Republic, RG

2.6 WATER LEVELS

A data set consisting of water-level information (i.e., depth to water or static water level elevation measurements) for the model area has been developed for this study. The primary data sources were the NWIS, SNWA website, and the Nevada Division of Water Resources (NDWR, 2011). The NWIS, SNWA, and NDWR data have been supplemented by the following reports: Eakin (1964), Rush (1964), Mifflin and Zimmerman (1984), Pohlmann et al. (1988), Mifflin et al. (1989), Pohlmann and Wert (1989, 1990, 1991, and 1992), Black and Rascona (1991), Buqo et al. (1992), Brothers et al. (1993), Pohlmann (1993, 1994, 1995, and 1996), Enright (1996), MVWD (1997, 1998, 1999, and 2000), Converse (2000, 2001, 2004, and 2005), Kleinfelder (2000), LVVWD (2001), Johnson et al. (2001), VVWD and Entrix (2006), LCWD and VWC

(2007), and SAHRA (2008). These data were used as calibration targets in the steady-state and transient groundwater flow models.

3.0 GEOHYDROLOGY

This section describes the geologic setting of the study area and then provides information pertaining to the movement of water in the groundwater system. A key component of the groundwater hydrology is the rate at which water enters and leaves the study area. Thus, much of this section relates to the water budget for the area and the locations where water enters and leaves the study area. Additional information is provided in Section 5, which provides information on the groundwater flow model.

3.1 GEOLOGIC SETTING

In 2005, the Nevada Bureau of Mines and Geology published Map 150, Geologic Map of Parts of the Colorado, White River, and Death Valley Groundwater Flow Systems, prepared by Page, Dixon, Rowley, and Brickey (Figure 3.1-1). This work, which was supported by the SNWA, National Park Service, FWS, and Virgin Valley Water District, summarized the results of many investigators over several decades. Accompanying text describes the stratigraphic and structural features within the current study area, and provides the basis for the discussion below.

3.1.1 STRATIGRAPHY

Rocks and sediments range in age from Early Proterozoic through Holocene. For purposes of this discussion, they have been grouped according to their age and role in the movement of groundwater in the study area.

Early Proterozoic – The Early Proterozoic rocks are low-permeability metamorphic gneiss and schist, and intrusive granite. They are located in the Beaver Dam and Virgin Mountains along the eastern side of the study area, and in the core of the Mormon Mountains. They act as groundwater barriers where present.

Late Proterozoic and Lower Cambrian – Late Proterozoic sedimentary rocks are primarily quartzite, conglomerate, sandstone, siltstone, and shale that may contain limestone and dolostone. They are well-cemented and have low permeability. These rocks are located in the Desert and Sheep Ranges in the western part of the study area, and in the Delamar Mountains in the northern part. The younger Lower Cambrian are similar in lithology to the Late Proterozoic clastic rocks. The combined Late Proterozoic and Lower Clastic rocks are thickest in the Desert Range on the west side of the study area. The Late Proterozoic rocks thin to the east, and are absent in the Mormon, Virgin, and Beaver Dam Mountains. The Lower Cambrian rocks are represented by the Tapeats sandstone and Bright Angel shale in the eastern part of the study area.

Middle Cambrian through Lower Permian – These rocks are predominately limestones and dolostones, and form the widespread regional carbonate-rock aquifer in the study area, and in areas to the north and west of the study area. These rocks can be very permeable because of faulting, fracturing, and dissolution. As discussed below, low-angle thrust faults have resulted in repeated stacking of these rocks, resulting in thickness of the aquifer greater than the original stratigraphic thickness of the sequence. The younger rocks contain higher proportions of clastic material (Dunderberg Shale, Eureka Quartzite, Chainman Shale, Indian Springs Formation, and Lower Permian redbeds), which can serve as confining units in local areas.

Lower Permian through Cretaceous – These rocks include the Lower Permian Kaibab and Toroweap Formations; Triassic Chinle and Moenkopi Formations; Jurassic Aztec and Navajo Sandstones, Kayenta and Moenave, Carmel, and Temple Cap Formations; and Cretaceous sandstones, conglomerates, siltstones, mudstones, and shales. Generally these rocks are much less permeable than the underlying carbonate rocks, although the Navajo serves as an aquifer in southeastern Utah and northeastern Arizona because of its thickness there. The Lower Permian through Cretaceous rocks are present in the southeastern part of the study area, especially the Muddy and Virgin Mountains.

Upper Cretaceous through Miocene intrusive rocks – These low-permeability rocks are locally present near Lake Mead, beneath the Clover Mountains, near the Caliente caldera complex, and north and west of Kane Springs Wash.

Tertiary Volcanic Rocks – The northern part of the study area contains several caldera complexes, the largest being the Caliente complex, which deposited ash-flow and air-fall tuffs. The ash-flow tuffs can serve as local aquifers. The calderas are likely floored by lower-permeability intrusive rocks. Volcanoes are also present in the study area north of Lake Mead.

Tertiary through Quaternary sedimentary rocks and deposits – Extensional tectonics created several deep basins which have been filled with fluvial and lacustrine deposits of variable lithology. The older deposits are more consolidated than the younger deposits, and would thus tend to be less permeable. Deposits of tuffaceous sandstones, tuff, conglomerates, limestones, siltstones, mudstones, gypsum, and halite are present. The Miocene and Oligocene-aged Horse Spring Formation is at least 8,500 feet thick beneath the Muddy Mountains, and may be more than 10,000 feet thick in deeper basins. The younger Muddy Creek Formation is less well consolidated. It is widespread, and is at least 3000 feet thick in some areas, and may be thicker in deep basins. It contains halite and other evaporite minerals near the Overton Arm of Lake Mead. The Muddy Creek Formation is hydrologically significant near the Muddy River Springs area; where thin or absent, water can discharge from the underlying carbonate aquifer as springs and seeps near and beneath the Muddy River. Further downstream, its presence above the carbonate rocks prevents substantial discharge into the Muddy River.

3.1.2 STRUCTURAL FEATURES

There are several different styles and times of faulting, ranging from Mesozoic through the present (Figure 3.1-2). The Sevier deformation, beginning during the Cretaceous and continuing through the Paleocene, produced eastward movement of sheets of the late Proterozoic and Paleozoic rocks creating repeated stratigraphic sections. The Gass Peak thrust (present near the western edge of the study area in and north of the Las Vegas Range) and the Muddy Mountain thrust (along the east side of California Wash and extending north-north-eastward through the Mormon Mountains) are the most significant of these Sevier faults.

During the Tertiary, normal-style Basin-and-Range faulting created the north-trending basins and mountain ranges observed today. Examples include the west-dipping unnamed fault on the western side of the Arrow Canyon Range and extending northward beneath Coyote Spring Valley, and the west-dipping Piedmont fault on the east side of the Virgin Valley. The East Arrow Canyon Fault system on the east side of the Arrow Canyon Range appears to be significant in the development of the groundwater discharge zone in the Muddy River Springs area. Both east- and west-dipping normal faults are likely to be present buried beneath the basin-fill deposits. Page et al. (2005) mapped hidden normal faults forming a graben beneath the Tule Desert.

Some of the basins are very deep (the USGS interpretation is presented below in Figure 4.1-1). Gravity and seismic data indicate that the Virgin River basin might exceed 8,000 meters (26,000 feet) in the northwestern corner of Arizona, and more than 6,000 meters in Nevada. California Wash has two sub-basins, separated by a high near the Muddy River and Lower Meadow Valley Wash.

Additionally, more recent right- and left-lateral faulting has occurred. The right-lateral faults strike approximately northwest to southeast, and the conjugate system left-lateral faults strike to the southwest. The most apparent nearby example is the right-lateral Las Vegas Valley shear zone which strikes northwest to southeast, and borders the study area on the south. To the west of the study area, movement along this fault has caused rotation of Basin-and-Range mountain blocks along the fault. The left-lateral Pahranagat shear zone forms the northwestern boundary of the study area. Left-lateral faults within the study area include the Kane Springs Wash fault zone, which extends to the southwest to Coyote Spring Valley and merges with the unnamed normal fault on the west side of the Arrow Canyon Range, and several faults in the Lake Mead fault zone near the southeastern edge of the study area.

3.2 AQUIFER PARAMETERS

Within the study area, there have been few aquifer tests conducted to measure transmissivity or hydraulic conductivity and storativity. The tests that have been conducted to date were located in the basin fill and carbonate units only. However, there is a high variability of values obtained even for wells located close together. For example, carbonate wells Arrow Canyon and Arrow Canyon #2 have transmissivities that vary by a factor of about 3 even though the wells are located about 25 feet apart. Table 3-1 summarizes aquifer test results within the study area.

Table 3-1. Summary of Aquifer Test Data within the Study Area

Well ID	HSU	T (ft^2/d)	K (ft/d)	S (-)	Date	Reference
MX-4	Carbonate	40,000 200,000	-	-	12/1980 1985	Bunch and Harrill (1984) Dettinger et al. (1995)
MX-5	Carbonate	250,000 250,000	-	- 0.14	7-9/1981 1985	Bunch and Harrill (1984) Dettinger et al. (1995)
MX-6	Carbonate	13,000	-	-	12/1986	Dettinger et al. (1995)
Arrow Canyon	Carbonate	310,880	-	-	12/1993	Buqo (1994)
Arrow Canyon #2	Carbonate	92,940	-	-	6/2004	Buqo (2002)
EH-4	Carbonate	360,000	-	-	6/2004	Buqo (1994)
CSV-2	Carbonate	1,600	-	-	6/1986	Dettinger et al. (1995)
CE-VF-2	Basin Fill	3,000	-	-	2/1986	Dettinger et al. (1995)
ECP-2	Carbonate	109,500	-	0.0081	7/2000	Johnson et al. (2001)
TH-2	Carbonate	53,820	-	0.00031	7/2000	Johnson et al. (2001)
TH-1	Carbonate	80,110	-	0.039	7/2000	Johnson et al. (2001)
Breedlove North	Basin Fill	24,120 72,360	- -	- -	2000 2001	Buqo (2000) URS (2001)
Breedlove South	Basin Fill	87,100	-	-	2000	Buqo (2000)
KPW-1	Carbonate	4,313 to 11,667	-	0.00019	1/2006	URS (2006)
CSI-2	Carbonate	18,000	28	-	2005	Johnson (2005a)
CSI-1	Carbonate	16,000	34	-	2005	Johnson (2005b)
CSI-3	Carbonate	12,000	19	-	2006	Johnson (2007)
CSI-4	Carbonate	130,000	190		12/2007	Johnson (2008)
RW-2	Carbonate	308,200 to 415,400	-	-	2002	Converse (2002)
Well #3	Basin Fill	4,824 to 23,584	-	-	2001	URS (2001)
MW-1A	Basin Fill	5,494 to 12,998	-	-	2001	URS (2001)
RW-1	Carbonate	64,000 to 530,000	-	0.00015 – 0.0068	2001	SRK (2001)
PW-1	Carbonate	1554 to 2117	-	0.005	2001	Hydrosystems (2002)
PW-2	Carbonate	683.4	-	0.00038	2007	BLM (2009)
WL31	Basin Fill	4,844 to 19,900	9.8 to 17.7	.0012 to .107	2003	Burbey et al., 2005

Aquifer test data outside the study area has also been compiled to support multiple versions of the Death Valley Regional Flow System model (Belcher, 2001; IT, 1996) and the NTS regional model (IT, 1997). Another study by Maurer et al. (2004) presents a summary of hydraulic conductivity values by rock type in Nevada.

3.3 ESTIMATED INFLOW AND OUTFLOW ACROSS STUDY AREA BOUNDARIES

Table 3-2, modified from Harrill (2007) gives Harrill's estimated groundwater flux value across different segments of the external boundary of the study area. Figure 3.3-1 shows the locations of these boundary segments. There is a net inflow into the area, most water coming into Coyote Spring Valley from Tikapoo Valley on the west side of the Sheep Range (CSV-2) and from Pahranagat Valley (CSV-3). Harrill estimated that the flow into or out of the model was low along most of the study-area boundary.

Table 3-2. Summary of boundary flux estimates

Boundary Segment	Flux (ac-ft/yr)	Comments
LVV-1	0	No flow
LVV-2	0 to -500	Outflow. Water for Corn Creek discharge area, use only if model performance is improved.
LVV-3	0	No flow
CSV-1	0	No flow
CSV-2	2,600 to 7,300	Includes up to 2,200 acre-ft/yr from Pahranagat Valley
CSV-3	32,300	35,000 less 2,200 to CSV and 500 that flow directly from Delamar Valley
CSV-4	250	Flow directly from Delamar Valley
KSV-1	250	
KSV-2	0	No flow
LMVW-1	0	No flow
LMVW-2	100 to 300	Shallow flow in alluvium. May be some deep flow in carbonate rocks not estimated here.
CV-1	0	No flow. May be some deep flow in carbonate rocks not estimated here.
VRV-1	0	No flow
VRV-2	2,123	Calculated from streamflow measurements and recharge estimates
VRV-3	8,700	Subsurface flux, 8,700 af/yr plus recharge E flank of BDM plus drainage from north and south areas.
VRV-4	254	Calculated from streamflow measurements and recharge estimates
VRV-5	0	No flow
VRV-6	-2,000 to -4,000	Rough estimate by author. Estimate in Reconnaissance Report 51 is probably high.
LMV-1	-1,100	Subsurface outflow
BMA-1	Less than -30	From local recharge
BMA-2	-2,000 to -3,000	Primarily discharge from carbonate rocks
BMA-3	Less than -30	From local recharge
BMA-4	Less than -30	From local recharge
BMA-5	Less than -50	From local recharge.

[Estimates in acre-ft/yr unless otherwise indicated; positive values indicate flow into the study area. Abbreviations: LVV-Las Vegas Valley; CSV-Coyote Spring Valley; KSV-Kane Springs Valley; LMVW-Lower Meadow Valley Wash: CV-Clover Valley: VRV Virgin River Valley; BDM-Beaver Dam Mountains; BMA-Black Mountains Area]

3.4 PRECIPITATION/RECHARGE

For this model, recharge was estimated based on a modification of the Maxey-Eakin method (Maxey and Eakin, 1949). The Maxey-Method method identified five precipitation zones, and assigned a recharge factor, or efficiency, to each of the zones. The recharge was then calculated by multiplying the precipitation rates by the correct recharge efficiency, and summing the values. In the Maxey-Eakin method, recharge was calculated using the precipitation zones defined by the Hardman map (1965), and the recharge efficiencies from Maxey-Eakin (Table 3-3).

Table 3-3. Original Hardman Precipitation Zones and Corresponding Maxey-Eakin Recharge Efficiencies.

Hardman Precipitation Zone	Recharge Efficiencies
< 8 in	0.00
8-12 in	0.03
12-15 in	0.07
15-20 in	0.15
> 20 in	0.25

In this study, the Maxey-Eakin method was modified by using a different source of information to estimate the annual precipitation (Figure 3.4-1, PRISM dataset), and a polynomial equation based on Table 3-3 to represent the recharge efficiencies, rather than the actual values in Table 3-3. The estimated annual recharge is presented in Figure 3.4-2. Additional information is provided in Section 5.2.1.

3.5 Discharge

3.5.1 Springs

There are three major groupings of springs within the study area (Figure 3.5-1). The greatest discharge occurs from springs located along the Muddy River on the east side of the Arrow Canyon Range upstream from Moapa. Water from the carbonate aquifer discharges either as discrete springs or as diffuse seepage into the Muddy River. The discharge rate prior to significant development of wells and pumping of groundwater from the shallow basin fill sediments or from the carbonate aquifer was approximately 34,000 af/yr, as measured at the stream gage 09416000 "Muddy River near Moapa". With development, pumping had decreased the discharge to approximately 22,000 af/yr in 2004. The discharge increased to approximately 27,000 af/yr in 2011.

The second group of springs are Rogers and Blue Point Springs, located within the Lake Mead National Recreation Area. The springs, which discharge at rates of 1,200 and 400 af/yr, respectively, are located on the upgradient side of the Rogers Spring Fault. The temperature and chemistry of the water, and the limited (but present) variation in discharge rate, indicate that the discharge is a mixture of deep carbonate aquifer water and a smaller amount of shallower water that is recharged locally.

The third group includes the remaining springs, which are small springs that discharge water that is believed to be locally recharged. Nearly all are located in the higher elevation areas. Many of the springs may be perched.

3.5.2 EVAPOTRANSPIRATION

Evapotranspiration (ET) is a process by which water from the earth's surface is transferred to the atmosphere. ET, for the purposes of this model, includes evaporation from open water and soils, and transpiration from plants. Recently, the NPS funded the USGS to delineate the distribution of and to quantify the amount of annual discharge from ET for the study area (DeMeo et al., 2008). Seven ET units were identified: dense meadowland vegetation (200 acres), dense woodland vegetation (7,000 acres), moderate woodland vegetation (6,000 acres), dense shrubland vegetation (6,000 acres), moderate shrubland vegetation (21,650 acres), agricultural fields (3,000 acres), and open water (280 acres). Figure 3.5-2 shows the location of these ET units within the study area. The ET units are typically located on valley floors and usually include naturally vegetated areas. Annual total ET was computed using micrometeorological field stations in four ET-unit areas and estimated based on previous ET studies in southern Nevada at the other 3 ET-unit areas. Annual groundwater discharge from ET totaled 98,000 acre-feet for the entire study area. These areas are fed entirely or largely by groundwater discharge. The ET rate varies throughout the year, because water usage by plants increases during the summer growing season (Figure 3.5.3). Table 3-4 lists the average-annual ET discharge for each hydrologic basin within the study area.

Table 3-4. Average annual ET discharge by Hydrographic Area

Hydrographic Area	Total ET discharge (acre-feet/year)
Black Mountains Area (215)	2,000
California Wash (218)	6,000
Muddy River Springs Area (219)	4,000
Lower Moapa Valley (220)	11,000
Virgin River Valley (222)	52,000
Lower Meadow Valley Wash (205)	17,000
Clover Valley (204)	6,000
Coyote Spring Valley (210), Kane Springs Valley (206), Tule Desert (221), Hidden Valley North (217), Garnet Valley (216)	0
TOTAL	**98,000**

3.5.3 STREAMS

The principal streams in the study area are the Muddy River and the Virgin River. These rivers flow into northern part of the Overton Arm of Lake Mead. They are perennial in their downstream portions, but upstream segments are intermittent.

Muddy River – The channel of the Muddy River enters the study area from Pahranagat Valley. The channel passes to the south through Coyote Spring Valley. The confluence with Kane Springs Wash (an intermittent stream) is in the northern part of Coyote Spring Valley. The channel continues to the south until near where Highway 168 enters Coyote Spring Valley northwest of Moapa, where the channel turns to the southeast through the Arrow Canyon Range. In Coyote Spring Valley, there is no baseflow in the river. However, limited groundwater discharges into the river within the Arrow Canyon Range approximately 5 miles further downstream. Approximately four and one-half miles further to the southeast, the Muddy River leaves the higher relief area of the Arrow Canyon Range and enters a more open, lower relief area. At this point, significant groundwater discharge into the river begins, creating the Muddy River Springs area, and turning the Muddy River into a perennial stream. The Muddy River continues to flow to the southeast to Lake Mead. At the location of the USGS stream gage at Moapa, the baseflow in the river was approximately 40 cfs in the early 1970s.

Near Moapa, Meadow Valley Wash enters the Muddy River. Meadow Valley Wash is fed by groundwater at different points downstream of where it enters the study area (near Caliente) and its confluence with the Muddy River. Meadow Valley Wash is fed by groundwater within the lower 5 to 6 miles above the confluence, but is intermittent for about 8 or 9 miles above that.

Downstream from the confluence with Meadow Valley Wash, water is diverted from the Muddy River to the extent that flow in the river is so greatly diminished that the flow at the gage at Lewis Avenue is only about 4 cfs.

Virgin River – The Virgin River enters the study area at an area known as the Virgin River Narrows, where Interstate 15 passes through the Virgin Mountains. It is perennial where it enters the study area. At Littlefield, AZ, Beaver Dam Wash joins the Virgin River. Beaver Dam Wash is intermittent over most of its course, but is fed by groundwater near Littlefield. There is a group of springs known as Littlefield Springs that is located on the east side of the Virgin River where Interstate 15 crosses the river. The highest springs are tens of feet higher than the river.

Downstream to Mesquite, NV, groundwater is shallow and provides discharge to the river in areas. From Mesquite downstream to Lake Mead, groundwater is discharged by evapotranspiration, and perhaps by discharge to the river. Several dry tributary channels, including Toquop Wash, enter the Virgin River between Mesquite and Lake Mead.

3.5.3.1 GAGING STATIONS

Stream gaging stations at different stretches along the Muddy River provide information on the spatial and temporal changes in stream flow. (See Figure 3.5-1 for the locations of washes, streams, gaging stations.) Their periods of record differ, and do not provide information over the entire timeframe of interest. The gage identified as Muddy River at Moapa has the longest period of record, and provides information at a critical location with respect to groundwater discharge into the Muddy River (Figure 3.5-4). The earliest measurements (approximately 47 cfs, or 34,000 af/yr) were made in 1914. Groundwater pumping and surface-water diversions upstream of the gage have caused measureable declines in the streamflow, beginning in approximately 1960.

3.5.3.2 SYNOPTIC STUDIES ALONG THE MUDDY AND VIRGIN RIVERS

The U.S. Geological Survey conducted two synoptic ("Snapshot-in-time") studies of discharge of the Muddy River in February 2001 (Beck and Wilson, 2006) and of the Virgin River in February 2003 (Beck and Wilson, 2005).

The study of the Muddy River Springs Area and the Muddy River (Figure 3.5-5) focused on streamflow at different locations on a single day, February 7, 2001. In particular, by compiling flow data, the USGS was able to quantify the rate at which the Muddy River was gaining or losing water over the measured reach on that particular day. Above the Moapa gage, the river gains nearly all of its flow over about a 2-mile reach. Below the Moapa gage, there is almost no gain. The discharge measured at the Muddy River at Anderson Wash near Logandale (09419490), approximately one-half mile upstream of the Bowman Reservoir diversion, is nearly the same as measured below the refuge. Beck and Wilson concluded that the difference is less than the measurement error. Further downstream, at Lewis Avenue, the discharge had decreased to 4.17 cfs because of diversion downstream of the measurement near Anderson Wash.

The study of the Virgin River provided flow measurements between the Virgin River Narrows and Lake Mead, Nevada (Figure 3.5-6). Evaluation of 14 discharge measurement locations and 3 diversions suggests that while the Virgin River gains significantly between the Narrows and Littlefield Springs (nearly 70 cfs), streamflow decreases between Littlefield Springs and Bunkerville by approximately 30 cfs and then remains relatively consistent between Bunkerville and Lake Mead, with some stretches that gain and others that lose. The study indicates that the Virgin River is hydraulically connected to the saturated Muddy Creek Formation, and that groundwater is supplying water for evapotranspiration between Bunkerville and Lake Mead, but is not discharging into the river at rates high enough to increase its baseflow within this reach. Together, DeMeo, et al. (2008, p. 19) and Beck and Wilson (2005, p. 7) showed that the total ET is almost identical to the loss from Littlefield to Overton on the Virgin River. This shows that there is not a large net gain or loss to/from the river to/from the aquifer system over this reach.

3.6 HISTORICAL GROUNDWATER USE

Figure 3.6-1 shows the locations of major production wells within the study area, and indicates groupings of wells based on location. Figure 3.6-2 provides the estimated or measured annual production for these groupings. In the Muddy River Springs area, groundwater withdrawal within the study area has occurred since the Lewis Well field began production in the late 1940s, ranging from 500 af/yr to nearly 2,000 af/yr until the early 1980's. Pumping increased to values of approximately 5,500 af/yr over the next 20 to 25 years. Groundwater production was from the surficial materials until 1991, when the Arrow Canyon well was drilled to produce water from the carbonate aquifer.

Figure 3.6-3 shows the locations of springs and production wells in the Muddy River Springs area. The discrete springs are located on the southwest side of the valley, at elevations higher than the nearby Muddy River. Diffuse groundwater discharge also occurs throughout the Muddy River Springs area, and collects in spring-brooks and rivulets that contribute to the flow of the Muddy River. The production wells are not located near the discrete springs, but upstream of, across the river from, or downstream of them.

Water production in the Virgin Valley has been increasing in the last decade. The earliest reported production was in 1998, but data for earlier years are not available. The production reached nearly 7,400 af/yr in 2005, but has decreased slightly in recent years. Production is from basin-fill materials, primarily the Muddy Creek formation.

Another area where groundwater production has been significant is in the Apex area and vicinity in Garnet Valley. Pumping in this area began in in the early 1960's. In 1993, the rate of production increased to provide water for several industrial operations, reaching rates of about 3,200 af/yr in the 2000's. This production is from the carbonate aquifer.

The Moapa Band of Paiutes have installed several wells into the carbonate aquifer on their reservation. However, there has been only limited production from these wells to date.

Water production in Coyote Spring Valley began in 2005. In 2010, the Order 1169 pumping began; the pumping rate was approximately 5,800 af/yr in 2011.

3.7 POTENTIOMETRIC RELATIONS

3.7.1 FLOW PATHS

Groundwater flow generally begins as recharge in the Clover Mountains, the Delamar Mountains, and the Sheep Range where precipitation infiltrates and moves through the carbonate aquifers discharge areas at streams and springs. In the Virgin River Valley, the groundwater table intersects the land surface at the southern end of Beaver Dam Wash, where it gradually increases in flow and merges with the Virgin River. The Virgin River enters the Virgin Valley on the east side, and flows until it enters Lake Mead. Although groundwater likely flows toward the Virgin River throughout its path to the lake, these potential gains are lost to evapotranspiration along the way, and the Virgin River does not gain substantially in flow, other than in the stretch upstream from Littleton.

Flow in Meadow Valley Wash generally is parallel to the valley itself, infiltrating into the basin fill and carbonates at the northern end, then discharging to Meadow Valley Wash west of the Mormon Mountains.

Flow in Coyote Spring Valley comes from a combination of recharge in the Delamar Mountains and underflow at the northern-most end of Coyote Spring Valley where most of the groundwater enters from Pahranagat Valley and/or Tikapoo Valley. Flow continues south through carbonate rocks. Some of the groundwater flow discharges into the Muddy River either through the Muddy River Springs, or into the Muddy River upstream of the gaging station at Moapa. Some regional groundwater flow likely continues southeast into California Wash in an extensive area of highly permeable carbonate rock. This water moves under the influence of a very mild hydraulic gradient in the area until it eventually makes its way northeast back to the Muddy River, or flows generally southeastward through the California Wash fault and discharges at Rogers and Blue Point Springs. A small amount likely discharges into Lake Mead. Additional contributions to groundwater along this flow path include recharge in the Sheep Range, and minor amounts in the Muddy Mountains.

3.7.2 GEOLOGIC CONTROL ON GRADIENTS

Gradients are generally controlled by a combination of highly permeable carbonates, relatively low-permeability basin fill including the Muddy Creek Formation, and structural features which have formed thrust sheets of large areal extent, as well as localized impediments to flow. In particular the Kane Springs Wash Fault and the Las Vegas Valley Shear Zone play influential roles in channeling groundwater flow.

4.0 DEVELOPMENT OF GEOLOGIC MODEL

A three-dimensional geologic model was constructed in order to provide information on the spatial distribution of hydrogeologic units (HGUs) to the flow model. This geologic model was developed to be compatible with MODFLOW's Hydrologic Unit Flow (HUF) package, which allows the assignment of hydrologic properties to specified HGUs for calculation of hydrologic properties of the individual model cells. The geologic model was developed using a regular grid with a spacing of 250 meters (820 feet). The flow model was developed using a variable grid; properties for the flow-model cells were sampled from the geologic model grid using the locations of the center points of the flow-model grid cells.

4.1 SUMMARY OF APPROACH

Twenty-seven different HGUs were defined to account for the stratigraphy and the effect of thrust faults (Figure 4.1-1). Geologic sections developed by Page and others (2011) and Dixon and Katzer (2002) were used to provide information on the effects of faulting on the three-dimensional distribution of the different HGUs (Figure 4.1-2). The sections were also used to provide information on the tops of the different HGUs. Drill hole and geophysical information was also used.

The lateral extents of the 27 HGUs were estimated using the geologic mapping by Page and others (2005) and the cross sections mentioned above. Where HGUs were bounded by faults, the interpretation of fault locations presented in Figure 4 of Page and others (2005) was adopted. The three-dimensional locations of HGU surficial contacts were used in development of the geologic model to provide information on where the HGU thicknesses were zero and on their elevations. Elevations of the contacts were determined by finding the intersection of the contact lines with the land surface, using ArcGIS and a Digital Elevation Model (DEM) downloaded from the USGS Seamless on-line database. The DEM database used in this project had cell dimensions of approximately 28 m on a side. Stratigraphic information provided from drillholes was also used to determine the elevations of HGU contacts.

Interpreted structural contour maps of the tops of the HGUs were prepared by a geologist using the information discussed in the previous paragraph. Because of the number of HGUs and the structural complexity and resulting high relief of the HGU contacts, these structural contour maps were sometimes inconsistent with each other. In other words, the thicknesses of the HGUs (calculated by subtracting the elevations of superjacent contacts) were quite variable and sometimes negative. Because of the number of stacked HGUs, manual adjustment of the structural contour maps to correct inconsistencies the HGU elevations was untenable.

A methodology based on PEST (Doherty, 2011) and pilot points was developed to calculate the elevations of the tops of the HGUs based on the available geologic mapping information, structural interpretations provided by the cross sections (in which the HGU elevations were consistent), and drillhole data. PEST is a software package designed for calibration of models to data (observations) using non-linear multiple regression techniques. These techniques involve multiple estimations of model parameters to improve the goodness of fit between values of model-calculated values and observed values of the variables of interest. For this application, the estimated parameters were chosen to be the thicknesses of HGUs at specific locations. The variables of interest (calibration targets) were the interpreted elevations of the tops of the HGUs, as expressed in the interpreted structural contour maps. In addition, the combined thickness of the basin-fill units at different locations, as estimated by Morin (2006) and Scheirer et al. (2006) based on gravity and seismic-survey data , were also used as calibration targets.

The pilot-point technique is one in which a grid of values is calculated based on values assigned to "pilot points" using a kriging approach. Kriging is an estimation tool originally developed for interpolating between measurements of ore grade, and has since been widely adapted for interpolating between other types of measurements. The technique takes into account the spatial correlation among measurements (expressed as a semi-variogram) and the locations of the measurements. For the geologic model, it was assumed that the correlation between HGU thicknesses at different locations could be described with a exponential semi-variogram, using a characteristic length of 6,000 meters, and a sill (half variance) of 36,000 meters. These values were derived by evaluating the thicknesses of several HGUs determined from Page's cross sections, and selection of representative values that appeared representative of all HGUs. Interpolation between pilot points was performed to a 250-meter uniform grid.

Three categories of pilot points were developed for this process:

- PPK – These pilot points (<u>P</u>ilot <u>P</u>oint <u>K</u>nown) were developed from HGU thicknesses determined from the geologic sections developed by Page and others (2010) and from drillhole lithologic information. Even though the geologic sections are interpretive, it was assumed that they were accurate representations of the subsurface geology, as they incorporated both stratigraphic and structural information.
- PPK0 – These pilot points (<u>P</u>ilot <u>P</u>oint <u>K</u>nown <u>Z</u>ero) represent the locations of contacts between HGUs, where the thickness of the subject HGU was mapped as zero. The PPK0 pilot points are located along the unit extent boundaries of the respective HGUs.
- PPE – These pilot points (<u>P</u>ilot <u>P</u>oint <u>E</u>stimated) represent locations within the Unit Extent of an HGU where PEST would develop estimates of the HGU thickness for that HGU. These locations were selected to be somewhat distant from PPKs and PPK0s to provide control for the kriging process in other areas. The geologic modeling process involved using PEST to estimate the thicknesses of each HGU in order to develop an acceptable agreement with the structural contour maps and basin-fill thickness map. Thicknesses at the PPEs were constrained using a process called "regularization" by Doherty; this technique will be discussed in more detail below.

These three categories of pilot points were developed for each HGU. At each pilot-point location, information on the thickness (either known or being estimated) of each HGU was used in the kriging process to develop the HGU-thickness datasets. The thickness datasets were then used to calculate the elevations of the top of the HGUs.

Doherty (2003) described the use of pilot points and regularization to estimate hydraulic conductivity during calibration of a MODFLOW model. The same approach was used for developing the geologic model for the flow model. The use of pilot points was discussed previously. Regularization is an approach to increasing the stability of the iterative regression process by adding additional constraints or information on the estimated parameters (HGU thickness, in this case). For the geologic modeling performed here, the regularization equations that were used were based on the idea that the stratigraphic thickness of an HGU at a PPE should be similar to that at a nearby PPE. Stated differently, the regression process should attempt to make an HGU a uniform thickness if the agreement between the model-calculated HGU elevations and the structural contour maps is good. The manner in which regularization is implemented in PEST ensures that the agreement is given higher priority than having uniform thickness.

The parameter estimation software package PEST, in combination with a FORTRAN program (gmcalc) that was written for this project, was utilized to create estimated tops and thicknesses of each HGU based on regularized thicknesses. Briefly, this involved the following steps:

1. Create PPEs, PPK0s, and PPKs for each HGU for use in developing a grid of HGU thickness values.
2. Calculate kriging factors for use in interpolating values at pilot points to the 250-meter geologic model grid, and a reduced set of kriging factors (using PPEs only) for use in developing the regularization equations, based on the locations of the pilot points.
3. Develop an input data set for PEST which provides PEST control parameters, initial estimates for the HGU thicknesses at each PPE, calibration targets (based on the structural contour maps and basin-fill thickness map), and regularization equations.
4. Run PEST, which performs the following steps
    a. Develop estimates for HGU thicknesses for all of the PPEs
    b. Calculate thickness arrays for each HGU using thickness values for PPKs, PPK0s, and PPEs. Figure 4.1-3 is an example of the kriging-calculated thickness of one of the carbonate thrust sheets, PC4.
    c. Execute a FORTRAN program (gmcalc) to calculate the tops of the HGUs, based on the land surface elevation from the DEM, and arrays (one for each HGU) of the thickness of the HGUs. For each geologic model cell location, the elevations of the top of the HGUs were calculated by sequentially subtracting the HGU thicknesses from the elevations of the overlying HGU. The subtraction process was performed

from the top downward (shallowest HGU to the deepest HGU). In addition, the program calculates the sensitivity of the HGU elevation to the thickness of other HGUs, for use by PEST.

   d. Compare model-estimated elevations and basin-fill thicknesses with structural-contour map values and basin-fill thickness map values, respectively
   e. Based on these comparisons and parameter-sensitivity information, develop new estimates of HGU thicknesses at PPEs
   f. Repeat steps b through e until convergence criteria are satisfied

5. Compare results of the PEST optimization with cross sections and structural contour maps, and adjust or add PPEs, and repeat the process, as necessary.

4.2 RESULTS

Examples of the extents and reliefs of the tops of four stratigraphic units are shown in Figure 4.2-1. These represent combined HGUs. For example, all of the thrust sheets of the Paleozoic Carbonates (PC) are shown. The surfaces shown are based on a 250 m by 250 m grid. Units are absent where the surface is gray. In the northern parts of Meadow Valley Wash and Beaver Dam Wash, the QCD is thin (only tens of feet) and was thus omitted from the geologic model.

The widespread occurrence of Cenozoic basin fill relative to the higher elevation ranges (gray areas) is apparent. The Tertiary volcanics are prevalent in the northern part of the study area, and also present adjacent to Lake Mead in the south. The Mesozoic rocks are present primarily in the eastern part of the study area, where the Paleozoic carbonates are present throughout most of it. On the carbonate depiction, the gray areas are where either Tertiary or Proterozoic crystalline rocks are present and the carbonate rocks were either intruded or eroded.

A comparison of sections by Page et al. (2011) (see figure 4.2-2 for locations) with sections derived from the digital geologic model (developed using EVS) is shown in Figure 4.2-3. The underlying crystalline rocks are not shown in the EVS sections. In general, the correspondence between the geologic model and original sections is quite good, with some smoothing of the detail in the original sections. This would be expected, as PPKs were used along the original section lines.

Sections are also presented in locations between the Page et al. sections (figure 4.2-4). The section labeled "North of A'A'" show the dominance of the crystalline basement (white areas) with a "relative" thin layer (greater than 1000 m thickness in most areas) on top. The sedimentary rocks are present in the eastern part of the section, but are thinner than in section A-A'.

A section was drawn using EVS between the Page et al. (2011) sections C-C' and D-D'. It shows the effect of the Gass Peak thrust on the west side (at approximately 5,000 to 8,000 m from the left end of the section), the great thickness of carbonate rocks between distances of 10,000 to 50,000 m from the left end, and the great thickness of basin-fill deposits beneath the Virgin Valley.

The next section, which crosses the Black Mountains, is similar to the one above it, but shows the effect of the Muddy Mountain thrust, the presence of the Mesozoic units (in yellow), and the faulted and overturned section in the Muddy Mountains (depicted by the Permian red beds both underlying and overlying the Kaibab/Toroweap (in light green) and Mesozoic rocks (in yellow). The last section ("Between F-F' and G-G'") shows the effects of the Gass Peak and Muddy Mountain thrusts, and the thick section of carbonates present between them.

These sections are constrained by the location of contacts on the geologic map and on the Page et al. (2011) cross sections, by gravity and seismic reflection data, as well as by geologic interpretations that were expressed in the structural contour maps. They indicate that the procedure used to develop the geologic model produces reasonable interpretations of the geology in a structurally complicated area.

Attachment I contains maps (ordered from top to bottom) which show the distribution of each of the HGUs in the geologic model, and the elevations (in meters) of their tops. The color gradation is the same for each map. The outline of the model is shown as a red line, which is not visible when the HGU is mapped to the edge of the model. The dots represent the pilot points (PPE) that were used to estimate the thickness of the HGU shown.

5.0 FLOW MODELING APPROACH

The flow model was developed using MODFLOW-2000, a widely used finite-difference flow-modeling code developed by the USGS. This section describes the development of the flow model, and how rock-property and water-budget information was provided to the model. Section 6 provides the results.

5.1 DEVELOPMENT OF FLOW-MODEL COMPUTATIONAL GRID

In order to conduct hydrologic simulations of groundwater flow within the geologic framework, a separate grid was constructed for use with MODFLOW. Although the geologic framework model was based on a regular spacing (250 meters) between nodes, the flow-model grid was telescoped to permit focus on the specific areas of interest while remaining computationally efficient. The flow-model grid consists of model layers of uniform cell thickness, each deeper layer being approximately 25% thicker than the layer above it. The top of the upper-most layer was assigned at the water table, permitting the model to be run in a fully confined manner.

In designing the flow-model grid, multiple factors were taken into account with specific consideration for where the model needed to be most accurate, how to allow it to potentially be used in conjunction with other models in the area, and how to make the model computationally efficient.

5.1.1 GRID REFINEMENT IN MUDDY RIVER SPRINGS AREA

The primary factor of concern in designing the model lay in ensuring the highest level of confidence in the model results for the area in and around the Muddy River Springs. Due to the intention of using the model to simulate pumping impacts on the springs, and because of the greater amount of information in the Muddy River Springs Area, Coyote Spring Valley, and California Wash on the hydrology and the effects of pumping, a fine grid was warranted in these areas.

5.1.2 ALIGNMENT WITH DVRFS MODEL GRID

The Death Valley Regional Flow System (DVRFS) model (Belcher, 2004) was created to simulate groundwater flow for the area immediately adjacent to this model, and to the west. 1500-meter cells were employed in construction of the DVRFS model. Model cells were therefore aligned to be consistent with the model cells of the DVRFS model, to provide the option for potentially linking the models in the future.

5.1.3 COMPUTATIONAL EFFICIENCY

Computational efficiency was a factor in deciding how the model grid was developed because of concerns that an 18-layer model with more than 300 stress period model with maximum cell dimensions of 250 meters on a side would become unwieldy to run. A variable-grid was judged the most effective way to minimize the number of model cells while preserving the reduced model cell size in the Muddy River Springs area.

5.1.4 GRID DESIGN

The model domain and horizontal discretization is shown in Figure 5.1-1. The model grid consists of 314 rows, 209 columns, and 18 active model layers. The active portion of the model grid consists of Hydrographic Areas (HA) 204-206, 210, 215-222, and part of HA 212 that is north of the Las Vegas Valley Shear Zone and east of the crest of the Sheep Range. The horizontal grid shaping is spatially variable, telescoping from 1,500 m x 1,500 m cells in the corners to 250 m x 250 m cells in the vicinity of Muddy River Springs. The grid spacing was chosen to be identical to the Death Valley Regional Flow System (DVRFS) Model (Belcher, 2004), or to be as easily translated to the DVRFS grid as possible. (Note: the horizontal grid spacing is specified in meters, because the UTM coordinates system was used in GIS; the units of the flow model are in feet and days). Future versions of this model could include grid refinement in other areas of interest and linking this model to the DVRFS model.

The model grid vertical discretization is based on an approach used in the development of the regional groundwater flow model for the Underground Testing Area Project of the Environmental Restoration Program at the Nevada Test Site (IT Corporation, 1996). This approach has been incorporated into the Hydrogeologic Unit Flow (HUF2) package for MODFLOW-2000 (Anderman and Hill, 2003), and was used by the USGS in the development of the Death Valley Regional Flow System model (Belcher, 2004). The complex structural geology in the region imposes a need to use an approach that can effectively incorporate the effects of fault displacement. The approach uses model layers that are not defined on the basis of geology, but on a vertical spacing from an arbitrary two-dimensional surface, such as sea level or the elevation of the water table. The HSUs present within a model cell are identified, and their hydraulic properties are used to calculate the hydraulic property values assigned to that cell. A large number of model layers is required to accurately represent the geology. For this model, eighteen layers are used, resulting in a total thickness of 15,630 feet. Table 5-1 shows the thicknesses of each model layer and their corresponding depths below the approximate elevation of the water table.

Table 5-1. Model Layer Thicknesses

Model Layer	Thickness (ft)	Depth (ft below water table)
1	100	100
2	125	225
3	150	375
4	180	555
5	230	785
6	275	1,060
7	350	1,410
8	450	1,860
9	550	2,410
10	650	3,060
11	720	3,780
12	825	4,605
13	950	5,555
14	1,175	6,730
15	1,500	8,230
16	1,900	10,130
17	2,400	12,530
18	3,100	15,630

The thicknesses of the model layers increase with depth, which allows for inclusion of greater detail near the top of the groundwater system. The top of layer 1 is an approximation of the water table, as initially developed by gridding of static water-level elevation data from wells and springs. When lack of data caused the interpolated water table to be above land surface, an elevation that was 10 feet below the land surface elevation was used as the top of the model.

One of the capabilities of HUF2 is the ability to simulate the decrease in hydraulic conductivity with increasing depth caused by the weight of overlying rocks. In studies of hydraulic conductivity values in southern Nevada (IT Corporation, 1996; D'Agnese et al., 1997, Belcher, 2001, Belcher, 2004) it has been found that there is an identifiable trend of decreasing hydraulic conductivity with depth, although there is considerable uncertainty with respect to the rate at which the hydraulic conductivity decreases. The decrease in hydraulic conductivity has been found to be describable by an exponential decay function. At great depth, this function results in unrealistically low values, as pointed out by Belcher (2004). The MODFLOW source code was modified for this model to incorporate a minimum hydraulic conductivity value to prevent unrealistically low k values in this model according to the modified exponential decay function:

$$K_{Depth} = \left(K_{Surface} - K_{\min})10^{-\lambda d}\right) + K_{\min}$$

where K_{Depth} is the hydraulic conductivity at depth d; K_{min} is the minimum hydraulic conductivity; $K_{Surface}$ is the hydraulic conductivity projected to land surface; λ is the depth-decay coefficient; and *d* is the depth below land surface. Figure 5.1-2 shows an example of how the hydraulic conductivity changes with depth as calculated by the equation above. In this model, the depth-decay coefficients derived from IT Corporation (1996) for several different lithologies were used as initial values in the calibration process.

The USGS Hydrogeologic-Unit Flow (HUF) package (Anderman, E.R. and Hill, M.C., 2000) allows the model to be run in a fully-confined format, removing the necessity for MODFLOW to solve unsaturated flow equations and thereby significantly reducing model run times. A later modification of the initial HUF package (HUF2) allows for the use of the specific yield term for the upper-most mode layer (Anderman, E.R. and Hill, M.C., 2003)). The model was constructed using this option for computational efficiency, while allowing use of both specific yield and specific storage terms for individual HGUs or zones within HGUs.

5.2 BOUNDARY CONDITIONS AND OTHER MISCELLANEOUS DATASETS

Besides the datasets that describe the geometry of the HGUs and their hydraulic properties, there are other modeling datasets that describe how water moves into and out of the groundwater system (called Boundary Condition datasets) and where Horizontal Flow Barriers (representing zones of reduced permeability perpendicular to faults) are present and their properties. These are described in this section.

5.2.1 RECHARGE

Recharge was implemented using the MODFLOW Recharge package (RCH). Recharge was applied to the model as a constant flux. No seasonal or climatic variation was integrated. This may represent a place where future model refinement would be appropriate.

Groundwater recharge to the model starts as precipitation. The most important source of recharge is snow, but summer storms can also contribute appreciable amounts of water. Recharge was estimated using a modification of the original Maxey-Eakin approach. The first modification was in the use of the PRISM (Parameter-elevation Regressions on Independent Slopes Model) precipitation dataset in place of the Hardman map, as it represents a more recent interpretation using a longer period of record and more measurement locations. PRISM-precipitation datasets are developed by the PRISM Group at Oregon State University (PRISM Group, 2008). PRISM is designed to map climate, such as precipitation, in difficult locales, such as mountainous locations and rain shadows. This model uses the mean monthly precipitation data from 1971-2007 provided on an 800 m by 800 m grid. Figure 3.4-1 shows the precipitation distribution over the model area. As expected, higher altitude locations, such as the Clover Mountains, have greater precipitation than lower elevations.

Second, a polynomial equation was developed from the original Maxey-Eakin coefficients to produce a continuous, rather than step-wise, function between precipitation and recharge rate. A cubic equation was derived using the Solver Add-in in Microsoft Excel to obtain with the amount of recharge in each model cell based on precipitation:

$$Percentage = -0.60551 + 1.0117P + 0.06572P^2 - 0.00175P^3$$

where *Percentage* is the percentage of precipitation that becomes recharge, and *P* is precipitation minus 7(in/yr). This equation thus does not calculate any recharge occurring when the annual precipitation is less than 7 inches per year. The precipitation values were sampled onto the variably-spaced model grid, and a weighted average precipitation value was calculated for each model grid cell using ArcGIS. Figure 3.4-2 shows the calculated recharge for each model cell.

It should be noted that the Maxey-Eakin method was developed to estimate basin-wide estimates of recharge, and has several simplifications that can affect the estimated distribution and rates of recharge. First, it assumes that recharge occurs at or very near to where the precipitation occurs. It does not consider runoff processes with the recharge occurring in downstream locations such as alluvial fans or beneath stream channels. Second, it does not consider the hydrologic properties of the materials at a location. It may calculate a recharge rate that is greater than the vertical hydraulic conductivity of the surface and create unrealistically high water levels in the model at that location. These simplifications are incorporated into the modified approach used in this model.

The average annual precipitation in the Muddy Mountains is below the minimum amount needed to yield appreciable recharge, but the data from Rogers and Blue Point springs, and the presence of small springs in the eastern part of the Muddy Mountains, indicate that part of the discharge is from local recharge. The recharge dataset developed using the modified Maxey-Eakin approach was modified to add local recharge to the Muddy Mountains through the use of MODFLOW's matrix arithmetic capabilities. The local recharge rate was adjusted during model calibration.

Because of the use of a different precipitation dataset and use of a polynomial for the recharge efficiency, the rate of recharge was different than the value that would be calculated using the original Maxey-Eakin approach. The basin water budget information was used to estimate a factor by which to reduce the calculated recharge rates to be consistent with discharge rates.

5.2.2 SPRINGS

Discharge from springs was simulated using two approaches:

- DRAIN package – Springs that did not cause significant surface water flow were simulated using the DRAIN package. The largest springs simulated with DRAIN package were Rogers and Blue Point Springs. Discharge from these springs was simulated by defining DRAIN cells in all 18 layers, reflecting a conceptual model that water could travel upward along the Rogers Spring fault. Both springs were located in the same model cell. Numerous small springs in the Clover and Delamar Mountains were also simulated with this boundary-condition package. These were simulated using a DRAIN cell only in layer 1. The combined discharge at Rogers and Blue Point Springs are calibration targets for the steady-state and transient flow models.

Figure 5.2-1 shows the locations of the springs simulated in the model. Horizontal coordinates for some of the springs were adjusted hundreds to thousands of feet based on aerial photography. The USGS NWIS web site gives horizontal accuracy for each spring location and some springs were specified with an accuracy of 6,000 ft.

- Stream-Routing Package – Springs in the Muddy River Springs area, which result in surface-water discharge, were simulated with SFR2. SFR2 was also used to simulate surface-water/groundwater interactions in other areas. The Muddy River Springs complex has several springs that create tributaries that flow into the Muddy River: Muddy Spring (or Big Muddy Spring), Baldwin, Pipeline-Jones (or Apcar), Pederson and Pederson-East, and Plummer (Iverson). The Pederson and Iverson spring complexes flow into Refuge Stream, which then flows into the Muddy River. These five springs were classified at separate segments in the SFR2 dataset.

5.2.3 ET DATASET

The ET units were sampled onto the model grid and an ET rate for each model cell was calculated based on the area occupied by the ET unit multiplied by the calculated or estimated ET rate from DeMeo et al. (2008) (Figure 5.2-2). The well package was used to remove groundwater from the subsurface as ET on an annual or monthly basis. Since ET is the only water budget component that can be measured with some level of confidence, it was explicitly used in the model to remove groundwater instead of using the ET package. Also, ET was not applied to model cells that contained springs (e.g., Rogers and Blue Point) so the model could remove groundwater via discharge from the springs and not ET.

5.2.4 EXTERNAL BOUNDARY FLUX DATASET

The external boundaries in each model layer are specified using the well package, except for Lake Mead. The flow rate for each individual boundary cell was calculated based on the estimated flow rate for the boundary segment containing the cell, the conductances for the cells in the boundary segment, and the conductance for the individual cell.

Early in the calibration process, the Multinode-Well (MNW) Package was being used to distribute the estimated boundary-segment flow rate, but caused model-stability problems. When these stability problems became apparent, the steady-state calibration process had progressed to the point that the hydraulic-conductivity parameters were not changing significantly. These conductivity values were used to calculate the cell conductances used to develop the well-package dataset for the boundary fluxes.

Lake Mead was simulated as a constant-head boundary in this model to allow the model to estimate the discharge into the lake and to determine the impact of changes in lake stage. The elevation of the lake was set to the mean lake stage for each stress period. Constant heads were set in model layers 1, 2, 3, and/or 4 depending on the floor elevation of the lake (Twichell et al., 2003).

5.2.5 PRODUCTION WELL DATASET

Groundwater production (see Figure 3.6-1) was simulated using the MNW Package. This package distributes the pumping from individual model cells that are contained within the screened interval for a well, based on the cell conductances and the water-level calculated for each cell. For example, if the well penetrates two different cells, one with a high conductance (because the rock represented by the cell is very permeable) and another with low conductance, most of the water pumped from the well will be simulated as being produced from the high-conductance cell.

Estimates of annual pumping amounts presented in LVVWD (2001) are used prior to 1987 in this model. If water production information for a well field was given (rather than for individual wells), it was assumed that all wells in the well field pumped an equal amount for that stress period. Beginning in 1987, monthly withdrawal amounts are available from a number of data sources listed in Table 2-1. Monthly stress periods are used in the model beginning in 1987 because of the availability of monthly pumping data from that time on.

5.2.6 STREAM-ROUTING PACKAGE

Streams in the model are simulated using the Streamflow-Routing (SFR2) package (Figure 5.2-3). The gaging station on the Muddy River at Moapa is used at a calibration target for the steady-state and transient flow models. In addition, stream segments in which there was not surface flow except in response to storms were identified, and calibration targets (with a streamflow rate of 0 cfs) were established at appropriate locations for use in model calibration.

Parameters for the streamflow-routing package were determined using ArcGIS. The length and width of each reach were estimated using satellite and aerial photography. Slopes and stages in the rivers and streams were estimated from the 9.8-m digital elevation model (DEM) of the study area. The hydraulic conductivity and thickness of the streambeds were set to 2 and 10 ft, respectively and modified during the calibration process. The five springs mentioned above were classified at separate segments so they could be given higher hydraulic conductivities to simulate spring flow from the aquifer into the stream, because the SFR2 package performs an interpolation of parameter values from the uppermost location to the lowermost location along a segment.

5.2.7 FAULTS AS HYDROLOGIC FLOW BARRIERS

Several of the mapped faults within the model domain may impede groundwater flow across them. The following faults were implemented in the flow-model utilizing the MODFLOW Horizontal Flow Barrier (HFB) package: Tule Desert Fault system, Kane Springs Wash Fault, Glendale Thrust, California Wash Fault, and the Las Vegas Valley Shear Zone where it runs within the model domain between the Muddy Mountains and Lake Mead (Figure 5.2-4). An additional fault has been inferred based on water levels in the vicinity of the Muddy River Springs. This fault was placed at the White Narrows of the Muddy River and represents a north-south oriented expression of the East Arrow Canyon Range Fault Zone as shown on Figure 3.1-2.

5.3 CALIBRATION

Development of groundwater models is a two-step process. The first step is setting up the modeling datasets providing information on the geometry of the system and how water moves into and out of the groundwater system. This process was described in section 4 of this report. The second step is called model calibration. During model calibration, the values assigned to the hydrologic properties of the HGUs and other modeling parameters (such as recharge rates) are adjusted so that output variables calculated by the model reasonable agree with observations. These observations can include water levels, changes in water levels, spring discharge rates, and streamflow measurements.

It is important for users of a model to recognize that models are approximations of the natural groundwater system. The natural system is more complex than can be represented in a computer model, and information on the natural system is incomplete. As a result, a model should be considered to be non-unique (i.e., other models can be developed for the system which may match observations equally well, but use different system geometries and properties). A model should also be considered to produce modeling results that are uncertain. Uncertainty in model predictions will be greater in areas where data are limited. For example, in this model, considerably more data are available in near the Muddy Springs area than in other part of the model domain. Thus, the model will provide predictions with less uncertainty near the Muddy Springs area than in other areas.

5.3.1 CALIBRATION APPROACH

Calibration of the flow model was performed using a combination of manual and automated calibration approaches. Information used to constrain (or guide) calibration included water-level information, changes in water levels in response to pumping and seasonal changes in

ET rates, and streamflow and spring discharge measurements. Commonly, groundwater flow models are calibrated to steady-state and pumping conditions, assuming that adequate information on the effects of pumping is available, in separate steps because of the longer simulation time for a transient model. A similar approach was used for calibration of this model, except that one “steady state” model and two different transient models were developed. The “steady-state” model included a simulation for steady-state conditions plus a 38-year period of limited pumping, primarily near the Muddy River springs area. The pumping was included to account for changes in the groundwater system that occurred prior to the time that observation data generally became available. One of the transient models covered the timeframe from 1949 to 2011, and the second covered the much shorter period (October 2008 through December 2011) including pumping and data collection associated with Order 1169 .

The calibration approach consisted of iteratively using manual calibration to test different model configurations, such as different applications of boundary conditions and parameter zonations, and automated parameter estimation methods (PEST, see Doherty, 2010) to estimate values of model parameters. PEST (which was also used to develop the three-dimensional geologic model) is a computer program which is designed to develop parameter estimates which minimize the value of an objective function using regression procedures. The objective function is the sum of the squared weighted residuals, where a residual is the difference between a measured value (observation) and the corresponding model-calculated value. For example, water-level measurements can be used as observations, and the residuals would be the differences between the measured and simulated water levels. Other types of measurements can also be used, such as calculated drawdown and measurements of spring discharge.

5.3.2 CALIBRATION TARGETS

Information used to calibrate the model included:

- 15307 observed water-level elevations in wells throughout the model domain
- 186 combined discharge measurements at Rogers and Blue Point Springs
- 179 discharge measurements in the Muddy River at Moapa
- 70 spring-flow discharge measurements at Baldwin Spring
- 71 spring-flow discharge measurements at Big Muddy Spring
- 173 combined spring-flow discharge measurements at Pederson and Pederson East Springs
- 65 spring-flow discharge measurements at Pipeline-Jones (Apcar) Spring
- 25 spring-flow discharge measurements at Plummer (Iverson) Spring
- 178 discharge measurements in the Muddy River at Glendale
- One-time measurements of stream flow at different locations along the Muddy and Virgin Rivers

For the transient models, individual measurements were used, reflecting conditions at specific times. However, for the steady-state model, values representative of conditions prior to significant groundwater production were selected, if possible.

There are both ephemeral and perennial stretches along the stream channels. These are depicted in Figure 5.3-1. Sections of Meadow Valley Wash below Rainbow Canyon and above the confluence with the Muddy River at I-15, Muddy River segments in and upstream of Arrow Canyon, and Beaver Dam Wash segments downstream between the Clover Mountains and the confluence with the Virgin River were observed in aerial photographs to be dry. They also lacked phreatophyte vegetation indicative of shallow groundwater. These sections represent segments in which water probably only flows ephemerally. Cells within these sections of the rivers were selected and used as zero-flow targets for calibration.

5.3.3 CALIBRATION MODELS

The pre-production model was developed to use develop estimates of hydraulic conductivity for HGUs throughout the domain of the model. Simulation time for this model was considerably shorter than for the transient models, allowing more parameters to be estimated. This simulation did not include any groundwater production. Types of observations relied on for calibrating this model included water-level data at selected wells throughout the model domain (Figure 5.3-2), locations of perennial and ephemeral streams, discharge rates at the larger springs, and “pre-development” streamflows, where possible.

A map of the locations of stream-flow and spring discharge targets was presented in Figure 5.2-1. Measured discharges at the Muddy River near Moapa (09416000), Muddy River at Glendale (09418890), Muddy River at Lewis Avenue (09419507), and discharges estimated during the Muddy River Synoptic study before the power plant diversion provided information on groundwater interactions with the stream. Additional discharge targets were placed to simulate the USGS gage on Meadow Valley Wash at Caliente Spring, a gaging location used in the USGS synoptic study located downstream on Muddy River from where Baldwin Spring enters (MR above Upper Confluence, 09415880), the USGS gage on the Virgin River at Littlefield (09415000), and the Virgin River gage site (09415240) located near Overton.

Because data on streamflow are generally unavailable for pre-development conditions, the streamflow data are considered to be approximate. For example, diversions of water from the Muddy and Virgin Rivers have been occurring for decades, but the synoptic streamflow studies were only conducted in the past few years. This model included diversions upstream from Moapa, but did not include diversions between I-15 on the Muddy River at Lewis Avenue. As a result, the simulated streamflow at Lewis Avenue was many-fold larger than measured, and a low weighting factor was applied at the Lewis Gage to minimize the impact on the PEST-estimation process.

Spring Discharge targets were placed at Baldwin Springs, the Warm Springs weir which monitors flow from Pederson and Pederson East Springs, Pipeline-Jones/Apcar Spring, Plummer/Iverson spring, and the Big Muddy Spring.

Prior to construction of Hoover Dam (1931- 1936), a topographical survey of Black Canyon and the Overton Arm was performed as part of a dam siting and impact evaluation. No observations of substantial-volumetric-rate springs were noted during the resulting maps developed as part of the study, suggesting that very little, if any groundwater originating within the Lower Colorado Flow System discharges to Lake Mead, other than where it contributes to flow in the Muddy River or Virgin River prior to entering the Lake, or from Rogers and Blue Point Springs. This pre-development observation was also used to constrain the calibration of the model through a mass-balance calculation of water entering the model cells used to simulate Lake Mead, and attempting to maintain minimal discharges.

The pre-production model included three stress periods. The first stress period was set up to be steady state. However, the model would not consistently satisfy convergence criteria because of the use of head-dependent boundary conditions, specifically the stream-routing package. Therefore, a second stress period was added with identical boundary conditions and material properties as the first, steady-state, stress period. For the model calibration process, this stress period was 400 years long. However, for the final model, the length of the stress period was increased to 10,000 years to ensure that water levels and discharges were stable. Differences of a few feet in water levels occurred between the 400-year and 10,000 year simulations in areas that were distant from flowing stream segments. The third stress period in the “pre-production” model incorporated average pumping rates from non-carbonate wells in the Muddy River Springs area for a 39-year period ending in 1987.

A transient model for the period October 2008 through December 2011 (the Order 1169 Model) was the primary model used to refine the groundwater model in the vicinity of the Muddy River Springs and Coyote Spring Valley, and to provide estimates of aquifer storage parameters. This time period included the effects of pumping near the springs, pumping in Coyote Spring Valley, and changing rates of evapotranspiration near the springs. This model is termed the Order 1169 model, because it focuses on the time period in which pumping and data collection pursuant to Order 1169 occurred. The carbonate aquifer (HGU PC4) is the primary aquifer in this area. In order to account for spatial variability of the hydraulic conductivity of this HGU, a pilot-point approach was used. There were 24 pilot points defined over the extent of PC4, and kriging was used to interpolate hydraulic-conductivity values at each of the pilot-point locations to other cells in the model grid. The pre-production model was used to estimate hydraulic-conductivity values for the PC4 at these pilot points, and the Order 1169 model was used to refine the pilot-point values near the Muddy Springs area and in central Coyote Spring Valley.

A map of the locations of drawdown targets is presented in Figure 5.3-3. These targets were based off of the water level measured in each well as close to the beginning of the model run (October 2008) as possible. However, in some cases transient seasonal effects from pumping during the summer of 2008 were apparently still dissipating. Drawdown values in these wells were adjusted so that zero drawdown coincided with water levels measured during the winter months when pumping and evapotranspiration effects would have subsided.

The Order 1169 model used water levels calculated from the pre-production model as initial heads. Monthly stress periods were used in the Order 1169 model so that changes in ET rates and pumping rates could be incorporated. The Order 1169 model began in October 2008, allowing approximately two years of monthly changes in ET and pumping to be simulated prior to the increase in pumping in Coyote Spring Valley. The simulation was conducted with monthly stress periods through the end of December 2011.

The longer-term transient model (1949 through 2011) was not used in PEST, but was run separately to confirm that the model provided results consistent with the longer term observations. This model used 38 year-long stress periods, using different estimates of the pumping for each year, before switching to monthly stress periods for the remainder of the simulation.

6.0 CALIBRATED MODEL

6.1 HYDROLOGIC PROPERTIES OF HGUS

The primary properties of HGUs that affect groundwater flow are hydraulic conductivity and storage parameters. In MODFLOW, the user has the ability to provide hydraulic conductivity information in the x-, y-, and z-directions relative to the model grid for each cell, if desired. In this model, the model layers were defined to be parallel to an estimate of the water table, which was determined from previous model results developed after extensive model calibration had already been performed. The model assumes that the hydraulic conductivity in the x- and y-directions are equal to each other, but different than in the z-direction. In addition, because of the vertical thickness of the modeled system and the effects of the weight of the overlying rock on the hydraulic conductivity, the KDEP capability of the HUF package was used. Thus, parameters needed to be provided to describe the reduction in hydraulic conductivity that results from increasing depth of burial.

When water levels change, water is released from or put into storage in the aquifer, through (1) draining or refilling pore space at the water table, or by (2) de-compressing or compressing the water and aquifer beneath the water table. The amount of water released from or put into storage, from these two different processes, is described by the parameters specific yield and specific storage, respectively.

6.1.1 HYDRAULIC CONDUCTIVITY

Table 6-1 contains the calibrated values for horizontal hydraulic conductivity and horizontal-to-vertical anisotropy for each of the HGUs, except for the hydraulic conductivity of the HGU termed PC4. The technique used to calculate the hydraulic-conductivity field for PC4 is presented below. The distribution of the property zones for the CAU is shown in Figure 6.1-1, while the zones of the TVC and XLB are provided in Figure 6.1-2.

Table 6-1. Hydraulic Conductivity Values by HGU in the Calibrated Model

HGU	Kx and Ky	VANI	HGU	Kx and Ky	VANI
QCD	150	10	PR4	0.1	100
CAU Zone 1	3.0	100.0	PC4 (See Table 6-2 below)	Varies	40
CAU Zone 2	10.0	100.0	PC3	15.16	100
CAU Zone 3	66.0	100.0	PR3	0.1	100
CAU Zone 4	7.13	100.0	KT3	5	100
CAU Zone 5	18.0	100.0	MU3	5	30
CAU Zone 6	40.0	100.0	MU2	5.59	30
CAU Zone 7	40.0	100.0	KT2	5	100
THS	0.1	60	PR2	0.1	100
TAU	1.0	60	PC2	200.0	100
TVC North	2.0	10	MU1	0.5	100
TVC Black Mtns	0.1	10	KT1	70.81	100
PC6	500	2.0	PR1	0.5	100
LC6	50	2.6	PC1	80.0	100
PC5	200	2.0	LC1	10.0	1.0
LC5	50	3.0	XLB North Zone	200	0.5
MU4	3.71	100	XLB South Zone	0.1	0.5
KT4	8	100			
Note:					
Kx, Ky: Horizontal Hydraulic Conductivity (feet per day) projected to land surface (no overburden)					
Vani: Horizontal to Vertical Anisotropy Ratio					

The hydraulic conductivity dataset for PC4 was developed using Pilot Point techniques and utility programs provided as part of PEST. Spatial variation in hydraulic conductivity of an HGU is expected to be present because of differences in depositional environment, in structural setting, and in alteration history, among other factors. In most models, there is insufficient information with which to estimate properties in different area, and either homogeneity is assumed, or parameter zones (in which it is assumed that the properties in each zone are homogeneous) are used. For the PC4 HGU (in the western part of the model), it was anticipated that results from the Order 1169 pumping in Coyote Spring Valley might allow the hydraulic conductivity to be estimated in different locations.

The pilot point technique (which was previously used in the development of the geologic model to estimate thicknesses of the HGUs) uses kriging to interpolate values provided for values specified at "pilot points". The goal is to develop a spatially varying distribution of hydraulic conductivity that reflects the average hydraulic conductivity near a location. Because there is limited information on the distribution of hydraulic conductivity with which to calculate a semi-variogram, a semi-variogram was assumed that resulted in a smoothly varying hydraulic-conductivity field constrained by the estimated values at the pilot-point locations.

Table 6-2 provides the estimated hydraulic-conductivity values at the 24 pilot-point locations. The locations of the pilot points, and the resulting hydraulic-conductivity field, is shown in Figure 6.1-3. The most striking feature is the high hydraulic conductivity estimated for pilot point #1, near the location of the Muddy River Springs. The PEST-estimated value for that pilot point was approximately 19,500 ft/day. Other hydrologists have postulated that there is a northwest-trending zone of increased permeability extending from the area of the Muddy River Springs into Coyote Spring Valley. Pilot point #2 is near MX-5, and the PEST-derived estimate of its hydraulic conductivity was approximately 4600 ft/day.

Table 6-2. Hydraulic Conductivity at Pilot Points used in Interpolation of PC4 Hydraulic Conductivity Field

PC4 Pilot Point	Kx	PC4 Pilot Point	Kx
1	19488.9	13	24.4
2	4560.3	14	1500.0
3	1000.0	15	421.0
4	679.1	16	300.0
5	1500.0	17	56.7
6	5.0	18	50.0
7	6.5	19	100.0
8	141.7	20	1500.0
9	134.3	21	1500.0
10	5.0	22	20.0
11	15.5	23	1836.4
12	23.2	24	200.0

Table 6-3 provides the values of lambda and Kmin used by HUF in the model. The Kmin value is the smallest value assigned to the HGU. For example, the QCD has a hydraulic-conductivity value of 150 ft/day at land surface, and the value decreases exponentially to a minimum value of 0.0001 ft/day. The value of lambda is 0.0017/ft, meaning that the hydraulic conductivity decreases by an order of magnitude every 588 ft. The minimum value assigned for the carbonate HGUs is 0.0003 ft/day; their hydraulic conductivity decreases by an order of magnitude every 1,333 ft in the model. The values of lambda were obtained from studies of the relationship between hydraulic conductivity and depth in the Death Valley flow system to the west of this study area. While these studies determined that there were definite trends of reducing hydraulic-conductivity values with increasing depth of burial, there was considerable uncertainty for the rate at which hydraulic conductivity declined with depth because of the high degree of variability in hydraulic conductivity in the rocks.

Table 6-3. HUF Parameters by HGU

HGU	Lambda (1/ft)	Kmin (ft/d)
QCD/CAU/THS/TAU	1.70E-03	1E-04
TVC	7.10E-04	1E-06
MU	4.57E-04	5E-04
KT	4.57E-04	3E-04
PR	4.57E-04	5E-04
PC	7.50E-04	3E-04
LC	4.57E-04	1E-05
XLB	1.00E-03	1E-04

Table 6-4 provides the calibrated values for specific storage and specific yield (SYTP) for each HGU. The SYTP values are only applied to layer 1 in the model, the layer which contains the water table. With the exception of the storage parameters for PC, these values were estimated from literature values. The PC values were based on pumping tests for ECP-2.

Table 6-4. Calibrated Storage Parameters by HGU

HGU	SS (1/ft)	SYTP
QCD	1.0E-05	0.25
CAU	1.0E-05	0.2
THS/TAU	1.0E-05	0.10
TVC	1.0E-05	0.10
MU	1.0E-05	0.10
KT	1.0E-05	0.10
PR	1.0E-05	0.10
PC	1.1E-06	0.02
LC	1.0E-05	0.05
XLB	1.0E-05	0.05

Table 6-5 provides the values given to the HFBs. The values for all but two of the HFBs were set to 1.0E-06 ft/d, in spite of efforts to estimate their values using PEST. With the available information, PEST was not able to develop consistent estimates of these parameters. When lower values were initially provided to PEST, they were commonly increased by PEST.

The values provided for Kane Springs Wash fault and the Tule Desert fault are those values being used by PEST at the time that calibration efforts were concluded. These values are similar in magnitude to values being used in the SNWA model for their Clark, Lincoln, and White Pine Counties groundwater development project.

Table 6-5. Conductances assigned to the Horizontal Flow Barriers

Fault	Parameter	HFB conductance (ft/d)
White Narrows fault	hf_wnf	1.00E-06
Kane Springs Wash fault	hf_kswf	4.74E-06
Tule Desert fault	hf_tdf	1.31E-06
Glendale thrust	hf_glent	1.00E-06
California Wash fault (north)	hf_cwf_n	1.00E-06
California Wash fault (south)	hf_csf_s	1.00E-06
Rogers Spring fault	hf_rsf	1.00E-06
LVVSZ (west)	hf_lvvsz_w	1.00E-06
LVVSZ (east)	hf_lvvsz_e	1.00E-06

During model calibration, two changes to the boundary conditions were implemented.

1. The calibrated hydraulic conductivity for the northern Tertiary volcanics was low enough to cause hydraulic heads to mound above land surface in the Delamar Mountains. Based on evaluation of aerial photographs from the area, several drains were added and set to the land surface elevations of the bottom of several steep-walled valleys which appeared to contain vegetation patterns suggestive of a spring flow source, allowing part of this recharge to leave the model.
2. In evaluating flow contributions to the Muddy River in the vicinity of the Muddy River Springs complex, significant budgetary shortfalls were discovered. To address part of this, the Cardy-Lamb spring, whose flow was historically used for irrigation, was added to the springs complex, and assumed to contribute to flow in the Muddy River at approximately the same confluence as Baldwin Springs. For calibration purposes, the flow at Cardy-Lamb springs was estimated to be 3340 af/yr, or approximately 4.6 cfs, and assigned a spring discharge elevation of 1797.16 ft. The spring was implemented in the same way as the rest of the Muddy River Springs complex, using reaches of the stream-flow routing package, extending vertically downward to model layer 8.

6.2 SIMULATED WATER LEVELS

6.2.1 WATER-TABLE MAP

Figure 6.2-1 shows a map of simulated pre-production water levels for the model area. This represents water-level conditions for the steady-state simulation used as initial conditions for the long-term simulation. Figure 6.2-2 shows the residuals for pre-production water levels in comparison to the target locations used in calibration. The correlation between measured and simulated water levels is presented in Figure 6.2-3. The correlation coefficient is 0.961.

The simulated water-table map is characterized by areas of low hydraulic gradient (parts of Coyote Spring Valley, Hidden Valley, Garnet Valley, and California Wash), high gradients (Sheep Range, Delamar Mountains, Clover Mountains, Tule Desert and Tule Springs Hills), and intermediate gradients (Mormon Mountains, Virgin River Valley, Muddy Mountains, and Black Mountains). These gradients reflect the underlying geology and amounts of recharge. The lowest gradients occur where the carbonate aquifer (PC4 sheet) is relatively shallow. The highest gradients occur where significant precipitation falls on areas of low permeability rock.

The areas where there is interaction between the simulated groundwater system and the streams are apparent in the water-table contours. For example, along the Virgin River, the flow converges toward the river, and the groundwater system discharges into the river. [Near the downstream end of the Virgin River, there is a closed contour (1200 ft) that is the likely result of the removal of water by ET.] Beaver Dam Wash is simulated as a gaining stream over most of its length, although the southern and middle parts of Beaver Dam Wash are ephemeral, not perennial.

In the upper stretches of Meadow Valley Wash, groundwater is simulated as discharging into the river. Further downstream, where the simulated water-table elevation is between 2600 and 2700 ft, the stream begins to lose water into the groundwater system for a short distance. Approximately 15 miles upstream of the confluence of Meadow Valley Wash and the Muddy River, Meadow Valley Wash becomes a gaining stream again.

The contour lines also reflect the discharge of water into the Muddy River in the Muddy River Springs area, but the amount of contour-line deflection (considering the volume of discharge) is not as pronounced as in some areas, because of the high transmissivity of the carbonate aquifer in the Muddy River Springs area.

The impacts of some of the HFBs are very apparent in the spacing of some contour lines. The most apparent impacts are along the HFBs representing the Rogers Spring Fault, the Glendale Thrust, and the Tule Desert Fault System. In these three examples, there are high gradients or obvious deflections of the contour lines simulated by the model. More subtle examples occur along the Lake Mead Fault System, the southern part of the California Wash Fault, parts of the Kane Springs Wash Fault, and the White Narrows Fault.

There are three closed contour lines (1800 ft) in the northwestern part of the Muddy Mountains. These result from the application of a small amount of recharge in this area.

The model matches water levels in the basins reasonably well, given the complex geology, but tends to simulate water levels in the Clover Mountains that are too low. The water-level data in the high relief areas may represent perched conditions. In these areas, it is likely that interbedding of fine-grained sediments, and/or detail of individual flows within a volcanic sequence are sufficient to perch water independently of the regional groundwater flow system.

6.2.2 DRAWDOWN IN COYOTE SPRING VALLEY AND MUDDY RIVER SPRINGS AREA

The Order 1169 pumping provided an opportunity for calibrating the parameters of the groundwater flow model based on the observed impacts associated an increase in the amount of pumping in Coyote Spring Valley that occurred as a result of Order 1169. Limited pumping began in well MX-5 with pumping in August and increased to approximately 50% of production capacity pumped in September of 2010 (Figure 6.2-4). The pumping rate was increased again in October 2010. Pumping associated with the test was simulated through the end of December 2011.

During this period, changes in groundwater discharge at other locations also occurred, specifically water supply for irrigation, increased evapotranspiration and power generation during summer months. These changes complicate the analysis of the effects of the Order 1169 pumping but have been incorporated into the model. There are other changes that are not accounted for in the model, notably changes in recharge rates related to climatic variability, and changes in boundary flows. In short, a part of the variation that affects water levels in the area is not accounted for.

Figure 6.2-5 shows the comparisons between measured and simulated drawdowns for the Order 1169 simulation. The locations for these wells were shown on Figure 5.3-3. The drawdown figures show the observed (in red) and simulated (in blue) drawdowns from the start of the simulation (October 1, 2008). For carbonate wells that were pumped significantly during the simulation period, the monthly pumping is shown in green. The larger plot at the bottom of the figure also shows the monthly pumping from these wells on a single plot. In addition to the time-varying pumping associated with the Order 1169 pumping in Coyote Spring Valley, pumping and ET from the valley fill in the Muddy River Springs area also varied monthly.

Pumped Carbonate Wells – The model simulates in increases in drawdown when these wells are pumped at higher rates. However, the simulated increase in drawdown is less than measured. This model behavior should be expected, because the drawdown in the well results partially from the convergence of flow lines to the wells, which have diameters of approximately 1 foot, where as the model cell has a dimension of 820 feet. Even though this cell dimension is small for a regional model, the model is not capable of accurately simulating the drawdown in pumped wells.

Coyote Spring Valley – The non-pumped wells in Coyote Spring Valley are, approximately from north to south, CSVM-3, CSVM-7, KMW-1, CSVM-4, CE-VF-2, DF-1, CSI-4, CSVM-6, CSI-3, CSI-2, CSI-1, CSV-RW2, MX-4, CSVM-1, CSV-3, and CSVM-2. For the wells to the north (CSVM-3, CSVM-7, KMW-1, CSVM-4, CE-VF-2, and DF-1) the model calculates a small amount of drawdown (which increase to the south), and the measurements (although noisy) suggest a comparable amount of drawdown occurred.

Wells that are closer to the pumping wells in Coyote Spring Valley (primarily MX-5, CSI-3, and CSI-4) include CSVM-6, CSV-RW2, and CSVM-1. The total amount of simulated drawdown at these wells is, in general, slightly less than observed, and the shorter term temporal variations (responses to changes in pumping rates) are smaller than observed. The observation-well data indicate short-term temporal changes during the first two years of the simulation that are not reflected in the model results. Simulation results at CSVM-1 show little seasonal response (but do show a downward trend of water levels) while the model response at CSVM-6 (which is further from the seasonal ET and groundwater pumping near the Muddy River Springs area) shows a greater seasonal response. This difference suggests that the source of the seasonal response in SCVM-6 is not the Muddy River Springs area, but is likely pumping in Coyote Spring Valley, such as at CSI-4. When pumping starts in MX-5 (approximately at the end of the second year of the simulation) the effects of the pumping are quite discernible in CSV-RW2 and CSVM-1, but less so in CSVM-6.

The measured responses in CSVM-2 and CSV-3 are similar to those observed in Paiutes M-1, Paiutes M-3, and Paiutes ECP1, as well as wells closer to the Order 1169 pumping, showing both general declines in water level and the presence of shorter term temporal changes. The simulated results show less overall decline and essentially no short-term variation. These differences suggest that the model is using hydraulic conductivity values that may be too high in some areas, too low in others, storage coefficients that are too high, or combinations of these.

Muddy River Springs Area – These wells are closer to the Arrow Canyon wells, shallower wells that pump from the alluvial material and Muddy Creek, and the areas where ET occurs. The model simulates the approximate overall decline in water levels in EH-4, EH-5B, and Cardy-Lamb, and simulates the short-term changes reasonably well. In the Battleship Wash well, the simulated drawdown is approximately one-third of that observed.

Eastern Wells – Measurements in EH-3 and EH-7 indicate that there has not been a consistent trend in water levels, or short-term changes that appear to be caused by changes in ET or pumping rates. The water-level changes observed in EH-3 appear to be local and short-lived. The simulation has little change in water levels in these two wells.

Summary – The simulated drawdowns during the Order 1169 simulation period agree reasonably well with the overall drawdown observed in the wells, but typically have lower amplitude short-term responses than were observed. In some wells, no short-term variability is simulated. Thus, the model results appear to be better suited to evaluating the longer-term average response than the short-term variability.

Figure 6.2-6 shows the drawdown from simulation of the pumping from MX-5 only for the time period covered by the Order 1169 model. MX-5 was the primary production well in Coyote Spring Valley during the time period. The figure indicates that the simulated drawdown was less than 0.8 ft except for the immediate vicinity of MX-5, where a drawdown greater than 3 feet was simulated. Because of numerical "noise", the outer boundary of the extent of drawdown should be considered as approximate. The model estimates that drawdown has occurred more than 10 miles from the pumping well, but the magnitude of the drawdown will be too low to measure over much of the area that is affected.

Figure 6.2-7 is a map of the simulated drawdown at the water table that considers pumping over the period of 1949 through December 2011. In the western part of the model, the effects of pumping in three different areas are evident. Pumping from both basin-fill and carbonate aquifers has occurred. Near the Muddy River Springs area, the model-simulated drawdown is greater than 5 feet, and greater than 10 feet near Arrow Canyon 1 and 2. There is also drawdown associated with pumping along the I-15 corridor northeast of Las Vegas. The third pumping area in the western part of the model is in Coyote Spring Valley, associated with the pumping of MX-5. The model predicts that drawdown is greater than 2 feet over most of this area. The simulated drawdown nearly reaches the western boundary of the model west-northwest of MX-5. This model does not use a head-dependent boundary condition anywhere except at Lake Mead, and thus does not simulate the increase in flow across the boundary that would occur when water levels change along the boundary. Adding a head-dependent boundary condition would likely decrease the amount of drawdown calculated by the model as water was captured from outside the model area.

A second area of pumping is in the Virgin River valley, near Mesquite. This pumping is from basin-fill sediments, and therefore the drawdown is greater and does not extend laterally as far as pumping from the carbonate aquifer in the western part of the model.

There is a third area of simulated drawdown along Meadow Valley Wash. This is a location that flow in the wash was simulated as occurring prior to any groundwater pumping, but that dried up at later time. When the wash was flowing, water was lost from the stream and recharged the groundwater. With the loss of the recharge water, water levels declined. It is not clear whether the drying of the stream was caused by pumping effects, or numerical oscillations in the model.

6.3 COMPARISON OF SIMULATED AND MEASURED SPRING DISCHARGE

Figure 6.3-1 shows the observed and simulated spring discharges in the model domain. The agreements between the simulated and observed discharges are good. The simulated discharge from Pederson Combined agrees well with the sum of the Pederson and Pederson East discharge values. There is a significant, sudden decline in the measured values for Iverson Flume. During calibration of the model, it was assumed that maintenance was performed at the gaging site and that the later measurements were more accurate.

Simulated values decline through the simulation period. Significant increases in simulated pumping do not occur in the model until 1987. Although observed spring flow in Muddy Spring does not significantly change between 1960 and 1990, simulated flows do decrease. Spring flow is highly dependent on groundwater elevations, and the simulated pumping in the Lewis wellfield prior to 1987 causes declines in groundwater elevations (approximately 5 feet at EH-4, slightly upgradient of the Muddy River Springs). These simulated spring discharge declines are relatively minor (less than 10%), and may reflect the need for more detailed evaluation of recharge variation over time, or localized detail in the geology that is not being simulated.

Rogers and Blue Point spring flow are simulated as a combined-flow single spring. Flow at the spring is caused by a combination of elevated heads in the deep Paleozoic carbonates (PC1) and local recharge in the Muddy Mountains. The combined discharge from these two springs is approximately 2.35 cfs; the simulated value was 2.25 cfs (Figure 6.3-2).

6.4 COMPARISON OF SIMULATED AND MEASURED TEMPORAL STREAMFLOWS

Figure 6.4-1 shows a comparison between the locations of the simulated perennial reaches with the observed locations. On average, the model simulates that the perennial reaches are more widespread than observed. Beaver Dam Wash is simulated as flowing all the way to its confluence with the Virgin River but only the upper part is perennial. The uppermost stretch of Meadow Valley Wash is also simulated as perennial but is ephemeral. The wash does become perennial further downstream, but has an ephemeral stretch at the approximate latitude of the upper part of Kane Springs Wash; the model simulates the wash as perennial in this location. Further to the south, the model simulates the wash as perennial for approximately 15 miles above the confluence with the Muddy River. Aerial photographs suggest that the wash may be perennial through much of this stretch.

The model simulates that Kane Springs Wash and Pahranagat Wash are ephemeral, and that the Muddy River becomes perennial a short distance upstream from where it actually becomes perennial near the Muddy River Springs. Aerial photographs show that there is an short reach of the Muddy River where groundwater discharge occurs as it cuts through the Arrow Canyon range that was not mapped as perennial, but that the Muddy River is not perennial between that discharge location and the much more significant discharge area approximately four miles downstream.

Figure 6.3-1 also shows the observed and simulated streamflow discharges for the gaging locations for the Muddy River at Moapa. Not shown is the information for the gage on the Muddy River at Overton. Uncertainty in pumping and diversion information between Glendale and Overton makes simulation results of flow for the Muddy River at Overton inaccurate, as the Overton gauge is consistently overestimated.

Simulated flow in the "Muddy River at Moapa" gage is 20,324 af/yr, around 70% of observed flow. Approximately 50% of observed flow originates in the Muddy River Springs. As noted above, the spring flow contribution is accurately represented by the model in simulation. The other 30% is believed to come from a combination of irrigation return flow, unidentified spring flow, and groundwater contributions to what is a gaining reach of the Muddy River.

Evaluation of aerial photography of the Muddy River between Arrow Canyon and a stream gage located below the confluence of the Muddy and Baldwin Springs (09415880) suggests that although groundwater is shallow in the river alluvium, indications of gains in flow as suggested by the consistent phreatophytic vegetation around the stream channel and/or visible width of stream, do not occur until approximately 1,100 feet above the gage. What appears to be a return flow ditch is visible entering the stream channel to the north of the gaging station. The source of this water may represent a significant portion of the un-simulated stream flow at the Moapa Gage.

Observed flow at the Muddy River at Glendale stream gage averages approximately 31,400 acre-feet per year. Stream flow during the pre-development simulation at the Glendale gage is simulated at 48,046 af/yr, or 153% of observed flow. This likely reflects overestimated heads along the Muddy River between the springs area and Glendale, and inflow from Meadow Valley Wash (8,325 af/yr) that is too high. Water levels simulated in Well EH-2A, located along this reach, are overestimated by approximately 90 feet at the end of the pre-development simulation. Overestimated water-level elevations in this area may indicate that a combination of higher carbonate hydraulic conductivity values in the vicinity of EH-2A, and flow restriction in the form of fault-barriers or zones of reduced conductivity between EH-2A and the Muddy River Springs may exist beyond what is currently implemented in the model as the White Narrows Fault.

Simulated flow at the Virgin River gage near Overton, Nevada (09415240) is generally within 10% of observed flow. Simulated groundwater elevation contours indicate convergent flow and a gaining reach of the Virgin River; however these influxes of water are essentially balanced by the removal of water due to evapotranspiration processes, and pumping near Mesquite, Nevada.

6.5 COMPARISON OF SIMULATED AND ESTIMATED BOUNDARY FLUXES

Information on the water balance for the overall model prior to any groundwater development is provided in Table 6-5. These results are from the transient part of the pre-production model at 10,000 years, prior to pumping of groundwater in the model.

Fixed boundary fluxes in the groundwater model include influx of water at the basin edges, estimated by retired USGS hydrologist Jim Harrill (Harrill, 2007) (Table 3-2), and seasonal estimates of evapotranspiration, based on estimates performed by the USGS. These fluxes were assumed to be known and were not varied in calibration. Other elements of boundary flux in the simulation include recharge, groundwater-surface water interaction along streams, and discharge of groundwater to Lake Mead constant head cells.

Stream fluxes and spring discharges are discussed in earlier sections. Table 6-5 provides information at the external boundaries. The volume of water leaving the model by the Muddy River is much higher than is actually occurring, because the diversions downstream of I-15 are not measured.

Applied recharge was simulated based on the approach described in the model development section of this report. Recall that the modification of the Maxey-Eakin approach employed in this model resulted in an increase in the recharge from the original Maxey-Eakin method. As a result, the recharge rates calculated by the modified Maxey-Eakin approach were reduced by 35% to be consistent with the overall water balance estimates based on more recent studies. Recharge in the Muddy Mountains was implemented at a rate of 0.5 inches per year in areas with elevations over 3000 ft.

Steady-state mass balance conditions reflect a distribution of water in the model such that approximately 50% of incoming water exits the model through streamflow, 40% exits through evapotranspiration, and the remaining 10% is divided between groundwater discharge to Lake Mead, and spring discharge including Rogers and Blue Point springs, as well as other springs placed in the areas in the Delamar Mountains to avoid simulated heads greatly above land surface. Table 6-6 provides information on where water is exiting the model into Lake Mead. The total discharge to Lake Mead is simulated to be approximately 4,500 af/yr.

Table 6-5. Mass Balance from the Pre-Development Model

Model Boundary Fluxes			
IN			
		ft^3/d	af/yr
	Model Boundary Segments	4542177	38086
	Recharge	13066496	109562
	Virgin River Inflow	7819200	65564
	Storage In	158	1
OUT			
	Lake Mead Outflow	535153	4496
	Evapotranspiration	10656596	89355
	Drains, including Rogers & Blue Point Springs	1064216	8923
	Muddy River Flow	5030900	42184
	Virgin River Flow	7115200	59661
	Diversions without Return Flow	786970	6599
	Model Boundary Segments	238240	1998
	Storage Out	822	7
TOTALS	IN		213223
	OUT		213223
	NET		-1

Table 6-6. Simulated discharge into Lake Mead

Zone	Lake Mead Inflow Zone	ft^3/d	af/yr
1	Muddy River	69363	582
2	Virgin River	169520	1421
3	East of Rogers Fault	30125	253
4	Rogers Fault to Black Mtns	67002	562
5	East of Black Mtns	5569	47
6	South of Black Mtns	152240	1277
7	Bottom of Lake	41254	346

6.6 SENSITIVITY ANALYSES

Sensitivity analyses were completed on the groundwater flow model for the pre-development and Order 1169 pumping model simulations. The objective of the sensitivity analyses was to provide an evaluation of how parameter changes impact simulated water levels, spring discharges, and drawdown resulting from pumping in Coyote Spring Valley.

A selected set of parameters were evaluated for their sensitivity to the resulting model simulation, including effects on hydraulic head distribution, drawdown, and spring flow. Parameters were selected based on observations of model responses during calibration. These parameters include five pilot points used in interpolating Kx for the PC4 thrust sheet, Kx-values for CAU in Zone 3, and Kx for the Paleozoic carbonate in the other extensive thrust sheet, PC1. They also include specific storage and specific yield for the Paleozoic Carbonate units, and for the Muddy Creek (CAU), fault conductance for the California Wash Fault fault (HFB), recharge rates, and spring conductances for the Muddy River springs. Sensitivity analysis was performed by simulating each parameter using multiples of the calibrated value of 2x and 0.5x for hydraulic-conductivity, specific storage, HFB conductance, and spring conductance parameters; 1.25x and 0.8x for recharge parameters; and 1.125x and 0.8x for specific-yield parameters.

Changes in the simulated heads and spring flow rates for the pre-development simulation were compared against pre-development observed measurements at the end of 10,000-year transient stress period implemented using non-pumping conditions. Because different factors were used for different types of parameters, sensitivities were expressed as the scaled sensitivity. The scaled sensitivity is the estimated change in the model output variable, such as water level or spring discharge, that would occur if the parameter were doubled, assuming that the model response to the change in the parameter value was constant. For the pre-production model, the output variables (water level and discharge rates) were evaluated directly. For the Order 1169 transient model, an estimate of drawdown at selected wells was developed by calculating the simulated range in heads (difference between the maximum head and minimum head). Scaled sensitivities for the range were calculated and tabulated. In addition, plots of measured and simulated drawdown were prepared for each sensitivity run. These are provided in Attachment II.

6.6.1 PRE-PRODUCTION

Table 6-7 provides the scaled sensitivities for the hydraulic heads at the indicated wells. These values are color coded so that the parameters which produce the largest changes in water level can be more readily identified. Green is used to indicate a positive scaled sensitivity (increase in water level as a result of an increase in the value of the parameter), and red indicates a negative scaled sensitivity.

The scaled sensitivities for the spring discharge rates and streamflow in the Muddy River at Moapa and at Glendale are provided in Table 6-8. These values are also color coded. Green indicates an increase in discharge or flow, and red indicates a decrease, as a result of increasing the value of the parameter.

The tables provide the scaled sensitivities calculated by increasing the parameter values (forward difference formulation). The sensitivities calculated by reducing the values were similar.

Table 6-7. Scaled sensitivities of simulated water levels to selected parameters

		Parameter														
Basin	Well	k_pc4_1	k_pc4_2	k_pc4_6	k_pc4_14	k_pc4_24	kx_cau_3	kx_pc1	sfac	sfacmm	ss_pc4	sy_pc4	sy_cau	hf_cwf_n	hf_cwf_s	MRS_cond
Clover Valley	W204	-0.009	-0.002	-0.002	0.000	0.000	-0.001	-0.270	11.831	0.000	0.000	0.000	0.000	0.000	0.000	-0.001
	W206	-0.314	-0.072	-0.195	0.000	-0.002	-0.031	-6.450	372.415	0.004	0.000	0.000	0.008	0.000	0.000	-0.013
Lower Meadow Valley Wash	LMVW-11	-3.905	-0.676	0.000	-0.077	-0.041	-5.544	-0.013	6.611	0.185	0.001	0.000	0.000	-0.004	-0.047	-2.333
	LMVW-20	-2.108	-0.493	-1.388	-0.004	-0.016	-0.206	-40.784	1132.636	0.008	0.001	0.000	0.037	0.001	-0.001	-0.085
	LMVW-42	-15.481	0.085	0.001	-0.036	-0.005	-2.735	0.008	2.752	0.091	0.000	0.000	0.000	-0.001	-0.023	-1.153
	Breedlove	-2.678	-0.470	0.000	-0.052	-0.028	-3.755	-0.014	4.650	0.126	0.001	0.000	0.000	-0.002	-0.031	-1.580
	W182	-0.440	-0.151	-0.002	-0.001	-0.004	-0.072	-0.222	5.156	0.000	0.000	0.000	0.000	0.000	-0.001	-0.030
Tule Desert	PW-1	-21.273	-4.506	-0.167	-0.029	-0.166	-1.777	-83.379	268.770	0.051	0.000	0.000	0.068	0.000	-0.012	-0.737
	FF-1	-14.668	-2.914	-0.104	-0.029	-0.111	-1.647	-40.071	219.669	0.052	0.000	-0.008	0.108	0.002	-0.012	-0.699
	W170	-22.325	-4.739	-0.174	-0.030	-0.174	-1.809	-78.963	263.708	0.047	0.000	-0.008	0.056	0.000	-0.013	-0.749
	W191	-5.343	-1.163	-0.518	-0.010	-0.042	-0.454	-108.078	1153.207	0.012	0.000	0.000	0.068	0.000	-0.003	-0.187
Kane Springs Valley	KMW-1	-19.004	-9.378	-0.004	-0.424	-0.218	-26.479	-0.131	28.764	0.888	0.002	0.000	0.004	-0.018	-0.231	-11.103
	KS-GEYSER	-36.701	-28.567	-0.152	-0.301	-0.187	-17.865	-1.273	375.756	0.598	0.002	0.000	0.136	-0.011	-0.156	-7.516
Virgin River Valley - Beaver Dam Wash	W168	-0.032	-0.005	0.000	0.000	0.000	-0.004	-1.917	6.002	0.005	0.000	0.000	0.005	0.001	0.000	-0.001
	W172	-0.268	-0.053	-0.005	-0.001	-0.002	-0.031	-0.243	29.377	0.000	0.000	0.000	0.004	0.000	-0.001	-0.013
	W175	-0.097	-0.019	-0.002	0.000	-0.001	-0.011	0.993	13.514	0.000	0.000	0.000	0.004	0.000	0.000	-0.005
	W185	-1.253	-0.253	-0.043	-0.002	-0.009	-0.124	-27.710	218.212	0.004	0.000	0.000	0.032	0.001	0.000	-0.051
	W188	-0.625	-0.127	-0.028	-0.001	-0.005	-0.061	-29.890	148.810	0.004	0.000	0.000	0.016	0.000	0.000	-0.025
	W190	-1.742	-0.358	-0.102	-0.003	-0.013	-0.164	-68.704	433.949	0.004	0.000	0.000	0.044	0.001	-0.001	-0.068
	MW-8	-8.775	-1.835	-0.157	-0.014	-0.067	-0.787	-48.617	461.081	0.024	0.001	0.010	0.137	0.001	-0.004	-0.326
Virgin River Valley	VVWD31	-0.611	-0.095	-0.005	-0.003	-0.005	-0.120	2.428	24.792	0.004	0.000	-0.008	0.016	0.000	-0.002	-0.053
	VV_OV	0.010	0.006	0.000	0.000	0.000	-0.007	0.139	0.790	0.008	0.000	0.000	0.000	0.002	0.001	-0.011
Coyote Spring Valley	CSI-2	-1.875	0.059	0.004	-0.406	-0.057	-27.517	-0.089	17.574	0.912	0.001	0.000	0.000	-0.020	-0.236	-11.550
	CSVM-1	-1.529	0.626	0.003	-0.400	-0.055	-27.541	-0.089	17.386	0.912	0.000	-0.008	-0.004	-0.020	-0.237	-11.562
	CSVM-2	0.130	1.464	0.003	-0.516	-0.054	-27.965	-0.106	17.937	1.014	0.000	0.000	0.000	-0.020	-0.267	-11.526
	CSVM-3	-24.144	-11.742	-0.009	-0.453	-0.257	-26.903	-0.116	30.877	0.904	0.002	0.000	0.008	-0.018	-0.236	-11.277
	CSI-3	-2.165	-0.567	0.003	-0.413	-0.060	-27.496	-0.090	17.750	0.912	0.000	0.000	-0.004	-0.020	-0.237	-11.539
Muddy River Springs Area	Behmer	2.193	0.936	0.002	-0.169	-0.008	-4.719	-0.045	9.000	0.503	0.000	0.000	0.000	-0.011	-0.128	-7.220
	EH-4	3.781	1.596	0.003	-0.287	-0.021	-27.191	-0.080	15.345	0.861	0.001	0.000	0.000	-0.019	-0.219	-11.767
	EH-5b	1.910	1.598	0.003	-0.330	-0.038	-27.434	-0.080	15.891	0.877	0.001	0.000	0.000	-0.019	-0.224	-11.656
	UMVM-1	0.093	1.498	0.003	-0.372	-0.046	-27.569	-0.085	16.772	0.904	0.000	-0.009	-0.004	-0.020	-0.233	-11.606
	CSV-2	1.216	1.584	0.003	-0.347	-0.039	-27.453	-0.078	16.318	0.884	0.000	-0.008	-0.004	-0.020	-0.228	-11.595
	S_CMW	1.792	0.905	0.001	-0.174	-0.014	-7.371	-0.044	8.837	0.488	0.000	0.000	0.000	-0.011	-0.126	-8.292
California Wash	MP_M1	5.068	1.881	0.003	-0.166	0.064	-30.181	-0.089	15.795	0.928	0.000	0.000	0.000	-0.023	-0.229	-11.275
	MPECP1	2.218	1.756	0.003	-0.068	-0.040	-28.899	-0.153	17.953	1.270	0.000	0.000	-0.004	-0.019	-0.321	-11.366
	MBTH1	2.202	1.764	0.003	-0.044	-0.040	-28.910	-0.158	18.068	1.305	0.001	0.000	0.000	-0.018	-0.328	-11.352
	MP-M2	1.978	1.725	0.003	-0.039	-0.046	-28.740	-0.173	18.423	1.376	0.000	0.000	0.000	-0.018	-0.361	-11.334
	MP-M3	1.820	1.696	0.003	-0.122	-0.047	-28.657	-0.159	18.423	1.301	0.001	0.000	0.000	-0.018	-0.349	-11.366
	EH-2a	4.587	1.894	0.003	-0.216	-0.145	-28.964	-0.076	16.262	0.967	0.000	-0.008	-0.004	-0.059	-0.232	-11.104
Hidden Valley	Sheep Range	-11.413	-4.799	0.004	-5.162	-0.117	-27.915	-0.154	929.021	1.152	0.003	0.025	0.053	-0.017	-0.347	-11.409
Garnet Valley	GV-1	1.452	1.668	0.003	-0.283	-0.060	-28.390	-0.188	19.819	1.442	0.000	-0.008	-0.004	-0.018	-0.467	-11.321
	CRYST1	1.894	1.715	0.003	-0.052	-0.047	-28.645	-0.176	18.551	1.395	0.001	0.000	0.000	-0.017	-0.375	-11.329
	MIRANT	1.426	1.659	0.003	-0.260	-0.059	-28.342	-0.194	19.951	1.474	0.001	-0.008	0.000	-0.017	-0.493	-11.310
Black Mountains Area	RB_S	0.194	0.035	0.001	0.200	0.030	-0.457	-0.058	0.371	1.738	0.000	0.000	0.000	0.002	0.240	-0.218
	RB_D	0.574	0.420	0.000	0.086	0.016	-0.631	-1.164	0.582	0.731	0.000	0.000	0.000	0.019	0.230	-0.369

Table 6-8. Scaled sensitivities of spring discharge rates to selected parameters.

	Parameter													
Discharge Location	k_pc4_1	k_pc4_2	k_pc4_6	k_pc4_14	k_pc4_24	kx_cau_3	kx_pc1	sfac	sfacmm	ss_pc4	sy_pc4	sy_cau	hf_cwf_n	hf_cwf_s	MRS_cond
Rogers and Blue Pt	-149571	-9113	1	-27754	-3451	33874	36845	-20926	-135868	-26	321	-260	-157	-18971	18566
Muddy River at Moapa	186600	80182	100	-13700	-1100	-827000	-3900	760859	41669	2100	1600	22800	-1000	-10800	455900
Muddy River at Glendale	-126900	-21495	700	-21800	-3300	219800	-57800	7022391	73117	3500	3200	38000	-1000	-17600	80600
Baldwin	13960	6988	10	-1240	-130	-110550	-340	66675	3695	190	160	2000	-80	-940	111490
Pederson	24516	9936	21	-1600	-109	-54379	-478	94166	5169	263	208	2780	-114	-1318	-51555
Pipeline-Jones	14660	6329	20	-1050	-80	-98137	-300	59537	3341	170	160	1800	-70	-840	54730
Plummer	23850	9068	20	-1440	-70	-143420	-430	84380	4717	240	240	2560	-100	-1200	201610
Cardy-Lamb	52660	29883	60	-5430	-600	-398594	-1440	286917	15803	810	640	8560	-350	-4050	-75490
Muddy Springs	51850	17256	40	-3010	-230	-229550	-810	164215	9081	470	400	4920	-190	-2310	251670

Water levels in the Muddy River Springs area, Coyote Spring Valley, California Wash, and Garnet Valley are very sensitive to the hydraulic conductivity of the Muddy Creek/CAU (kx_cau_3). Doubling of this hydraulic-conductivity parameter lowers simulated water levels in these areas by 5 to 10 feet (Figure 6.6-1). Because the vertical hydraulic conductivity is calculated from the horizontal hydraulic conductivity, the model sensitivity is to changes in both the horizontal and vertical conductivity parameters. Although water flows primarily through the high permeability Paleozoic carbonates to reach the springs area, its discharge to Muddy River is impeded by the presence of the CAU sediments. The CAU is several orders of magnitude less permeable than the carbonates, and acts as a hydraulic dam. Discharge to the individual springs is simulated as occurring through restricted conduits from the underlying carbonate aquifer (PC4) to the surface. Increasing the hydraulic conductivity for the CAU allows more water to discharge to the Muddy River (as indicated by the increase in discharge at the Glendale gage), lowers hydraulic heads in carbonate wells in the vicinity, and causes a discharge in the discharge of the individual springs. These effects also propagate away from the springs area to affect water levels in much of the surrounding area because of the high hydraulic conductivity of the Paleozoic carbonates.

Downgradient of the Muddy River Springs, water levels rise because of the net decrease in the discharge in the springs area, which causes an in increase in the hydraulic gradient needed to transmit the extra water to other discharge areas further downgradient.

Another parameter which has a large effect on simulated water levels is the hydraulic conductivity of the lowest carbonate thrust sheet, PC1. The greatest effect of increasing the conductivity is in the northern part of the model area, in the Clover Mountains and Tule Desert areas (Figure 6.6-2). Doubling the conductivity lowers the simulated water table by more than 100 feet in some areas. Waters levels increased in areas that were close to discharge areas (e.g., Beaver Dam Wash, Virgin River, and lower part of Meadow Valley Wash), in response to the increased flow toward these discharge points. Impacts on discharge from the springs above Moapa and flow in the Muddy River are minor. The largest volumetric effect was on the Muddy River flow at Glendale, which decreased about 1%. However, the greatest percentage change was for the combined discharge from Rogers and Blue Point Springs, which declined 308 af/yr (18%). The discharge into Lake Mead increased 376 af/yr (9.2%), slightly more than the decrease in discharge from Rogers and Blue Point Springs.

The hydraulic conductivity of the carbonate aquifer in thrust sheet 4 would also be expected to have a large impact on the model results. Because 24 pilot points were used to define its properties, the sensitivity to changes at individual pilot points was investigated rather than for the entire PC4 thrust sheet. Sensitivities to hydraulic conductivity at five pilot points were investigated. Three (2, 1, and 24) are located near a line running between central Coyote Spring Valley through the Muddy River Springs area (Figure 6.1-3). Pilot point 1 is in the area of the springs, and had the highest hydraulic conductivity value (19,486 ft/day) in the model.

Pilot point 2, in central Coyote Spring Valley, had the second highest (4,560 ft/day). Of the five pilot points investigated, the model was most sensitive to changes at pilot point 1. The greatest changes in head occurred in northern Coyote Spring Valley, Kane Springs Wash, and in the Tule Desert. Doubling the hydraulic conductivity value caused simulated heads to decline by more than 50 feet in some areas (Figure 6.6-3). However, in the Muddy River Springs area, simulated water levels increased by nearly 4 feet. Water levels in the downgradient part of the PC4 thrust sheet generally increased, and on the west side of the Glendale Thrust they increased by more than 20 feet. Smaller increases occurred beneath California Wash and further to the south and west. The discharge from the springs in the Muddy River Springs area increased. These responses indicate that increasing the hydraulic conductivity of the carbonates in PC4 near PP1 causes an increase in the volume of water captured by the carbonate aquifer from areas to the north. While the flow in the Muddy River at Moapa increased by 8%, the flow in the Muddy River at Glendale decreased by 2%. The discharge from the combined Rogers and Blue Point Springs increased.

Changes in the values of hydraulic conductivity at pilot point 24 had little effect on the water levels or flows. Changing the hydraulic conductivity at pilot point 6 (k_pc4_6), in the northernmost part of Coyote Spring Valley, also had very little effect on the model results. Neither did changing values at pilot point 14 (k_pc4_14), on the boundary of Garden and Hidden Valleys. Doubling the conductivity at pilot point 14 lowered simulated water levels in the Muddy River Springs area a few tenths of a foot, and therefore decreased streamflow a small amount. Because the PC4 thrust sheet extends to the Rogers and Blue Point Springs area, doubling k_pc4_14 increased the simulated discharge from these springs by 29 af/yr (14%), by diverting flow from central Coyote Spring Valley into the southern part of the valley.

The parameter with the greatest impact on water levels and discharge in the model is the recharge. In the model, the recharge has two parameters. The most important is a multiplier (Rech_sfac) for the recharge array, which was used to adjust the recharge over the entire model domain. The second parameter (sfacmm) is a value that was added to the recharge array in the area of the Muddy Mountains. Sensitivity testing was performed by increasing these by a factor of 1.25, and decreasing these by a factor of 0.8. Results were similar. Figure 6.6-4 shows the change in simulated water levels from increasing the value of Rech_sfac by 25%. The greatest increases in water levels are in the upland areas, as these are the areas with the greatest recharge and that are also distant from the areas where groundwater discharge occurs (springs, perennial reaches of streams, and Lake Mead). In the sensitivity simulation in which the regional recharge was increased by 25%, the simulated overall recharge increased by nearly 27,000 af/yr. The increase in discharge from all the springs was 3,337 af/yr, of which the combined Rogers and Blue Point Springs discharge accounted for only 44 af/yr. The discharge into Lake Mead was only 11 af/yr higher than in the base-case (calibrated model) simulation. The flow at the Muddy River near Moapa gage increased by 1,600 af/yr. On the other hand, the simulated flow in the Muddy River at the Glendale gage (which is below the confluence of the Muddy River and

Meadow Valley Wash) increased by 14,766 af/yr. The remaining 8,865 af/yr discharged into Beaver Dam Wash, the Virgin River, and the lower part of the Muddy River. Thus, approximately 88% of the increased recharge was through discharge into the streams [this percentage includes discharge from the springs in the Muddy River Springs area, which was simulated using the Stream Routing Package.]

The recharge added to the Muddy Mountains (2,011 af/yr) is a small component of the total recharge in the model (109,560 af/yr). Doubling this recharge is predicted to increase the water levels in California Wash nearly 1.5 ft, and approximately 1.7 feet at the Rogers and Blue Point Springs. In the sensitivity simulation, the recharge was increased by 503 af/yr. Simulated discharge from the combined Rogers and Blue Point Springs increased by 290 af/yr, approximately 2/3 of the increased recharge. Groundwater flow from other springs increased by about 7 af/y. The simulated discharge from the groundwater system into Lake Mead was 18 af/yr. Thus, not all of the increased recharge discharged near the Muddy Mountains. Figure 6.3-1 showed that some of the recharge on the Muddy Mountains flows to the northwest. The increase in water levels simulated to occur in California Wash causes discharge to increase in upstream areas as well. The discharge above the Muddy River near Glendale gage increased by 156 af/yr.

Groundwater flow discharge at Rogers and Blue Point springs is simulated as a combination of local recharge and distant-sourced waters. Flow occurs primarily through the California Wash Fault at depth where the fault barrier properties are less influential, eventually exiting through the springs at the Rogers Fault. Spring discharge is most sensitive to the conductance of the pilot point 1 for the PC4, and the recharge applied at the Muddy Mountains. Increasing the values of these parameters increases the simulated discharge at Rogers and Blue Point Springs. Increasing the hydraulic conductivity for zone 3 of the CAU and for the PC1 decreases the simulated discharge.

Water levels had little sensitivity to the values used for the conductances of the California Wash fault. The simulated discharges to the Muddy River at Glendale and at Moapa, and from Rogers and Blue Point springs were slightly sensitive to the value assigned to the southern part of the California Wash fault HFB. However, other parameters were much more important in determining these discharge rates.

A sensitivity evaluation was done in which the conductances for the springs in the Muddy River Springs area were changed, by factors of 2 and 0.5. When the conductances are increased, the simulated discharges for most springs increase, as do the simulated flows in the Muddy River near Moapa and Glendale. However, the discharges at Pederson and Cardy-Lamb springs declined. These springs have higher elevations than the others, and the decline in heads in the groundwater system that is also caused by increasing the conductances causes a decrease in the head difference (water level – spring elevation) that is proportionally greater than the increase in conductance. When the conductances were decreased by a factor of 0.5, the spring discharge declined at all springs except Pederson, where it increased. At Pederson, the increase in water levels had a larger effect than the decrease in conductance, but at the lower elevation springs (including Cardy-Lamb) the decrease in conductance had a larger effect.

6.6.2 ORDER 1169 MODEL

Sensitivity analyses were also performed using the transient Order 1169 model to evaluate the effects of changing selected model parameters on drawdown calculations for wells in the vicinity of Coyote Spring Valley and the Muddy River Springs area. The sensitivities were determined for the same parameters as used for the pre-production model sensitivity analyses, with the exception that the spring-conductance parameters were not evaluated. The starting heads for each of the Order 1169 model simulations were obtained from the pre-production model results at the end of 2008, for the same parameter data set as used for the Order 1169 simulation. The effects on the simulated drawdowns were evaluated, in two different ways. As discussed above, the range of drawdowns at each of the wells was determined, and the sensitivity of the range to the changes in the model parameter was calculated. Table 6-9 gives the calculated scaled sensitivities to the parameters that were investigated. The values are estimates of the change in the range of drawdown for doubling of the parameter.

Results are also presented in a set of drawdown plots for each of the investigated parameters (Attachment II). The figures are similar in format to the figure that presented the results of the calibrated model. Drawdown values (using the scale on the left) are provided in feet. For each well, the calibrated, or base-case, model results are presented as a purple line. The results for the sensitivity simulation are shown as blue dots. Measured values are shown by a red line. For wells which were pumped during this time period, the pumping rate is provided by a green line, using the scale provided to the right (in cubic feet per day).

In the vicinity of the major pumping in Coyote Spring Valley (from MX-5), the simulated drawdown is most sensitive to the values for hydraulic conductivity at pilot points 1 and 2 (k_pc4_1 and k_pc4_2), and the specific yield of the CAU (sy_cau). Pilot point 1 is located in the Muddy River Springs area, and pilot point 2 is near MX-5. Increasing any of these values decreases the simulated drawdown in the observation wells close to the pumping well. The effects of changing k_pc4_1 and k_pc4_2 are observable not only in Coyote Spring Valley, but also in the Muddy River Springs area. As would be expected, pilot point 2 has a larger effect on drawdown at MX-4 and MX-5 than pilot point 1 does. Drawdown in other wells (e.g., CSI-1, CSI-2, CSV-RW1, and CSVM-1) close to MX-5 also decreases when the hydraulic conductivity at pilot points 1 and 2 are increased. In contrast, the drawdown at wells further away (e.g., Moapa Band of Paiutes' M-1, M-3, ECP1, and TH-2; CSVM-2, -3, -4; and CSV-3) increases when the hydraulic conductivity at these pilots points in increased. Larger hydraulic conductivities allow the drawdown to extend further.

Table 6-9. Scaled sensitivity of total range of water levels for selected parameters, Order 1169 simulation.

	Parameter													
Well	k_pc4_1	k_pc4_2	k_pc4_6	k_pc4_14	k_pc4_24	kx_cau_3	kx_pc1	sfac	sfacmm	ss_pc4	sy_pc4	sy_cau	hf_cwf_n	hf_cwf_s
eh-3	4.27E-03	-1.34E-03	-1.22E-04	-1.22E-04	0.00E+00	2.81E-03	-6.10E-04	1.02E-02	4.80E-04	1.10E-03	-1.86E-09	-5.86E-03	1.22E-04	1.22E-04
eh-4	-0.1363527	-2.98E-02	-1.22E-04	-4.52E-03	-1.83E-03	0.1732173	-1.19E-07	-2.43E-02	-2.40E-03	-3.82E-02	-4.20E-02	-0.431641	0.00E+00	4.88E-04
eh-5b	-0.286377	-3.54E-02	0.00E+00	-3.05E-03	-1.34E-03	0.12316883	4.88E-04	-6.28E-02	-4.32E-03	-3.82E-02	-4.79E-02	-0.4296905	2.44E-04	1.34E-03
eh-7	2.44E-04	3.66E-04	1.22E-04	1.22E-04	1.22E-04	-1.71E-03	1.22E-04	1.95E-03	9.60E-04	0.00E+00	0.00E+00	-4.35E-02	1.22E-04	0.00E+00
mbp_m-1	2.48E-02	-1.04E-02	0.00E+00	-1.10E-03	1.46E-03	-1.46E-02	0.00E+00	-5.35E-03	-9.60E-04	-2.99E-02	-3.12E-02	-0.3168948	0.00E+00	3.66E-04
mbp_m-3	5.00E-02	7.32E-03	-1.22E-04	1.79E-02	7.32E-04	-5.58E-02	-1.22E-04	1.56E-02	4.80E-04	-2.00E-02	-1.76E-02	-0.1914062	0.00E+00	-2.44E-04
mbp_ecp1	4.37E-02	5.86E-03	-1.22E-04	1.01E-02	7.32E-04	-4.87E-02	-1.22E-04	1.36E-02	4.80E-04	-1.54E-02	-1.37E-02	-0.1484375	2.98E-08	-2.44E-04
csi-2	-0.1472173	-0.1614636	-1.22E-04	-3.66E-03	-1.22E-03	-3.91E-03	0.00E+00	4.86E-04	-4.79E-04	-3.20E-02	-3.42E-02	-0.437501	1.19E-07	1.22E-04
csv-rw2	-0.306152	-0.4547344	0.00E+00	-4.52E-03	-2.20E-03	-1.73E-02	0.00E+00	3.41E-03	-4.79E-04	-3.80E-02	-4.00E-02	-0.5146486	0.00E+00	1.22E-04
csvm-1	-0.2387695	-0.2933926	-1.19E-07	-4.40E-03	-1.71E-03	-1.46E-02	1.22E-04	2.92E-03	0.00E+00	-3.81E-02	-4.10E-02	-0.5136701	1.22E-04	2.44E-04
csvm-2	4.91E-02	2.29E-02	1.22E-04	1.10E-03	2.44E-04	-3.85E-02	0.00E+00	1.22E-02	9.60E-04	-2.80E-02	-4.30E-02	-0.3129883	1.22E-04	0.00E+00
csvm-3	6.96E-03	3.91E-03	0.00E+00	-7.32E-04	-1.22E-04	-3.31E-02	-1.22E-04	1.07E-02	4.80E-04	-1.59E-03	-1.95E-03	-2.49E-02	-1.22E-04	-2.44E-04
csvm-4	3.15E-02	2.60E-02	2.98E-08	-1.46E-03	2.44E-04	-5.10E-02	-1.22E-04	1.85E-02	9.60E-04	-1.75E-02	-1.46E-02	-0.1552735	0.00E+00	-2.44E-04
csvm-5	-2.39E-02	4.74E-02	-1.22E-04	-9.77E-04	-4.88E-04	-3.75E-02	-2.44E-04	1.12E-02	0.00E+00	-3.37E-02	-4.39E-02	-0.4238285	-1.22E-04	-1.22E-04
csvm-6	-9.84E-02	-6.21E-02	0.00E+00	-3.54E-03	-1.10E-03	-2.25E-02	0.00E+00	5.84E-03	-4.80E-04	-3.50E-02	-3.52E-02	-0.4843765	0.00E+00	-1.22E-04
csvm-7	6.96E-03	4.15E-03	-1.22E-04	-6.10E-04	0.00E+00	-3.33E-02	-1.22E-04	1.12E-02	9.60E-04	-1.59E-03	-1.95E-03	-2.49E-02	-1.22E-04	-2.44E-04
umvm-1	-9.67E-02	-4.81E-02	0.00E+00	-4.15E-03	-1.10E-03	1.72E-02	1.22E-04	-9.73E-03	-9.59E-04	-3.98E-02	-4.30E-02	-0.4663092	1.22E-04	3.66E-04
csi-3	-0.1854247	-0.4106764	0.00E+00	-1.95E-03	-1.83E-03	-2.81E-03	0.00E+00	9.72E-04	0.00E+00	-1.66E-02	-1.56E-02	-0.337401	-1.22E-04	-1.22E-04
kmw-1	2.60E-02	1.62E-02	1.22E-04	-9.77E-04	2.44E-04	-4.58E-02	1.22E-04	1.70E-02	1.44E-03	-1.07E-02	-7.81E-03	-9.08E-02	0.00E+00	-1.22E-04
a_cn	-0.3278813	-3.43E-02	-1.22E-04	-3.66E-03	-1.22E-03	9.77E-02	2.44E-04	-3.21E-02	-3.36E-03	-3.85E-02	-4.79E-02	-0.4077168	0.00E+00	7.32E-04
a_cn_2	-0.2901617	-3.39E-02	-1.22E-04	-3.66E-03	-1.34E-03	9.44E-02	2.44E-04	-2.87E-02	-2.88E-03	-3.83E-02	-4.79E-02	-0.4038111	-1.19E-07	6.10E-04
c_l	-0.1773686	-7.55E-02	-1.22E-04	1.29E-02	7.32E-04	-0.2585444	3.78E-03	-0.4059792	-3.98E-02	-2.22E-02	-2.44E-02	-0.7641622	8.54E-04	1.11E-02
cry_mw1	-7.31E-02	-2.79E-02	-1.22E-04	0.00E+00	0.00E+00	-0.502686	1.22E-04	-0.2424181	-6.24E-03	-5.74E-03	-7.82E-03	-0.5219728	0.00E+00	2.44E-04
cox-mw1	-1.51E-02	-6.10E-03	-1.22E-04	6.10E-04	0.00E+00	-7.75E-02	1.22E-04	-2.97E-02	-1.92E-03	-3.30E-03	-3.91E-03	-0.6591817	1.22E-04	3.67E-04
csi-1	-0.1384282	-0.1556059	0.00E+00	-4.15E-03	-1.46E-03	-2.16E-02	-1.22E-04	5.36E-03	0.00E+00	-3.59E-02	-3.71E-02	-0.4946285	-1.22E-04	0.00E+00
csi-4	-0.1126713	-0.1199692	-1.22E-04	-2.56E-03	-1.59E-03	-3.30E-02	-1.22E-04	1.07E-02	4.80E-04	-2.92E-02	-2.54E-02	-0.4594739	1.19E-07	-1.22E-04
csv3011m	1.90E-02	1.68E-02	0.00E+00	-1.10E-03	1.22E-04	-3.81E-02	-1.22E-04	1.31E-02	9.60E-04	-1.14E-02	-5.86E-03	-8.20E-02	0.00E+00	-2.44E-04
mx-6	-8.85E-02	-3.41E-02	-1.22E-04	-3.30E-03	-9.77E-04	3.91E-02	1.22E-04	-1.17E-02	-1.92E-03	-3.70E-02	-4.79E-02	-0.4008785	0.00E+00	3.66E-04
coburn	-0.3177495	-0.1750109	-4.89E-04	3.50E-02	3.42E-03	-1.0389409	9.40E-03	-1.1750968	-0.1050918	-1.76E-02	-1.95E-02	-0.7153341	2.20E-03	2.69E-02
mbpth-2	5.87E-02	5.37E-03	5.96E-08	7.81E-03	9.77E-04	-4.41E-02	5.96E-08	1.07E-02	4.80E-04	-2.10E-02	-2.05E-02	-0.2182618	5.96E-08	5.96E-08
csv-3	3.06E-02	2.78E-02	0.00E+00	-7.32E-04	-1.22E-04	-3.13E-02	-1.22E-04	9.25E-03	4.80E-04	-3.25E-02	-4.69E-02	-0.359375	0.00E+00	-1.22E-04
bw-01	-6.24E-02	-2.09E-02	-1.22E-04	-3.05E-03	-9.77E-04	4.90E-02	5.96E-08	-1.46E-02	-1.44E-03	-3.12E-02	-3.71E-02	-0.3139644	5.96E-08	3.66E-04
csv-1	-0.1159667	-8.18E-02	0.00E+00	-4.15E-03	-1.10E-03	-1.95E-03	1.22E-04	-9.74E-04	-4.80E-04	-3.87E-02	-4.30E-02	-0.5019523	1.22E-04	2.44E-04
csv-2	-0.1051024	-3.42E-02	-1.22E-04	-3.78E-03	-1.22E-03	4.66E-02	1.22E-04	-2.00E-02	-2.40E-03	-4.10E-02	-4.39E-02	-0.4394527	0.00E+00	6.10E-04
mx-5	-0.4815664	-0.7833966	0.00E+00	-4.27E-03	-3.17E-03	-1.28E-02	-1.22E-04	2.92E-03	-4.80E-04	-3.72E-02	-3.91E-02	-0.5126916	0.00E+00	1.22E-04
mx-4	-0.5434577	-0.9106897	-1.23E-04	-4.39E-03	-3.54E-03	-1.70E-02	-1.23E-04	3.41E-03	-4.84E-04	-3.77E-02	-4.00E-02	-0.5141603	0.00E+00	-9.54E-07
df-1	-9.83E-02	-6.53E-02	0.00E+00	-3.54E-03	-9.76E-04	-2.60E-02	0.00E+00	7.30E-03	0.00E+00	-3.54E-02	-3.52E-02	-0.4794911	0.00E+00	0.00E+00
ce-vf-2	-4.87E-02	-4.39E-03	0.00E+00	-2.56E-03	-6.10E-04	-3.83E-02	-1.22E-04	1.17E-02	0.00E+00	-3.09E-02	-2.64E-02	-0.4291991	-1.22E-04	-2.44E-04
ce-vf-1	-4.54E-02	-9.76E-04	0.00E+00	-2.56E-03	-6.10E-04	-3.88E-02	-1.22E-04	1.22E-02	4.80E-04	-3.05E-02	-2.54E-02	-0.4267581	-1.22E-04	-1.22E-04

The value of the specific yield of the CAU affects the drawdown over a large area (Muddy River Springs area, Coyote Spring Valley, and California Wash). Increasing this value decreases the drawdown in all of the wells evaluated. The greatest effects are in the Muddy River Springs area, but the effects are only slightly less in Coyote Spring Valley. The sensitivity of the calculated drawdown to this parameter are about two orders of magnitude higher than the sensitivity of the model to the specific yield of the PC4 HGU. This is likely because of the limited area where the PC4 is present at the water table compared to the CAU.

Drawdowns are less sensitive to the value of the hydraulic conductivity of zone 3 of the CAU (kx_cau_3) than to the parameters discussed above. The drawdown in the Coburn well (near the Arrow Canyon wells and completed only in Layer 1) decreases when kx_cau_3 is increased. This is likely because the drawdown caused by changes in seasonal ET rates and shallow pumping is less when the hydraulic conductivity is higher. In contrast, the simulated drawdown in wells completed in the underlying carbonate increases, as the drawdown caused by the seasonal stresses are transmitted downward more.

Examination of the drawdown figures reveals that, with the exception of the parameters discussed above, there is little noticeable of changing the model parameters evaluated on the simulated drawdown. Thus, the Order 1169 pumping provides information for the estimation of the PC4 near the pumped well and in the Muddy River Springs area and of the specific yield of the CAU, but limited information on other parameters.

7.0 SUMMARY AND CONCLUSIONS

A new three-dimensional model has been completed of all or parts of 13 hydrographic areas within the Colorado Regional Groundwater Flow System in SE Nevada. This model simulates the movement of groundwater in an area ranging from the Clover and Delaware Mountains on the north to the Las Vegas Valley Shear Zone and Lake Mead on the south, and from the Sheep Range on the west to the Virgin and Beaver Dam Mountains on the east.

Development of this new model was based, in part, on studies funded by federal bureaus: (1) geophysical studies, geologic mapping, and new geologic cross-sections; (2) synoptic discharge-measurement runs on the Muddy and Virgin rivers; (3) an ET study over the whole model area; (4) boundary flux estimates developed by Jim Harrill (retired USGS hydrologist);; and (5) preliminary hydrogeochemical investigations. Other information, such as lithologic information from new drillholes and recent water-level and water-use data, has been provided by other (non-federal) parties and organizations with interest in the groundwater resources of the study area. All of this new information has been quite useful in development of this simulation tool.

Initial development of this model was funded by the National Park Service and the U.S. Fish & Wildlife Service intermittently from 2000 – 2005. The model was completed with funding through the Southern Nevada Public Lands Management Act (SNPLMA) Conservation Initiatives Program, as part of a project on behalf of the National Park Service, the U.S. Fish & Wildlife Service, and the Bureau of Land Management (collectively, the DOI bureaus).

The impetus for the DOI bureaus to develop this model is to have a tool with which to make quantitative estimates of the future impacts on springs and streams throughout the model area as a result of ongoing pumping of existing groundwater rights and additional groundwater applications currently pending before the Nevada State Engineer. The DOI bureaus are interested in the potential adverse effects to springs and streams on federal lands for which they have responsibility.

The model is based on a new geologic framework model which was developed as part of this modeling effort. It incorporates information from surface mapping, lithologic information from drillholes, geophysical investigations, and interpretative cross sections and structural contour maps. Twenty-seven Hydrogeologic Units (HGUs) were used to describe the different lithologic units and the complications caused by the tectonic history of the area.

MODFLOW-2000 was used for the groundwater model. The HUF package, which was developed to allow areas of complicated geology to be simulated by MODFLOW, was used in this model, allowing hydrologic properties to be assigned to each HGU. Other packages which were instrumental in the development of the model include the MNW (which allowed pumping to be allocated to different model layers using information on the geology and hydrologic properties) and SFR2 packages. The SFR2 package allowed streamflow data to be used in the calibration process, and for the model to predict changes in streamflow that might occur as a result of pumping of the groundwater. Calibration was performed using a combination of regression (using PEST) and manual approaches.

The model has 18 layers, representing different depths below the water table. The uppermost layer is 100 feet thick, and the thickness of the layers increases with depth. The total model is 15,630 feet thick. The grid has 314 rows and 209 columns, and the model cells range in length from 1,500 meters (4921 feet) down to 250 meters (820 feet). The grid is oriented north-south, east-west. The grid spacing is finest (250 meters) in the Muddy River Springs Area, Coyote Spring Valley, and California Wash to take advantage of the greater number of drillholes, and better information on pumping rates, groundwater discharge, and water-level changes in these areas.

The model was calibrated based on many different types of information, including measurements of water levels and drawdown, discharge rates for springs, streamflow measurements, reported pumping rates that varied through time, seasonal estimates of ET based on field measurements and satellite mapping of plant communities, and estimates of model boundary fluxes based on regional information. A "pre-production" model was developed to match water levels and water-budget information. Simulated water levels agree well with observed water levels. The correlation between measured and simulated water levels was 0.96. The largest model residuals are in high gradient areas, where model errors can result in large differences, in the Clover Mountains where the volcanic stratigraphy is greatly simplified, and in the Tule Desert where some of the structural complexity may not be incorporated in the geologic model and the model grid is relatively coarse.

The model was also calibrated to the effects of time-varying pumping and seasonal ET during the period October 2008 through December 2011, primarily in the area of the Muddy River Springs, Coyote Spring Valley, and California Wash. The simulated drawdowns agree reasonably well with the observed drawdowns. In California Wash, the seasonal variation observed in the measurements is not present in the simulated water levels but the longer term trends are present.

The simulated discharge rates in the Muddy River Springs area and at Rogers and Blue Point springs agree very well with measured values. The simulated streamflow in the Muddy River near Moapa is less than measured, indicating that more water discharges directly into the stream above the gage than is being simulated, rather than downstream of the gage. In the lower part of Meadow Valley Wash, simulated water levels are higher than observed, causing simulated discharge into the stream over a larger area than it occurs. Similarly, simulated water levels are higher than measured in the lower parts of Beaver Dam Wash, causing simulated flow in the stream over a larger reach than observed. In these areas, the model is likely to underestimate the drawdown that occurs because of the larger area in which buffering of drawdown is simulated to occur. The effects of the drawdown on the Muddy River Springs and discharge into the Muddy River may occur sooner than would be predicted by the model because of the simulated capture in lower reaches of the Muddy River and in the lowermost reaches of Meadow Valley Wash.

Pertinent observations and comments about the model are provided so that the user of the model is aware of limitations that may affect decisions made related to modeling predictions:

1. The responses of the groundwater system to pumping are determined primarily by the local geology and the hydrologic properties of the aquifers being pumped. Pumping in the carbonate aquifer in the western part of the model produces widespread drawdown because of the high transmissivity and low storativity of the carbonate aquifer. The model predicts that pumping in the Virgin River basin causes more local (less widespread) drawdown of greater magnitude. Elsewhere, current groundwater development is more limited. In the volcanic rocks in the Clover and Delaware Mountains, the complex stratigraphy of the volcanic rocks will likely limit the extent of drawdown, and the productivity of the rocks will likely be highly variable. The complex stratigraphy is not incorporated in the model. The drawdown is reduced by proximity to large-volume springs, and to perennial reaches of streams. This local effect is caused by the buffering of drawdown caused by capture of water at these locations by pumping.
2. Groundwater production from the Virgin Valley is primarily from the Muddy Creek (CAU HGU). This HGU is treated as homogeneous and isotropic both laterally and vertically in this area. Water levels in the Virgin River Valley are primarily determined in the model by the elevation of the Virgin River, and not by the geology or by the hydraulic conductivities used in the model. In addition, detailed pumping information and responses to pumping were not available. Therefore, a transient model calibration has not been completed in this area, and predictions of the effects of pumping should be used with caution.
3. Cross sections developed in the Tule Desert by consultants for Vidler Water Company were not used in the construction of the geologic model. There are differences between the interpretations presented in these cross sections and other cross sections developed by Page and others (2011). Given the scale of the modeling and the use of the sections by Page and others in the remainder of the model, some of the information contained in the sections developed by Vidler Water Company was not incorporated. In future work, evaluation and incorporation of some of the more detailed information might improve the model in the Tule Desert.
4. The use of the Well Package to simulate ET (so that seasonal changes in ET rates could be used as a driving function during model calibration) may cause head changes to be exaggerated during the long-term predictions of pumping in areas where ET rates are high

and where drawdown from pumping occurs. In nature, as the water table declines, the ET decreases and the decrease in ET decreases the drawdown. However, in the simulation the rate of ET will remain constant and produce a greater drawdown. This effect has only been observed in a small reach of Meadow Valley Wash, where it appears that drawdown could be oversimulated by tens of feet over a small area. Effects in other areas do not appear to be significant, but are unknown.

Prediction of the effects of groundwater pumping will be more reliable in areas where data are available on the responses to pumping and time-varying ET. The best dataset is from the vicinity of the Muddy River Springs and nearby areas (Coyote Spring Valley and California Wash). Thus, predictions for these areas will be most reliable. An evaluation of the uncertainty in model predictions would be a significant effort, and certainly was outside the scope of this current evaluation. An estimate (based on experience with this model and the sensitivity testing that was performed) of the prediction uncertainty for drawdown in these areas would be in the range of 20 to 30 percent over a period of 20 to 30 years. With increasing distance from the area of the Muddy River Springs, the uncertainty increases. In other areas where pumping is occurring (Garnet Valley and the Virgin River Valley), the simulated drawdowns are reasonable, but cannot be compared with measured drawdowns. Thus, the there is more uncertainty of the model results to pumping in these areas. There are aquifer-testing data available in the Tule Desert, but no long-term pumping has yet occurred, and thus there is no information on long-term productivity or on response to pumping in areas distant from wells. Thus, there is substantial uncertainty on the magnitude and timing of drawdown in the Tule Desert. The most uncertainty is in the Clover and Delaware Mountains. The drawdown that will occur will be very dependent on local conditions and rock properties because of the complex volcanic stratigraphy, which has been generalized.

In summary, this model is a great improvement over previous models of the area, because of the advances in information on the geology and hydrology of the study area, and improvements in modeling codes available. This is also the first model to include the Virgin River Valley and Tule Desert, the lower White River Flow System, and the area of Lower Meadow Valley Wash. It can be used to evaluate cumulative effects of pumping in different areas within the model, and to estimate the magnitude and timing of changes that will occur as a result of use of the groundwater. Predictions made using the model will be approximate, but can be used to guide decisions about management of the groundwater resource and to determine whether there will be impacts on sensitive environments and on other users of the water. The uncertainty in the predictions will primarily affect the timing of when impacts become significant, not whether there will be impacts.

8.0 REFERENCES

Anderman, E.R., and Hill, M.C., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model – Documentation of the Hydrogeologic-Unit Flow (HUF) Package: U.S. Geological Survey Open-File Report 00-342, 89 p.

Anderman, E.R., and Hill, M.C., 2003, MODFLOW-2000, the U.S. Geological Survey modular ground-water model – Three additions to the Hydrogeologic-Unit Flow (HUF) Package: Alternative storage for the uppermost active cells, Flows in hydrogeologic units, and the Hydraulic-conductivity depth-dependence (KDEP) capability: U.S. Geological Survey Open-File Report 03-347, 36 p.

Belcher W.R., Elliott, P.E., and A.L. Geldon, 2001, Hydraulic-Property Estimates for use with Transient Ground-Water Flow Model of the Death Valley Regional Ground-Water Flow System, Nevada and California, U.S. Geological Survey, Water Resources Investigation 01-4120, 28p.

Belcher, W.R., ed., 2004, Death Valley regional ground-water flow system, Nevada and California—Hydrogeologic framework and transient ground-water flow model: U.S. Geological Survey Scientific Investigations Report 2004-5205, 408 p.

Berger, D.L., Kilroy, K.C., Schaefer, D.H., 1988, Geophysical logs and hydrologic data for eight wells in the Coyote Spring Valley area, Clark and Lincoln Counties, Nevada, U.S. Geological Survey, Open-File Report 87-679, 59 p.

Beck, D.A., Wilson, J.W., 2005, "Discharge and Physical-Property Measurements from Virgin River Narrows, Arizona, to Lake Mead, Nevada, February 12, 2003" U.S. Geological Survey, Scientific Investigations Report 2005-5286

Beck, D.A., Wilson, J.W., 2006, "Synoptic Discharge, Water-Property and pH Measurements for Muddy River Springs Area and Muddy River, Nevada, February 7, 2001" U.S. Geological Survey, Scientific Investigations Report 2006-5237

Black, K.R. and S.J. Rascona, 1991, Maps Showing Groundwater Conditions in the Virgin River Basin, Mohave County, Arizona, Lincoln and Clark Counties, Nevada – 1991, Department of Water Resources, Hydrologic Map Series Report Number 22.

Burbey, T.J., Warner, S.M., Blewitt, Geoff, Bell, J.W., and Hill, Emma, 2005, Three-dimensional Deformation and Strain Induced by Municipal Pumping, Part 1: Analysis of Field Data: Journal of Hydrology, v. 319, p. 123-142

Bureau of Land Management (BLM), 2009, Final Environmental Impact Statement, Lincoln County Land Act Groundwater Development and Utility Right of Way Project, FES 09-05, May 2009.

Brothers, K., Katzer, T., Mojib, R.M., Grinnell, G., Bernholtz, A., and M. Johnson, 1993, Addendum to Hydrology and Interactive Computer Modeling of Ground and Surface Water in the Lower Virgin River Valley, Primarily in Clark County, Nevada, Las Vegas Valley Water District, 35pp.

Bunch and Harrill, 1984, Compilation of Selected Hydrologic Data from the MX Missile-Siting Investigation, East-Central Nevada and Western Utah, U.S. Geological Survey, Open-File Report 84-702, 123 pp.

Buqo, T.S., Drici, Q., and Goings, D.B., 1992, Hydrology and steady-state ground-water model of Coyote Spring Valley, Clark and Lincoln Counties, Nevada: Las Vegas Valley Water District,

Cooperative Water Project, Report No. 3, 84 p.

Buqo, T.S., 2000, Preliminary Hydrogeologic and Water Supply Assessment, Lewis Farm Area, Lower Meadow Valley Wash Hydrographic Basin (Basin 205), Prepared for Moapa Valley Water District, 20 p.

Buqo, T.S., 2002, Preliminary Results of Testing of the Arrow Canyon #2 Well, Prepared for Moapa Valley Water District, July 2002.

Buqo, T.S., 1994, Results of Long-Term Testing of the Arrow Canyon Well, Prepared for Moapa Valley Water District, June 1994.

Converse Consultants, 2000, Groundwater level monitoring program 1999 annual report Moapa, Nevada, Prepared for Nevada Power Company, 14 p.

Converse Consultants, 2001, Groundwater level monitoring program 2000 annual report Moapa, Nevada, Prepared for Nevada Power Company, 24 p.

Converse Consultants, 2002, Production Well Construction and Testing, RW-2 Well, Coyote Spring Valley, Clark County, Nevada, Prepared for Nevada Power Company, June 2002.

Converse Consultants, 2004, Groundwater level monitoring program 2003 annual report Moapa, Nevada, Prepared for Nevada Power Company, 26 p.

Converse Consultants, 2005, Groundwater level monitoring program 2004 annual report Moapa, Nevada, Prepared for Nevada Power Company, 27 p.

DeMeo, G.A., Smith, J.L., Damar, N.A., and J. Darnell, 2008, Quantifying Ground-Water and Surface-Water Discharge from Evapotranspiration Processes in 12 Hydrographic Areas of the Colorado Regional Ground-Water Flow System, Nevada, Utah, and Arizona, U.S. Geologic Survey, Scientific Investigations Report 2008-5116, 23 p.

Dettinger, M.D., Harrill, J.R., Schmidt, D.L., and Hess, J.W., 1995, Distribution of carbonate-rock aquifers and the potential for their development, southern Nevada and adjacent parts of California, Arizona, and Utah: U.S. Geological Survey Water-Resources Investigations Report 91-4146, 100 p. and 2 plates.

Dixon, G.L, and Katzer, Terry, 2002, Geology and Hydrology of the Lower Virgin River Valley in Nevada, Arizona, and Utah: Report VVWD-01, 113 p. + appendices and plates.

Doherty, J., 2003, Ground Water Model Calibration Using Pilot Pints and Regularization: Ground Water, v. 41, no. 2, p. 170-177.

Doherty, J. 2010, PEST: Model-Independent Parameter Estimation, version 12, Watermark Numerical Computing.

Eakin, T.E., 1964, Ground-water appraisal of Coyote Spring and Kane Spring Valleys and Muddy River Springs area, Lincoln and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources Reconnaissance Series, Report 25, 40 p.

Enright, M., Selected Hydrologic Data for the Beaver Dam Wash Area, Washington County, Utah, Lincoln County, Nevada, and Mohave County, Arizona, 1991-1995, U.S. Geological Survey, Open-File Report 96-493, 36p., 1 pl.

ESRI 2011, ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Harrill, J.R., 2007, Evaluation of boundary fluxes for the ground-water flow model being prepared as part of the SNPLMA-5 project: unpublished consultant report, December 2007, 17 p.

Hess, J.W., 1986, Summary of Deep Drilling Activities at NPC Reid Gardner Facility, Clark County, Nevada, October, 1985 – May, 1986, 26 p.

Hydrosystems, 2002, Tule Desert Field Activity and Data Report, Prepared for Lincoln County, Nevada and Vidler Water Company, April 26, 2002.

IT Corporation, 1996, Underground test area subproject, Phase I data analysis task – Volume IV, hydrologic parameter data documentation package: IT Corporation, Las Vegas, Nevada, Report ITLV/10972-181, 78 p.

IT Corporation, 1997, Underground test area subproject, Phase I data analysis task – Volume VI, groundwater flow model documentation package: IT Corporation, Las Vegas, Nevada, Report ITLV/10972-181, 222 p.

Johnson, C., Mifflin, M.D., Johnson, R.J., and Haitjema, H., 2001, Hydrogeologic and groundwater modeling analyses for the Moapa Paiute Energy Center – A Calpine Company project in cooperation with the Moapa Band of Paiute Indians, Moapa Indian Reservation, Clark County, Nevada: Prepared by Mifflin and Associates, Inc., Las Vegas, NV, February 2001, 78 p. and 6 appendices.

Johnson, M.E., 2005a, Drilling and Development of CSI Well No. 1 for Coyote Springs Investment, LLC, August 2005.

Johnson, M.E., 2005b, Drilling and Development of CSI Well No. 2 for Coyote Springs Investment, LLC, December 2005.

Johnson, M.E., 2007, Drilling and Development of CSI Well No. 3 for Coyote Springs Investment, LLC, January 2007.

Johnson, M.E., 2008, Drilling and Development of CSI Well No. 4 for Coyote Springs Investment, LLC, Coyote Spring Valley, Clark County, Nevada.

Kleinfelder, 2000, 1999 Hydrologic Impacts from Groundwater Withdrawals in the Upper Muddy River Valley, Nevada, February 2000, 22 p.

Las Vegas Valley Water District, 2001, Water resources and ground-water modeling in the White River and Meadow Valley flow systems, Clark, Lincoln, Nye and White Pine Counties, Nevada.

Lincoln County Water District (LCWD) and Vidler Water Company (VWC), 2005, A Status Report of Tule Desert Valley Water Monitoring Operations, Prepared for the Nevada State Engineer and the National Park Service, September 2005.

LCWD and VWC, 2007, A Status Report of Tule Desert Valley Water Monitoring Operations, Prepared for the Nevada State Engineer and the National Park Service, March 2007.

Maurer, D.K., Lopes, T.J., Medina, R.L., and J.L. Smith, 2004, Hydrogeology and hydrologic landscape regions of Nevada, U.S. Geological Survey, Scientific Investigations Report 2004-5131, 35 p.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 8, 59 p.

Mifflin, M.D., Johnson, C.L., and R.J. Johnson, 1989, Hydrogeologic Assessment, Upper Muddy River Valley, Nevada: Mifflin & Associates, 47 p.

Mifflin, M.D., and Zimmerman, D.E., 1984, Ground-water availability in the Lower Meadow Valley Wash near Glendale, Nevada: Desert Research Institute, Water Resources Center, 51 p.

Moapa Valley Water District, 1997, Muddy Springs Interim Monitoring Report, February 1997, 9 p.

Moapa Valley Water District, 1998, Muddy Springs Area Monitoring Report, April 1998, 10 p.

Moapa Valley Water District, 1999, Muddy Springs Area Monitoring Report, April 1999, 10 p.

Moapa Valley Water District, 2000, Muddy Springs Area Monitoring Report, May 2000, 10 p.

Nevada Division of Water Resources, 2011, Accessed multiple times during 2011, http://water.nv.gov/mapping/order1169/

National Information Water System, 2012, Accessed multiple times between 2001 and 2012, http://waterdata.usgs.gov/nwis

Page, W.R., Scheirer, D.S., Langenheim, V.E., and Berger, M.A., 2011, Revised Geologic Cross Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2006-1040, 1 sheet, 25 p. pamphlet.

Page, W.R., Dixon, G.L., Rowley, P.D., and Brickey, D.W., 2005, Geologic Map of Parts of the Colorado, White River, and Death Valley Groundwater Flow Systems, Nevada, Utah, and Arizona: Nevada Bureau of Mines and Geology Map 150, Plate plus text.

Pohlmann, K.F., Morris, T.M., and Patterson, P.A., 1988, Nevada Power Company Reid-Gardner Groundwater Level Monitoring Program 1987 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 15 p.

Pohlmann, K.F., Wert, B.L., 1989, Nevada Power Company Reid-Gardner Groundwater Level Monitoring Program 1988 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 11 p.

Pohlmann, K.F., Wert, B.L., 1990, Nevada Power Company Reid Gardner Groundwater Level Monitoring Program 1989 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 26 p.

Pohlmann, K.F., Wert, B.L., 1991, Moapa Valley Ground-water Level Monitoring Program 1990 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 56 p.

Pohlmann, K.F., Wert, B.L., 1992, Moapa Valley Ground-water Level Monitoring Program 1991 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 72 p.

Pohlmann, K.F., Wert, B.L., 1993, Moapa Valley Ground-water Level Monitoring Program 1992 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 72 p.

Pohlmann, K.F., 1994, Moapa Valley Ground-water Level Monitoring Program 1993 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 38 p.

Pohlmann, K.F., 1995, Moapa Valley Ground-water Level Monitoring Program 1994 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 42 p.

Pohlmann, K.F., 1996, Moapa Valley Ground-water Level Monitoring Program 1995 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 48 p.

Pohlmann, K.F., Russell, C.E., 1997, Moapa Valley Ground-water Level Monitoring Program 1996 Annual Report: Desert Research Institute, Water Resources Center, Prepared for the Nevada Power Company, 55 p.

Rush, E.F., 1964, Ground-water appraisal of the Meadow Valley area, Lincoln and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-water resources - Reconnaissance Report 27, 43 p.

SAHRA, 2008, Wells Database, Accessed multiple times between 2007-2008, http://www.sahra.arizona.edu/wells/

Southern Nevada Water Authority and Las Vegas Valley Water District, 2003, Survey of Wells and Stream Gages in the Black Mountains Area, California Wash Basin, Coyote Spring Valley, Garnet valley, Hidden Valley, and Muddy River Springs Area, March 2005, 13 p.

Southern Nevada Water Authority and Las Vegas Valley Water District, 2005, Addendum #1 to Survey of Wells and Stream Gages in the Black Mountains Area, California Wash Basin, Coyote Spring Valley, Garnet valley, Hidden Valley, and Muddy River Springs Area, March 2005, 9 p.

Southern Nevada Water Authority, 2012, Portal, Accessed multiple times between 2003 and 2012, http://www.snwawatershed.org/portal.

SRK Consulting, 2001, Installation Report, Harvey Well Replacement, RW-1, Prepared for Nevada Power Company, September 2008.

Twichell, D.C., Cross, V.A., and S.D. Belew, Mapping the floor of Lake Mead (Nevada and Arizona): Preliminary discussion and GIS data release, U.S. Geologic Survey, Open-File Report 03-320, http://pubs.usgs.gov/of/2003/of03-320/index.htm.

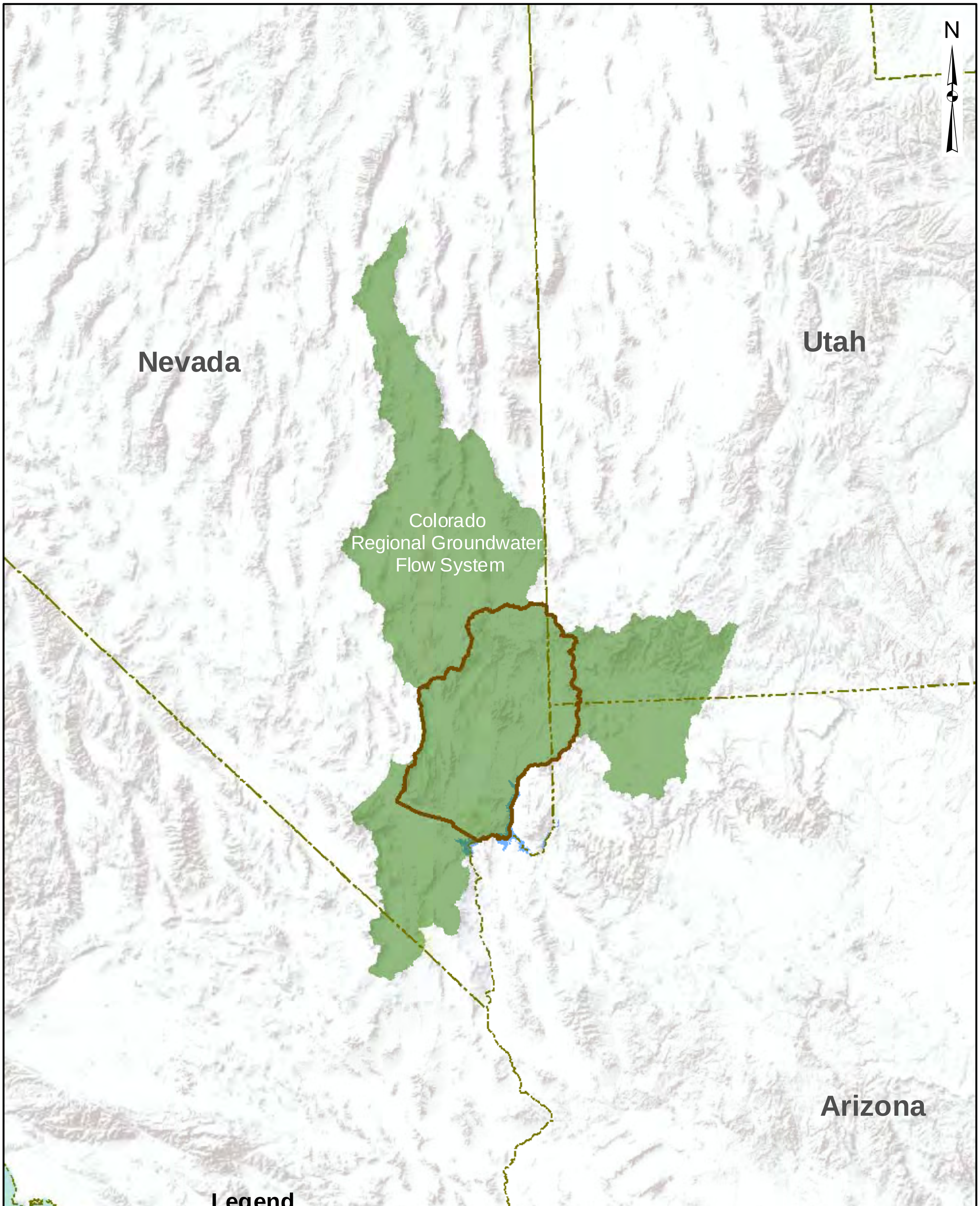
URS, 2001, Report of Groundwater Assessment – Lower Meadow Valley Wash, Meadow Valley Generating Project, Clark and Lincoln Counties, Nevada, Prepared for PG&E National Energy Group, November 1, 2001.

URS, 2006, Final Well Completion Report, Kane Springs Valley, Lincoln County, Nevada, Prepared for Lincoln County Water District and Vidler Water Company, March 2006.

Virgin Valley Water District (VVWD) and Entrix, 2006, Hydrological Monitoring and Mitigation Plan, Virgin River Basin, Nevada, Prepared for the City of Mesquite, September 2006, 36 p.

FIGURES

SE ROA 12280



Legend

Active Model Domain

Colorado River Regional Groundwater Flow System

0 50 100 Miles

TITLE: **Location of Study Area**

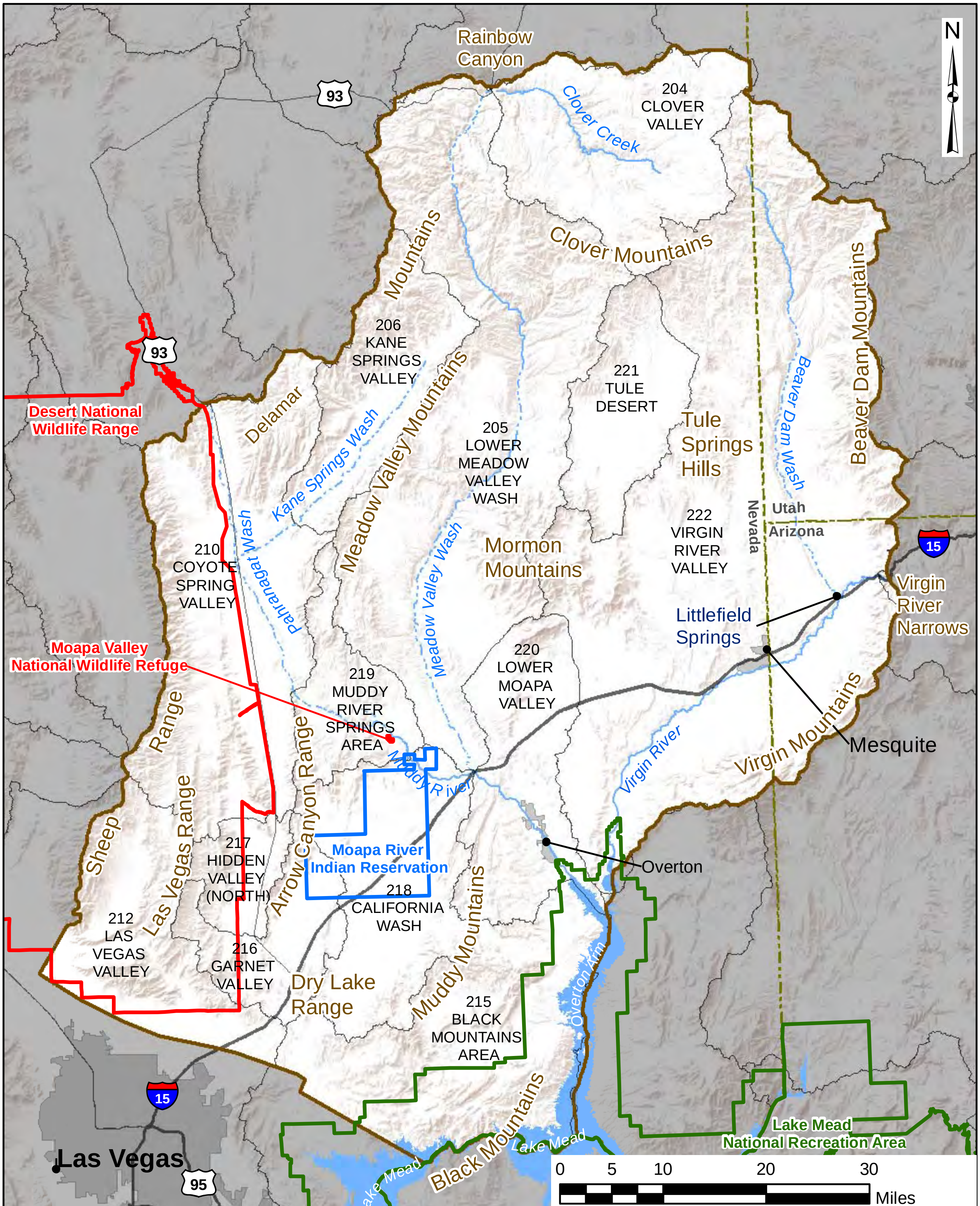
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada, Utah, and Arizona**

TETRA TECH

FIGURE **1.1-1**

SE ROA 12281

JA_5043



Legend

219 Active Model Domain

Hydrographic Area

TITLE: **Physiographic Features of Study Area**

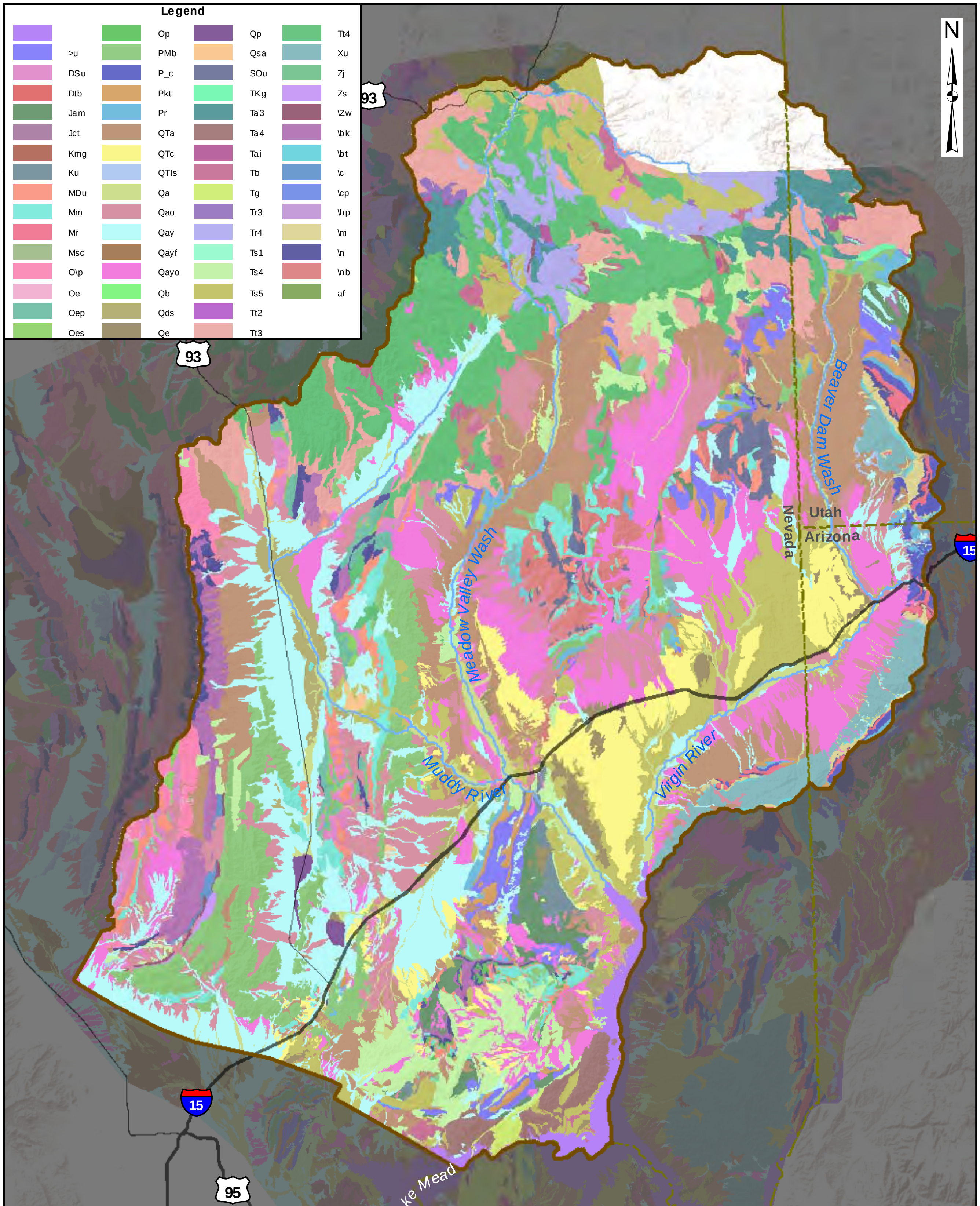
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **1.1-2**

SE ROA 12282

JA_5044



0 5 10 20 30

Miles

From Page et al., 2011, Revised Geologic Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona.
OFR2006-1040, Revised June 2011

TITLE:

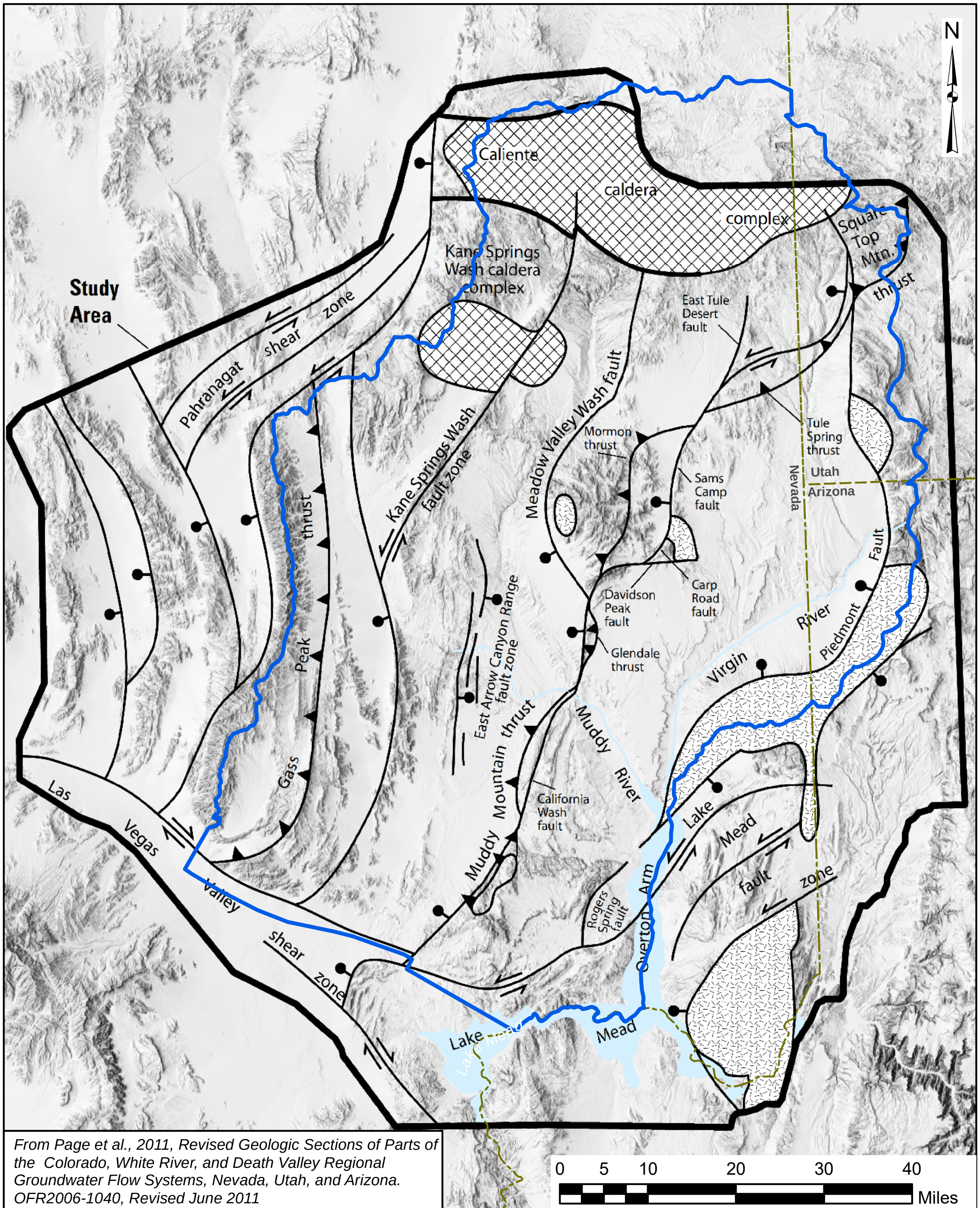
Geologic Map

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE

3.1-1



From Page et al., 2011, Revised Geologic Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona. OFR2006-1040, Revised June 2011

0 5 10 20 30 40 Miles

Legend

Active Model Domain

Tertiary caldera complex

Early Proterozoic crystalline rocks

Thrust fault

Normal fault

Strike-slip fault

TITLE:

Major Faults

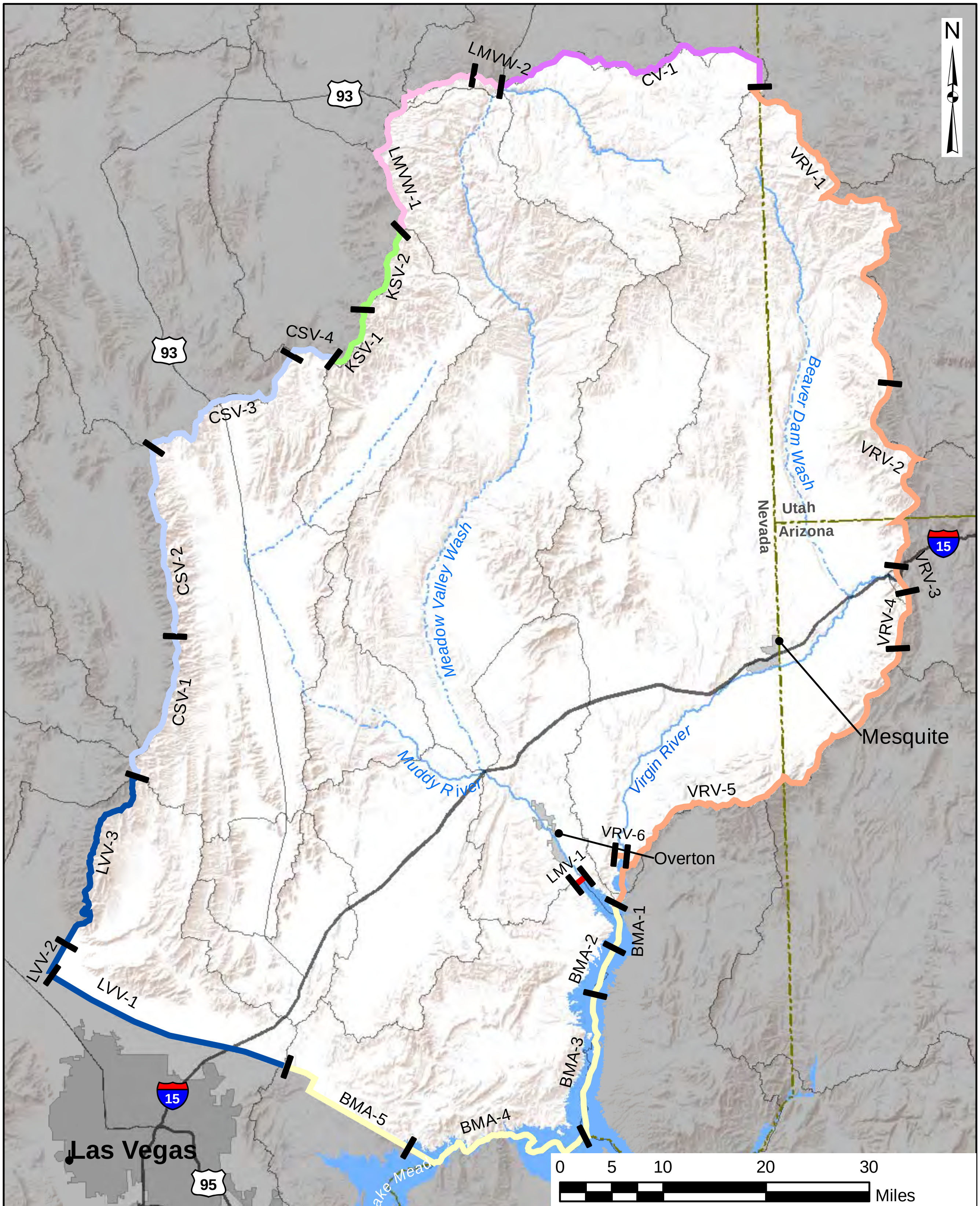
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE

3.1-2

SE ROA 12284



Legend

Hydrographic Area

CV-1 Boundary Segment

Source: Harrill, 2007

TITLE: **Location of Harrill's Boundary Segments**

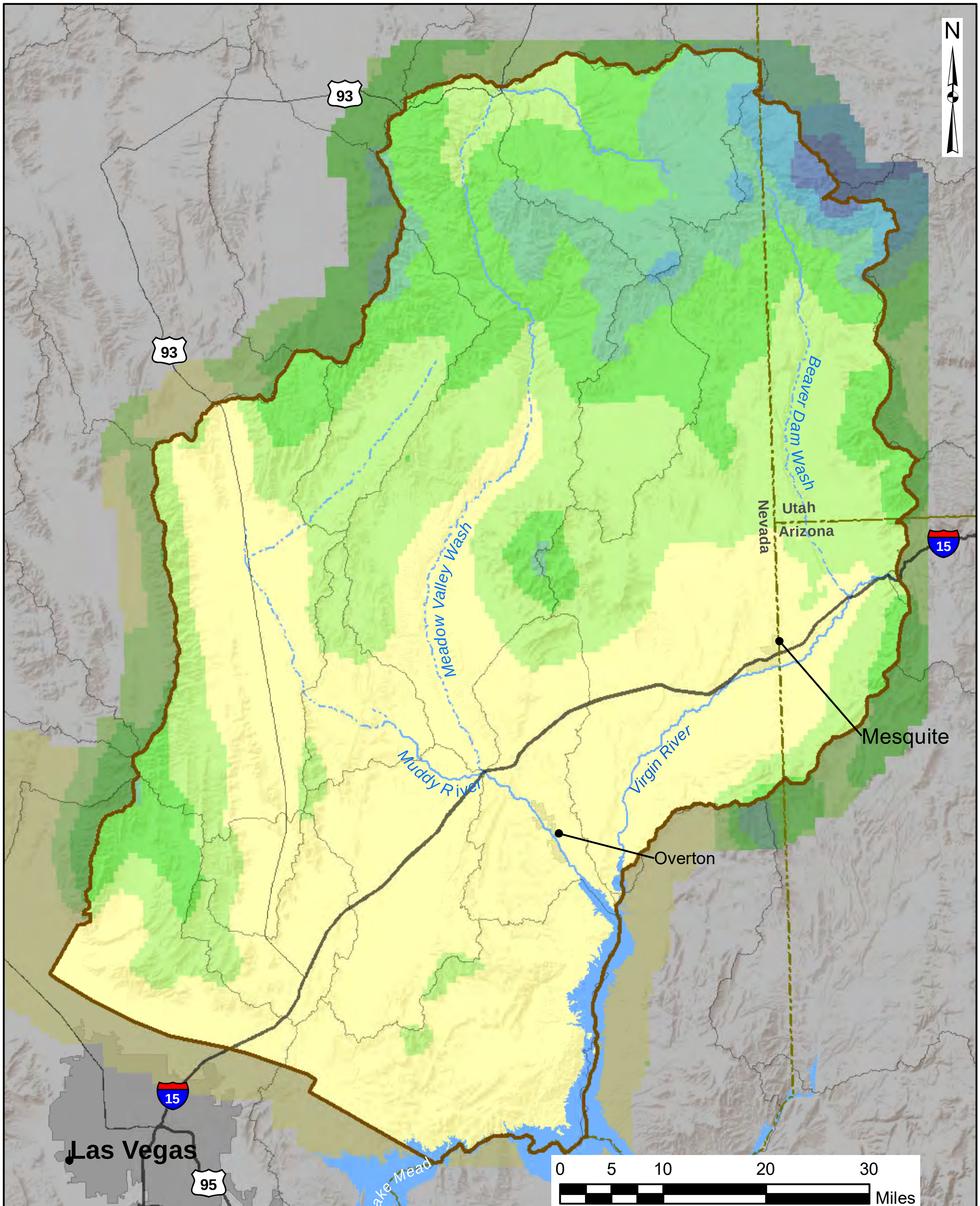
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.3-1**

SE ROA 12285

JA_5047



Legend

- Active Model Domain
- Hydrographic Region
- 10 - 20 cm
- 21 - 30 cm
- 31 - 40 cm
- 41 - 50 cm
- 51 - 60 cm
- 61 - 70 cm
- 71 - 80 cm

Source: PRISM 2006

TITLE: **Estimated Annual Precipitation**

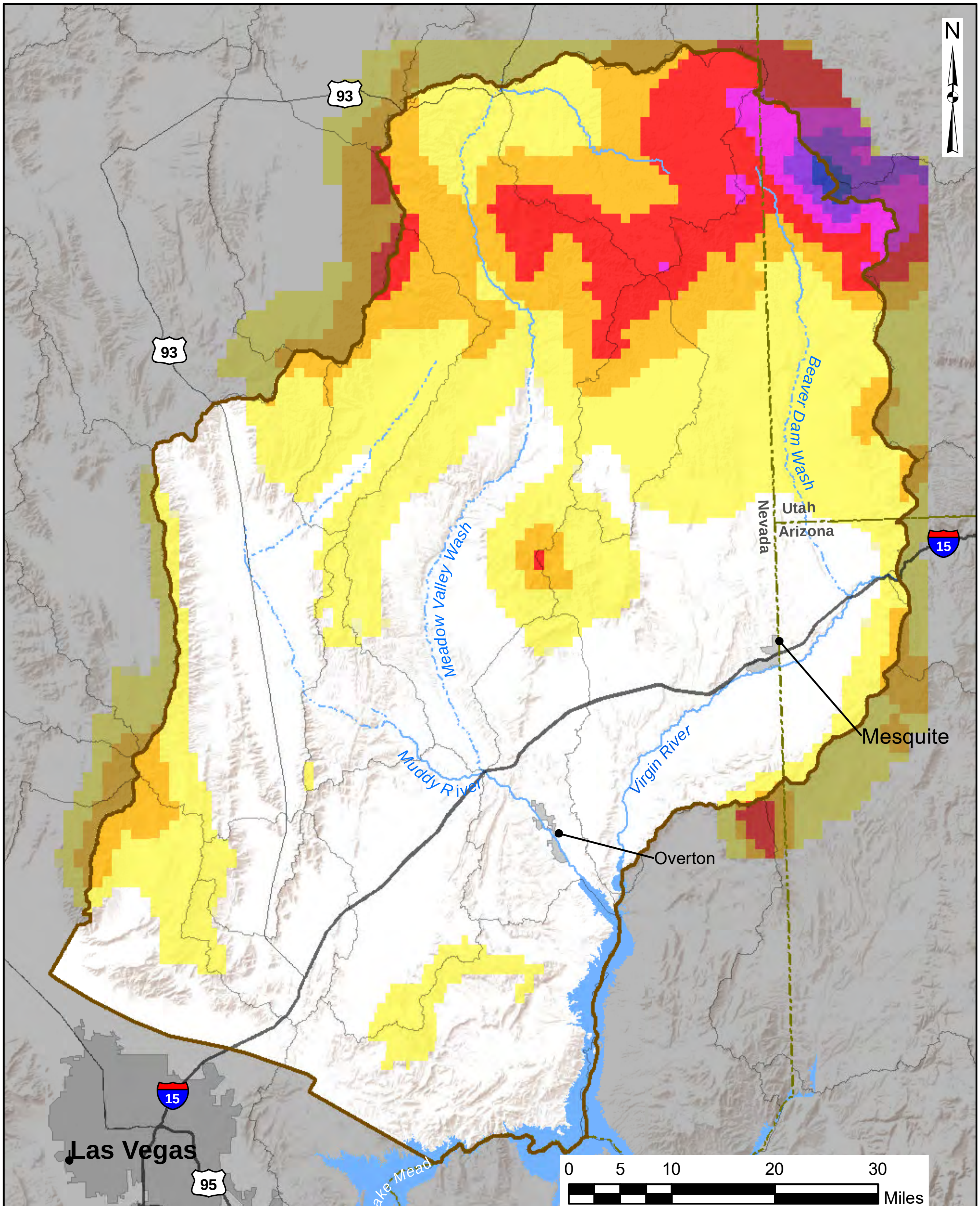
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.4-1**

SE ROA 12286

JA_5048



Legend

Active Model Domain

Hydrographic Region

Recharge (in/yr)

- 0.1 - 1.0
- 1.1 - 2.0
- 2.1 - 4.0
- 4.1 - 6.0
- 6.1 - 8.0
- 8.0 - 10.0

TITLE: **Estimated Annual Recharge Rate**

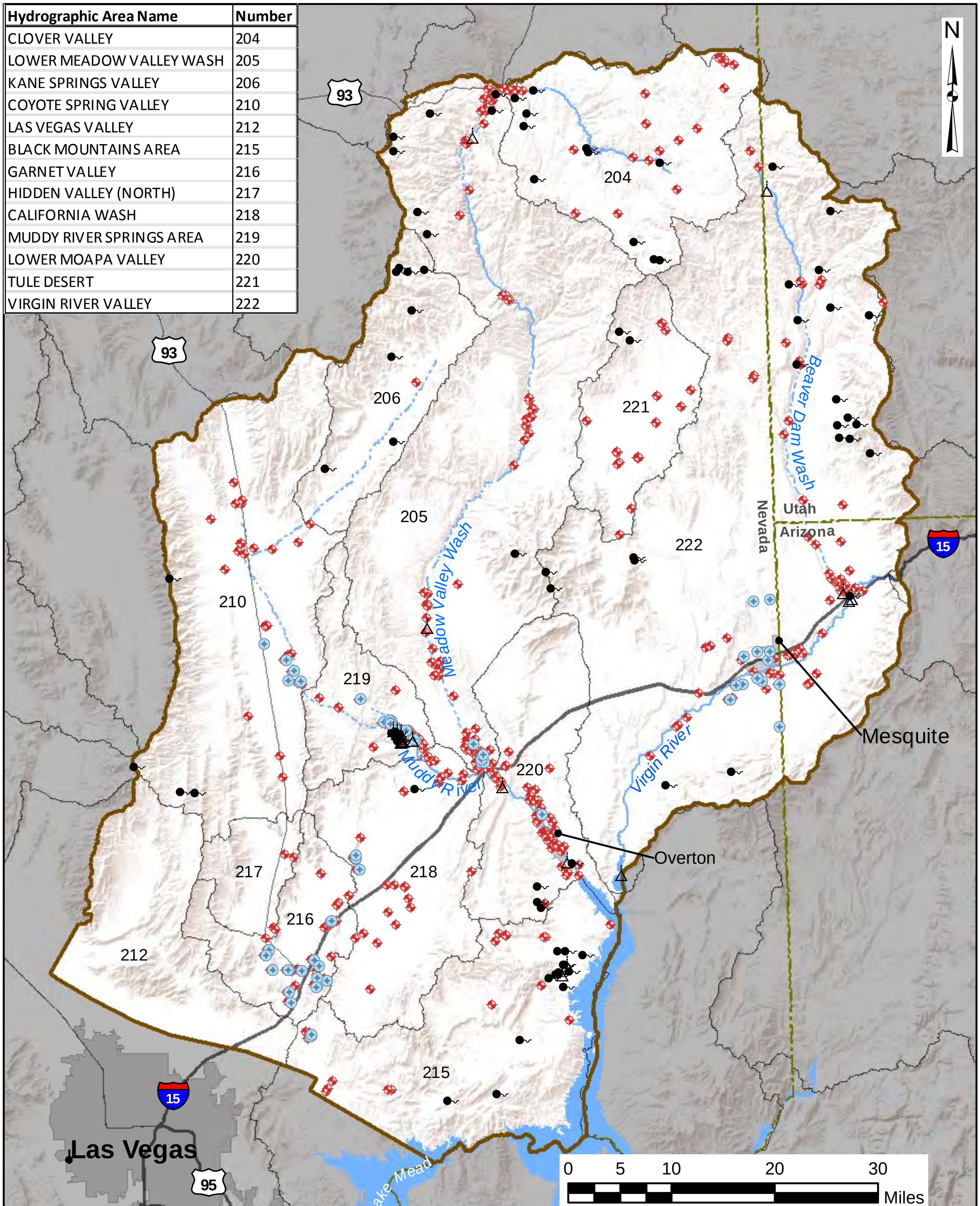
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.4-2**

SE ROA 12287

Hydrographic Area Name	Number
CLOVER VALLEY	204
LOWER MEADOW VALLEY WASH	205
KANE SPRINGS VALLEY	206
COYOTE SPRING VALLEY	210
LAS VEGAS VALLEY	212
BLACK MOUNTAINS AREA	215
GARNET VALLEY	216
HIDDEN VALLEY (NORTH)	217
CALIFORNIA WASH	218
MUDDY RIVER SPRINGS AREA	219
LOWER MOAPA VALLEY	220
TULE DESERT	221
VIRGIN RIVER VALLEY	222



Legend

	Spring		Water Level Observation Well
	Gauging Station		Active Model Domain
	Production Well	219	Hydrographic Area

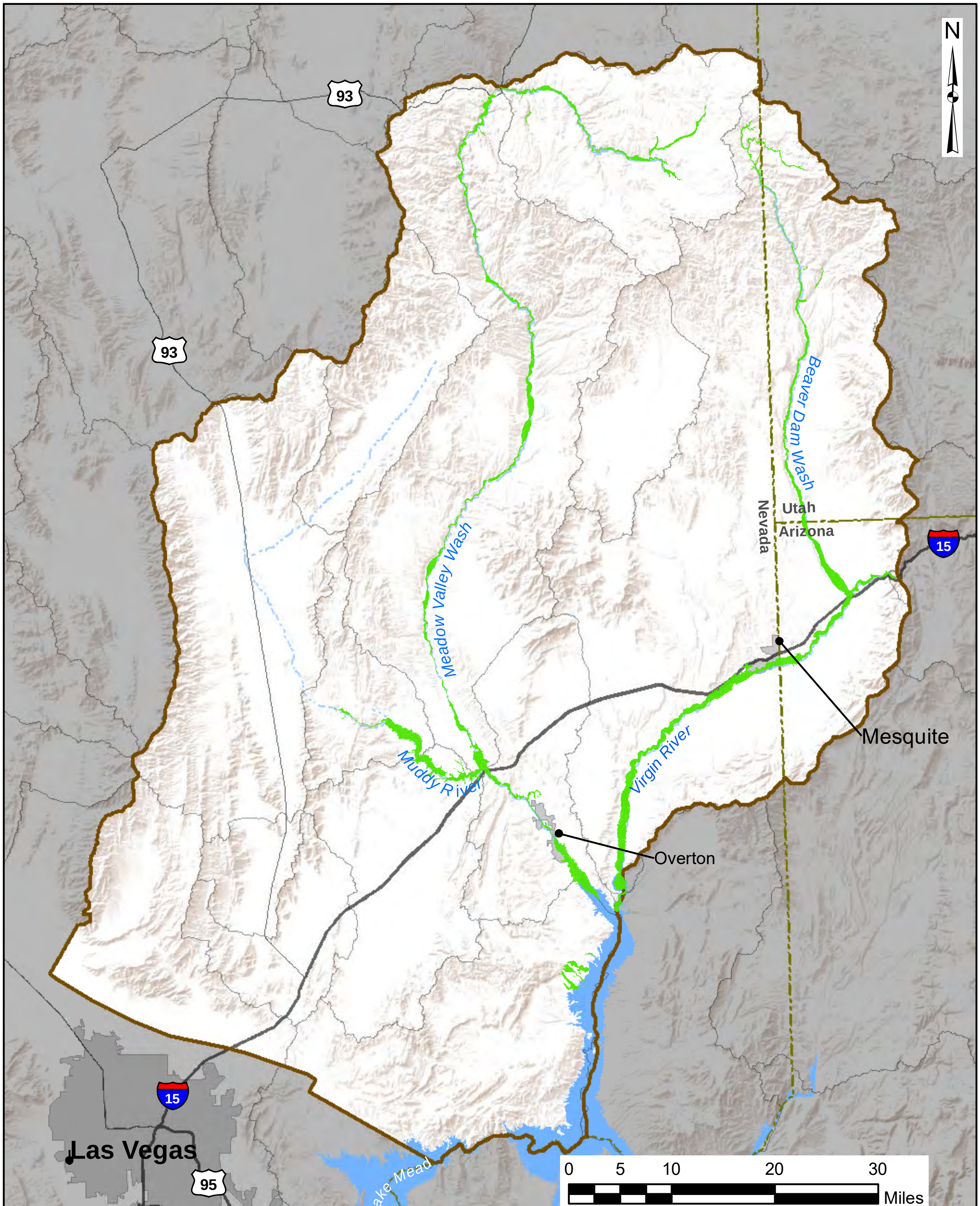
TITLE: **Locations of Wells, Springs, Stream Reaches, and Gauging Stations**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.5-1**

SE ROA 12288



Legend

- Evapotranspiration Area
- Active Model Domain
- Hydrographic Region

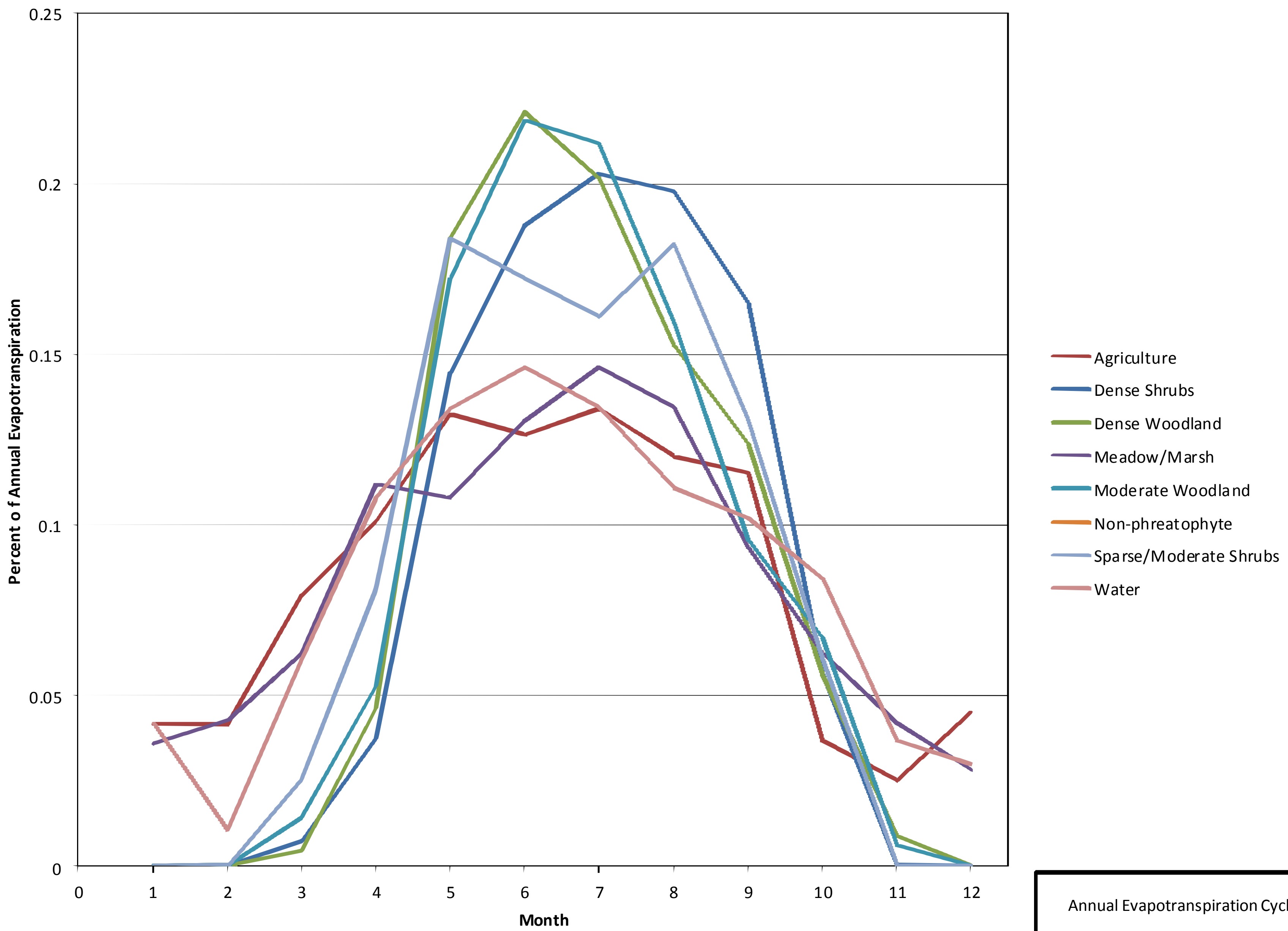
Source: DeMeo et al., 2008

TITLE: **Designated Areas of Evapotranspiration**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.5-2**



Source: DeMeo et al., 2008; Bureau of Reclamation, 2004

Annual Evapotranspiration Cycle

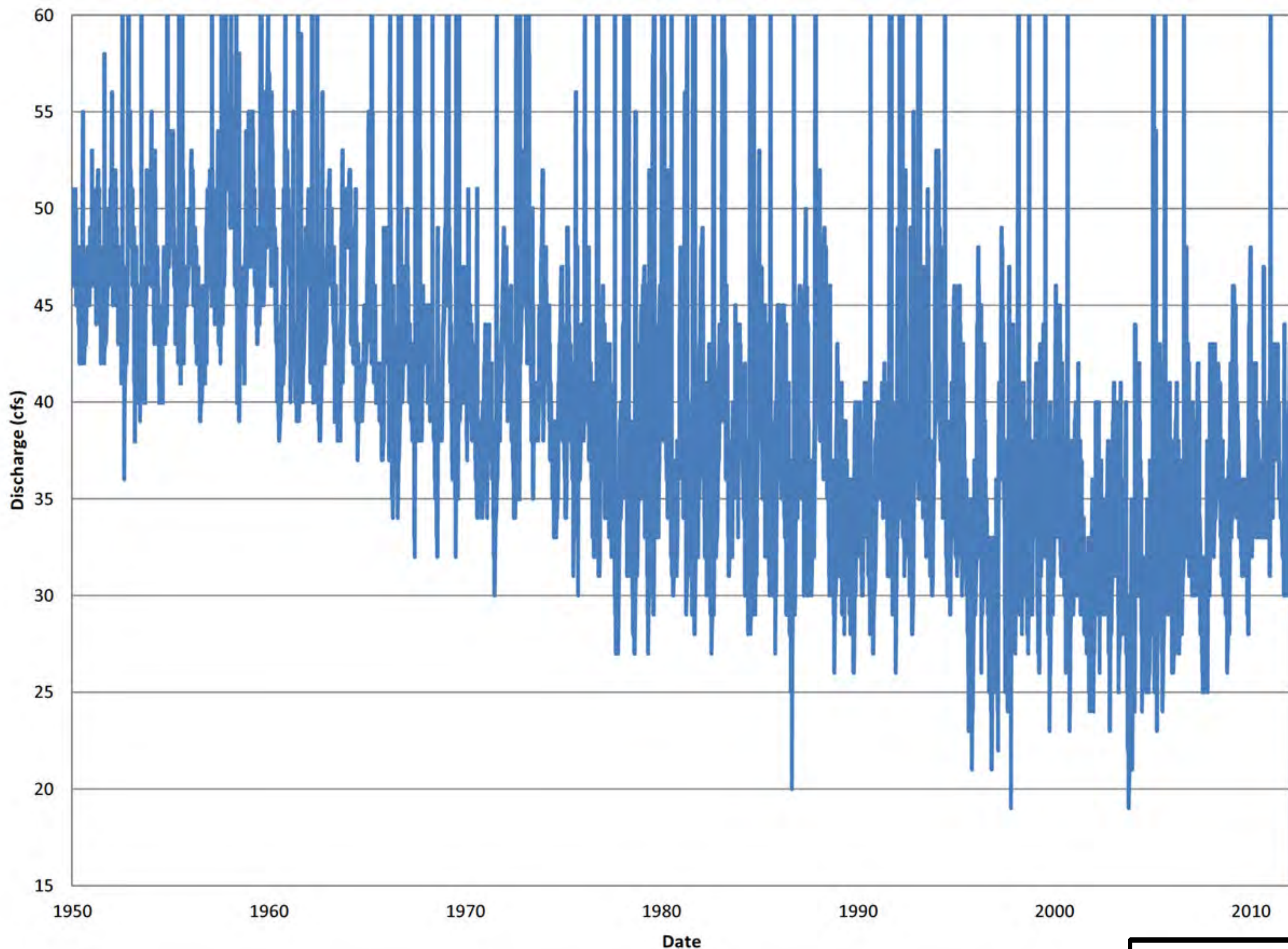
Lower Colorado River Flow System

TETRA TECH GEO

Figure 3.5-3

SE ROA 12290

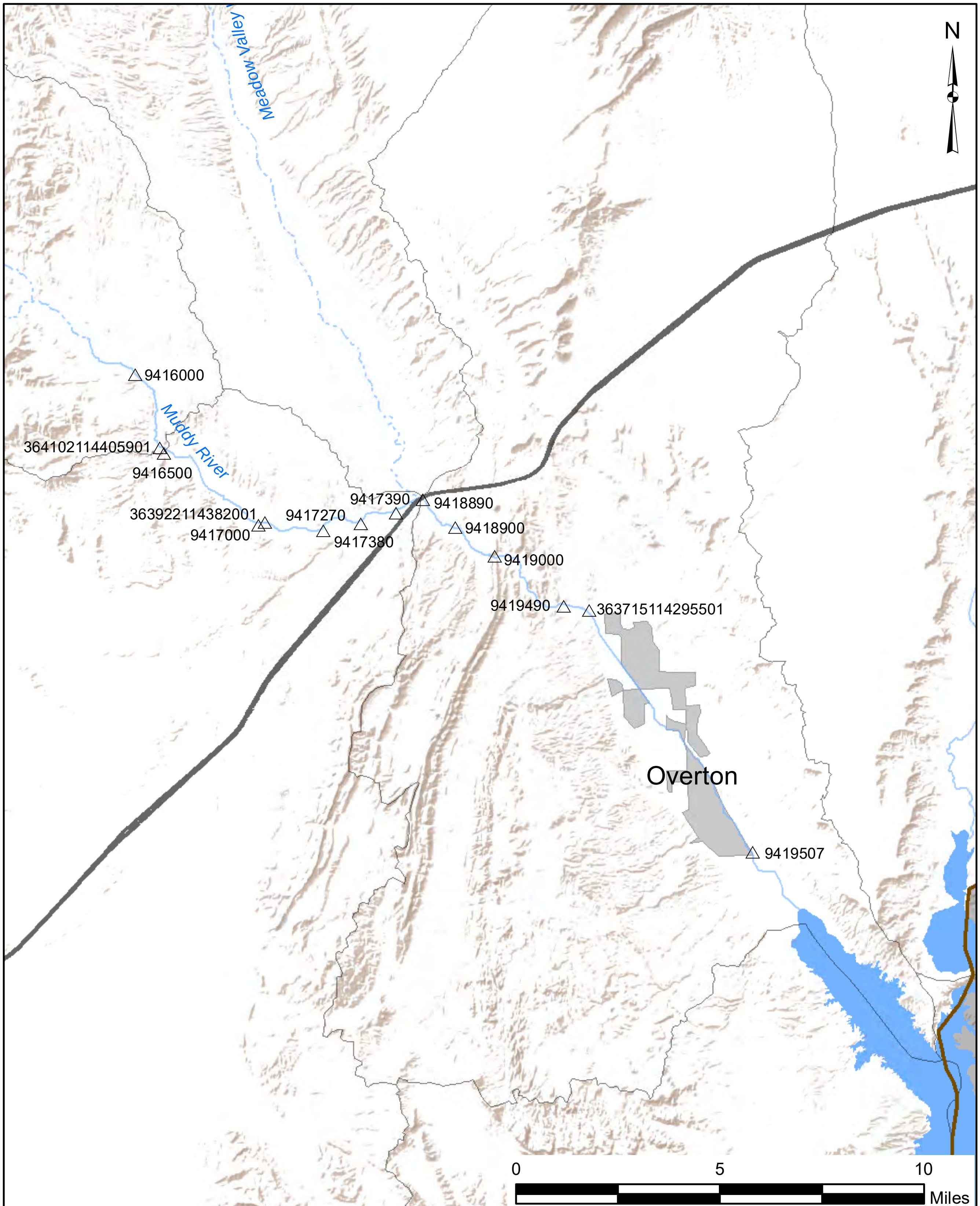
JA_5052



Note: Magnitude of storm peaks are not shown.

Discharge at Muddy River near Moapa	
Lower Colorado River Flow System	
TETRA TECH GEO	Figure 3.5-4

SE ROA 12291



Legend

△ Discharge Measurement Site

Active Model Domain

Hydrographic Area

TITLE: **Streamflow-Measurement Locations, Muddy River Synoptic Study**

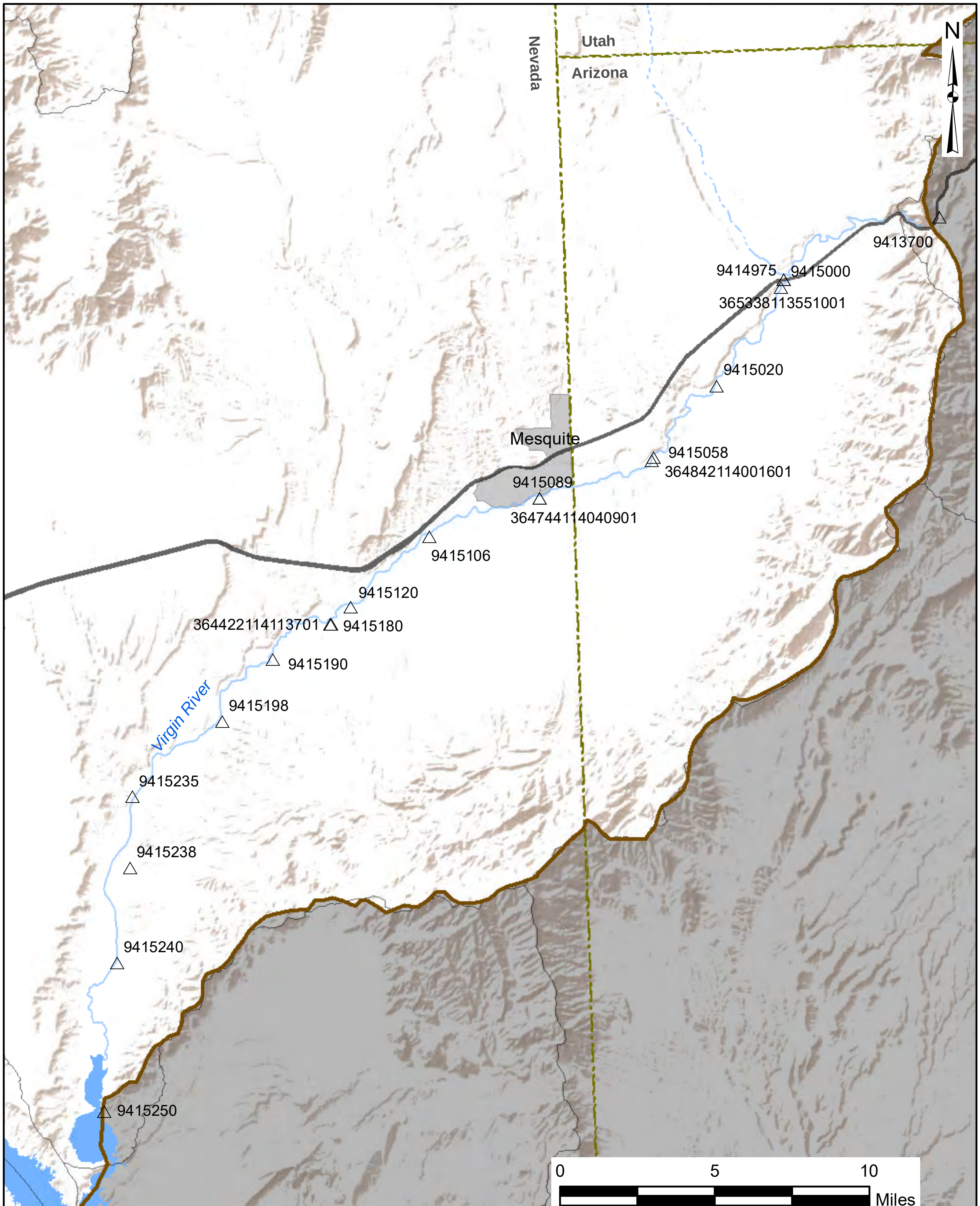
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.5-5**

SE ROA 12292

JA_5054



Legend

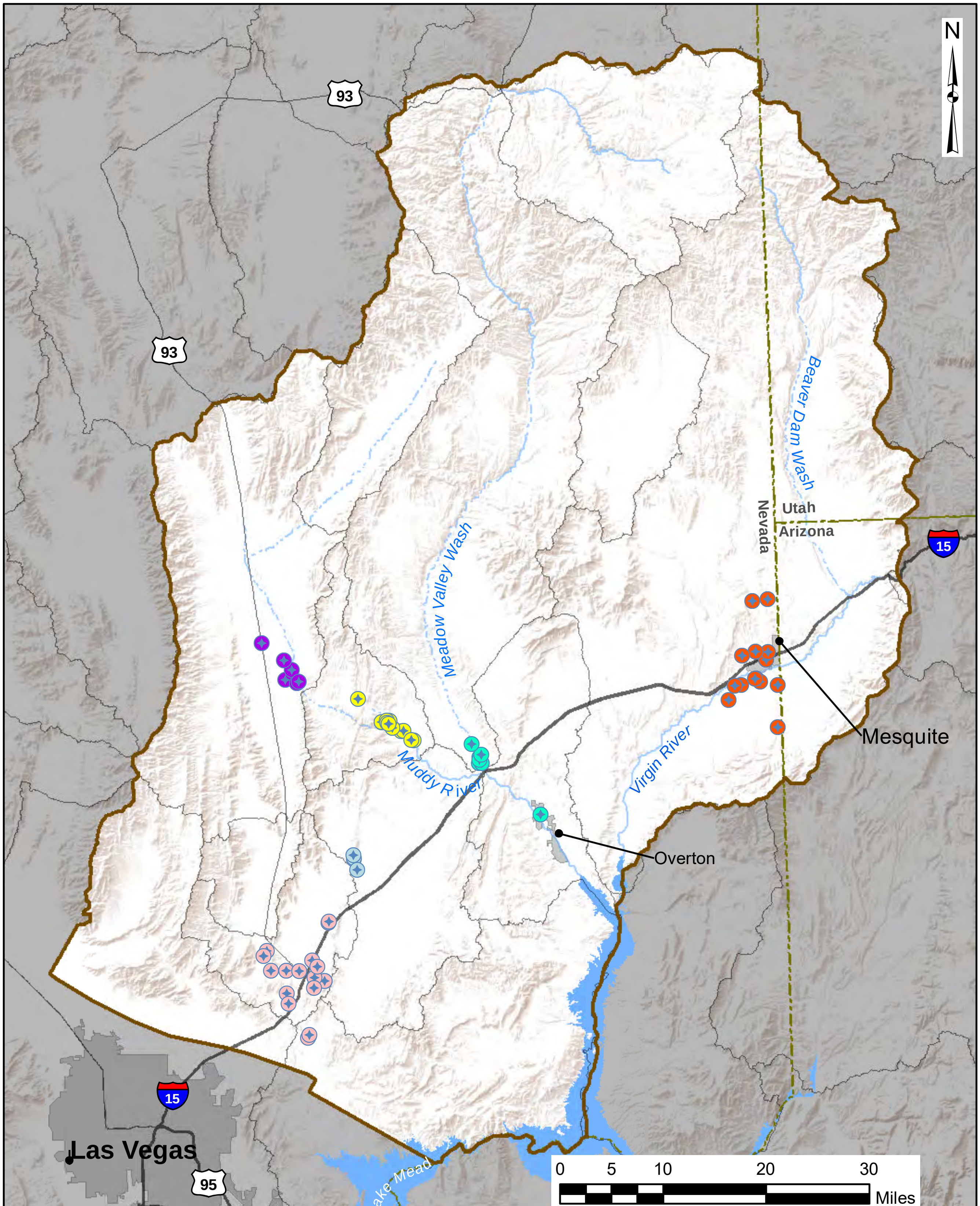
- △ Discharge Measurement Site
- Active Model Domain
- Hydrographic Area

TITLE: **Streamflow-Measurement Locations, Virgin River Synoptic Study**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.5-6**



Legend

Hydrographic Area
Active Model Domain
California Wash Wells
Coyote Spring Valley Wells
Garnet Valley Wells
Lower Meadow Valley Wash Wells
Muddy River Springs Area Wells
Virgin Valley Wells

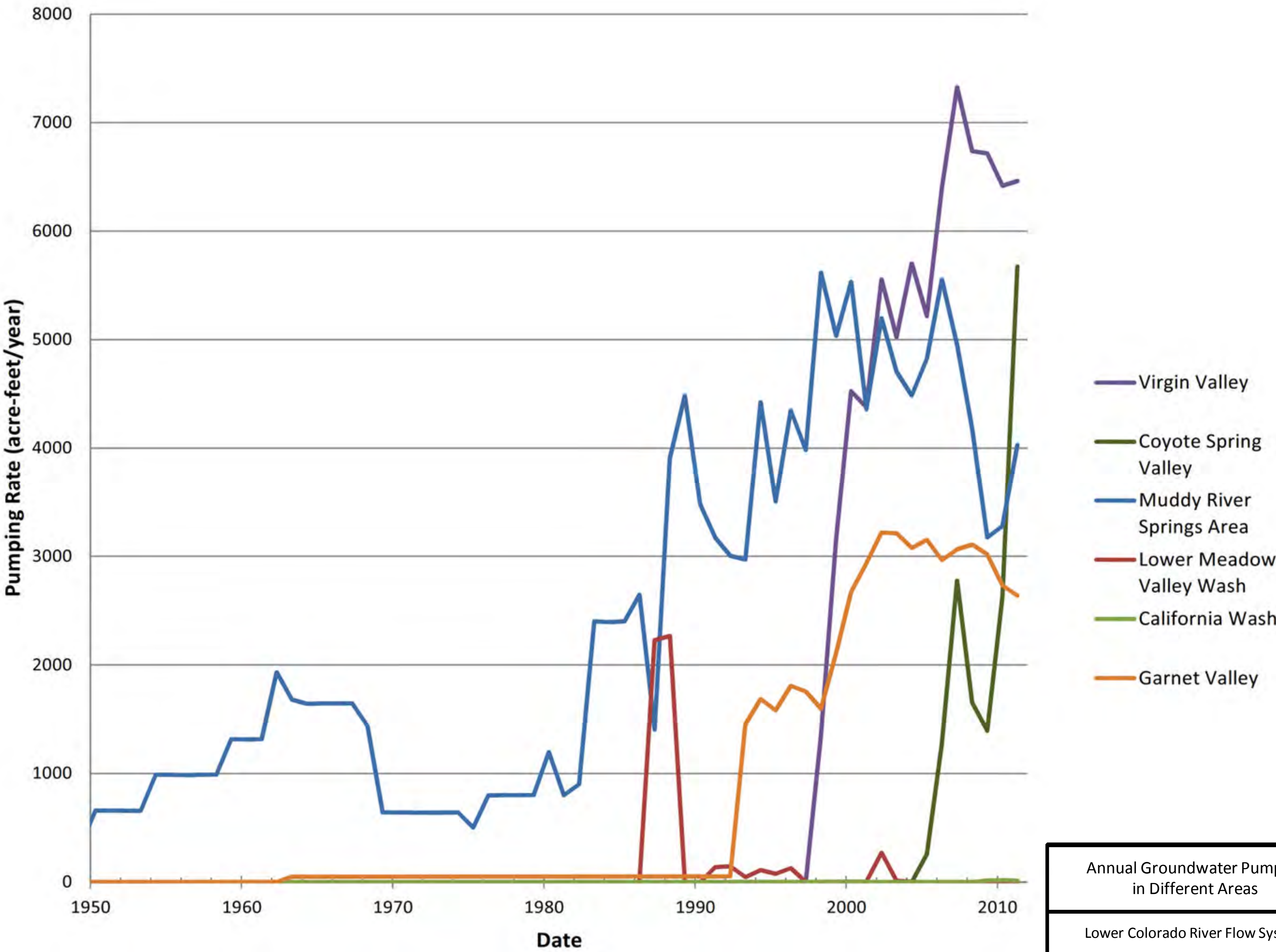
TITLE:
Locations of Production Well Groups Used in Figure 3.5-3

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

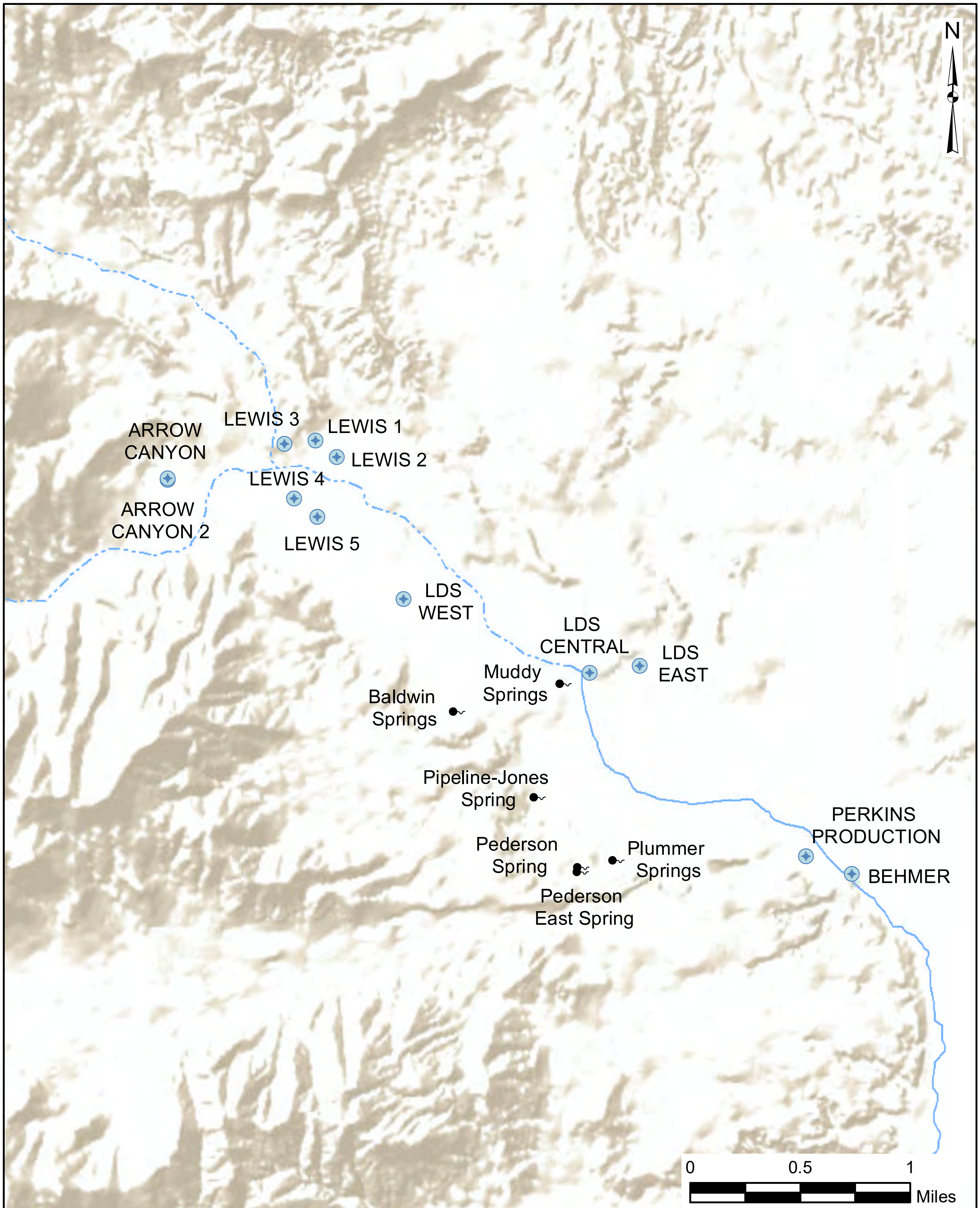
TETRA TECH

FIGURE
3.6-1

SE ROA 12294



Annual Groundwater Pumping in Different Areas	
Lower Colorado River Flow System	
TETRA TECH GEO	Figure 3.6-2



Legend

Springs

Production Wells

Active Model Domain

TITLE: **Location of Production Wells and Springs in Muddy River Springs Area**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **3.6-3**

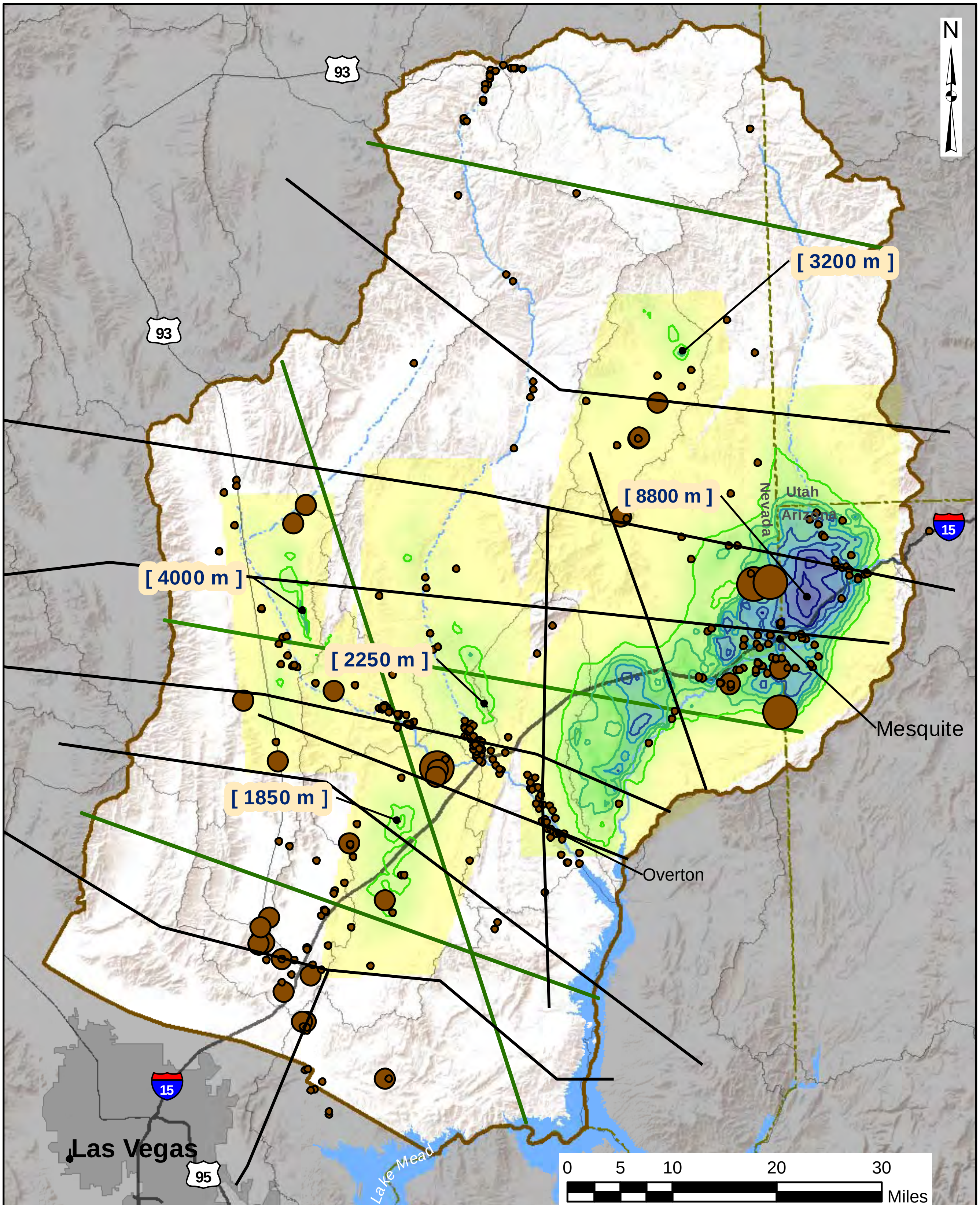
	HGU	Description
Basin Fill	QCD	Quaternary Channel Deposits / Recent Alluvium
	CAU	Cenozoic Alluvium, Undivided. Incl. Muddy Creek Fm, and Surface Colluvium
	THS	Tertiary Horse Springs Fm.
	TAU	Tertiary Alluvium, Undivided
	TVC	Tertiary Volcanics and Clastics
Gass Peak Thrust	PC6	Paleozoic Carbonates
	LC6	Lower Clastic Sequence
Delamar Thrust	PC5	Paleozoic Carbonates
	LC5	Lower Clastic Sequence
Model Over Low Angle Thrust	MU4	Mesozoic Undivided
	KT4	Kaibab-Toroweap
	PR4	Permian Redbeds
	PC4	Paleozoic Carbonates
Overturned Stratigraphy in Muddy Mtns	PC3	Paleozoic Carbonates
	PR3	Permian Redbeds
	KT3	Kaibab-Toroweap
	MU3	Mesozoic Undivided
Overthrust Stratigraphy in Muddy Mtns	MU2	Mesozoic Undivided
	KT2	Kaibab-Toroweap
	PR2	Permian Redbeds
	PC2	Paleozoic Carbonates
Model Under Low Angle Thrust	MU1	Mesozoic Undivided
	KT1	Kaibab-Toroweap
	PR1	Permian Redbeds
	PC1	Paleozoic Carbonates
	LC1	Lower Clastic Sequence
	XLB	Crystalline Basement

Stacking of
Hydrostratigraphic Units

Lower Colorado River Flow System

TETRA TECH GEO

Figure
4.1-1



Legend

- Sections Derived from Geologic Model
- USGS Section Lines
- Active Model Domain
- State Boundary

Borehole Depth
- 0 - 1333
- 1334 - 2667
- 2668 - 4000

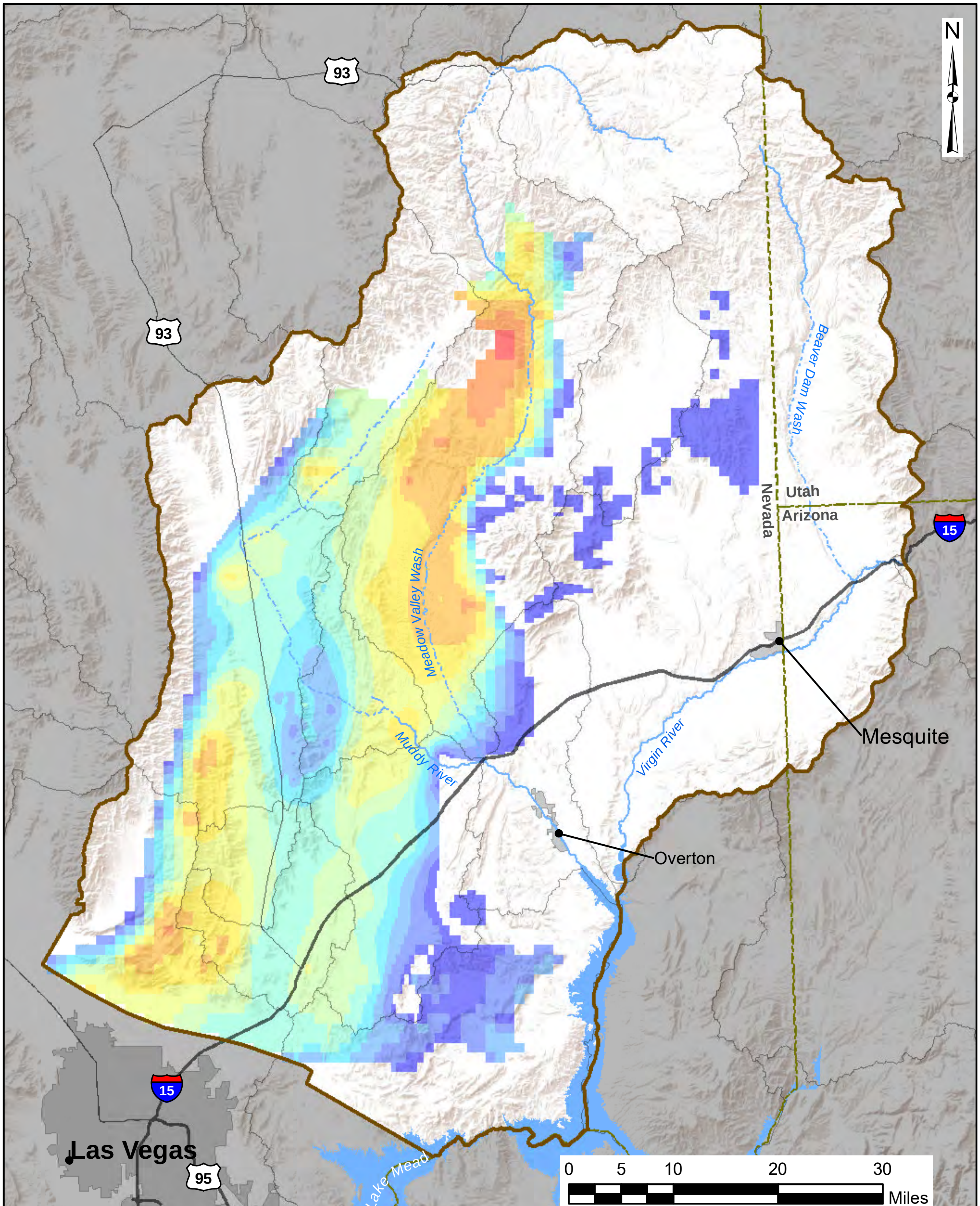
Sediment Thickness (m)
- High : 8830
- Low : 0

TITLE:
Locations of Geologic Sections, Drill-Hole Control, and Gravity Interpretation

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **4.1-2**



Legend

Active Model Domain

Hydrographic Region

Approximate Unit Thickness

22000 ft

12000 ft

6000 ft

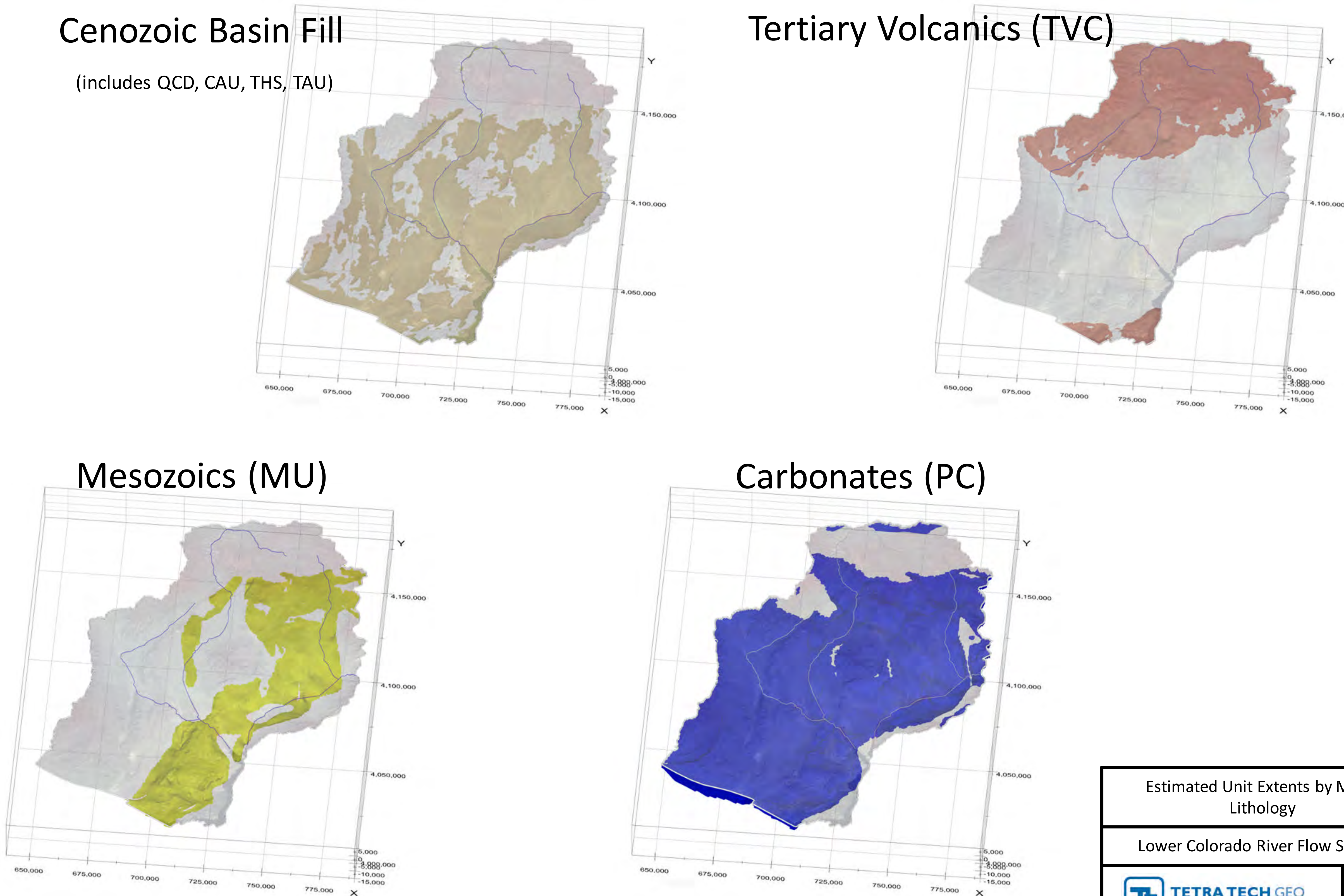
2000 ft

TITLE: **Kriging-Interpolated Thickness, PC4**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **4.1-3**

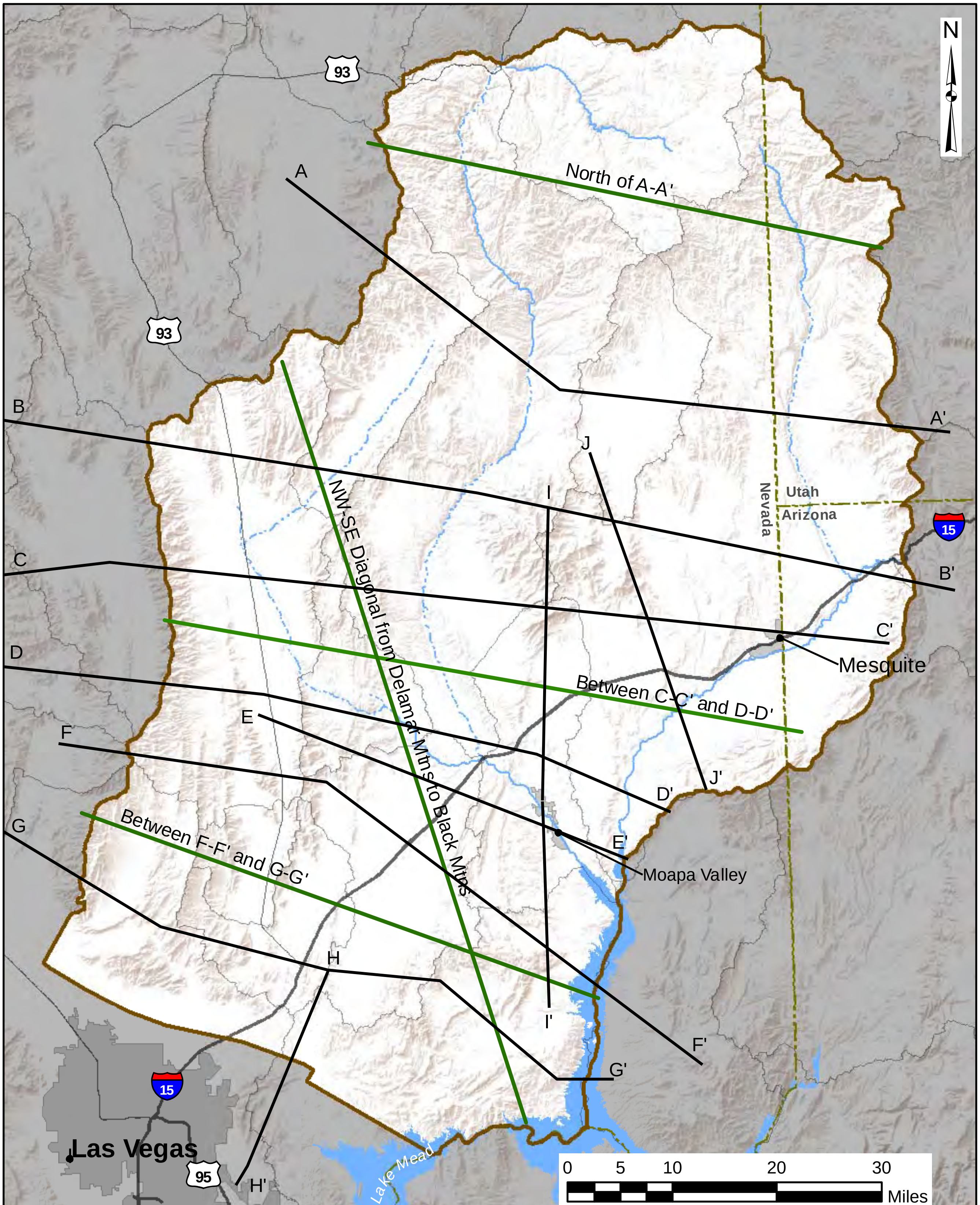


Estimated Unit Extents by Major Lithology

Lower Colorado River Flow System

TETRA TECH GEO

Figure 4.2-1



Legend

Active Model Domain

State Boundary

Sections Derived from Geologic Model

USGS Section Lines

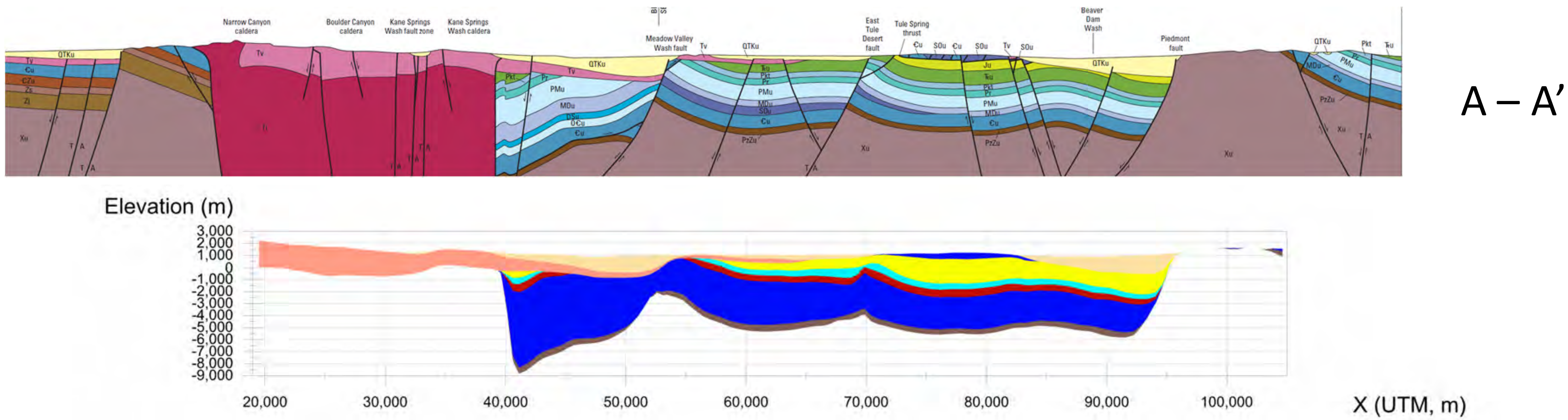
TITLE:

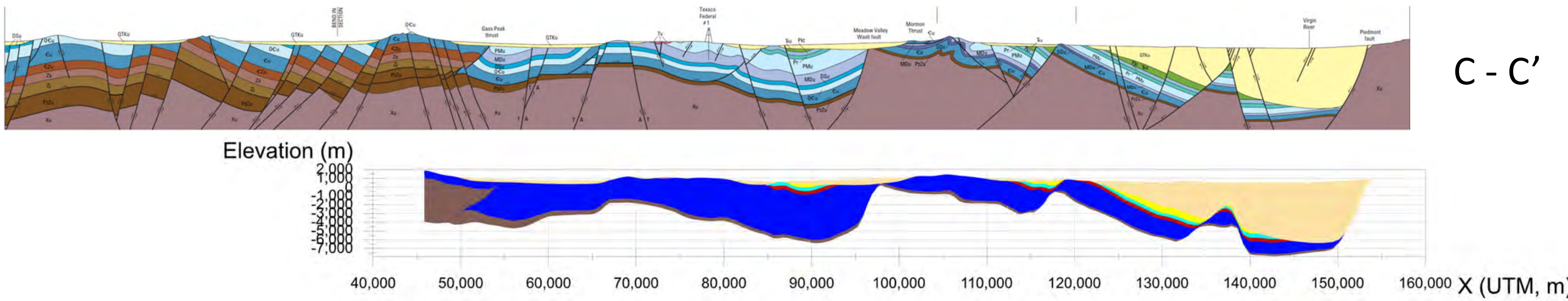
Locations of Geologic Sections

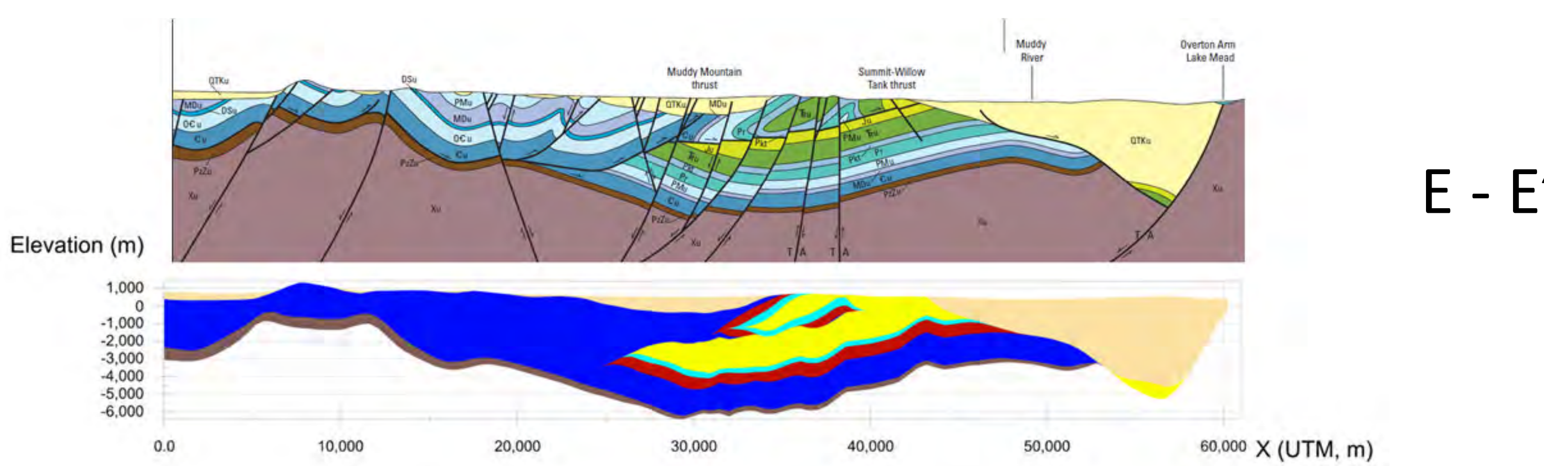
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **4.2-2**



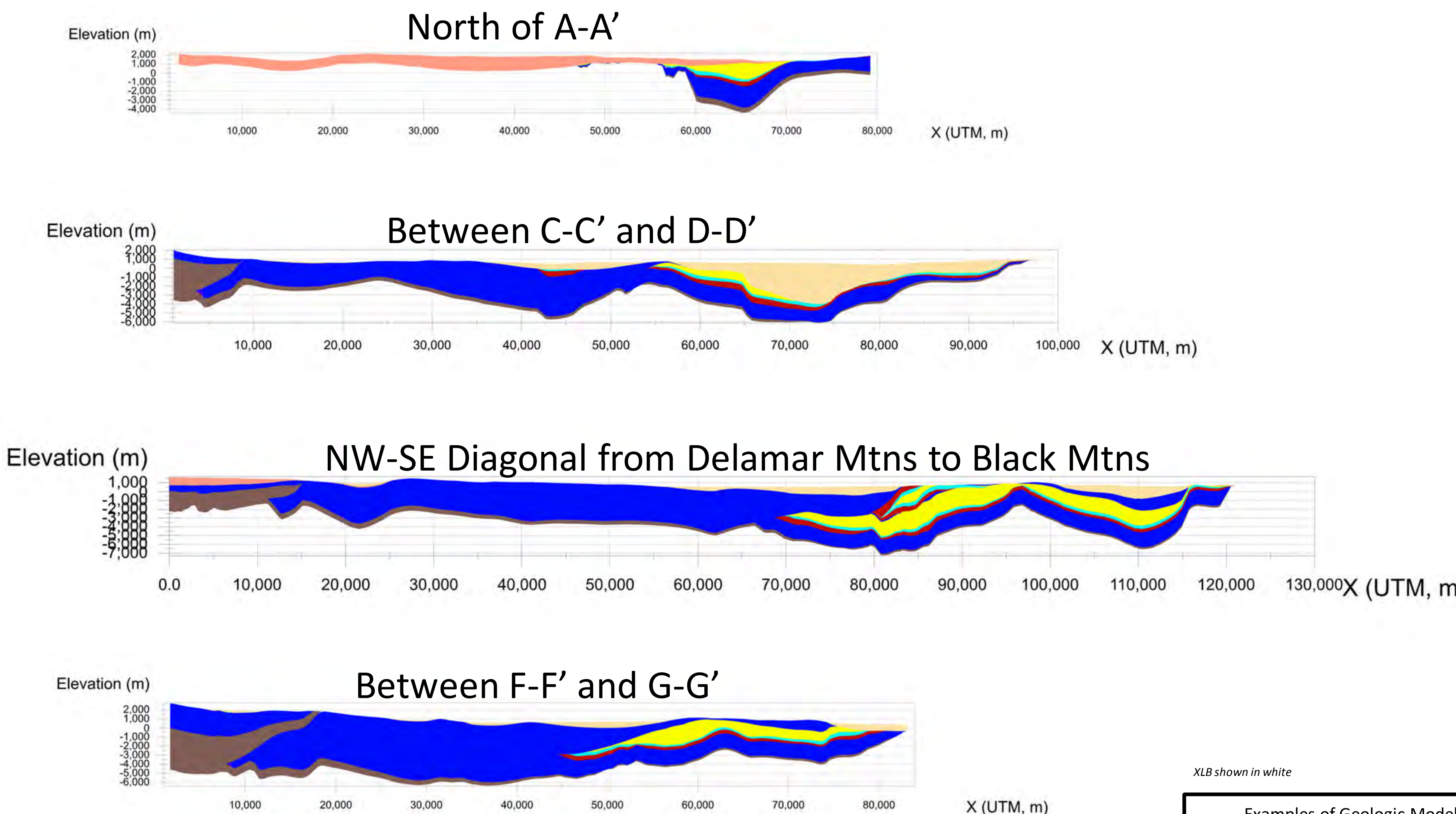




XLB shown in white

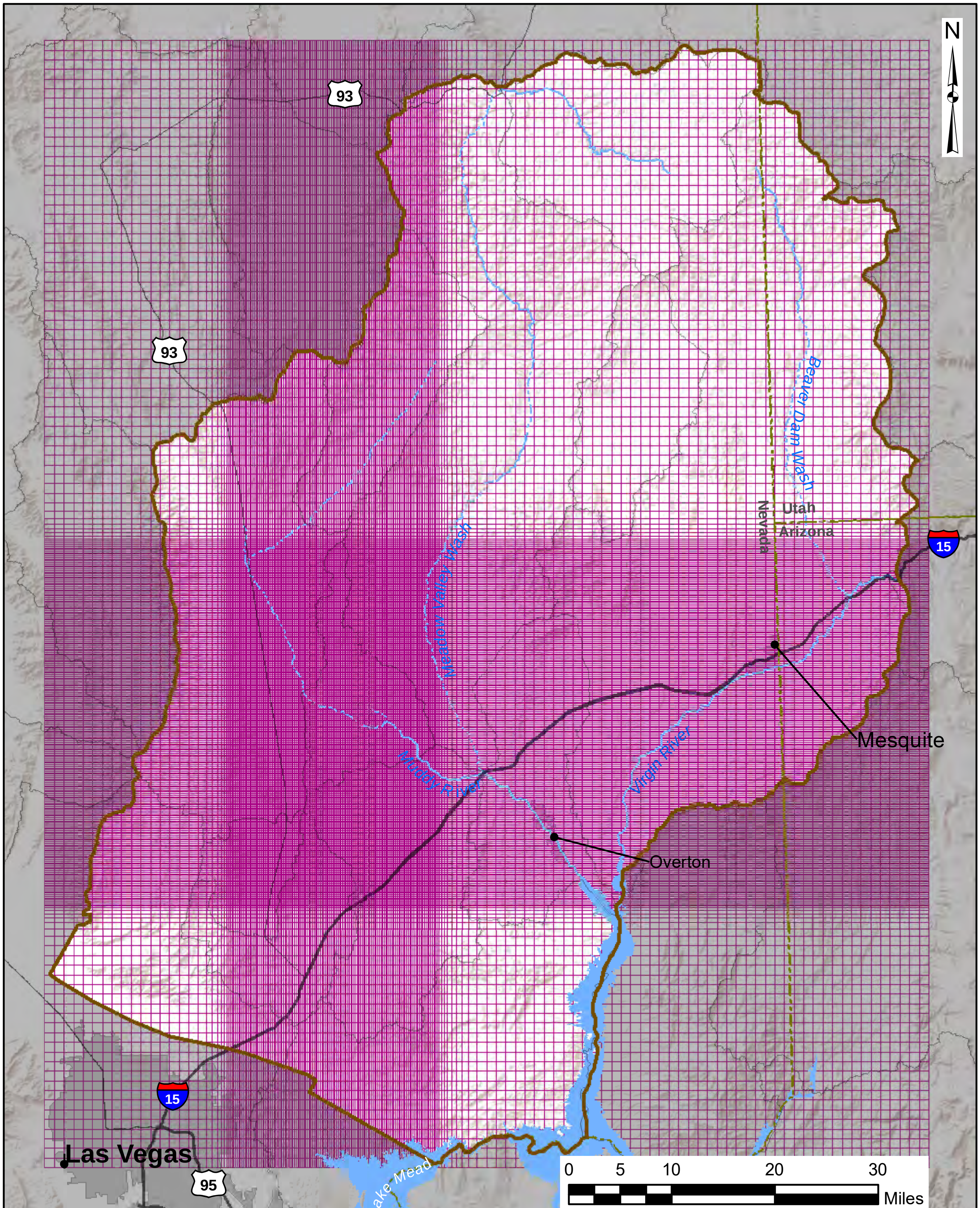
Drafted sections from Page et al., 2011, Revised Geologic Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona. OFR2006-1040, Revised June 2011

Comparison of Selected USGS and Geologic Model Sections	
Lower Colorado River Flow System	
TETRA TECH GEO	Figure 4.2-3



XLB shown in white

Examples of Geologic Model Sections between USGS Sections	
Lower Colorado River Flow System	
TETRA TECH GEO	Figure 4.2-4



Legend

Active Model Domain
Hydrographic Region
Flow-Model Grid

TITLE: **Flow-Model Grid**

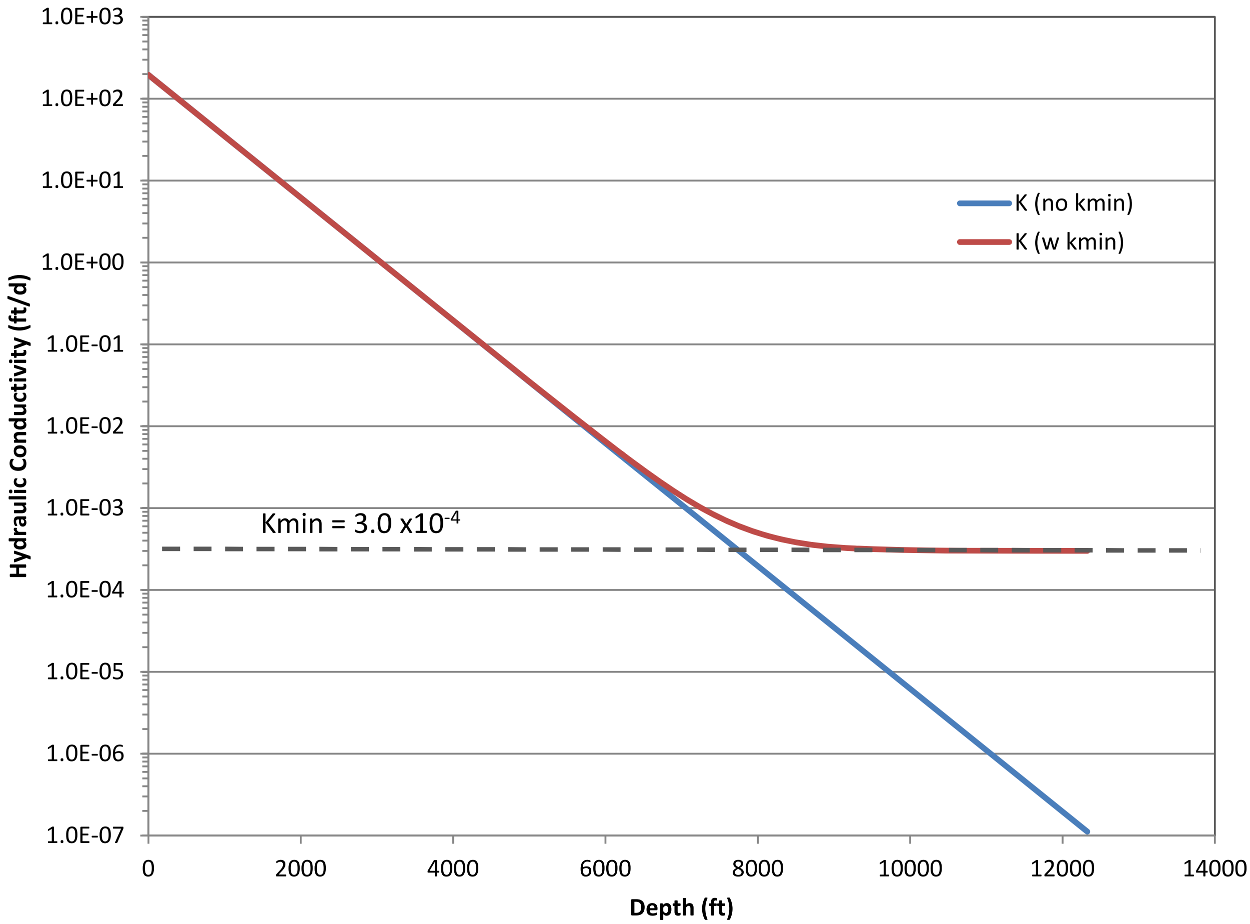
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.1-1**

SE ROA 12304

JA_5066



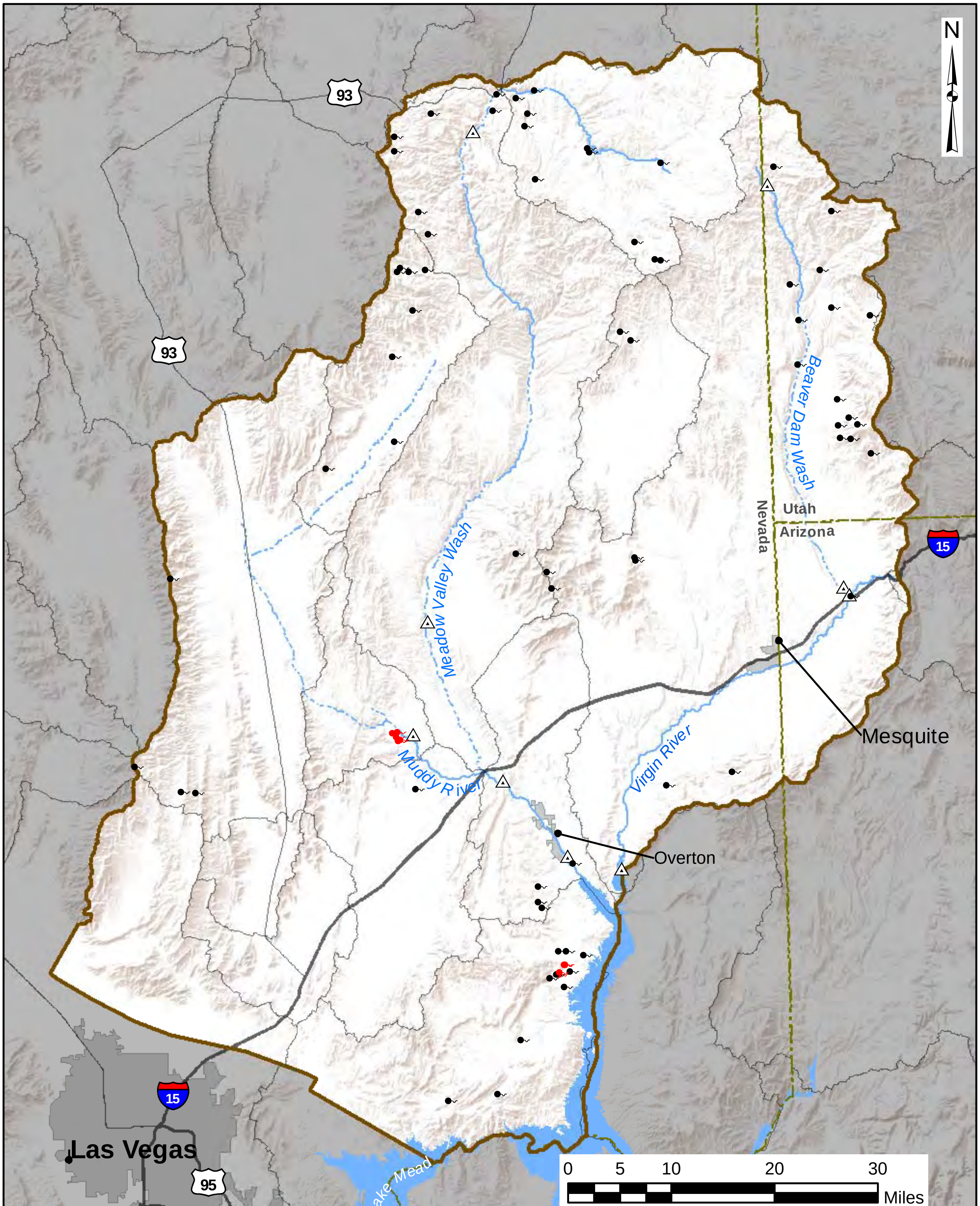
Lambda = 7.5E-04/ft

Example of Depth-Decay Relationship

Lower Colorado River Flow System

TETRA TECH GEO

Figure 5.1-2



Legend

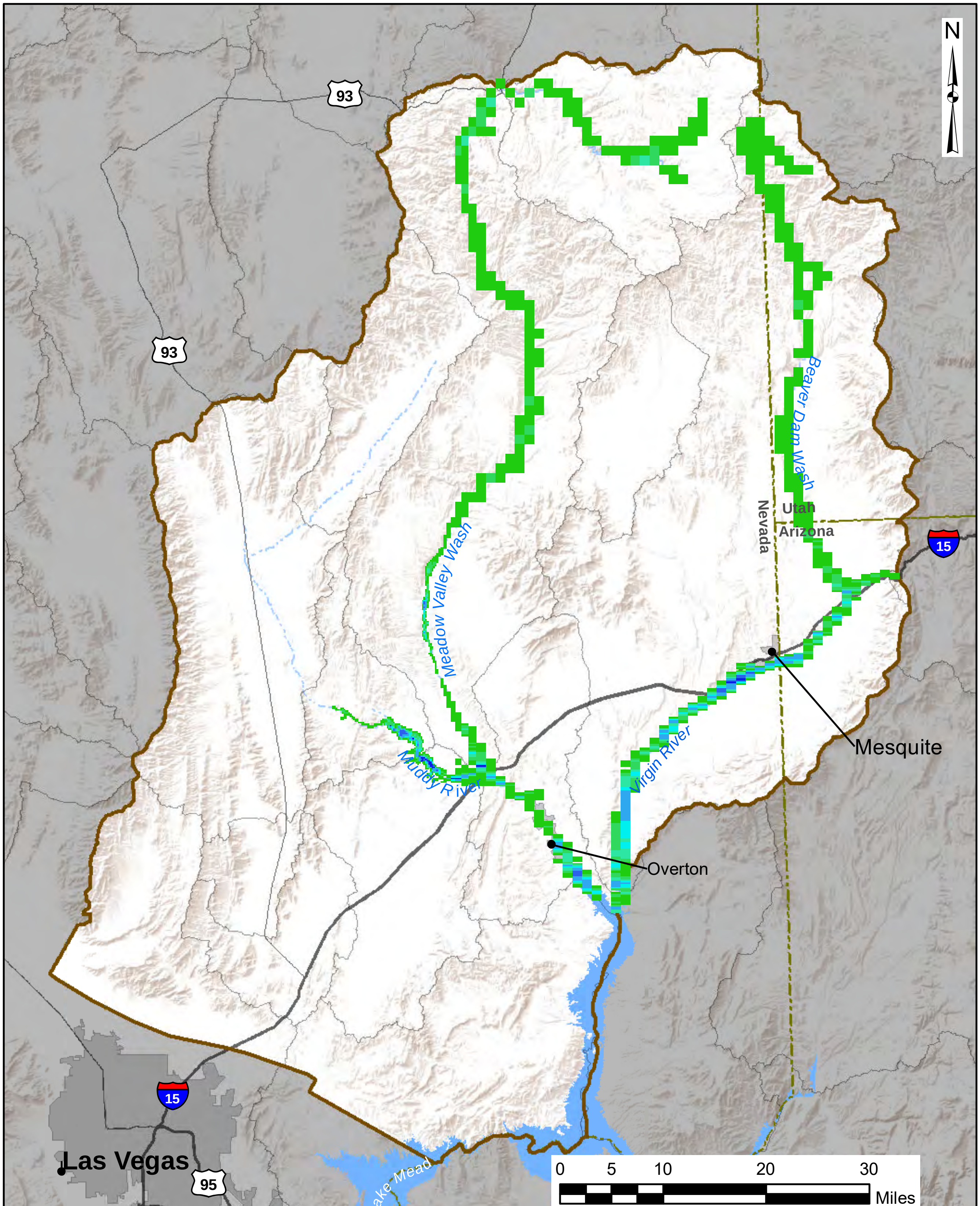
- Spring Simulated with DRN Package
- Spring Discharge Target
- Stream-flow Target
- Active Model Domain
- Hydrographic Area

TITLE: **Locations of Springs, Stream-Flow Targets, and Spring-Discharge Targets**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.2-1**



Legend

Evapotranspiration (in/yr)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.3

Active Model Domain

Hydrographic Region

Based on: DeMeo et al., 2008

TITLE: **Designated Areas of Evapotranspiration**

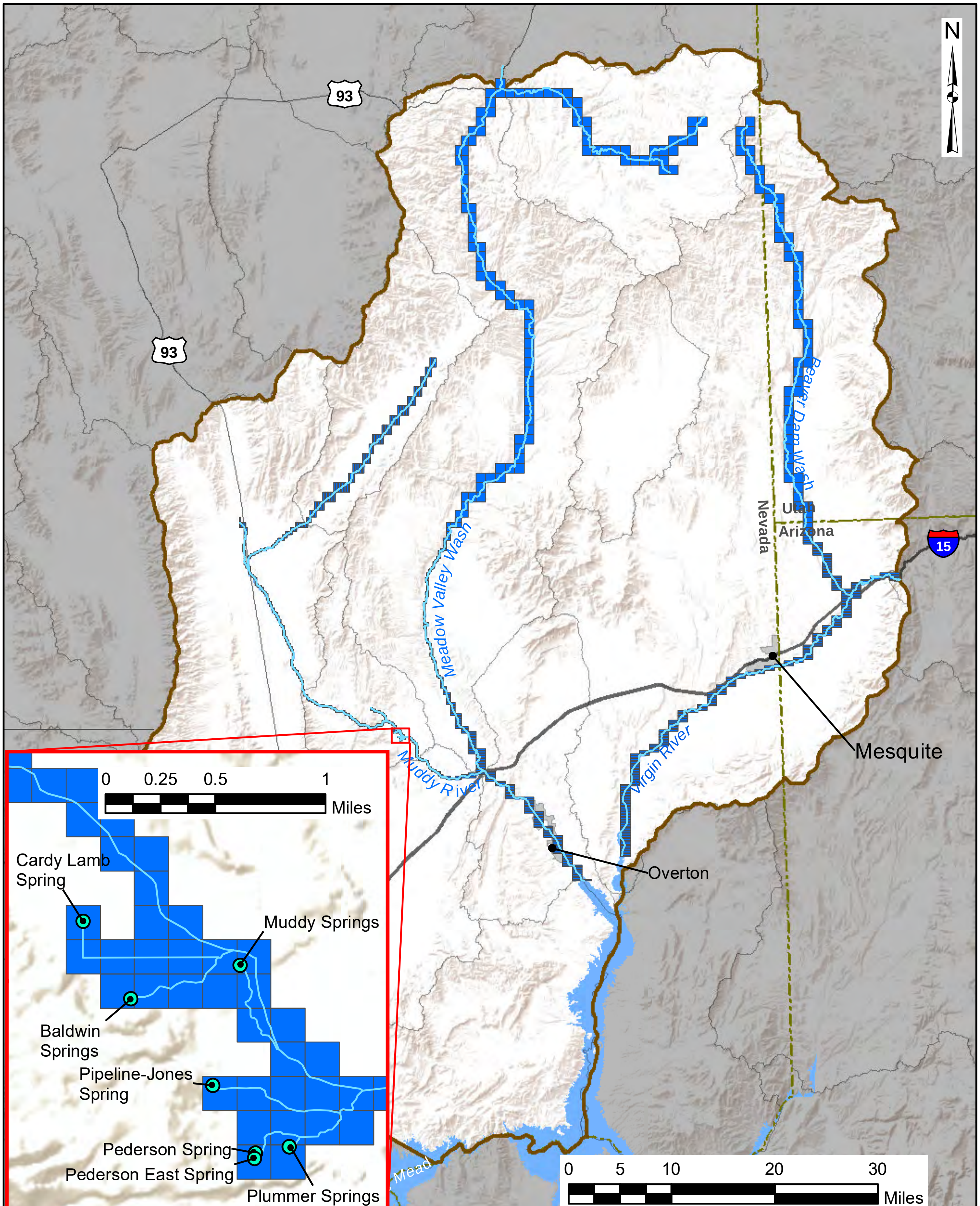
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.2-2**

SE ROA 12307

JA_5069



Legend

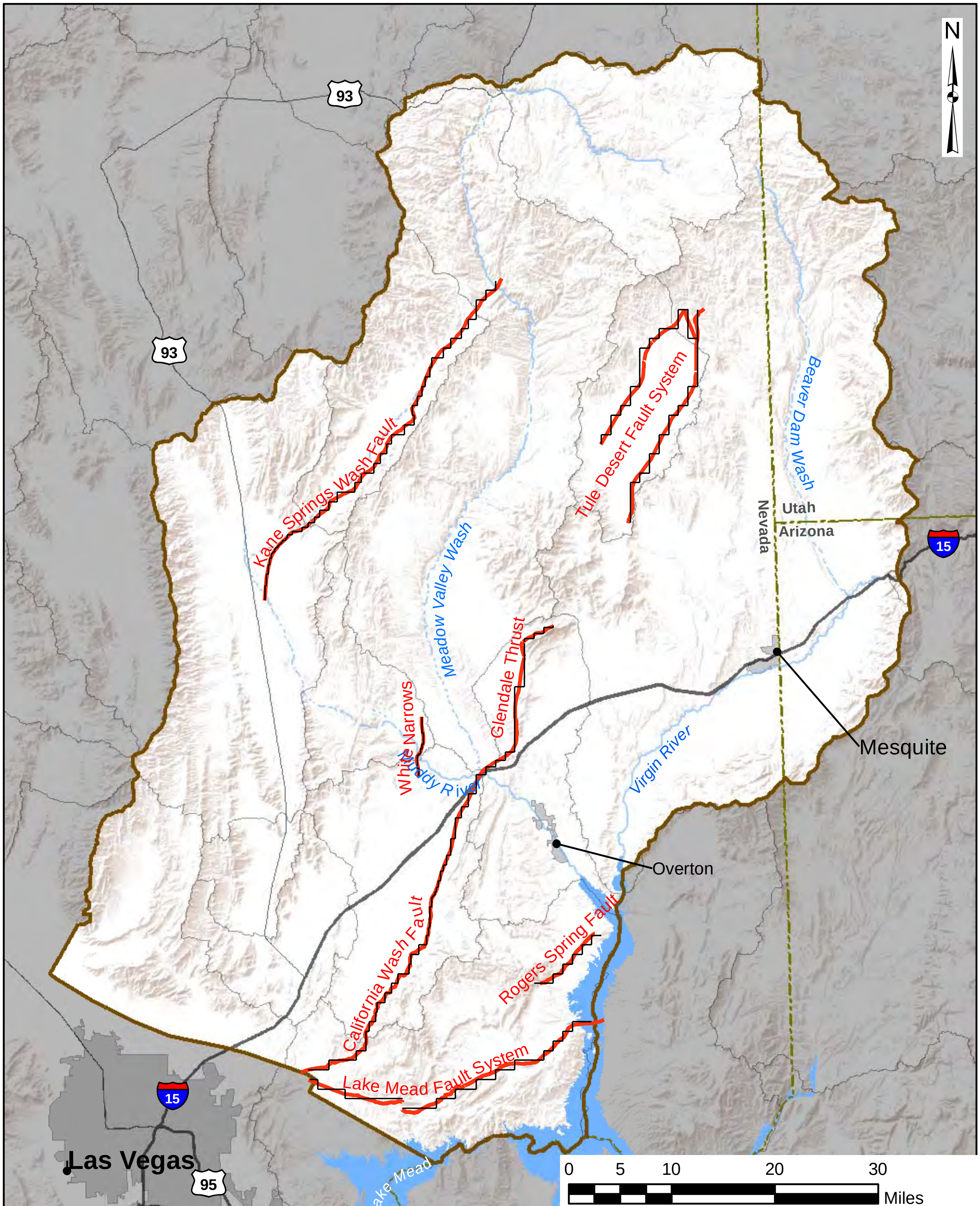
- Stream
- Streamflow-Routing Cell
- Active Model Domain
- Hydrographic Region

TITLE: **Streamflow-Routing Package Cells**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.2-3**



Legend

- Faults as HFB Boundaries
- Mapped Faults
- Active Model Domain
- Hydrographic Region

TITLE: **Faults Simulated Using HFB Package**

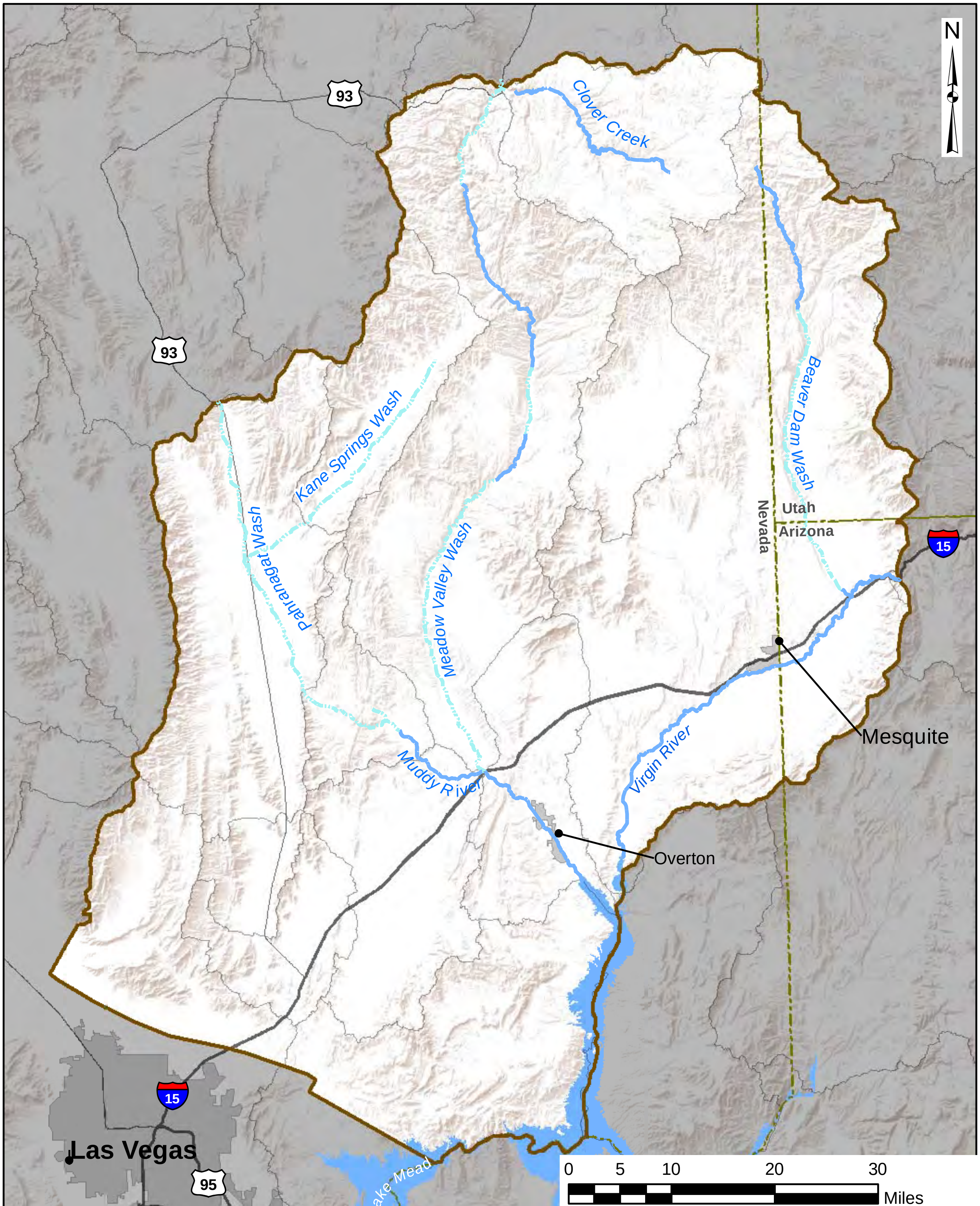
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.2-4**

SE ROA 12309

JA_5071



Legend

Ephemeral / Perennial Streams

- Ephemeral
- Perennial
- Active Model Domain
- Hydrographic Region

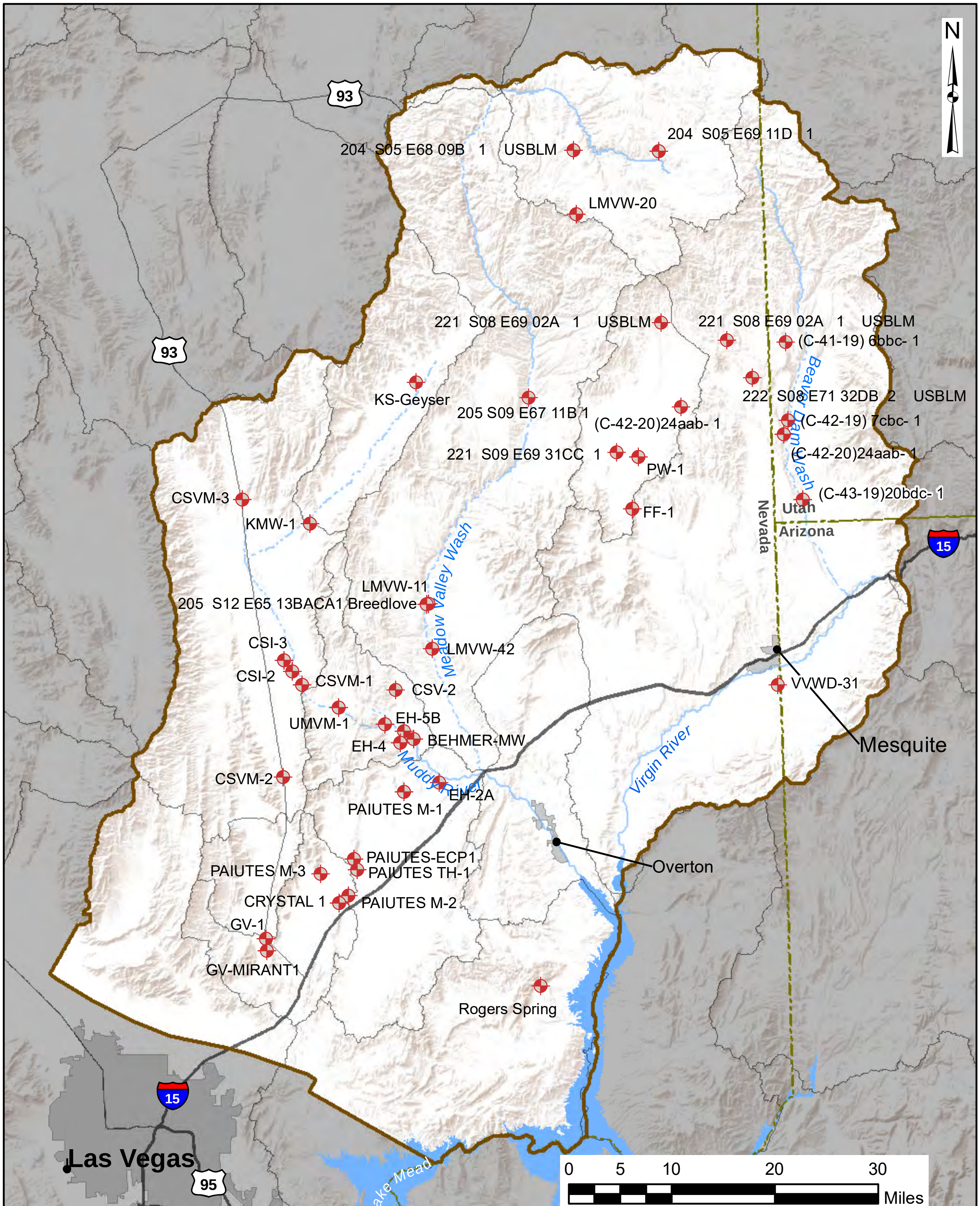
TITLE: **Ephemeral and Perennial Stream Segments**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.3-1**

SE ROA 12310



Legend

- Pre-Production Water-Level Target Well
- Active Model Domain
- Hydrographic Area

TITLE:

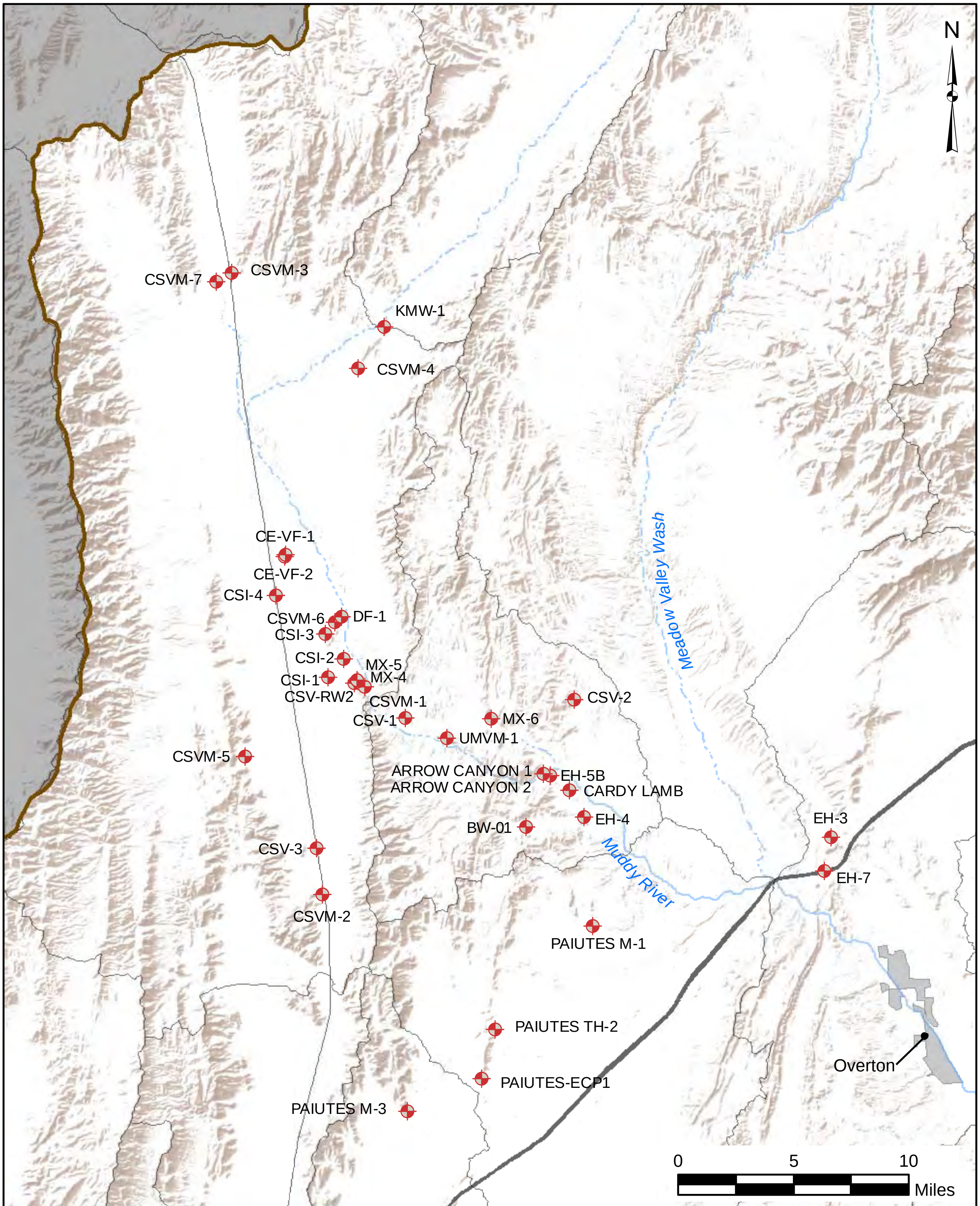
Pre-Production Water-Level Target Locations

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE

5.3-2



Legend

- Drawdown Target Wells
- Active Model Domain
- Hydrographic Area

TITLE: **Locations of Drawdown Target Wells**

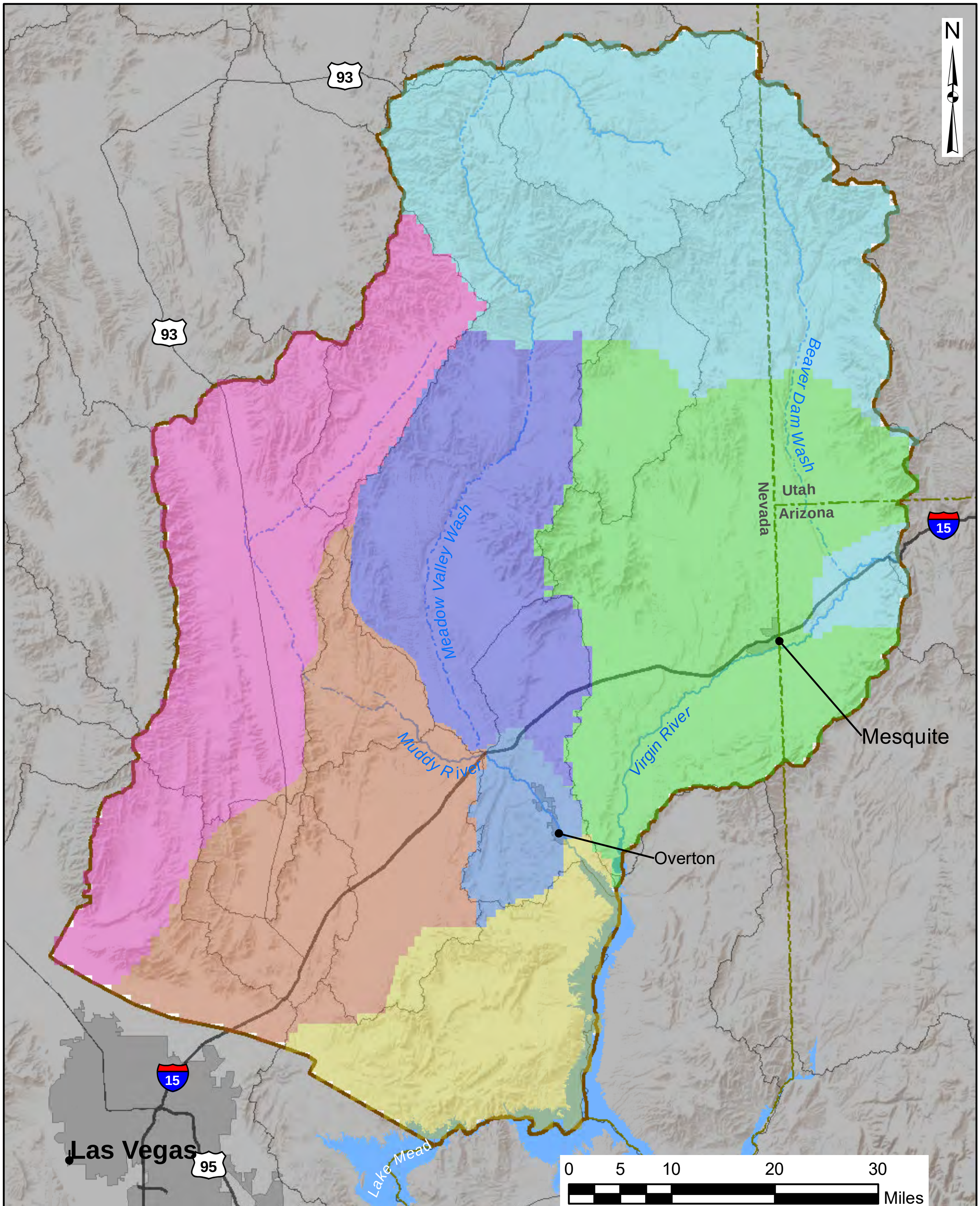
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **5.3-3**

SE ROA 12312

JA_5074



Legend

Active Model Domain	**CAU Zone**			4
Hydrographic Area		1		5
		2		6
		3		7

TITLE: **Zonation of CAU**

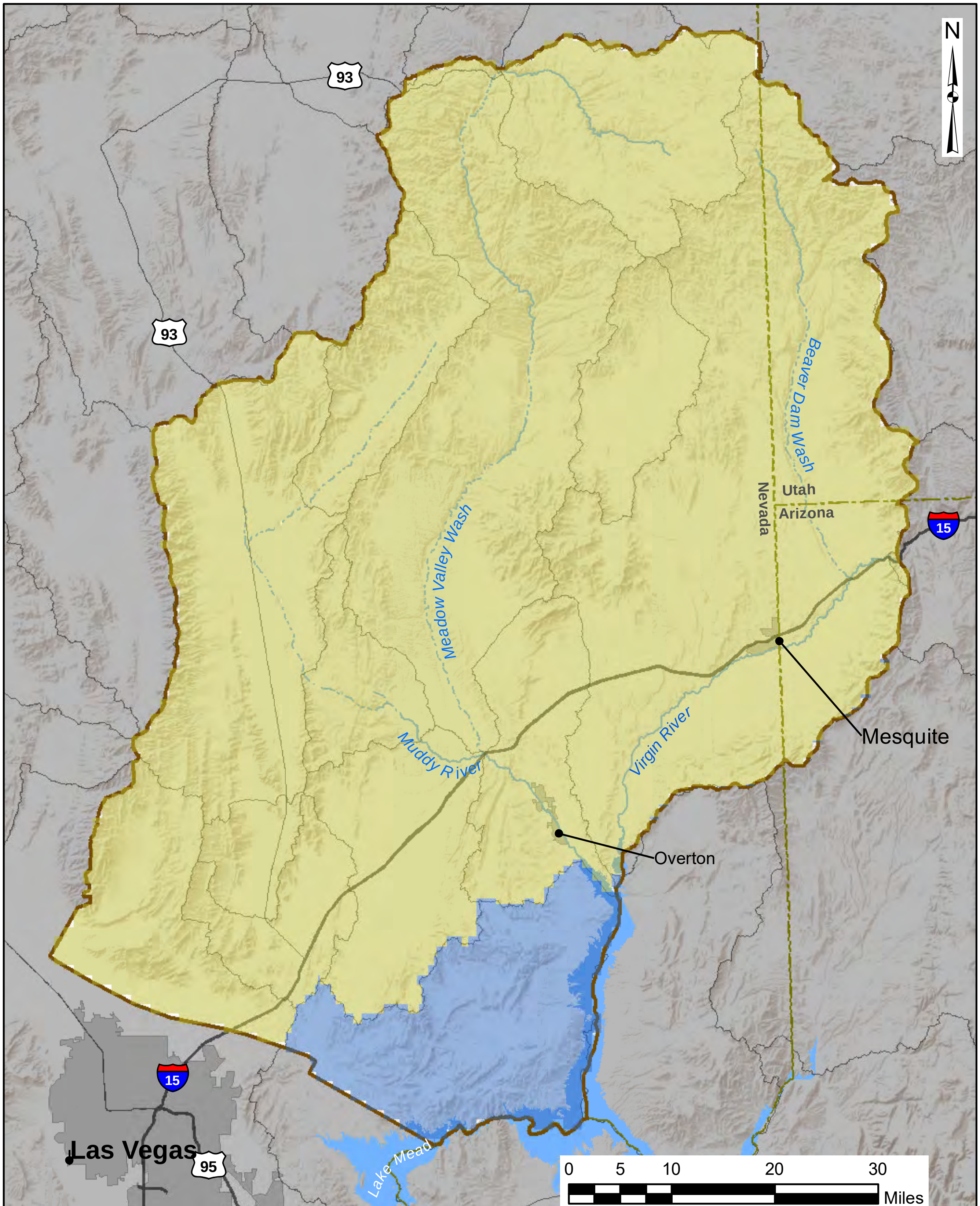
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.1-1**

SE ROA 12313

JA_5075



Legend

Active Model Domain
Hydrographic Area

Zones of TVC and XLB

1
2

TITLE: **Zonation of TVC and XLB**

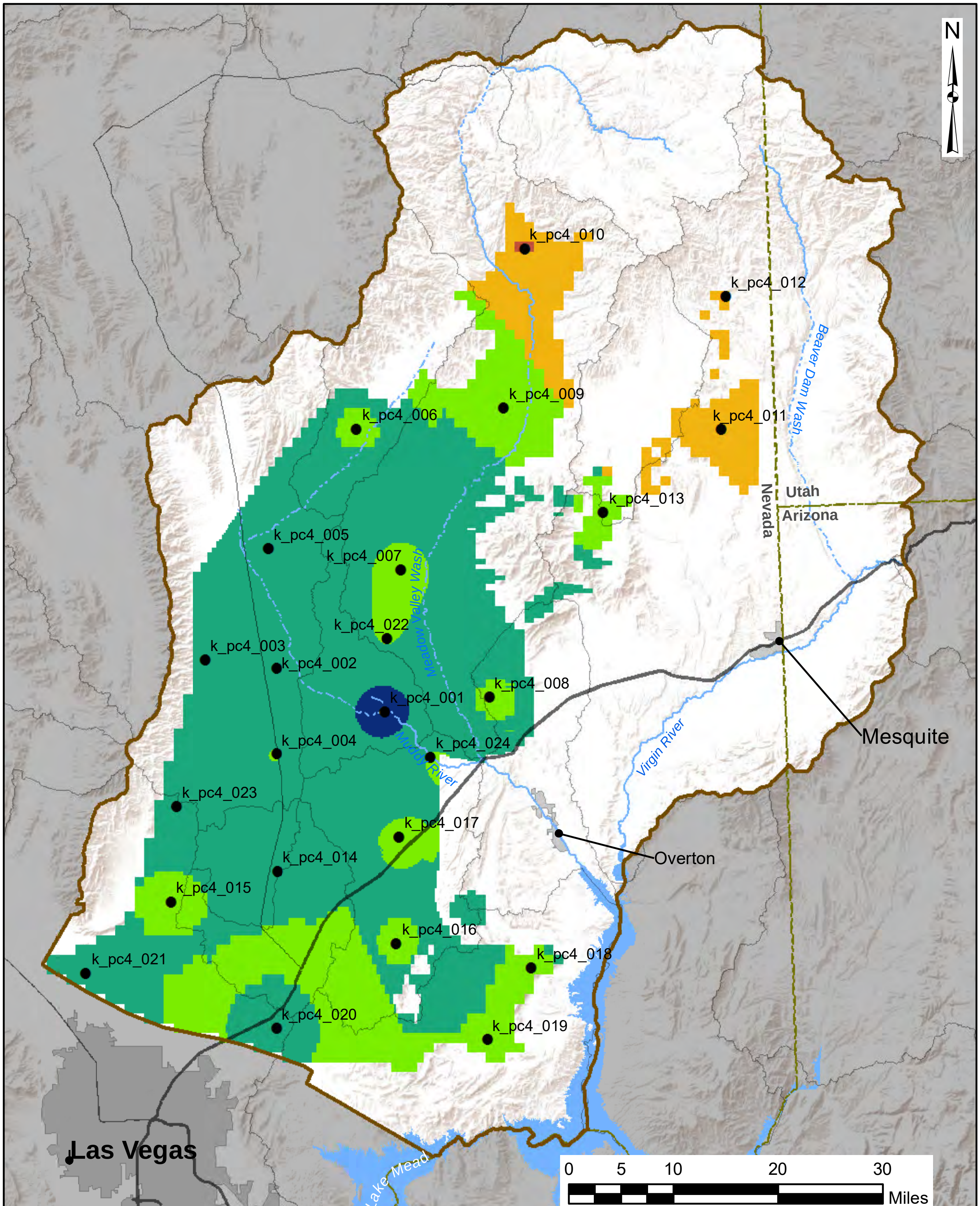
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.1-2**

SE ROA 12314

JA_5076



Legend

Log of Hydraulic Conductivity of PC4 (ft/d)

- 0.9997 - 1.0000
- 1.0001 - 2.0000
- 2.0001 - 3.0000
- 3.0001 - 4.0000
- 4.0001 - 5.0000

- PC4 Pilot Points
- Active Model Domain
- Hydrographic Region

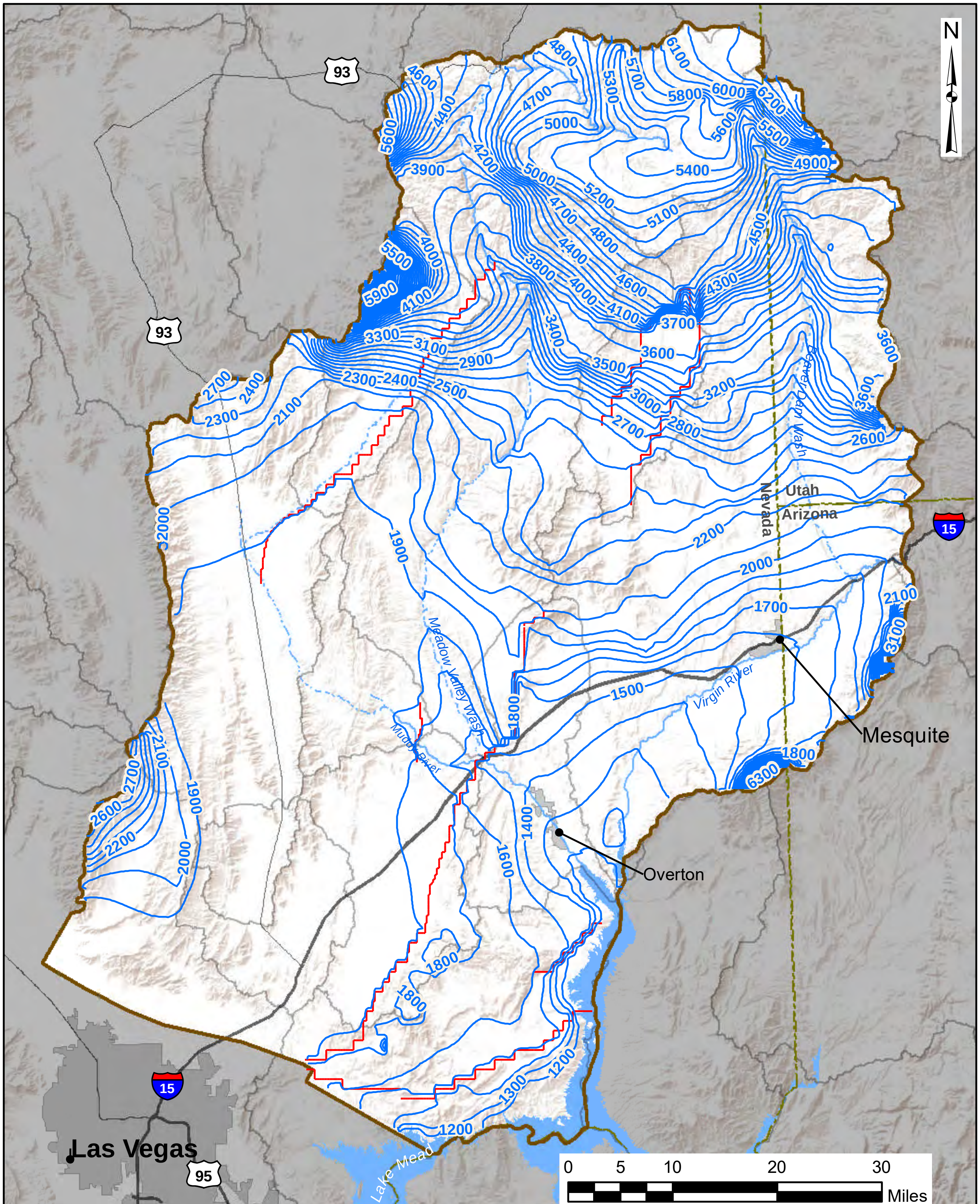
TITLE:

Hydraulic Conductivity of PC4

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.1-3**



Legend

Water Level Elevation Contour (ft amsl)

Faults as HFB Boundaries

Active Model Domain

Contour Interval = 100 feet

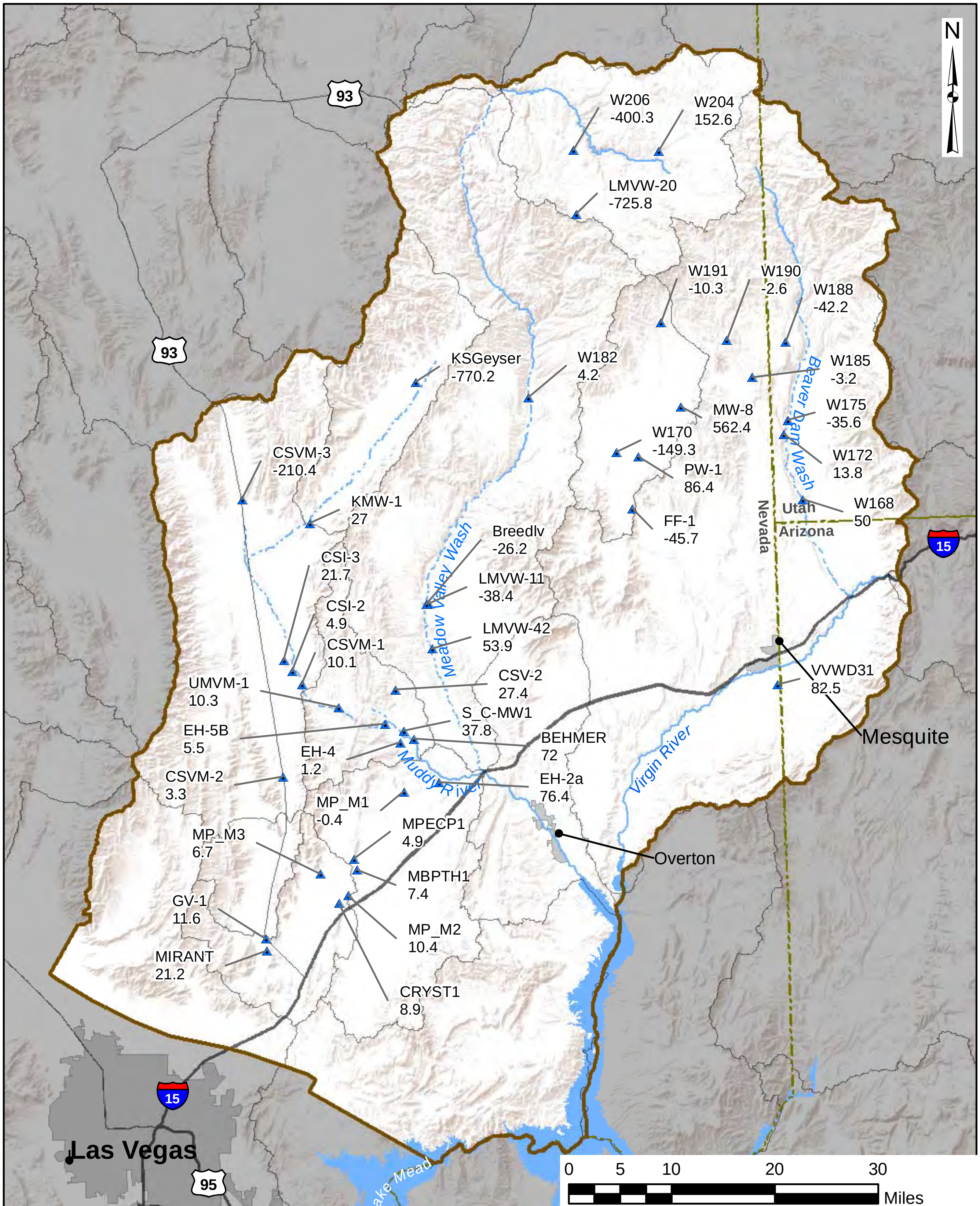
TITLE: **Pre-Production Simulated Water Table**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.2-1**

SE ROA 12316



Legend

- Pre-Production Target Locations
- Active Model Domain
- Hydrographic Area

Residuals represent the difference between simulated water levels in 1949 and earliest appropriate measured water level at a location.

TITLE:

Pre-Production Water Level Residuals

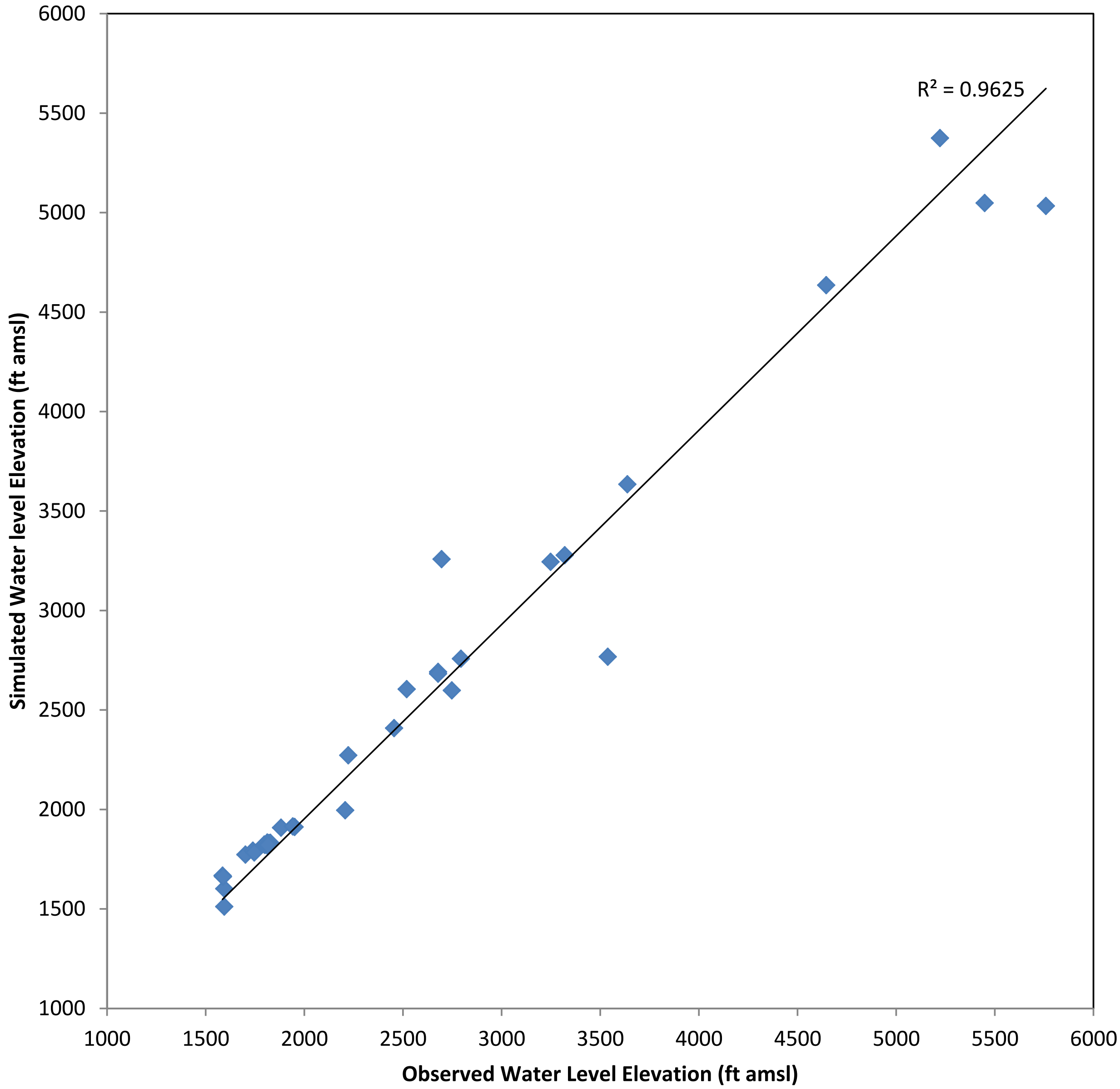
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.2-2**

SE ROA 12317

JA_5079

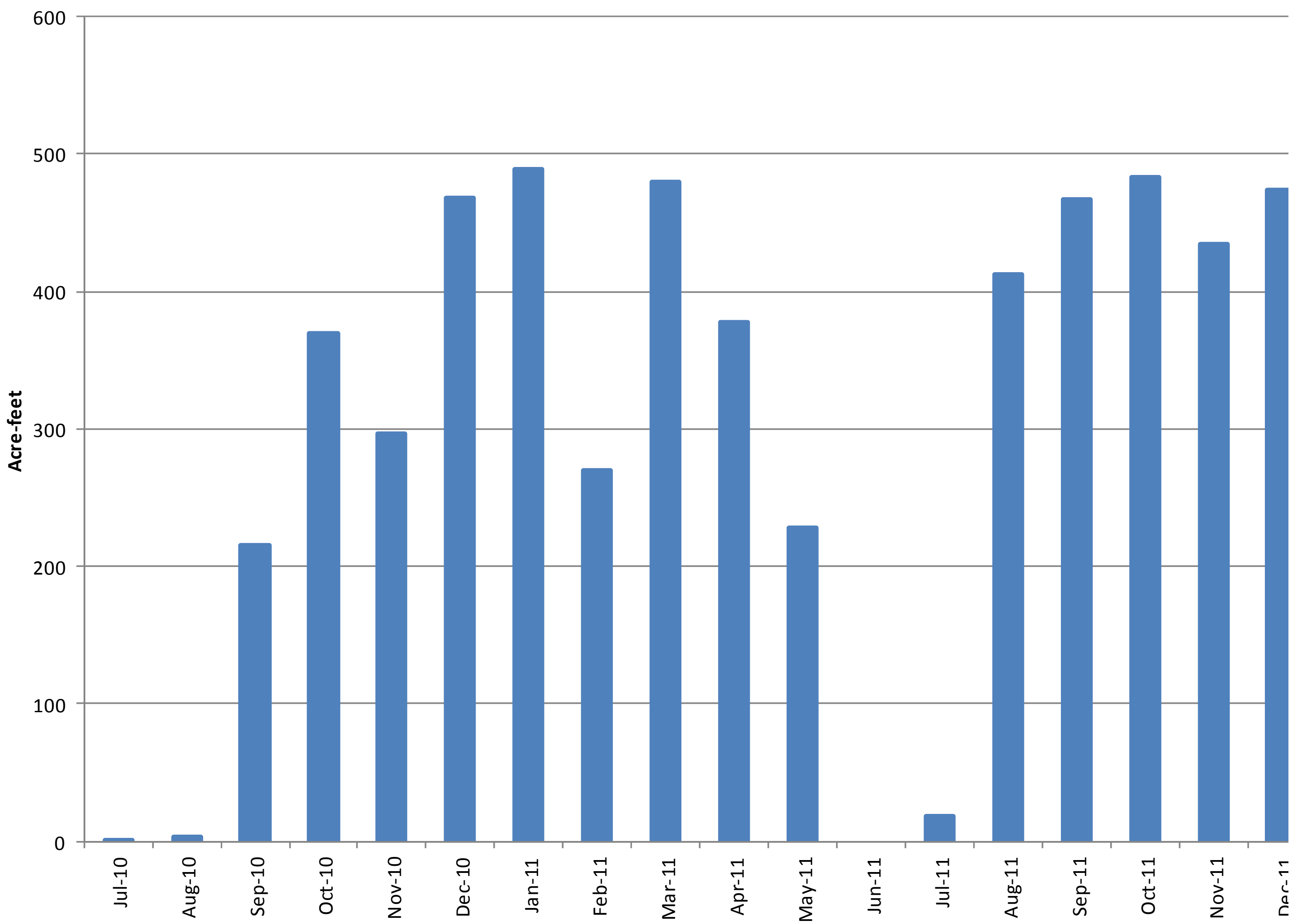


Correlation Between Measured and Simulated Water Levels, Pre-Production Model

Lower Colorado River Flow System

TETRA TECH GEO

Figure 6.2-3

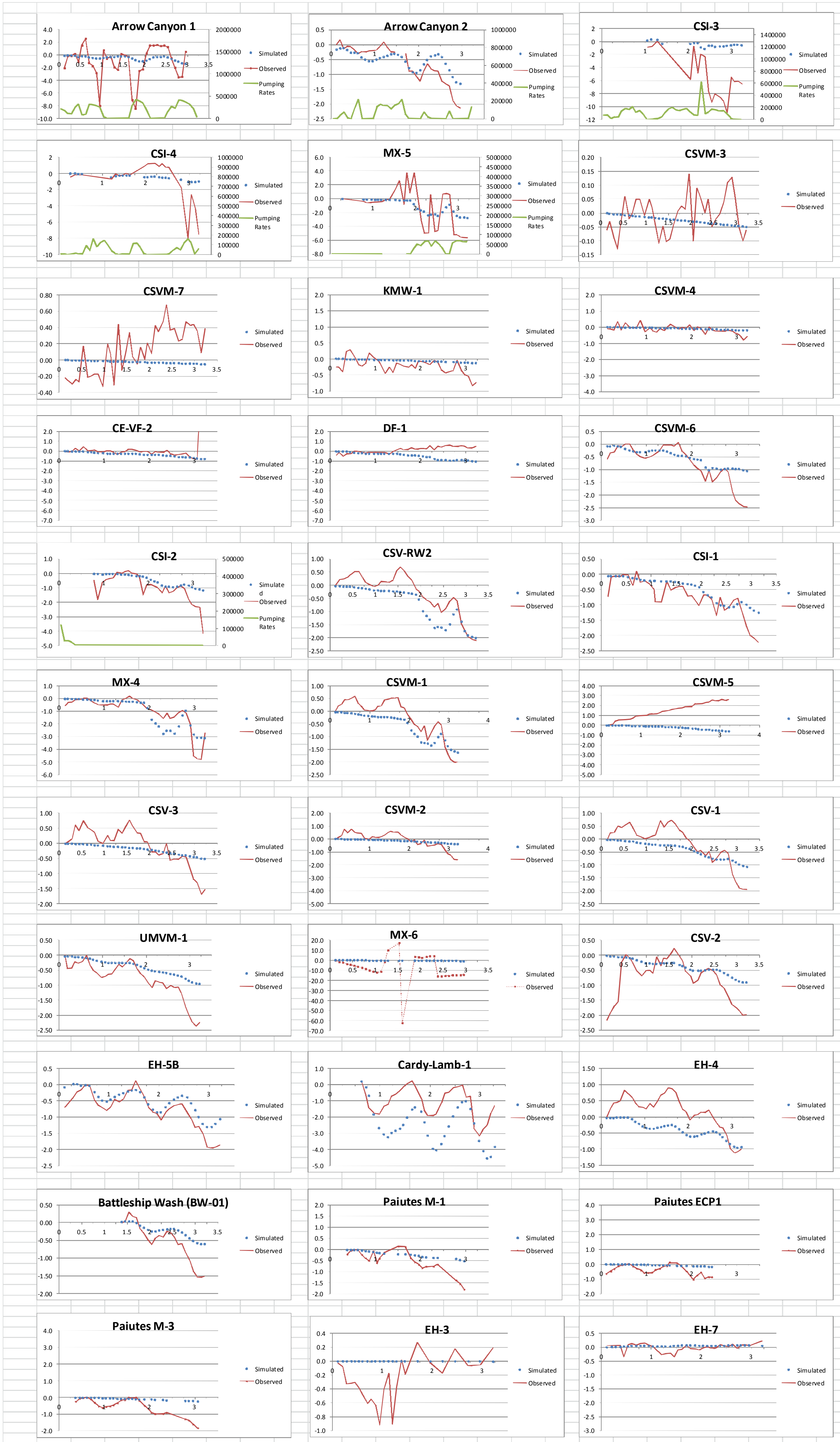


Order 1169 Pumping
July 2010 – December 2011 for MX-5

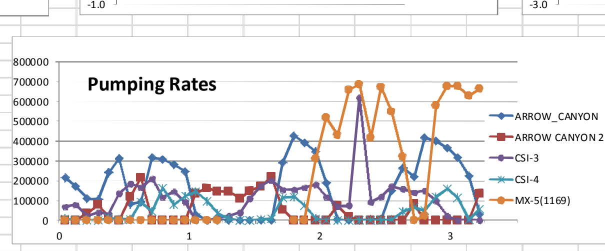
Lower Colorado River Flow System

TETRA TECH GEO

Figure 6.2-4



Note: Arrow Canyon 2 water level measurements corrected by 2.51 feet from 7/1/10 to end.
CSI-1 water level measurements corrected by 12.4 feet from 12/1/09 to end.

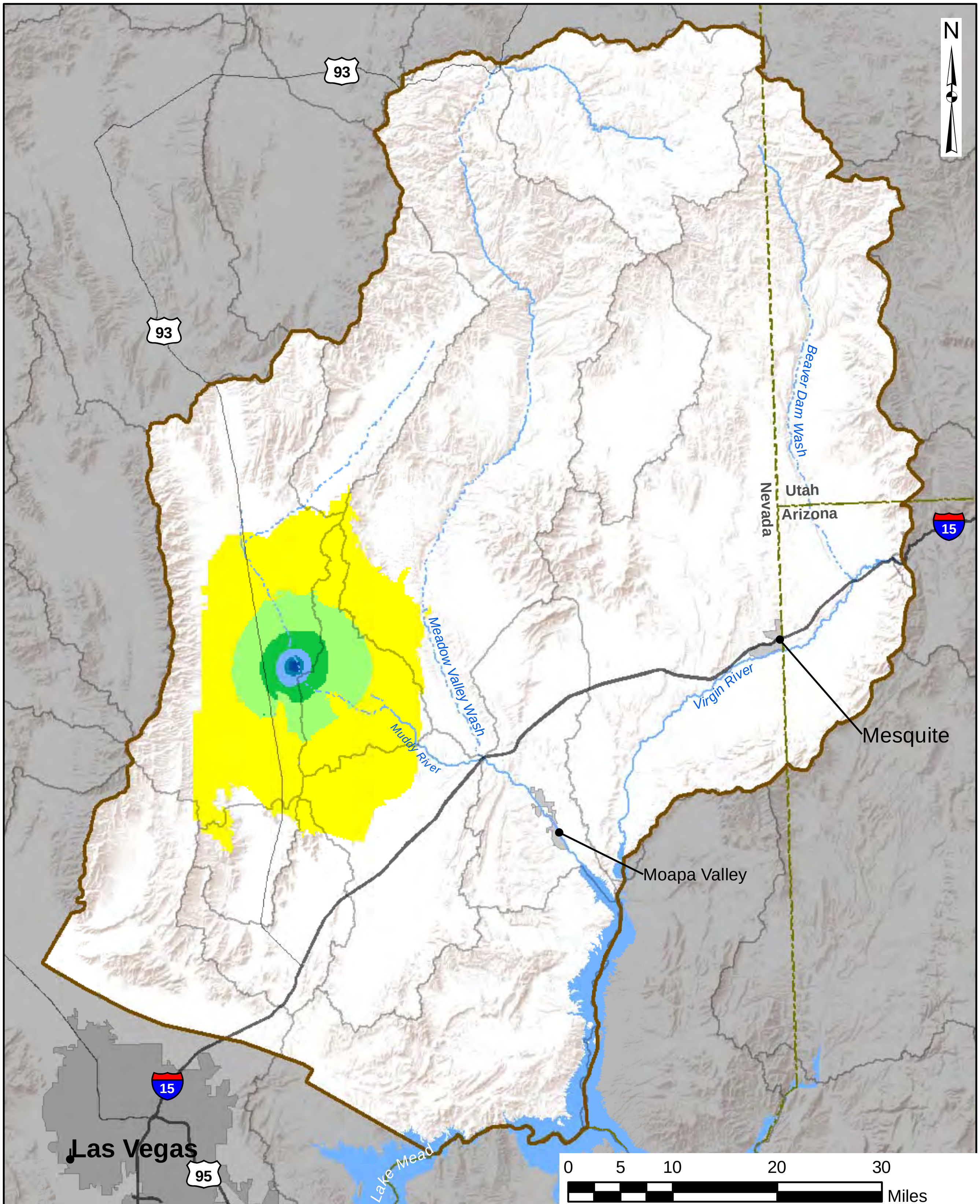


Comparison of Observed and Simulated Drawdown Order 1169 Simulation

Lower Colorado River Flow System

TETRA TECH GEO

Figure 6.2-5



Legend

Active Model Domain
State Boundary

Drawdown

2.01 - 4.00	0.41 - 0.60
1.01 - 2.00	0.21 - 0.40
0.81 - 1.00	0.01 - 0.20
0.61 - 0.80	

Drawdown is in feet

Drawdown calculated based MX-5 pumping

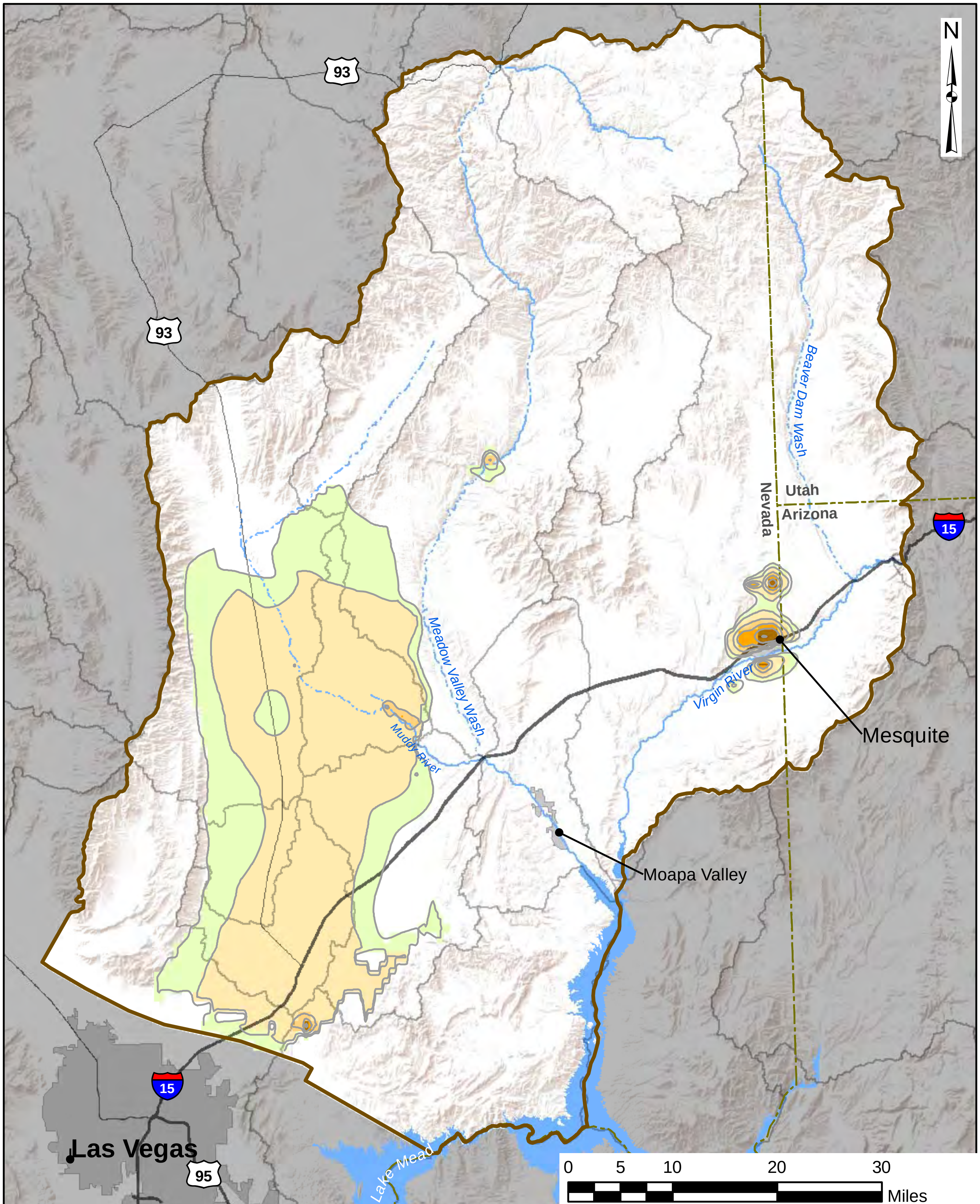
TITLE:

Drawdown from MX-5 Pumping, October 2009 - December 2011

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.2-6**



Legend

< 1	20 - 50	Active Model Domain
1 - 2	50 - 100	State Boundary
2 - 5	100 - 200	
5 - 10	200 - 500	
10 - 20	> 500	

Drawdown is in feet

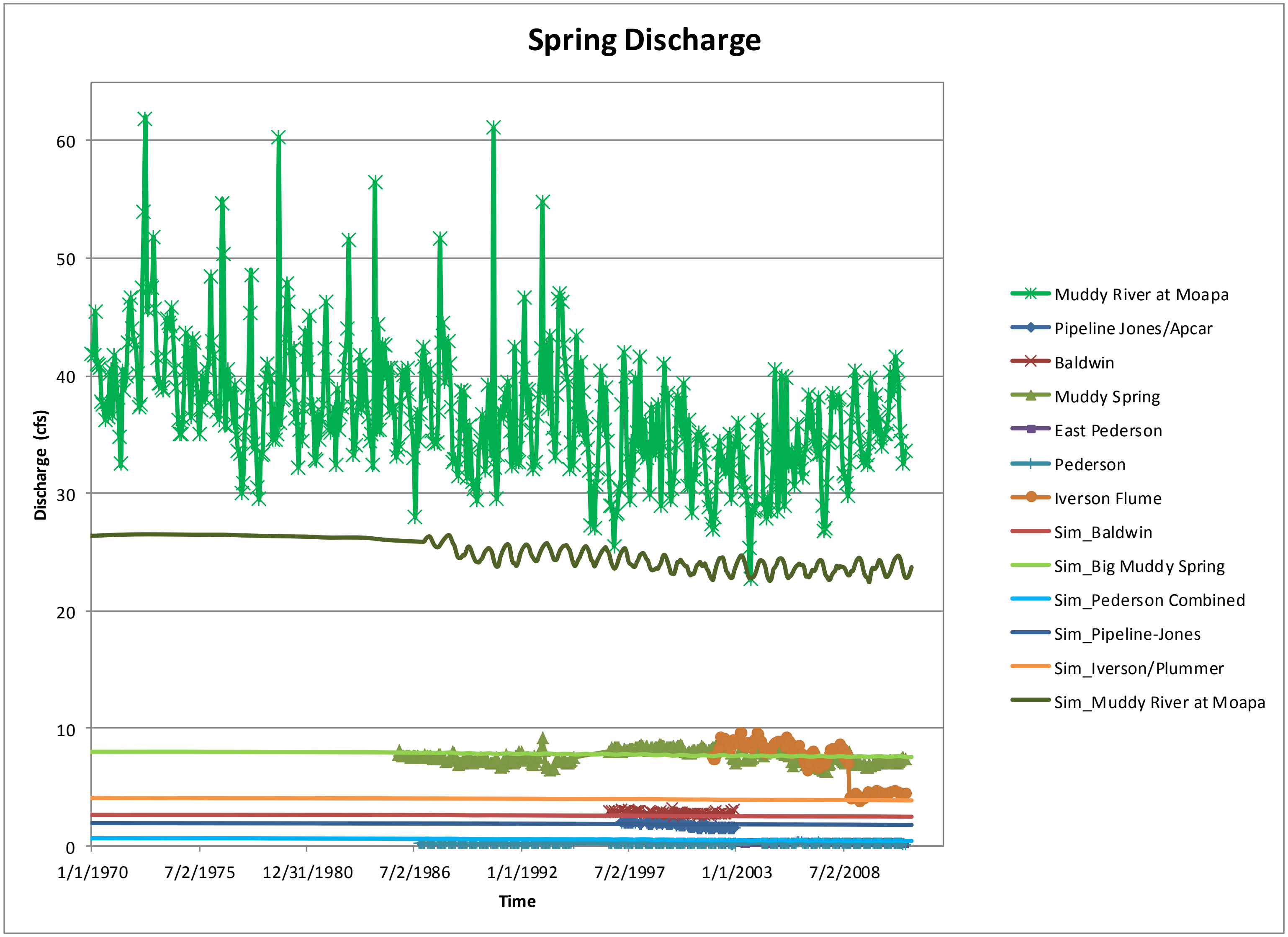
Drawdown calculated as change in water level elevation between1949 and December 2011

TITLE: **Simulated Drawdown, December 2011**

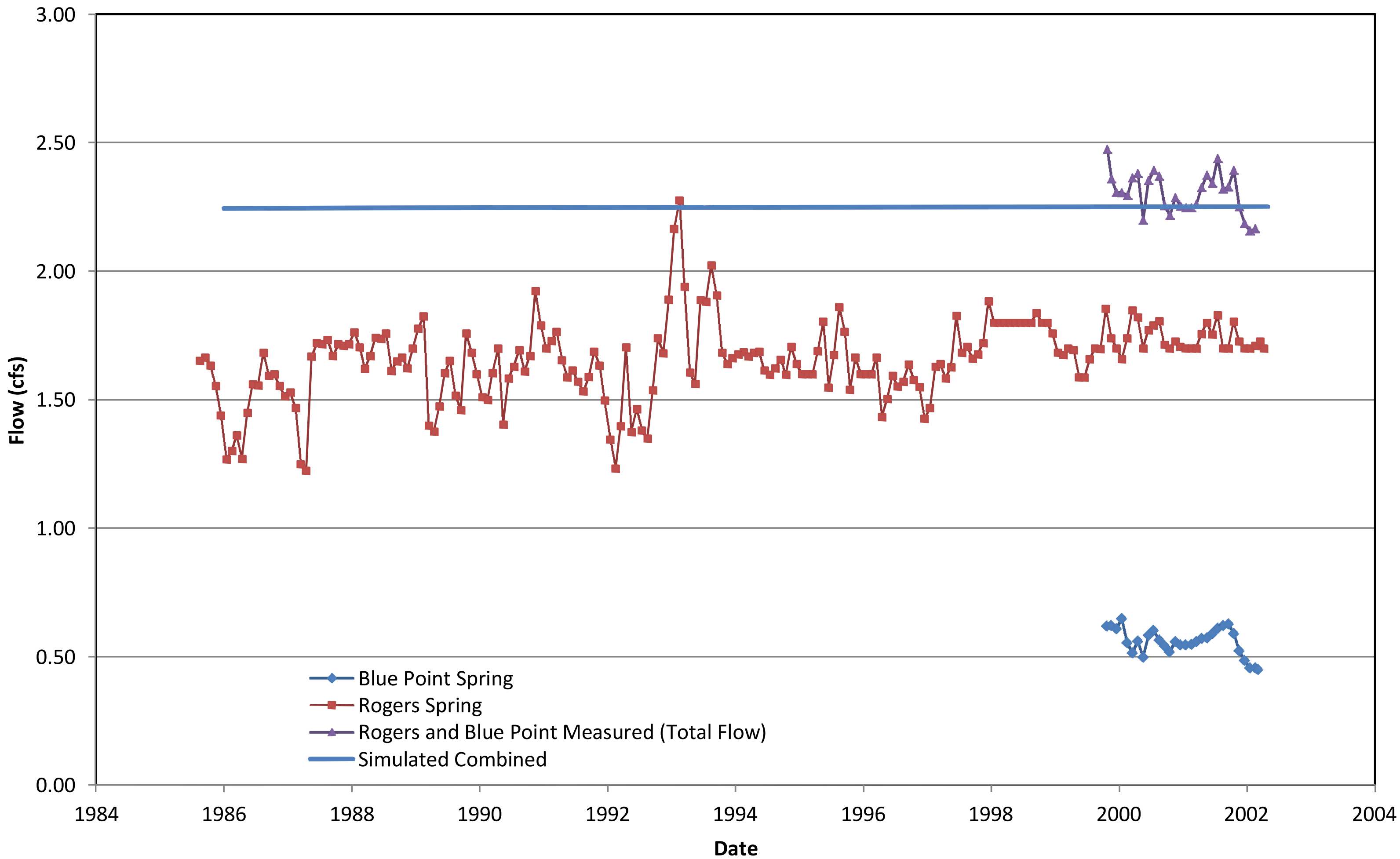
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.2-7**



Observed and Simulated Spring Discharge	
Lower Colorado River Flow System	
TETRA TECH GEO	Figure 6.3-1

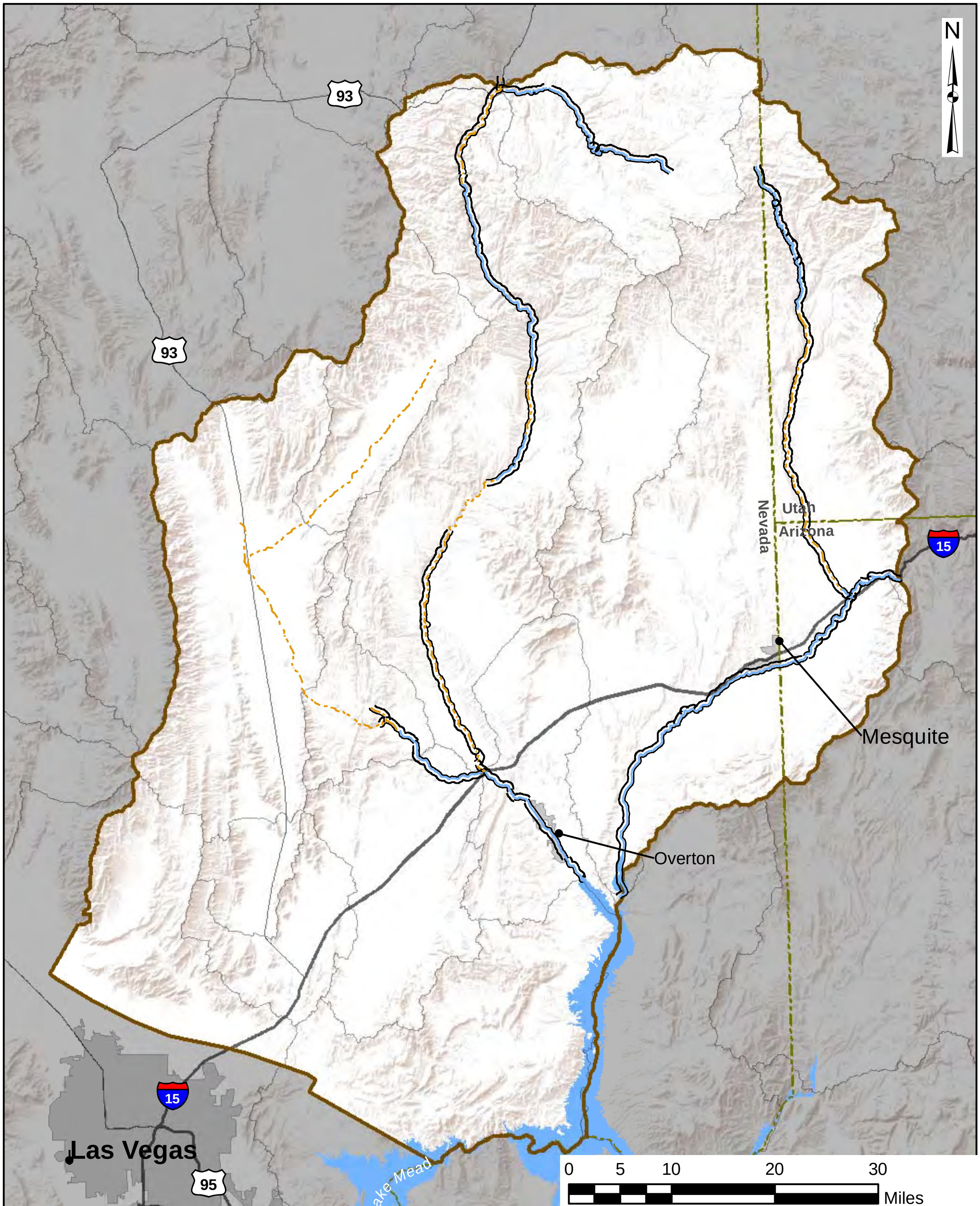


Observed and Simulated
Rogers and Blue Point Spring Discharge

Lower Colorado River Flow System

TETRA TECH GEO

Figure
6.3-2



Legend

- Simulated Perennial Stream
- Ephemeral Stream
- Perennial Stream
- Active Model Domain
- Hydrographic Region

TITLE: **Observed and Simulated Ephemeral and Perennial Stream Segments**

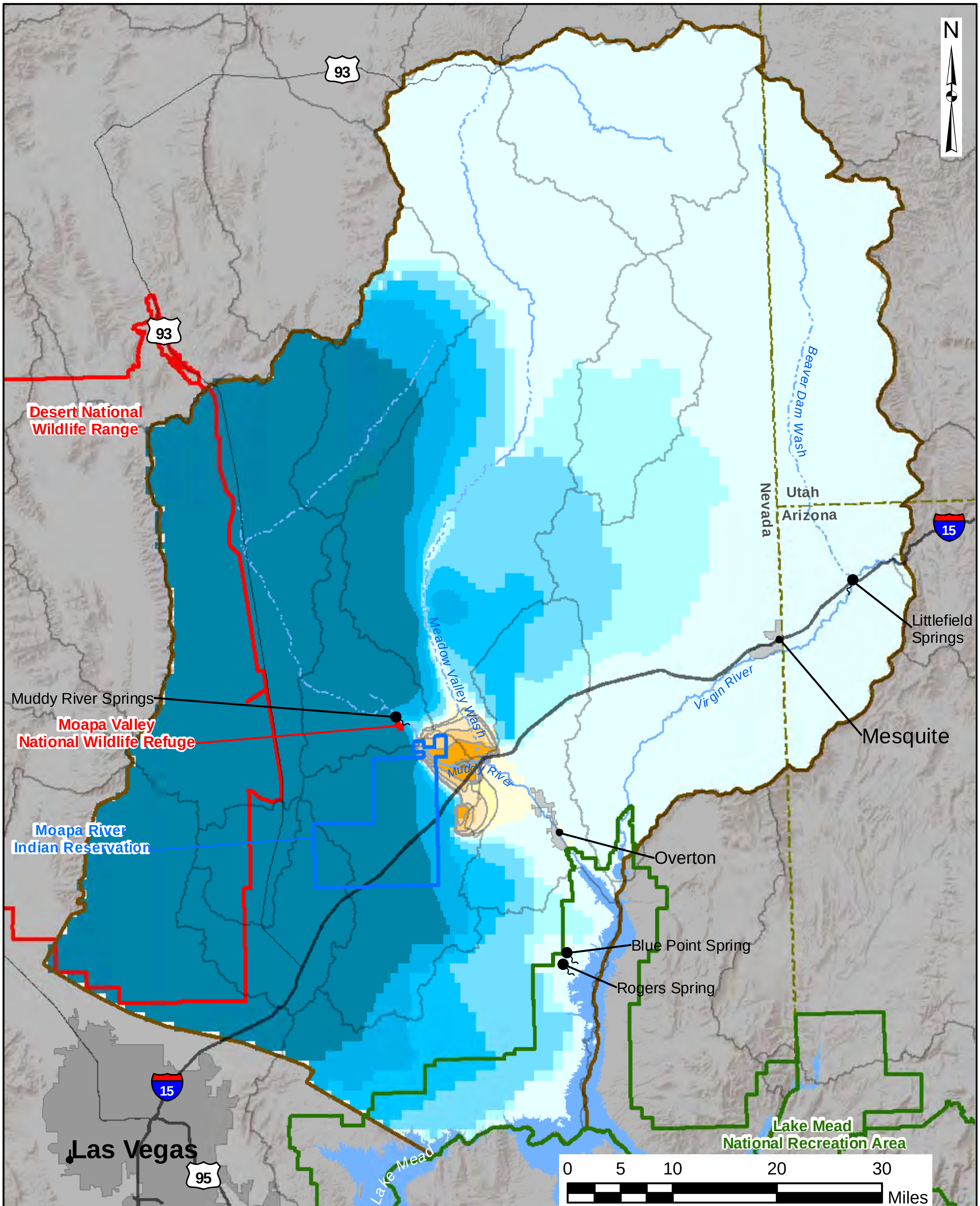
LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.4-1**

SE ROA 12325

JA_5087



Legend

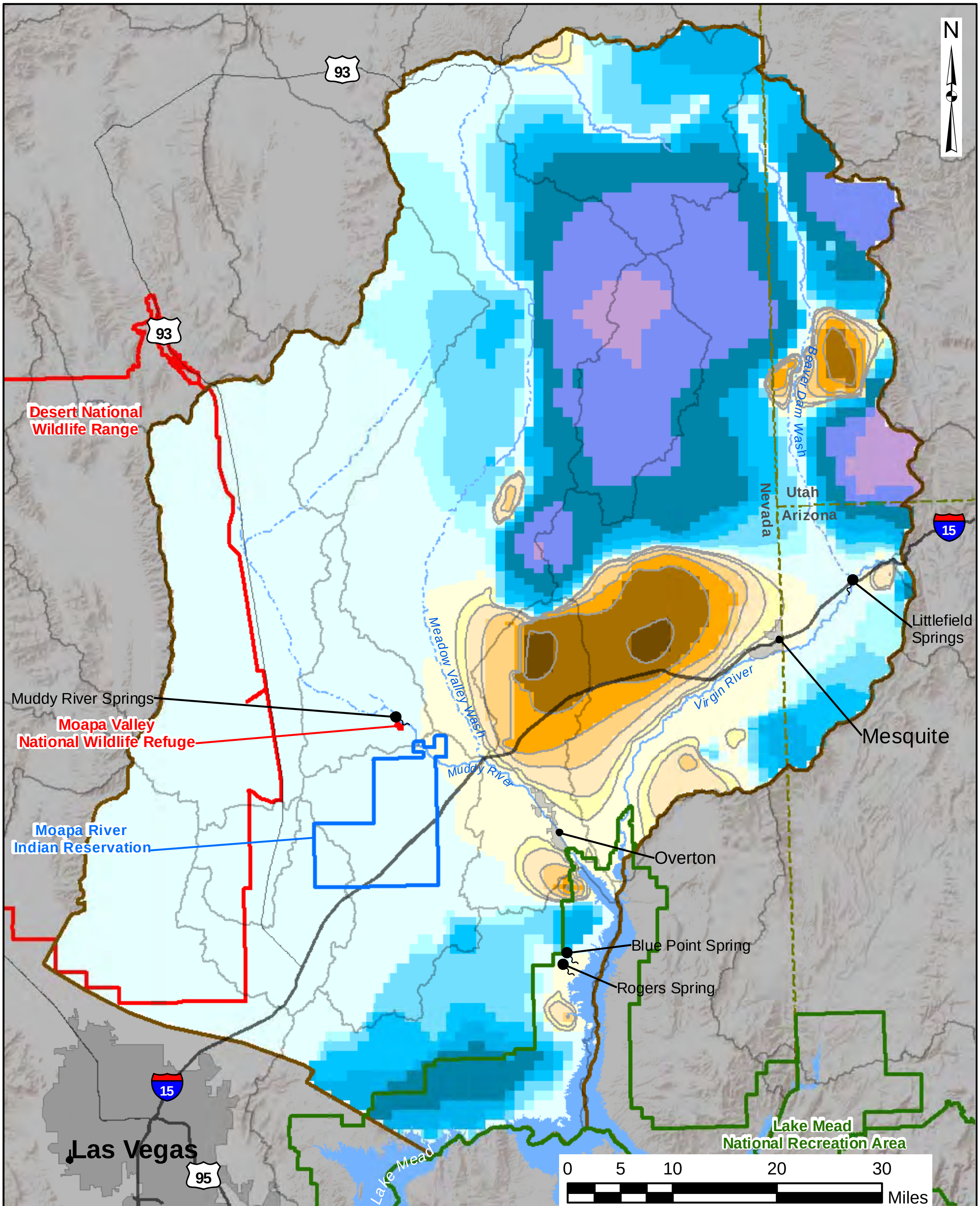
-200 to -100	1 to 2	Active Model Domain
-100 to -50	2 to 5	State Boundary
-50 to -20	5 to 10	
-20 to -10	10 to 20	
-10 to -5	20 to 50	
-5 to -2	50 to 100	
-2 to -1	100 to 200	
-1 to 0	> 200	
0 to 1	Simulated change is in feet.	

TITLE: **Simulated Changes in Water Level 100 Percent Increase in Horizontal Hydraulic Conductivity of CAU**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.6-1**



Legend

-200 to -100	1 to 2	Active Model Domain
-100 to -50	2 to 5	State Boundary
-50 to -20	5 to 10	
-20 to -10	10 to 20	
-10 to -5	20 to 50	
-5 to -2	50 to 100	
-2 to -1	100 to 200	
-1 to 0	> 200	
0 to 1		

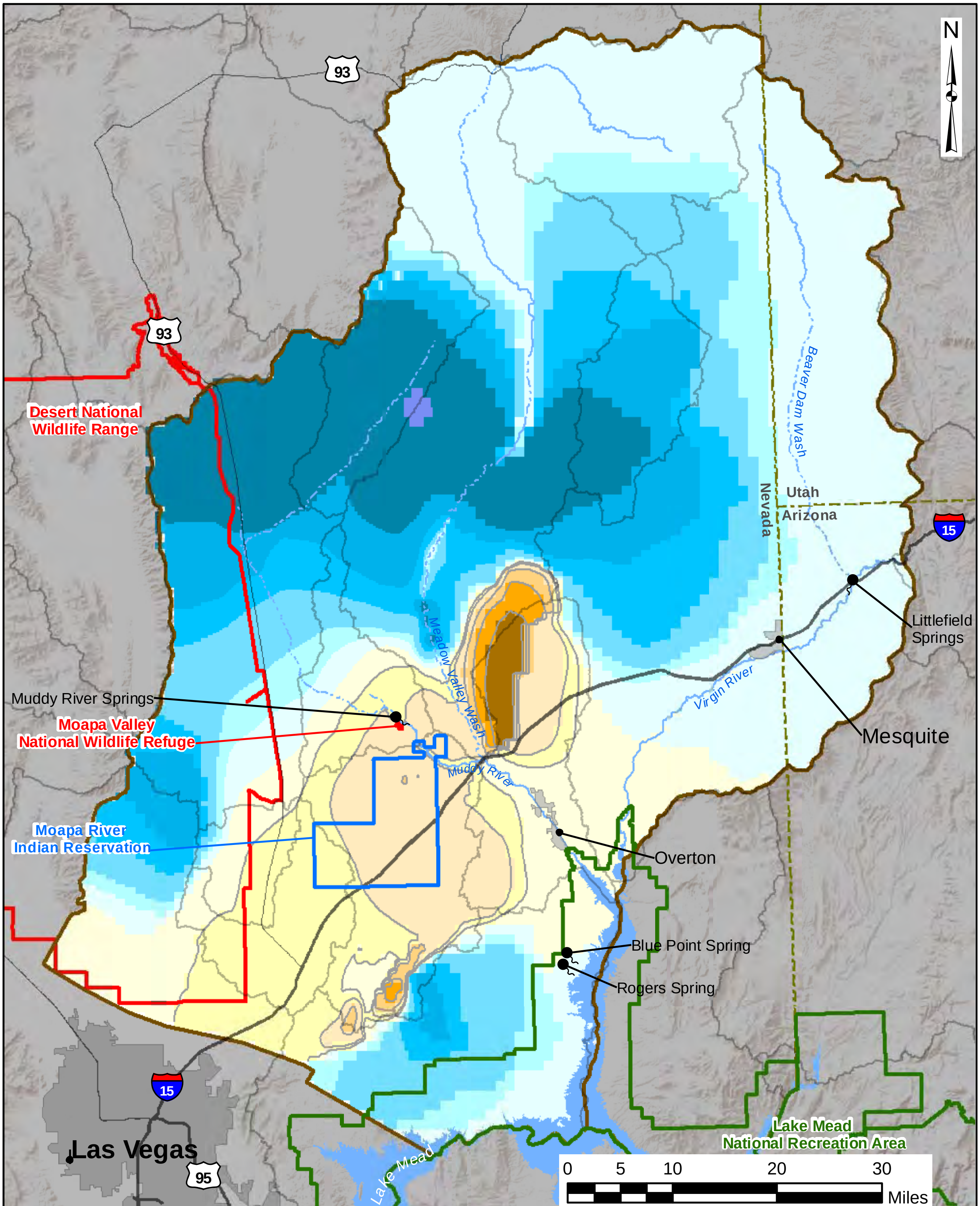
Simulated change is in feet.

TITLE: **Simulated Changes in Water Level 100 Percent Increase in Horizontal Hydraulic Conductivity of PC1**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.6-2**



Legend

-200 to -100	1 to 2	Active Model Domain
-100 to -50	2 to 5	State Boundary
-50 to -20	5 to 10	
-20 to -10	10 to 20	
-10 to -5	20 to 50	
-5 to -2	50 to 100	
-2 to -1	100 to 200	
-1 to 0	> 200	
0 to 1		

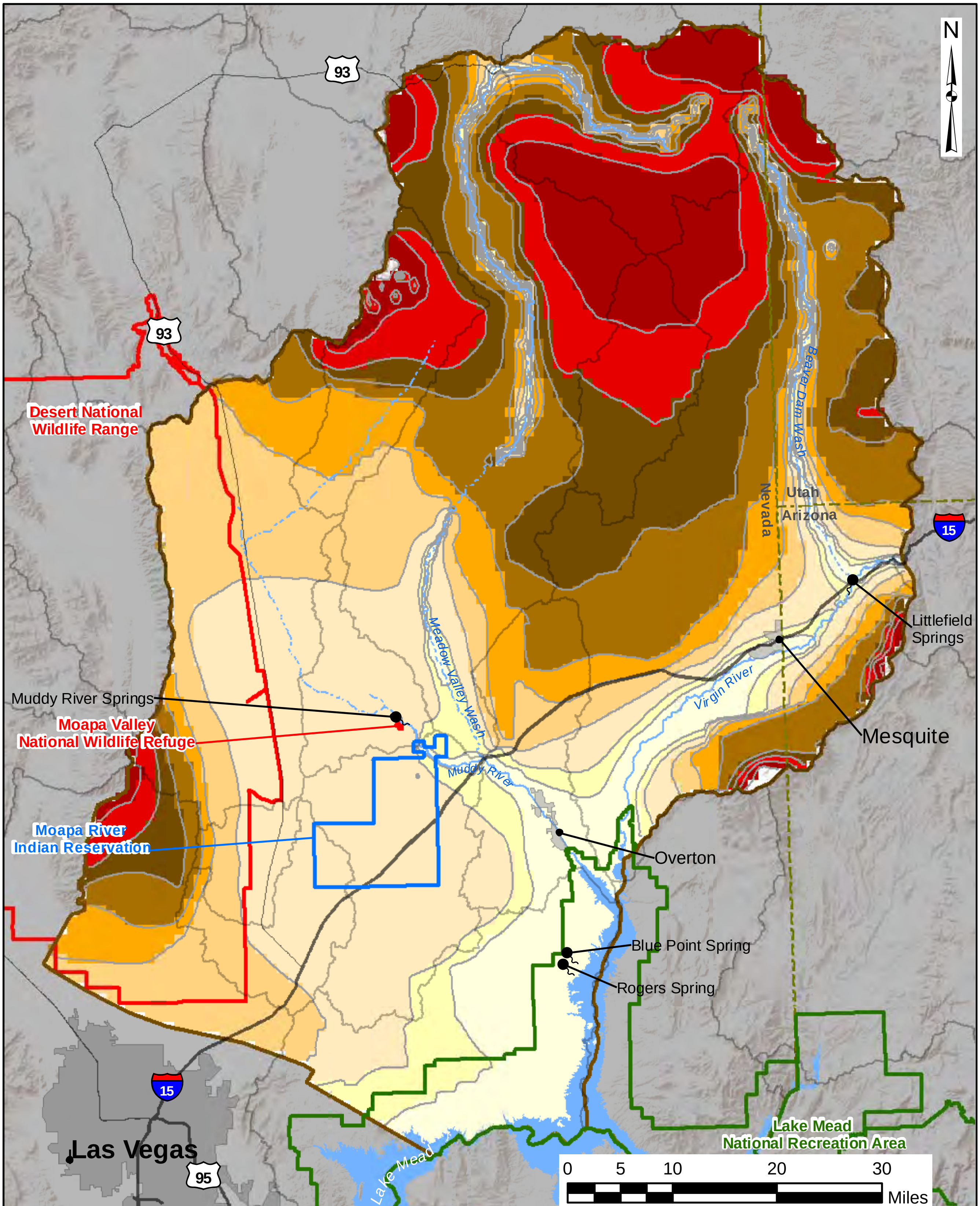
Simulated change is in feet.

TITLE: **Simulated Changes in Water Level 100 Percent Increase in Hydraulic Conductivity of PC4_1**

LOCATION: **Colorado Regional Groundwater Flow System Southeastern Nevada**

TETRA TECH

FIGURE **6.6-3**



Legend

-200 to -100
-100 to -50
-50 to -20
-20 to -10
-10 to -5
-5 to -2
-2 to -1
-1 to 0
0 to 1
1 to 2
2 to 5
5 to 10
10 to 20
20 to 50
50 to 100
100 to 200
> 200

Active Model Domain
State Boundary

Simulated change is in feet.

TITLE:
Simulated Changes in Water Level
25 Percent Increase in Regional Recharge

LOCATION: **Colorado Regional Groundwater Flow System**
Southeastern Nevada

TETRA TECH

FIGURE
6.6-4

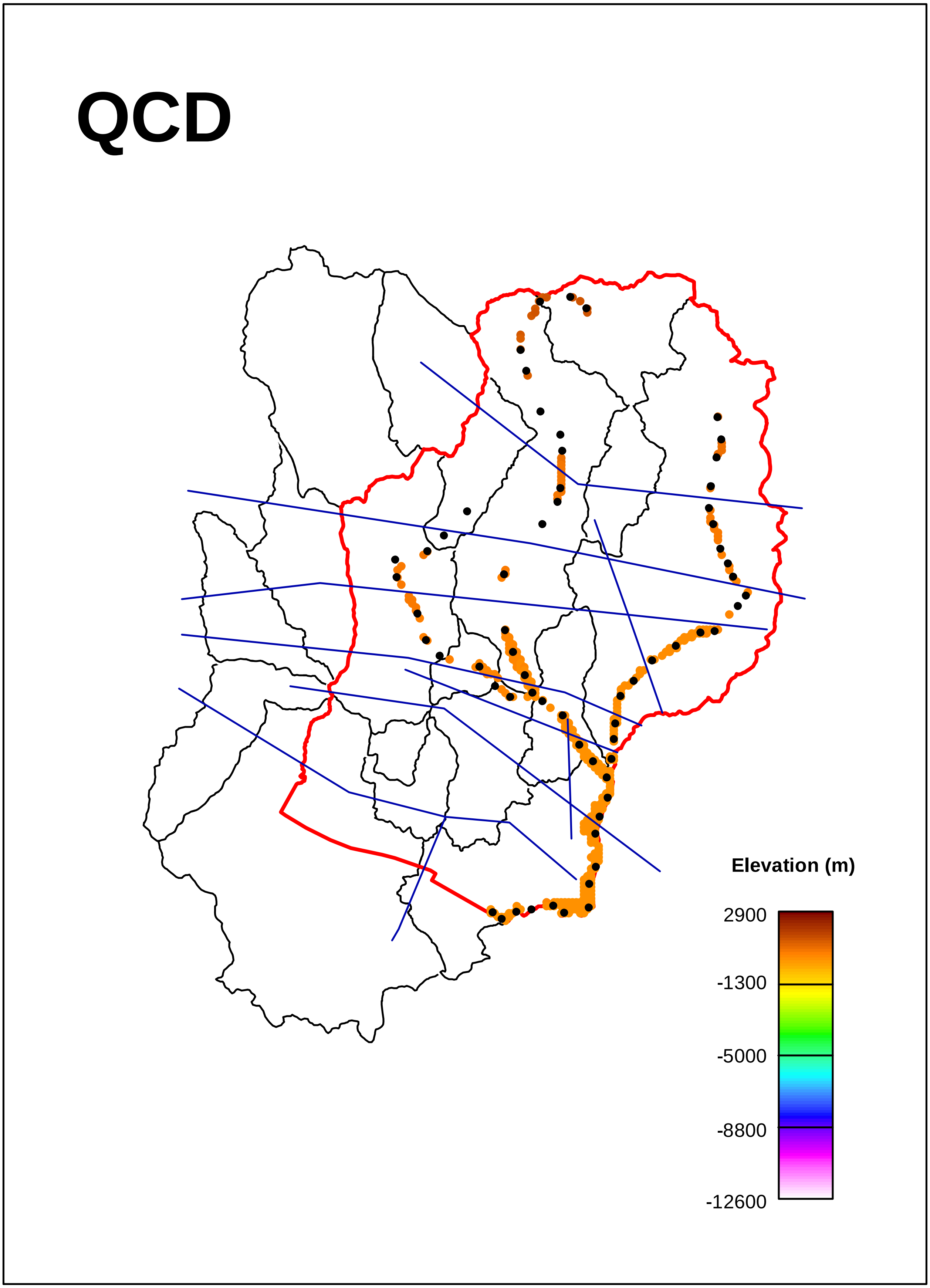
SE ROA 12330

ATTACHMENT I

Distributions and Top Elevations of Hydrogeologic Units

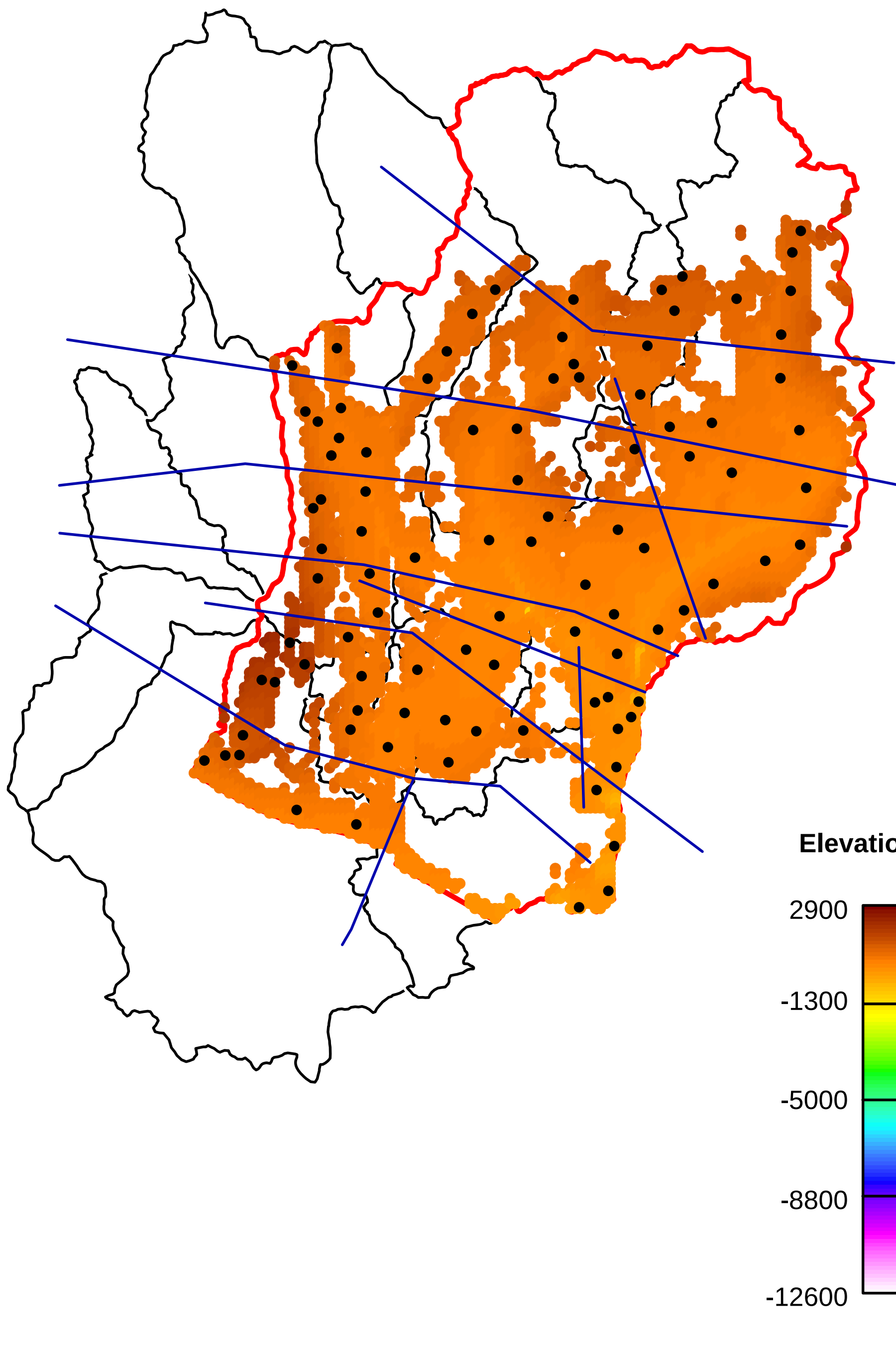
SE ROA 12331

SE ROA 12332



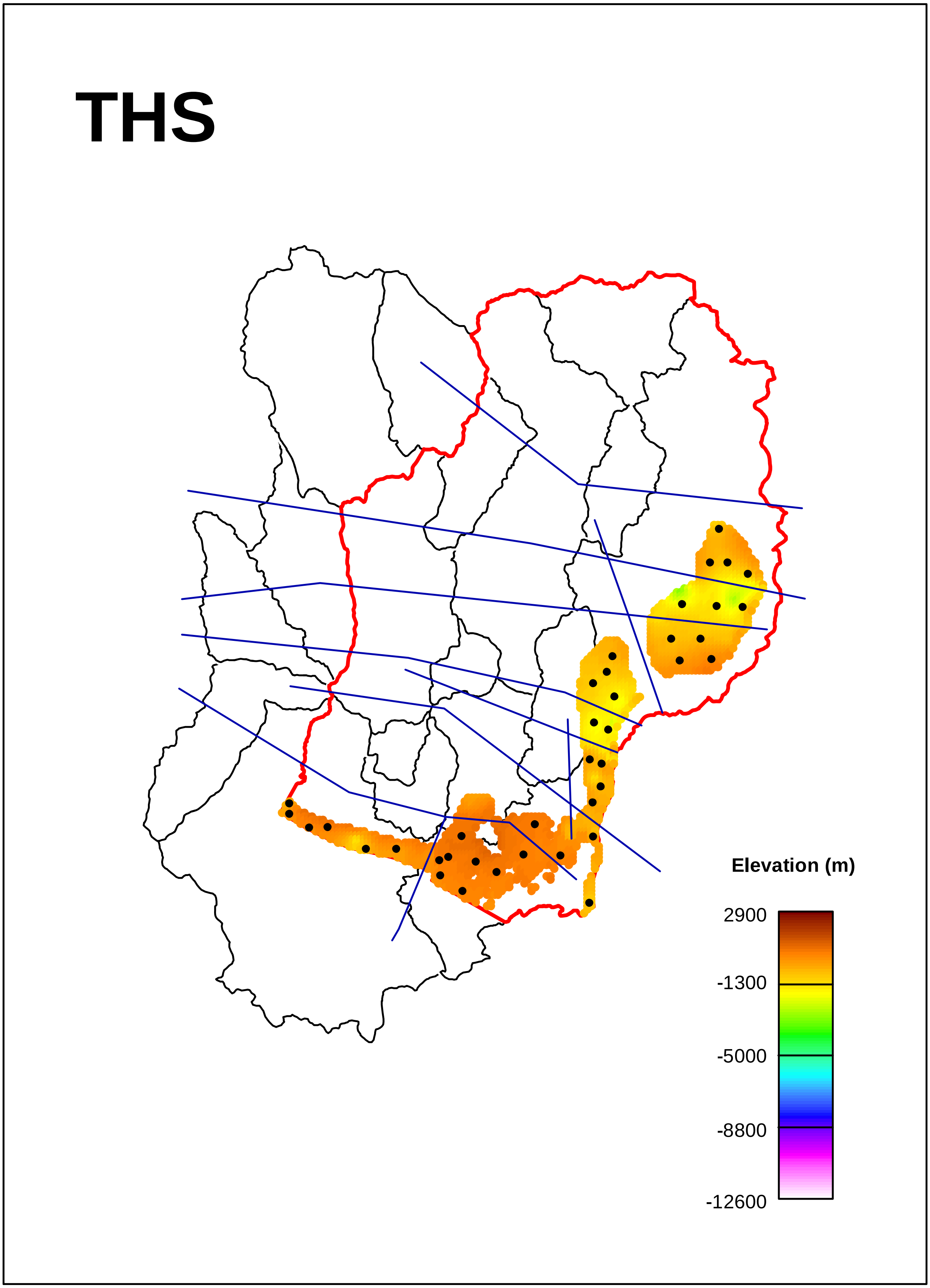
SE ROA 12333

CAU



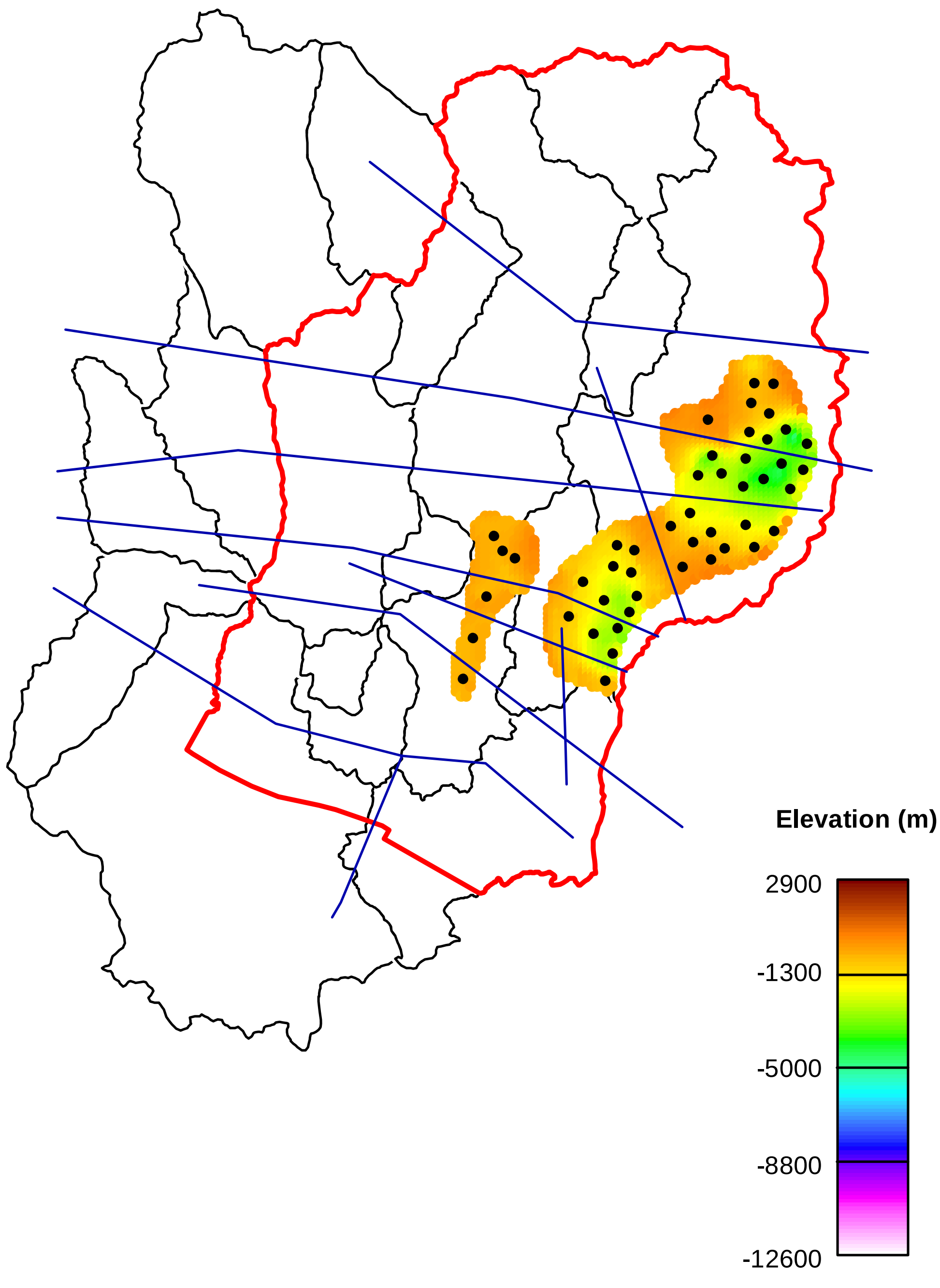
SE ROA 12334

JA_5096



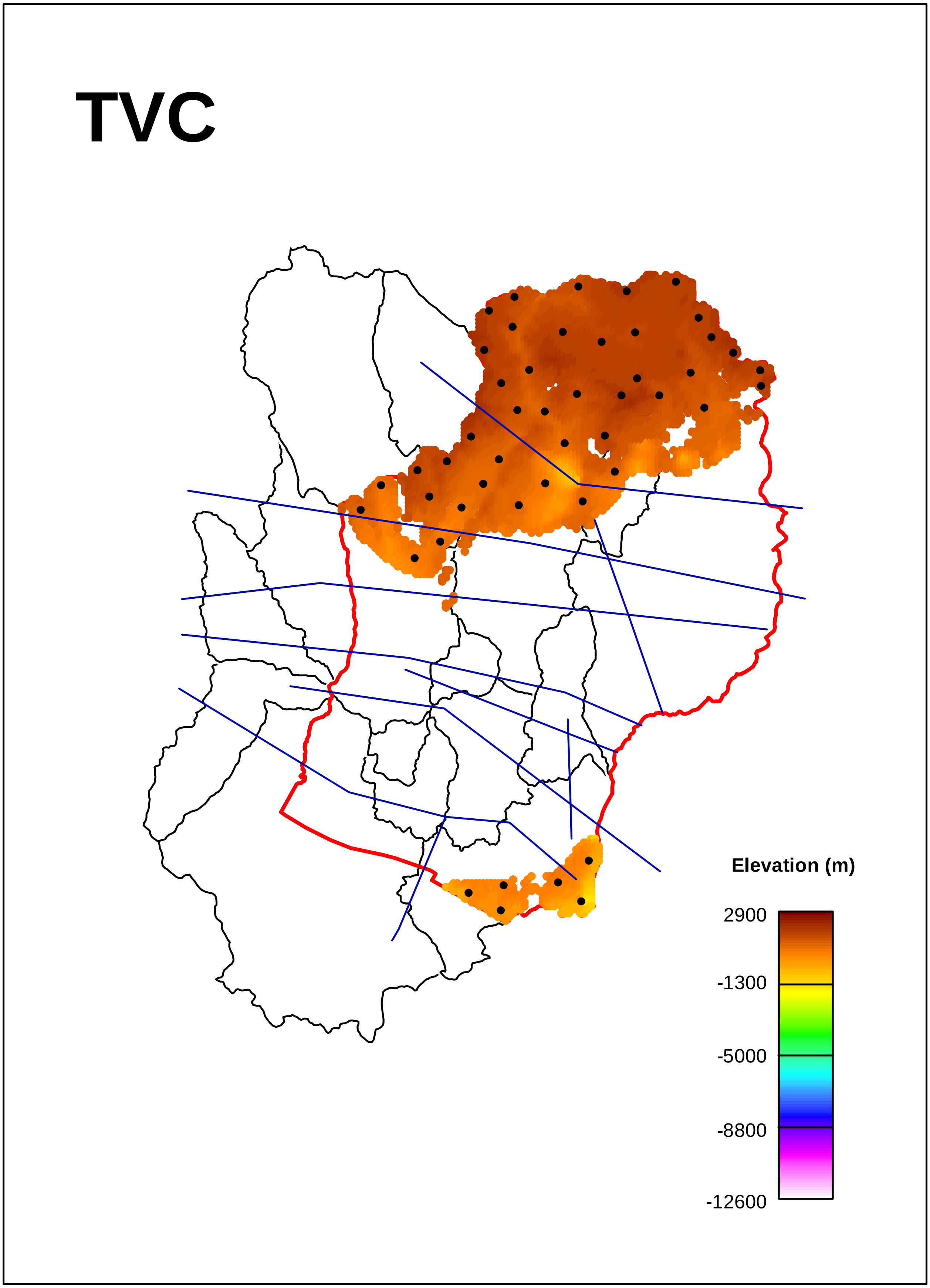
SE ROA 12335

TAU

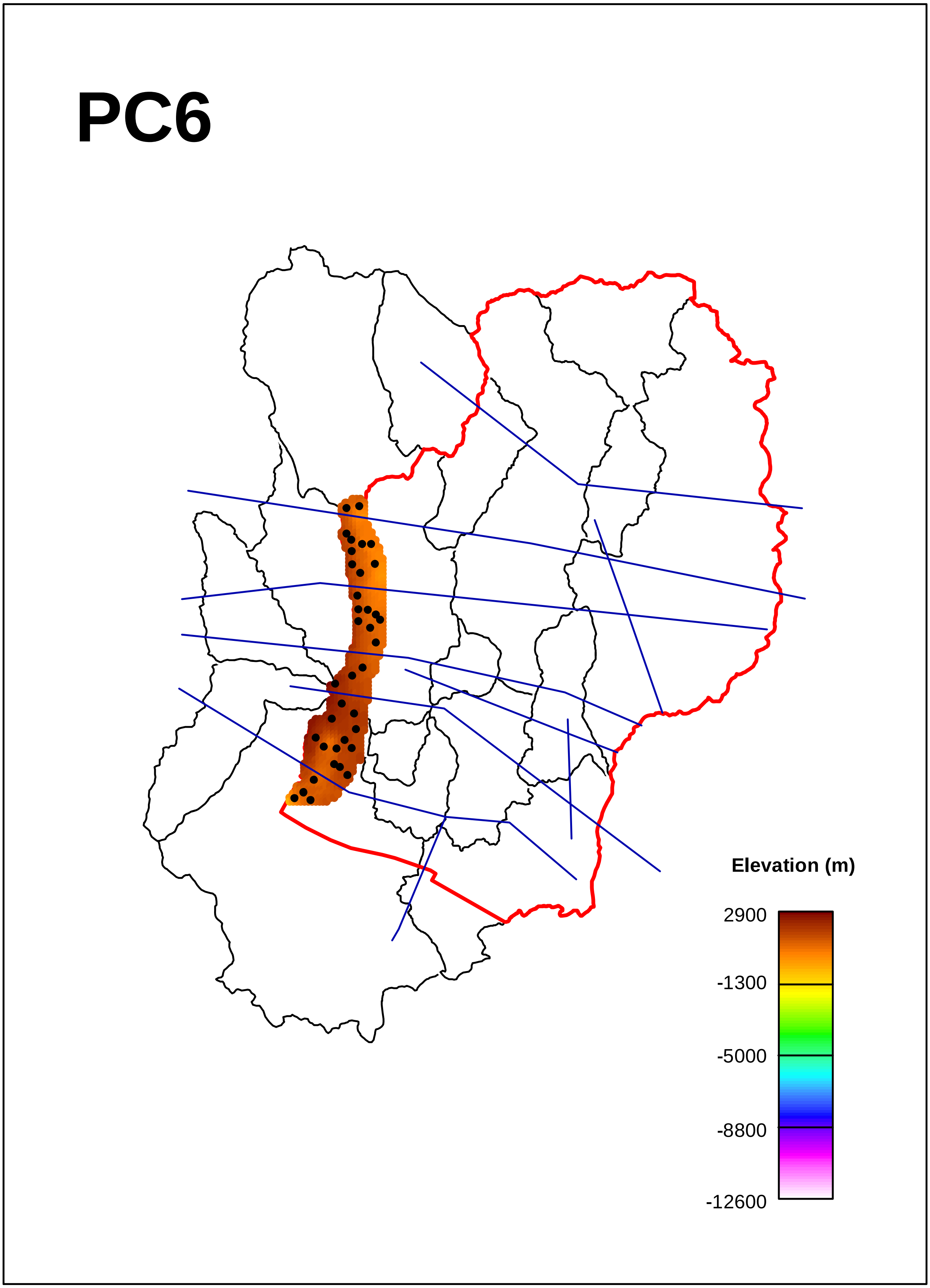


SE ROA 12336

JA_5098

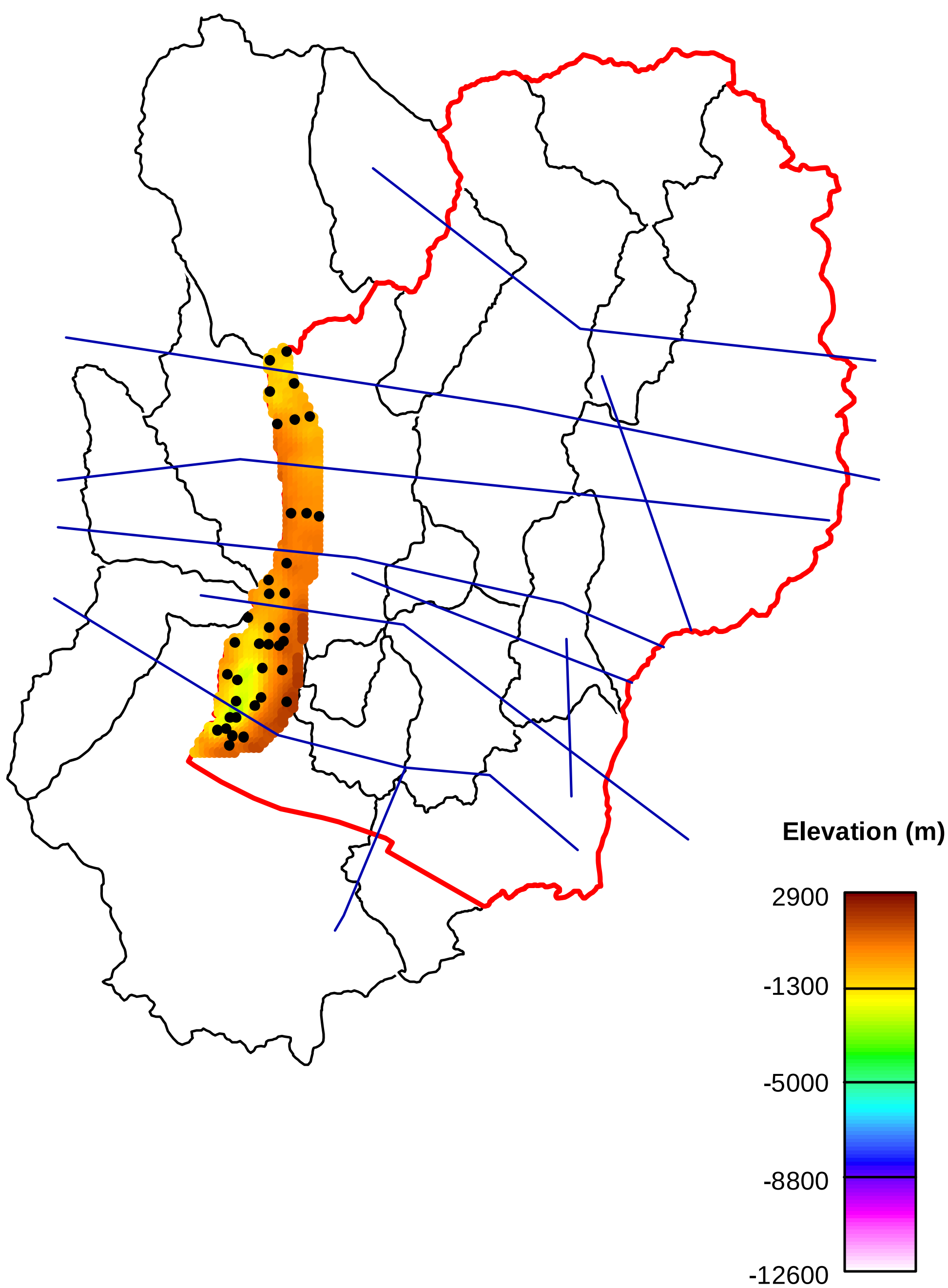


SE ROA 12337



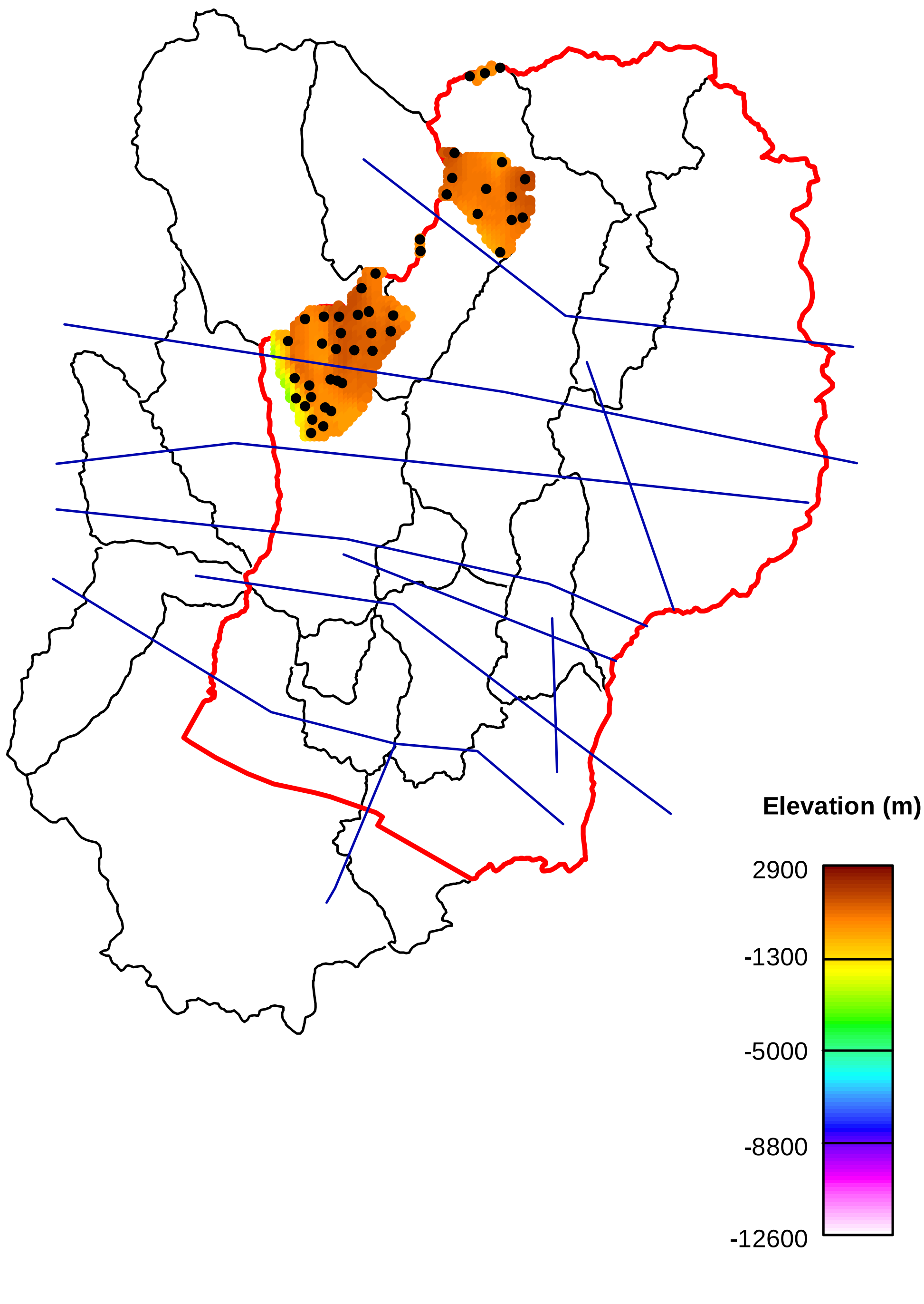
SE ROA 12338

LC6



SE ROA 12339

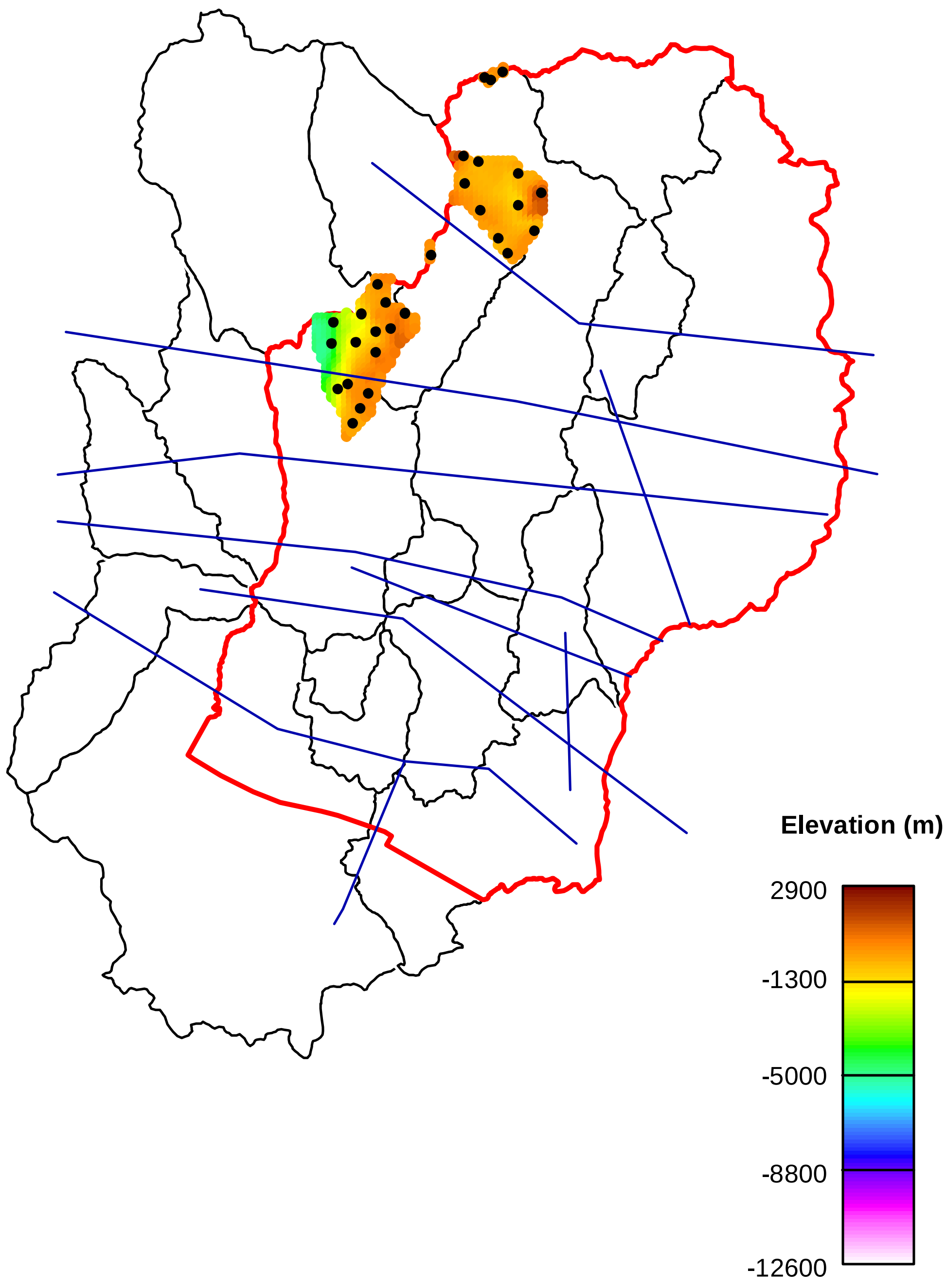
PC5



SE ROA 12340

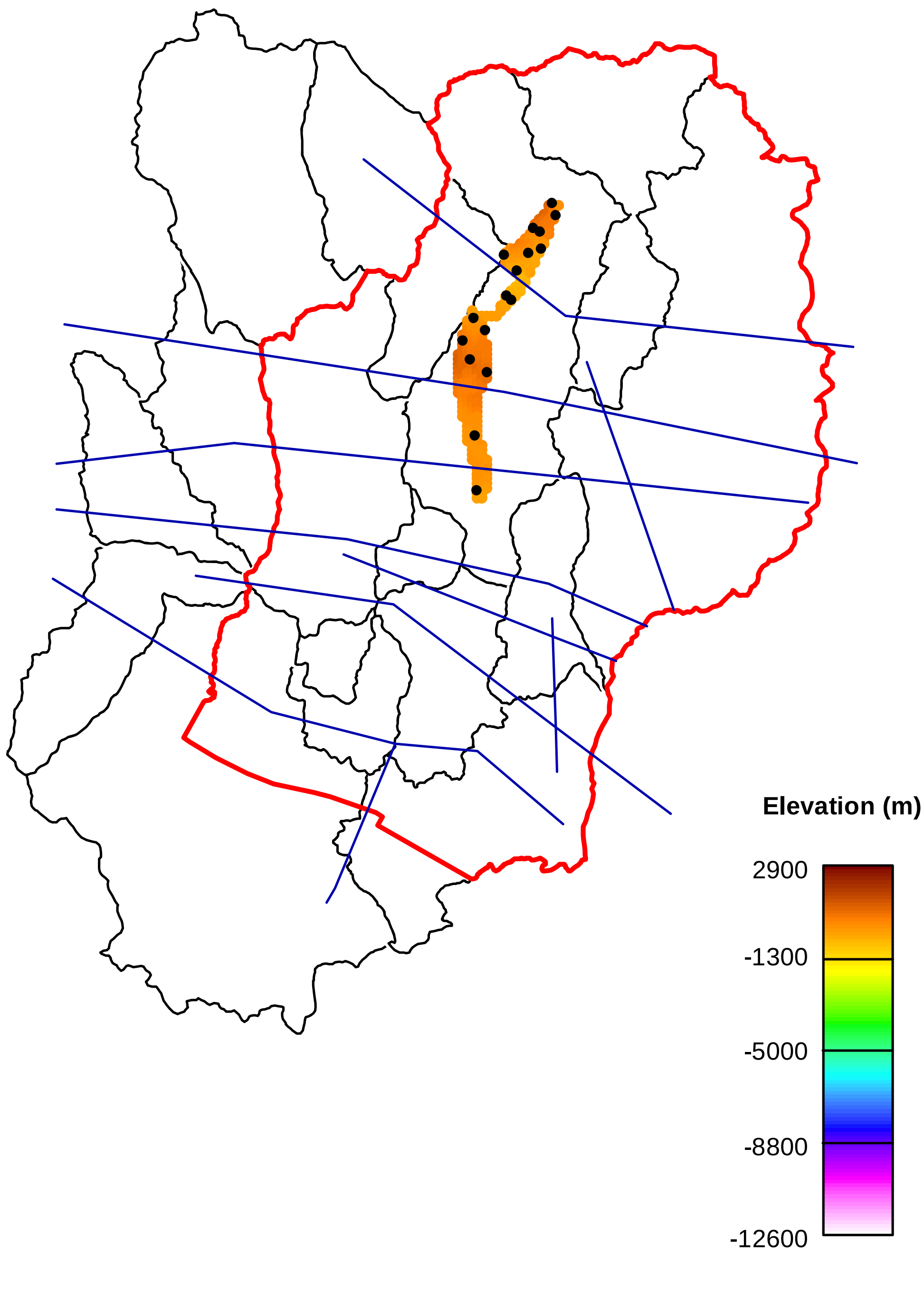
JA_5102

LC5

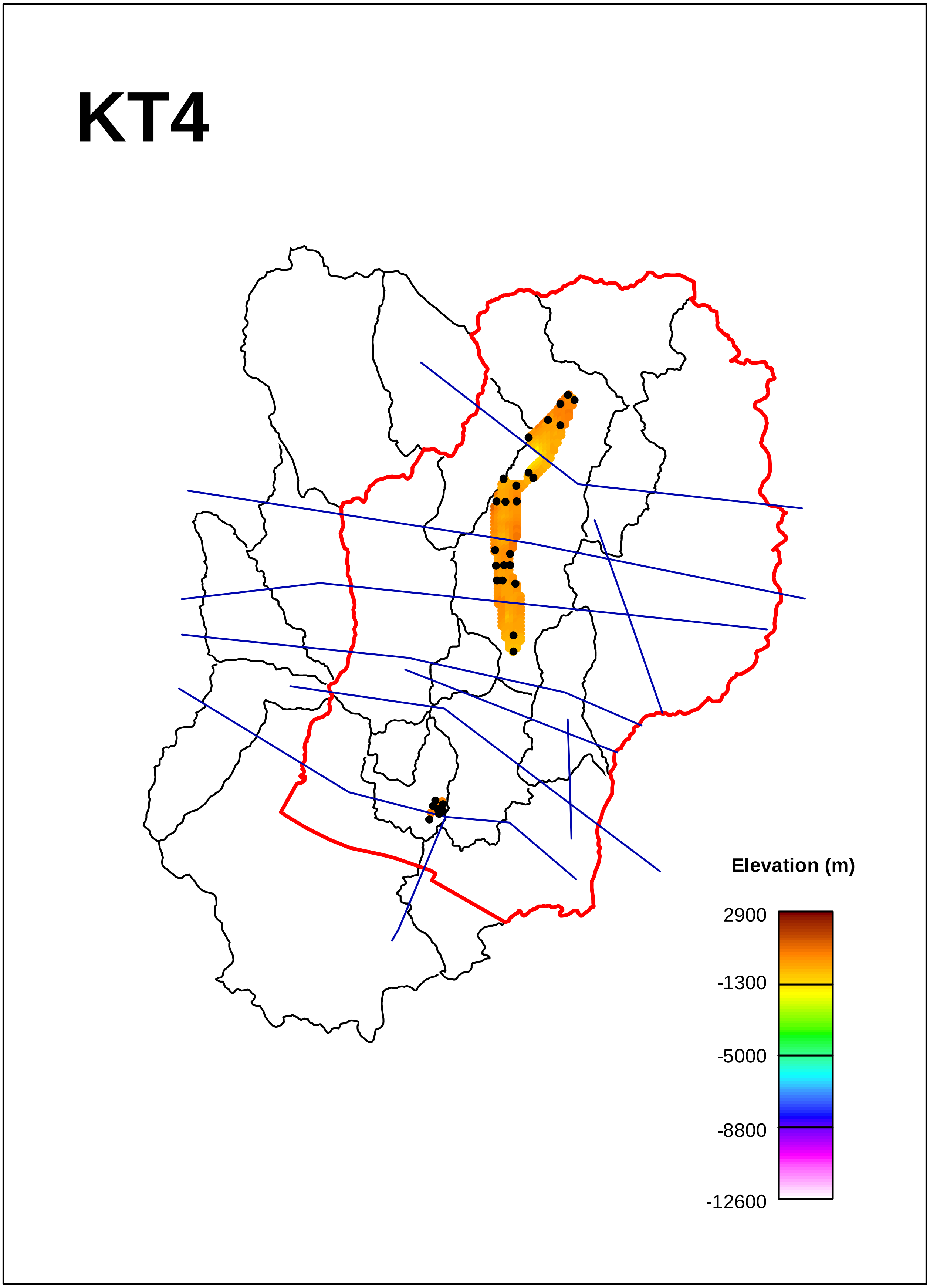


SE ROA 12341

MU4

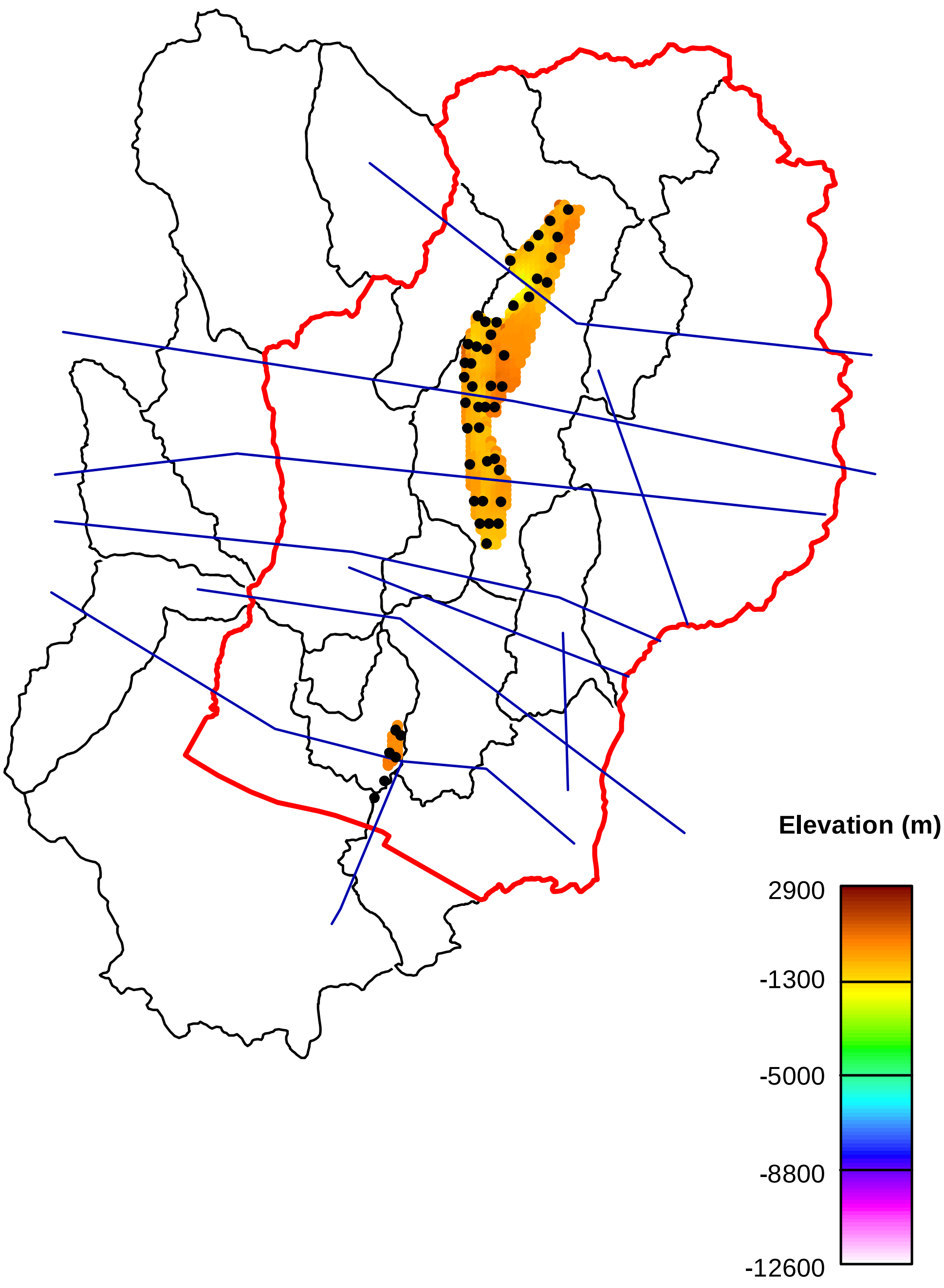


SE ROA 12342



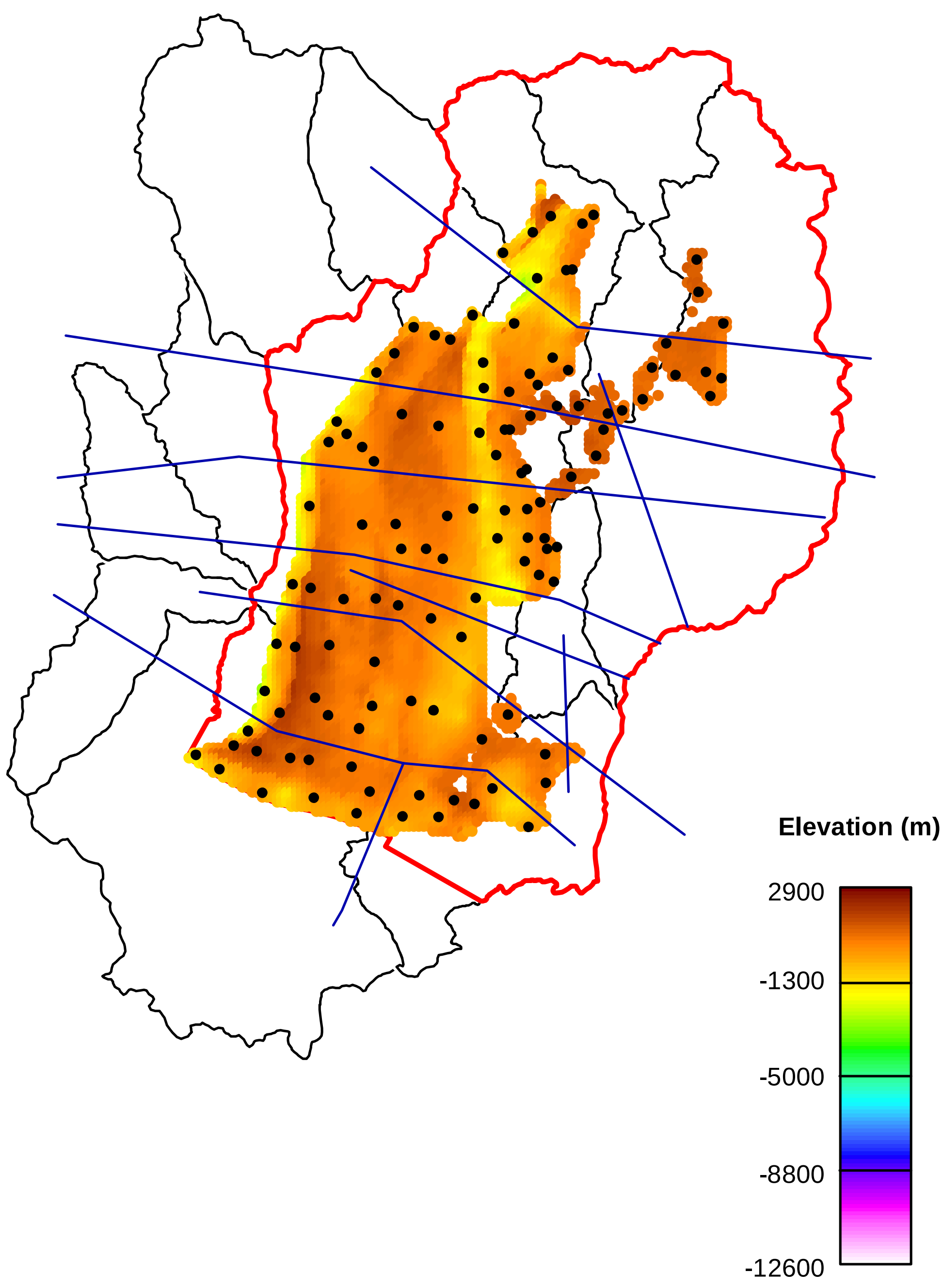
SE ROA 12343

PR4



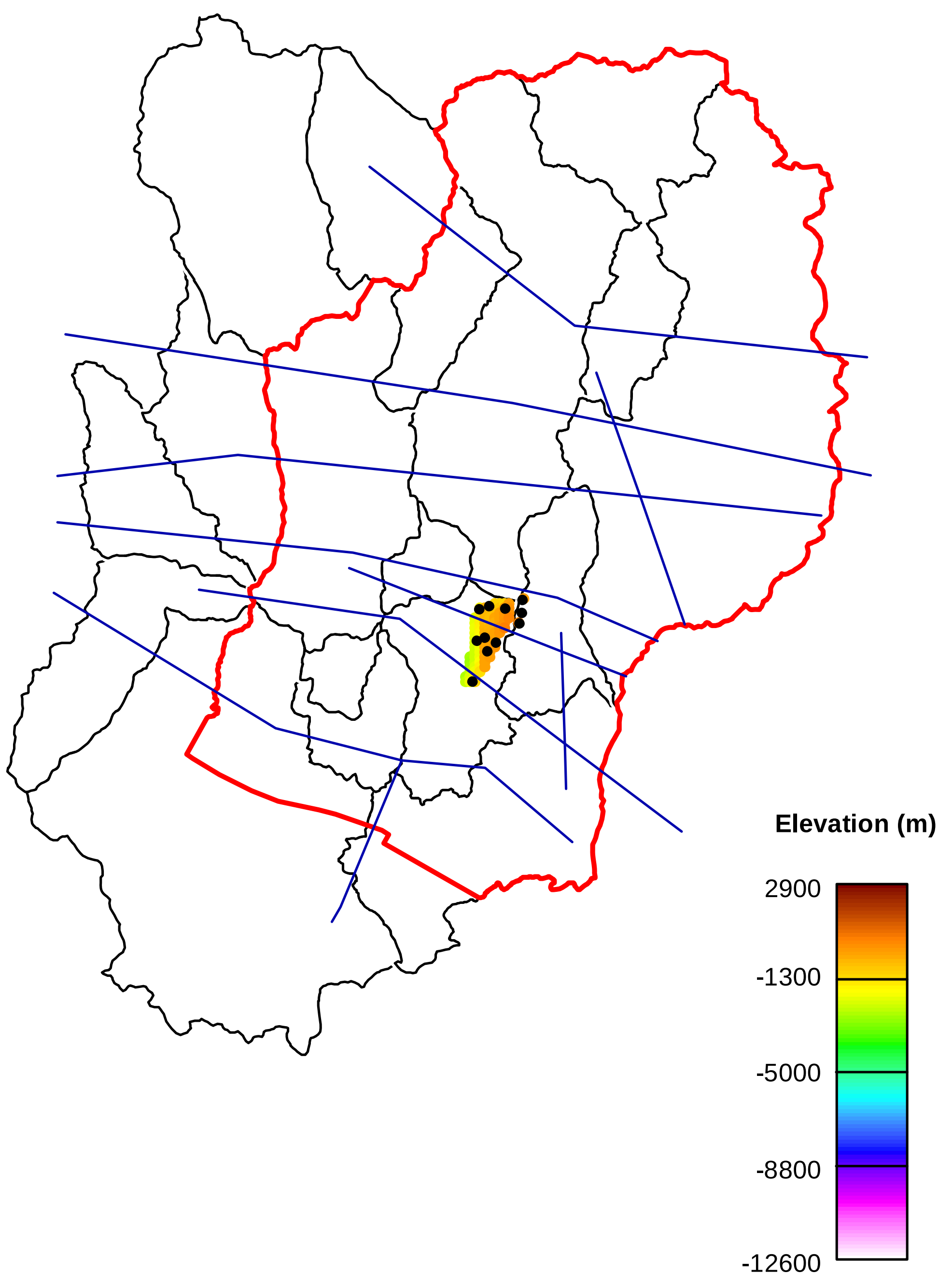
SE ROA 12344

PC4



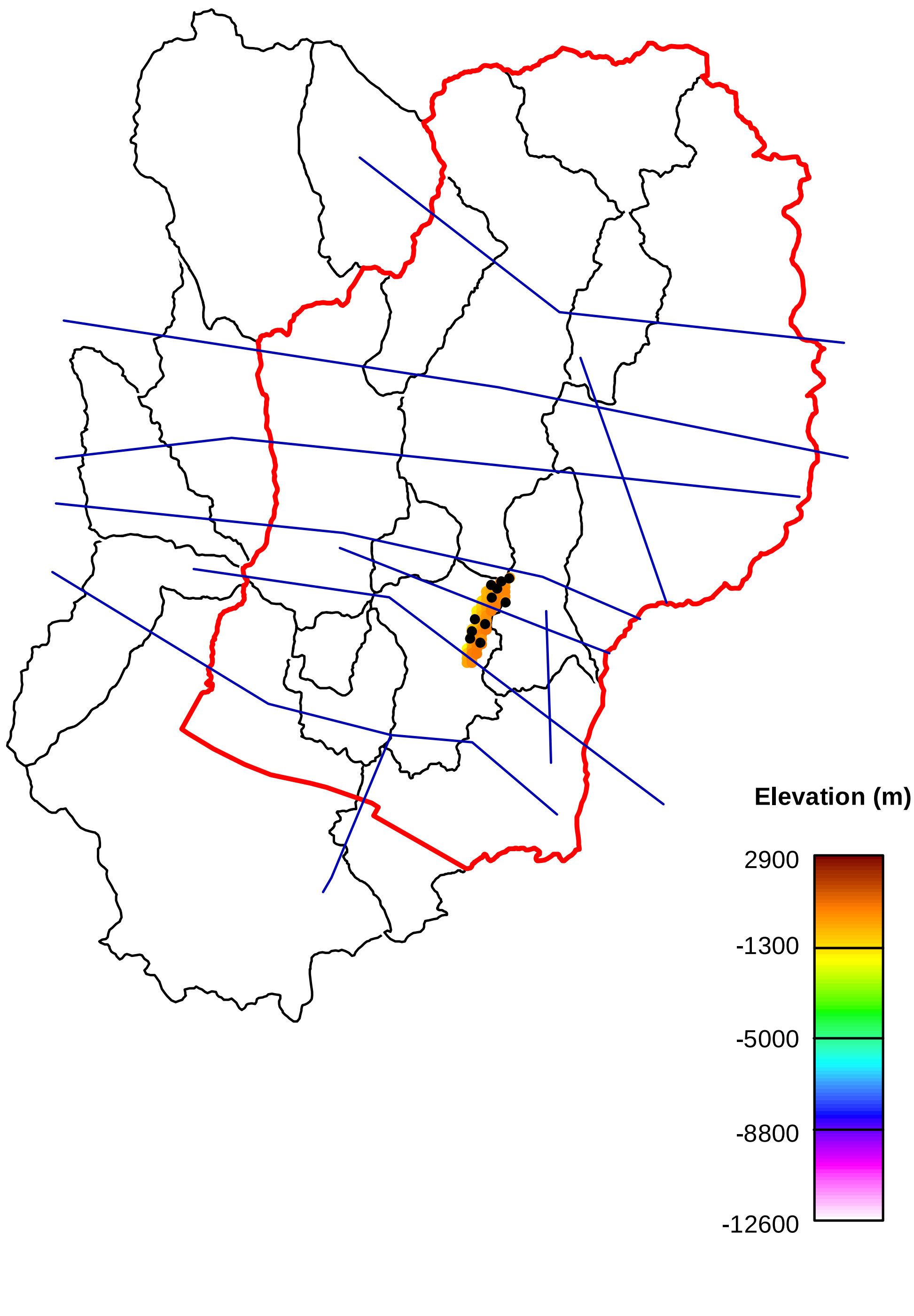
SE ROA 12345

PC3



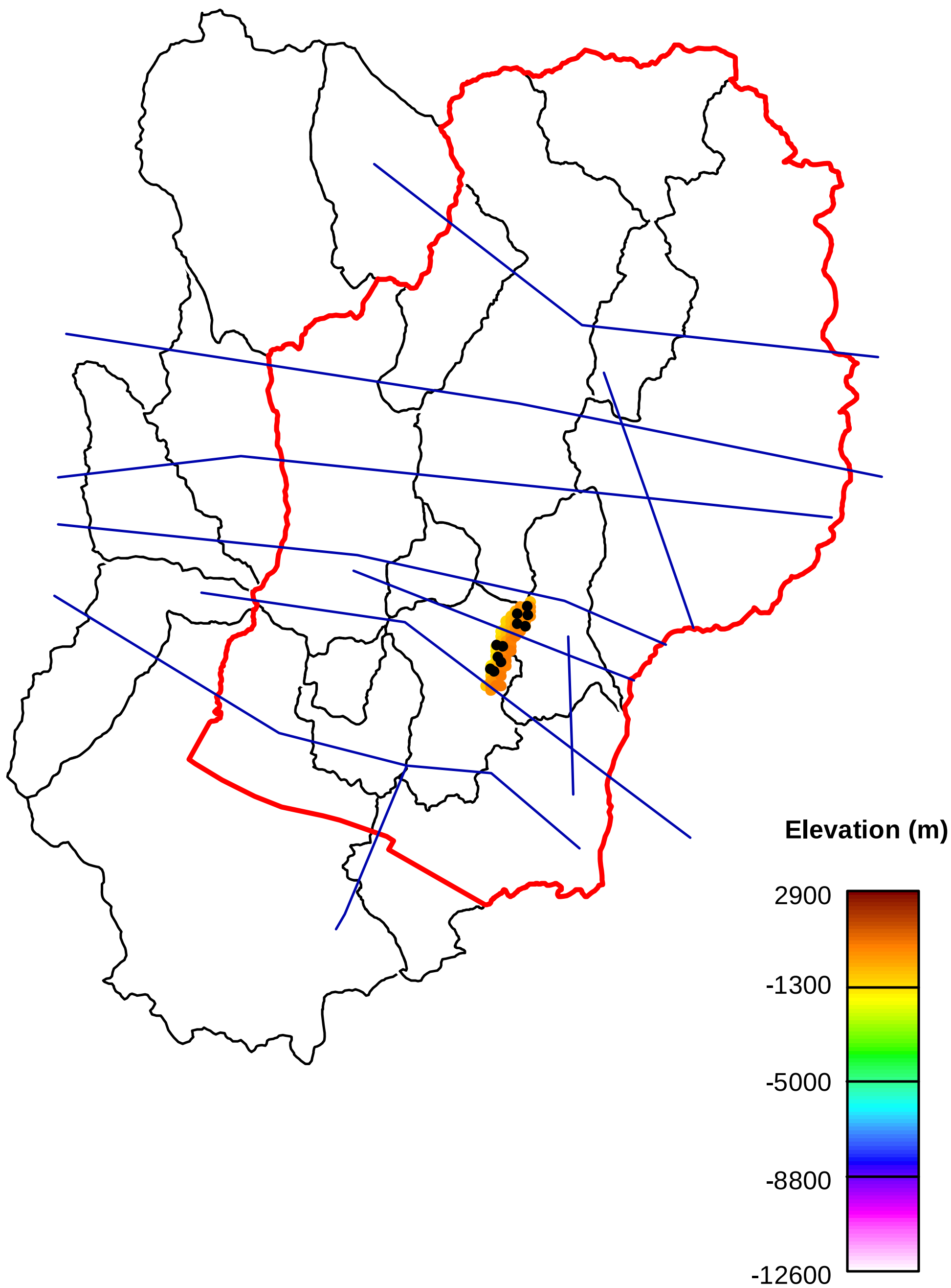
SE ROA 12346

PR3



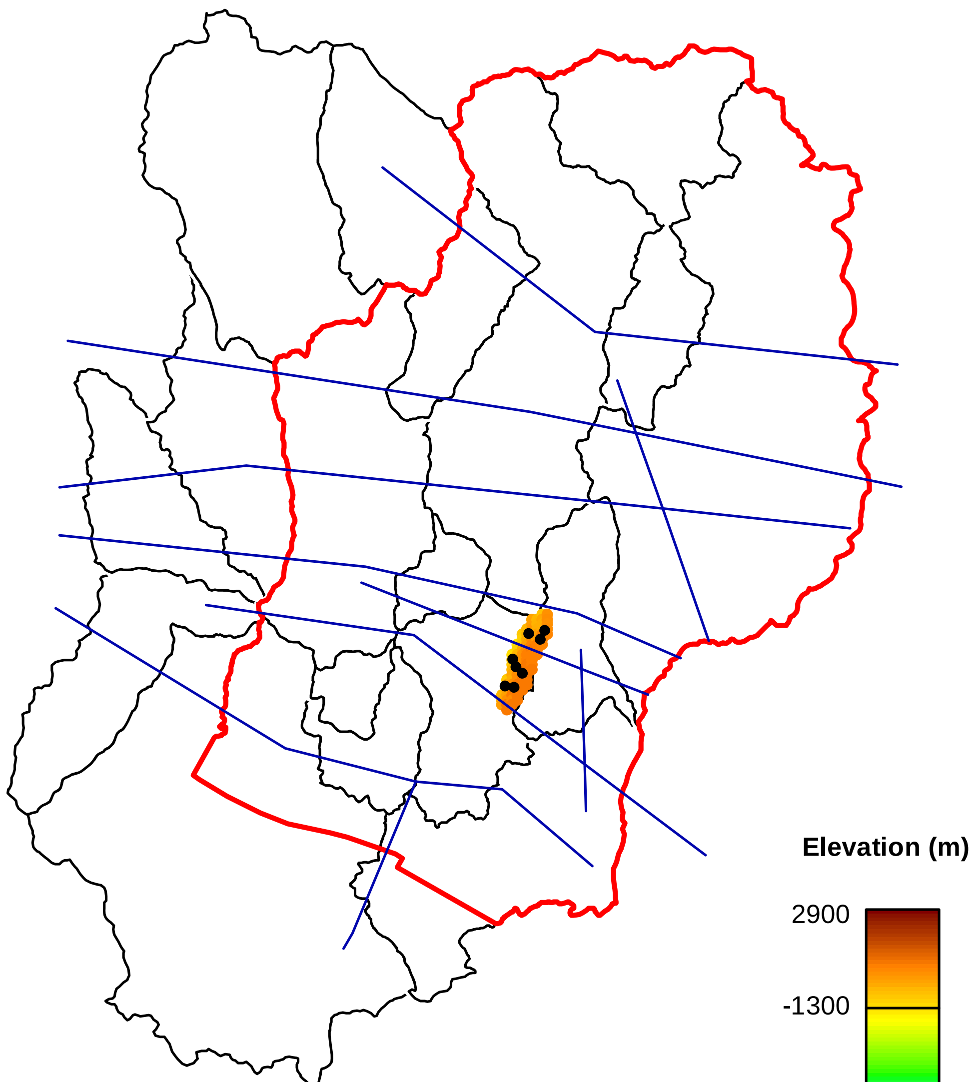
SE ROA 12347

KT3



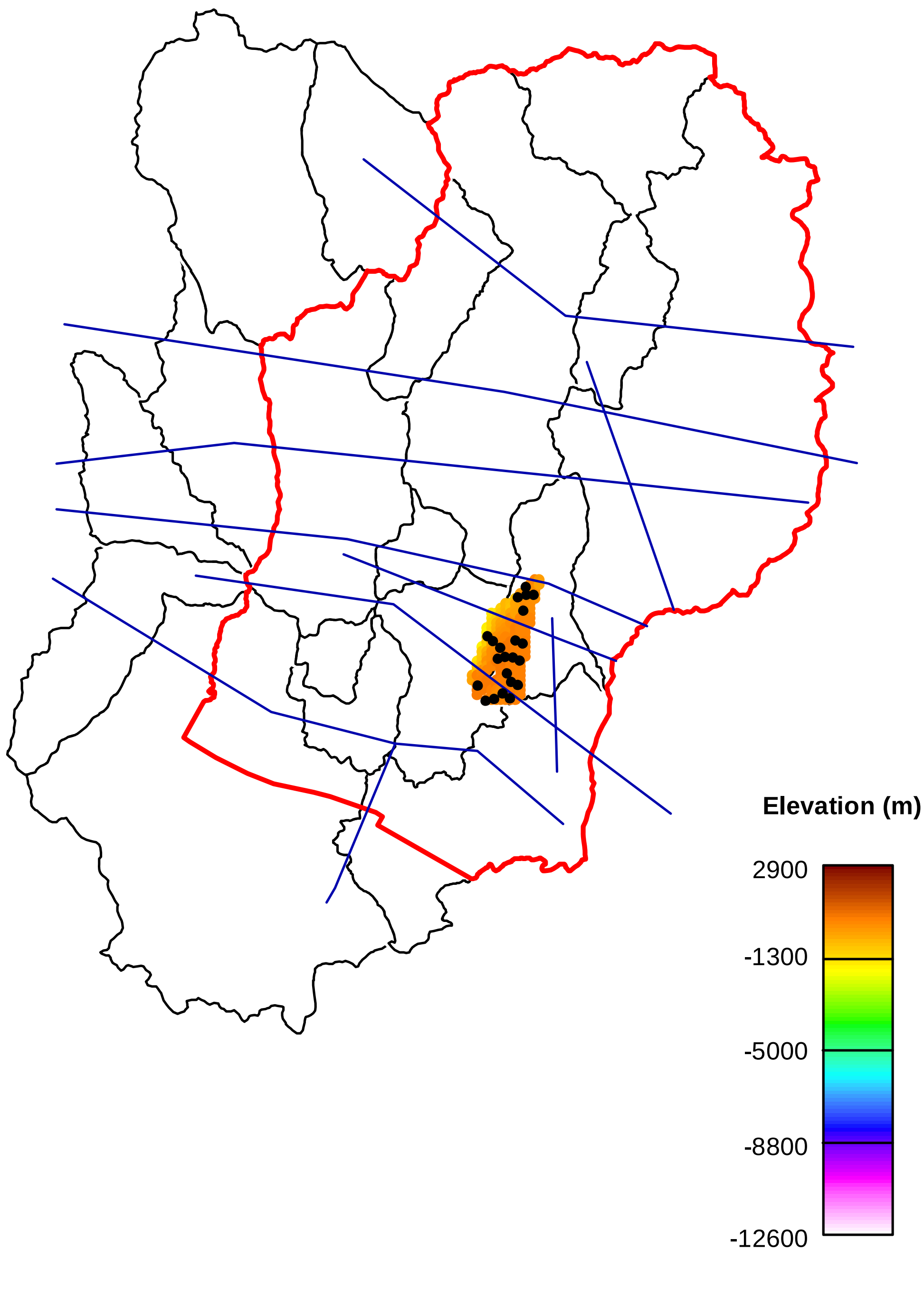
SE ROA 12348

MU3



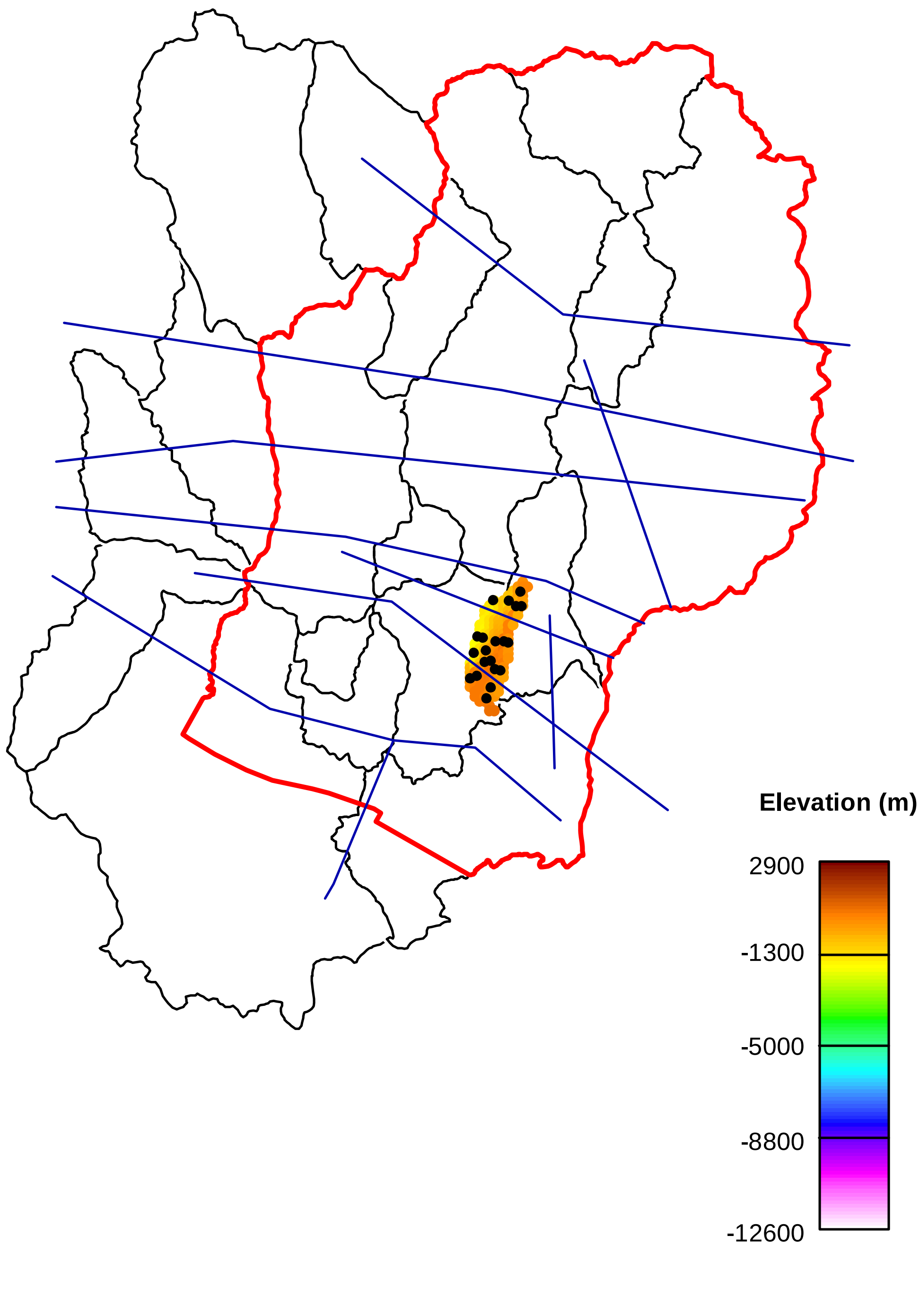
SE ROA 12349

MU2



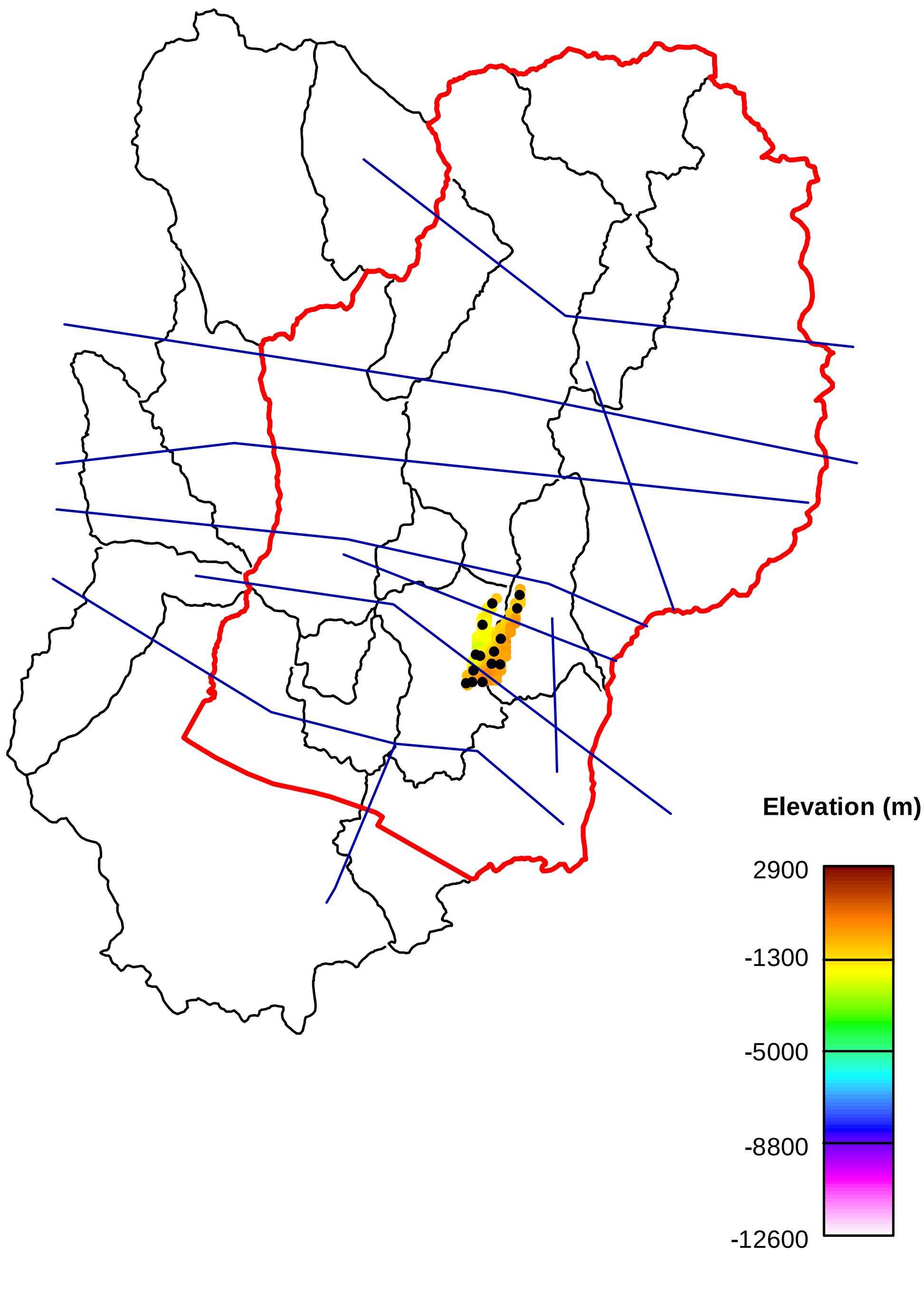
SE ROA 12350

KT2



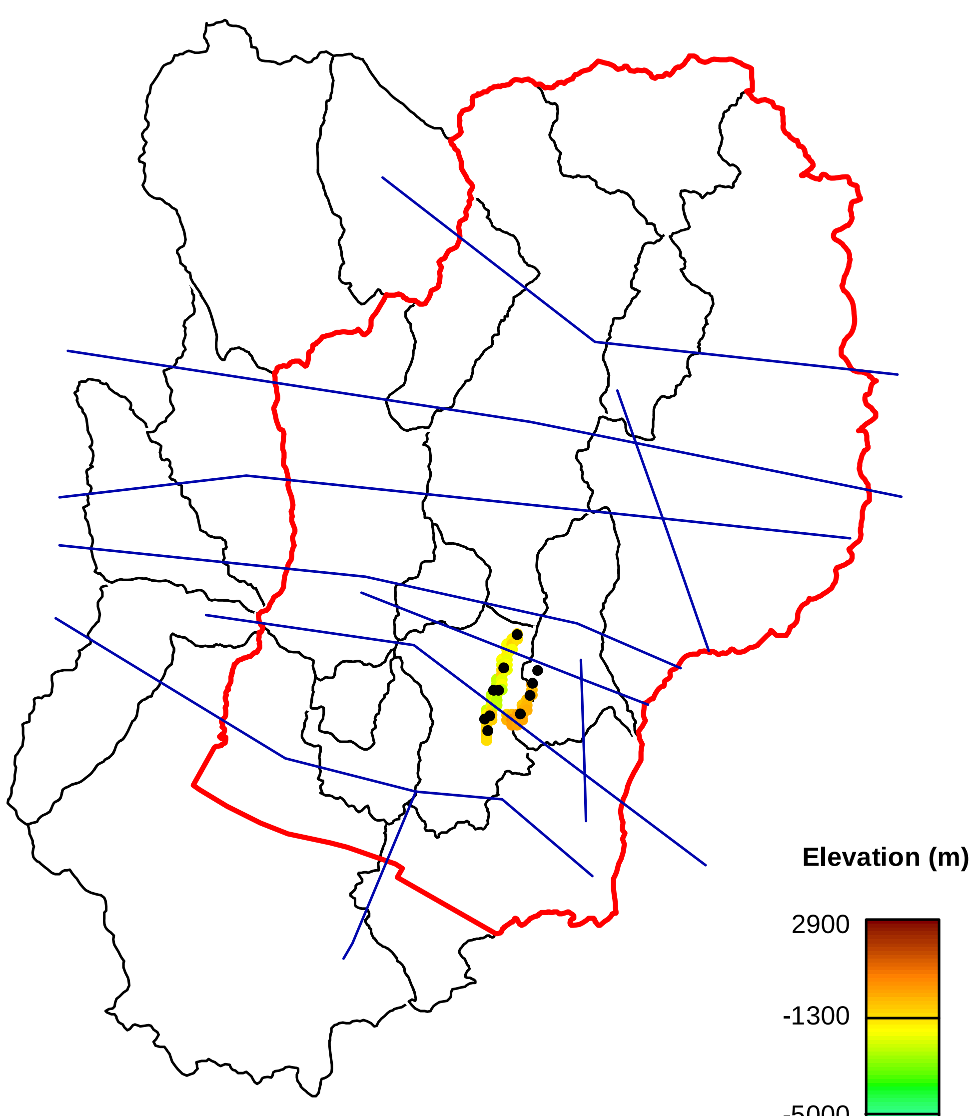
SE ROA 12351

PR2



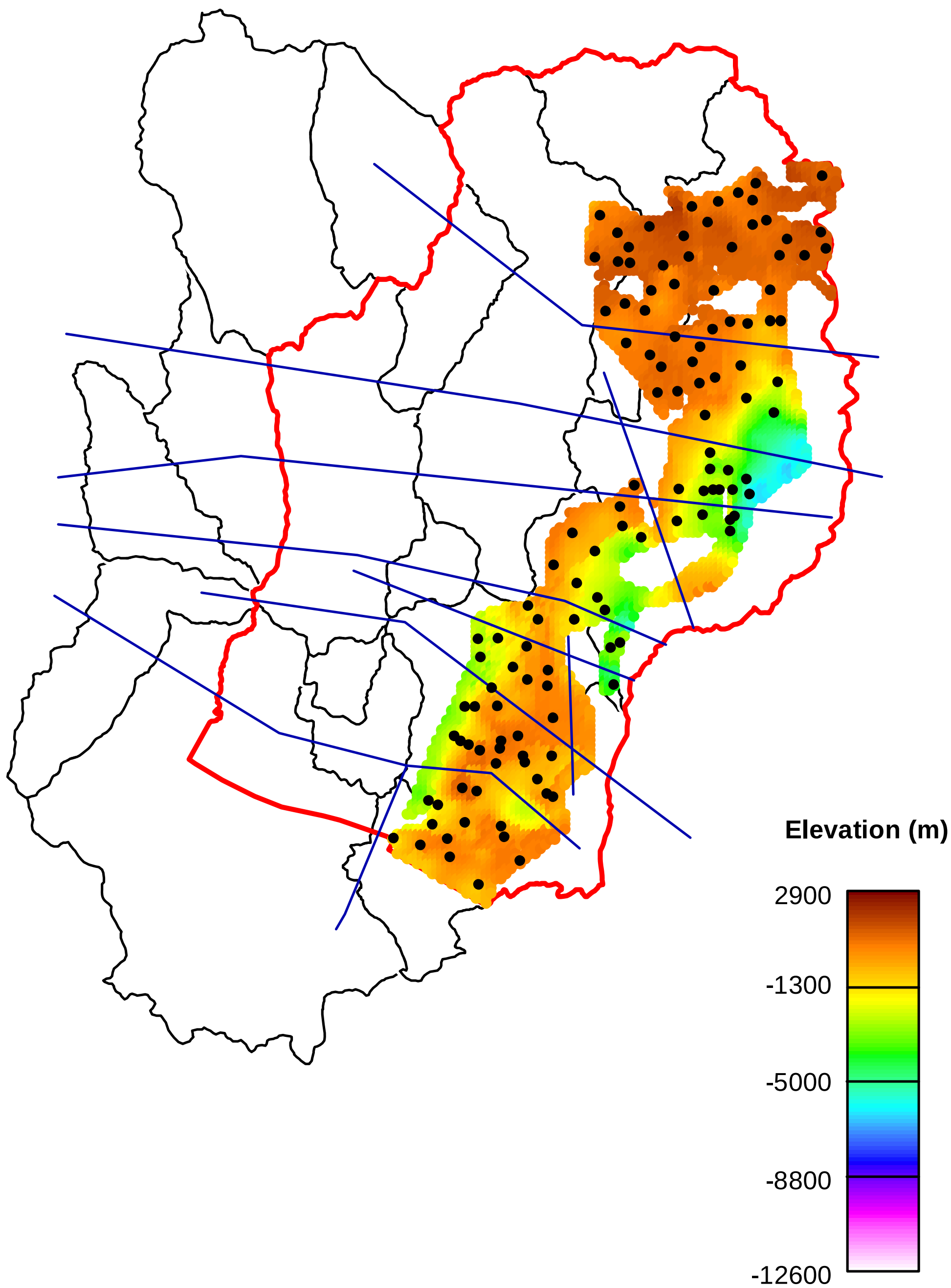
SE ROA 12352

PC2



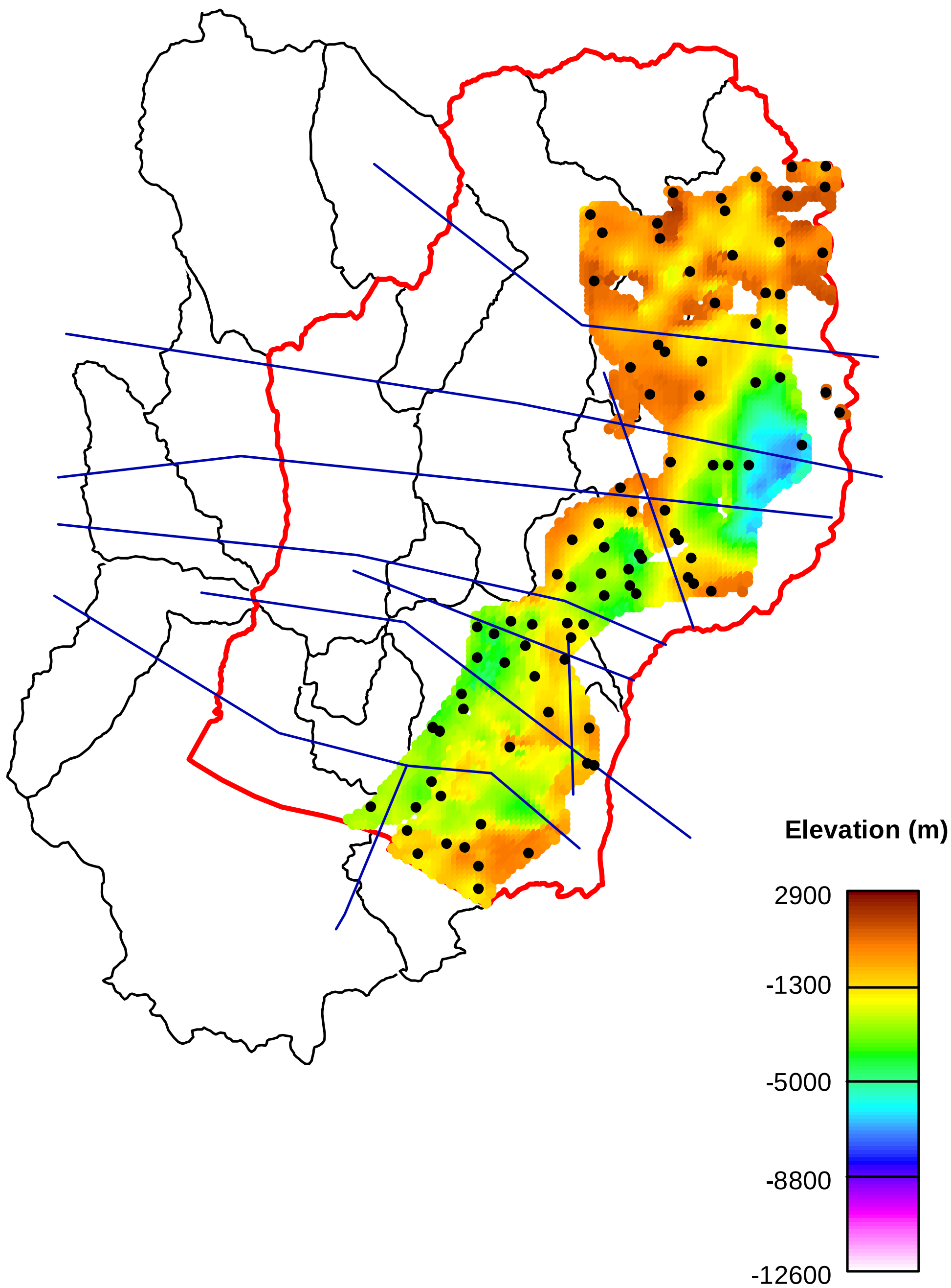
SE ROA 12353

MU1



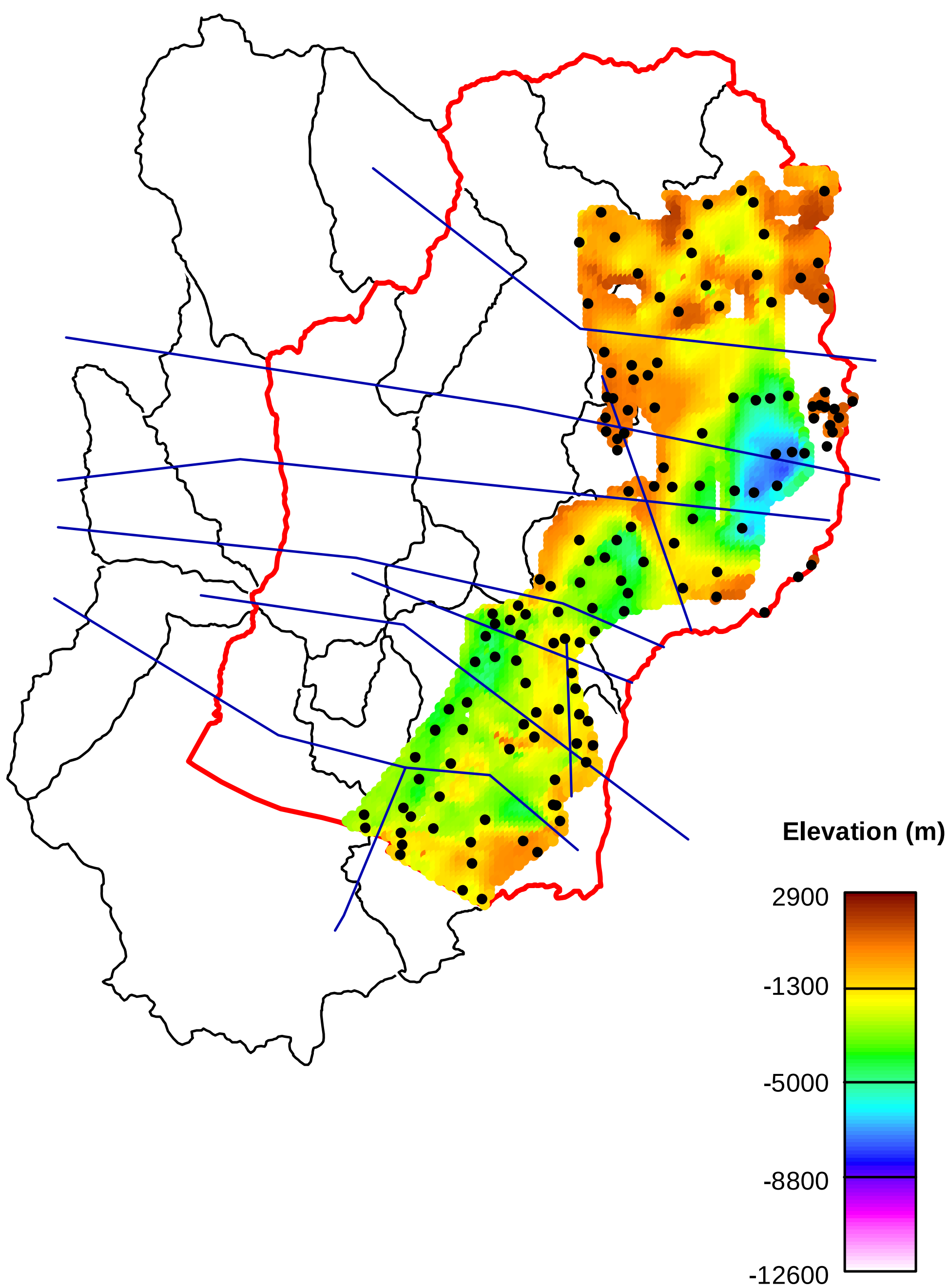
SE ROA 12354

KT1

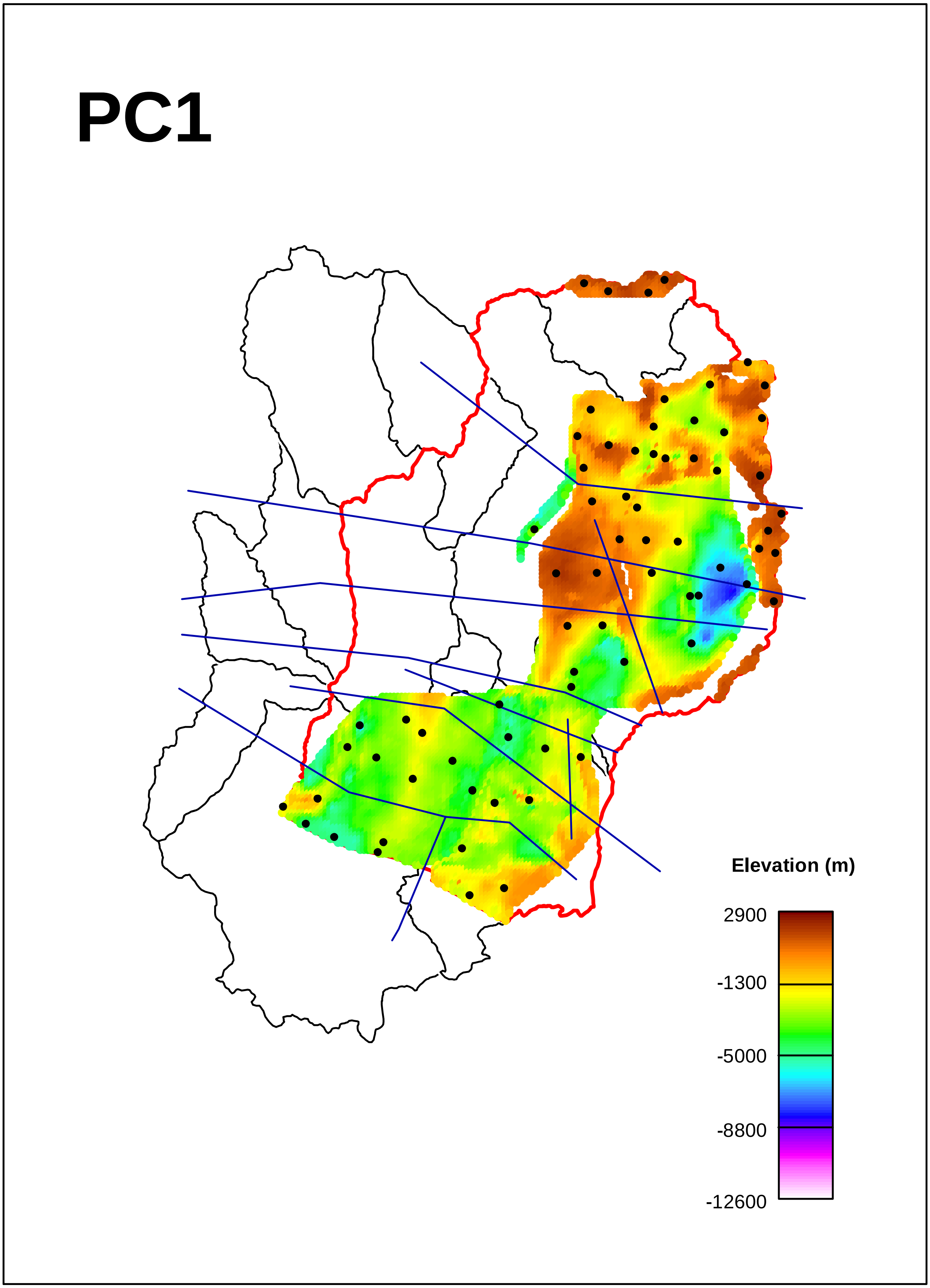


SE ROA 12355

PR1



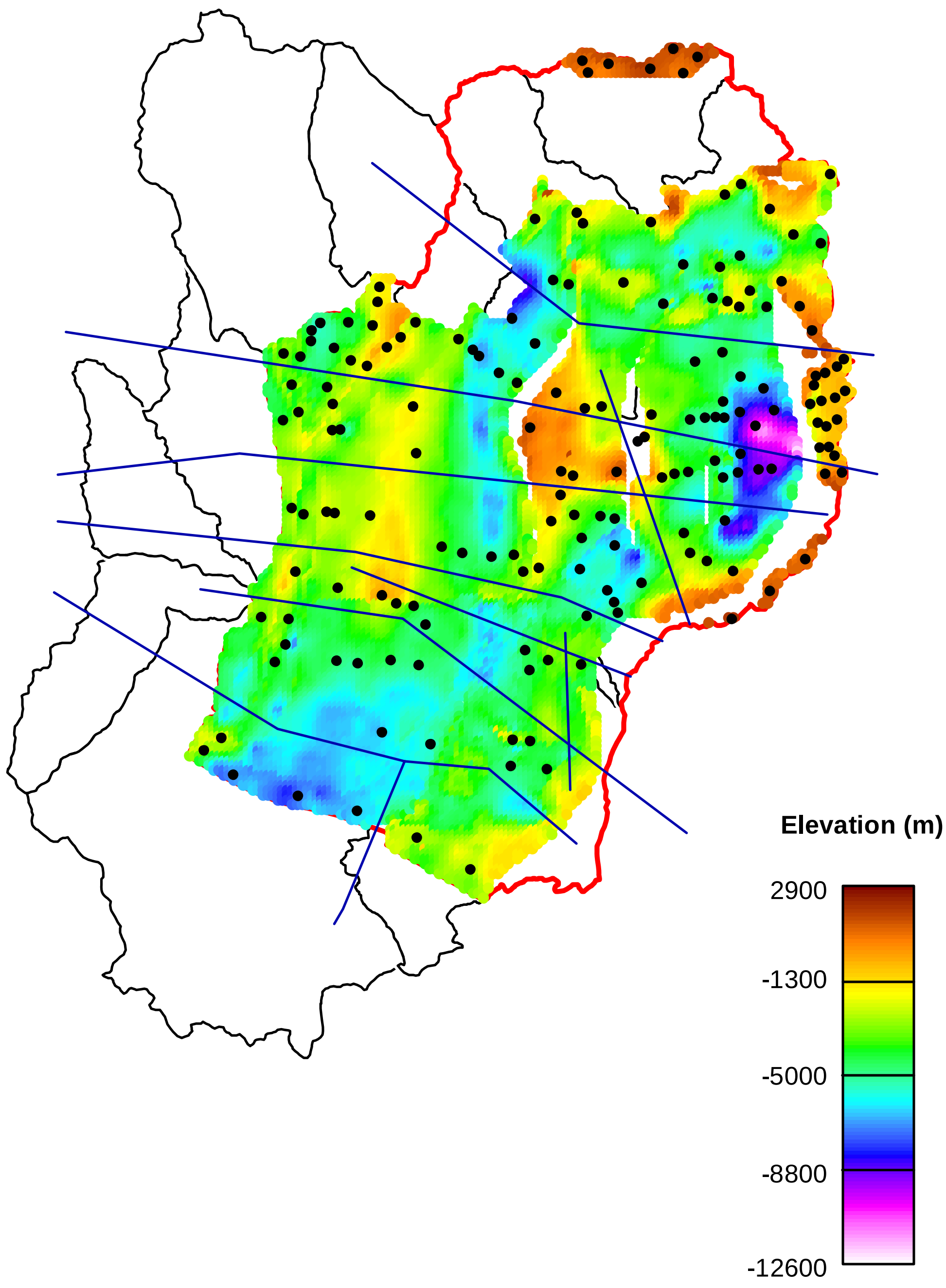
SE ROA 12356



SE ROA 12357

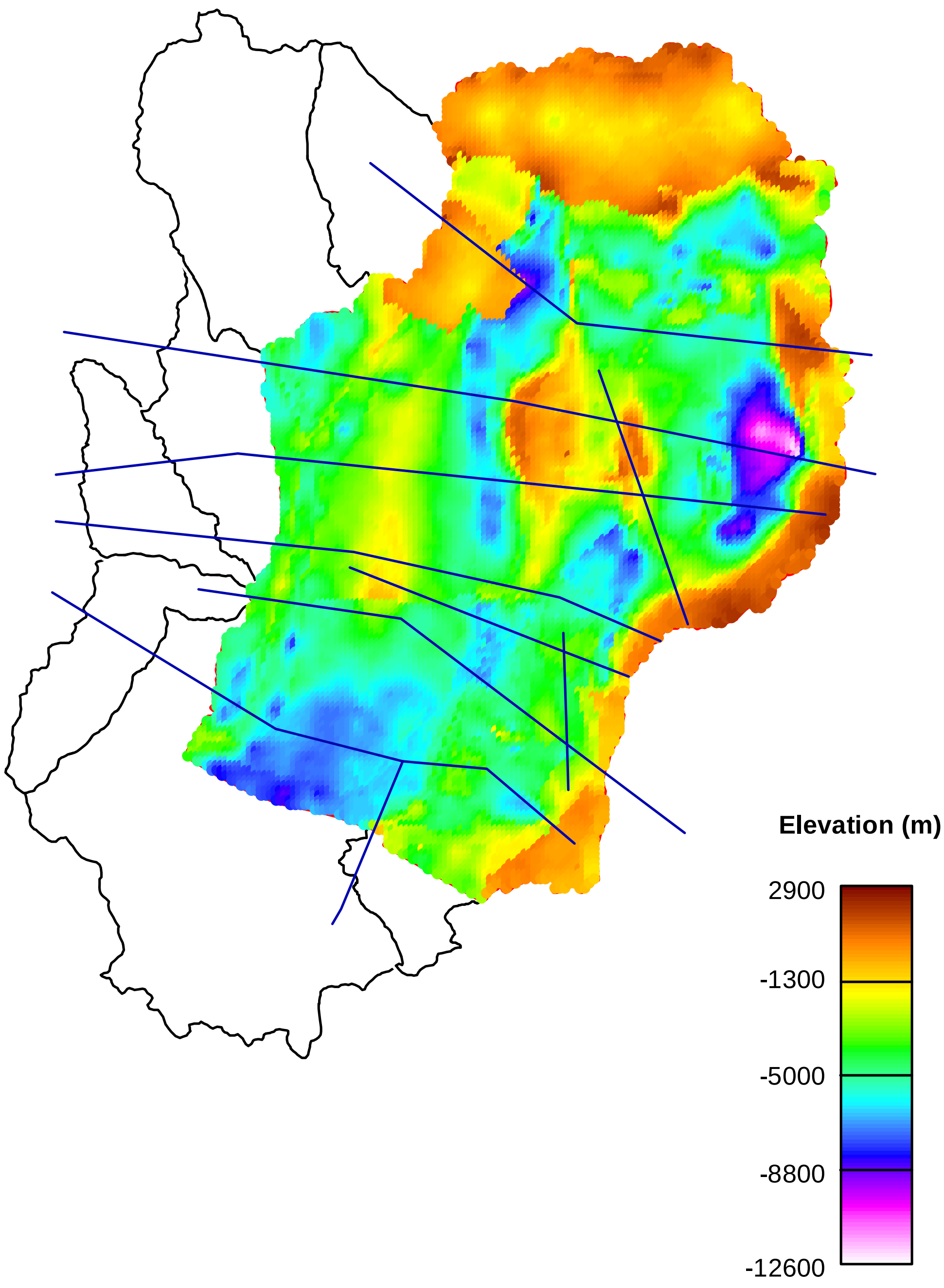
JA_5119

LC1



SE ROA 12358

XLB



SE ROA 12359

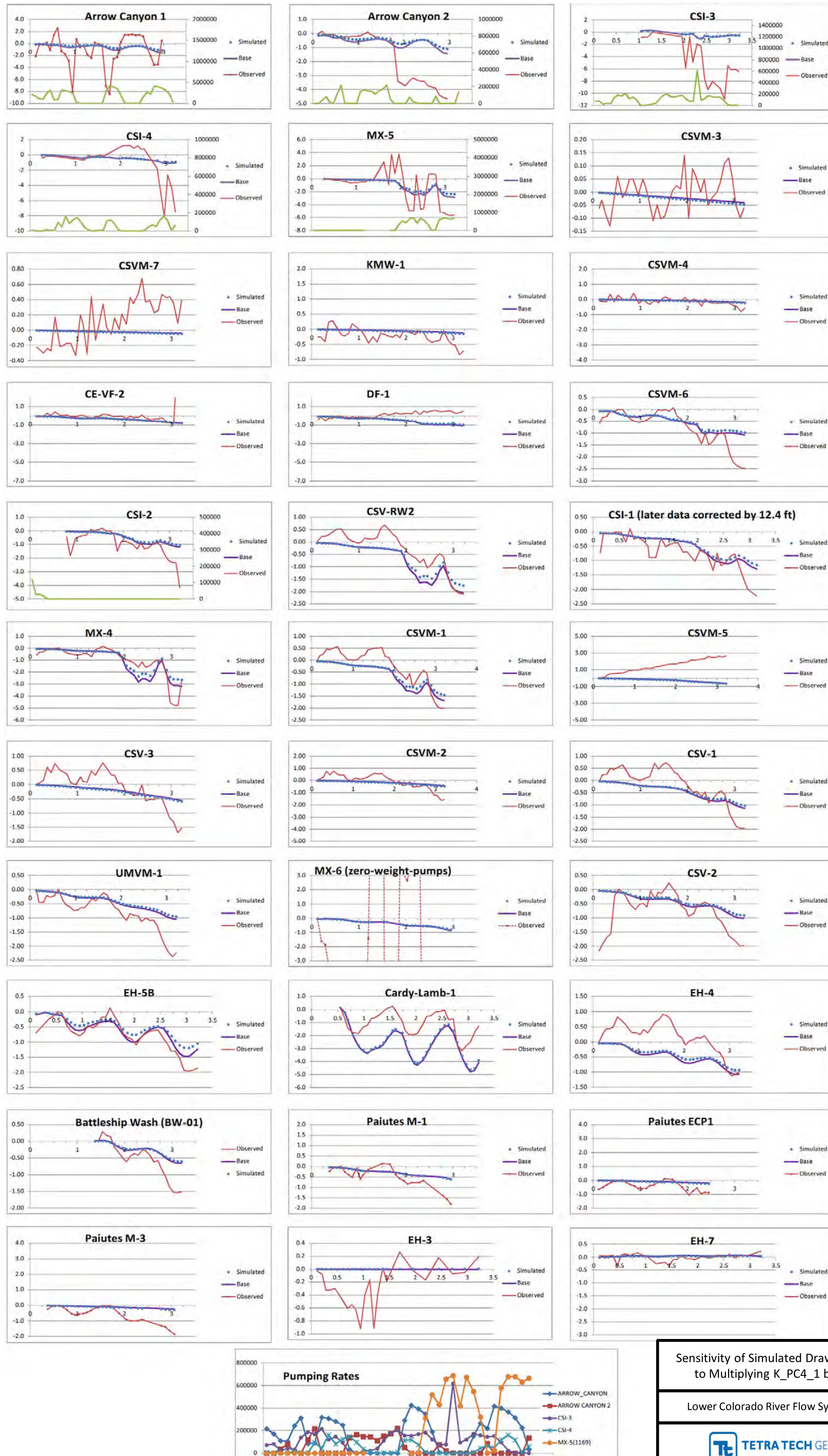
SE ROA 12360

ATTACHMENT II

Sensitivity Testing – Simulated Drawdowns

SE ROA 12361

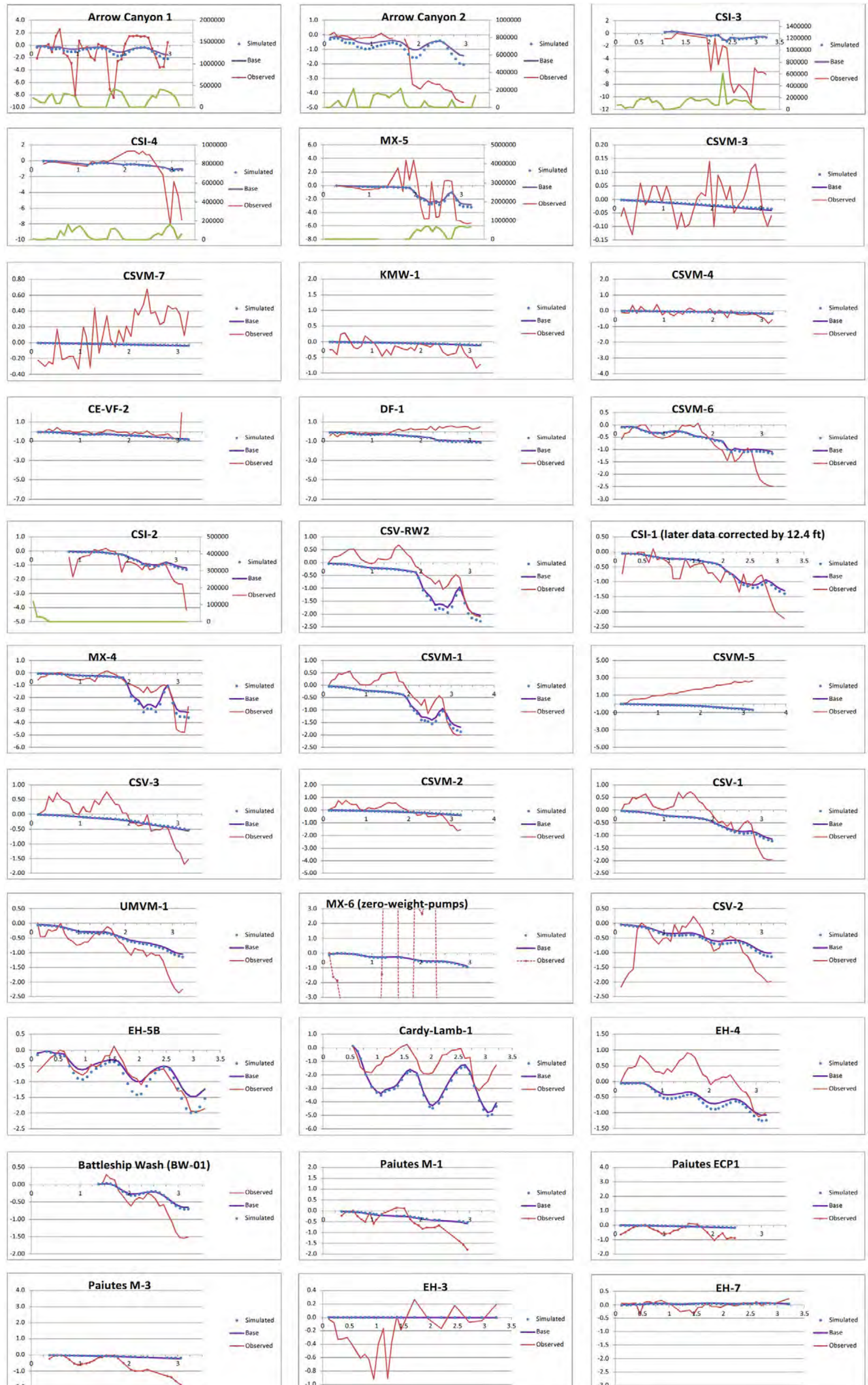
SE ROA 12362

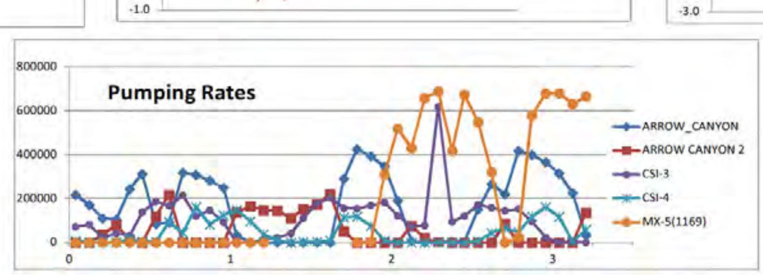


Sensitivity of Simulated Drawdown to Multiplying K_PC4_1 by 2

Lower Colorado River Flow System

TETRA TECH GEO

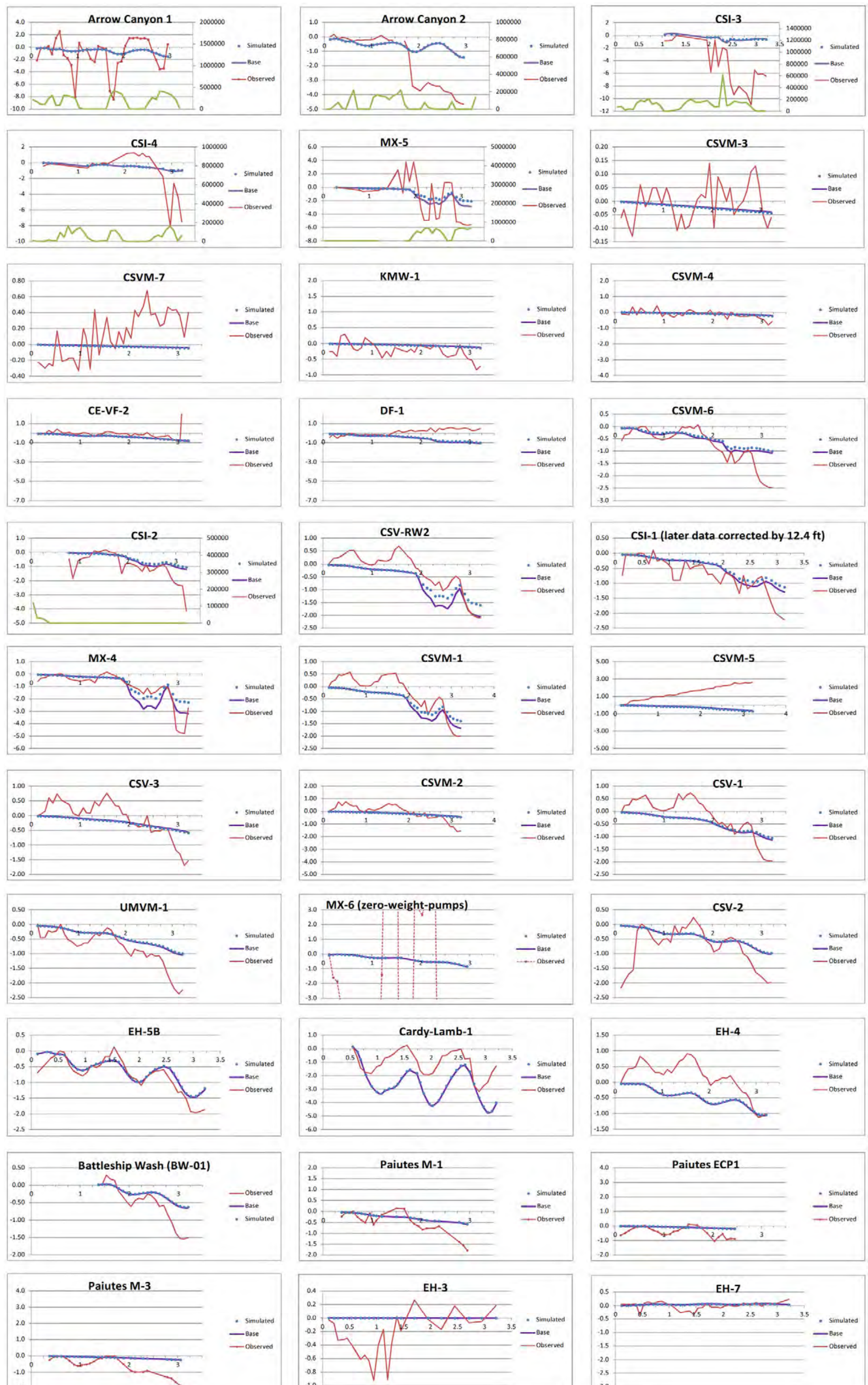


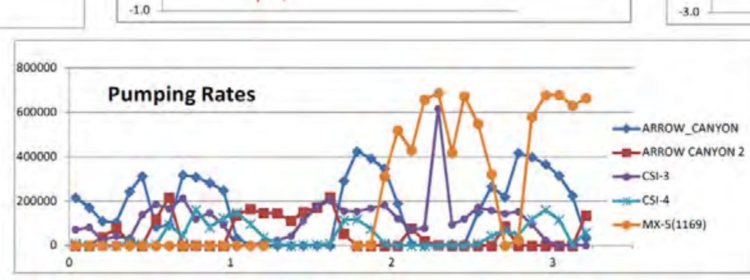


Sensitivity of Simulated Drawdown to Dividing K_PC4_1 by 2

Lower Colorado River Flow System

TETRA TECH GEO

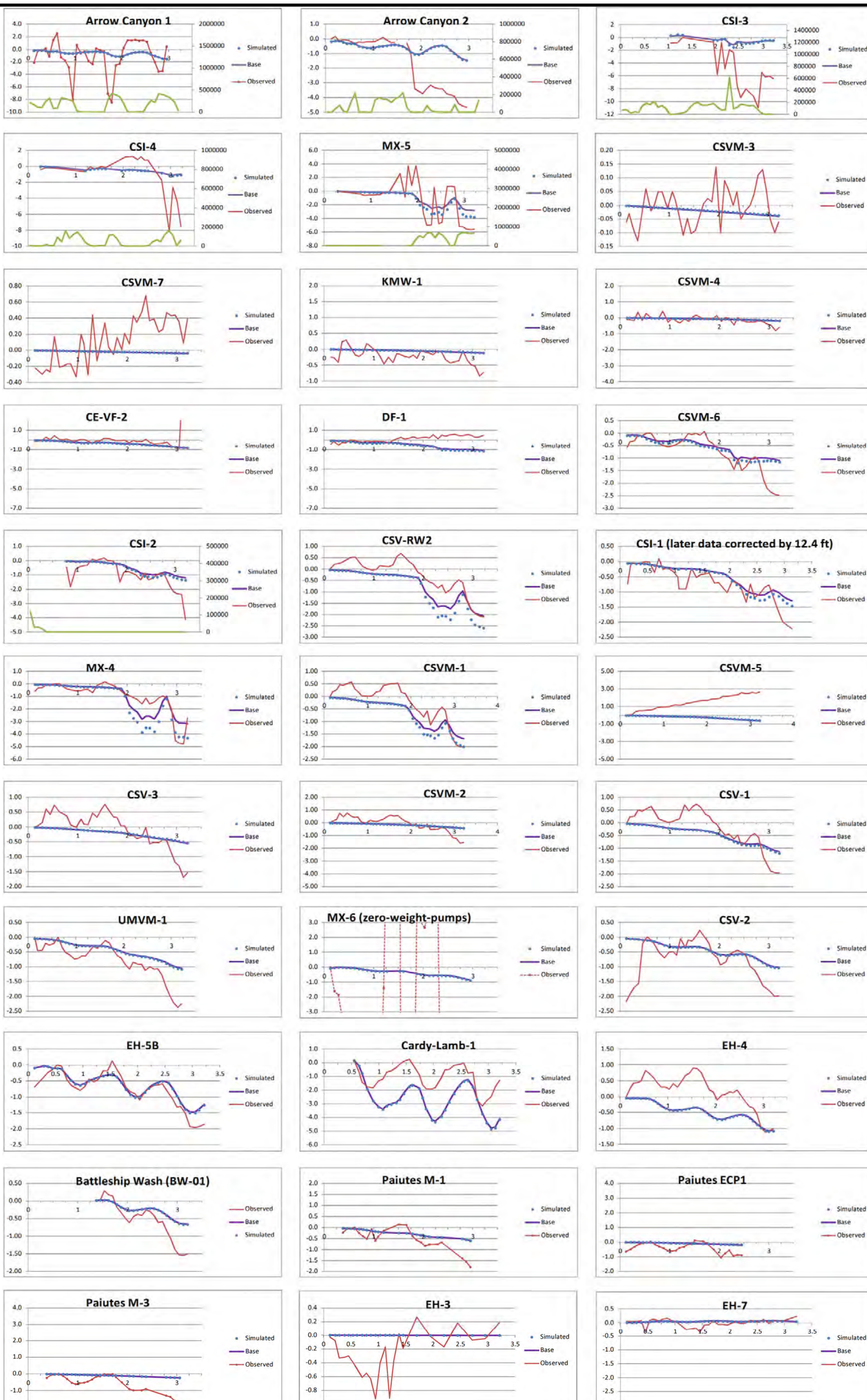


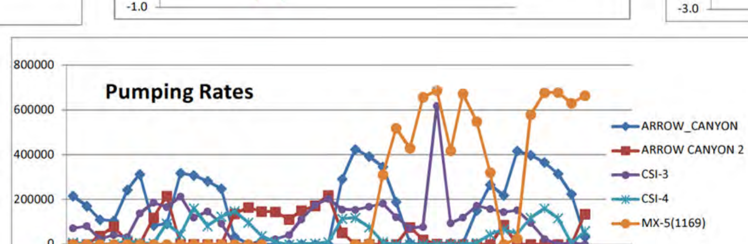


Sensitivity of Simulated Drawdown to Multiplying K_PC4_2 by 2

Lower Colorado River Flow System

TETRA TECH GEO

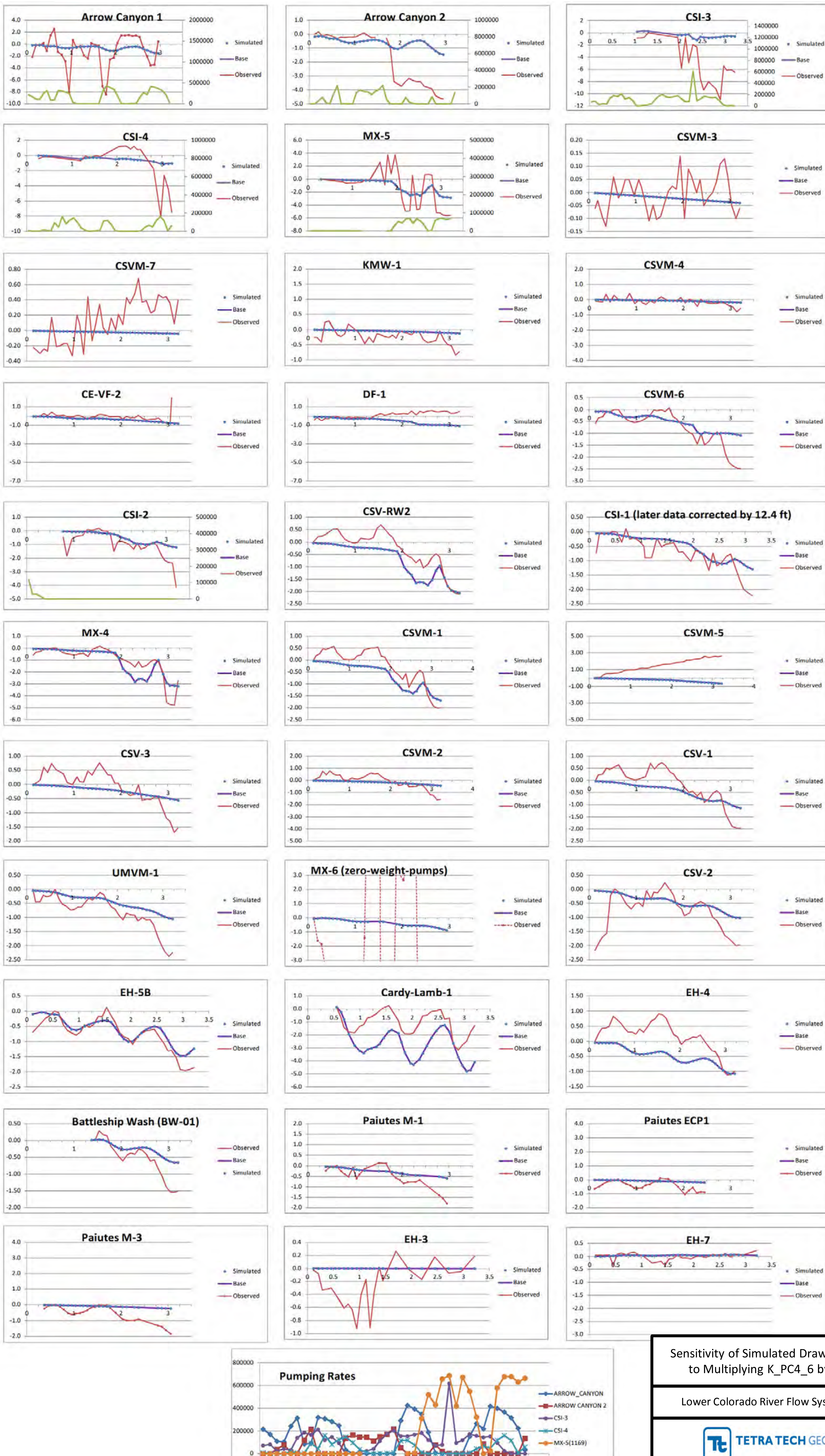




Sensitivity of Simulated Drawdown to Dividing K_PC4_2 by 2

Lower Colorado River Flow System

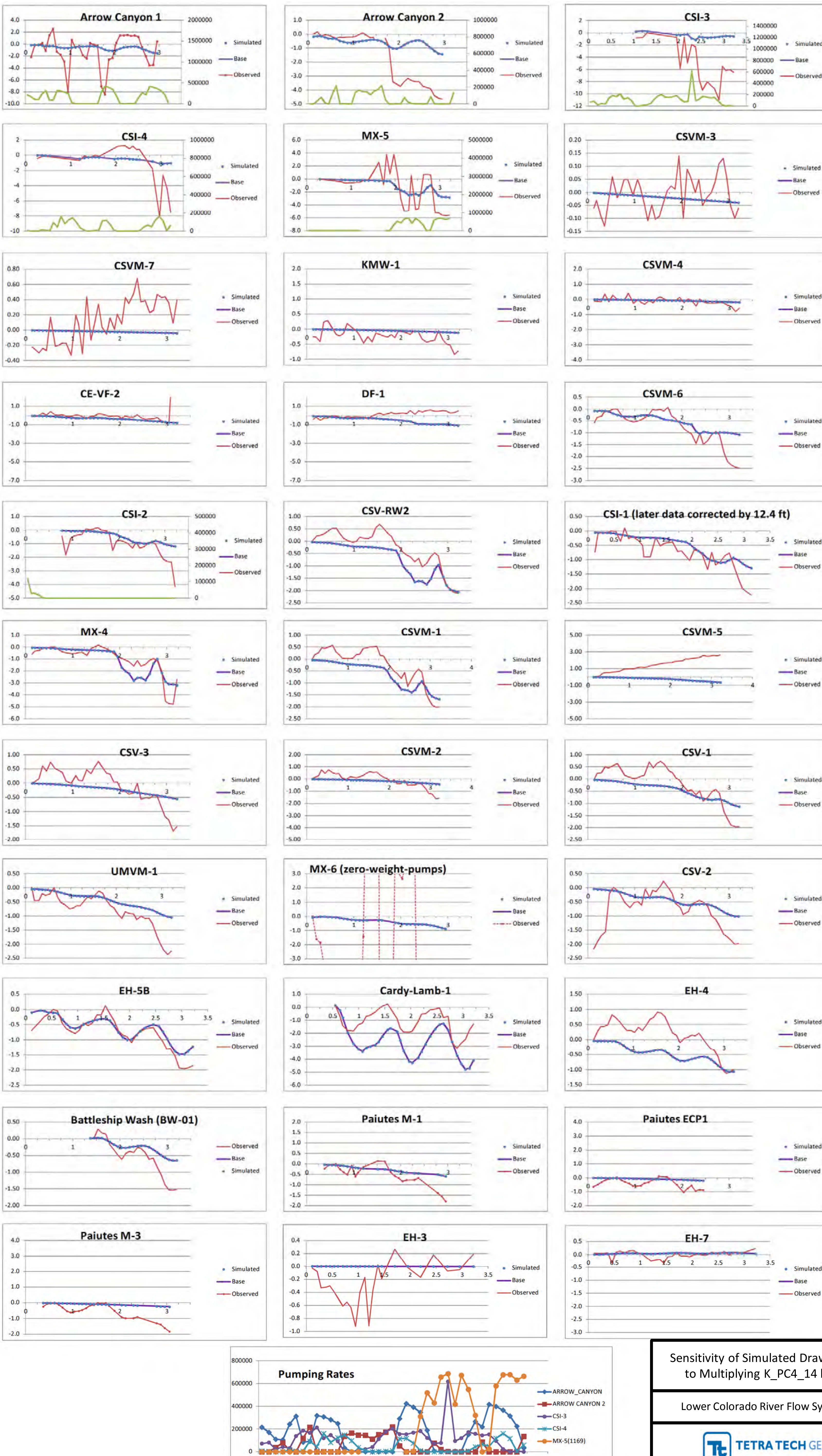
TETRA TECH GEO



Sensitivity of Simulated Drawdown to Multiplying K_PC4_6 by 2

Lower Colorado River Flow System

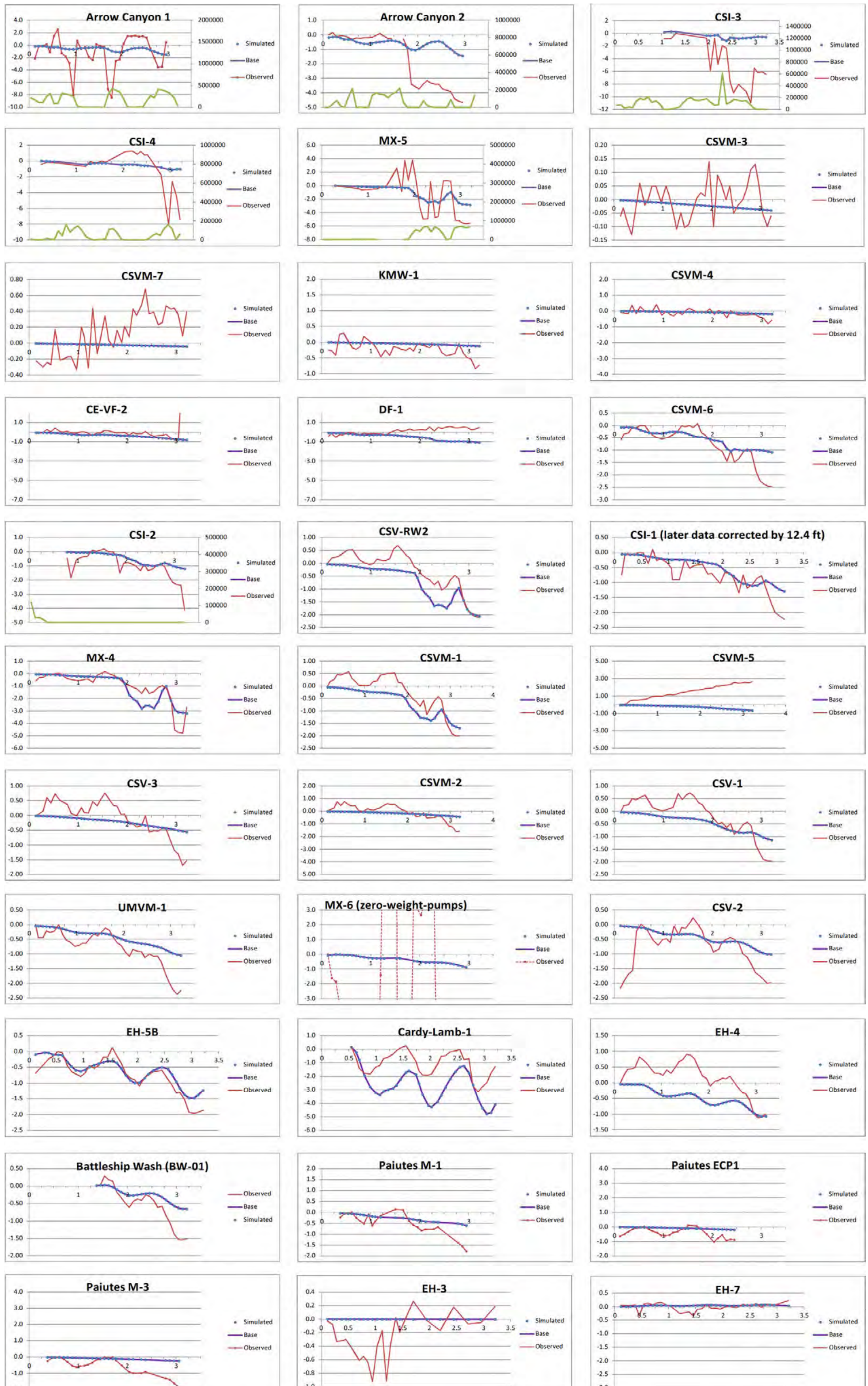
TETRA TECH GEO

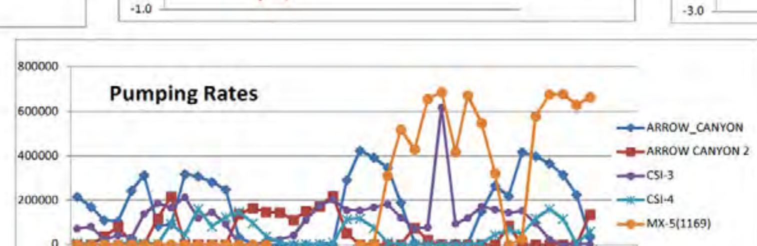


Sensitivity of Simulated Drawdown to Multiplying K_PC4_14 by 2

Lower Colorado River Flow System

TETRA TECH GEO

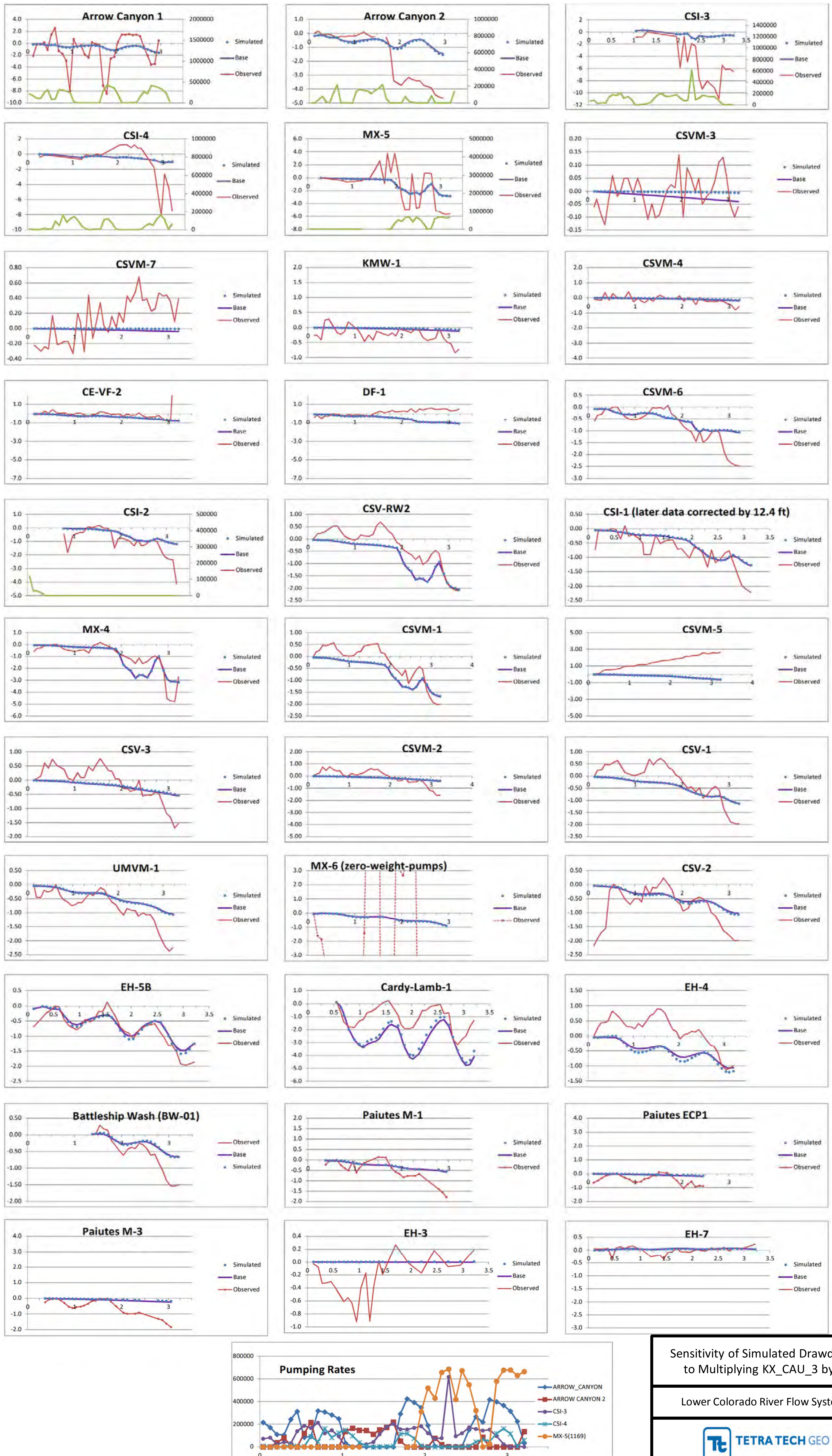




Sensitivity of Simulated Drawdown to Multiplying K_PC4_24 by 2

Lower Colorado River Flow System

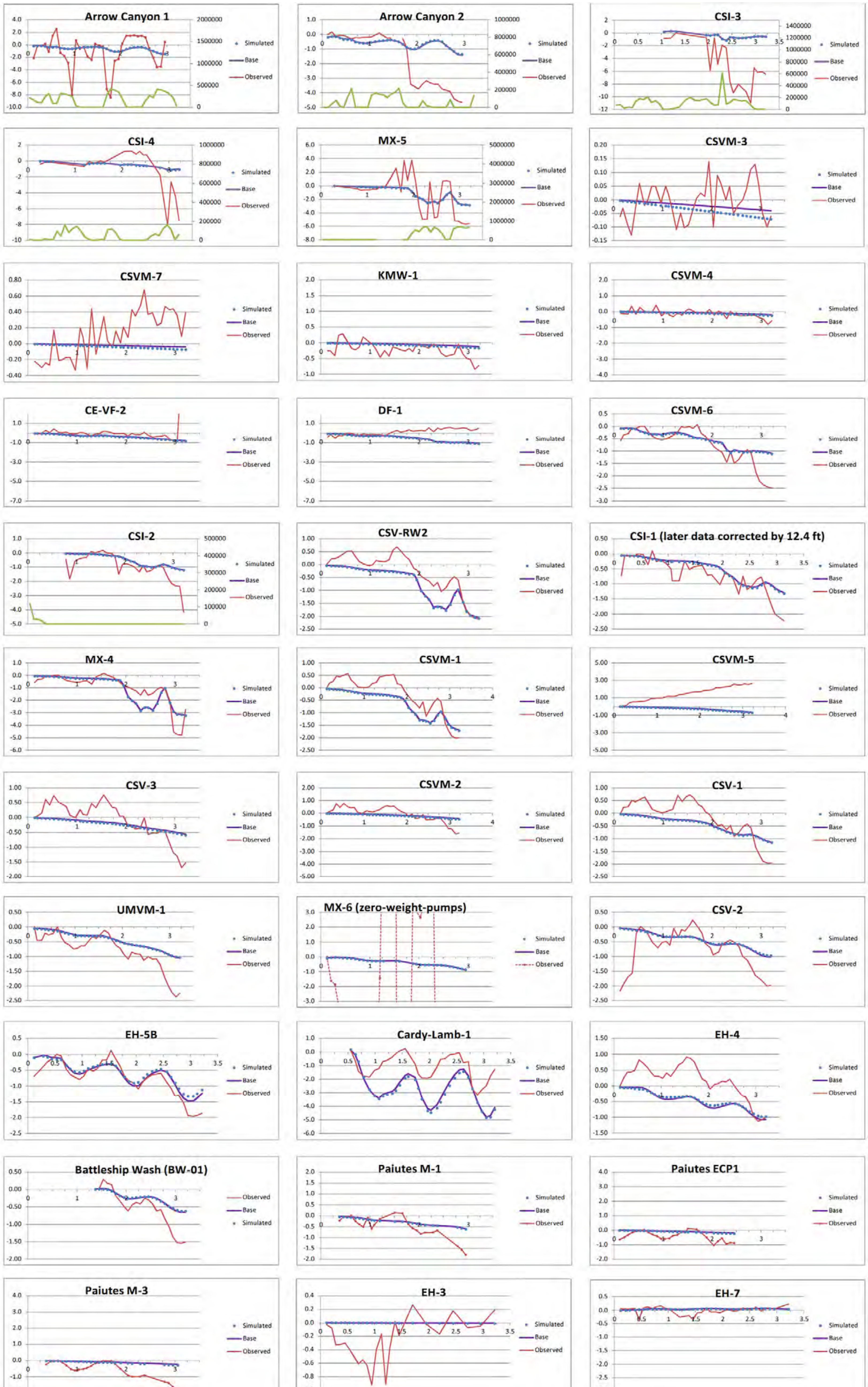
TETRA TECH GEO

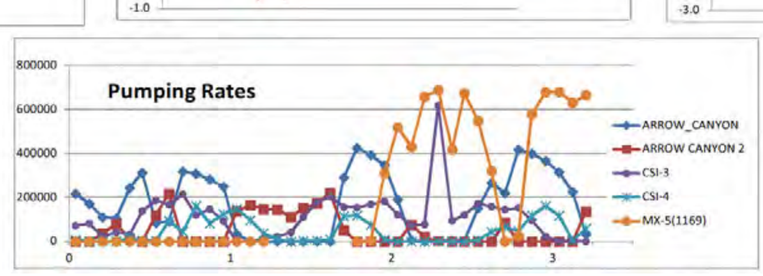


Sensitivity of Simulated Drawdown to Multiplying KX_CAU_3 by 2

Lower Colorado River Flow System

TETRA TECH GEO

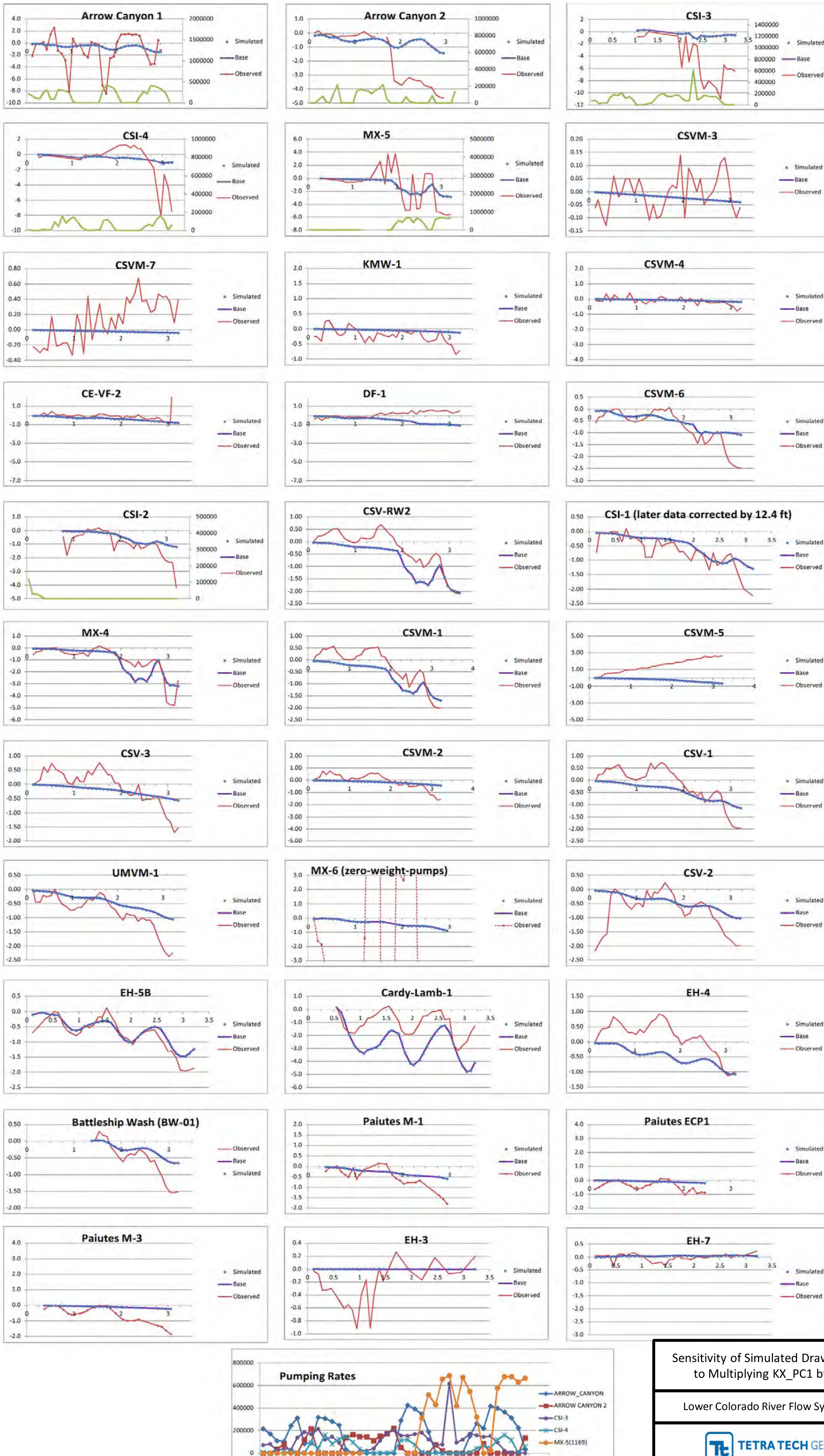




Sensitivity of Simulated Drawdown to Dividing KX_CAU_3 by 2

Lower Colorado River Flow System

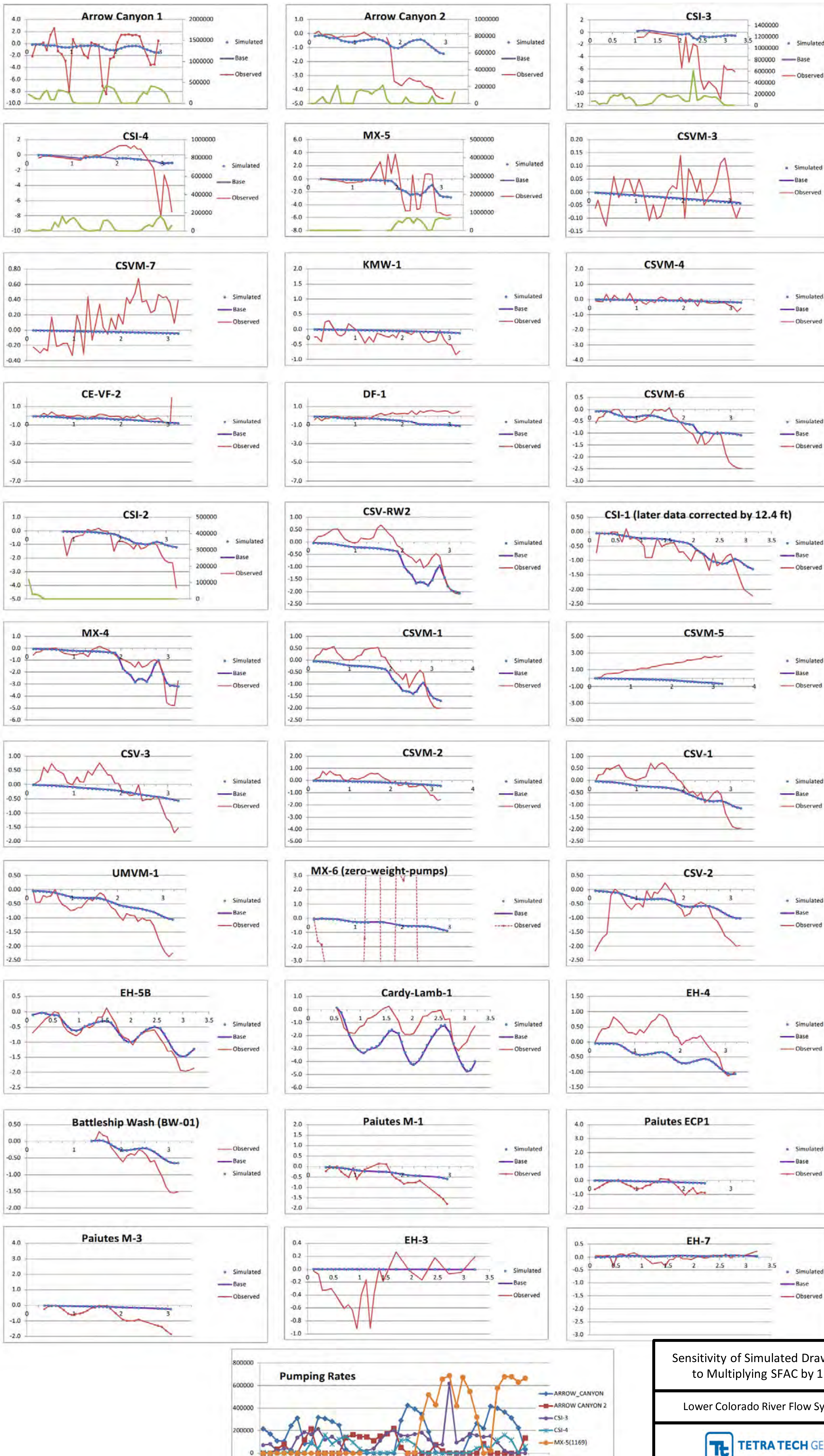
TETRA TECH GEO



Sensitivity of Simulated Drawdown to Multiplying KX_PC1 by 2

Lower Colorado River Flow System

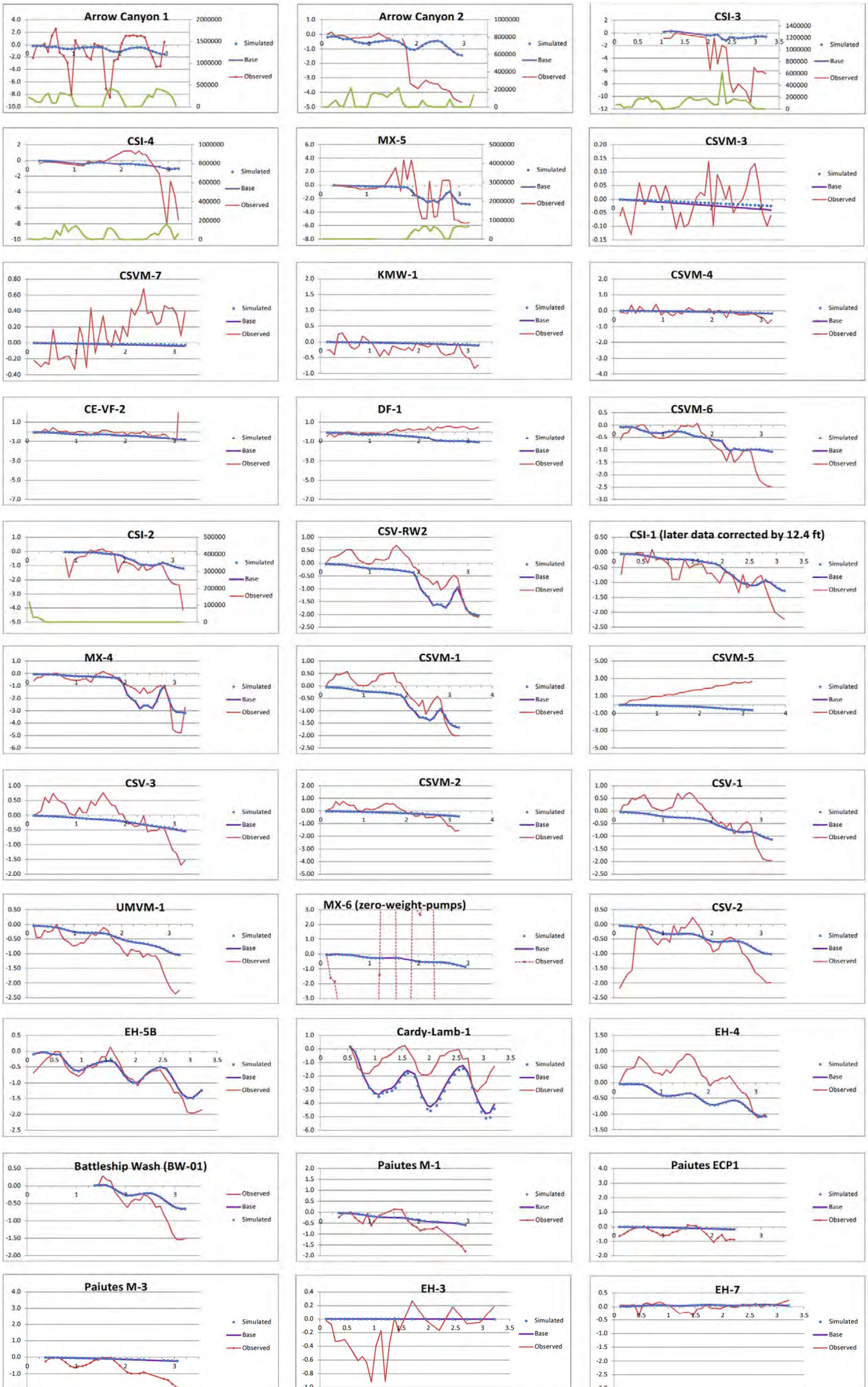
TETRA TECH GEO

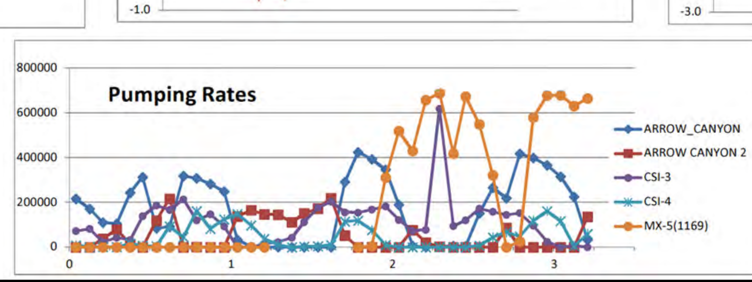


Sensitivity of Simulated Drawdown to Multiplying SFAC by 1.25

Lower Colorado River Flow System

TETRA TECH GEO

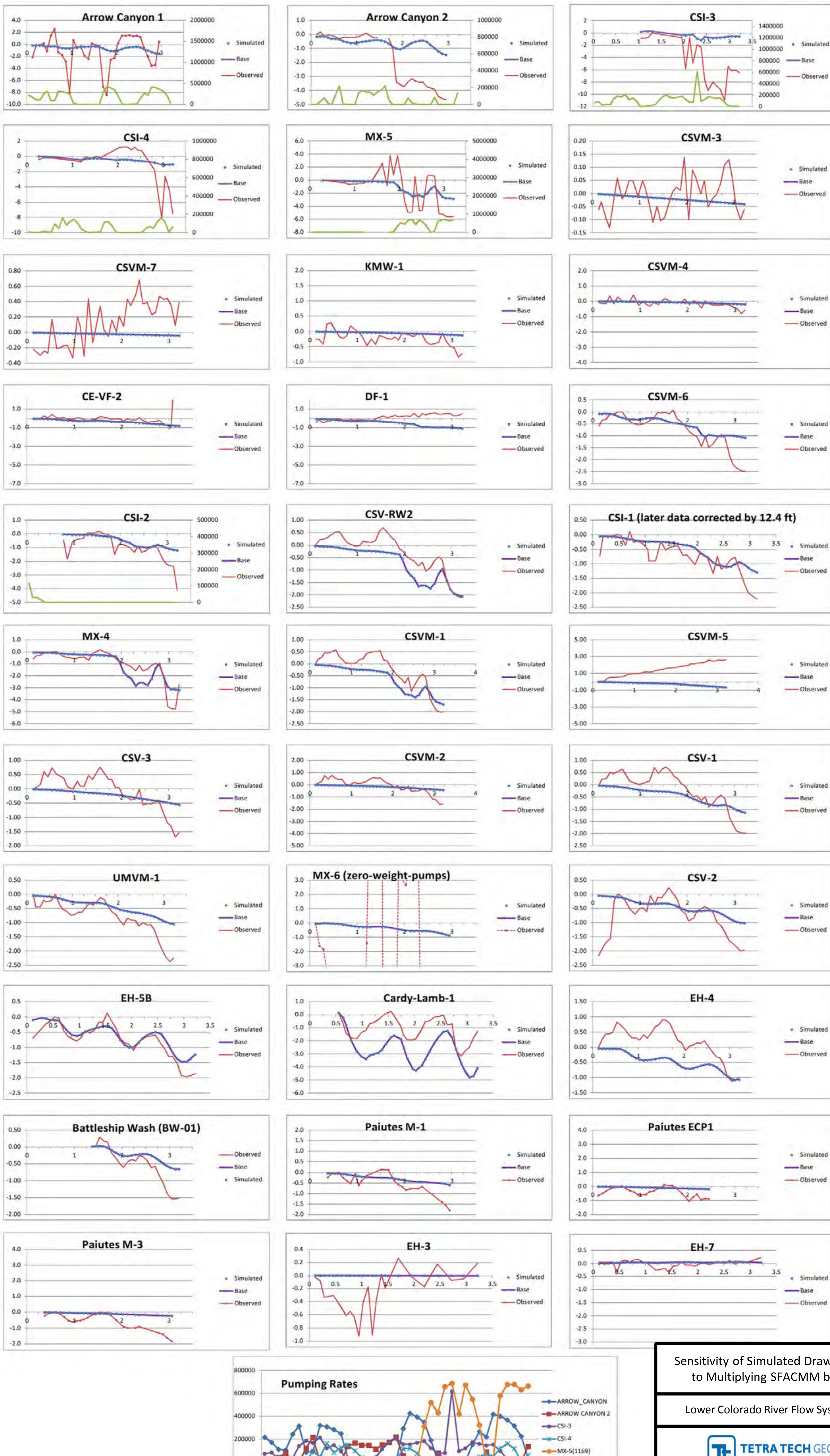




Sensitivity of Simulated Drawdown to Multiplying SFAC by 0.8

Lower Colorado River Flow System

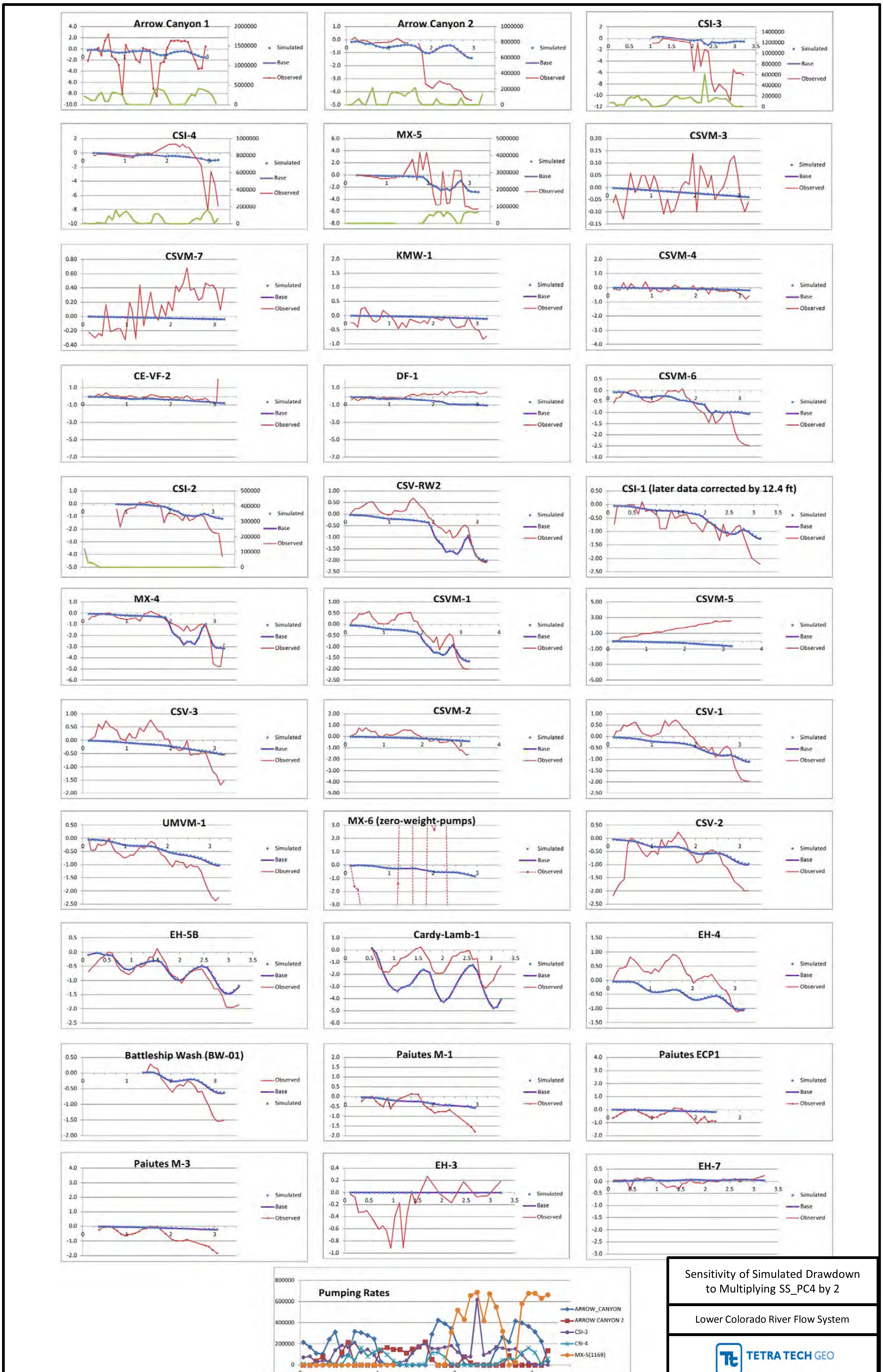
TETRA TECH GEO

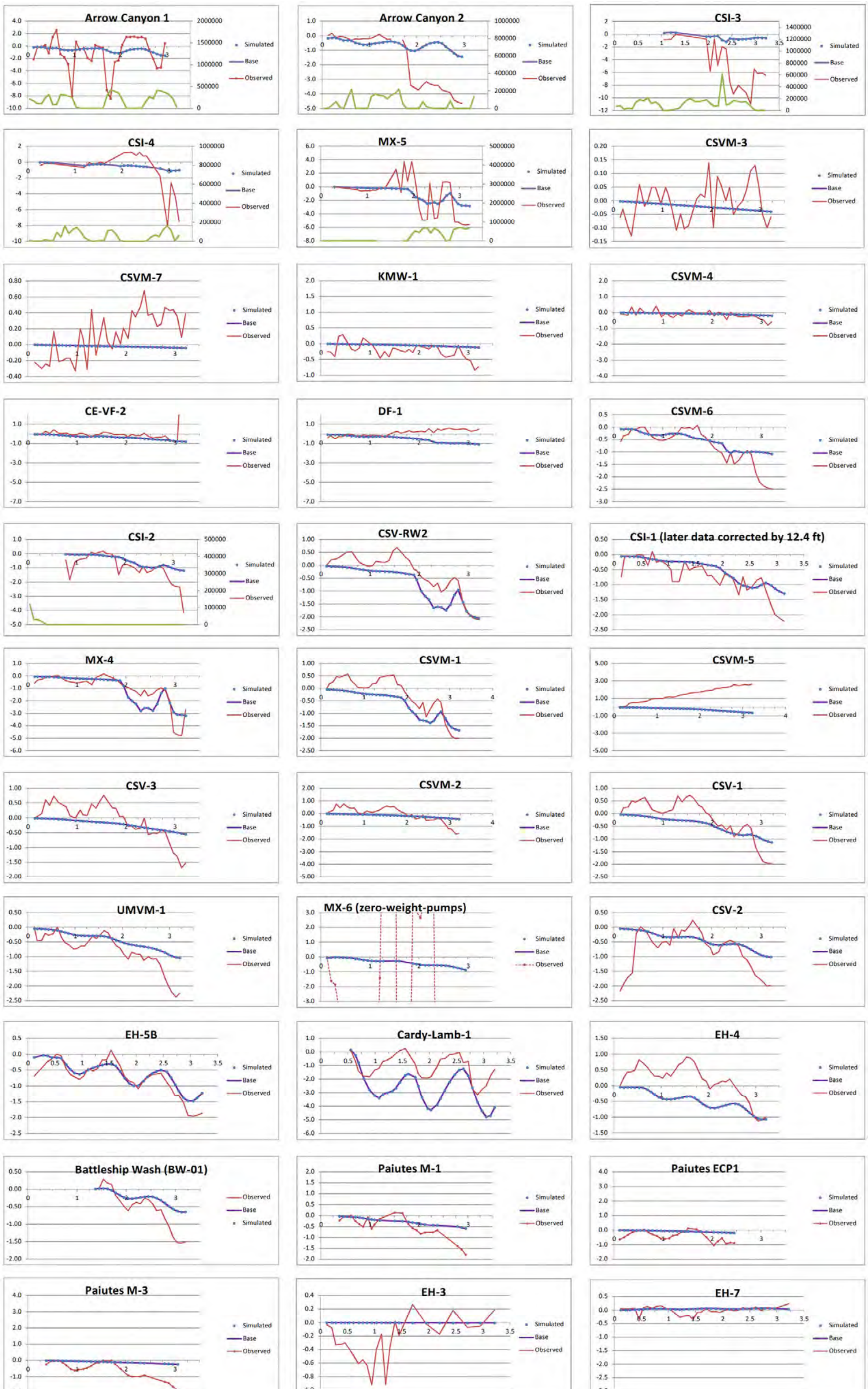


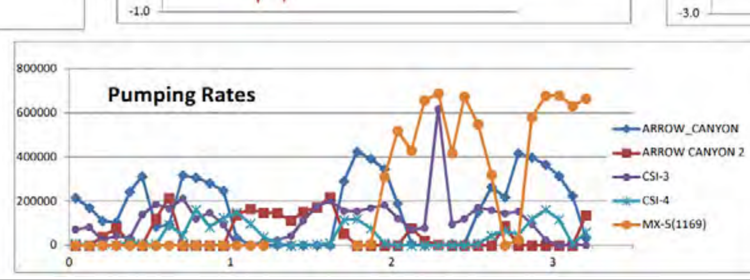
Sensitivity of Simulated Drawdown to Multiplying SFACMM by 2

Lower Colorado River Flow System

TETRA TECH GEO


Arrow Canyon 1
Arrow Canyon 2
CSI-3
CSI-4
MX-5
CSVM-3
CSVM-7
KMW-1
CSVM-4
CE-VF-2
DF-1
CSVM-6
CSI-2
CSV-RW2
CSI-1 (later data corrected by 12.4 ft)
MX-4
CSVM-1
CSVM-5
CSV-3
CSVM-2
CSV-1
UMVM-1
MX-6 (zero-weight-pumps)
CSV-2
EH-5B
Cardy-Lamb-1
EH-4
Battleship Wash (BW-01)
Paiutes M-1
Paiutes ECP1
Paiutes M-3
EH-3
EH-7
Simulated
Base
Observed
Pumping Rates
ARROW_CANYON
ARROW CANYON 2
CSI-3
CSI-4
MX-5(1169)
Sensitivity of Simulated Drawdown to Multiplying SS_PC4 by 2
Lower Colorado River Flow System
TETRA TECH GEO

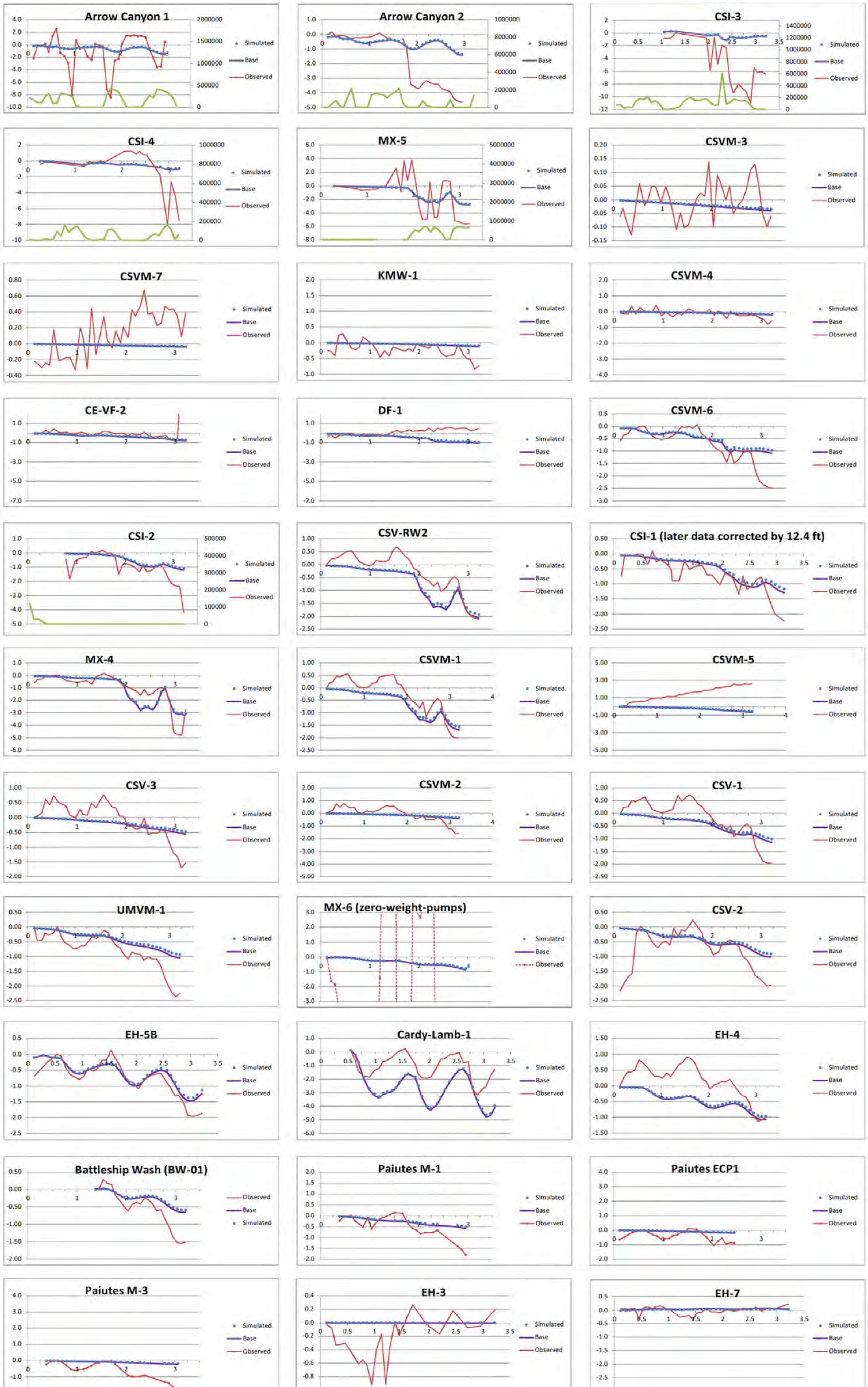


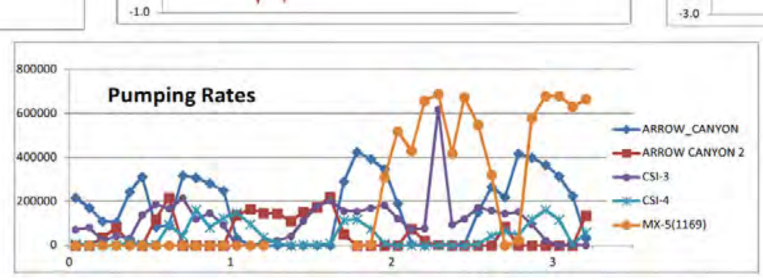


Sensitivity of Simulated Drawdown to Multiplying SY_PC4 by 1.125

Lower Colorado River Flow System

TETRA TECH GEO

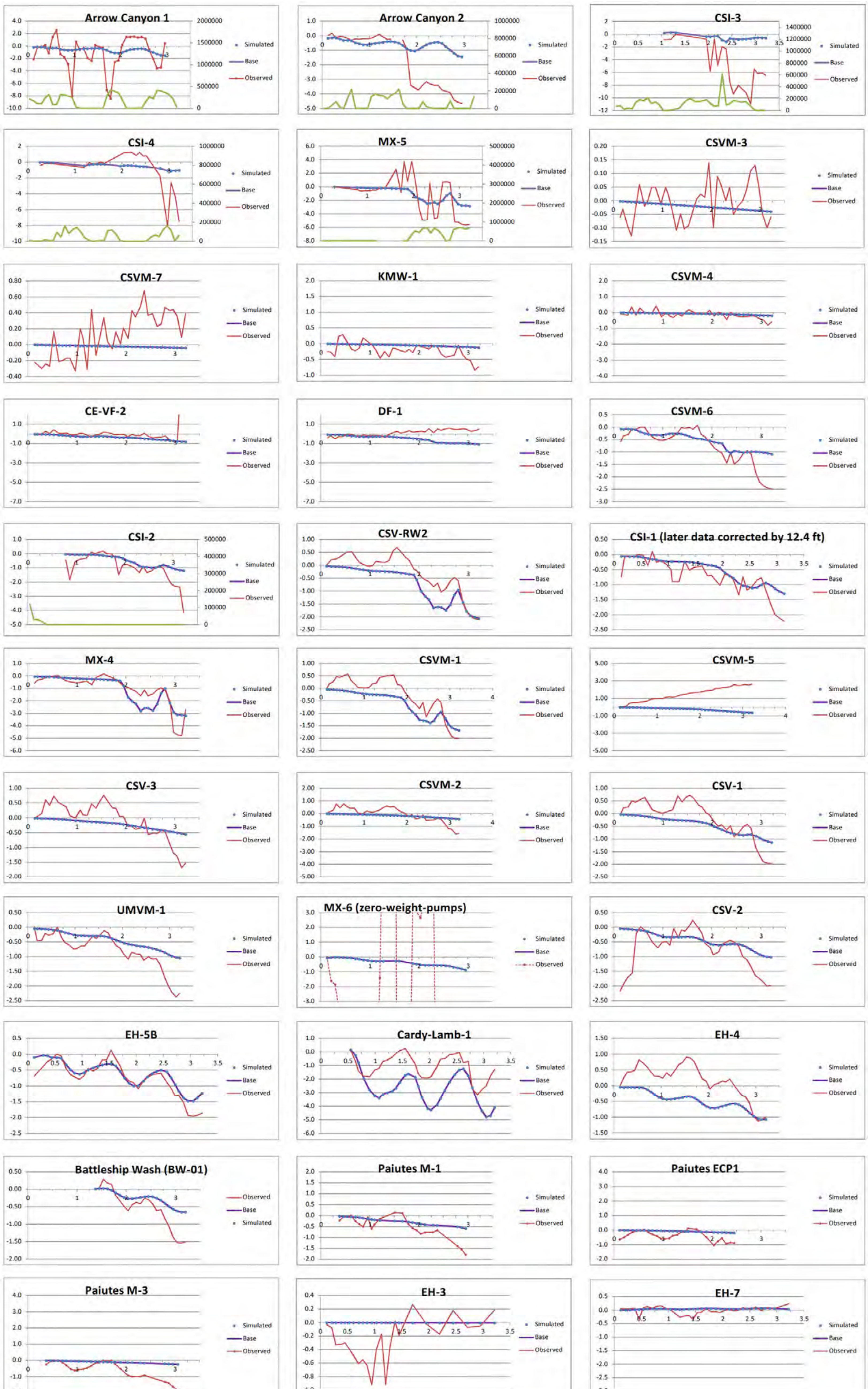


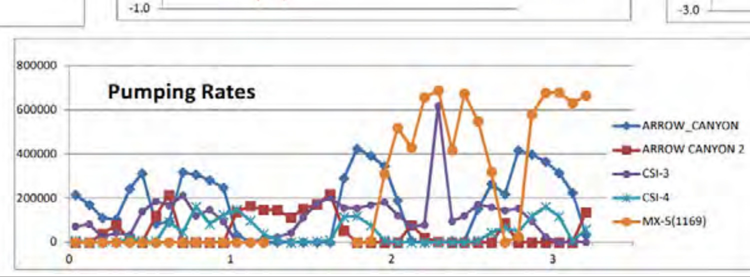


Sensitivity of Simulated Drawdown to Multiplying SY_CAU by 1.125

Lower Colorado River Flow System

TETRA TECH GEO

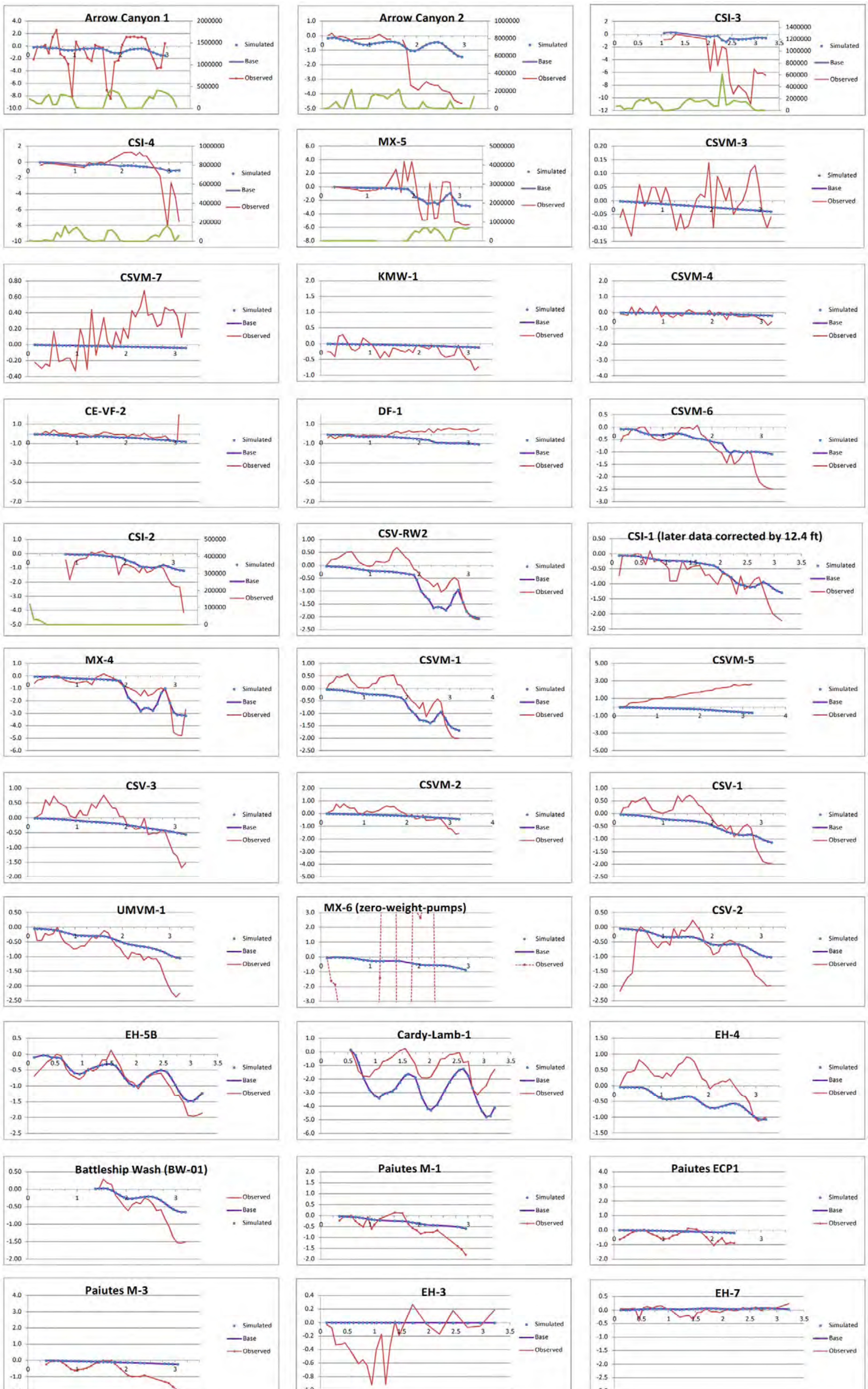


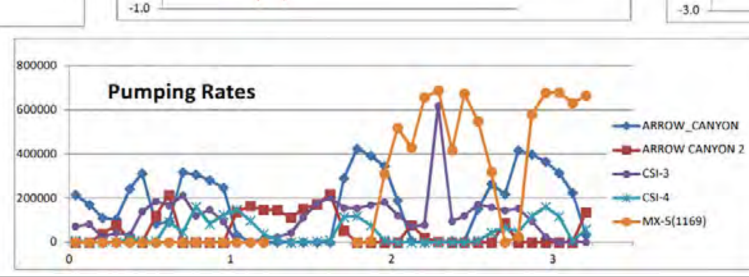


Sensitivity of Simulated Drawdown to Multiplying HF_MMT_N by 2

Lower Colorado River Flow System

TETRA TECH GEO





Sensitivity of Simulated Drawdown to Multiplying HF_MMT_S by 2

Lower Colorado River Flow System

TETRA TECH GEO