Aquifer Compaction due to Groundwater Pumping

ACTIVE
By **Land Subsidence in California** **October 18, 2018**

Overview

- Science

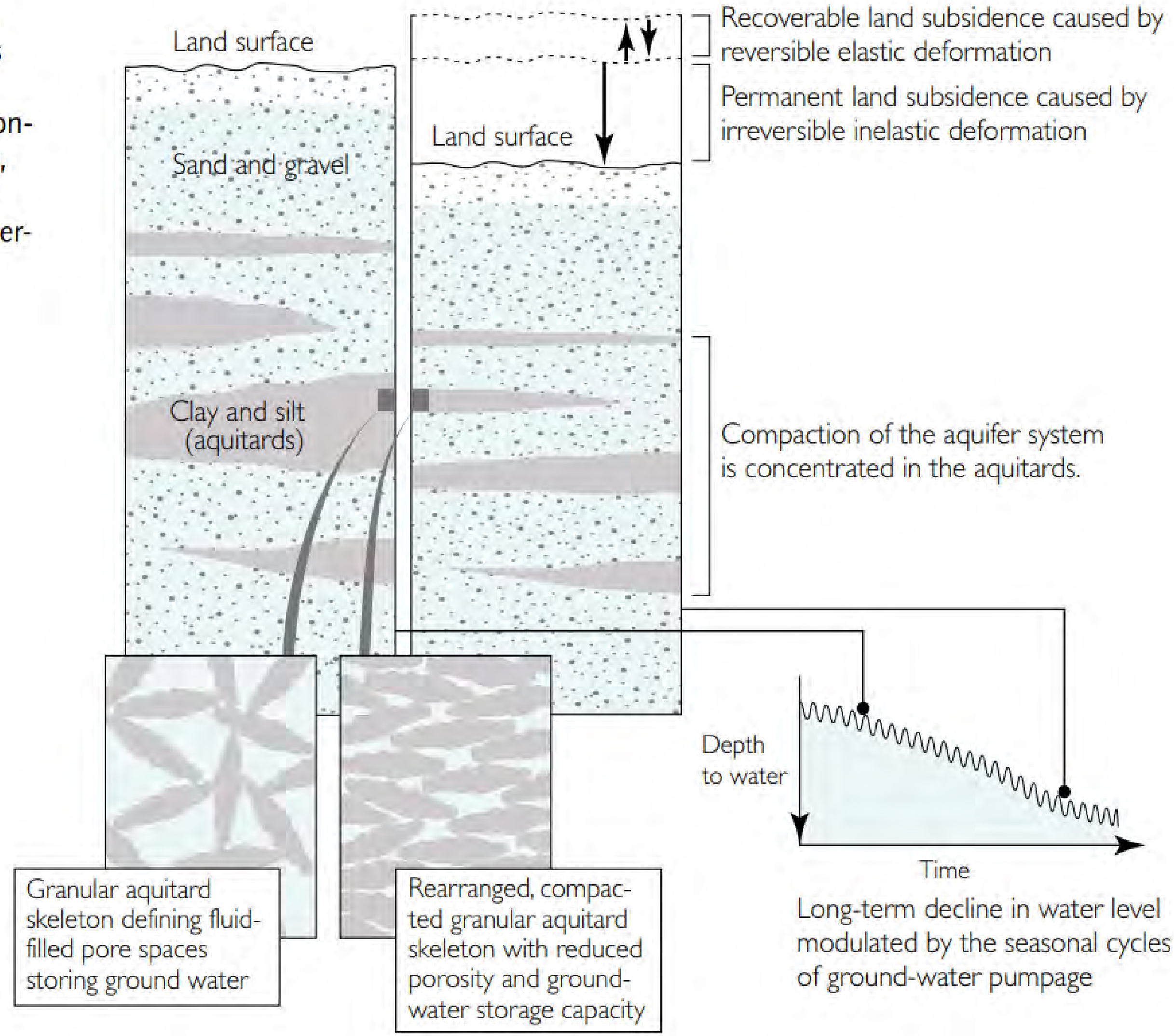
Although land subsidence caused by groundwater pumping has caused many negative effects on human civil works for centuries, especially in the highly developed urban or industrialized areas of Europe, the relation between subsidence and groundwater pumpage was not understood or recognized for a long time. Recognition began in 1928 when pioneer researcher O.E. Meinzer of the U.S. Geological Survey realized that aquifers were compressible. At about that same time, Karl Terzaghi, working at Harvard University, developed the one-dimensional-consolidation theory. The theory states generally that compression of soils results from the slow release of pore water from stressed clay materials and the gradual transfer of stress from the pore water to the granular structure of the clay.

Cause

Fine-grained sediments (clays and silts) within an **aquifer** system are the main culprits in land **subsidence** due to **groundwater** pumping. **Fine-grained sediments are special because they are composed of platy grains (imagine the shape of dinner plates). When fine-grained sediments are originally deposited, they tend to be deposited in random orientations (imagine haphazardly placing your dinner plates in the sink). These randomly oriented sediment grains have a lot of room between them to store water. However, when groundwater levels decline to historically low levels, those randomly oriented sediments are rearranged into stacks (imagine plates stacked in the cupboard). These stacks occupy less space and also have less space between them to store water.**

Media

When long-term pumping lowers ground-water levels and raises stresses on the aquitards beyond the preconsolidation-stress thresholds, the aquitards compact and the land surface subsides permanently.



Sources/Usage: Public Domain. [View Media Details]

Effect

The effects of compaction fall into two categories: those on manmade infrastructures and those on natural systems. The greatest effects occur to infrastructures that traverse a subsiding area. In the San Joaquin Valley, CA, the main problems reported are related to water conveyance structures. Many water conveyance structures, including long stretches of the California Aqueduct, are gravity driven through the use of very small gradients; even minor changes in these gradients can cause reductions in designed flow capacity. Managers of the canals, such as the California Department of Water Resources, the San Luis Delta-Mendota Authority, the Bureau of Reclamation, and the Central California Irrigation District, have to repeatedly retrofit their canals to keep the water flowing...albeit at reduced amounts. While water conveyance structures tend to be the most sensitive to subsidence, damage to roads, railways, bridges, pipelines, buildings, and wells also can occur.

While more focus has been placed on the highly visible infrastructure damage from subsidence, which generally can be repaired, **compaction of the aquifer system, sight unseen, may permanently decrease its capacity to store water; subsidence occurring today is a legacy for all tomorrows. Even if water levels rose, compacted sediments would remain as-is; most compaction that occurs as a result of historically low groundwater levels is <u>irreversible</u>**. Additionally, as the topography of the land changes by varying amounts in different places, the low areas, such as wetlands, will change size and shape, migrate to lower elevations, or even disappear. Rivers may change course or erosion/deposition patterns to reach a new equilibrium.

https://www.usgs.gov/centers/land-subsidence-in-california/science/aquifer-compaction-due-groundwater-pumping https://azgs.arizona.edu/news/sinking-feeling

Search

ARIZONA GEOLOGICAL SURVEY

Social Media

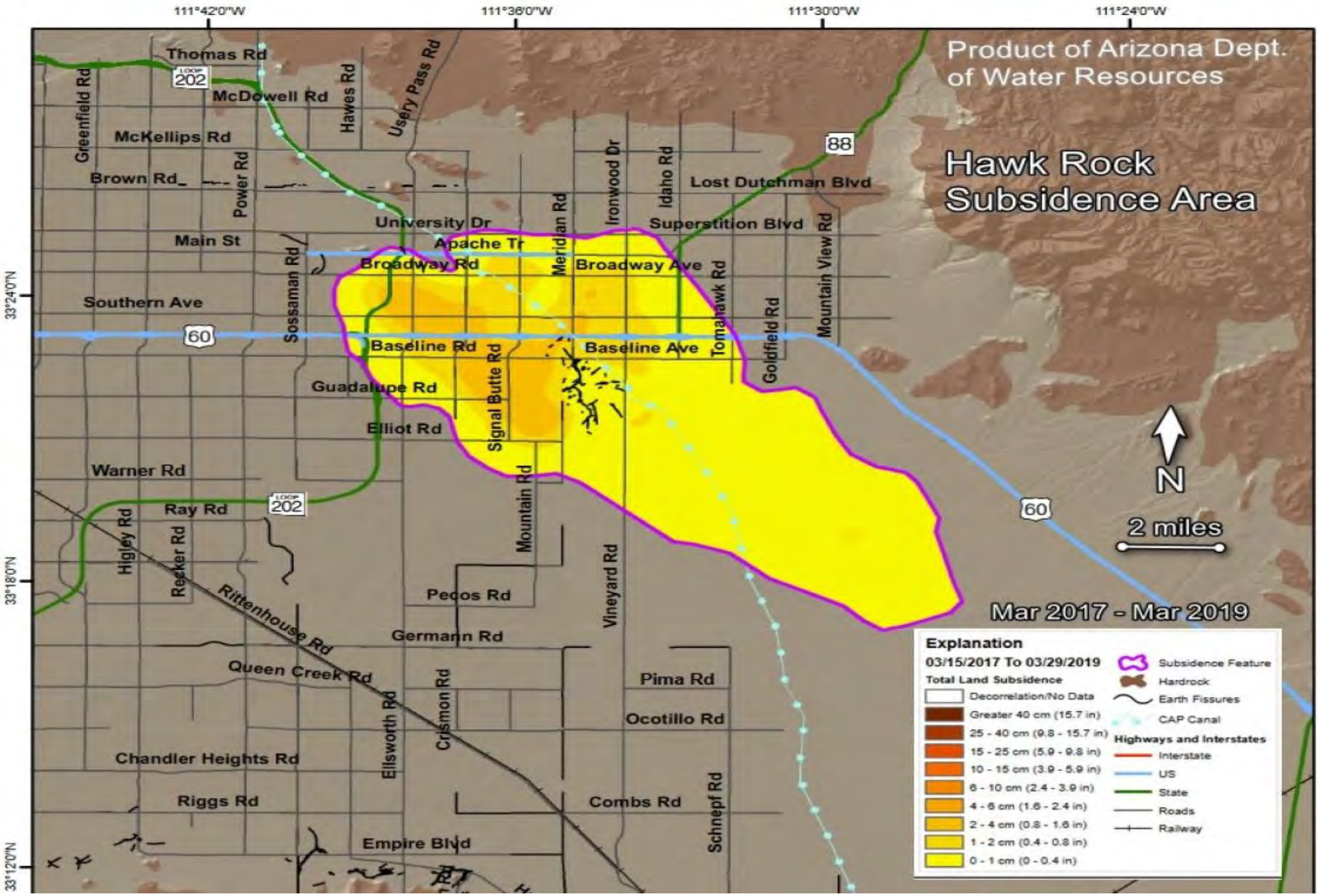
1. Home
2. News
3. That sinking feeling

That sinking feeling

Nov. 12, 2019

Arizona is sinking. Well, not all of Arizona, just certain groundwater basins in south-central and southern Arizona. Subsidence is a nation-wide and world-wide problem; subsidence as great as 19 feet has occurred since the 1950s in the areas near Luke Air Force Base and the Town of Eloy.

Land subsidence is the result of decades of excessive groundwater withdrawal that exceeds natural recharge, resulting in declining groundwater levels. As the groundwater declines, the pore spaces within the aquifer that were once supported by water pressure start to collapse, resulting in subsidence of the ground surface.



Product of Arizona Dept. of Water Resources
Hawk Rock Subsidence Area
Mar 2017 - Mar 2019
2 miles
N
Explanation
03/15/2017 To 03/29/2019
Total Land Subsidence
Decorrelation/No Data
Greater 40 cm (15.7 in)
25 - 40 cm (9.8 - 15.7 in)
15 - 25 cm (5.9 - 9.8 in)
10 - 15 cm (3.9 - 5.9 in)
6 - 10 cm (2.4 - 3.9 in)
4 - 6 cm (1.6 - 2.4 in)
2 - 4 cm (0.8 - 1.6 in)
1 - 2 cm (0.4 - 0.8 in)
0 - 1 cm (0 - 0.4 in)
Subsidence Feature
Hardrock
Earth Fissures
CAP Canal
Highways and Interstates
Interstate
US
State
Roads
Railway
111°42'0"W
111°36'0"W
111°30'0"W
111°24'0"W
33°24'0"N
33°18'0"N
33°12'0"N

In Arizona, land subsidence has produced 167 miles of mapped earth fissures, according to data provided by the Arizona Geological Survey (AZGS). Fissures frequently damage infrastructure: roads, canals, pipelines, railways, buildings, and highways. Land subsidence also has changed the natural drainage slopes, causing areas to flood that hadn't flooded in the past. It has reversed flood control canals, changed aquifer properties, **and led to the permanent loss of groundwater storage due to compaction**. ADWR has detected more than 3,400 square miles of land subsidence (see: subsidence areas in salmon color).

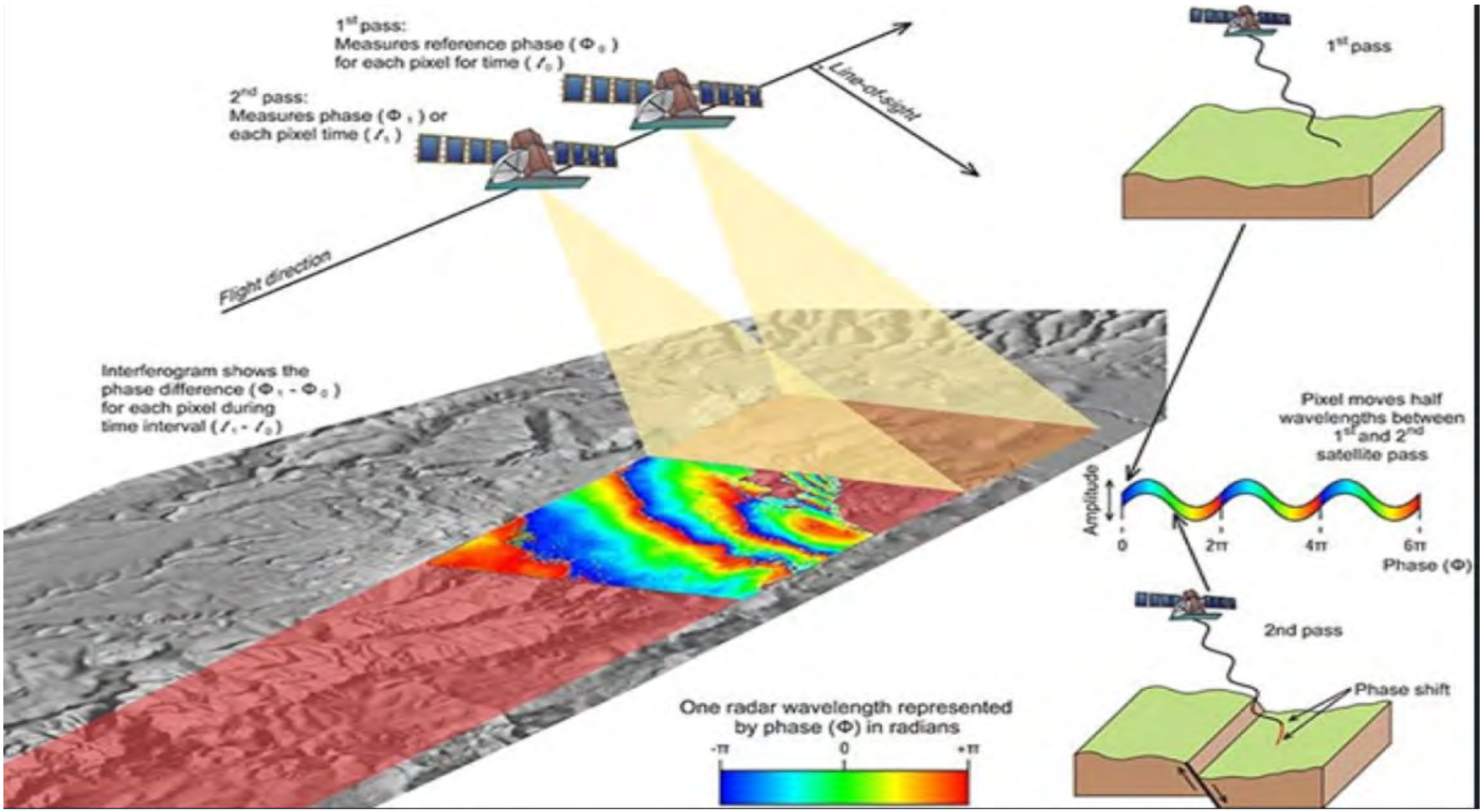
Interferometric Synthetic Aperture Radar (InSAR) techniques, using satellite-based SAR platform data, are used to produce land-surface deformation (subsidence and uplift) products with centimeter-scale vertical resolution. Changes in land elevation are detected through the change in phase of the radar signal. InSAR is used to detect surface displacement over otherwise undisturbed open land and deformation along active faults, on volcanoes, landslides, sinkholes, and other geologic features and hazards.

Besides monitoring land subsidence, InSAR data from ADWR has the following applications:

- monitor seasonal deformation (uplift and subsidence);
- track natural and artificial aquifer recharge events;
- serve as a tool for geological mapping and investigations;
- locate earth fissures;
- identify areas where conditions may exist for future earth fissure formation;
- provide dam mitigation;
- monitor floodplains that have been altered due to land subsidence.

InSAR Drives Groundwater Management. InSAR data have yielded some very interesting results in groundwater basins around the State. Land subsidence rates within the Phoenix and Tucson Active Management Areas (AMAs) have decreased between 25% and 90% compared to the 1990s. This is a result of decreased groundwater pumping, increased groundwater recharge, and recovering groundwater levels in the two AMAs.

Image: InSAR2.png.webp



Land subsidence in groundwater basins outside established AMAs that lack access to renewable surface water supplies have seen subsidence rates increase anywhere from two to five times when compared to the 1990s (InSAR data). This includes the Ranegras Plain and Willcox groundwater basins, Douglas Irrigation Non-Expansion Area, and the San Simon Valley groundwater sub-basin. Land subsidence as high as 16 cm/year (6.3 inches) is being measured in the Willcox groundwater basin.

ADWR's partners in subsidence monitoring include: Flood Control District of Maricopa County; Pinal County Flood Control District; Metropolitan Domestic Water Improvement District; Central Arizona Project; Arizona Department of Transportation; Arizona State Land Department; Arizona Geological Survey; Community Water Company of Green Valley; City of Scottsdale; Cochise County; Salt River Project; Petrified Forest National Park; City of Mesa; the City of Phoenix; and the City of Glendale.

ADWR currently collects InSAR data over more than 50,000 square miles across Arizona and InSAR data are collected throughout the year to monitor seasonal deformation. ADWR's extensive library of over 1,500 SAR scenes - used to process InSAR data - covers an area greater than 150,000 square miles at a cost of more than $1.5 million, predominantly purchased through grants and cooperators. ADWR's statewide InSAR dataset for active land subsidence areas spans time periods from 1992 to 2000, 2004 to 2010, 2006 to 2011, and 2010 to the present depending on the satellite used. ADWR now identifies more than 26 individual land subsidence features in Arizona, collectively covering more than 3,400 square miles.

ADWR provides land subsidence maps for download from ADWR's website. As of July 2017, 404 land subsidence maps are available for download and are used daily by geologists, hydrologists, engineers, planners, surveyors, floodplain managers, GIS analysts, water resources managers, and other interested parties. The maps can be accessed at this link: http://www.azwater.gov/AzDWR/Hydrology/Geophysics/LandSubsidenceInArizo...

Guest Blog Post by Brian Conway, Hydrologist/Geophysics-Surveying Unit Supervisor, Arizona Dept. of Water Resources, Phoenix, Arizona

https://azgs.arizona.edu/news/sinking-feeling

ARIZONA GEOLOGICAL SURVEY

Contact Info

520.621.2352 | 1955 East 6th Street, P.O. Box 210184, Tucson, AZ 85721

White Mountain Ambulance Service
PO Box 1670
Springerville AZ 85938
(928) 333-4202

May 28, 2026

TO: Apache County Planning and Zoning Commission

Apache County Board of Supervisors

After reviewing the paper “White Mountains Radio Users’ Statement of Concerns” dated May 27, 2026, regarding signal interference caused by Wind Turbines/Wind farms upon public and private emergency communications & radio signals. I agree with the **Need** for two (2) studies to be done, as stated in this paper, before **any** wind farms are issued County permits to build here.

As a Radio User on Greens Peak and Emergency Services with a Service Area consisting of the Towns of Springerville, Eagar, Greer, Alpine, and Vernon, and, the outer geographical boundaries that would be encompassed by the following points: Starting on Hwy 60 at milepost 355 on Hwy 60; then on a straight line Northeast to about Milepost 382 on Hwy 180/666 excluding Lyman Lake; then on a straight line east to the Arizona/New Mexico Border; then due south along the Arizona/New Mexico Border to a point adjacent to Blue in Greenlee County; then on line from Arizona/New Mexico Boarder through Blue to Hannagan Meadows in Greenlee County to Reservation Line, then straight line northwest from reservation line to Milepost 374 or A-1 Lake on Hwy 260, including Sunrise Ski Lodge and slopes; then continuing on a straight line northwest to Milepost 355 on Hwy 60; the point of origin.

Additionally, our Base Hospital is Summit Healthcare Regional Medical Center in Show Low, AZ, and we are required to coordinate with it for all patient transport. We are greatly concerned about the possible interference with our essential communications caused by the proposed wind farms/turbines.

Thank you for your consideration in this matter.

Mark Wade
Director of Operations
White Mountain Ambulance Service
Cell: (928) 205-9443
Email: chief1700@gmail.com

Date: 05/27/2026

To: Apache County Planning & Zoning Commission
75 West Cleveland Street
St. Johns, AZ 85936

Subject: Request for Independent Communications and Radar Impact Studies Prior to Approval of Additional Wind Energy Projects

Dear Members of the Apache County Planning & Zoning Commission,

Round Valley Fire & Medical Department respectfully submits this letter regarding concerns associated with proposed wind energy developments within Apache County and their potential impacts on emergency communications systems, public safety operations, and critical infrastructure serving the White Mountains region.

After reviewing documentation and statements of concern submitted by residents, licensed radio operators, and other stakeholders, we believe there is sufficient justification for Apache County to require additional independent analysis prior to the approval of additional wind energy projects in close proximity to Greens Peak, TV Knoll, and other critical communications sites.

Emergency communications infrastructure in this region supports fire suppression operations, emergency medical services, law enforcement, emergency management, public utilities, hospitals, transportation systems, and interagency mutual aid coordination across a large and geographically challenging response area. Reliable radio and communications capabilities are essential to public safety and emergency response operations.

Based upon the concerns outlined in the submitted materials, we respectfully request that Apache County require the following studies before issuing additional permits or approvals for wind energy development projects:

1. **Independent Existing Baseline Communications Study**
   An independent, professionally conducted baseline study should be completed to identify and document all existing communications systems currently operating within the affected region. This study should evaluate public safety radio systems, emergency management communications, microwave links, cellular communications, aviation systems, utility communications, amateur radio systems, and any other critical communications infrastructure potentially affected by wind turbine development.
2. **Cumulative Communications and Radar Impact Analysis**
   A comprehensive cumulative impact analysis should be conducted to evaluate the combined effects of existing, approved, and proposed wind energy projects on communications systems, radar operations, emergency response interoperability, and aviation safety. This analysis should include consultation with affected public safety agencies, communications professionals, and applicable federal and state agencies including the FCC and FAA.

Given the critical importance of uninterrupted communications during emergencies, we believe these studies are necessary to ensure that future development does not unintentionally compromise emergency response capabilities, responder safety, or public safety communications throughout Apache County.

This request is not intended to oppose responsible energy development. Rather, it is intended to ensure that development decisions are informed by objective technical analysis and that appropriate safeguards are established to protect critical public safety infrastructure relied upon by residents, visitors, and emergency responders.

We appreciate the Commission's consideration of these concerns and respectfully request that these studies be completed prior to the approval of additional wind energy projects within the region.

Sincerely,

Brannon Eagar

Brannon Eagar
Town Manager

P.O. Box 1300 * 22W 2nd Street * Eagar, AZ 85925 *
928-333-4128 * eagaraz.gov

Gateway to the White Mountains

Town of
SPRINGERVILLE
Arizona

418 E. Main Street, Springerville, AZ 85938 • Phone (928)333-2656

May 28, 2026

Community Development
Attn: Apache County Planning and Zoning Commission
75 W. Clevland
PO Box 238
St. John, AZ 85936

Dear Commission:

I am writing in support of two proposed studies: a baseline study to document radio frequency (RF) communications and a study of the cumulative effect of wind turbines on RF communications. Law enforcement and emergency service agencies need to know that their communications will not be degraded by the proposed wind turbines.

Thank you,

Ted Soltis
Interim Town Manager

May 31, 2026

TO: Apache County Planning and Zoning Commission

Apache County Board of Supervisors

Subject: **Need for further Impact Studies prior to approval of proposed wind energy projects in Apache County**

As Manager of the Amateur Radio Emergency Operators in Arizona, (some 23,700 strong), we provide communications support and public service operations to all the counties here in our state. We utilize local repeater facilities which support and backup our first responders and their managerial staff as well. We recently assisted in maintaining communications here in Apache County when the major trunks of digital and analog communications were severed. We maintain repeaters on several local mountaintops which are connected by Microwave, to the rest of Arizona which includes a backup Internet capability for Emergency Operations in each county.

We rely on clear and reliable communications capability and are concerned that the introduction of the proposed wind towers and high-tension power lines, as well as the increases in electromagnetic spectral noise that will adversely affect our ability to support operations both here in Apache County and our linked systems across the Rim Counties.

My Chief Emergency Communications Coordinator Dennis Bietry, at the DEMA office in Phoenix, supervises the activities of each of our District teams and has warned me of the detriment these wind turbine installations will have in our ability to provide support for Apache County and the surrounding Rim Country.

The proposed wind machines not only emit broadband noise: The presence of hundreds of microwave transponders (one for each tower) and the associated internet spectral crowding will deplete the ability to communicate here in the areas near Greens Peak. Our UHF links to other major peaks in Arizona depend on low RF background noise and presence of reflective radiation which would be caused by the tower installations and their support facilities creates multi-path interference which degrades our already limited path loss capabilities.

We suffer from already overcrowded Cell and Internet facilities in the remote locales where we rely on the ability to notify Authorities using our daily SKYWARN and ARES reporting networks.

We support the local authorities here in Eagar and Springerville in the need for a Baseline Communications Study which would expose the jeopardy the increased spectrum crowding would pose to our daily and emergency support communications abilities. The report from these studies should combined effects on Aviation, GPS, Cellular, Utilities, Amateur Radio Emergency Support and the many other agencies here in the county that have to have reliable response operability.

Given the necessity of guaranteeing existing and future emergency communications capabilities, we urge the Commission to insist on conducting comprehensive and independent studies, to assure that we who provide support in this county can continue to supply necessary capabilities.

Sincerely,

***/s/* Richard Paquette** W7RAP

ARRL Manager Arizona

W7RAP@ARRL.Org

(520) 425-6877
72 Spring Road CR N1047 and Springerville AZ

To: **Apache County Planning and Zoning Commission** June 1, 2026

and **Apache County Board of Supervisors**

As a representative of the Greens Peak Users Group and as an RF Engineering professional with extensive experience in public safety communications systems throughout Northern Arizona, I am writing to formally express significant concern regarding any proposed wind-energy development projects within Apache County and Navajo County that may impact the Greens Peak communications environment.

Greens Peak serves as one of the most critical high-elevation communications sites in the region and supports numerous public safety, government, utility, transportation, and emergency communications systems. Due to its unique geographic elevation and wide-area RF (radio frequency) coverage characteristics, many agencies rely upon Greens Peak for dependable line-of-sight radio communications across large portions of northeastern Arizona.

Based upon well-documented industry findings and real-world engineering studies, wind turbines have the potential to negatively affect radio communications systems through signal reflection, diffraction, multipath distortion, obstruction of line-of-sight paths, and degradation of microwave and land-mobile radio systems. These effects can become especially problematic for modern digital public safety systems such as P25 trunked radio networks, microwave backhaul infrastructure, dispatch systems, utility SCADA systems, railroad communications, and interoperability channels relied upon during emergency operations.

Of particular concern is the potential for turbine blade movement and large tower structures to introduce multipath interference and signal fading into critical communications paths serving law enforcement, fire, EMS, search and rescue, public works, forestry/wildfire-fighting, utilities, and emergency management agencies operating throughout Apache and Navajo Counties.

For these reasons, I strongly recommend that no wind-energy project move forward within visual or RF line-of-sight proximity to Greens Peak until **comprehensive, independent** Baseline and RF Impacts studies are completed by unbiased, qualified communications engineering professionals. Such a study should include, at minimum:

- Public safety land-mobile radio analysis (VHF, UHF, 700/800 MHz)
- Microwave path and Fresnel-zone obstruction analysis
- P25 digital simulcast and interoperability impact assessment
- Existing licensed spectrum coordination review
- Terrain and propagation modeling
- Pre-construction field measurements and baseline signal studies
- Evaluation of impacts to utility, transportation, and emergency communications infrastructure

Public safety communications are mission-critical systems that directly affect responder safety, emergency coordination, wildfire response, medical dispatch operations, and regional interoperability. Any degradation to these systems could have serious consequences during emergency incidents and natural disasters.

It is my professional opinion that Apache County and Navajo County planning authorities should require a formal RF communications baseline and impact assessments as part of any permitting or zoning review process associated with future wind-energy development proposals near Greens Peak or within the surrounding regional communications footprint.

Enclosed is a brief summary paper on this topic.

Thank you for your consideration of this important matter and for your commitment to protecting the integrity and reliability of public safety communications systems serving the citizens of Northern Arizona.

Respectfully,

/s/ Matt Lunati

Vice President, Greens Peak Users Association

CET (ms RF) , FCC GROL (PG-00069876)

Encl.: **Wind Farm Impacts on Public Safety Radio Communications**

Wind Farm Impacts on Public Safety Radio Communications

Professional White Paper for Public Safety Agencies, Utilities, and County Planning Commissions

Prepared for RF Engineering, Public Safety Communications, and Infrastructure Planning

Executive Summary

Wind turbines can affect radio communications by blocking, reflecting, and scattering radio signals. The effects are most significant where turbine structures intrude into line-of-sight radio paths. Microwave systems, radar installations, and digital control networks are the most vulnerable. Public safety VHF, UHF, and 700/800 MHz systems can experience localized degradation in fringe coverage areas. While analog systems tend to degrade gradually, digital systems often exhibit a sudden loss of communications when signal quality falls below operational thresholds.

Public Safety Frequency Band Comparison

Frequency Band	Typical Service	Impact Level	Most Affected Mode
30-50 MHz	Low-Band Public Safety	Low	Analog FM
150-174 MHz	Fire, EMS, Public Works	Moderate	Analog FM, P25
220 MHz	Rail and Control Systems	High	Digital Data
450-470 MHz	Public Safety / Utilities	Moderate	DMR, NXDN, P25
700 MHz	Statewide P25 Systems	Moderate	P25 Digital
800 MHz	Trunked Public Safety	Moderate	P25 Simulcast
>1 GHz	Microwave Backhaul	High	Digital Microwave

Turbine-Induced Multipath Diagram

Radio Site ---------> Wind Turbine ---------> Mobile User

Direct Path: Radio Site ------------------------------> Mobile User
Reflected Path: Radio Site ---> Turbine Reflection ---> Mobile User

When reflected signals arrive later than the direct signal, fading, distortion, and digital bit errors can occur. This phenomenon is known as multipath propagation.

Key Findings

The greatest risks are associated with microwave links, radar systems, and digital control networks. For public safety systems, turbine-related impacts are generally localized and most likely in weak-signal areas. Proper engineering studies including path analysis, propagation modeling, and field measurements are recommended before approving wind-energy projects near critical communications infrastructure.

References and Citations

• Ofcom. Tall Structures and their Impact on Fixed Wireless Links.

• Ofcom. Wind Farm Impact Studies on Fixed Wireless and Telemetry Systems.

• U.S. Department of Transportation. Wind Farm Interference Impact on 220 MHz Communications.

• NTIA Technical Report TR-08-454. Assessment of Wind Farm Effects on Radar Systems.

• ITU-R Recommendations concerning propagation, diffraction, and obstruction effects.

WHITE MOUNTAINS RADIO USERS' STATEMENT of CONCERNS

Regarding Signal Interference Caused by Wind Turbines/Wind Farms
Upon Public and Private Emergency Radio Communications & Radar Signals

May 27, 2026

TO: Apache County Planning and Zoning Commission
Apache County Board of Supervisors
Apache County IT Dept., County Sheriff's Dept., Apache Co. Emergency Mgmt. & Preparedness
US Representative Eli Crane, AZ District 2
Other local/regional Law Enforcement and Emergency Services Agencies

EXECUTIVE SUMMARY

- A **County Moratorium** is clearly justified by state law (ARS 11-833 attached) based on law enforcement and emergency services communications that will be compromised by multiple wind turbine (WT) interference to two-way radio, cell towers, microwave and other radio frequency (RF) signals.

- Such **communications interferences are well known** by the US Government, RF telecommunications companies, and also the wind energy industry.

- **FCC Regulations and involvement** are explained, but ***CORRECT WIND FARM LOCATION SITING IS CLEARLY THE RESPONSIBILITY OF THE LOCAL JURISDICTION THAT ISSUES LAND DEVELOPMENT PERMITTING.***

- US AZ District 2 **Representative Eli Crane** is quite concerned about this issue here in Apache County. His detailed February 2026 letters to the heads of the Federal Communications Commission (FCC) and the US Dept. of Transportation are provided here.

- **Draft 8 Renewable Energy Ordinance** (Section 804 "FCC Compliance") language is reviewed with constructive criticism and recommendations.

- The **locations** currently proposed by Lava Run and Black Ridge wind projects in Apache Co., and others in Navajo Co., are **graphically shown** in relation to **Greens Peak and TV Knoll summits** which are critical for RF communications of several government/emergency agencies, as well as citizen users.

- **Known user groups**, including **law enforcement/emergency services agencies** and FCC-licensed citizen groups are identified and explained.

- The County must **require two key types of studies** be done to prevent WT-caused RF interference, and to protect emergency communications capabilities:

    - An independent EXISTING BASELINE TECHNICAL STUDY including ALL government and user groups to establish the current levels of communications in use now.

- An Ordinance requirement for wind developers to provide an independent, RF professionally-prepared, cumulative COMMUNICATIONS IMPACTS ANALYSIS, disclosing all predicted wind farm(s) interferences upon the known BASELINE situation of existing capabilities, at the developer's expense, and provided to both Apache Co. and concerned user groups before a CUP is approved.

- **A Moratorium** postponing P&Z CUP application acceptance for wind projects will provide the County time for:
  - Placing correct requirements into the renewable ordinance revision; and
  - Commencing with the BASELINE STUDY needed to clarify existing RF communications in use now.

INTRODUCTION

Wind Turbines (WTs) and wind farms tend to obstruct, distort, or reflect: UHF-VHF two-way radio, aviation navigation and tracking radar, and Doppler weather radars, microwave, shortwave, fixed telemetry, AM/FM radio, cell phones and cell towers, digital TV, satellite and Wi-Fi Networks. This problem is well-known in the RF Communications industry, and also in the wind energy development industry. It interferes with governmental and private emergency services radio, broadcast radio and terrestrial television, meteorological radar, and some internet and satellite networks. Fixed transmitters and receiver stations are typically affected more than mobile units, although mobiles are also impacted (Docs. **1 through 14**), especially when they depend on fixed repeaters to relay their signals. The inability of UHF telemetry systems to operate through obstructed paths is one feature that creates a significant potential for incompatibility with WTs (Docs. **2 & 11**). Tall WTs that stand in the direct line-of-sight between signals from fixed transmitters to receivers (and repeaters) are the most direct problem, although other locations can also be troublesome, making correct wind farm location siting a very important consideration (Docs. **1, 3, 4** -pgs. 38-39, **9, 10, 11**).

Each single WT emits a small amount of radio interference that can radiate out in all directions, but is minor enough to be compliant with FCC regulations. HOWEVER, the potential for hundreds of WTs in S. Navajo and S. Apache Counties combined, risks a cumulative interference that can exceed the signal tolerance limit for receivers/repeaters across the White Mtns., including those frequencies used by law enforcement.

KEY FCC REGULATIONS

- **Part 15 Regulations** (signals from "Unintended Radiators"): Wind turbines must comply with FCC Part 15 rules, which state that electrical equipment must not cause or radiate harmful interference and must accept any interference received.
- **Protection of Microwave Links**: Wind developers must analyze potential impacts on existing microwave communication links, which are often used by utilities, telecommunications (telcom) companies, and public safety agencies. The FCC maintains a database of these links, and developers often use this data to avoid siting turbines in the Fresnel Zone (line-of-sight) of these links.
- **Interference Resolution**: If an operating wind farm causes harmful interference to licensed services, the FCC Enforcement Bureau may intervene to investigate and require mitigation.
- **Local Ordinance Control**: While the FCC regulates the radio frequency spectrum, **local jurisdictions** manage wind turbine siting and the potential for electromagnetic interference via local ordinances.

FCC's INVOLVEMENT at Different Stages of Wind Development and Operations

While the Federal Communications Commission has statutory responsibilities for protecting radio-frequency (RF) spectrum, public safety communications, and coordinates with the Federal Aviation Administration, US Dept. of Defense, National Telecommunications and Information Administration, and Natl. Weather Service, they have no legal jurisdiction over wind turbines. **It is the local governmental planning-zoning authority that is responsible for permitting specific wind turbine site locations** (Apache and Navajo Counties in this case, regardless of land ownership). However, the FCC does vigorously regulate and protect approved cell phone towers, radio transmitters-receivers-repeaters, microwave towers, and other communications facilities-equipment, which they license.

The FCC generally stays inactive during the local permitting-stages of wind turbine/wind farm development. Their policy is to wait until AFTER the wind energy facility has been built, to see if they receive any complaints filed from public safety entities, radio or cell users about communications interferences. Only then does the FCC's Enforcement Bureau investigate the source of that reported interference. The Bureau works with Federal, State, and local public safety agencies to resolve harmful interference to public safety communications and critical infrastructure communication systems. They work closely with commercial wireless carriers and other licensees to investigate claims of harmful interference (Doc. **12** – FCC Interference Resolution). If the Enforcement Bureau field agents determine that the interference is caused by wind turbines, then they require remediation by the turbine owner/operator to restore communications back to the level of service that existed before the wind turbines were built. -(This is WHY an EXISTING BASELINE STUDY of the current RF communications situation across the White Mountains is NEEDED BEFORE any wind turbines are approved for construction, to establish what that the existing pre-construction level is or was.)

Proper maintenance of turbine nacelle insulation can minimize electrical interference from the generator system. In the event of confirmed interference, the FCC suggests further mitigation measures that may be tried to eliminate or reduce the turbine-caused interference, such as:

1. Redirecting the transmitter's-receiver's antenna;
2. Relocating the transmitter's-receiver's antenna;
3. Upgrading the RF equipment used by the public and government agencies;
4. Possibly directing the local permitting government to require the turbine owner/CUP or building permit-holder to relocate or remove the offending wind turbine(s).

In the case of so many repeaters, translators, and other RF electronics located in southern Apache County on the summits of Greens Peak, and TV Knoll (directly north of US Hwy.60 at mile marker 368 across from Cerro Montosa = see Images 1 & 4 below), which have been built and continuously operated there for many decades, these mitigation measures are not feasible, for the following reasons:

1. Most antennas there are already **omni-directional**, for a good reason, and "redirecting" them makes no sense.
2. Greens Peak was chosen as a **strategic location** ideal for such RF uses. And all that fixed equipment cannot just be picked up and moved some 15 to 20+ miles away to another hilltop.
3. Upgrading RF equipment on Greens Peak would take **considerable time, at considerable expense** to the owners/users, with no guarantee it will fully solve the problem. Most citizen users of mobile and hand-held two-way radios cannot afford to purchase new, upgraded equipment. Many private owners of fixed antennas also would be impacted. **Many government agencies would have trouble budgeting to finance upgraded equipment quickly enough to ensure continuous RF**

communications for law enforcement and emergency services essential to public safety at all times.

4. Relocating or removing the offending turbines is an action the wind facility owner will fight strongly due to the cost and difficulty to get new FAA, US Fish and Wildlife Service, and other government approvals for new turbine locations after their permit and lease agreements have been approved specifically for the exact original turbine locations. Just turning a turbine off permanently does not entirely eliminate its ability to continue interfering with RF signals while still standing.

Prevention of RF interference by project denial, or by proper original site location, of wind farms is the key to success, rather than mitigations after the fact. **Preconstruction studies with mapping and modeling** has become the normal way to avoid inappropriate siting of turbines, using FCC microwave path and other RF data to properly site turbines (Docs. **1 ,3, 4, 5, 9, 10, 11).**

ESSENTIAL LAW ENFORCEMENT and GOVERNMENT EMERGENCY SERVICES USERS

Both the **Apache** and Navajo **County Sheriffs' Depts**. as well as the Apache-Sitgreaves Natl. Forests field personnel, rely heavily upon repeaters sited on Greens Peak summit for daily radio service, especially given the long distances some must travel to do their jobs, often in remote areas where cell phone service is lacking. **EMS dispatchers** for various county, state and federal agencies in both counties regularly use government repeaters on Greens Peak. Numerous other State and Federal department-agency personnel, and utility companies also rely upon Greens Pk. towers/electronics for their 2-way radio communications:

- FEDERAL: US Forest Service, US Bureau of Land Management, US Dept. of Homeland Security, US Border Patrol, US Fish and Wildlife Service, NOAA-US Weather Service, possibly others;
- STATE: AZ Dept. Public Safety, AZ Game & Fish Dept., AZ Dept. of Transportation, AZ Dept. of Emergency and Military Affairs, AZ Dept. of Fire & Forestry Management;
- COUNTY: Apache Co. Sheriff's Dept., Apache Co. Emergency Mgmt. & Preparedness, occasionally Navajo Co. Sheriff's Dept.
- MUNICIPAL: Round Valley Police & Fire-Medical Depts.(EMS), Vernon Fire Dist., Greer Fire Dist.
- ELECTRIC UTILITY COMPANIES: Salt River Project (SRP), Tucson Electric Power (TEP), Navopache Electric Cooperative (NEC)

Both the Round Valley (Springerville + Eagar) Police and Fire-Medical Departments now use dispatching services located in the Show Low-Pinetop-Lakeside area – which places the Black Ridge and Lava Run Wind projects (and others proposed?) in the near-path between dispatching services and Greens Peak. And communications towers/translators, plus cell/microwave towers, erected on the summits of Cerro Montosa-TV Knoll (see Image 4 below) are used by FM and AM public radio stations broadcasting from the Show Low-Pinetop-Lakeside transmitters (and some from Flagstaff and Snowflake) to listeners in Vernon, Concho, Springerville, Eagar, St. Johns, Nutrioso, Alpine, and into western New Mexico. Wind turbines are planned on the Cerro Montosa-TV Knoll summits, and on all near-sides surrounding them (see Image 4), which could interfere with those cell phones and public-private radio broadcasts, also important for local information to citizens during times of emergency events like large wildfires.

Round Valley and St. Johns Ambulance Services rely heavily upon the cell phone tower on Greens Peak, and on several other cell phone towers along US Hwy. 60 (like the one just east of Vernon), to communicate with Summit Regional Medical Center while transporting critical patients to that hospital. All citizens and government agencies rely equally upon the cell towers on Greens Peak, TV Knoll, and other cell towers in the vicinities of Round Valley, Vernon, Concho, St. Johns.

Moreover, utility companies critical for maintaining power for civilization, hospitals, water and sanitation, and public health, like NEC, SRP, TEP, and AZ Public Service Co. (APS) also use radio communication equipment-repeaters located on Greens Peak, and/or microwave towers on TV Knoll.

Due to our vast unobstructed airspace, rugged terrain, and sparse population, very low-altitude and high-speed military aviation training missions frequently occur over the Apache National Forest, across southern Apache County over the Springerville Volcanic Field grasslands, and sometimes at Springerville Municipal Airport. Various fighter jets, special ops aircraft, transports, and helicopters train here from Luke Air Force Base (AFB), Davis-Monthan AFB, Kirtland and Holloman AFBs, as well as Morris Air National Guard Base. Some fly as low as 200 feet above ground level (AGL) for terrain masking exercises, and others do night-vision exercises, both providing critical radar training for combat missions. Their military navigation, tracking and tactical radars could be at stake if the 2-3 proposed, and possibly more, wind farms move into this area.

The FAA and DoD should not be clearing each wind farm individually for aviation safety, but rather should be considering the cumulative effect of several wind farms proposed within so close a proximity to each other and near established military training routes. Civilian pilots are warned by the FAA to avoid flying over wind farms at any altitude due to the distortion of their onboard tracking radar signals by WTs (Docs. **8, 14**).

All of the many communications listed above qualify as authorized uses by the FCC, which means they must be maintained at existing levels of use.

Having clear, direct line-of-sight signals, without tall obstructions that reflect or distort radio and/or radar waves, is critical, and is well-known by wind industry consultants (Docs. **2, 3, 5, 10, 11**) that WTs block or interfere with those signals (Docs. **1 - 14**). Standard mitigation is *avoidance* by locating WTs out of the radio users' "near-field effect", &/or line of sight (called the "Fresnel Zone") to each other and/or to repeaters (Docs. **3, 4, 6, 9, 10 ,11**). Other expensive mitigation measures after construction might be of help, but correct original siting of multiple WT clusters is the best option.

Yet, correct WT siting alone may not be enough to eliminate impacts or reduce them to an acceptable level of interference (Docs. **1, 2, 3, 10, 11**). Each additional wind farm placed west of Hwy. 180/191 anywhere in Apache Co., when cumulatively added to the wind farms already located NW of Greens Peak in Navajo Co., can cumulatively increase radio interference for White Mtns. & N. Arizona regional users, thus reducing critical daily and/or emergency communications abilities.

CITIZEN USERS' CONCERNS

Here in southern Apache Co., as well as in Navajo County and across ALL White Mtns. communities, and the NE portion of this state south of Interstate-40 extending to Sanders and even Flagstaff, we have a large number of FCC-licensed civilian amateur radio users. We are some of them, as FCC-licensed Amateur Radio ("HAM") operators and GMRS (General Mobile Radio Service) users. FCC records now show over 1,000+ HAM operators plus another some 500+ GMRS radio users in Apache and Navajo Counties, and these numbers keep growing quarterly. On the Greens Peak summit there are at least 12 private HAM & GMRS repeaters within 4 distinct radio buildings, and ALL have been used in the past for urgent emergency communications, including our 2 largest AZ forest-wildfires in recent history (2002 Rodeo-Chediski evacuations and 2011 Wallow direct and indirect suppression), as well as the Greer Fire just last summer of 2025. These are fixed sites which cannot be easily moved.

Nine citizen radio associations whose members and users depend upon all these Greens Peak repeaters/electronics include:

- Greens Peak Users Association,
- Eastern AZ Amateur Radio Society (EAARS),
- AZ Repeater Assoc. (ARA),
- Kachina Amateur Radio Club,
- Rim Country Amateur Radio Club (RCARC),
- The Cactus Inter-tie System,
- White Mountains Volunteer Community Radio System,
- Southwest Community Radio System (SWCRS), and the
- American Radio Relay League (ARRL).

These are organized groups promoting expansion of HAM and GMRS users and capabilities across portions of AZ to ensure communications during widespread outages of cell phone and internet services. Nearly all use omni-directional antennas to operate with signals across all of NE and Central AZ. Most repeaters are privately-owned, and are under special use permits from the US Forest Service and licensed by the FCC. They are very expensive to operate and maintain once approved. Millions of dollars are invested in all the equipment, labor, licenses and permits associated with these many operators and users. Regional fixed repeaters are linked to many other fixed repeaters on other mountaintops or ridgelines, such that local two-way radio users can use Greens Peak as the primary means to connect with multiple other repeaters to talk with radio users hundreds of miles away. Several organized networks (called "Nets") of these citizen users connect weekly (some daily) to test the equipment ensuring emergency communications are possible in case all cell phones, landlines, internet, and Wi-Fi connections should go down. Leaders' names and contact info for these organizations are available on request to verify statements here, and for requested study coordination.

Some Greens Peak repeater owners are currently in the process of upgrading their equipment with more highly-sensitive receivers, to receive very weak signals sent by many area users of mobile and hand-held radios. The presence of WTs in southern Apache Co. will risk desensitizing repeater performance on Greens Pk., especially for citizens/officials in smaller communities and remote areas.

Properly working aircraft tracking radar and Doppler weather radar signals are also important for reporting critical safety information, and are altered by WTs in the immediate vicinity, capable of causing tragic results (Docs. **8, 1, 7, 9, 10**). According to US Dept. of Energy's Wind Turbine Radar Interference Mitigation Strategy Working Group: "… issues include turbine blades that rotate 360-degrees, spin to induce Doppler bin detections, and produce turbulent air with varying amounts of water vapor. **Wind turbine-radar interference issues are complex, and a full resolution may be difficult to achieve."** … "Replacing the National Airspace System and weather radar fleet with radars that are more robust to wind turbines is a **long-term** solution to wind turbine-radar interference." -(Doc. **13** - page 19). Therefore, the timeline to accomplish the objectives of their 2016 strategy was extended to 2035 based on the technology available and tested to date (Doc. **13** - Exec. Summary). So, in other words, don't expect clear technology solutions anytime soon. In the meantime, public and aviation safety are still at risk while poorly-located wind farms continue to operate and new ones are built. That does not have to be the case in Apache County, with better studies done to determine proper siting before permit issuance.

The Flagstaff NOAA Weather Radio transmitter (FCC Call Sign KXI-23, transmits on frequency of 162.525 MHz) fixed on Greens Peak also broadcasts round-the-clock daily local weather existing conditions and forecasts, used by USFS firefighters/other field employees, as well as outdoor recreationists, hunters, loggers, ranchers, resident gardeners, and travelers passing through.

These communications also qualify as <u>authorized uses by the FCC</u>, which means they <u>must be maintained at existing levels of use</u>.

All of these concerns are serious enough that **Arizona Congressman Eli Crane, House of Representatives for AZ District 2 in Washington DC**, has written to the Heads of FCC and the Dept. of Transportation/FAA about it (See his letters dated February 13, 2026 , attached to the end of this paper).

<u>Prevention</u> of these problems is essential <u>before</u> a wind facility is built, as once a wind farm is constructed, it's difficult to remedy the situation satisfactorily without removing the offending turbines to a better site location. Even standing still, turbines are capable of causing reflective/mirror interference, especially in the near-field zone. (Docs. **1, 3**, **10, 11**.)

<u>RECOMMENDATIONS</u> for 2026 APACHE COUNTY PLANNING & ZONING <u>ORDINANCE UPDATE</u>:

- **IMMEDIATELY ENACT a COUNTY MORATORIUM AGAINST the PLANNING-ZONING DEPT. ACCEPTING ANY CONDITIONAL USE PERMIT (CUP) APPLICATIONS for WIND PROJECTS FROM ANY COMPANY, UNTIL AFTER** a VERY **THOROUGH BASE-LINE STUDY** has been done by an independent 3rd-party consulting firm, of all communications currently in use across the white mountains: (types of users, numbers of users, current levels of signal transmission/reception, frequencies, band-widths, signal strengths, distances reached, repeaters needed, etc.). This is needed for compliance with Arizona Revised Statute **ARS 11-833** (see attached) for protection of essential emergency services and law enforcement. EXISTING RF CAPABILITIES MUST BE ESTABLISHED FIRST, IN ORDER TO DETERMINE LEVELS OF USE THAT MUST BE RESTORED AFTER TURBINE CONSTRUCTION, IF INTERFERENCES SHOULD RESULT. ALL agencies and private radio organizations, including the local Greens Peak Users Association, and American Radio Relay League (ARRL) State Section Manager for Amateur Radio Emergency Services, and communications equipment owners licensed/permitted for special uses on the summit of Greens Peak and Cerro Montosa-TV Knoll should be consulted in this study.

- **KEEP the text from existing 2021 Ordinance old <u>Section 439.E. text as required compliance with FCC Regulations</u>:**

  439.E. – "Renewable Energy Generation projects shall comply with applicable Federal Communications Commission (FCC) requirements, including those applicable to microwave communication links in the vicinity. Renewable Energy Generation facilities shall minimize and mitigate telecommunication interference (electromagnetic fields and communication interference generated by the project). No interference with public communication systems shall be allowed."

REVIEW of NEW ORDINANCE DRAFT VERSION 8 TEXT (5-20-26 full section text provided below, verbatim in Times New Roman font, and selected text highlighted here in light gray):

Draft 8
Article 8 Renewable Energy

Section 804. General Development Standards (439)

FAA and FCC Compliance

Communications Interference; Compliance; Investigation; Remediation; Waivers. The Applicant/Operator shall design, construct, operate, and maintain the Renewable Energy Facility in compliance with all applicable Federal Communications Commission (FCC) rules and regulations (including prohibitions on harmful interference, as defined by the FCC) and any other applicable federal or state authorizations, licenses, or permits governing RF, microwave, broadcast, public safety, and telecommunications systems. Prior to construction, the Applicant shall submit a pre-construction RF/microwave interference study prepared and sealed/signed by a qualified communications engineer and shall provide and maintain a local point-of-contact (name, 24/7 phone, and email) authorized to receive and act on interference complaints. Upon receipt of a written complaint, the CUP holder shall initiate an investigation within ten (10) business days and provide the complainant and the County a written status update. If interference is verified, the CUP holder shall, at its sole cost, implement corrective action sufficient to eliminate the verified interference and restore service to pre-project conditions, including as necessary operational curtailment or cessation, repair or replacement of affected equipment, filtering/shielding, and re-aiming or relocation of antennas or communications equipment, within thirty (30) calendar days of verification **unless the Community Development Director grants a written extension for good cause.** The County may require independent testing and/or engineering analysis by a qualified third party to confirm the presence, source, and resolution of interference; all reasonable costs shall be paid by the Applicant/Operator. Any person or entity may waive application of this subsection as to a specific receiver, facility, or parcel by executing a written waiver identifying the affected location and scope of waiver and recording the waiver with the County Recorder to provide notice to successors.

___________________*END of DRAFT 8 DIRECT QUOTE*___________________________________

SPECIFIC PROBLEMS IDENTIFIED WITH THIS PROPOSED ORDINANCE LANGUAGE:

- *"…Prior to construction, the Applicant shall submit a pre-construction RF/microwave interference study prepared and sealed/signed by a qualified communications engineer…"*

This text is a good improvement. It is required by state and local permitting agencies in other states -(see pgs 38-39 of Doc. **4** by US Dept. Of Energy,+ Docs. **10 & 11**). Yet, the methodology and results of such studies should further be subject to review by the Senior RF Engineer who is Vice-President of the Greens Peak Users Association, representing multiple entities that could be impacted, to ensure their technical issues have also been considered and modeled in that developer-commissioned study.   THE COUNTY ALSO NEEDS to COMMISSION an INDEPENDENT EXISTING BASELINE STUDY of ALL COMMUNICATIONS CAPABILITIES and USES OCCURING NOW, BEFORE ANY WIND FACILITIES ARE PERMITTED TO BE BUILT WHERE THEY ARE PROPOSED NEAR GREENS PEAK. If a baseline study is not required to be done before approval of the wind farm's Conditional Use Permit to PROVE the level of RF capabilities present before the project starts, then there is no way for radio users to pursue reception restoration back to that level after post-construction problems become apparent, as required by the FCC.

- *"...and [the Applicant] shall provide and maintain a local point-of-contact (name, 24/7 phone, and email) authorized to receive and act on interference complaints.*

The appropriate means for citizen radio users, public safety agencies, and telcom companies/others to report interference complaints is NOT through the wind developer or permit-holder, but rather to report issues directly to the FCC's website established for this purpose. Otherwise, the FCC will not be aware of the problems that RF users are experiencing, and appropriate resolution of the issues is not documented or guaranteed. It is up to the FCC, not the CUP permit-holder, to determine if interference is occurring and from what source. By making this a requirement in the new Ordinance Article 8, the County is placing responsibility upon themselves and the developer for liability claims and possible FCC violation penalties.

- *"Upon receipt of a written complaint, the CUP holder shall initiate an investigation within ten (10) business days and provide the complainant and the County a written status update."*

The CUP-holder has no expertise to conduct an investigation, as that is the job of the FCC Enforcement Bureau (Doc. **12**). The CUP-holder will be required to implement mitigations or remediations as specified by the FCC. The CUP-holder's responsibility to the County should be to keep them advised of the situational status.

- "*...re-aiming or relocation of antennas or communications equipment..."*

It is NOT within the authority of the County or the wind energy facility owner/operator/permit-holder to use this as a mitigation option, because all such communications equipment belong to private/government owners under license with the FCC. All antennas & RF equipment on Greens Peak CANNOT be relocated, as this summit was intentionally selected as a strategic location for the entire White Mtns. area. Many Millions of $$ worth of equipment are mounted there, under Special Use Permits from the US Forest Service.   Nobody can simply pick up this mountain and move all that equipment to a "better" location to suit poorly-sited wind turbines causing communications interference after turbine construction. Many of those fixed antennas are already omni-directional, so "re-aiming" them is not an option.

- *"The County may require independent testing and/or engineering analysis by a qualified third party to confirm the presence, source, and resolution of interference; all reasonable costs shall be paid by the Applicant/Operator."*

This is good language we agree with. It is required by state and local permitting agencies in other states. - (see pgs 38-39 of Doc. **4** by US Dept. Of Energy).

- "… *Any person or entity may waive application of this subsection as to a specific receiver, facility, or parcel by executing a written waiver identifying the affected location and scope of waiver and recording the waiver with the County Recorder to provide notice to successors."*

If Apache County permits this as an Ordinance provision, then the County is inviting liability for vital communications needed by critical emergency services to be impacted when needed most at times of public distress. No individual citizen as a private landowner has the right to permit construction of a structure that jeopardizes overall public safety, and the County has no right to permit this either. In fact, doing so likely violates the County's legal responsibilities under state law to provide for the public health, safety and welfare.

- **Therefore, the revised ordinance must require wind project developers to provide a Communications Impact Analysis, or its equivalent, to demonstrate that pathways between communicating 2-way radio/radar towers are unobstructed prior to approval of wind project CUP operational permit, including potential adverse impacts possible after construction. This is required by state and local permitting agencies in other states. -(**see pgs 38-39 of Doc. **4** by USDOE, + see Doc. **11** as one example**).**

- **For this Analysis, REQUIRE COORDINATION WITH: Local HAM/GMRS licensed leadership, repeater owners via the Greens Peak Users Assoc., and US Weather Service, National Telecommunications And Information Administration (NTIA), utilities, other federal & state agencies and county, all owners & users to establish the baseline of existing radio signal transmission/reception capabilities in the proposed project area vicinity before county CUP permit is approved. IT SHOULD INCLUDE THE CUMULATIVE EFFECTS of ALL EXISTING and POTENTIALLY PROPOSED WIND PROJECTS KNOWN.**

- ***If done correctly, a thorough EXISTING BASELINE STUDY will be very useful to help evaluate all proposed wind projects and their projected COMMUNICATIONS IMPACT ANALYSIS results.***

- **DO - Keep wind turbines and wind farms well away from the area between Greens Peak, TV Knoll, and the majority of our radio user locations who are dependent upon these repeaters, which is key to maintaining these communication networks as fully functional.**

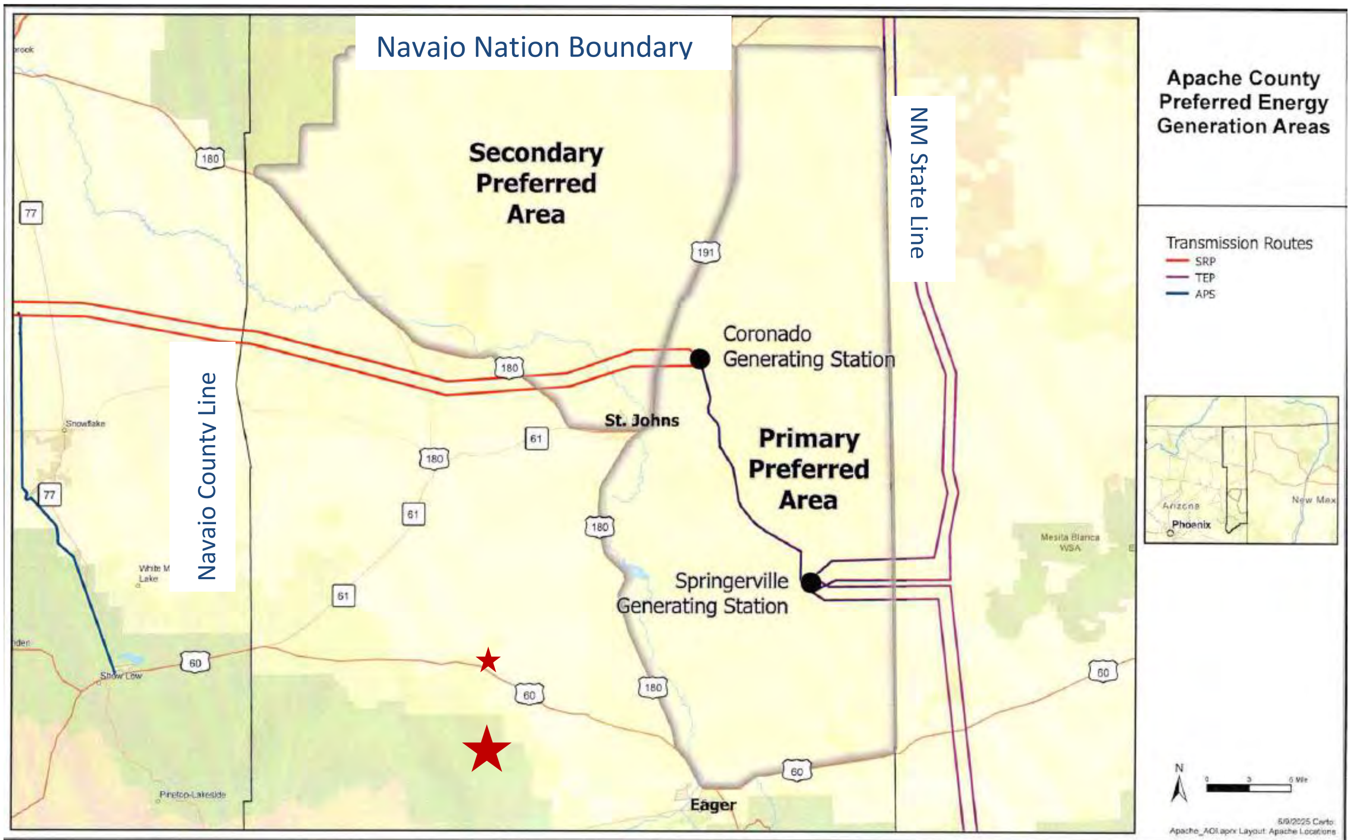
- **DO – Adopt the County's proposed "Preferred Areas" into the Comprehensive Plan.**

- **DO - Locate wind turbines and wind farms in the Preferred Area which can be a solution for most users, as that area is less populated (especially the "Primary" Preferred Area), and is away from the Greens Peak Fresnel Zone.** See Apache County's proposed "Preferred Area" map **Image 1** on following pages.

- **DO - Require wind project owners/operators to cooperate with the FCC and local RF users throughout the life of the wind project whenever signal interference is reported.**

- **DO PLEASE CONSIDER - The wisdom of placing a turbine height limit capped at 500 feet total height in the Ordinance. As WTs keep increasing in total heights, this issue will continue to intensify.** (For example, another large wind farm near Seligman in Coconino Co. is now proposed with 850-ft. turbines.) But, such a height limit will NOT prevent all WF communications interference.

<u>IMAGE 1</u>: Apache County Proposed Preferred Area(s)

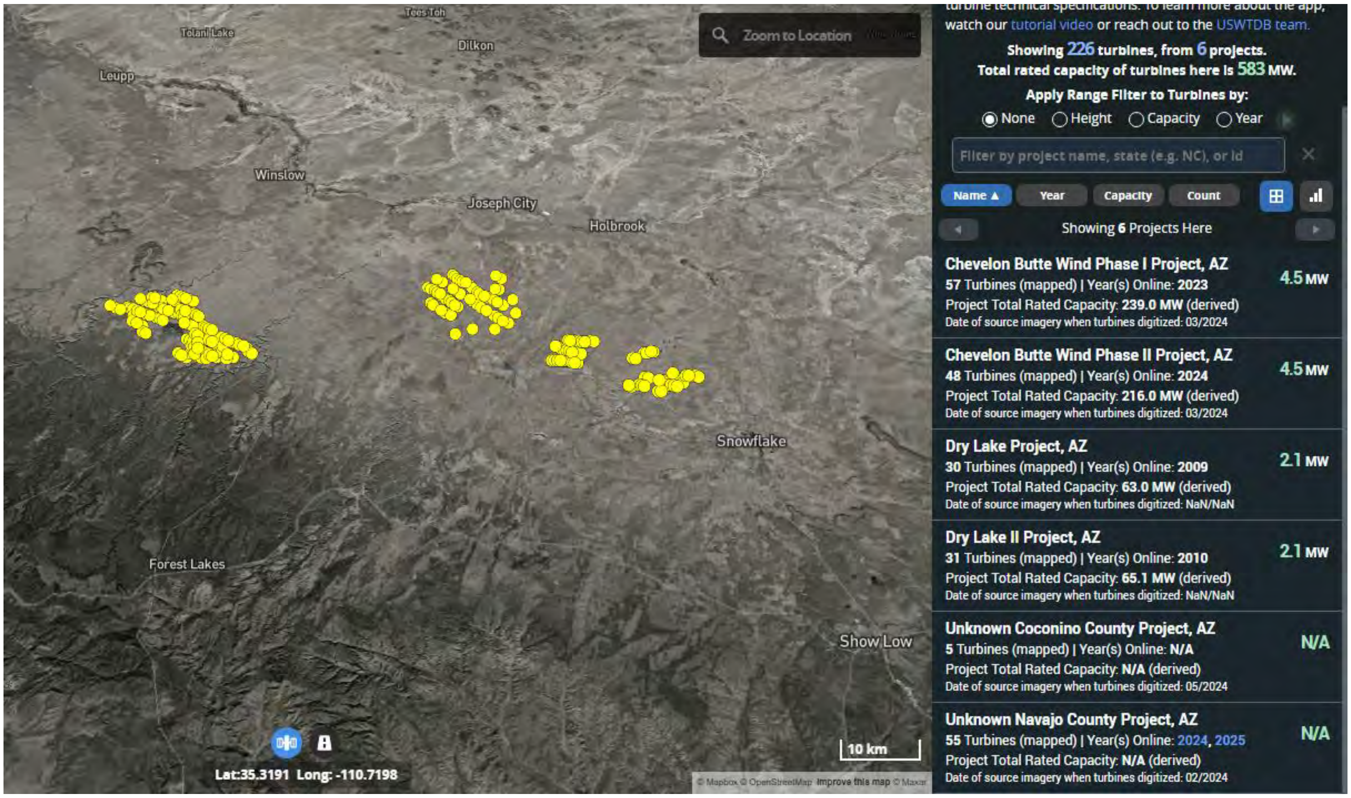


[Map Source: Apache County GIS, for 2025-26 proposal to add to County Comprehensive Plan. **Large red star = Greens Peak, Small red star = TV Knoll,** added by this paper's authors]

CURRENT WIND PROJECT SITUATON IN-NEAR THE WHITE MOUNTAINS

Six (6) existing wind farms are currently operating in <u>Navajo & Coconino Counties</u>, with a total of 226 turbines installed thus far between Flagstaff and Greens Peak (see <u>Image 2</u> below), with more under construction and/or proposed. The average <u>total height</u> of those 226 turbines ranges from 412 ft. in the Dry Lake project to 745 ft. in the "Chevelon Butte" project. Because these are all at a rough average 6,200 ft. elevation above sea level, some turbine heights could possibly interfere with communications, but need to be studied carefully to know for sure. "West Camp-1" construction has recently completed and is now in full operation, and the "West Camp-2" Development Agreement was just approved on 4/28/26 by Navajo County, thus *another* 144 wind turbines (600-774 feet tall) will soon be added somewhere in this same field of view shown below in <u>Image 2</u>.

IMAGE 2: Six wind farms exist now in Navajo and Coconino Counties between Flagstaff and Greens Peak, (with 4+ more proposed or approved to begin construction):



[2025 Map Source: USGS Wind Turbine Data Base Website. "Unknown" project in Navajo Co. includes West Camp-1.]

Additionally, in Apache County, three (3) proposed wind farms near Greens Peak are known at this time (see roughly-drawn Image 3 below):

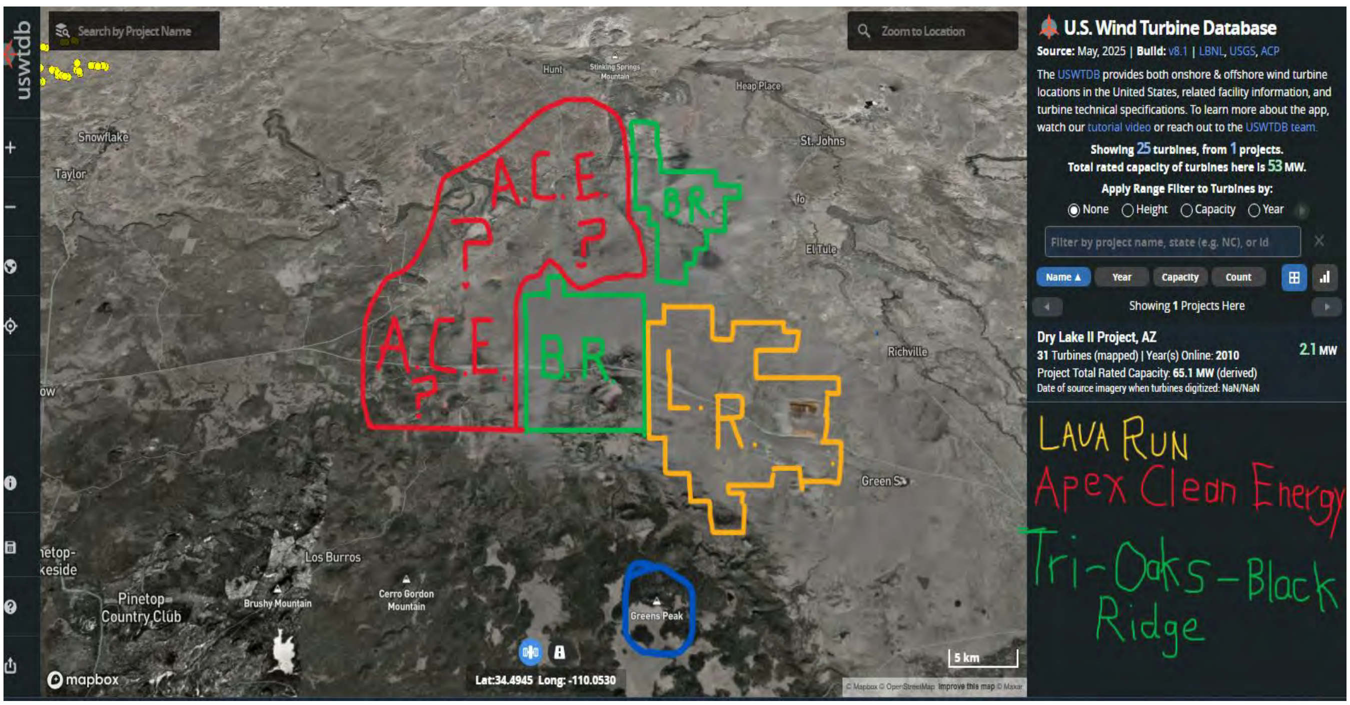
- "Lava Run" Wind project (proposed by CG ApacheCountyWind,LLC of Repsol Renewables) along both sides of US Hwy. 60 between **Springerville** and Greens Peak Hideaway Subdivision, plans to install a total of 112 wind turbines in two phases across nearly 55,000 acres (all on State Trust Lands), at a total turbine height of 654 ft., at average elevation of 7,000' above sea level. **Adding 654 ft. atop this ground elevation could very likely obstruct RF signals from the ground to Greens Peak, such as dispatchers in St. Johns.** Project boundary mapped here in yellow is a rough approximation of the company's public map.

- "Black Ridge" Wind project (proposed by Triple Oaks Power) planned from **Vernon** to **Concho** just southwest of **St. Johns** (on a mix of State Trust and private lands), proposes 146 WTs (130 now in Phase-1, with more possible in a later phase), many straddling US Hwy 60. Total turbine height supplied to the FAA is 780 ft. tall. Concho sits at approx. 5,952 ft. above sea level. Vernon sits at average 6,943 ft. above sea level. **Adding 780 ft. atop these ground elevations could very likely obstruct RF signals from the ground to Greens Peak, such as dispatchers in St. Johns, or the Vernon**

fire station. The Black Ridge boundary mapped here in green is a rough approximation of the company's map posted on their project website.

- Apex Clean Energy (no known project name yet) has been recently soliciting private landowners in and around the community of **Vernon** to lease to them participating private properties to install wind turbines. If they can gain enough cooperators in that community, they likely will link the turbines into a wind farm. Turbine size or number is unknown. Vernon sits at approx. 6,943 above sea level. Boundary mapped here in red is a very rough guestimation.

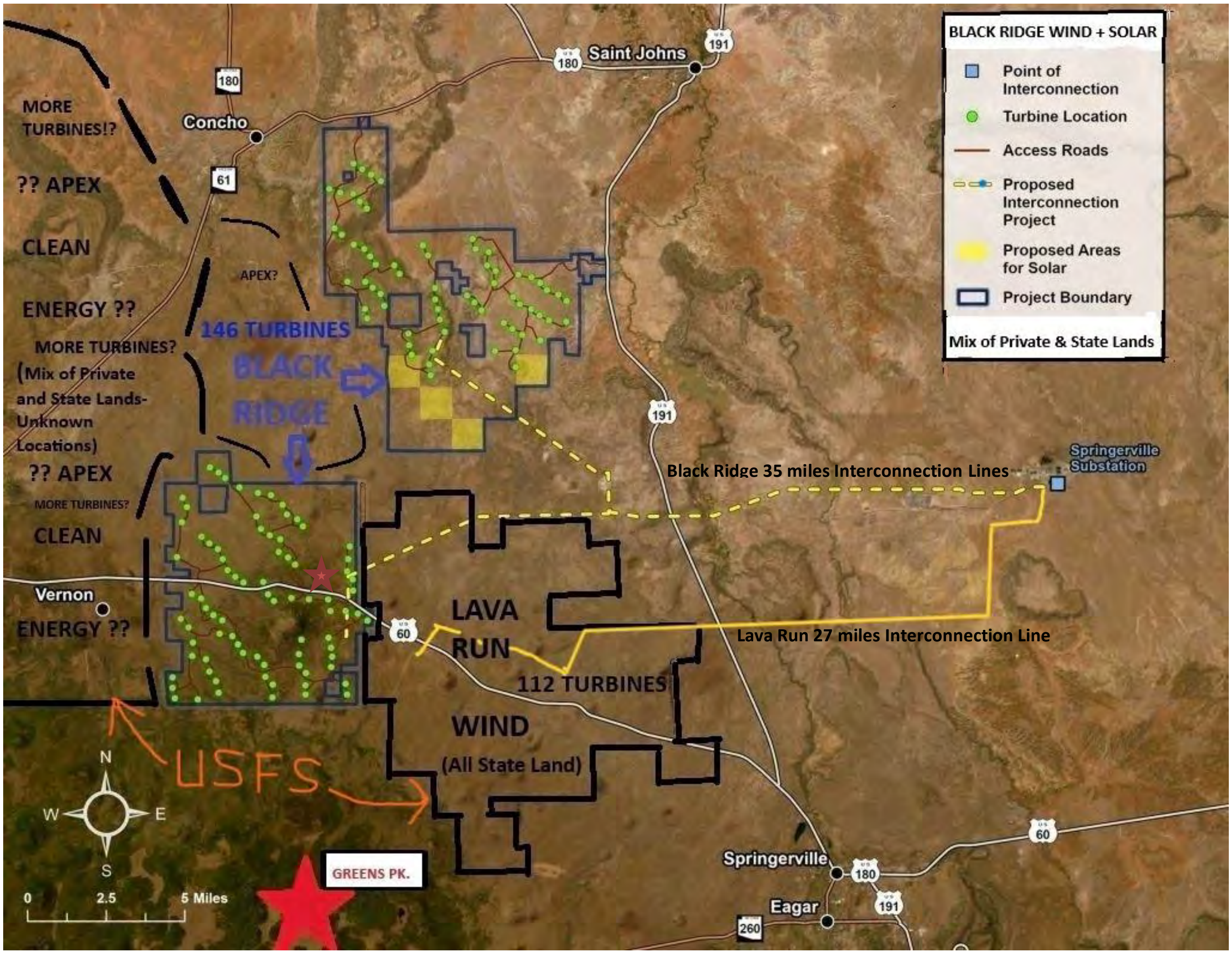
IMAGE 3: Dry Lake II windfarm near Snowflake (in upper left corner), with open area shown in Apache County where 3 more are approximately proposed to the north, northeast, and northwest of Greens Peak near between Springerville, Vernon, Concho, and St. Johns:



[Map Source: USGS Wind Turbine Data Base website, with Lava Run (L.R.), Black Ridge (B.R.), and Apex Clean Energy (ACE) roughly hand-drawn in for perspective. Notice Greens Peak circled in blue.]

(continued next page)

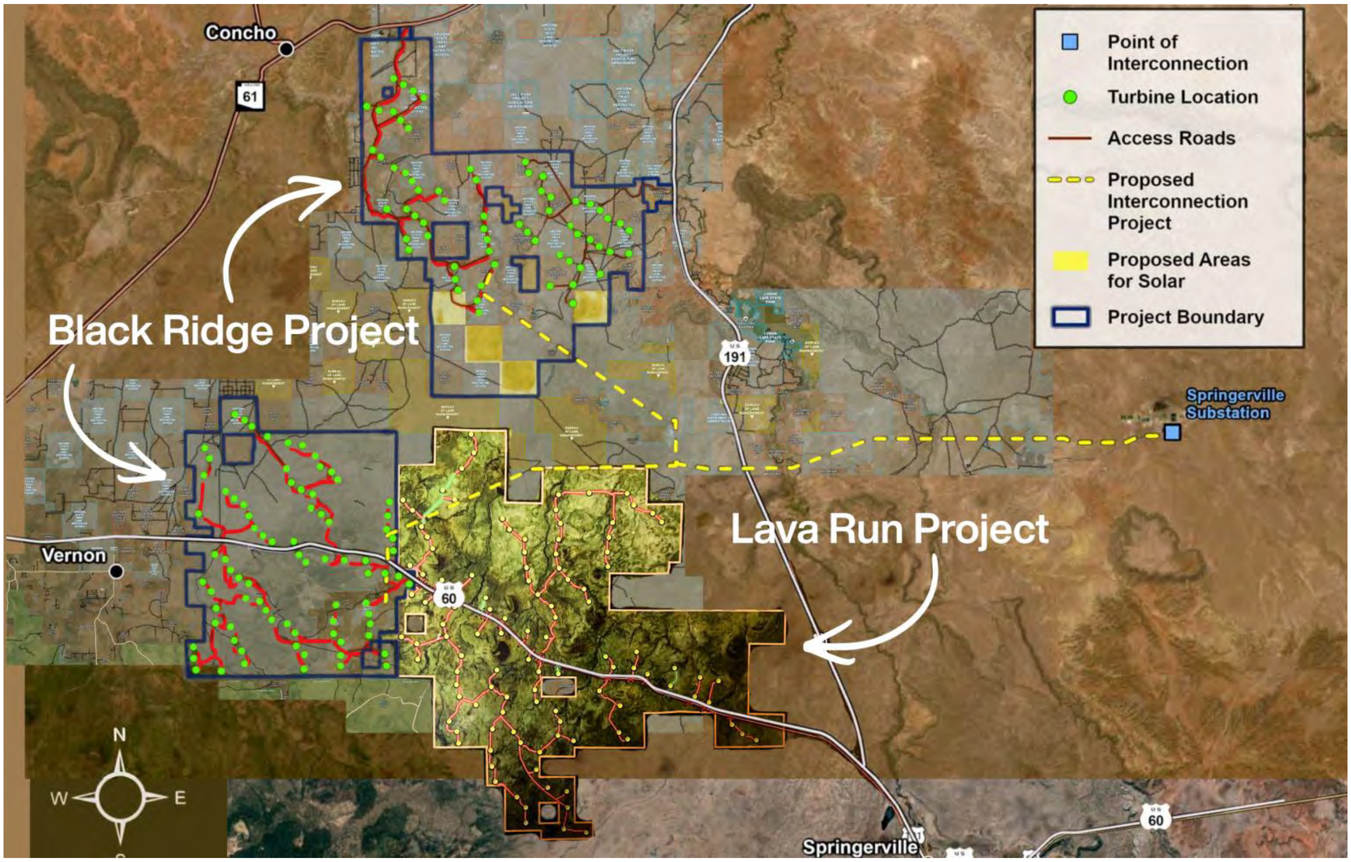
IMAGE 4: Closeups of Black Ridge (146 total Wind Turbines proposed)
+ Lava Run (112 total WTs proposed) = See proximity to Greens Peak and TV Knoll



[Map Sources: Black Ridge project website Map by Triple Oak Power, with hand-drawn additions to show close proximities of Lava Run, Greens Peak and US Forest Service (Apache-Sitgreaves NFs) boundary.] **Large red star** indicates Greens Peak location, while **small red star** shows "TV Knoll" location.

(continued next page)

IMAGE 5: Closeups of Black Ridge (146 total Wind Turbines proposed)
+ Lava Run (112 total WTs proposed)



[Map Sources: Black Ridge project website Map by Triple Oak Power, and Lava Run open house Map by Repsol, (graphically merged into one image at same scale.)]

US Representive Eli Crane's letters to the FCC & US Dept. of Transportation are replicated on the following pages. Therein, he expresses many of the same concerns that we've outlined here. BELOW are two strong excerpts from his US DOT letter (bold emphasis added here, and See **Doc. 11**):

"I applaud the updated federal policies governing wind turbine setbacks near highways and railroads. These policies restore safety recommendations previously overruled by the prior administration after it was discovered that dozens of wind energy projects had been approved, despite **engineering warnings that wind turbines can interfere with the radio-frequency spectrum that is used for critical safety communications.** The Department's recent technical review found that 'wind farm deployment could potentially obstruct radio communication links and/or degrade radio RF signal reception by means of lowering signal-to-noise ratio through several mechanisms and factors such as diffraction, scattering, wind farm density, distance, speed, etc.' **In response to these findings, USDOT now recommends a minimum 1.2-mile setback for wind turbines constructed near major highways and rail corridors.**

Radio-frequency interference: **Turbines placed within the 1.2-mile buffer may obstruct or degrade radio communications essential for highway safety, emergency response, and transportation operations.** Based on the project maps publicly shared by Repsol, **at least 41 turbines in the proposed Lava Run Wind Project appear to be located within 1.2 miles of the shoulder of U.S. Highway 60, placing them inside the newly recommended federal safety buffer."**

ELI CRANE
2ND DISTRICT, ARIZONA

COMMITTEE ON
OVERSIGHT AND
GOVERNMENT REFORM

COMMITTEE ON
HOMELAND SECURITY

Congress of the United States
House of Representatives
Washington, DC 20515–0302

OFFICE LOCATIONS

307 CANNON HOUSE OFFICE BUILDING
WASHINGTON, DC 20515
(202) 225-3361

122 NORTH CORTEZ STREET
SUITE 211
PRESCOTT, AZ 86301
(928) 286-5338

February 13, 2026

The Honorable Brendan Carr Chair
Federal Communications Commission
45 L Street NE
Washington, DC 20554

Dear Chair Carr,

I write to request information and raise significant concerns regarding the potential aviation-signal, radar, and emergency-communications interference associated with the proposed Lava Run Wind Project in Apache County, Arizona. Given the FCC's statutory responsibilities over radio-frequency spectrum, public-safety communications, and aviation-related signal integrity, I respectfully request that the Commission review the project's potential impacts and clarify the extent of its oversight.

Properly functioning aircraft-tracking radar and Doppler weather radar are essential for aviation safety, emergency response, and severe weather reporting. Wind turbines located in close proximity to radar systems can distort or obscure radar returns, creating false targets, signal clutter, or degraded detection capability. Military aviation training missions occur periodically over the Apache National Forest and at the Springerville Municipal Airport, raising additional concerns about interference with military navigation radar.

Given the number of wind farms proposed in this region, the FCC and FAA should not evaluate each project in isolation. The cumulative effect of multiple wind farms clustered within a limited geographic area may exceed acceptable interference thresholds. Southern Apache and Navajo Counties are now facing the prospect of hundreds of turbines from multiple wind projects. When combined, these installations pose a significant risk of cumulative interference to:

1. Law-enforcement radio frequencies
2. Emergency-services communications
3. Aviation navigation and radar systems
4. Public-safety repeaters
5. Amateur radio and GMRS networks

Turbine siting alone may not be sufficient to mitigate these impacts. Each additional wind farm west of US-180/191, when added to existing and proposed projects near Greens Peak, increases the likelihood of regional RF degradation. Additionally, the western boundary of the Lava Run Wind Project lies approximately five miles northeast of Greens Peak, a critical communications hub at 10,134 feet elevation. Greens Peak hosts:

1. Federal, state, county, and municipal emergency-services repeaters
2. Law-enforcement radio infrastructure
3. Natural-resource agency communications
4. More than 12 private HAM and GMRS repeaters
5. Equipment used during major wildfire emergencies and regional disasters

FCC records show 1,000+ licensed amateur radio operators and approximately 500 GMRS users across the White Mountains. These networks have repeatedly provided essential emergency communications during wildfire events and outages when cellular, landline, and internet systems failed.

Any turbine-induced interference affecting Greens Peak repeaters would pose a serious threat to public safety, emergency response, and daily law-enforcement operations across northeastern Arizona.

In light of these concerns, I respectfully request that the FCC:

1. Evaluate the potential RF interference posed by the Lava Run Wind Project to aviation radar, weather radar, and military navigation systems.
2. Assess cumulative interference impacts from all existing and proposed wind farms in southern Apache and Navajo Counties.
3. Review potential impacts to emergency-services communications, including law-enforcement, EMS, and natural-resource agency repeaters on Greens Peak.
4. Determine whether additional FCC review, mitigation requirements, or interagency coordination with FAA, NTIA, and DOD are warranted.
5. Clarify whether the FCC will require a cumulative-impact analysis rather than project-by-project approvals.

Given the critical importance of aviation safety and emergency communications, we believe these issues merit immediate and thorough review.

Thank you for your attention to this matter. I look forward to your response.

Sincerely,

Eli Crane
Member of Congress

(continued on next page)

ELI CRANE
2ND DISTRICT, ARIZONA

COMMITTEE ON
OVERSIGHT AND
GOVERNMENT REFORM

COMMITTEE ON
HOMELAND SECURITY

Congress of the United States
House of Representatives
Washington, DC 20515–0302

OFFICE LOCATIONS
307 CANNON HOUSE OFFICE BUILDING
WASHINGTON, DC 20515
(202) 225-3361

122 NORTH CORTEZ STREET
SUITE 211
PRESCOTT, AZ 86301
(928) 286-5338

February 13, 2026

The Honorable Sean Duffy
Secretary of Transportation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Dear Secretary Duffy,

I write to request information and raise concerns regarding the proposed Lava Run Wind Project located in Apache County near Springerville AZ. I am specifically concerned about the placement of wind turbines near major transportation corridors and the project's potential conflict with the new federal safety recommendations announced by the Department of Transportation on July 29, 2025.[1]

I applaud the updated federal policies governing wind turbine setbacks near highways and railroads. These policies restore safety recommendations previously overruled by the prior administration after it was discovered that dozens of wind energy projects had been approved, despite engineering warnings that wind turbines can interfere with the radio-frequency spectrum that is used for critical safety communications. The Department's recent technical review found that "wind farm deployment could potentially obstruct radio communication links and/or degrade radio RF signal reception by means of lowering signal-to-noise ratio through several mechanisms and factors such as diffraction, scattering, wind farm density, distance, speed, etc." In response to these findings, USDOT now recommends a minimum 1.2-mile setback for wind turbines constructed near major highways and rail corridors.

Based on the project maps publicly shared by Repsol, at least 41 turbines in the proposed Lava Run Wind Project appear to be located within 1.2 miles of the shoulder of U.S. Highway 60, placing them inside the newly recommended federal safety buffer. Additionally, turbines are planned on both sides of U.S. 60, and Repsol intends to use this federal highway as the primary access route for construction and long-term operations.

This raises several significant concerns:

1. Radio-frequency interference: Turbines placed within the 1.2-mile buffer may obstruct or degrade radio communications essential for highway safety, emergency response, and transportation operations.
2. Pavement damage: Transporting turbine components, cranes, concrete, and other heavy equipment will impose substantial wear on U.S. 60, creating costly repair needs for a highway that serves as the region's main commercial corridor.
3. Traffic disruption: Oversized trailers carrying turbine blades and tower sections require extra-wide turning radii and slow-moving convoys, which will cause extended interruptions to normal traffic flow.
4. Emergency response delays: Of greatest concern is that ambulances transporting patients to medical facilities in Show Low, the region's largest town, could face life-threatening delays due to construction congestion or blocked lanes.

[1] President Trump's Transportation Secretary Sean P. Duffy: Biden-Buttigieg Ignored the Dangers of Wind Turbines Near Railroads & Highways, Put Climate Religion Ahead of Safety | US Department of Transportation

Given these issues, I respectfully request clarification on the following:

1. Has the Department of Transportation conducted an updated safety assessment of the Lava Run turbine locations in light of the July 29, 2025, policy announcement?
2. Do any of the proposed turbine sites violate the new 1.2-mile setback recommendation, and if so, what corrective actions will be required?
3. Will DOT require modifications to turbine placement, height, or construction access routes to ensure compliance with federal safety guidance, or terminate approval of this project due to violations?
4. How will DOT coordinate with the Federal Aviation Administration and state transportation agencies to ensure that highway safety, emergency response, and critical communications are not compromised?

My intent is to ensure that any project proceeds in a manner fully consistent with federal safety standards and does not endanger the traveling public or emergency responders.

Thank you for your attention to this matter. I appreciate any information you can provide and look forward to your response.

Sincerely,

Elijah Crane

Eli Crane
Member of Congress

___________________END of Representative Crane’s 2 Letters____________________________________

By using the Triple Oak’s company map of Black Ridge (see Image 4), we count at l*east 27 more turbines proposed within 1.2 miles of US Hwy. 60*, precisely where multiple cell phone towers, microwave, and radio broadcast towers are located along the US 60 corrridor. (See Doc. **11** and US Secretary Duffy’s DOT recommendations document cited by Rep. Crane’s second letter.)

(continued on next page)

ARS 11-833 - Standards for enactment of moratorium; land development; limi...
https://www.azleg.gov/ars/11/00833.htm

11-833. Standards for enactment of moratorium; land development; limitations; definitions

A. A county shall not adopt a moratorium on construction or land development unless it first:

1. Provides notice to the public published once in a newspaper of general circulation in the community at least thirty days before a final public hearing to be held to consider the adoption of the moratorium.

2. Makes written findings justifying the need for the moratorium in the manner provided for in this section.

3. Holds a public hearing on the adoption of the moratorium and the findings that support the moratorium.

B. For urban land or land subject to potential urbanization, a moratorium may be justified by demonstration of a need to prevent a shortage of essential public facilities that would otherwise occur during the effective period of the moratorium. This demonstration shall be based on reasonably available information and shall include at least the following findings:

1. A showing of the extent of need beyond the estimated capacity of existing essential public facilities expected to result from new land development, including identification of any essential public facilities currently operating beyond capacity and the portion of this capacity already committed to development, or in the case of water resources, a showing that, in an active management area as defined in section 45-402, an assured water supply cannot be provided, or outside an active management area, a sufficient water supply cannot be provided, to the new land development, including identification of current water resources and the portion already committed to development.

2. That the moratorium is reasonably limited to those areas of the county where a shortage of essential public facilities would otherwise occur and on property that has not received development approvals based on the sufficiency of existing essential public facilities.

3.That the housing and economic development needs of the area affected have been accommodated as much as possible in any program for allocating any remaining essential public facility capacity.

C. A moratorium not based on a shortage of essential public facilities under subsection B of this section may be justified only by a demonstration of compelling need for other public facilities, including police and fire facilities. This demonstration shall be based on reasonably available information and shall include at least the following findings:

1. For urban land or land subject to potential urbanization:

(a) That application of existing development ordinances or regulations and other applicable law is inadequate to prevent irrevocable public harm from development in affected geographical areas.

(b) That the moratorium is sufficiently limited to ensure that a needed supply of affected housing types and the supply of commercial and industrial facilities within or in proximity to the county are not unreasonably restricted by the adoption of the moratorium.

(c) The reasons that alternative methods of achieving the objectives of the moratorium are unsatisfactory.

(d) That the county has determined that the public harm that would be caused by failure to impose a moratorium outweighs the adverse effects on other affected local governments, including shifts in demand for housing or economic development, public facilities and services and buildable lands and the overall impact of the moratorium on population distribution.

(e) That the city or town proposing the moratorium has developed a work plan and time schedule for achieving the objectives of the moratorium.

2. For rural land:

(a) That application of existing development ordinances or regulations and other applicable law is inadequate to prevent irrevocable public harm from development in affected geographical areas.

(b) The reasons that alternative methods of achieving the objectives of the moratorium are unsatisfactory.

(c) That the moratorium is sufficiently limited to ensure that lots or parcels outside the affected geographical areas are not unreasonably restricted by the adoption of the moratorium.

(d) That the county proposing the moratorium has developed a work plan and time schedule for achieving the objectives of the moratorium.

D. Any moratorium adopted pursuant to this section does not affect any express provision in a development agreement entered into pursuant to section 9-500.05 or as defined in section 11-1101 governing the rate, timing and sequencing of development, nor does it affect rights acquired pursuant to a protected development right granted according to chapter 9 of this title or title 9, chapter 11. Any moratorium adopted pursuant to this section shall provide a procedure pursuant to which an individual landowner may apply for a waiver of the moratorium's applicability to its property by claiming rights obtained pursuant to a development agreement, a protected development right or any vested right or by providing the public facilities that are the subject of the moratorium at the landowner's cost.

E. A moratorium adopted under subsection C, paragraph 1 of this section shall not remain in effect for more than one hundred twenty days, but such a moratorium may be extended for additional periods of time of up to one hundred twenty days if the county adopting the moratorium holds a public hearing on the proposed extension and adopts written findings that:

1. Verify the problem requiring the need for the moratorium to be extended.

2. Demonstrate that reasonable progress is being made to alleviate the problem resulting in the moratorium.

3. Set a specific duration for the renewal of the moratorium.

F. A county considering an extension of a moratorium shall provide notice to the general public published once in a newspaper of general circulation in the community at least thirty days before a final hearing is held to consider an extension of a moratorium.

G. This section does not prevent a city or town from complying with any state or federal law, regulation or order issued in writing by a legally authorized governmental entity.

H. A landowner aggrieved by a county's adoption of a moratorium pursuant to this section, at any time within thirty days after the moratorium has been adopted, may file a complaint for a trial de novo in the superior court on the facts and the law regarding the moratorium. All matters presented to the superior court pursuant to this section have preference on the court calendar on the same basis as condemnation matters. The court may award reasonable attorney fees incurred in the appeal and trial pursuant to this section to the prevailing party.
I. For the purposes of this section:

1. "Compelling need" means a clear and imminent danger to the health and safety of the public.

2. "Essential public facilities" means water, sewer and street improvements and water resources to the extent that these improvements and water resources are provided by the county or private utility.

3. "Moratorium on construction or land development" means engaging in a pattern or practice of delaying or stopping issuance of permits, authorizations or approvals necessary for the subdivision and partitioning of, or construction on, any land. It does not include denial or delay of permits or authorizations because they are inconsistent with applicable statutes, rules, zoning or other ordinances.

4. "Rural land" means all property in the unincorporated area of a county or in the incorporated area of the city or town with a population of two thousand nine hundred or less persons.

5. "Urban land or land subject to potential urbanization" means all property in the incorporated area of a city or town with a population of more than two thousand nine hundred persons.

6. "Vested right" means a right to develop property established by the expenditure of substantial sums of money pursuant to a permit or approval granted by the city, town or county.

END of Arizona Revised Statute 11-833

(continues next page)

DOCUMENTS CITED: (Digital Versions provided in a separate Appendix Folder or flash-drive upon request)

1 "Impact Analysis Of Wind Farms On Telecommunication Services", by I. Angulo, D. de la Vega, I. Cascón, J. Cañizo, Y. Wu., D. Guerra, P. Angueira, 12/29/13, publ. by Science Direct Journal, Elsevier Ltd., - Renewable and Sustainable Energy Reviews 32 (2014) pgs. 84-89.
https://doi.org/10.1016/j.rser.2013.12.055

2 "Radio Link Coordination With Wind Farms", by Joint Radio Company, Coventry, UK, 2019
https://www.jrc.co.uk/what-we-do/wind-farms

3 "Identifying And Avoiding Radio Frequency Interference For Wind Turbine Facilities" – White Paper by Lester E. Polisky of Comsearch, 2005 Andrew Corporation, Bulletin TP-100321-EN (03/05)
https://www.avw.co.nz/images/andrew/docs/TP-100321-EN.pdf

4 "Land-Based Wind Energy Siting: A Foundational and Technical Resource", US Dept. of Energy, Office of Energy Efficiency & Renewable Energy, August 2021. (see pgs.38-39)
https://docs.nrel.gov/docs/fy21osti/78591.pdf

5 "RF Studies For Wind Farm Impacts On Communication Networks" Information & Communication Technologies , by Titan ICT, 2025 website:
https://titanict.com.au/rf-studies-for-wind-farm-impacts-on-communication-networks/

6 Google AI Search/Overview of how wind turbines can interfere with radio communications signals, systems affected, mitigation strategies, and literature search.
(Paper doc. only, no hyperlink possible.)

7 "Wind Farm Interference Shows Up On Doppler Radar", by Marc Kavinsky, Senior Meteorologist of the National Weather Service (Wisconsin), https://www.weather.gov/mkx/windfarm

8 "FAA Aeronautical Information Manual – Publication On Air Traffic Control Systems – Section 5. Surveillance Systems, 4-5-1. Radar, b. Limitations (g) Wind Turbines, &
Figure 4-5-2 = 'Wind Turbine Farm Area of Potential Interference'" ,
https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap4_section_5.html

9 "The Impacts of Terrestrial Wind Turbine's Operation on Telecommunication Services", by Ukashatu Abubakar, Saad Mekhilef, Hazlie Mokhlis, Mehdi Seyedmahmoudian, Alex Stojcevski and Muhyaddin Rawa, Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. Publ. 12/28/2022, by *Energies* ***2023****, 16,* 371. https://doi.org/10.3390/en16010371;
https://www.mdpi.com/journal/energies

10 "Technical Information and Guidelines on the Assessment of the Potential Impact of Wind Turbines on Radiocommunication, Radar, and Seismoacustic Systems", by the Radio Advisory Board of Canada (RABC) Canadian Wind Energy Association (CanWEA). Publ. April 2007.
https://docs.wind-watch.org/rabc-canwea-technicalinformationguidelinesrepotentialimpactofwindturbines_2.pdf

11 "Assessment of Wind Farm Interference Impact on ITC Communications in 220 MHz Frequency Band" – Research Technical Report, Doc. Rev. 1.3, by Meteorcomm LLC, 07/29/2025. For US Dept. of Transportation: https://www.transportation.gov/sites/dot.gov/files/2025-08/Wind%20Farm%20Interference%20Impact%20on%20ITC%20Communications%20in%20220%20MHz%20%281%29.pdf

12 FCC Website: "Interference Resolution" – Federal Communications Commission Enforcement Web Page https://www.fcc.gov/enforcement/areas/interference-resolution

13 "Federal Interagency Wind Turbine Radar Interference Mitigation Strategy", by US DOE Office of Energy Efficiency & Renewable Energy, August 2023. https://www.energy.gov/sites/default/files/2023-08/federal-interagency-wind-turbine-radar-interference-mitigation-strategy_082023.pdf

14 "The Winds of Change - Wind Turbines And Their Effects On The National Airspace System", FAA Safety Briefing Magazine – Nov/Dec. 2023 Issue, article by Michael Rauchle of the FAA. https://medium.com/faa/the-winds-of-change-b49520f350ed

Other Related Articles:

- "WindEnergy-TheFactsWebsite-Electromagnetic-Interferences" https://www.wind-energy-the-facts.org/electromagnetic-interferences/
- "How Wind Turbines Fake Rain"_byPagerPower_2020 https://www.pagerpower.com/news/how-wind-turbines-fake-rain/
- Good for our enemies: Wind turbines scramble the Air Force radars, and provide cover for jets « JoNova 2023

We the undersigned submit this STATEMENT of CONCERNS to Apache County Officials (Planning & Zoning, and Board of Supervisors, + others) to express our determination to protect our existing White Mountains radio communications capabilities under FCC regulations.

SIGNATURES of WHITE MTNS. LICENSED RADIO USERS/OPERATORS:

NEATLY PRINTED NAME + *SIGNATURE* / Nearest Town / FCC RADIO CALL SIGN/s

(SIGNATURES NOT INCLUDED IN THIS ELECTRONIC DOCUMENT, ORIGINALS BEING COLLECTED and TO BE SUBMITTED in the NEAR FUTURE as an ATTACHMENT of SUPPORTING CITIZEN INVOLVEMENT)

(Signatures continued on MANY following pages)

Apache County selected

azwater.gov/drought/drought-data-dashboard

Drought Resources

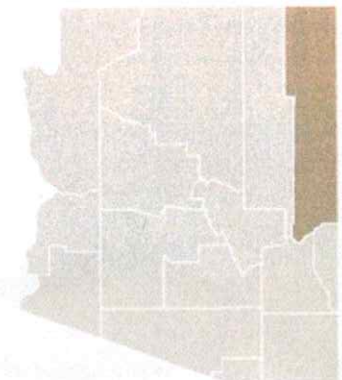
Drought in Arizona (2000-Present)

Drought Level
All

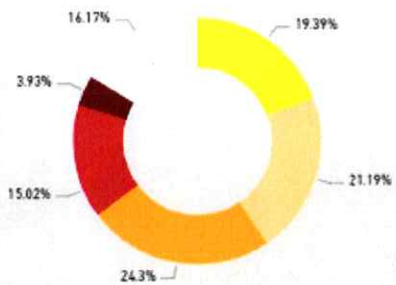
Drought Level Definitions: = No Drought, D0= Abnormally Dry, D1= Moderate Drought, D2= Severe Drought, D3= Extreme Drought, D4= Exceptional Drought

arizonadrought@azwater.gov

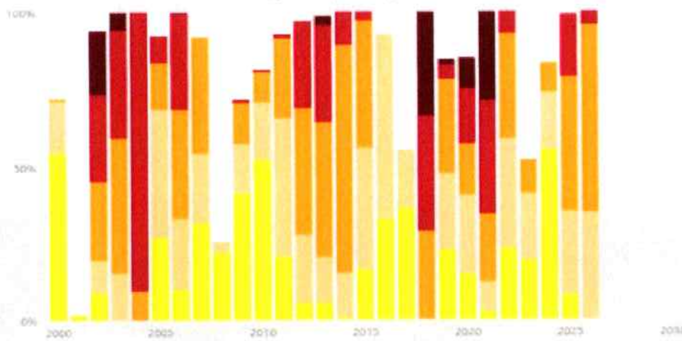
(602)771-6146



Occurence of Each Drought Level



Average Yearly Drought Levels

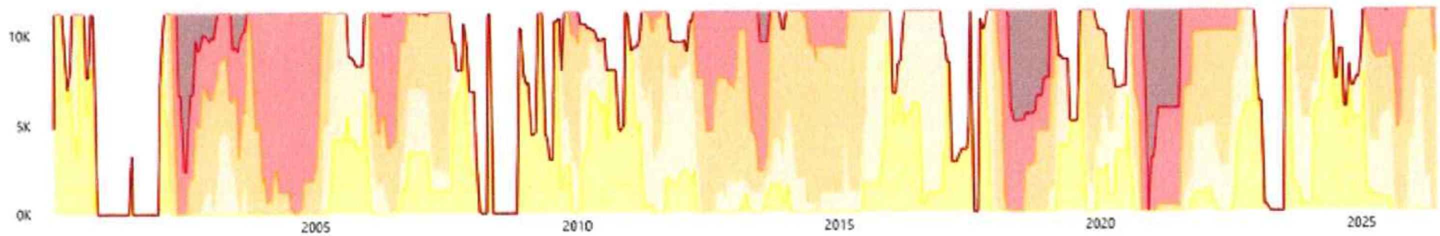


Valid_start
1/4/2000 6/16/2026

Year
All

Year

Weekly Drought Levels (sq. mi.)



75%

Microsoft Power BI

6/21/26

Jun 21 11:38

SUPPLY & DEMAND

2025

LITTLE COLORADO RIVER PLATEAU

ACKNOWLEDGMENTS

Thomas Buschatzke
Director

ADWR Employees Past and Present

Alexandra Garden
Alyssa Ainna
Amanda Long-Rodriguez
Amanda Overholt
Ben Calleros
Bradley Niska
Brandon Lofgreen
Bruce Hallin
Carl Job
Carol Ward
Catherine Riedel
Cera Linehan
Cole Pihl
Collin Wogenstahl
Colton Dodson
Daniela Kenny
David Keadle
David Lawlor
Dianne Yunker
Doug MacEachern
Emily LoDolce
Emily Petrick
Isabella Holt
Gwendolyn DeNeal
Haley Doran
James Dieckhoff
James Heffner
James Taylor
Jeff Heilman
John Riggins
Josephine Knab
Joshua Pallapati
Karen Nielsen
Keith Nelson
Kennedy Shepard
Kevin Hadder
Kevin Lane
Khayrun Nahar
Kimberly Parks
Kristen Johnson
Kyle Miller
Laleh Ranjbaran
Laney Meeker
Lauren Roberson
Leandra Marshall
Maggie Martin
Makenna Welsch
Lisa Williams
LuDean Stone
Madison Moreno
Mary Wuertz
Melissa Sikes
Michaela Jones
MirandaeRae Stusen
Natalie Mast
Nick Redendo
Nicole Klobas
Paul Alder
Paul Strong
Quinn Buzzard
Rachael King
Ryan Mitchell
Sarah Medeiros
Shannon Curtis
Sharon Scantlebury
Shauna Evans
Soujit Ray
Steven Legacki

2025 SUPPLY AND DEMAND ASSESSMENT
LITTLE COLORADO RIVER PLATEAU BASIN

1 INTRODUCTION

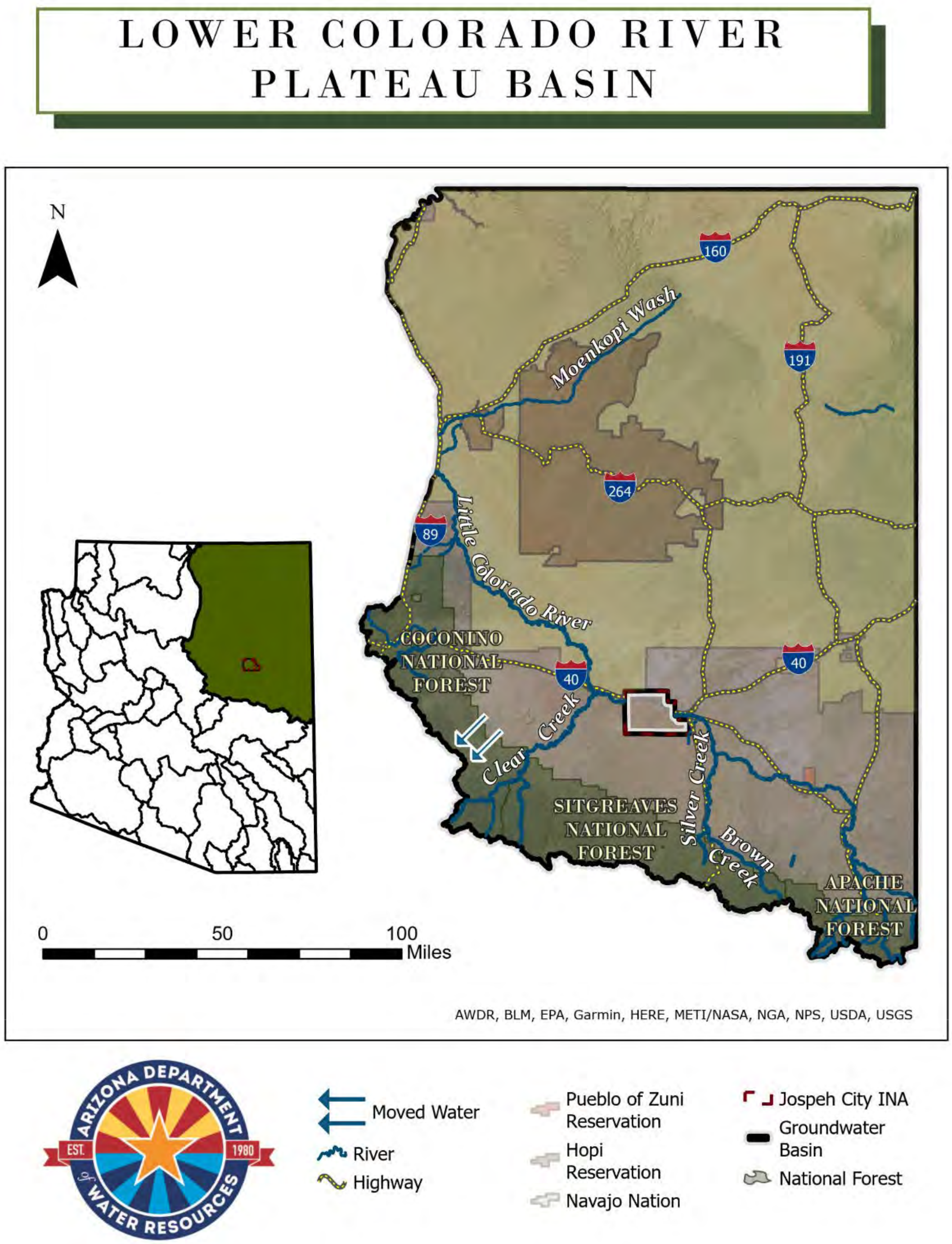


Figure 1. Map of the Little Colorado River Plateau Basin.

1.1 REPORT BACKGROUND AND PURPOSE

Preparing the Supply and Demand Reports (SDRs) is a duty of the Director of the Arizona Department of Water Resources (ADWR) required by statute, as stated in Arizona Revised Statutes (A.R.S.) § 45-105(B)(14).[1] Beginning in 2023, the Director must ensure that a water supply and demand assessment for at least six of Arizona's fifty-one groundwater basins are prepared and issued by December 1st of each year.

Although similar assessments have been completed periodically, 2023 was the first time ADWR was allocated dedicated funding and staff to conduct assessments of all of Arizona's groundwater basins on a recurring cycle. By the end of 2027, ADWR will complete assessments for all 51 groundwater basins throughout the state, and each basin will be reassessed at least every five years. The SDRs may be used to inform the Water Infrastructure Finance Authority on funding decisions in the future (see A.R.S. § 49-1304(A)(14)[2]). The SDRs may also be used as a planning tool for water resource management by ADWR, policymakers, community members, and other interested stakeholders.

The basins and subbasins assessed in 2025 include Aravaipa Canyon, Bill Williams (Alamo Reservoir, Burro Creek, Clara Peak, Santa Maria, and Skull Valley Subbasins), Bonita Creek, Coconino Plateau, Dripping Springs Wash, Duncan Valley, Hualapai Valley, Little Colorado River Plateau, Morenci, Sacramento Valley, Safford (San Carlos Valley, Gila Valley, and San Simon Valley Subbasins), Salt River (Black River, White River, Salt River Canyon, and Salt River Lakes Subbasins), and San Simon Wash.

---

[1] Arizona Revised Statutes § 45-105(B)(14). https://www.azleg.gov/ars/45/00105.htm

[2] Arizona Revised Statutes § 49-1304(A)(14). https://www.azleg.gov/ars/49/01304.htm

1.2 PROCEDURE AND SCOPE

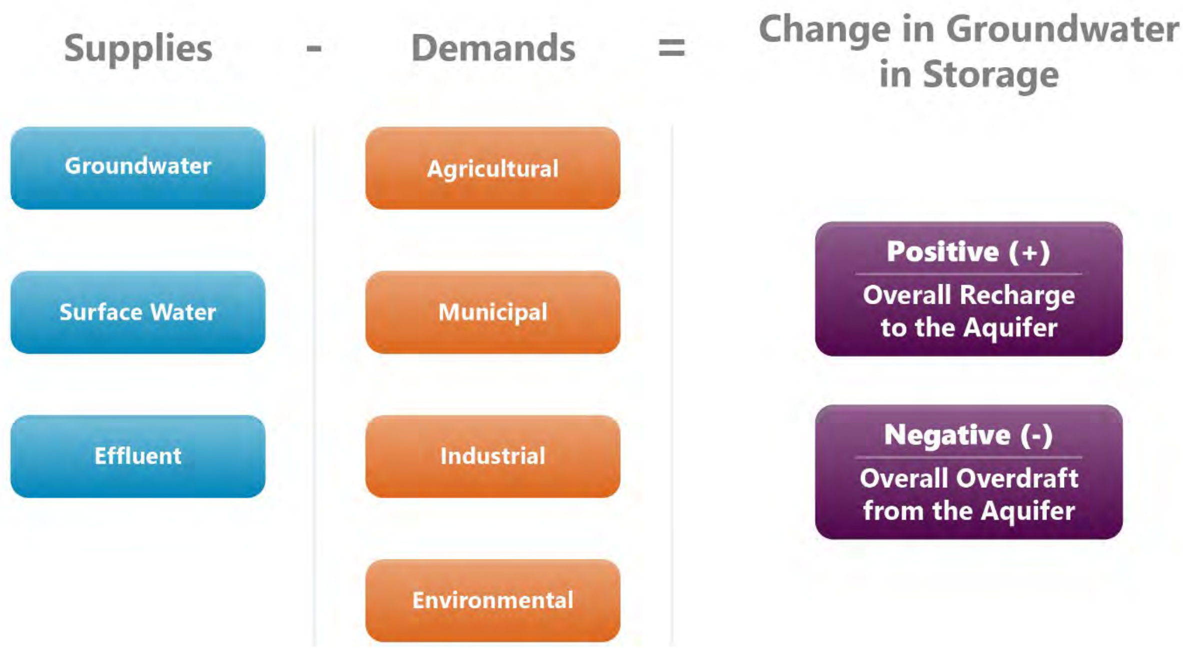


Figure 2. Depiction of the Little Colorado River Plateau water budget, including all available supplies and demands and how they contribute to changes in groundwater in storage.

The SDRs are structured as water budgets, focusing on total inflows and outflows at the basin scale. The SDRs estimate the volumes of water demands from all uses (categorized into sectors of Agricultural, Industrial, Municipal, and Other) and the volumes of water supplies (Surface Water, Groundwater, Effluent, Incidental Recharge, Transportation Water, and Moved Water) available to meet those demands. The reports also include projected demands and supplies under various influences of future scenarios.

The SDRs are not groundwater flow models with finer geographic results. The development of regional groundwater flow models for each basin is an extensive technical process and is not feasible within the time constraints of this project. Outside of Arizona's regulated Active Management Areas (AMAs) and Irrigation Non-Expansion Areas (INAs), data is much more limited. In instances where data does exist, the data may be outdated or lack reliability. ADWR has endeavored to acquire local and specific data to generate the SDRs. However, when such information was not obtainable, staff utilized scientific literature estimates, averages, or assumptions to formulate water usage estimates.

The SDRs attempt to answer the following questions:

1. What is the estimated annual volume of water demand?
2. What is the estimated annual volume of available water supply?
3. Is there sufficient available water supply to balance water demand annually?

The water budget was calculated by subtracting the estimated annual demand from the estimated annual available supply. If demand exceeds supply in a year, the difference is subtracted from the estimated aquifer storage. If supply exceeds demand, the difference is added to estimated aquifer storage. In this manner, the process is like balancing a checkbook, totaling the credits and debits made to the account through the year to understand how much estimated groundwater is available in storage.

The SDRs are designed to be understandable to the general public. The Methods Appendix includes specific technical information and additional details regarding data and methods: [Methods Appendix]. Additional SDRs and an interactive dashboard are available for further information: [Dashboards].

1.3 METHODOLOGY AND LIMITATIONS

This study reviewed and compiled data for two primary purposes:

1. Estimate supply and demand volumes in the basin.
2. Project changes in supply and demand from possible future scenarios.

ADWR developed and compiled baseline data for the period from 1990 to 2024. Staff then developed scenarios based on the most likely impacts on water demands and supplies over 51 years (from 2025 to 2075), and then projections were generated from the baseline data. The results from these scenarios and the combined baseline data were used to estimate whether supply could meet demand each year from 1990 to 2075. ADWR independently developed both the supply and demand estimates.

Due to the limited reported water data available outside Arizona's AMAs and INAs, the supplies and demands outlined in the SDRs are estimates only. When available, ADWR used high-quality data from credible sources. Due to the need to focus staff bandwidth on developing initial methods for analysis of all 51 groundwater basins by the December 1, 2027, statutory deadline, outreach was limited to major water users in the basin. When data could not be obtained, research into existing literature and the use of representative data were necessary to develop estimates.

Please see the Methods Appendix for an in-depth discussion of the methodologies and assumptions ADWR applied to create each estimate: [Methods Appendix].

2 RESULTS

2.1 BASIN SUMMARY

The Little Colorado River Plateau Basin encompasses 26,700 square miles in northeastern Arizona. Located at the southern end of the Colorado Plateau, the basin is characterized by relatively high elevation, semi-arid mesas, and several high-elevation mountain ranges, such as Black Mesa to the South, the San Francisco Peaks to the West, and the White Mountains along the southeastern boundary of the basin. Approximately 63.9% of the basin is comprised of federally recognized Tribal lands, including the Navajo Nation, the Hopi Reservation, the Pueblo of Zuni Reservation, the White Mountain Apache, and Tribal lands of the San Juan Southern Paiute encompassed by the Navajo Nation through an intertribal treaty. The basin is also composed of U.S. Forest Service (USFS) National Forest lands (10.5%), State Trust Land (eight percent), National Park Service lands (1.4%), and U.S. Bureau of Land Management (BLM) lands (1.2%). The Joseph City INA, which was established in 1980 by the Groundwater Management Act, lies within the boundaries of the Little Colorado River Plateau Basin. 14.8% of the basin is privately owned, and the basin has an estimated population of 272,231 people. The principal aquifers in the basin consist of stream alluvium deposits and regional sedimentary aquifers, such as the D, N, and C aquifers, which are found in sandstone and limestone formations separated by impermeable shales and siltstones. Groundwater storage was previously estimated to be 508,000,000 acre-feet (AF) to a depth of 1,200 feet.[3] The basin contains a significant portion of Lake Powell, a large reservoir of the Colorado River. The Little Colorado River is the major drainage in the basin, and it flows perennially near the river's headwaters and below Silver Creek. Numerous other perennial streams are found at higher elevations in the basin.

2.2 SUPPLIES

2.2.1 Surface Water

ADWR examined all water sources defined as surface water in each basin. Surface water includes all water flowing in streams, canyons, ravines, or other natural channels, or in definite underground channels, whether perennial or intermittent, floodwater, wastewater, or surplus water, and of lakes, ponds, and springs discharging to the surface (A.R.S. § 45-141).[4] After examining these sources and deducting any existing surface water diversions (stockponds, reservoirs, and agricultural diversions) from the resulting volumes, ADWR generated a final estimate of the remaining water available for diversion or use. When possible, streamgage data were used to estimate surface water volumes. Where active streamgages were absent, which often applies to areas with intermittent and ephemeral streamflow, the Drainage-Area Ratio (DAR) method (see the Methods Appendix) was used to estimate surface water volume.

For this report, all subflow was accounted for as groundwater in storage. "Subflow" is subterranean or underground water, usually found bordering or beneath a stream, which is considered part of the surface stream and subject to the same laws and rules as other types of surface water, unlike groundwater. ADWR recognizes the extensive and complex interactions between surface water and groundwater. Although some of the estimated water in storage may be legally classified as part of the "subflow zone," ADWR did not differentiate subflow from groundwater in storage. ADWR also did not determine whether wells outside the subflow zone withdraw water from the subflow zone. Since the characteristics of subflow zone delineation are

---

[3] ADWR (2009). Arizona Water Atlas, Volume 2, Section 2.1, pg. 93, Table 2.1-6. https://infoshare.azwater.gov/docushare/dsweb/Get/Document-10427/Volume_2_final_web.pdf

[4] Arizona Revised Statutes § 45-141. https://www.azleg.gov/ars/45/00141.htm

subject to change based on the adjudication of the Little Colorado River and its tributaries, ADWR considered the subflow zone as part of the basin-fill aquifer to accurately determine the overall hydrogeological status of the basin, allowing ADWR to complete a water budget analysis.

While Colorado River water is subject to a different legal framework, the term "surface water" necessarily encompasses Colorado River water, including Central Arizona Project ("CAP") water. Therefore, Colorado River water, including CAP water, is incorporated in the estimates of available surface water supplies. The availability of Colorado River water in Arizona will be subject to operations to be determined by the Secretary of the Interior in an ongoing federal process. While significant uncertainty surrounds the reliability of Colorado River water supplies, particularly on the mainstem of the Colorado River in the Lower Basin, this report assumes that Non-Indian Agricultural (NIA) Priority CAP water will generally not be available during the projection period, but that all other Colorado River water and CAP water will be available.

2.2.2 Groundwater

This report refers to the "inflow to" and "outflow from" the aquifer each year as groundwater. This volume is distinct from the volume of groundwater considered to be available in storage. "Inflow to" represents the annual recharge or replenishment of groundwater through processes such as the percolation of precipitation or surface water into the subsurface, which is observed through processes such as streamflow infiltration, groundwater inflow, and mountain-front recharge. "Outflow from," the movement of water leaving the system, is represented by such processes as baseflow and groundwater outflow. See the Methods Appendix for more information on how streamflow, baseflow, groundwater inflow/outflow, and mountain-front recharge estimates were obtained.

The total groundwater storage volume provided in this report reflects the volume of groundwater reasonably accessible at the average depth of the wells in the basin, rather than at the 1,200 feet groundwater storage depth used in previous ADWR reports. The water level falling below the basin's average well depth suggests that wells will have begun to go dry. Using this approach to estimate groundwater storage effectively illustrates the impact of declining water levels on the current existing infrastructure of property owners, residents, and other water users in each basin. Please note that this report does not address potential subsidence or permanent loss of aquifer storage that could occur if the estimated water volume in storage were to be removed from the basin. See the Methods Appendix for more information on how groundwater storage was estimated.

2.2.3 Effluent

Effluent is defined as "water that has been collected in a sanitary sewer for subsequent treatment in a facility that is regulated pursuant to Title 49, Chapter 2."[5] ADWR used effluent data provided by the Arizona Department of Environmental Quality (ADEQ) to estimate the amounts of effluent

---

[5] Arizona Revised Statutes § 45-101(4). https://www.azleg.gov/ars/45/00101.htm

available for reuse. These effluent estimates are based on effluent volumes produced from wastewater treatment plants designated for reuse. These volumes do not include wastewater discharged from the treatment plants. Effluent volumes also do not include septic tanks or other wastewater collection systems. Recharge from septic tanks is included in the Incidental Recharge estimation.

2.2.4 Incidental Recharge

Incidental recharge is defined as water from human use that replenishes groundwater supplies. Incidental recharge is associated with agricultural, industrial, and municipal water demands. ADWR used data derived from demand analyses to estimate incidental recharge volumes.

2.2.5 Transportation Water

Certain basins have been identified in A.R.S. Title 45, Chapter 2, Article 8.1[6] as basins from which groundwater may be withdrawn for transportation to an AMA. Where such transportation has been authorized, that groundwater is referred to as "Transportation Water" in this report.

2.2.6 Moved Water

Any water that crosses basin boundaries through artificial means and that does not fall under the Transportation Water definition is referred to as "Moved Water" in this report. Moved Water includes groundwater that is transported between basins that are not AMAs, pursuant to A.R.S. Title 45, Chapter 2, Article 8.[7]

2.3 SUPPLY RESULTS

This subsection contains ADWR's estimates of annual supplies available to the Little Colorado River Plateau Basin.

2.3.1 Surface Water

In the Little Colorado River Plateau Basin, ADWR identified the following surface water conveyances (USGS streamgages in parentheses):

- Alder Creek
- Anderson Canyon
- Auger Creek
- Ball Court Wash
- Benny Creek
- Benton Creek
- Big Hollow Wash
- Billy Creek
- Brookback Canyon
- Brown Creek

[6] Arizona Revised Statutes Title 45, Chapter 2, Article 8.1. https://www.azleg.gov/arsDetail/?title=45

[7] Arizona Revised Statutes Title 45, Chapter 2, Article 8. https://www.azleg.gov/arsDetail/?title=45

- Canyon de Chelly Creek
- Canyon del Muerto
- Carnero Creek
- Chevelon Creek (09398000, 09397500)
- Chinle Creek (09379025)
- Citadel Wash
- Clear Creek
- Colter Creek
- Coyote Creek
- Davis Creek
- Deadman Wash
- Dodson Wash
- Doney Mountain Wash
- East Clear Creek
- East Fork LCR
- Fish Creek
- Fivemile Wash
- Grapevine Canyon
- Hall Creek
- Jacks Canyon (09399400)
- Laguna Creek
- Lee Valley Creek
- Little Colorado River (09383400, 09385700, 09386030, 09386300, 09397000, 09400350)
- Lukachukai Creek
- Mineral Creek
- Moenkopi Wash (09401260)
- Nazlini Wash
- Newman Canyon (09400815)
- Nutrioso Creek
- Paddy Creek
- Pasture Canyon Spring (09401265)
- Porter Creek
- Pueblo Colorado Wash
- Puerco River (09396100)
- Pulcifer Creek
- Riggs Creek
- Rio de Flag
- Rosey Creek
- Show Low Creek
- Silver Creek
- South Fork LCR
- Walnut Creek
- Water Canyon Creek
- West Fork LCR
- Willow Creek
- Yeager Canyon

Currently, flows on the Little Colorado River and its tributaries are measured with several streamgages (09383400, 09385700, 09386030, 09386300, 09397000, 09397500, 09398000, 09399400, 09400350, 09400815, 09401260, 09401265). Flow on the Chinle Creek is measured with a streamgage (09379025). Historically, flows on the Puerco River were measured with a streamgage (09396100). For streams without streamgage data, the DAR method was applied to estimate streamflow volumes. The streamflow volume estimates provided in the table below are composites of the streamgage and DAR estimation methods.

Table 1. Estimated Surface Water Volumes in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Basin	Streamflow Minimum	Streamflow Maximum	Average Streamflow (Streamgage Method)	Average Streamflow (DAR Method)	Total Average Streamflow	Median Streamflow
Little Colorado River Plateau	44,103 (2014)	315,937 (2005)	122,591	6,214	128,805	110,726

All values are shown in AF. Parentheses indicate the year the streamflow volume was recorded.

Streamflow in the Little Colorado River Plateau Basin fluctuates, ranging from a minimum of 44,103 AF in 2014 to a maximum of 315,937 AF in 2005. The total average streamflow of 128,805 AF annually indicates a trend of frequent high-flow events.

Table 2. Estimated Surface Water Volumes Diverted for Use in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Year	Diverted Streamflow
1990	1,952,805
2007	1,957,973
2024	1,929,628
Average Annual Diverted Streamflow from 1990-2024	1,951,865

All values are shown in AF.

The estimated surface water volumes were diverted from the Little Colorado River Plateau Basin for use, either for storage in reservoirs or for municipal or industrial uses.

2.3.2 Groundwater

The following groundwater volumes were estimated in the Little Colorado River Plateau Basin:

Table 3. Estimated Streamflow Infiltration Volumes in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Basin	Average Annual Streamflow Infiltration (Perennial)	Average Annual Streamflow Infiltration (Intermittent & Ephemeral)	Total Average Annual Streamflow Infiltration
Little Colorado River Plateau	10,420	6,065	16,485

All values are shown in AF.

- Streamflow Infiltration: Infiltration for perennial streams was estimated using the fixed percentage listed in the Methods Appendix. Infiltration for intermittent and ephemeral streams, was estimated using infiltration rates from the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Soil Quality Indicators.[8] The predominant soil type was fine-loamy.[9] The standard storm duration utilized was 1.5 hours.[10] Total estimated streamflow infiltration peaked in 2005 at approximately 33,827 AF and was lowest in 2014 at 5,365 AF.

Table 4. Estimated Groundwater Volumes in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Basin	Average Annual Baseflow	Average Annual Groundwater Inflow	Average Annual Groundwater Outflow	Average Annual Mountain-Front Recharge	Calculated Initial Groundwater Storage
Little Colorado River Plateau	-31,207	2,600	-210,400	280,071	72,555,539^(2001)

All values are shown in AF. Negative numbers indicate demands or water flows leaving the basin Parentheses indicate the representative year chosen to calculate initial storage.

[8] USDA NRCS. (2008). Soil Quality Indicators. United State Department of Agriculture Natural Resource Conservation Service. https://www.nrcs.usda.gov/sites/default/files/2022-10/Infiltration.pdf

[9] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture (NRCS, USDA). (2016). Web Soil Survey (STATSGO2). http://websoilsurvey.nrcs.usda.gov/

[10] Food and Agriculture Organization of the United Nations (FAO). (2024). Annex 2 Infiltration Rate and Infiltration Test. https://www.fao.org/4/s8684e/s8684e0a.htm

- Baseflow: ADWR estimated baseflow using the USGS Hydrologic Toolbox in ArcGIS.[11] Streamgage data were utilized when available. Any gaps in the data were filled using precipitation data from PRISM[12] and the USGS StreamStats website.[13]
- Groundwater Inflow/Outflow: Inter-basin underflow volumes were based on USGS predevelopment maps and scientific literature estimates.[14]
- Mountain-Front Recharge: The mountain-front recharge estimates were calculated using precipitation data, model data, scientific literature estimates for groundwater inflows/outflows,[15] and a water budget accounting for the inflows/outflows that affected the mountain-front recharge volume.
- Groundwater Storage: Storage was calculated using either a model data plus water budget method, if model data were available for the basin, or a GIS-based geological data non-model method, if model data were unavailable for the basin (Section 2.5.4, Methods Appendix). Initial groundwater storage was calculated using wells located within alluvial aquifer boundaries in the basin. A representative year was selected containing the most water level measurements at those wells. The estimated storage volume was calculated to the basin's average well depth, 387 feet.

2.3.3 Effluent

Effluent reuse began in the Little Colorado River Plateau Basin in 2003 with the establishment of the Forest Highland Water Reclamation Company's water reclamation facility near Flagstaff and a wastewater treatment plant in the Town of Snowflake. Beneficial uses of effluent in the Little Colorado River Plateau Basin include golf course irrigation, snowmaking, wetland habitat, and agriculture. The Rio de Flag Water Reclamation Plant in Flagstaff is one of the largest producers of reclaimed effluent in the basin.

---

[11] Barlow, P.M. et al. (2022). U.S. Geological Survey Hydrologic Toolbox — A graphical and mapping interface for analysis of hydrologic data: U.S. Geological Survey Techniques and Methods, book 4, chap. D3, 23 p. https://doi.org/10.3133/tm4D3

[12] PRISM Climate Group. (2024). 30-Year Normals [dataset] https://prism.oregonstate.edu/explorer/

[13] USGS. (n.d.-b). StreamStats [dataset]. https://www.usgs.gov/streamstats

[14] Tillman, F. et al. (2011). Water Availability and Use Pilot: Methods Development for a Regional Assessment of Groundwater Availability, Southwest Alluvial Basins, Arizona (Scientific Investigations Report 2011–5071). United States Geological Survey. https://media.kjzz.org/s3fs-public/field/docs/2011/09/21/sir2011-5071_text.pdf

[15] Tillman, F. et al. (2011). Water Availability and Use Pilot: Methods Development for a Regional Assessment of Groundwater Availability, Southwest Alluvial Basins, Arizona (Scientific Investigations Report 2011–5071). United States Geological Survey. https://media.kjzz.org/s3fs-public/field/docs/2011/09/21/sir2011-5071_text.pdf

Table 5. Estimated Effluent Reuse Volumes in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Year	Quantity
1990	0
2007	3,951
2024	5,231

All values are shown in AF.

The average estimated annual effluent reuse from 2003 to 2024 was 4,908 AF.

2.3.4 Incidental Recharge

Sources of incidental recharge in the Little Colorado River Plateau Basin are agricultural, municipal, and industrial.

Table 6. Estimated Incidental Recharge Volumes in the Little Colorado River Plateau Basin for 1990-2024. (SDR 2025)

Sector	1990	2007	2024
Agricultural	11,176	2,637	5,914
Municipal	4,375	5,737	6,164
Industrial	516	722	730

All values are shown in AF.

- Agricultural Incidental Recharge: Agricultural incidental recharge depends on the total irrigation withdrawals and irrigation efficiency within a basin. Aligned with trends in agricultural water demand for the basin, the estimated volume of agricultural incidental recharge decreased from 1990 into the 2000s but has increased in recent years.
- Municipal Incidental Recharge: Municipal incidental recharge is a byproduct of lost and unaccounted for (L&U) water from water providers and seepage from septic tanks. Between 1990 and 2024, municipal incidental recharge volumes have exhibited a consistent upward trend.
- Industrial Incidental Recharge: Industrial incidental recharge occurs from the irrigation of turf facilities and is influenced by irrigation systems' total withdrawals and efficiency. The estimated volume of industrial incidental recharge increased steadily from 1990 until 2009, when incidental recharge peaked at 797 AF. Since 2009, industrial incidental recharge has had minor fluctuations annually.

2.3.5 Transportation Water

Certain basins have been identified in A.R.S. Title 45, Chapter 2, Article 8.1 as basins from which groundwater may be withdrawn for transportation to an AMA. Where such transportation has been authorized, that groundwater is referred to as “Transportation Water” in this report.

The Little Colorado River Plateau Basin was not identified as a transportation water basin.

2.3.6 Moved Water

Any water that crosses basin boundaries through artificial means and that does not fall under the Transportation Water definition is referred to as "Moved Water" in this report. Moved Water includes groundwater that is transported between basins that are not AMAs, pursuant to A.R.S. Title 45, Chapter 2, Article 8.

The Little Colorado River Plateau Basin was identified as a basin with moved water. From 2019 to 2024, an average of 1,048 AF was moved annually from the Little Colorado River Plateau Basin to the Verde River Basin (Verde Canyon Subbasin) via the C.C. Cragin Pipeline. From 2019 to 2024, an average of 524 AF was moved annually from the Little Colorado River Plateau Basin to the Tonto Creek Basin via the C.C. Cragin Pipeline. No water was moved prior to 2019.

Table 7. Estimated Moved Water Volumes from the Little Colorado River Plateau Basin to the Verde River Basin (Verde Canyon Subbasin) and Tonto Creek Basin for 1990 - 2024. (SDR 2025)

Year	Volume to Verde River Basin (Verde Canyon Subbasin)	Volume to Tonto Creek Basin
1990	0	0
2007	0	0
2024	859	430

All values are shown in AF.

2.4 DEMAND RESULTS

The Demand subsection contains ADWR's estimates of annual demands in the Little Colorado River Plateau Basin.

Table 8. Estimated Demand Volumes for the Little Colorado River Plateau Basin by Sector for 1990-2024. (SDR 2025)

Sector	Subsector/Water Type	Year		
		1990	2007	2024
Agricultural	Agriculture	-36,333	-8,800	-20,485
Municipal	Residential Provider	-21,678	-28,985	-31,215
	Residential Non-Provider	-347	-463	-499
	Non-Residential	-9,179	-11,467	-12,242
	L&U	-4,320	-5,663	-6,084
Industrial	Dairies	0	0	0
	Feedlots	0	-542	-542
	Grazing	-1,060	-1,124	-1,801
	Mining	-4,450	-1,171	0
	Power	-59,057	-66,164	-16,238
	Sand and Gravel	-539	-948	-1,017
	Turf	-4,403	-6,482	-6,904
	Other	-15,479	-14,485	-84
Environmental	Riparian	-67,743	-67,743	-67,743

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

2.4.1 Agricultural

Agricultural demand is defined as water applied to two or more acres of land to produce plants or parts of plants for sale for human consumption or use as feed for livestock, range livestock, or poultry.

ADWR estimates there are 10,461 acres of cultivated land within the Little Colorado River Plateau Basin. Rye grass, alfalfa, and wheat are the predominant crop types, accounting for about 80% of the total acreage. Overall irrigation efficiency across the basin is estimated at 78% to 79% from 2008 to the present. More than 80% of the acreage in the basin is flood irrigated. The rest is either sprinkler irrigated or cultivated with dry farming methods, which are traditionally practiced by Native American tribes including the Hopi, Navajo, and Pueblo of Zuni Tribes.

Historical data shows that agricultural withdrawals declined from over 35,000 acre-feet in the early 1990s to less than 10,000 acre-feet in the 2000s and 2010s. More recent data shows that agricultural withdrawals have increased since the mid-2010s and now total around 20,000 acre-feet annually.

2.4.2 Municipal

Municipal demand is defined as the non-agricultural and non-industrial uses of water supplied by a city, town, private water company, irrigation district, domestic water improvement district, water cooperative, or private domestic well.

The Little Colorado River Plateau Basin has an estimated population of 272,231, with no incorporated towns or cities. A significant portion of residents live on federally recognized Tribal lands belonging to the Navajo Nation, Hopi Tribe, and Pueblo of Zuni. Water demand is influenced by visitation to federally managed sites such as the Wupatki National Monument, Walnut Canyon National Monument, and Lyman Lake State Park, where water is used for visitor centers, ranger housing, and recreational facilities. Transitory water use also occurs along major transportation corridors, including U.S. Routes 89, 160, and 191, as well as Interstate 40, which serve as vital corridors for regional travel and tourism.

- Residential Provider: Residential provider use is supplied by a municipal provider, or a Community Water System (CWS), as defined in A.R.S. § 45-341.[16] The Little Colorado River Plateau Basin has approximately 267,947 residents served by a CWS. Between 1990 and 2024, residential provider water demand in the basin increased by 44%, with the highest average annual growth rate of approximately 1.5% occurring from 1990 to 2007. After 2007, the average annual growth rate slowed to 0.36%, indicating a shift in service area population and water use patterns over time.
- Residential Non-Provider: Residential non-provider use is any residential water use that is not supplied by a municipal provider but rather by a non-public water system or domestic well. An estimated 4,284 residents in the basin rely on self-supplied water resources. From 1990 to 2024, residential water demand among non-provider users rose by 44%. Similar to residential providers, the average annual population growth rate was at its highest at 1.5% from 1990 to 2007. After 2007, the average annual growth slowed to 0.36%, indicating changes in water use among self-supplied households.
- Non-Residential: Non-residential use is defined as municipal water not used for residential purposes but instead used for commercial, institutional, recreational, or transitory uses. Between 1990 and 2024, non-residential water demand grew by 41%, driven in part by increased tourism and other economic activities.
- Lost and Unaccounted for Water: Lost and Unaccounted for (L&U) water is defined as the total quantity of water from any source that enters a water distribution system minus the total amount of authorized deliveries from the distribution system during the calendar year. L&U does not account for water loss from a non-public water system or domestic well. During the baseline period, the volume of L&U water increased by 33%, with the

[16] Arizona Revised Statutes § 45-341. https://www.azleg.gov/ars/45/00341.htm

highest increase occurring between 1990 and 2007. While increases in L&U slowed after 2007, they have continued to increase through the baseline period.

2.4.3 Industrial

Industrial demand is water used by an industrial facility, such as a golf course, dairy, feedlot, power plant, mine, or paper mill.

The current industrial water demands in the Little Colorado River Plateau Basin come from feedlots, grazing, mining operations, power production, sand and gravel facilities, turf, and other industrial demands.

- Feedlots: Water that is consumed on the site of a feedlot for the purposes of animal husbandry or dust control is considered feedlot demand. Over the baseline period, annual feedlot demand increased to 542 AF due to the addition of a concentrated animal feeding operation in the mid-1990s.
- Grazing: Grazing demand is defined as the water used to maintain stock ponds for the sole purpose of watering livestock. Over the baseline period, grazing demands increased due to a rising population of both livestock animals and feral horses on the Navajo Nation. The population of grazing animals in the Little Colorado River Plateau Basin is estimated to have increased from 105,477 animals in 1990 to 195,142 animals in 2024.
- Mining: Mining demand is defined as water use that is consumed for the purposes of extracting or processing ores or minerals. Mining water use fell significantly over the baseline period in response to the closures of two mines operated by Peabody Energy. Following the 2005 closure of the Black Mesa mine, mining demand decreased by 3,279 AF per year. In 2019, the Kayenta mine ceased operations, and mining demand in the basin fell to 0 AF per year.
- Power: Power demand is defined as the water use for the generation of power at thermal or renewable power plants. Power production has historically been the largest industrial water user in the Little Colorado River Plateau Basin. Recent actions to decommission and transition away from coal power plants, however, have decreased water use for power generation significantly in the basin. The largest decrease in water use occurred following the 2019 closure of the Navajo Generating Station.
- Sand and Gravel: Sand and gravel demand accounts for the water use of any facility or establishment that produces aggregates or quarried materials. From 1990 to 2024, total water use for sand and gravel operations increased by 478 AF, or 89%. Increased water demand can be attributed to the addition of new facilities starting operations in the basin. The majority of new facilities in the basin produce sand and gravel or cinders. The Little Colorado River Plateau Basin is a significant producer of cinders at the national scale due to the presence of cinder cones in the San Francisco volcanic fields.

- Turf: Turf demand is defined as the irrigation or maintenance of any area of landscaping that is not part of a private residence. From 1990 to 2024, irrigation for turf facilities increased by 57%. The increase in irrigation can be attributed to the addition of new turf facilities, including several golf courses.
- Other: Other industrial demand is defined as water use consumed by any facility that does not fit into one of the preexisting subsectors of industrial demand. In the Little Colorado River Plateau Basin, other industrial demand includes the water use from manufacturing facilities, greenhouses, compressor stations, and the production of oil and gas. Water use in this sector has fallen significantly over the baseline period due to the closure of the Catalyst Paper mill in 2012.

2.4.4 Environmental

Environmental demand is quantified within this report as evapotranspiration along streams, rivers, lakes, and drainage ways. Some examples of riparian habitats in the Little Colorado River Plateau Basin are found along the Little Colorado River, the Puerco River, and Chinle Creek. There is also significant riparian habitat in forested mountain areas around the Mogollon Rim in the southernmost part of the basin. The riparian demand values in the SDRs represent a high-end estimate of the potential water needs of riparian plants within a basin. In the absence of site-specific data, these estimates assume an average value for riparian plants' water needs, which does not consider local environmental conditions. Please see the Methods Appendix for an in-depth explanation of the methodologies.

- Annual net water requirements for the riparian plants are estimated to be 67,743 AF.

3 COMBINING SUPPLY AND DEMAND

Estimates show that the Little Colorado River Plateau Basin has a long-term imbalance between water supplies and demand. Demand has outweighed supply at least twofold throughout the baseline period, reaching a maximum of 230,847 AF in 1995 and slowly decreasing since then. Supply peaked in 1993 with an estimated 115,923 AF and remained relatively consistent near its baseline average of 83,498 AF. Groundwater storage has decreased throughout the baseline period due to this imbalance of demand consistently exceeding supply.

Table 9. Summary of Total Estimated Demand and Supply Values from 1990-2024 in the Little Colorado River Plateau Basin. (SDR 2025)

	1990	2007	2024
Supply	84,510	74,245	84,166
Demand	-224,587	-214,037	-165,939
Balance	-140,077	-139,792	-81,774
Resulting Water Available in Storage	74,053,640	71,705,020	69,989,306

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

4 RESULTS OF PROJECTION SCENARIOS

Staff developed scenarios based on the most likely impacts on water demands and supplies over 51 years (from 2025 to 2075). Projections were then generated from the baseline data.

The projection scenarios developed are:

1. Status Quo: baseline volumes were carried forward through the projection period.
2. Growth: volumes were assumed to increase within specific parameters throughout the projection period.
3. Conservation: volumes were assumed to be influenced by specific conservation practices through the projection period.
4. Technology: volumes were assumed to be influenced by technological advancements through the projection period.
5. Climate: volumes were adjusted for three different climate scenarios, using a 1-degree Fahrenheit temperature increase in the mean annual temperature for the projection period, following a lower emissions pathway for Arizona; a 5-degree Fahrenheit temperature increase, following a medium emissions pathway; and a 10-degree Fahrenheit temperature increase, following a high emissions pathway.

The Navajo Nation holds a contract for Upper Basin Colorado River water for the LeChee Chapter and sources this water directly rather than through the CAP system and the NIA water pool. The Hopi Tribe has a contract for Lower Basin Colorado River water that is utilized in the Lower Basin at this time. It was determined that no NIA water is currently used within the basin.

The Navajo Nation, the Hopi Tribe, and the San Juan Southern Paiute Tribe each have claims pending in the Little Colorado River General Stream Adjudication. The Navajo Nation have also asserted claims to Colorado River water in both the Upper and Lower Basins in Arizona. The Northern Arizona Indian Water Rights Settlement Agreement was executed in 2024 and, once authorized by Congress and enforceable, it will resolve all existing claims of the Hopi Tribe, the Navajo Nation, and the San Juan Southern Paiute Tribe to water supplies within Arizona.

4.1 SUPPLY PROJECTION RESULTS

4.1.2 Surface Water

For the Status Quo scenario, the estimated projected volume of surface water will remain constant until 2075.

Table 10. Estimated Surface Water Status Quo Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Scenario	Volume
Status Quo	150,050

All values are shown in AF.

Due to ongoing projection scenario improvements, no other projection scenarios were applied to surface water for this report.

4.1.3 Groundwater Storage

For the Status Quo scenario, the estimated projected balance between Supply and Demand will remain constant at -116,607 AF through 2075.

Table 11. Estimated Groundwater Storage Status Quo Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Scenario	2025	2050	2075
Status Quo	79,616,810	78,507,313	77,397,817

All values are shown in AF.

Due to ongoing projection scenario improvements, no other projection scenarios were applied to groundwater storage for this report.

4.1.4 Effluent

For the Status Quo scenario, the estimated projected volume of effluent for reuse will remain constant through 2075.

Table 12. Estimated Effluent Status Quo Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Scenario	Volume
Status Quo	5,794

All values are shown in AF.

Table 13. Estimated Effluent Growth Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Scenario	2025	2050	2075
Growth	5,782	5,358	4,679

All values are shown in AF.

For the Growth scenario, the volume of effluent decreases according to projected population change percentages by the Arizona Office of Economic Opportunity.[17]

4.1.5 Incidental Recharge

Table 14. Estimated Agricultural Incidental Recharge Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Sector	Scenario	2025	2050	2075
Agricultural	Status Quo	6,070	6,070	6,070
	Climate – Low	6,070	6,122	6,174
	Climate – Medium	6,070	6,328	6,586
	Climate - High	6,070	6,581	7,092
	Conservation	6,070	5,576	5,576
	Growth	6,070	7,960	9,849
	Technology	6,070	5,023	3,975

All values are shown in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: The Climate scenario is expected to result in rising temperatures and increased evapotranspiration, leading to larger irrigation withdrawals. Incidental recharge would be expected to increase with irrigation withdrawals. The projected increase in incidental recharge is about 1.7% for a 1° F rise in average temperature, 8.5% for a 5° F rise, and 16.8% for a 10° F rise.
- Conservation: The Conservation scenario implements requirements similar to those found in the AMAs' 5th Management Plan. In this scenario, irrigation efficiency is expected to improve, which reduces the amount of incidental recharge from system losses. The reduction in agricultural incidental recharge is projected to be approximately two percent in the Little Colorado River Plateau Basin.
- Growth: The Growth scenario considers historical growth trends and the land available for potential agricultural growth. In this scenario, incidental recharge is assumed to

[17] Arizona Commerce Authority (ACA). (2022a). Population Estimates. Arizona Commerce Authority. https://www.azcommerce.com/oeo/population/population-estimates/

increase proportionally to withdrawals. Remote sensing data shows an increasing trend in agricultural consumptive use in the basin from 2016 to 2023. If this trend continued to 2075, agricultural incidental recharge would increase by 62%.

- Technology: Irrigation systems are assumed to be upgraded with available technology to reduce overall water use. As in the Conservation scenario, this results in lower incidental recharge due to reduced system losses. Technology improvements are projected to reduce agricultural incidental recharge in the Little Colorado River Plateau Basin by as much as 35%.

Table 15. Estimated Municipal Incidental Recharge Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Sector	Scenario	2025	2050	2075
Municipal	Status Quo	550	550	550
	Climate – Low	579	582	584
	Climate – Medium	579	592	604
	Climate - High	579	605	630
	Conservation	579	528	480
	Growth	579	548	487
	Technology	579	540	503

All values are shown in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: The Climate scenario anticipates that rising temperatures and increased evaporation rates will elevate water usage demands in the Lower Colorado River Plateau. Projected incidental recharge volumes by 2075 are estimated to increase by approximately one percent under the low emissions scenario, four percent in the medium emissions scenario, and nine percent in the high emissions scenario.
- Conservation: The Conservation scenario implements requirements similar to those in the initial AMAs' 5th Management Plan. Under the scenario, the projected demand is expected to decrease 17% by 2075.
- Growth: Under the Growth scenario, population projections from the Arizona Commerce Authority Office of Economic Opportunity (ACA OEO)[17] were used to estimate that incidental recharge will decline 16% by 2075 due to decreasing population.
- Technology: The Technology scenario assumes widespread adoption of water monitoring technologies, such as advanced metering infrastructure (AMI) or home-based devices, with active leak detection and customer response. Estimated savings of 14,000 gallons per household per year reflect reductions from leaks and improved

water use efficiency. This reduction is projected to result in a decrease in incidental recharge of 13% by 2075.

Table 16. Estimated Industrial Incidental Recharge Projection Volumes for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Sector	Scenario	2025	2050	2075
Industrial	Status Quo	718	718	718
	Climate – Low	731	738	745
	Climate – Medium	732	767	803
	Climate - High	733	804	875
	Conservation	712	694	694
	Growth	718	718	718
	Technology	716	705	693

All values are shown in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: The Climate scenario assumes that rising temperatures will increase irrigation needs for turf. Increased irrigation is estimated to increase incidental recharge by 14 AF in the low emissions scenario, 71 AF in the medium emissions scenario, and 142 AF in the high emissions scenario.
- Conservation: The Conservation scenario assumes that turf facilities will increase irrigation efficiency over time. As irrigation efficiency increases, total irrigation is expected to drop, resulting in a reduction in incidental recharge. By the end of the projection period, the Conservation scenario is estimated to decrease incidental recharge by 18 AF, or three percent.
- Growth: Status Quo projections were applied in the absence of a defined Growth scenario.
- Technology: The Technology scenario assumes that eligible acres of natural turf will be replaced with synthetic turf. Synthetic turf requires less water to maintain than natural grass and reduces groundwater recharge. As a result of increased synthetic turf in the basin, the Technology scenario is estimated to decrease incidental recharge by three percent by 2075.

4.2 DEMAND PROJECTION RESULTS

4.2.1 Agricultural

Table 17. Estimated Projected Demand Volumes for the Agricultural Sector for the Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

Scenarios	Year		
	2025	2050	2075
Status Quo	-21,014	-21,014	-21,014
Climate - Low	-21,014	-21,211	-21,408
Climate – Medium	-21,014	-21,998	-22,983
Climate - High	-21,014	-22,983	-24,952
Conservation	-21,014	-20,553	-20,553
Growth	-21,014	-27,554	-34,094
Technology	-21,014	-20,039	-19,064

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: The Climate scenario is expected to result in rising temperatures and increased evapotranspiration, leading to increased irrigation withdrawals. Irrigation needs in the Little Colorado River Plateau Basin are estimated to increase by about two percent for a 1° F rise in average temperature, nine percent for a 5° F rise, and 19% for a 10° F rise.
- Conservation: The Conservation scenario assumes the implementation requirements similar to those in the AMAs' 5th Management Plan. This would decrease irrigation withdrawals in the Little Colorado River Plateau Basin by an estimated two percent by improving overall irrigation efficiency.
- Growth: The Growth scenario considers historical growth trends and the land available for potential agricultural growth. Remote sensing data shows a slight increasing trend in agricultural consumptive use in the basin from 2016 to 2023. Projecting this trend out to 2075 results in a 62% increase in irrigation withdrawals. Based on the analysis of land ownership and use in the basin, ADWR concluded that there is sufficient available land to accommodate the projected agricultural growth. See Methods Appendix for more information.
- Technology: Irrigation systems are assumed to be upgraded with available technology to reduce overall water use. In the Little Colorado River Plateau Basin, technology upgrades may reduce irrigation withdrawals by approximately nine percent.

4.2.2 Municipal

Table 18. Estimated Projected Demand Volumes for the Municipal Sector for Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

	Residential Provider			Residential Non-Provider		
	2025	2050	2075	2025	2050	2075
Status Quo	-29,679	-29,679	-29,679	-475	-475	-475
Climate – Low	-31,227	-31,361	-31,495	-499	-501	-504
Climate – Medium	-31,248	-31,918	-32,589	-500	-510	-521
Climate - High	-31,275	-32,615	-33,956	-500	-522	-543
Conservation	-31,116	-28,488	-25,859	-498	-456	-413
Growth	-31,319	-29,534	-26,246	-501	-472	-420
Technology	-31,141	-29,136	-27,130	-498	-466	-434

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

	Non-Residential			L&U		
	2025	2050	2075	2025	2050	2075
Status Quo	-12,242	-12,242	-12,242	-5,841	-5,841	-5,841
Climate – Low	-12,242	-12,242	-12,242	-16,614	-16,633	-16,652
Climate – Medium	-12,242	-12,242	-12,242	-16,617	-16,711	-16,805
Climate - High	-12,242	-12,242	-12,242	-16,621	-16,808	-16,996
Conservation	-12,242	-12,242	-12,242	-6,070	-4,073	-3,810
Growth	-12,283	-11,583	-10,294	-6,104	-5,756	-5,116
Technology	-12,242	-12,242	-12,242	-6,074	-5,793	-5,512

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: Under the Climate scenario, rising temperatures and increased evaporation rates are expected to increase water demands. By 2075, residential provider and residential non-provider demands are each projected to increase by approximately one percent under the low emissions scenario, five percent under the medium scenario, and 10% under the high scenario. Non-residential demand is expected to remain unchanged across all scenarios. Lost and Unaccounted for (L&U) water is anticipated to show no change under the low emissions scenario, a one percent projected increase for the medium emissions scenario, and two percent under the high emissions scenario.
- Conservation: The Conservation scenario assumes additional water-saving measures and requirements similar to those in the AMA 5th Management Plan are implemented. By 2075, residential provider and residential non-provider demand is projected to decline by 17%.

Non-residential demand is expected to remain constant throughout the projection period. The total volume of L&U water is projected to decrease by 37%.

- Growth: Under the Growth scenario, population projections by the Arizona Commerce Authority Office of Economic Opportunity (ACA OEO)[17] were used to estimate the growth in the basin. Projected demand for all sectors is expected to decline by 16% due to decreasing population growth rates.
- Technology: The Technology scenario assumes widespread adoption of water monitoring technologies, such as AMI or home-based devices, with active leak detection and customer response. Estimated savings of 14,000 gallons per household per year reflect reductions from leaks and improved water use efficiency. By 2075, the residential provider and residential non-provider demand is anticipated to decline by 13%. Non-residential demand is expected to remain constant with no changes. The total volume of L&U water is projected to reach a decrease of nine percent by 2075.

4.2.3 Industrial

Table 19. Estimated Projected Demand Volumes for the Industrial Sector for Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

	Grazing	Mining	Sand and Gravel	Other
Status Quo*	-1,704	0	-1,022	-82

** Status Quo projections were the only projection scenarios that were applied to grazing, mining, sand and gravel, and other industrial subsectors.*

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

Projections were not developed for the grazing, mining, sand and gravel, or other industrial subsectors due to the limited expected impact of a given scenario on the subsectors.

	Feedlots			Power			Turf		
	2025	2050	2075	2025	2050	2075	2025	2050	2075
Status Quo	-542	-542	-542	-20,634	-20,634	-20,634	-6,798	-6,798	-6,798
Climate – Low	-543	-545	-547	-14,211	-13,844	-14,257	-7,280	-7,343	-7,406
Climate – Medium	-543	-554	-565	-14,217	-13,999	-14,560	-7,290	-7,605	-7,921
Climate - High	-543	-567	-588	-14,236	-14,481	-15,507	-7,302	-7,933	-8,564
Conservation	-537	-514	-514				-6,742	-6,583	-6,583
Growth				-14,205	-2,447	-2,071			
Technology				-14,213	-1,135	-687	-6,778	-6,677	-6,575

Negative numbers indicate demands or water flows leaving the basin—all values in AF.
Status Quo projection values were applied in the absence of a defined scenario for a subsector.
This is indicated by a gray cell.

- Status Quo: The Status Quo scenario estimated projected volume of grazing, mining, sand and gravel, and other will remain constant through 2075.

- Climate
    - Feedlot: In the Climate scenario, it is assumed that animals will have increased drinking and cooling needs as temperatures rise. Demand is estimated to increase by less than one percent in the low emissions scenario, by four percent in the medium emissions scenario, and by eight percent in the high emissions scenario.
    - Power: The Climate scenario considers changes in consumer electrical demand and changes in power plant operations resulting from higher temperatures. The 2025 decommissioning of the Cholla Power Plant was also considered within the scenario. The low, medium, and high emissions scenarios are projected to increase demand in the basin by 46 AF, 343 AF, and 1,271 AF, respectively.
    - Turf: Increased temperatures and evapotranspiration are expected to raise overall turf irrigation requirements in the Climate scenarios. Irrigation is estimated to increase by 126 AF in the low emissions scenario, 631 AF in the medium emissions scenario, and 1,262 AF in the high emissions scenario.
- Conservation
    - Feedlots: The Conservation scenario increases the efficiency of cooling systems within feedlots. Once fully implemented, the Conservation scenario is estimated to decrease annual water use by four percent
    - Turf: Under the Conservation scenario, increased irrigation efficiency requirements are expected to have a modest impact on total water use. By 2075, irrigation is projected to decrease by two percent
- Growth
    - Power: The Growth scenario considers the impact that population growth, planned decommissions of existing power plants, and additions of permitted power plants will have on water demand for power production. The 2025 decommissioning of the Cholla Power Plant combined with the planned decommissioning of both the Springerville Generating Station and the Coronado Generating Station in the early 2030s is expected to decrease demand significantly. By 2075, it is projected that demand in the basin will decrease by 85%.
- Technology
    - Power: The implementation of consumer-side and utility-side technologies is projected to reduce demand by 13,526 AF, or 95%, by 2075. The substantial decrease in total demand in this scenario is driven by the 2025 decommissioning of the Cholla Power Plant and a projected transition away from coal power plants.

- Turf: Conversion of eligible natural turf acres to synthetic turf is estimated to have a modest impact on irrigation. By 2075, estimated irrigation withdrawals are projected to decrease by three percent.

4.2.4 Environmental

Table 20. Estimated Projected Environmental Demand Volumes for Little Colorado River Plateau Basin for 2025-2075. (SDR 2025)

	Environmental		
	2025	2050	2075
Status Quo	-67,743	-67,743	-67,743
Climate – Low	-67,757	-68,087	-68,391
Climate – Medium	-67,809	-69,352	-70,762
Climate - High	-67,873	-70,816	-73,228

Negative numbers indicate demands or water flows leaving the basin—all values in AF.

- Status Quo: The Status Quo scenario estimated projected volume will remain constant through 2075.
- Climate: The Climate scenarios for riparian use consider the impact of increased temperatures, increased evapotranspiration, and habitat transition. Under the set parameters of these scenarios, riparian use is expected to increase in the Little Colorado River Plateau Basin as the higher temperatures increase evapotranspiration from riparian plants. Riparian water use is estimated to increase by one percent in the low emissions scenario, four percent in the medium emissions scenario, and eight percent in the high emissions scenario.

5 CONCLUSION

A long-term imbalance between water supplies and demand in the Little Colorado River Plateau Basin has led to depletion in the amount of groundwater in storage through the entire baseline period. Demand outweighed Supply values by two to three times, which led to groundwater storage decreasing from approximately 74 million AF in 1990 to just under 70 million AF in 2024. If groundwater levels were to drop below the basin's average well depth of 387 feet, approximately 61% of existing wells would become dry. The average recorded water level of wells in Little Colorado River Plateau Basin is 260 feet.

Streamflow values for the basin constituted a wide range, with the minimum of 44,103 AF occurring in 2014, and a maximum of 315,937 AF in 2005. Large volumes of groundwater left the basin due to groundwater outflow, averaging 210,400 AF a year. Mountain-front recharge was a major positive contributor to supply values.

Demand values remained consistently over 200,000 AF for the first two-thirds of the baseline period. Starting in 2013, demand decreased gradually before reaching its minimum of 164,557 AF in 2021. Agricultural demand underwent a steep decline from 1990 to 2017 before steadily increasing for the remainder of the baseline period. Other large constituents of demand included residential provider, power, and Environmental.

The Little Colorado River Plateau Basin's water budget was negative throughout the baseline period due to demand values far exceeding supply.

5.1 ATTACHMENTS

- **Acronyms and Definitions**
- **References (Sources) – general**

ASU Kyl Center for Water Policy at Morrison Institute
Arizona State University

ASU LightWorks®
Arizona State University

Water Rights and Water Use of Coal Facilities in the Colorado River Basin

August 2022

Water Rights and Water Use of Coal Facilities in the Colorado River Basin

Prepared by The Kyl Center for Water Policy at ASU's Morrison Institute and ASU Lightworks Just Energy Transition Center

Authors: Benjamin Longbottom, Lena Zeebuyth, Rhett Larson, Kris Mayes, Amanda Ormond, and Sarah Porter

Contents

Background

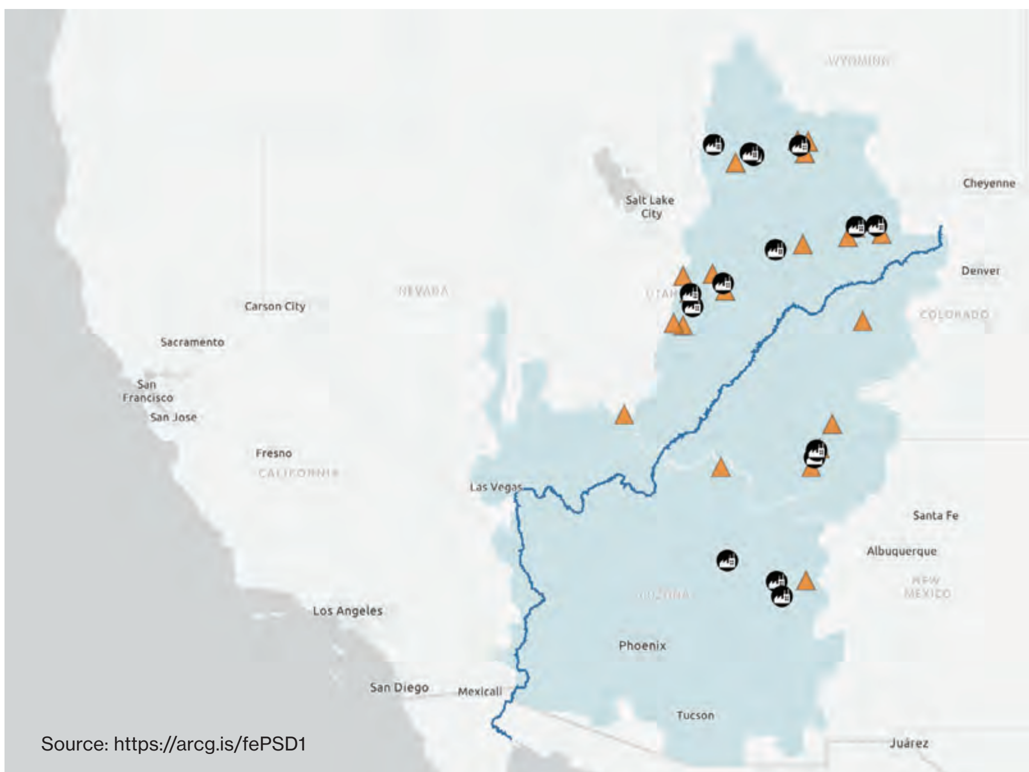
Energy production from coal is on a downward trajectory, and many coal power plants and mines are expected to cease operations in the next two decades.[1] As a result, communities whose economies are centered on coal are vulnerable to disruption. By the same token, the closure of coal mines and coal power plants may free up water supplies and create opportunities for sustainable economic development based on those supplies.

In this report, the Just Energy Transition Center at Arizona State University Lightworks and ASU's Kyl Center for Water Policy at Morrison Institute have inventoried the water used for coal power plants and mines within the Colorado River Basin. **This first-of-its-kind report summarizes findings from extensive research to identify and describe the amount, source, and ownership of water rights used by coal-fired power plants and coal mines throughout the Colorado River Basin.**

This report is intended to help policymakers and community stakeholders impacted by the closure of coal-fired power plants and coal mines in the Colorado River Basin understand the water resources implications and opportunities to inform decision-making about the future use of those resources.

As used in this report, "**impacted communities**" means communities situated near coal-fired power plants and coal mines that are disproportionately impacted by the pollution and environmental impacts created by those facilities and/or that can reasonably demonstrate ways in which changes in the coal industry have caused or will cause serious consequences in local economies.

Coal Power Plants and Mines in the Colorado River Basin



Source: https://arcg.is/fePSD1

Colorado River Basin

Coal Power Plants

Coal Mines

Colorado River

1 Howard Gruenspecht, Brookings, *The US Coal Sector: Recent and Continuing Challenges* 10-15 (Jan. 2019), https://www.brookings.edu/research/the-u-s-coal-sector/.

Summary

There are currently about **37 coal-fired power plants and coal mines in the Colorado River Basin**. These plants and mines are located in five states – Arizona, Colorado, New Mexico, Utah and Wyoming – and together they withdraw an estimated 131,130 acre-feet of water each year.[2] Coal plants use the vast majority of this water, about 130,000 acre-feet per year, while coal mines collectively use a modest 1,130 acre-feet.*

There are more than 800 industrial water rights associated with the 37 coal facilities, entitling their owners to approximately 1.8 million acre-feet of water annually. Facilities use less than their full entitlement for a variety of reasons: permits may include efficiency requirements or a facility operator may temporarily lease water to another part of the operation (such as waste disposal or remediation). In general, these rights give their owners a claim to use a specific quantity of water for a particular purpose, enforceable against other water users with lower priority rights, also known as junior water rights.[3] Many of these rights can be purchased independently under state law, but some (e.g., all the rights associated with Arizona coal facilities) may be bought and sold only as part of the sale of land.

Most of the coal facilities in the Colorado River Basin get their water through water rights owned by the same companies that own and operate the facilities. PacifiCorp, a six-state power company, has water rights associated with coal facilities ("coal water rights") that entitle it to at least 490,000 acre-feet of water each year in three states (Colorado, Utah, and Wyoming), the highest total quantity controlled by any single owner identified in this report. Salt River Project, an Arizona-based utility, owns coal water rights that entitle it to around 100,000 acre-feet of surface water each year in Arizona and Colorado. A variety of other companies – including Peabody Energy, Public Service Co. of New Mexico, Tucson Electric Power Co., and Tri-State Generation and Transmission Co. – own large coal water rights representing more than 300,000 acre-feet of water each year in total. In most states, the water supplying coal facilities comes primarily from rivers, streams, and reservoirs, while the rest comes from underground wells.

	Arizona	Colorado	New Mexico	Utah[4]	Wyoming	Total (Basin)
Total Coal Water Rights (acre-feet per year)	141,750	928,638	73,820	481,718	188,685	1,803,752
Percent Groundwater	100	0.5	2.8	5.1	20.7	11.7
Percent Surface Water	0	99.5	97.2	94.9	79.3	88.3

* As used in this report, the term "use" does not necessarily equate with "consumptive use." This study did not investigate whether any water uses by power plants or mines result in water returned to a surface water or water treatment system.

2 *Thermoelectric Cooling Water Data, Energy* Info. Admin. (Nov. 1, 2021), https://www eia gov/electricity/data/water/. An acre-foot is 325,851 gallons, or about the amount of water used by three to four Arizona single-family households in a year. *How Many Homes in Arizona, On Average, Share an Acre-Foot of Water Each Year?,* Ariz. Dep't of Water Res. (Apr. 19, 2021), https://new azwater gov/news/articles/2021-19-04. Annual water usage information was not available for any of the coal mines in this study except those located in Utah, so figures regarding mine annual water usage are estimates.

3 See page 6 for a summary of western water law.

4 As Utah does not distinguish between surface water and groundwater, these percentages represent the source of the water and not its legal designation.

Considerations for Future Water Uses

As these facilities are retired, the water supplies used to support them will potentially become available for alternative uses. The best future uses for the water currently consumed by coal facilities in the Colorado River Basin will depend on a variety of factors, including the environment, applicable state and federal laws and regulations, and the goals and needs of each impacted community. As communities and stakeholders consider new uses, they will want to bear in mind the following:

- The **laws governing water rights are complex** and may include decades of court decisions and settlement agreements. State laws could complicate or impede a community's plans to buy, lease, transfer or retire water rights.
- **Environmental remediation and land reclamation** will be required for some retiring plants and mines, and these post-operation requirements will have their own water demands.
- **Climate change** is impacting the surface water flows in the Colorado River Basin. As the magnitude and severity of future impacts are uncertain, community planners should use caution in relying on historic hydrologic patterns for estimating future water supplies and **consider recent climate models** for predictions of water availability and plan based on diverse availability scenarios.[5]
- The amount of economic value that water supplies can generate varies: water can be dedicated to agriculture, the environment, commercial and industrial purposes or residential uses. Within agriculture there are higher and lower value crops, just as there are higher and lower earning industries. Communities may want to evaluate the economic benefits of various water uses; for example, **value of product or well-paying jobs produced per acre foot**.
- **Groundwater overdraft is a risk in many parts of the Colorado River Basin**.[6] In much of the arid and semi-arid West, groundwater is considered a non-renewing resource, because it can be withdrawn much faster than it is replenished. De-watering an aquifer means the resource will not be available for future needs and may lead to subsidence, a condition in which the ground sinks in on itself and is no longer capable of storing water.
- In smaller communities, **comparatively modest supplies** of water can yield **significant** economic, environmental or community **benefits**.

5 See Appendix B for suggested research reports on how climate change may impact surface water flows.

6 Stephanie L. Castle et al., *Groundwater Depletion During Drought Threatens Future Water Security of the Colorado River Basin*, Geophysical Rsch. Letters (Aug. 29, 2014).

Western Water Law Basics

While the Colorado River Basin states vary in specifics of how they govern water rights, they share some important similarities in their approaches.

Throughout the region, the two main sources of water are **surface water** – that is, water in rivers and streams – and **groundwater** – that is, water lying in rock and soil pore spaces beneath the Earth's surface. Groundwater is generally pumped from wells.

One of the most important concepts in western water law is the **relationship between surface water and groundwater**. In some states, there is effectively no difference – their "**unified**" systems treat all water as one and the same resource. Other states have "**bifurcated**" their water rights systems such that they govern surface water and groundwater differently. In those states, surface water is (usually) legally defined as water that flows in definable channels, such as streams and rivers, which can be both above and below the ground. Groundwater, by contrast, is defined as water that percolates through undefined underground aquifers. In bifurcated water rights states, the legal line between what is groundwater and what is surface water is the foundation for longstanding water rights litigation.

Both unified and bifurcated states use some variation of the **prior appropriation** system to govern their surface water rights. Prior appropriation is a "first in time, first in right" legal regime. In other words, the first person to put water to beneficial use without waste[7] has superior water rights relative to all those who come later. The relative priority of each water right is delineated by a "priority date," which is (usually) the date that a person first put water to beneficial use – the earlier the date, the more senior the water right. Prior appropriation rights entitle a person to a specified amount of water, frequently measured as cubic feet per second or acre-feet per year, for a specific set of uses.

A variety of factors may affect water rights and their relative priorities, including non-use resulting in forfeiture of all or part of the right and private agreements and settlements. An array of laws controls the purchase, sale, lease and transfer of these water rights, including requirements of public notice and opportunities for other water rights holders to object to such transfers if the transfer would impact other rights on the river.

In states with unified systems, the rules for groundwater are the same as for surface water. In states with bifurcated systems, the rules for groundwater are different: groundwater pumping must be "reasonable" or else limited to a specific amount of water (sometimes correlating to the size of the parcel of land on which the water is pumped). The exact definition of reasonableness is often determined by courts in water rights litigation according to a variety of complicated factors. Groundwater rights are frequently appurtenant to the land, meaning they cannot be bought or sold separate from the land on which the water is being pumped.

To illustrate a typical bifurcated system, if Person A began diverting 10 acre-feet of water from the Blue River to grow turnips in 1900, they would have a prior appropriation surface water right to 10 acre-feet per year to grow turnips from a particular diversion point on the River. If Person B began diverting 5 acre-feet of water from the Blue River to water cattle in 1910, they would have a right to 5 acre-feet per year to water cattle. Person B's right would be junior to Person A's. This means that if there were 13 acre-feet in the Blue River, Person A would get their full 10-acre-foot allocation and Person B would get only 3 acre-feet. If there were only 9 acre-feet in the river, Person A would get all of it and Person B would get nothing. By contrast, if Person C owned 30 acres of

---

7 These are legal terms with specific definitions unique to each state.

farmland, they could pump a "reasonable" or state-specified amount of groundwater from beneath their land. Person C could not sell these rights to their neighbor, and there may be rules governing whether they could sell the water itself for use off their land.

In "unified" systems, both surface water and groundwater rights operate just like the example of Person A and Person B on the Blue River. If, in addition to Person A's 10-acre-foot surface water right, they began pumping 5 acre-feet of groundwater from beneath their land in 1960, they would have a 5-acre-foot groundwater right with a priority date of 1960. There would be no "reasonableness" requirement for Person A's use, and A's right would be superior to anyone who began pumping after them.

Water Rights and Use of Coal Plants and Mines

ARIZONA

Arizona Water Law. Arizona treats surface water and groundwater as two legally distinct resources subject to different rules. Surface water rights are allocated according to prior appropriation. Groundwater is heavily regulated in five "Active Management Areas" (AMAs) in central and southern Arizona and subject to limited regulation in three "Irrigation Non-expansion Areas" (INAs). In the remainder of the state, groundwater pumping is limited to a "reasonable and beneficial use." Outside of AMAs, groundwater rights in Arizona are generally tied to ownership of the overlying surface land, meaning they cannot be bought or sold separate from the land.

The fact that water is withdrawn from a well does not necessarily mean the water is legally groundwater. Depending on their location, wells may be deemed to be pumping a river's subsurface flow that under Arizona law is considered surface water, even though it is underground. This distinction is important because the right to use water from wells pumping subflow may be subject to senior surface water rights.[8]

The state's primary water regulatory authorities are the Arizona Department of Environmental Quality, the Arizona Corporation Commission and the Arizona Department of Water Resources. Water rights are regulated by the Department of Water Resources.

Arizona Coal Facilities. Arizona has four coal facilities within the Colorado River Basin. All four facilities are in the Little Colorado Watershed in the north and east parts of the state. The Little Colorado Watershed is currently under adjudication, a proceeding in which the rights to use surface water and to pump water from the subflow zone will be definitively determined.

Coronado Generating Station is owned by Salt River Project ("SRP") and located near St. Johns. Coronado used about 5,200 acre-feet of water in 2020, all of which came from about 30 groundwater wells with a combined pumping capacity of 44,000 acre-feet annually. All of the wells are owned by SRP. The station is not located in an AMA or INA.

8 Kathleen Ferris et al., Kyl Ctr. for Water Policy, *The Price of Uncertainty* 5 (Mar. 2018), https://morrisoninstitute.asu.edu/sites/default/files/the_price_of_uncertainty.pdf.

Cholla Power Plant is owned by Arizona Public Service Co. (APS) and located near Joseph City. Cholla used about 9,200 acre-feet of water in 2020. It gets its water from approximately ten groundwater wells, all owned by APS, capable of pumping 9,550 acre-feet annually. The Cholla Plant is located within the Joseph City INA. Accordingly, for parcels of two acres or greater, only land that was irrigated in the five years prior to the INA's creation in 1980 may be irrigated. The right to irrigate is tied to these lands and not transferrable to other lands. Moreover, owners of wells withdrawing over 35 gallons per minute must use a water measuring device and file annual reports with the Department of Water Resources.[9]

Springerville Generating Station is owned by Tucson Electric Power Co. ("TEP"), SRP and Tri-State Generation & Transmission Co. ("Tri-State G&T") and located near the Town of Springerville. The Springerville plant used about 10,400 acre-feet of water in 2020. The plant gets its industrial and power production water from about 32 groundwater wells, owned by SRP, TEP and Tri-State G&T, that can pump a total of 77,000 acre-feet each year.

Kayenta Mine is owned by Peabody Energy and located near Kayenta, AZ, within the boundaries of the Navajo Nation. Kayenta Mine closed in 2019, but most coal mines in the Colorado River Basin for which water usage is known use less than 100 acre-feet each year. The mine gets its water from 7 wells, all owned by Peabody, capable of pumping 11,200 acre-feet each year.

Navajo Generating Station, a coal-fired power plant located in the Navajo Nation, closed in 2019. The largest coal-fired plant in the US West, Navajo Generating Station was statutorily entitled to 34,000 acre-feet of water from Arizona's allocation of Upper Colorado River Basin water. Now that the plant has ceased operations, this water supply could be used in settlement of federal reserved water rights claims of the Navajo Nation and Hopi Tribe, both of whose homelands are located in northeastern Arizona.[10]

COLORADO

Colorado Water Law. Similar to Arizona, Colorado water law considers surface water and groundwater to be distinct resources. All water rights require some version of a permit from the state Division of Water Resources or an adjudication by a Colorado Water Court, and changes to or transfers of permits generally require approval from the state.

Surface water in Colorado is allocated according to the law of prior appropriation,[11] which provides that an earlier appropriator of water has higher priority to limited water supplies than later appropriators.[12] Colorado law specifies, however, that if there is insufficient water to satisfy all those with rights to it, "those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes."[13] Thus, Colorado law waives some of the tenets of prior appropriation in times of water shortage.

In addition, Colorado has a legally-recognized pilot water banking program, but only in the Arkansas River Basin. There are proposals for this program to expand to the Colorado River Basin in the future. Additionally,

---

9 Ariz. Rev. Stat. tit. 45, art. 3.

10 *See Parker Shea, Navajo Generating Station Closure Leaves Questions of Water Ownership,* Ariz. Mirror, https://www.azmirror.com/2019/11/08/navajo-generating-station-closure-leaves-questions-of-water-ownership/; Gregor A. MacGregor, *When the Navajo Generating Station Closes, Where Does the Water Go?,* 31 Colo. Nat. Res., Energy & Env't L. Rev. 290 (2020).

11 Colo. Const. art. XVI, § 5.

12 Colo. Const. art. XVI, § 6.

13 Colo. Rev. Stat. Ann. § 37-92-203.

a partnership between The Nature Conservancy, Colorado's Southwestern Water Conservation District and the Colorado Water Conservation Board facilitates certain incentives for water conservation under a voluntary program within the Gunnison River sub-basin. Colorado has set a goal to conserve 50,000 acre-feet per year under these sorts of temporary voluntary agreements by 2030.

Groundwater rights, on the other hand, are governed by a complex array of different rules depending on the exact nature of the water. "Tributary groundwater," groundwater that is directly connected to surface water supplies, is similar to "subflow" in Arizona – underground water that is allocated according to prior appropriation.[14] "Designated groundwater," by contrast, is groundwater in specially designated basins that do not support surface water supplies and is allocated according to a "reasonableness" rule.[15] "Non-tributary groundwater" is groundwater within deep, confined aquifers with minimal connection to surface water or tributary groundwater outside of designated basins.[16] This groundwater is allocated based on overlying land ownership and according to a rigid 100-year standard that effectively concedes the long-term depletion of groundwater supplies.[17] Under the 100-year standard, the sum of all non-tributary groundwater permit holders may deplete the aquifer by a maximum of 1% each year.[18] Lastly, "not-nontributary groundwater" is groundwater with slightly greater connection to surface systems than non-tributary groundwater, and it is allocated under a 100-year standard, but permit holders must also submit an augmentation plan to the State Engineer's Office.[19]

Despite the differential treatment of surface water and groundwater, Colorado's water law regimes are integrated, meaning that surface water and groundwater rights are recorded together. Most sub-basins in Colorado have been fully adjudicated, meaning water rights in the state are substantially more certain and secure than in other Colorado River Basin states.

The primary regulatory authorities in Colorado are the Colorado Department of Natural Resources, Division of Water Resources, the Colorado Public Utilities Commission and the Colorado Department of Public Health and Environment. Water rights are administered and recorded by the Division of Water Resources and the Colorado Water Courts.

Colorado Coal Facilities. Colorado has eight coal facilities in the Colorado River Basin. Even though water rights in Colorado are relatively more certain than in other states, Colorado law does not require the owners of water rights to be recorded, making it difficult to know with certainty who owns any given water right. Owners are frequently recorded on imaged records available from the Colorado Division of Water Resources, but these records may not be up to date.

Nevertheless, it appears that the water rights for the Colorado coal facilities are owned mostly by the owners of each respective facility. Although our research failed to conclusively identify the specific water rights used at each facility, we were able to identify those rights that are likely owned by companies associated with the facilities and that have diversion points near the respective facilities. Each facility seems to get water from a mix of surface water and groundwater sources, but the largest coal water rights are surface water rights.

---

14 Colo. Rev. Stat. Ann. §§ 37-92-103(11), 37-90-137.

15 Colo. Rev. Stat. Ann. § 37-90-103.

16 Colo. Rev. Stat. Ann. § 37-90-103(10.5); Luke W. Harris & Christopher J. Sanchez, *Considerations for Analyzing Colorado Ground Water: A Technical Perspective*, 15 U. Denv. Water L. Rev. 105, 119 (2011).

17 Colo. Rev. Stat. Ann. § 37-20-137.

18 Id.; Colo. Rev. Stat. Ann. § 37-90-137.

19 Colo. Rev. Stat. Ann. §§ 37-90-103(10.7), 37-90-137.

West Elk Mine is owned by Mountain Coal Co. LLC and located near Paonia. Its precise water usage is unknown, but it produces roughly the same amount of coal as Sufco Mine in Utah, so we estimate that it uses around 50 acre-feet of water each year. This water comes from a mix of groundwater and surface water rights owned in whole or in part by Mountain Coal Co. and from surface water rights owned by irrigation companies, in which Mountain Coal is a shareholder. Together, these rights entitle Mountain Coal to about 13,000 acre-feet of water per year. This water is very likely used at other facilities in addition to West Elk Mine.

Deserado Mine is owned by Blue Mountain Energy, Inc. and located near Rangely. Like West Elk Mine, Deserado Mine's water usage is uncertain. However, it is about half the size of West Elk Mine, so it probably uses about 25 acre-feet of water each year. Blue Mountain Energy owns several groundwater permits entitling it to a total of about 3,300 acre-feet per year, but it is not clear whether or to what extent these rights are used at Deserado Mine. Blue Mountain Energy and Deseret G&T also own several surface water rights, including one with a total capacity of about 130,000 acre-feet per year. This water is very likely used at other locations besides Deserado Mine.

Colowyo Mine is owned by Colowyo Coal Co. and located near Axial. It likely uses around 25 acre-feet of water each year, since it is approximately the same size as Deserado Mine. Colowyo Coal Co. owns 15 groundwater permits entitling it to a total of about 500 acre-feet of water each year, but it is not clear that this water is used at Colowyo Mine. In addition, Colowyo Coal owns at least 25 different surface water rights associated with Colowyo Mine. The largest right entitles Colowyo Coal to nearly 300,000 acre-feet per year. This is the single largest water right identified in this study. It is not clear whether any of this water is used at Colowyo Mine, but its diversion point on the Yampa River is located within a few miles of the mine. In addition, Colowyo Coal owns several other surface water rights totaling nearly 20,000 acre-feet per year. Because Colowyo Mine itself uses only a small fraction of this, the water is likely used in several places.

Foidel Creek Mine is owned by TwentyMile Coal Co. and located near Milner. We estimate that it uses about 30 acre-feet of water each year, as it produces slightly more coal than the Deserado and Colowyo mines. TwentyMile Coal Co. owns a host of groundwater and surface water rights that may be used in part at the mine. The groundwater rights entitle TwentyMile Coal to around 250 acre-feet of water each year, while the surface water rights allow TwentyMile Coal to divert nearly 300,000 acre-feet each year. As with the other Colorado mines, these rights are likely used in many locations for a variety of purposes.

Trapper Mine is owned by Trapper Mining, Inc. and located near Craig. It probably uses around 25 acre-feet of water each year, as it is similar in size to Deserado Mine. This water comes primarily from a single surface water right owned by Trapper Mining and from 4 groundwater permits. The surface water right entitles Trapper Mining to about 18,700 acre-feet each year, while the groundwater permits total 800 acre-feet per year.

King II Mine is owned by GCC Energy LLC and located near Hesperus, in southern Colorado. It is the smallest coal mine in Colorado within the Colorado River Basin. The mine likely uses less than 10 acre-feet of water each year, which probably comes from a single groundwater permit owned by GCC Energy that allows it to pump 48 acre-feet per year. GCC Energy also owns several surface water rights, including one entitling it to about 7,600 acre-feet per year.

Craig Generating Station is owned by Tri-State G&T, PacifiCorp, Platte River Power Authority ("PRP"), SRP and the Public Service Company of Colorado ("PSCC") and is located near Craig, Colorado. It used about 13,300 acre-feet of water for cooling purposes in 2020. According to the EIA, all this water was surface water from the Yampa River. This accords with our research, which revealed that the primary water right associated with the power plant is a surface water right owned jointly by PacifiCorp, PSCC, PRP, SRP and Tri-State G&T. This right entitles its owners to about 43,440 acre-feet of water per year, but 25% of this is “conditional,” meaning it could potentially be taken away in the event of a conflict with higher priority water rights. Such conflict is unlikely at this point because of the advanced stage of most Colorado water rights adjudications. The same handful of companies own several additional (smaller) surface water rights that may be used at Craig Generating Station, but it is unclear whether or to what extent these rights overlap with the primary right.

Lastly, **Hayden Station** is owned by PSCC, PacifiCorp and SRP and is located near Hayden, Colorado. It used approximately 4,300 acre-feet of water for cooling purposes in 2020. Consistent with the EIA’s data indicating that all of this was surface water from the Yampa River, there are three primary surface water rights associated with Hayden Station. Two of these are owned jointly by PacifiCorp, PSCC and Tri-State G&T, and one is owned wholly by PSCC. Together, these rights entitle their owners to about 91,000 acre-feet of water each year. Since the power plant uses only a small fraction of this, it is very likely that the rights are used at many different locations. There are several other smaller surface water rights owned by the companies that own Hayden Station, but it is not clear whether these rights are used at the power plant.

NEW MEXICO

New Mexico Water Law. Like Arizona and Colorado, New Mexico law treats surface water and groundwater as two distinct resources, but, unlike Arizona and Colorado, the legal rules governing the allocation of these resources in New Mexico are mostly the same. Surface water is allocated according to the law of prior appropriation and may be severed and sold separately from the land.[20] Groundwater, while once largely unregulated and governed by the “reasonableness” standard, is now subject to the same prior appropriation system as surface water. Comprehensive groundwater regulation in the state began in 1931, when the legislature declared all water to be a public resource subject to appropriation.[21] These statutory changes authorize the State Engineer to “declare” groundwater basins, triggering heightened groundwater regulation.[22] As of 2006, every basin in New Mexico has been “declared.”[23]

New appropriations of both surface water and groundwater require a permit from the state, as do transfers of water rights. Under New Mexico law, conserved water can be shielded from forfeiture and banked under certain conditions. This option is available only to approved acequias and ditch companies and would thus require communities to comply with regulatory prerequisites before relying on banking as an option.

The primary regulatory authorities in New Mexico with jurisdiction over water are the New Mexico Office of the State Engineer, which administers and records water rights in the state, the New Mexico Environmental Department and the New Mexico Public Regulation Commission.

New Mexico Coal Facilities. There are five New Mexico coal facilities within the Colorado River Basin. Four of them – all but the El Segundo Mine – are located in the San Juan River sub-basin, which is currently undergoing a general stream adjudication that could impact the ownership and amount of existing water rights, as well as the availability of new rights. El Segundo is within the Little Colorado Watershed, along with the Arizona coal facilities.

---

20 N.M. Const. art. II, § 2.

21 N.M. Rev. Stat. Ann. § 72-12-1.

22 N.M. Rev. Stat. Ann. § 72-12-25.

23 *Declared Groundwater Basins*, N.M. Office of the State Engineer, https://www.ose.state.nm.us/WR/groundWater.php (last visited July 15, 2022).

Four Corners Power Plant is owned by APS, Pinnacle West, SRP, TEP and the Public Service Company of New Mexico (PNM) and is located near Fruitland, on land leased from the Navajo Nation. According to EIA data, the power plant used about 17,000 acre-feet of water for power generation and cooling in 2020, all from the San Juan River.

San Juan Generating Station is owned primarily by PNM and TEP and is located near Waterflow. EIA data show that in 2020, the generating station used approximately 6,200 acre-feet of water from the San Juan River.

Navajo Mine is owned by Navajo Transitional Energy Co. and Navajo Coal Co. and is located near Fruitland. We were unable to find information about the Navajo Mine's annual water usage. However, this mine produces about the same amount of coal as the Skyline Mine in Utah, so we estimate that it uses around 50 acre-feet of water each year.

San Juan Mine is owned by BHP Billiton and located near Farmington. The water usage of this mine is unknown, but it is about half the size of Navajo Mine, so we estimate that it uses about 25 acre-feet each year.

There are several large water rights associated with the four facilities above, but because the facilities are located near each other and are owned by the same group of companies, it is difficult to know which water rights are used at a particular location. It is most likely that the rights are shared between all four facilities. The first large water right is owned by Navajo Coal Co. and entitles the company to 51,600 acre-feet of surface water each year. The second right, owned by PNM and TEP, entitles these companies to 20,200 acre-feet of surface water annually. The third right is a 370-acre-foot groundwater right also owned by PNM and TEP. There is also a major water agreement between BHP Billiton, APS, PNM and the Jicarilla Apache Tribe which is meant to ensure a diverse water supply but does not allow for additional consumptive use.

Lastly, **El Segundo Mine** is owned by Peabody Energy and is located near Grants. This mine produces a little more coal than Sufco Mine in Utah, so we estimate that it uses about 60 acre-feet of water each year. The mine gets its water from two groundwater rights owned by Peabody, supplying a total of 1,650 acre-feet per year.

UTAH

Utah Water Law. Unlike most other states in the Colorado River Basin, Utah law treats surface water and groundwater as the same resource—both are governed by prior appropriation and all the rights are recorded together.[24] This legal structure is known as "unified." This means that, in contrast to New Mexico, groundwater rights in Utah may be severed and sold separately from the land, as can surface water rights. All new appropriations of water, whether surface water or groundwater, require a permit from the Utah Division of Water Rights.[25] "Perfected" water rights (i.e., rights that are finalized, certificated, decreed or proven by certain types of claims) are transferrable by deed, while unperfected rights are transferrable only via application to the Division of Water Rights.[26]

The primary regulatory authorities in Utah are the Utah Division of Water Resources, the Utah Division of Water Rights, the Utah Public Service Commission and the Utah Department of Environmental Quality. Water rights are administered and recorded by the Division of Water Rights.

24 Utah. Const. art. XVII, § 1; *Wrathall v. Johnson*, 40 P.2d 755 (Utah 1935).

25 Utah Code Ann. § 73-2-1.

26 Utah Code Ann. §§ 73-1-10, 73-3-18.

Utah Coal Facilities. Utah has eleven coal facilities within the Colorado River Basin, and an additional facility near the Basin's boundary. Most river basins in the state are undergoing general water rights adjudications, except for the Weber River, Sevier River and Green River basins. In these latter basins, water rights are relatively settled, although some litigation is still ongoing. Most of the Utah coal facilities receive their water from rights owned by operators and other parties, including nearby municipalities. These water rights use a mix of groundwater and surface water sources.

Coal Hollow Mine is owned by Alton Coal Development and located near Alton. Its exact water usage is unknown, but we estimate that it uses about 50 acre-feet of water each year. All of this water comes from a single water right owned by the nearby town of Alton, which entitles the town to a total of 138.9 acre-feet of water each year. Exactly 50 acre-feet of this is reserved for Coal Hollow Mine and purchased by Alton Coal from the town.

Sufco Mine is owned by Wolverine Fuels LLC and located near Salina. It used about 53.5 acre-feet of water in 2021. The mine gets its water primarily from three water rights, all owned by Canyon Fuel Company LLC (Wolverine Fuels' predecessor in interest at the mine), with a total capacity of 2,250 acre-feet per year. Canyon Fuel and Wolverine Fuels own several other smaller water rights near the mine that entitle them to a total of 175 acre-feet per year.

Emery Mine is owned by Bronco Utah Operations LLC and located near Huntington. It used only about 3.26 acre-feet of water in 2021. Bronco Utah Operations owns the primary water right associated with the mine, with a total capacity of approximately 2,345 acre-feet per year. This right is likely also used at other places besides the mine. Bronco Utah Operations and the Town of Emery also own several other water rights in the area that might be used in part at Emery Mine. These rights have a total capacity of about 3,800 acre-feet per year for mining and industrial uses.

Lila Canyon Mine is owned by Murray Energy and located near Sunnyside. Its exact water usage is not known, but it is approximately half the size of Sufco Mine, so we estimate that it uses around 25 acre-feet of water each year. The source of this water is unclear, but Emery County Coal Resources owns several water rights in the area, amounting to 480 acre-feet per year, that may be used at the mine. One other water right, owned by the Emery Water Conservation District, with a capacity of 3,200 acre-feet per year, may also be used at the mine.

Dugout Canyon Mine is owned by Wolverine Fuels LLC and located near Price. It has been closed since 2019, but that year the mine used 93.80 acre-feet of water. This water came from one primary water right owned by Canyon Fuels, entitling Canyon Fuels to 245 acre-feet of water from an underground spring. Canyon Fuels owns one other water right in the area with a capacity of 181 acre-feet per year for industrial uses, though it is unclear whether this water right is used at Dugout Canyon Mine.

Castle Valley Mine is owned by Castle Valley Mining LLC and located near Huntington. Its annual water use is not known, but the mine is a quarter of the size of Emery Mine, which used less than 4 acre-feet of water in 2021. Castle Valley Mining shares one water right with the Huntington-Cleveland Irrigation Company, entitling Castle Valley to 16.67 acre-feet of water each year.

Skyline Mine, a coal mine, is owned by Wolverine Fuels LLC and located near Helper. Its water usage in 2021 was 46.37 acre-feet. The primary water right associated with the mine is owned by Canyon Fuel Company LLC, supplying 427 acre-feet of water each year. Canyon Fuel owns three other water rights in the area surrounding the mine with a total capacity of 266 acre-feet per year, but it is not clear whether these rights are used at Skyline Mine.

Hunter Power Plant is owned by Utah Associations Power Systems, Deseret Power Electric Co-op, Provo City and PacifiCorp and located near Castle Dale. The plant used about 16,400 acre-feet of water in 2021. It gets its water from three primary sources: (1) water rights owned by the Cottonwood Creek Irrigation Company, in which PacifiCorp is a shareholder, supplying 4,845 acre-feet each year; (2) water rights owned by the Ferron Canal & Reservoir Co., in which PacifiCorp is a shareholder, and a corresponding water lease between Ferron and PacifiCorp, together supplying 5,913 acre-feet per year; and (3) a water supply contract between PacifiCorp and the Emery Water Conservancy District, supplying 5,683 acre-feet per year. This tracks with the EIA's records, which report that Hunter Power Plant obtained all its cooling water from Cottonwood Creek in Utah.

Sunnyside Cogeneration Facility is owned by ACI Energy and Colmac Utah Inc. and located near Sunnyside, Utah. The facility used 954 acre-feet of water in 2021. East Carbon City has one water right for 723 acre-feet that cited Sunnyside as one of the various uses. The rest of the water came from water rights owned by Sunnyside Cogeneration Associates, which total about 14,100 acre-feet of groundwater and surface water, though these water rights also supplied other facilities.

Huntington Power Plant is owned by PacifiCorp and located near Huntington, Utah. It used about 12,000 acre-feet of water in 2021. This water came primarily from several water rights owned by the Huntington-Cleveland Irrigation Co., in which PacifiCorp is a shareholder, and two rights owned directly by PacifiCorp. Together, these rights have a capacity of nearly 400,000 acre-feet per year, so they are very likely used in other places besides Huntington Power Plant. According to the EIA, Huntington Power Plant gets its cooling water entirely from Huntington Creek, but our research indicates that the sources are more varied.

Bonanza Plant is owned by Utah Municipal Power Agency and Deseret Generation & Transmission Co. ("Deseret G&T") and is located near Vernal. The plant used 5,442 acre-feet of water in 2021. As the EIA correctly reports, Bonanza Plant gets all this water from the Green River, under a water right jointly owned by Deseret G&T and the Utah Municipal Power Agency with a capacity of 10,859.5 acre-feet per year. Deseret G&T also owns another water right in the area entitling it to an additional 10,859.5 acre-feet of water per year, but it is not clear whether this right is used at Bonanza Plant. Because the plant's main water rights are on the Green River, they are relatively more secure compared to rights in other basins still undergoing general adjudications.

Finally, **Intermountain Power Plant** is owned by Intermountain Power Agency and is located near Delta. It used about 7,233 acre-feet of water in 2020. The mine gets its water rights from over a dozen water rights, all owned in whole or in part by Intermountain Power Agency, with a total capacity of 15,300 acre-feet per year. Intermountain Power Plant is not within the Colorado River Basin, but it is near the Basin's boundary, such that its water use could impact Basin water resources.

WYOMING

Wyoming Water Law. Wyoming law treats surface water and groundwater as two distinct resources. Surface water is allocated according to a relatively simple version of prior appropriation. Wyoming's constitution simply states: "Priority of appropriation for beneficial uses shall give the better right [to appropriable water]."[27] Like Colorado, Wyoming designates certain priorities of use, favoring domestic and municipal uses over agricultural and industrial uses.[28] Since statehood, the only way to obtain a surface water right in Wyoming is to apply for a permit from the State Engineer.[29] The state must also approve any changes or transfers of surface water rights.[30] Surface rights are severable from land and can be freely bought or sold, subject to the state's approval.

27 Wyo. Const. art. 8, § 3.

28 Wyo. Stat. § 41-3-102.

29 Wyo. Const. art. 8, § 5.

30 Wyo. Stat. § 4-3-104.

Groundwater rights, on the other hand, are tied to land ownership and generally divided according to the "reasonableness" standard.[31] All wells constructed after 1947 must have a permit from the State Engineer.[32] The State Engineer usually grants permit applications, unless the well is within a designated groundwater control area, where groundwater resources are particularly strained or conflicts between users are ongoing or likely to occur.[33]

The primary water regulatory authorities in Wyoming are the State Engineer's Office, which administers and records all water rights in the state, the Wyoming Public Service Commission and the Wyoming Department of Environmental Quality.

Wyoming Coal Facilities. Wyoming has eight coal facilities in the Colorado River Basin. All the facilities are located in the Green River sub-basin, which Wyoming shares with Utah and Colorado. For the most part, rights in the Green River basin have been fully adjudicated, although some litigation is still ongoing. On balance, the water rights within the Green River sub-basin are relatively more certain than other rights elsewhere in the Colorado River Basin.

Most of the water rights used by the Wyoming coal plants and mines are owned by the same companies that own and operate the facilities themselves. The Wyoming coal facilities generally utilize a mix of surface water and groundwater. For the facilities that rely mostly on groundwater (e.g., the Black Butte Leucite Hills Mine), there could be a similar subflow delineation problem as described for the Arizona coal facilities. However, water demand in Wyoming is currently lower than in other states, and its water resources are comparatively less strained. As a result, it is unlikely that, in the near future, groundwater rights associated with the coal facilities will be invalidated under the priority system for pumping subflow.

Naughton Power Plant is owned by PacifiCorp and located near Kemmerer. It used approximately 7,500 acre-feet of water in 2020, supplied entirely by surface water rights owned directly by PacifiCorp with a total capacity of 14,480 acre-feet per year. This tracks with the EIA's data, which indicates that all of Naughton Power Plant's cooling water was surface water from the Ham's Fork River.

General Chemical Green River Power Plant is owned by General Chemical and Tata Chemicals North America and is located near Green River. The power plant supplies electricity to an adjoining soda ash refining facility. Its water usage is not entirely clear, but we estimate that, judging by how much water larger power plants throughout the Colorado River Basin use, it utilizes less than 500 acre-feet per year (not including water used for other purposes at the refining facility). The plant gets its water exclusively from surface water rights owned by Tata Chemicals, totaling approximately 8,400 acre-feet of water each year.

Genesis Alkali Plant is owned by Genesis Alkali LLC and located near Green River. Like the General Chemical plant, Genesis Alkali Plant supplies electricity to an adjoining soda ash refining facility. Because it has a generating capacity similar to the General Chemical plant, we estimate that the Genesis Alkali Plant uses less than 500 acre-feet of water each year (not including water used for other purposes at the refining facility). The plant gets its water from surface water and groundwater rights owned by Genesis Alkali LLC amounting to 28,200 acre-feet per year.

31 Wyo. Stat. §§ 41-3-930, 41-3-930.

32 Wyo. Stat. § 41-3-905.

33 Wyo. Stat. §§ 41-3-930, 41-3-910, 41-3-912.

Kemmerer Mine is owned by Westmoreland Coal Co. and located near Kemmerer, Wyoming. The mine's exact water usage is unknown, but it produces approximately the same amount of coal as Skyline Mine in Utah, so we estimate that it uses less than 50 acre-feet of water each year. The mine gets all of its water from surface water and groundwater rights owned by Kemmerer Operations, totaling 3,185 acre-feet per year.

Black Butte Leucite Hills Mine is owned by Black Butte Coal Co. and located near Point of Rocks. Like the other mines in Wyoming, its exact water usage is not certain. However, it is about the same size as Kemmerer Mine, so we estimate that it uses less than 50 acre-feet of water each year. The mine appears to get its water exclusively from groundwater rights owned by Black Butte Coal Co. These rights entitle Black Butte Coal to 4,420 acre-feet of water each year.

Finally, **Jim Bridger Steam Plant** is owned by PacifiCorp and Idaho Power Corp. and **Jim Bridger Mine** and **Bridger Underground Coal Mine** are owned by Bridger Coal Co. All three facilities are located near Point of Rocks, within a few miles of each other. Together, the three facilities used about 22,000 acre-feet of water in 2020. The power plant used 21,800 acre-feet, while the mines used an estimated 200 acre-feet. We are reporting these three facilities together because they use water rights owned by the same company (i.e., PacifiCorp), making it difficult to parse out which specific rights are used at which facility. In total, PacifiCorp owns a mix of surface water and groundwater rights associated with the Bridger facilities entitling it to about 130,000 acre-feet each year. This accords with the EIA's records, which indicate that Jim Bridger Steam Plant gets all its water from the Green River, which has been largely adjudicated.

Appendix A: Water Rights and Usage of Coal Facilities in the Colorado River Basin

The following abbreviations are used throughout this table: SW (surface water), GW (groundwater), AF/YR (acre-feet per year), PC (parent company), MW (megawatts), and est. (estimated). Additional abbreviations are defined as they are used.

The state regulatory bodies listed in this table generally oversee and regulate various water resources and/or electric utilities. Each body does not necessarily have authority over each company listed as a facility owner or an owner of coal water rights. For instance, Salt River Project is not subject to the authority of the Arizona Corporation Commission ("ACC"). However, the ACC generally regulates most electric utilities in Arizona and, therefore, may play an important role in the transition away from coal power.

Colorado River Basin Coal Facilities: Water Rights and Usage

Facility	State	City	Production	Closure Date	Facility Owners	Regulators	Water Use	Water Rights Amount, Type	Water Rights Owners
Coronado Generating Station	AZ	St. Johns	762 MW	Units 1 and 2: 2032	Salt River Project (SRP) (100%)	Arizona Department of Environmental Quality Arizona Corporation Commission Arizona Department of Water Resources	5,200 AF/YR	44,000 AF/YR, GW only	SRP
Springerville Generating Station	AZ	Springerville	1,625 MW	Unit 1: 2027 Unit 2: 2032 Units 3 and 4: TBD	Tucson Electric (TEP) (50%, PC: UNS Energy) Tri-State (25%) SRP (25%)		10,400 AF/YR	77,000 AF/YR, GW only	SRP, TEP, Tri-State G&T
Cholla Power Plant	AZ	Joseph City	767 MW	Units 1 and 2: 2025 Unit 3: 2020	Arizona Public Service Company (APS) (100%, PC: Pinnacle West)		9,200 AF/YR	9,550 AF/YR, GW only	APS
Kayenta Mine	AZ	Kayenta	6.5 million short tons	Unknown	Peabody Energy (100%)		Unknown (est. less than 100 AF/YR)	11,200 AF/YR, GW only	Peabody

Colorado River Basin Coal Facilities: Water Rights and Usage

Facility	State	City	Production	Closure Date	Facility Owners	Regulators	Water Use	Water Rights Amount, Type	Water Rights Owners
West Elk Mine	CO	Paonia	4.7 million short tons	Unknown	Mountain Coal Company (100%, PC: Arch Resources)	Colorado Department of Natural Resources, Division of Water Resources Colorado Public Utilities Commission Colorado Department of Public Health and Environment	Unknown (est. 50 AF/YR)	13,000 AF/YR, SW & GW	Mountain Coal Company
Deserado Mine	CO	Rangely	2.07 million short tons	Unknown	Blue Mountain Energy (100%, PC: Deseret G&T)		Unknown (est. 25 AF/YR)	Approx. 133,300 AF/YR, SW & GW	Blue Mountain Energy, Deseret G&T
Colowyo Mine	CO	Axial	1.47 million short tons	2030	Colowyo Coal (100%, PC: Tri-State G&T)		Unknown (est. 25 AF/YR)	Approx. 320,500 AF/YR, SW & GW	Colowyo Coal
Foidel Creek Mine	CO	Milner	3.05 million short tons	Unknown	TwentyMile Coal (100%, PC: Peabody Energy)		Unknown (est. 30 AF/YR)	Approx. 300,250 AF/YR, SW & GW	TwentyMile Coal, Peabody Energy
Trapper Mine	CO	Craig	2.14 million short tons	2026-30	Trapper Mining (100%)		Unknown (est. 25 AF/YR)	19,500 AF/YR, SW & GW	Trapper Mining
King II Mine	CO	Hesperus	0.62 million short tons	2043	GCC Energy (100%)		Unknown (est. 10 AF/YR)	7,648 AF/YR, SW & GW	GCC Energy, Hay Gulch Ditch Inc.
Craig Generating Station	CO	Craig	1,285 MW	Unit 1: 2025 Units 2 and 3: 2028	Tri-State G&T (100% of Unit 3, 24% of Units 1 and 2) PacifiCorp (19% of Units 1 and 2, PC: MidAmerican Energy (PC: Berkshire Hathaway)) Platte River Power Authority (18% of Units 1 and 2) SRP (29% of Units 1 and 2) Public Service Company of Colorado (PSCC) (10% of Units 1 and 2, PC: Xcel Energy)		13,300 AF/YR	Approx. 43,440 AF/YR, SW & GW	Tri-State G&T, PacifiCorp, PSCC, Platte River Power Authority
Hayden Station	CO	Hayden	465 MW	Unit 1: 2027 Unit 2: 2028	PSCC (75.5% of Unit 1, 37.4% of Unit 2, PC: Xcel Energy) PacifiCorp (24.5% of Unit 1, 12.6% of Unit 2, PC: MidAmerican Energy (PC: Berkshire Hathaway)) SRP (50% of Unit 2)		4,300 AF/YR	Approx. 91,000 AF/YR, SW only	PacifiCorp, PSCC, Tri-State G&T, TwentyMile Coal, SRP, Platte River Power Authority

Colorado River Basin Coal Facilities: Water Rights and Usage

Facility	State	City	Production	Closure Date	Facility Owners	Regulators	Water Use	Water Rights Amount, Type	Water Rights Owners
Four Corners Power Plant	NM	Fruitland	1,636.2 MW	Units 1–3: 2013 Units 4 and 5: 2031	APS (63%, PC: Pinnacle West) Pinnacle West (7%) SRP (10%) TEP (7%, PC: UNS Energy) Public Service Company of New Mexico (PNM) (13%)	New Mexico Office of the State Engineer New Mexico Environment Department New Mexico Public Regulation Commission	17,000 AF/YR	72,170 AF/YR, SW & GW	Navajo Coal, PNM, TEP, APS
San Juan Generating Station	NM	Waterflow	924 MW	Units 2 and 3: 2017 Units 1 and 4: 2022	PNM (50% of Unit 1, 77.3% of Unit 4) TEP (50% of Unit 1) Various others (22% of Unit 4)		6,200 AF/YR		
Navajo Mine	NM	Fruitland	3.4 million short tons	Unknown	Navajo Transitional Energy Co. Navajo Coal (PC: New Mexico Coal (PC: BHP Billiton))		Unknown (est. 50 AF/YR)		
San Juan Mine	NM	Farmington	1.85 million short tons	Unknown	San Juan Coal Co. (100% PC: New Mexico Coal (PC: BHP))		Unknown (est. 25 AF/YR)		
El Segundo Mine	NM	Grants	5.55 million short tons	Unknown	Peabody Natural Resources (100%, PC: Peabody Energy)		Unknown (est. 60 AF/YR)	1,650 AF/YR, GW only	Peabody Energy
Coal Hollow Mine	UT	Alton	0.5 million short tons	Unknown	Alton Coal (100%)	Utah Division of Water Resources Utah Division of Water Rights Utah Public Service Commission Utah Department of Environmental Quality	Approx. 50 AF/YR	50 AF/YR, N/A	Alton UT
Sufco Mine	UT	Salina	4.9 million short tons	Unknown	Wolverine Fuels (100%)		Approx. 53 AF/YR	2,425 AF/YR, n/a	Canyon Fuels, Wolverine Fuels
Emery Mine	UT	Huntington	0.44 million short tons	Unknown	Bronco Utah Operations (100%)		Approx. 3 AF/YR	6,145 AF/YR, n/a	Bronco Utah Operations, Emery UT
Lila Canyon Mine	UT	Sunnyside	2.63 million short tons	Unknown	Emery County Coal (100%, PC: Utah American Energy (PC: Murray Energy))		Unknown (est. 25 AF/YR)	Approx. 3,680 AF/YR, n/a	Emery County Coal, Emery Water Conser-vancy District
Dugout Canyon Mine	UT	Price	0.55 million short tons	2019	Canyon Fuels (100%, PC: Wolverine Fuels)		Approx. 94 AF/YR	426 AF/YR, n/a	Canyon Fuels

Colorado River Basin Coal Facilities: Water Rights and Usage

Facility	State	City	Production	Closure Date	Facility Owners	Regulators	Water Use	Water Rights Amount, Type	Water Rights Owners
Castle Valley Mine	UT	Huntington	0.1 million short tons	Unknown	Castle Valley Mining (100%)	Utah Division of Water Resources Utah Division of Water Rights Utah Public Service Commission Utah Department of Environmental Quality	Unknown (est. 5 AF/YR)	16.67 AF/YR, n/a	Castle Valley Mining, Huntington-Cleveland Irrigation Company
Skyline Mine	UT	Helper	3.6 million short tons	Unknown	Canyon Fuels (100%, PC: Wolverine Fuels)		Approx. 46 AF/YR	693 AF/YR, n/a	Canyon Fuels, Price River Water Users Association
Hunter Power Plant	UT	Castle Dale	1,361 MW	2042	Utah Associated Municipal Power Systems (14.58% of Unit 2) Deseret G&T (25.11% of Unit 2) Provo City (6.25% of Unit 1) PacifiCorp (93.7% of Unit 1, 60.31% of Unit 2, 100% of Unit 3, PC: MidAmerican Energy (PC: Berkshire Hathaway))		15,100 AF/YR	16,441 AF/YR, n/a	Cottonwood Creek Consolidated Irrigation Company, Ferron Canal & Reservoir Company, PacifiCorp, Emery Water Conservancy District
Sunnyside Cogeneration Facility	UT	Sunnyside	51 MW	Unknown	Sunnyside Cogeneration Associates (100%, PC: ACI Energy and Colmac Utah Inc.)		Approx. 954 AF/YR	14,823 AF/YR, n/a	Sunnyside Cogeneration Associates
Huntington Power Plant	UT	Huntington	909 MW	2036	PacifiCorp (100%, PC: MidAmerican Energy (PC: Berkshire Hathaway))		7,000 AF/YR	Approx. 400,000 AF/YR, n/a	PacifiCorp, Huntington-Cleveland Irrigation Company
Bonanza Plant	UT	Vernal	458 MW	Unknown	Utah Municipal Power Agency (3.75%) Deseret G&T (96.25%)		4,000 AF/YR	21,720 AF/YR, n/a	Deseret G&T, Utah Municipal Power Agency
Intermountain Power Plant	UT	Delta	1,900 MW	2025	Intermountain Power Agency		7,200 AF/YR	Approx. 15,300 AF/YR, n/a	Intermountain Power Agency, City of Delta

Colorado River Basin Coal Facilities: Water Rights and Usage

Facility	State	City	Production	Closure Date	Facility Owners	Regulators	Water Use	Water Rights Amount, Type	Water Rights Owners
Jim Bridger Mine	WY	Point of Rocks	1.99 million short tons	Unknown	Bridger Coal Co. (100%, PC: MidAmerican Energy (PC: Berkshire Hathaway))	Wyoming State Engineer's Office Wyoming Public Service Commission Wyoming Department of Environmental Quality	Unknown (est. 100 AF/YR)	Approx. 130,000 AF/YR, SW & GW	PacifiCorp
Bridger Underground Coal Mine	WY	Point of Rocks	2.21 million short tons	2021	Bridger Coal Co. (100%, PC: MidAmerican Energy (PC: Berkshire Hathaway))		Unknown (est. 100 AF/YR)		
Jim Bridger Steam Plant	WY	Point of Rocks	2,119 MW	Unit 1: 2023 Unit 2: 2028 Units 3 and 4: 2037	PacifiCorp (67%, PC: MidAmerican Energy (PC: Berkshire Hathaway)), Idaho Power Corp. (33%)		21,800 AF/YR		
Black Butte and Leucite Hills Mine	WY	Point of Rocks	2.5 million short tons	Unknown	Black Butte Coal Co. (100%)		Unknown (est. 50 AF/YR)	4,420 AF/YR, GW only	Black Butte Coal Co.
Kemmerer Mine	WY	Kemmerer	4.02 million short tons	Unknown	Westmoreland Coal Co. (100%)		Unknown (est. 50 AF/YR)	3,185 AF/YR, SW & GW	Kemmerer Operations
Naughton Power Plant	WY	Kemmerer	832 MW	Unit 3: 2019 Units 1 and 2: 2025	PacifiCorp (100%, PC: MidAmerican Energy (PC: Berkshire Hathaway))		7,500 AF/YR	14,480 AF/YR, SW only	PacifiCorp
Genesis Alkali Plant	WY	Green River	41 MW	Unknown	Genesis Alkali LLC (100%, PC: Genesis Energy LP)		Unknown (est. 500 AF/YR)	Approx. 28,200 AF/YR, SW & GW	Genesis Alkali
General Chemical Green River Power Plant	WY	Green River	30 MW	Unknown	General Chemical (100%)		Unknown (est. 500 AF/YR)	8,400 AF/YR, SW only	Tata Chemicals

Appendix B: State Water Law Summaries for Laypersons

Arizona: Kathleen Ferris et al., Ariz. Town Hall, *Keeping Arizona's Water Glass Full* 30-52 (Nov. 2015), https://aztownhall.org/resources/Documents/107%20Background%20Report%20web.pdf.

Colorado: Gregory J. Hobbs, Jr., Water Education Colorado, *Citizen's Guide to Colorado Water Law* (2021), https://issuu.com/cfwe/docs/weco_cgwlaw_5thed_final.

New Mexico: Adrian Oglesby, ed., Univ. of New Mexico School of Law, *Water Matters*, ch.1 (Basic Water Law Concepts) (2015), https://uttoncenter.unm.edu/resources/research-resources/basic-water-law-concepts.pdf.

Utah: J. Craig Smith & Jeffry R. Gittins, Smith Hartvigsen PLLC, *Water Law for the Layman*, https://smithhartvigsen.com/water-law-for-the-layman/ (last visited July 15, 2022).

Wyoming: Pat Tyrrell, States West Water Resources Corp., *Bear River Basin Planning: Wyoming Water Law Summary* (2001), https://waterplan.state.wy.us/plan/bear/2001/techmemos/waterlaw.pdf.

Appendix C: Scholarly Articles on Climate Change Impacts on Surface Water Flows in the Colorado River Basin

Katrina E. Bennett et al., *Characterizing Drought Behavior in the Colorado River Basin Using Unsupervised Machine Learning*, Earth & Space Sci. (2022).

Katrina E. Bennett et al., *Climate-Driven Disturbances in the San Juan River Sub-Basin of the Colorado River*, 22 Hydrology & Earth Sys. Scis. 709 (2018).

P.C.D. Milly & K.A. Dunne, *Colorado River Flow Dwindles as Warming-Driven Loss of Reflective Snow Energizes Evaporation*, 367 Science 1252 (2020).

Homa Salehabadi et al., *White Paper No. 4: The Future Hydrology of the Colorado River Basin*, Ctr. for Colorado River Studies, Quinney College of Nat. Res., Utah State University (Aug. 31, 2020).

Connie A. Woodhouse & Brad Udall, *Upper Gila, Salt, and Verde Rivers: Arid Land Rivers in a Changing Climate*, 26 Earth Interactions 1 (2022).

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL061055

Key Points:
- Groundwater depletion in the Colorado River Basin is greater than we thought
- As GW disappears, the basin will struggle to supply water to the seven basin states
- It is time to bring groundwater under the water management umbrella

Supporting Information:
- Readme
- Figure S1
- Figure S2
- Figure S3
- Figure S4

Correspondence to:
J. S. Famiglietti,
jfamigli@uci.edu

Citation:
Castle, S. L., B. F. Thomas, J. T. Reager, M. Rodell, S. C. Swenson, and J. S. Famiglietti (2014), Groundwater depletion during drought threatens future water security of the Colorado River Basin, *Geophys. Res. Lett.*, *41*, 5904–5911, doi:10.1002/2014GL061055.

Received 1 JUL 2014
Accepted 21 JUL 2014
Accepted article online 24 JUL 2014
Published online 29 AUG 2014

Groundwater depletion during drought threatens future water security of the Colorado River Basin

Stephanie L. Castle[1,2], Brian F. Thomas[1,2,3], John T. Reager[1,2,3], Matthew Rodell[4], Sean C. Swenson[5], and James S. Famiglietti[1,2,3]

[1]UC Center for Hydrologic Modeling, University of California, Irvine, California, USA, [2]Department of Earth System Science, University of California, Irvine, California, USA, [3]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [4]Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [5]Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado, USA

Abstract Streamflow of the Colorado River Basin is the most overallocated in the world. Recent assessment indicates that demand for this renewable resource will soon outstrip supply, suggesting that limited groundwater reserves will play an increasingly important role in meeting future water needs. Here we analyze 9 years (December 2004 to November 2013) of observations from the NASA Gravity Recovery and Climate Experiment mission and find that during this period of sustained drought, groundwater accounted for 50.1 km^3 of the total 64.8 km^3 of freshwater loss. The rapid rate of depletion of groundwater storage ($-5.6 \pm 0.4\ km^3\ yr^{-1}$) far exceeded the rate of depletion of Lake Powell and Lake Mead. Results indicate that groundwater may comprise a far greater fraction of Basin water use than previously recognized, in particular during drought, and that its disappearance may threaten the long-term ability to meet future allocations to the seven Basin states.

1. Introduction

Over a decade, drought in the Colorado River Basin (Basin; Figure 1) has exposed the vulnerability [*Bureau of Reclamation*, 1975; *Barnett and Pierce*, 2008] of the most overallocated river system in the world [*Christensen et al.*, 2004]. Recently, the U.S. Bureau of Reclamation acknowledged the potential challenges [*Bureau of Reclamation*, 2012] to meeting future surface water allocations to the seven Basin states (Figure 1), noting that the contribution of local supplies, including groundwater withdrawals, will be required to offset anticipated shortages. While the need to exploit groundwater resources to meet Basin water demands has long been recognized [*Bureau of Reclamation*, 1975], withdrawals required to meet current demands remain undocumented and are uncertain in the future. In particular, water management under drought conditions focuses on surface water resources [*Basin Interim Guidelines*, 2007] without a regulatory framework to manage groundwater withdrawals outside of "river aquifer" systems [*Leake et al.*, 2013]. At question is the potential impact of solely managing surface water allocations and diversions in the Basin, without regard to groundwater loss, on meeting future water demands.

The ability to observe changes in water resources at large scales has been greatly facilitated by the deployment of recent Earth-observing satellites. One such satellite mission, the NASA Gravity Recovery and Climate Experiment (GRACE) [*Tapley et al.*, 2004], has measured the temporal variations in the Earth's gravity field since March 2002. These observations are now routinely applied to estimate the monthly changes in terrestrial or total land water storage (i.e., all of the snow, surface water, soil moisture, and groundwater) in regional areas that are 200,000 km^2 or larger [*Wahr et al.*, 2004] (Figure 2). Several studies have now demonstrated that GRACE observations, when combined with coincident data sets for snow water equivalent (SWE), surface water storage, and soil water content in a mass balance, can quantify changes in groundwater storage with sufficient accuracy [e.g., *Rodell et al.*, 2009; *Famiglietti et al.*, 2011] to influence regional water management decisions [*Famiglietti and Rodell*, 2013].

Our goal in this report is to identify changes in freshwater storage, including surface reservoir and groundwater storage, to assess the influence of conjunctive surface water and groundwater use on water availability in the Colorado River Basin during the recent drought. We evaluate the terrestrial water storage anomalies (TWSA) using GRACE observations during a 9 year period (December 2004 to November 2013) that begins 4 years into a prolonged drought in the southwestern United States, after water levels in Lake Powell

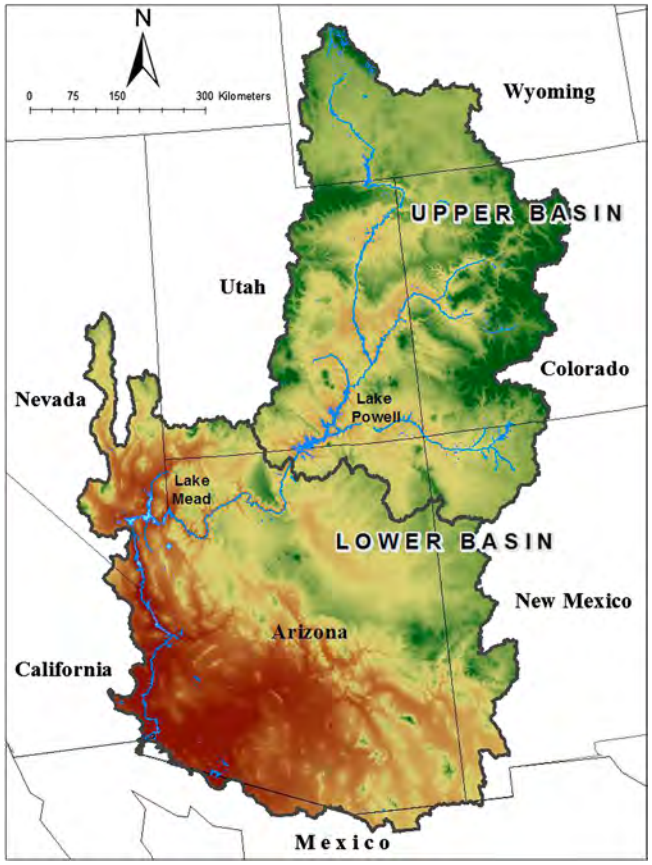


Figure 1. The Colorado River Basin of the western United States. The state and international boundaries are in light gray. The green and brown colors represent the high and low elevations, respectively [*McKay et al.*, 2012]. The upper Basin is that portion of the Basin upstream of Lake Powell. The lower Basin is the remainder of the basin downstream of Lake Powell. The basin outlines are in dark gray. The river, its main tributaries, and Lake Powell and Lake Mead are shown in blue.

and Lake Mead had declined precipitously [*Piechota et al.*, 2004] (see Methods section). In particular, we estimate the changes in groundwater storage during the 9 year drought period, when reservoir volumes were intensively managed to maintain hydropower production and to meet surface water allocations to the Basin states.

2. Methods

We used the Release 05 of the University of Texas Center for Space Research GRACE data [*Tapley et al.*, 2007] (ftp://podaac.jpl.nasa.gov/allData/grace/L2/CSR/RL05/). Average water storage changes for the Colorado River Basin were computed as anomalies of terrestrial water storage in equivalent water height (in millimeters, converted to cubic kilometers here using the area of the study basins) following *Swenson and Wahr* [2009] (Figure 2). Processing methods include filtering GRACE data to reduce noise [*Swenson and Wahr*, 2006] and later restoring the associated lost signal over a specific region by scaling the data correctively [*Velicogna and Wahr*, 2006]. This processing results in estimates of satellite measurement error and leakage error from out-of-basin signal, both of which are included in a Basin-specific time-invariant error estimate [*Wahr et al.*, 2006]. Figure 2 shows the Basin time series of terrestrial water storage changes from January 2003 to November 2013, nearly the complete available GRACE data record.

Because our focus here is on quantifying groundwater storage changes versus surface water storage changes during drought, we restrict our analyses to the 9 year period from December 2004 to November 2013. Prior to December 2004, the Basin had experienced four additional years of drought, effectively limiting surplus inflows that replenish Lake Powell and Lake Mead. This caused steep declines in reservoir storage prior to December 2004. Late 2004 also marked the beginning of a clear drought signal in the GRACE data, relative to its launch date in March 2002 (Figure 2).

To assess the accuracy of the GRACE data used here, we performed independent water budget analyses using regional precipitation (P) data from the PRISM system [*Daly et al.*, 2008] (http://prism.oregonstate.edu/recent/), satellite-based evapotranspiration (ET) from Moderate Resolution Imaging Spectroradiometer (MODIS) [*Tang et al.*, 2009], and the U.S. Bureau of Reclamation dam releases (Q) (usbr.gov; accessed December 2013) on the Colorado River. Uncertainty in the water balance estimate [*Rodell et al.*, 2004a, 2004b] was calculated assuming relative errors of 15% for P [*Jeton et al.*, 2005] and 5% in Q [*Rodell et al.*, 2004b]. A 15% bias on the daily ET was determined by *Tang et al.* [2009]; we assume the relative error increases to 25% on a monthly time scale. We computed the monthly storage changes, dS/dt, as $P - ET - Q$, and compared them to dS/dt derived from the GRACE terrestrial water storage anomalies using a discrete backward difference. Results illustrate a good agreement between dS/dt derived from the water budget and that

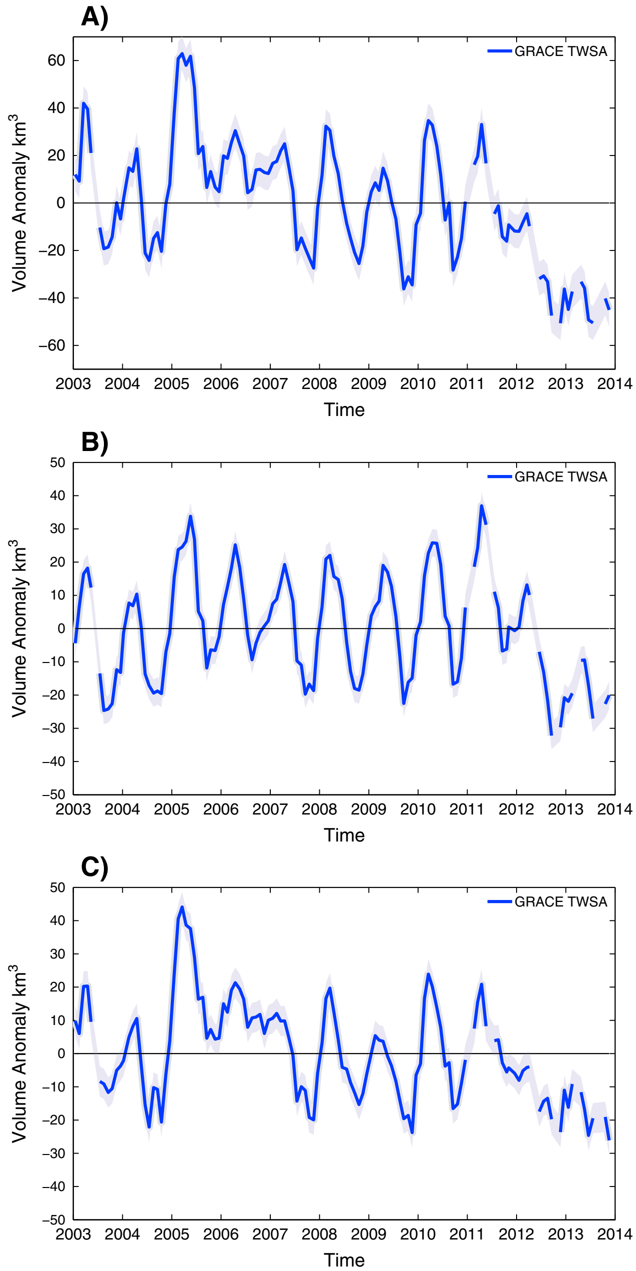


Figure 2. Monthly anomalies (deviations from the mean of the study period) of the total water storage (TWSA) for (a) the entire Basin, (b) the upper Basin, and (c) the lower Basin, from January 2003 to November 2013 (i.e., the full GRACE RL05 record available at writing). The three TWSA estimates were calculated independently using basin-specific scaling. The anomaly errors are shown in light blue shading. There are inconsecutive gaps in the GRACE data record, increasing in number toward the end of the time period due to recent declines in satellite power supply. Subsequent analyses focus on the period of prolonged drought extending from December 2004 to November 2013.

observed by the GRACE, for the entire Basin, and the upper and lower Basins (Figure S1 in the supporting information). Our comparisons were limited to March 2005 to March 2010 owing to the availability of *ET* estimates. Numerous additional studies have shown strong correspondence between GRACE water storage changes, hydrologic fluxes, and observations [see, e.g., *Swenson et al.*, 2006; *Famiglietti et al.*, 2011].

Accessible water storage changes (the combination of surface reservoir and groundwater storage changes) in the Basin are quantified using a water mass balance approach. Studies [e.g., *Rodell and Famiglietti*, 2002; *Rodell et al.*, 2009; *Famiglietti et al.*, 2011; *Scanlon et al.*, 2012] have shown that GRACE-observed water storage changes, in combination with additional data sets, can be used to isolate individual components of the terrestrial water balance. We assume that the total water storage in a region is composed of soil moisture (SM), snow water equivalent (SWE), surface water (SW), and groundwater (GW):

$$\mathrm{TWS}_t = \mathrm{SM}_t + \mathrm{SWE}_t + \mathrm{SW}_t + \mathrm{GW}_t, \quad (1)$$

where the subscript t indicates a function of time, and changes in these components balance in their sum. We apply GRACE observations of variations from the long-term mean of this total with estimates of soil moisture and SWE to quantify changes in accessible water. We simplify equation (1) by defining accessible water as the sum of groundwater and surface water storage:

$$\Delta\mathrm{AW}_t = \mathrm{TWSA}_t - \Delta\mathrm{SWE}_t - \Delta\mathrm{SM}_t, \quad (2)$$

where Δ indicates a variation from the time mean in an individual variable, and TWSA is the terrestrial water storage anomaly.

Soil moisture anomalies in equation (2) were estimated from the NASA Global Land Data Assimilation System (GLDAS) [*Rodell et al.*, 2004a] (http://disc.sci.gsfc.nasa.gov/) due to the lack of observational soil moisture data on large scales and for consistency with the previous studies [*Rodell et al.*, 2009; *Famiglietti et al.*, 2011]. We average the results of three land surface models from GLDAS (Variable Infiltration Capacity [*Liang et al.*, 1994], Noah [*Chen et al.*, 1996], and Community Land Model 2 [*Dai et al.*, 2003]) and apply the mean monthly standard deviation as an error estimate based on model structural biases (Figure S2 in the supporting information).

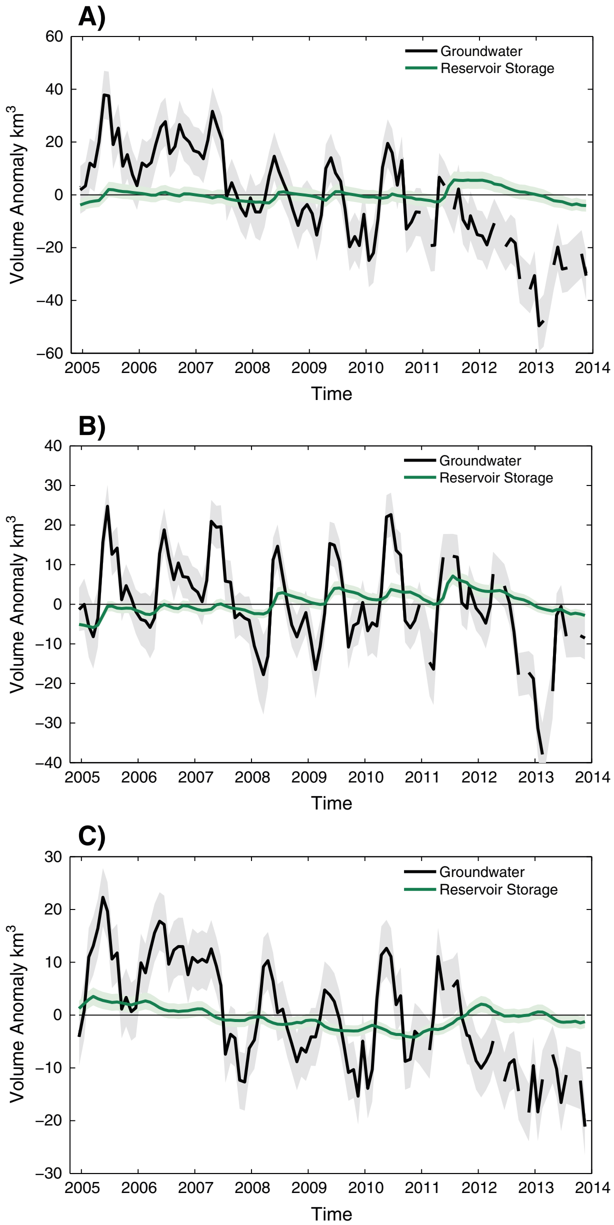


Figure 3. Monthly anomalies (km^3) of groundwater storage (black) and of surface reservoir storage (green) for (a) the entire Basin (trend: $-5.6 \pm 0.4\ km^3\ yr^{-1}$) and Lake Powell and Lake Mead combined (trend: $-0.9 \pm 0.6\ km^3\ yr^{-1}$), (b) the upper Basin (trend: $-1.7 \pm 0.4\ km^3\ yr^{-1}$) and Lake Powell (trend: $-0.6 \pm 0.6\ km^3\ yr^{-1}$), and (c) the lower Basin (trend: $-2.6 \pm 0.3\ km^3\ yr^{-1}$) and Lake Mead (trend: $-0.1 \pm 0.6\ km^3\ yr^{-1}$), from December 2004 to November 2013. The anomaly errors are shown in light gray shading for groundwater storage and in light green shading for reservoir storage. All trends are summarized in Table 1.

Data obtained from the Snow Data Assimilation System (SNODAS) [*National Operational Hydrologic Remote Sensing Center*, 2004] (http://nsidc.org/data/polaris/) were used for SWE in equation (2) (Figure S2 in the supporting information). SNODAS is the only gridded observation-based SWE product that assimilates ground, airborne, and satellite snow observations into its model structure and consequently has been used to represent SWE in other regional hydrologic studies [*Famiglietti et al.*, 2011; *Barlage et al.*, 2010]. Previous studies documented error of approximately 11% between SNODAS and snowpit observations in the Rocky Mountains [*Rutter et al.*, 2008] and 15% error for basin-wide analysis [*Famiglietti et al.*, 2011]. For this study, we assume 20% error due to the topographic and terrain heterogeneity throughout the Basin [*U.S. Geological Survey*, 2004].

We further separated the components of accessible water (Figure S3 in the supporting information) into surface water reservoir storage and groundwater storage (Figure 3). Reported reservoir storage time series from Lake Powell and Lake Mead were obtained from the U.S. Bureau of Reclamation [usbr.gov; accessed December 2013]. We assume that Lake Powell and Lake Mead account for the majority of the observed surface water change as they comprise approximately 4 times the annual flow of the river and make up 85% of surface water in the Basin [*Rajagopalan et al.*, 2009]. The U.S. Geological Survey (USGS) errors for hydrologic measurements ranging from "excellent (5%)" to "fair (15%)" [*Sauer and Meyer*, 1992] were used to provide error estimates for surface water reservoir storage. A two sample *t* test could not reject the null hypothesis that sample means were different using the USGS ranges in error, and throughout the rest of the analysis, we used a 10% error estimate for the surface water reservoir storage time series.

We rearranged equation (1) to isolate the contribution of groundwater storage changes (Figure 3) to changes in the total water storage (Figure 2). We used the reservoir storage changes in Lake Mead and Lake Powell with soil moisture and snow water equivalent data as described above:

$$\Delta GW_t = TWSA_t - \Delta SWE_t - \Delta SM_t - \Delta SW_t, \tag{3}$$

where ΔSW_t indicates the surface water anomaly from the reservoirs (Lake Powell and Lake Mead combined for the entire Basin: Lake Powell for the upper Basin and Lake Mead for the lower Basin). Equation (3) was

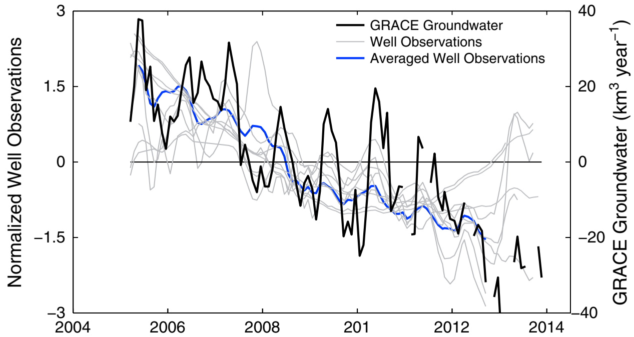


Figure 4. Entire Basin comparison between the GRACE groundwater storage anomalies (black line) in km^3 and the monthly USGS well observations. Because specific yield information is not available for all wells, we normalize each well time series by its standard deviation and then average (in blue). Selected well observations were only available from March 2005 to October 2012; thus, we calculated the average over this time period.

solved each month, and errors in the groundwater storage were estimated by propagating the errors of TWSA, SM, SWE, and SW, following *Rodell et al.* [2004b].

We compared our GRACE-based estimates of groundwater storage changes to groundwater level observations at 74 monitoring wells located throughout the Basin. These data were obtained from the USGS [*USGS Groundwater Climate Response Network*, 2014] and from the Arizona Department of Water Resources (ADWR; https://gisweb.azwater.gov/waterresourcedata/GWSI.aspx, accessed May 2014). The selection of wells for comparison was limited to the locations with observations that were concurrent with GRACE. Of these, 7 USGS and 65 ADWR were located in the lower Basin, and 2 USGS monitoring wells were identified in the upper Basin. GRACE-derived groundwater estimates generally capture the observed behavior well (see Results section and Figure 4).

The trends reported in the text and summarized in Table 1 were estimated employing a method that accounts for residual serial correlation and time series error, and subbasin trends may not sum linearly [*Johnston and DiNardo*, 1997]. We identified several significant trends over the entire 108 month time period studied, and in shorter time periods, from December 2004 to January 2010 and from February 2010 to November 2013 (Table 1).

Table 1. Trends in Water Budget Components Were Calculated Employing a Method Which Adjusts a Linear Model for Residual Serial Correlation and Time Series Error [*Johnston and DiNardo*, 1997][a]

Trends in Terrestrial Water in km^3/yr

Time	Component	Entire Colorado River Basin (CRB)	Upper CRB	Lower CRB
Entire time period	TWSA	**−7.18 ± 0.75**	**−2.34 ± 0.59**	**−3.90 ± 0.47**
December 2004 to November 2013	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	−1.29 ± 1.8	−0.861 ± 0.85	**−0.905 ± 0.24**
	Reservoirs	−0.865 ± 0.60	−0.638 ± 0.63	−0.057 ± 0.63
	GW	**−5.56 ± 0.44**	**−1.66 ± 0.40**	**−2.63 ± 0.30**
	AW	**−5.40 ± 0.47**	**−1.13 ± 0.44**	**−3.02 ± 0.30**
Time				
Piecewise analysis 1	TWSA	**−10.6 ± 1.4**	**−3.41 ± 1.1**	**−7.49 ± 0.90**
December 2004–January 2010	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	−2.67 ± 4.2	−1.74 ± 1.9	−1.45 ± 2.2
	Reservoirs	−0.428 ± 0.34	**1.31 ± 0.13**	**−1.20 ± 0.05**
	GW	**−6.23 ± 0.91**	**−1.91 ± 0.80**	**−4.06 ± 0.60**
	AW	**−6.29 ± 0.96**	−1.37 ± 2.2	**−5.27 ± 0.62**
Time				
Piecewise analysis 2	TWSA	**−19.2 ± 2.1**	**−11.5 ± 2.0**	**−9.14 ± 1.3**
February 2010 to November 2013	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	**−6.82 ± 1.2**	**−2.88 ± 0.76**	**−3.64 ± 0.62**
	Reservoirs	−8.42 ± 4.7	**−3.22 ± 1.2**	−0.085 ± 2.0
	GW	**−10.9 ± 1.5**	**−6.10 ± 1.5**	**−5.83 ± 0.89**
	AW	**−11.2 ± 1.6**	**−7.48 ± 1.6**	**−4.85 ± 0.90**

[a]The approach identified several significant trends (shown in bold) in accessible water (AW) in the Basin over the entire time period from December 2004 to November 2013 and a piecewise trend analysis conducted from December 2004 to January 2010 and from February 2010 to November 2013. The Basin TWSA estimates are calculated independently, and there is no assumption that subbasin trends will sum linearly.

3. Results

We find that during the 108 month study period, the entire Colorado River Basin lost a total of 64.8 km^3 of freshwater ($-7.2 \pm 0.8\ km^3\ yr^{-1}$, where ± represents the standard error of the slope coefficient) (Figure 2a) with a more severe rate of loss since February 2010 ($-19.2 \pm 2.1\ km^3\ yr^{-1}$). The upper Basin (Figure 1) lost 21.6 km^3 of water during the entire study period, with more severe loss rates after February 2010 ($-11.5 \pm 2.0\ km^3\ yr^{-1}$) (Figure 2b). Study period losses in the lower Basin of 34.7 km^3 were greater than in the upper Basin and declined at a faster rate ($-3.9 \pm 0.5\ km^3\ yr^{-1}$) (Figure 2c). All trends are listed in Table 1. As described in the Methods section, we compared our GRACE-derived water storage estimates to independent water balances for the entire, upper, and lower Basins with good agreement (Figure S1 in the supporting information). This comparison lends additional confidence to the results reported here.

Further analysis of trends in groundwater storage (Figure S4 in the supporting information) revealed two distinct phases of depletion prior to and following 2009–2010. From December 2004 to January 2010, groundwater storage declined more rapidly in the lower Basin ($-4.1 \pm 0.6\ km^3\ yr^{-1}$) compared to the upper Basin ($-1.9 \pm 0.8\ km^3\ yr^{-1}$). Groundwater losses from February 2010 to November 2013 were found to be even greater in the upper ($-6.1 \pm 1.5\ km^3\ yr^{-1}$) and lower Basins ($-5.8 \pm 0.9\ km^3\ yr^{-1}$).

A brief recovery in groundwater storage is apparent from June 2009 to March 2010, when moderately wetter conditions provided a combination of potential groundwater recharge and temporarily alleviated the need to augment surface water supplies. The steepest rate of groundwater storage decline (in the upper Basin in 2013) follows exceptional drought conditions in 2012 and record low Rocky Mountain snowpack (U.S. Drought Monitor, 2012; see Figure S2 in the supporting information). Such behaviors highlight the close connection between surface water availability and groundwater use [*Famiglietti et al.*, 2011].

We find that water losses throughout the Basin are dominated by the depletion of groundwater storage (Figure 3). Renewable surface water storage in Lake Powell and Lake Mead showed no significant trends during the 108 month study period, more recent declines (since 2011) and currently low (<50% of capacity) storage levels notwithstanding. Groundwater storage changes however accounted for the bulk (Table 1) of the freshwater losses in the entire Basin (50.1 km^3 and $-5.6 \pm 0.4\ km^3\ yr^{-1}$), the majority of which occurred in the lower Basin (Figure 3c). As mentioned in the Methods section, we examined the USGS and ADWR monitoring wells in the Basin during the study period. The observed behavior in these wells showed a good agreement with our GRACE-based estimates. Figure 4 shows the comparisons for the USGS wells. A Sen's slope trend comparison to the ADWR wells showed that measured groundwater table changes closely matched our GRACE-based estimates. These comparisons help confirm the groundwater depletion rates reported here.

4. Discussion

Drought in the Basin has effectively limited the surplus inflows that replenish Lake Powell and Lake Mead since the beginning of the 9 year study period, while active surface water management has prevented further declines in reservoir levels. Consequently, reservoirs show insignificant trends in storage levels ($-0.9 \pm 0.6\ km^3\ yr^{-1}$), while groundwater has been significantly depleted ($-5.6 \pm 0.4\ km^3\ yr^{-1}$). The vast difference may well be attributed to the regulatory framework already in place to manage surface waters, and to the general need for more active and enforceable groundwater management throughout the Basin, in particular, during drought.

The large, net negative change in groundwater storage is a clear indication that groundwater withdrawals are not balanced by recharge and must be greater than the observed depletion rate. The additional loss of 5.6 $km^3\ yr^{-1}$ of groundwater, relative to the annual Basin surface water allocations of 18 $km^3\ yr^{-1}$, indicates further that the Basin water supply was overallocated by at least 30% during the study period. Thus, we observe that groundwater is already being used to fill the gap between Basin demands and the annual renewable surface water supply.

Groundwater is typically used to augment sparse surface water supplies in the arid, lower Basin, and across the entire Basin during drought [*Hutson et al.*, 2004; *Kenny et al.*, 2009]. More generally, water managers around the world rely on groundwater to mitigate the impacts of drought on water supply [*Leblanc et al.*, 2009; *Famiglietti et al.*, 2011; *Famiglietti and Rodell*, 2013; *Taylor et al.*, 2013]. Groundwater represents the largest supply of water for irrigation within the Basin [*Hutson et al.*, 2004; *Kenny et al.*, 2009], while irrigated acreage in the Basin has increased during our study period [*Ward and Pulido-Velazquez*, 2008; *Cohen et al.*, 2013]. Furthermore, prolonged drought across the southwestern U.S. has resulted in overreliance on groundwater to minimize impacts on public water supply [*Famiglietti and Rodell*, 2013]. Long-term observations of groundwater depletion in the lower Basin (e.g., in Arizona—despite groundwater replenishment activities regulated under the 1980 Groundwater Code—and in Las Vegas [*Konikow*, 2013]) underscore that this strategic reserve is largely unrecoverable by natural means and that the overall stock of available freshwater in the Basin is in decline.

Future water management scenarios that account for both population growth and climate change also point to the inability of reservoir storage alone to meet the Basin allocations [*Barnett and Pierce*, 2008; *Bureau of Reclamation*, 2012]. These scenarios indicate that additional stresses will be placed upon the groundwater system, beyond those described here, to meet future Basin water demands. We believe that the combination of reduced surface water availability resulting from decreasing future snowpack [*Barnett et al.*, 2008] and groundwater depletion poses a significant threat to the long-term water security of the region. As groundwater supplies reach their limits, the ability to supply freshwater during drought, or to fill the predicted, increasing gap between supply and demand [*Bureau of Reclamation*, 2012], will be severely constrained.

The challenge to policy makers and water managers in the Colorado River Basin is to reliably meet freshwater demand under these dynamic conditions. Our work suggests that a conjunctive surface water and groundwater management plan is essential for sustainable water management in the Basin. Despite commendable efforts to craft solutions to meet required surface water allocations [*Bureau of Reclamation*, 2012], consideration of the ability of groundwater withdrawals to meet current and future demands remains dormant. We hope that the heightened awareness of the rates of the Basin groundwater depletion highlighted here will foster urgent discussion on conjunctive management solutions required to ensure a sustainable water future for the Colorado River Basin and for the western United States.

Acknowledgments
This research was funded by grants from the NASA GRACE Science Team and from the University of California Office of the President, Multicampus Research Programs and Initiatives. Jason Christensen of the U.S. Bureau of Reclamation provided the reservoir capacities and dam releases. We thank Q. Tang of the University of Washington for the use of the MODIS ET data and Min-Hui Lo of the National Taiwan University for the assistance with the GRACE validation. Access to all data sets used in this study is available through the links provided in the main text. Authors J.T. Reager and J.S. Famiglietti conducted some of this research at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

The Editor thanks Sandra Postel and an anonymous reviewer for their assistance in evaluating this paper.

References

Barlage, M., F. Chen, M. Tewari, K. Ikeda, D. Gochis, J. Dudhia, R. Rasmussen, B. Livneh, M. Ek, and K. Mitchell (2010), Noah land surface model modifications to improve snowpack prediction in the Colorado Rocky Mountains, *J. Geophys. Res.*, *115*, D22101, doi:10.1029/2009JD013470.

Barnett, T. P., and D. W. Pierce (2008), When will Lake Mead go dry?, *Water Resour. Res.*, *44*, W03201, doi:10.1029/2007WR006704.

Barnett, T. P., et al. (2008), Human-induced changes in the hydrology of the western United States, *Science*, *319*, 1080–1083, doi:10.1126/science.1152538.

Basin Interim Guidelines (2007), Record of decision: Colorado river interim guidelines for lower basin shortages and the coordinated operations for Lake Powell and Lake Mead. [Available at http://www.usbr.gov/lc/region/programs/strategies.html.]

Bureau of Reclamation (1975), Colorado River System Consumptive Uses and Losses Report 1971-1975. [Available at http://www.usbr.gov/uc/library/envdocs/reports/crs/pdfs/1971.pdf.]

Bureau of Reclamation (2012), Colorado river basin water supply and demand study. [Available at http://www.usbr.gov/lc/region/programs/crbstudy.html.]

Chen, F., K. Mitchell, J. Schaake, Y. Xue, H. Pan, V. Koren, Y. Duan, M. Ek, and A. Betts (1996), Modeling of land-surface evaporation by four schemes and comparison with FIFE observations, *J. Geophys. Res.*, *101*(D3), 7251–7268, doi:10.1029/95JD02165.

Christensen, N., A. W. Wood, N. Voisin, D. P. Lettenmaier, and R. N. Palmer (2004), The effects of climate change on the hydrology and water resources of the Colorado River Basin, *Clim. Change*, *62*, 337–363, doi:10.1023/B:CLIM.0000013684.13621.1f.

Cohen, M., J. Christian-Smith, and J. Berggren (2013), Water to supply the land: Irrigated agriculture in the Colorado river basin, Pacific institute.

Dai, Y., et al. (2003), The common land model, *Bull. Am. Meteorol. Soc.*, *84*, 1013–1023, doi:10.1175/BAMS-84-8-1013.

Daly, C., M. Halblieb, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris (2008), Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States, *Int. J. Climatol.*, *28*, 2031–2064, doi:10.1002/joc.1688.

Famiglietti, J., and M. Rodell (2013), Water in the balance. Science perspectives, *Science*, *340*, 1300–1301, doi:10.1126/science.1236460.

Famiglietti, J. S., M. Lo, S. L. Ho, J. Bethune, K. J. Anderson, T. H. Syed, S. C. Swenson, C. R. de Linage, and M. Rodell (2011), Satellites measure recent rates of groundwater depletion in California's Central Valley, *Geophys. Res. Lett.*, *38*, L03403, doi:10.1029/2010GL046442.

Hutson, S. S., N. L. Barber, J. F. Kenny, K. S. Linsey, D. S. Lumia, and M. A. Maupin (2004), Estimated use of water in the United States in 2000, USGS Circular 1268.

Jeton, A. E., S. A. Watkins, J. Thomas, and J. Hunnington (2005), Evaluation of precipitation estimates from PRISM for the 1961–90 and 1971–2000 data sets, Nevada, *U.S. Geol. Surv. Sci. Invest. Rep., 2005-5291*.

Johnston, J., and J. DiNardo (1997), *Econometric Methods*, McGraw Hill, New York.

Kenny, J. F., N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace, and M. A. Maupin (2009), Estimated use of water in the United States in 2005, USGS Circular 1344.

Konikow, L. (2013), Groundwater depletion in the United States (1900–2008), *U. S. Geol. Surv. Sci. Invest. Rep. 2013–5079*.

Leake, S. A., S. J. Owen-Joyce, and J. A. Heilman (2013), Potential depletion of surface water in the Colorado River and agricultural drains by groundwater pumping in the Parker-Palo Verde-Cibola area, Arizona and *U. S. Geol. Surv. Sci. Invest. Rep. 2013–5134*.

Leblanc, M. J., P. Tregoning, G. Ramillien, S. O. Tweed, and A. Fakes (2009), Basin-scale, integrated observations of the early 21st century multiyear drought in southeast Australia, *Water Resour. Res.*, *45*, W04408, doi:10.1029/2008WR007333.

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges (1994), A simple hydrologically-based model of land-surface water and energy fluxes for general-circulation models, *J. Geophys. Res.*, *99*, 14,415–14,428, doi:10.1029/94JD00483.

McKay, L., T. Bondelid, T. Dewald, J. Johnston, R. Moore, and A. Rea (2012), *NHDPlus Version 2: User Guide*, National Operational Hydrologic Remote Sensing Center, Washington, D. C.

National Operational Hydrologic Remote Sensing Center (2004), Snow Data Assimilation System (SNODAS) data products at NSIDC. [snow water equivalent], Natl. Snow and Ice Data Cent., Boulder, Colo., doi:10.7265/N5TB14TC.

Piechota, T., J. Timilsena, G. Tootle, and H. Hidalgo (2004), The western U.S. drought: How bad is it?, *Eos. Trans. AGU*, *85*(32), 301–304, doi:10.1029/2004EO320001.

Rajagopalan, B., K. Nowak, J. Prairie, M. Hoerling, B. Harding, J. Barsugli, A. Ray, and B. Udall (2009), Water supply risk on the Colorado River: Can management mitigate?, *Water Resour. Res.*, *45*, W08201, doi:10.1029/2008WR007652.

Rodell, M., and J. S. Famiglietti (2002), The potential for satellite-based monitoring of groundwater storage changes using GRACE: The high Plains Aquifer, Central U. S, *J. Hydrol.*, *263*, 245–256, doi:10.1016/S0022-1694(02)00060-4.

Rodell, M., et al. (2004a), The Global Land Data Assimilation System, *Bull. Am. Meteorol. Soc.*, *85*, 381–394, doi:10.1175/BAMS-85-3-381.

Rodell, M., J. S. Famiglietti, J. Chen, S. I. Seneviratne, P. Viterbo, S. Holl, and C. R. Wilson (2004b), Basin scale estimates of evapotranspiration using GRACE and other observations, *Geophys. Res. Lett.*, *31*, L20504, doi:10.1029/2004GL020873.

Rodell, M., I. Velicogna, and J. Famiglietti (2009), Satellite-based estimates of groundwater depletion in India, *Nature*, doi:10.1038/nature08238.

Rutter, N., D. Cline, and L. Li (2008), Evaluation of the NOHRSC Snow Model (NSM) in a one-dimensional mode, *J. Hydrometeorol.*, *9*, 695–711, doi:10.1175/2008JHM861.1.

Sauer, V. B., and R. W. Meyer (1992), Determination of error on individual discharge measurements, *U.S. Geol. Surv. Open File Rep., 92-144*.

Scanlon, B. R., L. Longuevergne, and D. Long (2012), Ground referencing GRACE satellite estimates of groundwater storage changes in the California Central Valley, USA, *Water Resour. Res.*, *48*, W04520, doi:10.1029/2011WR011312.

Swenson, S. C., and J. Wahr (2006), Post-processing removal of correlated errors in GRACE data, *Geophys. Res. Lett.*, *33*, L08402, doi:10.1029/2005GL025285.

Swenson, S. C., and J. Wahr (2009), Monitoring the water balance of Lake Victoria, East Africa, from space, *J. Hydrol.*, *370*(1–4), 163–176, doi:10.1016/j.jhydrol.2009.03.008.

Swenson, S. C., P. J.-F. Yeh, J. Wahr, and J. S. Famiglietti (2006), A comparison of terrestrial water storage variations from GRACE with in situ measurements from Illinois, *Geophys. Res. Lett.*, *33*, L16401, doi:10.1029/2006GL026962.

Tang, Q., S. Peterson, R. Cuenca, Y. Hagimoto, and D. P. Lettenmaier (2009), Satellite-based near-real-time estimation of irrigated crop water consumption, *J. Geophys. Res.*, *114*, D05114, doi:10.1029/2008JD010854.

Tapley, B. D., S. Bettadpur, J. C. Ries, P. F. Thompson, and M. M. Watkins (2004), GRACE measurements of mass variability in the Earth system, *Science*, *305*, 503–505, doi:10.1126/science.1099192.

Tapley, B., J. Ries, S. Bettadpur, D. Chambers, M. Cheng, F. Condi, and S. Poole (2007), The GGM03 Mean Earth Gravity Model from GRACE, *Eos. Trans. AGU*, *88*(52), Fall Meet. Suppl., Abstract G42A-03.

Taylor, R. G., et al. (2013), Groundwater and climate change, *Nat. Clim. Change*, *3*, 322–329, doi:10.1038/NCLIMATE1744.

USGS (2004), Climatic fluctuations, drought, and flow in the Colorado River Basin, U.S. Department of the Interior and the U.S. Geological Survey, USGS Fact Sheet 2004-3062.

USGS Groundwater Climate Response Network (2014). [Available at http://groundwaterwatch.usgs.gov/Net/OGWNetwork.asp?ncd=crn.]

Velicogna, I., and J. Wahr (2006), Acceleration of Greenland ice mass loss in spring 2004, *Nature*, *443*, 329–331, doi:10.1038/nature05168.

Wahr, J., S. Swenson, V. Zlotnicki, and I. Velicogna (2004), Time-variable gravity from GRACE: First results, *Geophys. Res. Lett.*, *31*, L11501, doi:10.1029/2004GL019779.

Wahr, J., S. Swenson, and I. Velicogna (2006), Accuracy of GRACE mass estimates, *Geophys. Res. Lett.*, *33*, L06401, doi:10.1029/2005GL025305.

Ward, F., and M. Pulido-Velazquez (2008), Water conservation in irrigation can increase water use, *Proc. Natl. Acad. Sci. U.S.A.*, *105*(47), 18,215–18,220, doi:10.1073/pnas.0805554105.

Shallow Monitoring Well — near St. Johns

app.azwater.gov/gwsi/Hydrograph.aspx?SiteID=342548109250301&ObjectID=5051642

Well Info | Map | Reset Graph | Auto Site Hydrograph | Email | Help

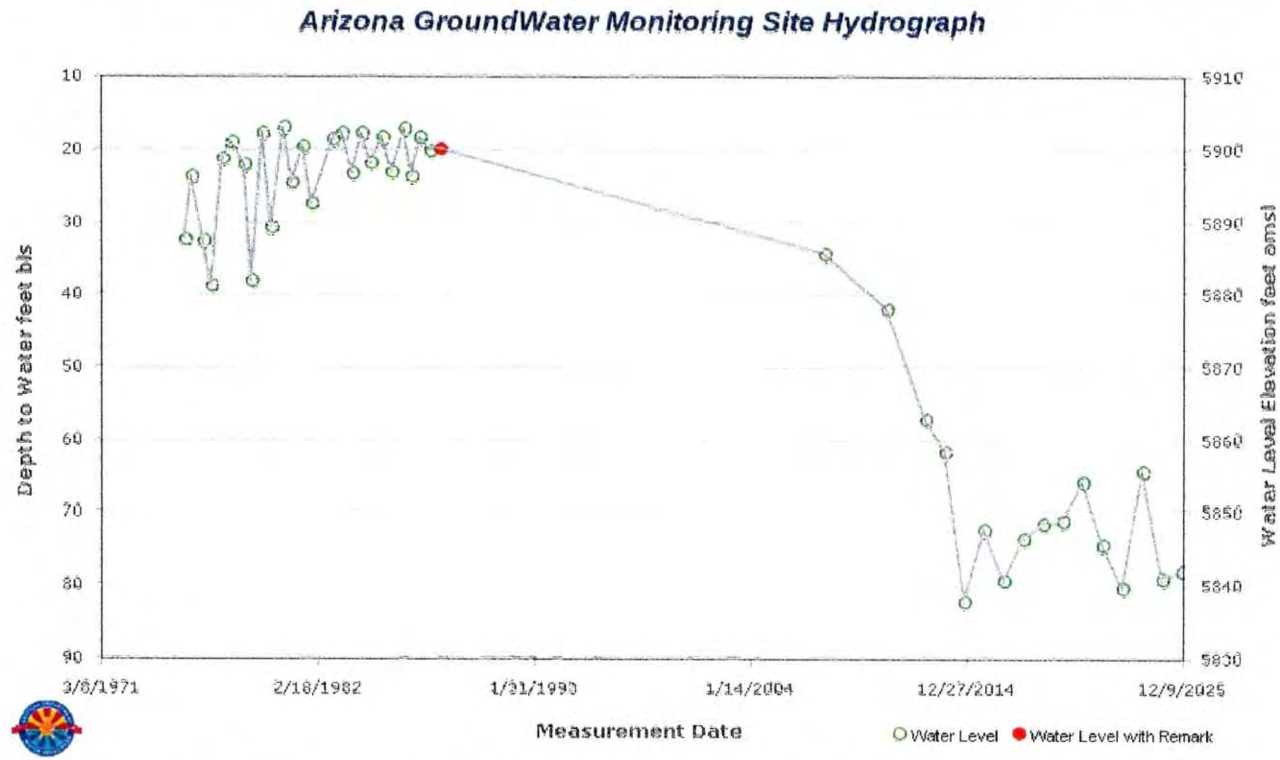
Local ID	Site ID	Registry ID	Latitude NAD27	Longitude NAD27	Alt. (ft amsl)	Water Use	Well Depth (ft)	Case Dia.(in)	Drill Date	Latest WL Date	DTW (ft)	WL Elv. (ft)
A-12-28 19BAD	342548109250301	620380	34° 25' 47.3"	109° 25' 2.3"	5920	DOMESTIC	650	8	1/1/1974	10/23/2025	78.1	5841.9

Enter a Date Range

Start Date mm/dd/yyyy:

End Date mm/dd/yyyy:

Refresh



Shallow Monitoring Well – near Lyman Lake

app.azwater.gov/gwsi/Hydrograph.aspx?SiteID=342024109220301&ObjectID=5047169

Well Info | Map | Reset Graph | Auto Site Hydrograph | Email | Help

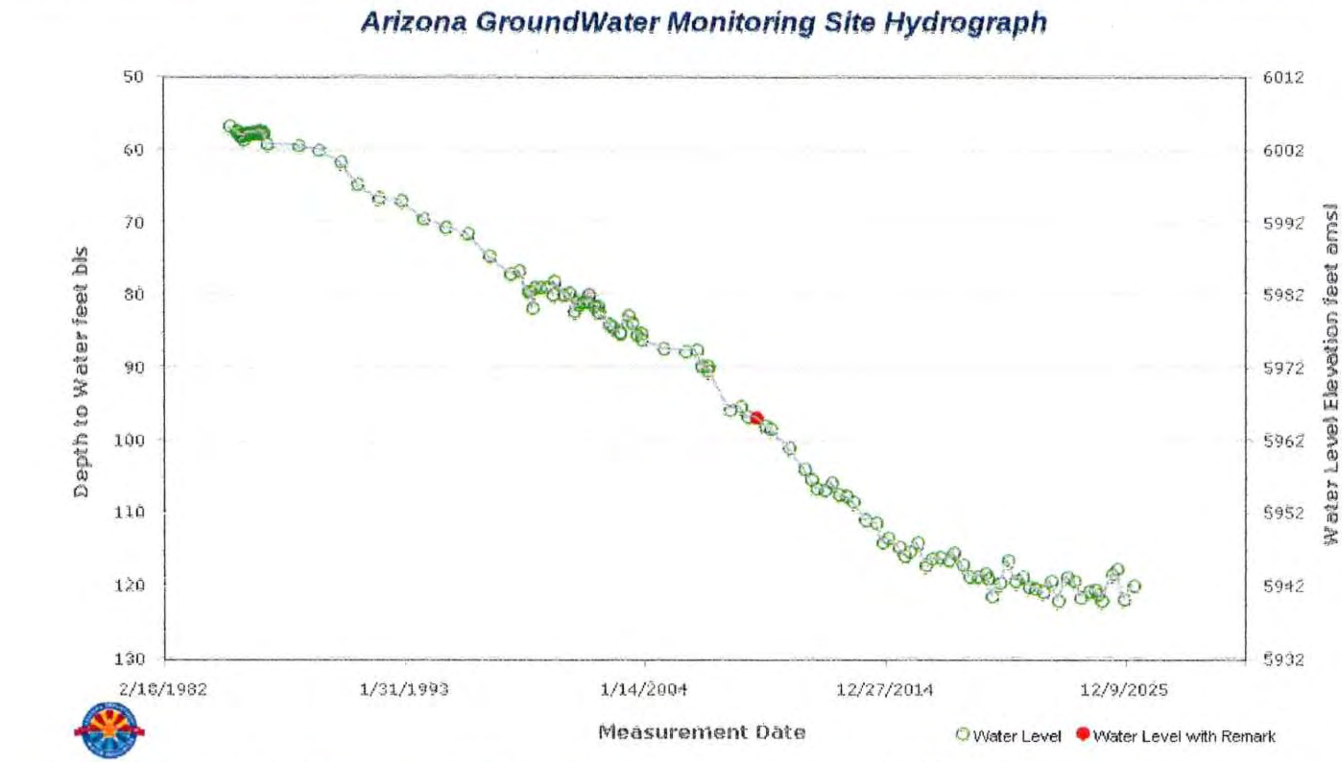
Local ID	Site ID	Registry ID	Latitude NAD27	Longitude NAD27	Alt. (ft amsl)	Water Use	Well Depth (ft)	Case Dia.(in)	Drill Date	Latest WL Date	DTW (ft)	WL Elv. (ft)
A-11-28 22BDD2	342024109220301	085863	34° 20' 18.5"	109° 22' 2.4"	6062	UNUSED	550	8	12/10/1980	3/19/2026	119.91	5942.09

Enter a Date Range

Start Date mm/dd/yyyy:

End Date mm/dd/yyyy:

Refresh



Deeper Monitoring Well – near Lyman Lake

Moratorium | CPU Wells | Groundwater | Arizona Grou | GWSI Hydro | Arizona Wat | DocuShare | DocuShare

app.azwater.gov/gwsi/Hydrograph.aspx?SiteID=342033109174101&ObjectID=

Well Info | Map | Reset Graph | Auto Site Hydrograph | Email | Help

Local ID	Site ID	Registry ID	Latitude NAD27	Longitude NAD27	Alt. (ft amsl)	Water Use	Well Depth (ft)	Case Dia (in)	Drill Date	Latest WL Date	DTW (ft)	WL Elv. (ft)
A-11-29 20ABB	342033109174101	611373	34° 20' 33.4"	109° 17' 37.6"	6521	UNUSED	1550	8		10/20/2022	652.4	5868.6

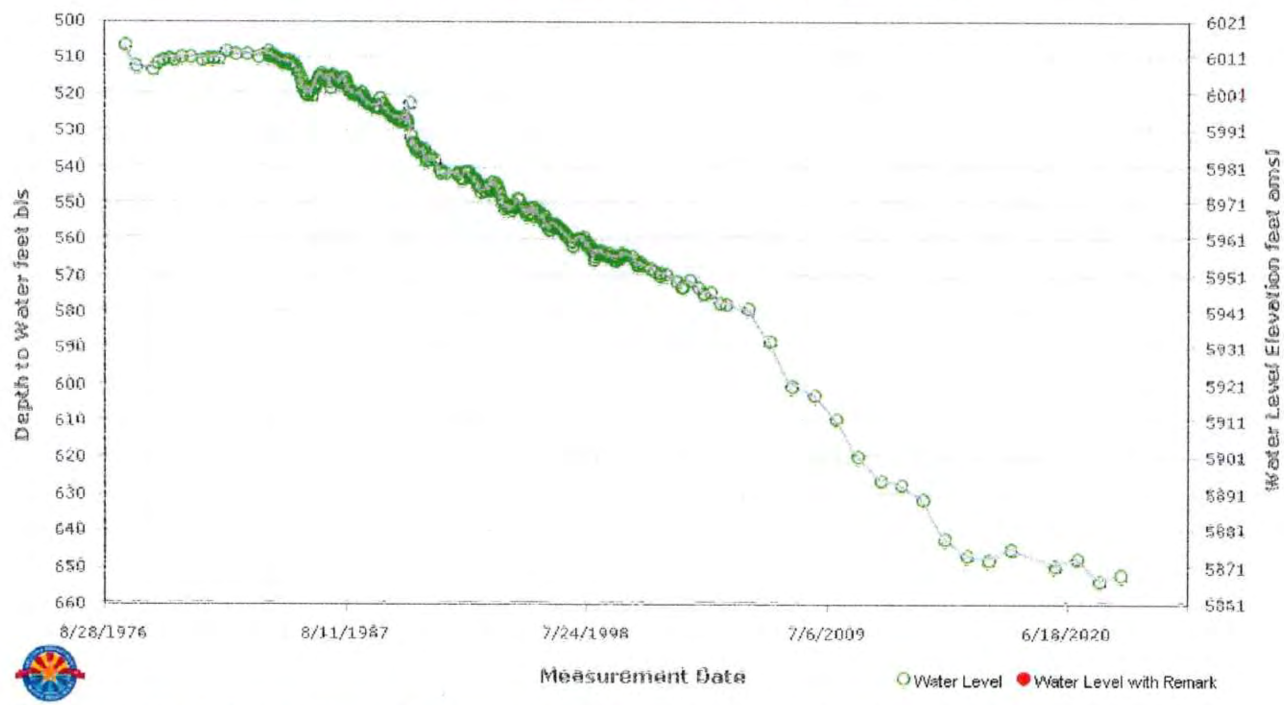
Enter a Date Range

Start Date mm/dd/yyyy:

End Date mm/dd/yyyy:

Refresh

Arizona GroundWater Monitoring Site Hydrograph



Jun 21 12:43