Coconino Plateau Watershed Partnership

Water-Related Ecosystem Services Assessment - Phase 1

Task 2: An Annotated Bibliography of Existing Datasets and Recommendations for Phase 2 of the Water-Related Ecosystem Services Assessment

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EXECUTIVE SUMMARY

The Coconino Plateau Watershed Partnership Technical Advisory Committee (CPTAC) hired Dr. Kira Russo of Global Water Policy Consulting to conduct Phase 1 of a Water-Related Ecosystem Services Assessment. In Phase 1 Task 1, Dr. Russo conducted a social survey of more than thirty stakeholders of water resources in the Coconino Plateau Watershed Partnership area of interest. Through the interview process, Dr. Russo recognized seven priority stakeholder concerns: 1) groundwater flow, 2) wildfire protection, 3) infrastructure needs, 4) climate change, 5) water reuse, 6) tourism/recreation, and 7) springs. Dr. Russo subcontracted with Sharon Masek Lopez of H_2O Consulting to complete Task 2. For Task 2, Ms. Masek Lopez identified the ecosystem services to be assessed, compiled relevant datasets, and made recommendations on how to use the data in Phase 2 of the assessment.

Assessment of water-related ecosystem services, specifically their importance and relative trends in their function, will help inform future water management decisions in the Coconino Plateau Watershed Partnership area of interest. Ecosystem Services are defined as "the benefits that people obtain from ecosystems and the direct and indirect contributions of ecosystems to human well-being." There are four categories of ecosystem services: provisioning, regulating, cultural, and supporting. Water-related ecosystem services associated with the CPWP stakeholders' seven priority concerns are as follows:

- Drinking Water (Provisioning),
- Water for Environmental Flow (Provisioning),
- Groundwater Recharge (Regulating),
- Flood Protection (Regulating),
- Erosion Prevention (Regulating),
- Water Purification (Regulating),
- Climate Change Adaptation and Disaster Risk Reduction (Regulating),
- Carbon Sequestration (Regulating),
- Recreation and Tourism (Cultural),
- Water for Non-Drinking Purposes (Provisioning),
- Maintaining Wildlife Populations and Habitats (Regulating), and
- Spiritual or Symbolic (Cultural).

To complete Task 2 of the Phase 1 Water-Related Ecosystem Services Assessment, Sharon Masek Lopez searched for datasets via the internet and received guidance from many CPTAC members and other natural resources professionals. Materials are delivered in multiple forms: 1) this annotated bibliography, 2) folders of data and literature files, and 3) GIS data files, including a GIS map package. Throughout the annotated bibliography and in the report conclusion, there are recommendations for how to use the data in the ecosystem services assessment.

INTRODUCTION

The Coconino Plateau Watershed Partnership (CPWP) contracted with Global Water Policy Consulting (GWPC) to complete Phase 1 of an ecosystem services assessment as part of a proposed framework for sustainable water management on the Coconino Plateau. The ecosystem services assessment focuses on the services provided by surface water and groundwater resources of the Coconino Plateau, specifically their importance and relative trends in their function, to help inform future water management decisions.

Dr. Kira Russo, owner of GWPC, completed Phase 1 Task 1. She interviewed more than 30 CPWP stakeholders to identify the water-related ecosystem services to be assessed. Dr. Russo subcontracted with Sharon Masek Lopez, owner of H_2O Consulting, to complete Phase 1 Task 2. Ms. Masek Lopez identified existing data sources necessary to assess trends in the ecosystem service functions and generated this annotated bibliography with 204 entries, as well as an ArcGIS project with 116 data layers (shapefiles, layers, raster data).

In Phase 2 of the ecosystem services assessment, a consultant will complete three tasks: Task #3 - Definition of the Services Study Area, Task #4 - Selection and Description of Assessment Methods and Metrics, and Task #5 - Current State of Selected Services and Future Study (Figure 1).

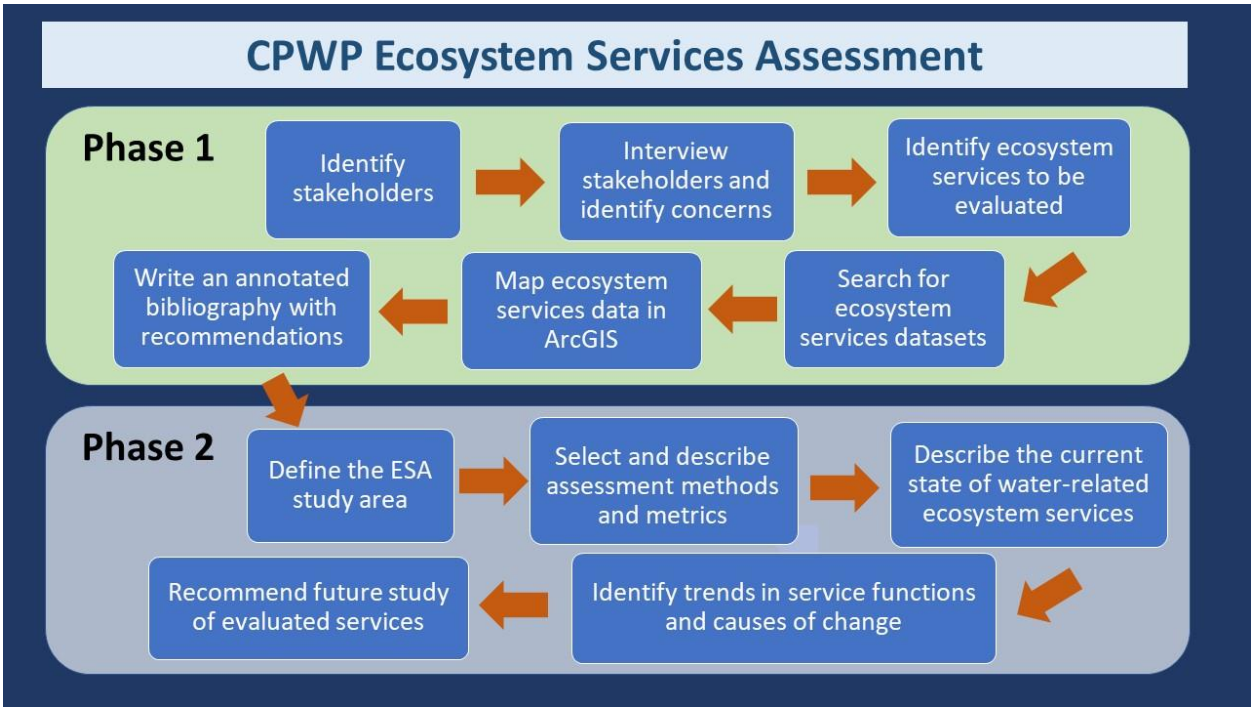

Figure 1. Flow chart for Phases 1 and 2 of the Coconino Plateau Watershed Partnership Water-Related Ecosystem Services Assessment.

This report is an annotated bibliography of datasets, reports, scientific articles, websites, and other relevant materials that provide data on water-related ecosystem services within the

Coconino Plateau Watershed Partnership area of interest (Figure 2). Along with this report, the Task 2 deliverables include a flash drive with hundreds of files. On the flash drive are GIS data and the datasets and documents described in this annotated bibliography. (Be aware that some scientific journal articles described in the annotated bibliography are copyright-restricted and may not be distributed without the journal's permission.) The GIS data include layers, shapefiles, and raster data, which are delivered both individually and in an ArcGIS map package.

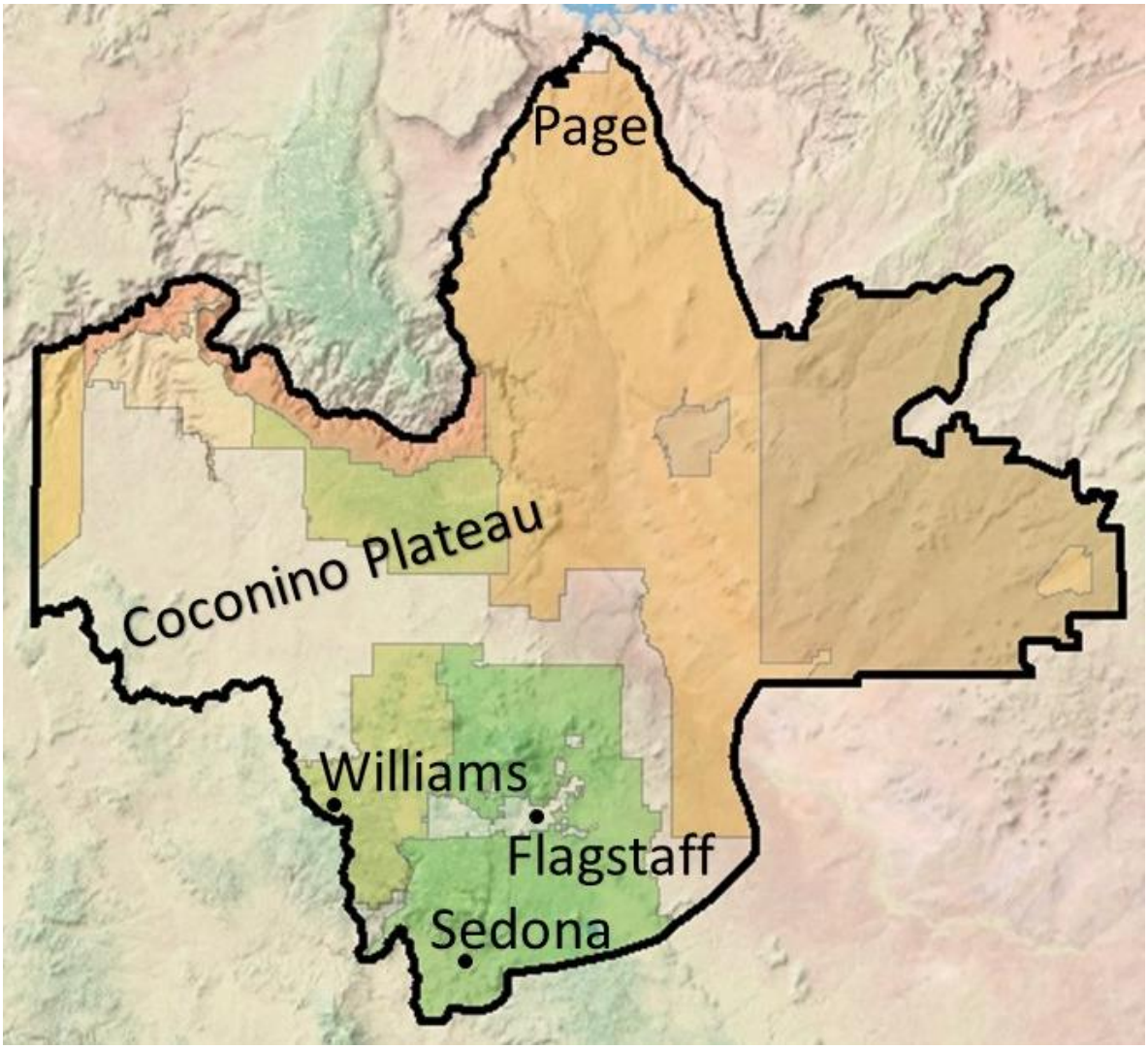

Figure 2. Coconino Plateau Watershed Partnership area of interest for the water-related ecosystem services assessment. Land control of some of the major partnership stakeholders are shown here, including The Hopi Tribe (brown), western Navajo Nation (orange), Grand Canyon National Park (red), Havasupai Tribe (yellow), Hualapai Tribe (gold), Kaibab National Forest (light green), Coconino National Forest (medium green), and the cities of Sedona, Flagstaff, Williams, and Page. (Map generated in ArcMap by Sharon Masek Lopez.)

Altogether, the delivered items constitute a database of materials for use in completing the Phase 2 Water-Related Ecosystem Services Assessment. Given how varied the forms of data are, it was not practical to enter all the data sources into a single relational database (e.g. Access database software). Many datasets are accessed online directly from the data provider; use the URLs provided to access these data. Check the data and literature folders on the accompanying flash drive for already downloaded materials; the folders are organized using the same structure as the annotated bibliography.

Water-Related Ecosystem Services

Ecosystem services are defined as the benefits that people obtain from ecosystems and the direct and indirect contributions of ecosystems to human well-being (Grizzetti et al. 2016). There are four categories of ecosystem services: provisioning, regulating, cultural, and supporting services. As part of the Millennium Ecosystem Assessment (MA), Aylward et al. (2005) identified the ecosystem services provided by fresh water and the hydrologic cycle. Later publications added to and refined the MA's original list of water-related ecosystem services to include those listed as follows (Capon et al. 2015, Grizetti et al. 2016, Brauman 2017).

Provisioning Services

Provisioning ecosystems services are products obtained from ecosystems. Water-related provisioning services include the following:

- Water for consumptive use (drinking water, domestic use, agricultural irrigation, and industrial use)
- Water for non-consumptive use (for generating power and transport/navigation)
- Aquatic organisms for food and medicines
- Raw biotic materials (e.g. algae for fertilizers, firewood from riparian areas)
- Raw abiotic materials (e.g. sand and gravel)

Regulating Services

Regulating ecosystem services are defined as the benefits obtained from the regulation of ecosystem processes. Water-related regulating services include the following:

- Water purification and maintenance of water quality (natural filtration, removal of excess nutrients by microorganisms)
- Flood protection (vegetation acting as a barrier for water flow)
- Erosion and sedimentation prevention (through water/land interactions and flood control infrastructure)
- Climate regulation (provision of sink for greenhouse gases)
- Reducing dryland salinization

Cultural Services

Cultural ecosystem services are non-material benefits that people obtain from ecosystems. Water-related cultural services include the following:

- Recreation (river rafting, kayaking, hiking, and fishing as a sport)
- Tourism
- Aesthetic appreciation (including artistic representations)
- Existence values (personal satisfaction from free-flowing rivers and aquatic ecosystems)
- Science and Education
- Spiritual, symbolic, inspirational, and religious values
- Existence values

Supporting Services

Supporting ecosystem services are those services that make other ecosystem services possible. Water-related supporting services include the following:

- Water and nutrient cycling to support habitats and populations
- Predator/prey relationships and ecosystem resilience

Ecosystem services assessments primarily focus on provision, regulating, and cultural services. Because stakeholders expressed very low interest in supporting ecosystem services, no datasets were gathered specifically for this type of service.

The Millennium Assessment

From 2001 to 2005, UNESCO joined together more than 1,360 experts worldwide to provide a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide. The resulting Millennium Ecosystem Assessment, or Millennium Assessment (MA), evaluated effects on human well-being due to ecosystem change (MA 2018). The MA serves as a model for ecosystem services assessments that offer a scientific basis for action to conserve ecosystems and use them sustainably for the benefit of people. In 2003, the MA conceptual framework defined an assessment as **"a social process to bring the findings of science to bear on the needs of decision-makers."** The Coconino Plateau Watershed Partnership (CPWP) has followed the process defined by the MA in producing Phase 1 of the CPWP Ecosystem Services Assessment.

Responding to Stakeholder Concerns

Two tasks were completed in Phase 1 of the Coconino Plateau Watershed Partnership Ecosystem Services Assessment. In Task 1, Dr. Kira Russo interviewed more than 30 stakeholders from within and adjacent to the CPWP area of interest (Figure 2) and analyzed

their responses. She identified seven priority concerns to inform selection of ecosystem services for assessment in Phase 2 (Table 1). In Task 2, Sharon Masek Lopez gathered relevant data sets for use in the Phase 2 ecosystem services assessment. See the "Conclusions and Recommendations" section at the end of this report for discussion about how to use datasets to address stakeholder concerns listed in Table 1.

Table 1. Coconino Plateau Watershed Partnership stakeholder concerns and related ecosystem services

Stakeholder Concern	**Ecosystem Services**
Groundwater Flow	Provisioning: Drinking Water, Water for Environmental Flow, Regulating: Groundwater Recharge
Wildfire Protection	Regulating: Flood Protection, Erosion Prevention, Water Purification, Provisioning: Drinking Water
Infrastructure Needs: Water Supply, Water Resources Monitoring	Provisioning: Drinking Water, Water for Non-Drinking Purposes, Water for Environmental Flows Regulating: Water Purification
Climate Change	Regulating: Climate Change Adaptation and Disaster Risk Reduction, Carbon Sequestration
Water Reuse	Regulating: Water Purification, Groundwater Recharge, Recreation, Provisioning: Water for Non-Drinking Purposes, Drinking Water
Tourism and Recreation	Provisioning: Drinking Water, Water for Non-Drinking Purposes, Water for Environmental Flow Cultural: Recreation/Tourism
Springs	Provisioning: Water for Environmental Flow Regulating: Maintaining Wildlife Populations and Habitats Cultural: Spiritual

Gathering Existing Datasets

For the Coconino Plateau Watershed Partnership's (CPWP) Phase 1 Water-Related Ecosystem Services Assessment (ESA), Dr. Kira Russo subcontracted with Sharon Masek Lopez (H_2O Consulting) to complete Task 2 – Gathering Existing Datasets. Ms. Masek Lopez searched online and also spoke with many stakeholder organizations to find relevant datasets for use in the Phase 2 assessment. The following annotated bibliography provides a citation for each dataset, describes the dataset, and ranks its usefulness for the ESA. In the report conclusion, Ms. Masek Lopez provides recommendations for utilizing the datasets to address the top seven stakeholder water sustainability concerns that were identified through interviews by Dr. Russo.

Please note, because a great deal of data is available online, many URLs are displayed in this document. However, these URLs do not appear as active links. To access a website using a listed

URL, copy and paste the URL into your internet browser. Be sure not to copy the period at the end of the bibliography entry, or the URL will not function.

Quick Dataset Prioritization Key

As a way to prioritize data sources, each source is ranked on a scale of 1 to 3, indicating its usefulness for the ecosystem services assessment (ESA). Following each citation is a symbol showing the data source's ranking. These rankings are qualitative judgments based on Sharon Masek Lopez' professional expertise and informed by comments provided during Dr. Kira Russo's stakeholder interviews.

The following are the symbols for rankings that indicate how useful a data source may be for Phase 2 of the Water-Related Ecosystem Services Assessment:

◄◄◄ = Important data source

◄◄ = Moderately useful data source

◄ = Somewhat useful data source

GENERAL DATA

CPWP Water Source Menu Maps

The following maps were prepared by the CPWP Technical Advisory Committee (TAC) in collaboration with U.S. Bureau of Reclamation.

CPWP. 2015. **Generalized Depiction of Surface Water Features**. Coconino Plateau Watershed Partnership website accessed October 15, 2018, http://www.cpwac.org/SWBmaps/CPWP_Surface_ReducedFileSize.pdf ◄◄◄

CPWP. 2016. **Generalized Depiction of Groundwater Aquifers**. Coconino Plateau Watershed Partnership website accessed October 15, 2018, http://www.cpwac.org/SWBmaps/CPWP_Groundwater_ReducedFileSize.pdf ◄◄◄

CPWP. 2016. **Generalized Summary of Water Demand and Use.** Coconino Plateau Watershed Partnership website accessed October 15, 2018, http://www.cpwac.org/SWBmaps/CPWP_DemandUse_ReducedFileSize.pdf ◄◄◄

Hydrography Data

AZGEO Clearinghouse

The AZGEO Clearinghouse is an initiative of the Arizona Geographic Information Council. AZGEO is designed to provide GIS users with links to Internet map services, Federal Geographic Data

Committee (FGDC) compliant metadata, and geospatial data downloads. To use AZGEO Clearinghouse, you must register, set up a log in and password, log in, query for datasets, and then download datasets, some of which are listed below. There is useful information on the "About" webpage (https://azgeo.az.gov/azgeo/about-azgeo). Follow these directions to download AZGEO data:

1. Go to: http://azgeo.az.gov/azgeo/
2. Log in or register
3. Go to catalog
4. Select type: dataset, Data Category: e.g. "Hydrography", and click filter results (results in 18 datasets)
5. Click on geospatial data of your desired dataset
6. Find contact information under General tab
7. Description of dataset under Data tab
8. Publication date and date of update under Status tab
9. Permissions under Access tab
10. Downloadable files under File tab. Downloadable files are typically layer packages and xml metadata files. The layer packages include symbolized geospatial data that can be brought into ArcMap.

AZGEO data include GIS layers for administrative boundaries, demographic, environmental factors, hydrology, imagery, indices, mining, natural features, transportation, and more. These data layers are listed below with ALRIS as the author. ALRIS is the Arizona Land Resource Information System provided by the Arizona State Land Department. The following nine datasets are generally helpful hydrography and geology GIS data layers. They were downloaded by Colleen Cassidy and will be provided as part of an ArcGIS map package to CPWP. The links listed will only work if you are logged into AZGEO. Alternatively, once logged in, you can find the datasets by searching within AZGEO using the recommended search terms.

ALRIS. 2006. **Hydro Line Features (Perennial).** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/hydro-line-features-perennial (Use search words "hydro line".) ◄

This dataset includes lines that represent perennial hydrography features (streams and rivers). The data were created to serve as base information for use in GIS and do not represent a legal record. This shapefile includes name, length, and type.

ALRIS. 2008. **Canals, Ditches and Pipelines.** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/AZGEO/datasets/canals-ditches-pipelines-nhd-line (Use search term "NHD".) ◄

This dataset includes lines that represent canals, ditches, and pipelines. This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. The shapefile includes name, length, and feature type.

ALRIS. 2008. **Dams and Weirs**. Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/dams-weirs-nhd-polygon (Use search words "dams and weirs".) ◄

This dataset includes polygons that represent dams and weirs and is part of the National Hydrography Dataset (NHD). The NHD provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes date, name, area, and feature type.

ALRIS. 2008. **Subbasin Boundaries (HUC 4).** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/subregion-4-digit-huc-boundaries-nhd (Use search term "NHD".) ◄

This dataset includes polygons that represent subbasin hydrologic unit boundaries for Arizona 4-digit Hydrologic Unit Codes (HUC 4). HUC 4 watersheds are larger than HUC 8 watersheds and contain HUC 8 watersheds. The more digits a HUC code has, the smaller the defined watershed area. This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes name and area.

ALRIS. 2008. **Subbasin boundaries (HUC 8).** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/subbasin-8-digit-huc-boundaries-nhd (Use search term "NHD".) ◄

This dataset includes polygons that represent subbasin hydrologic unit boundaries for Arizona using the 8-digit Hydrologic Unit Codes (HUC 8). This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes name and area.

ALRIS. 2008. **Washes.** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/washes-nhd (Use search term "NHD".) ◄

This dataset includes polygons that represent washes. This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes area and feature type.

ALRIS. 2009. **Lakes and reservoirs (all).** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/lakes-and-reservoirs-all-nhd (Use search words "lakes and reservoirs".) ◄

This dataset includes polygons that represent all lakes, playas, reservoirs, swamps, marshes, and inundation areas. This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes name, area, elevation, and feature type.

ALRIS. 2009. **Lake and reservoirs (major).** Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/azgeo/datasets/lakes-and-reservoirs-major-nhd (Use search words "lakes and reservoirs".) ◄

This dataset includes polygons that represent all lakes, playas, reservoirs, swamps, marshes, and inundation areas that are greater than 0.1 SqKm in area. This dataset is part of the National Hydrography Dataset and provides a nationally consistent framework for analyzing and addressing water-related entities. This shapefile includes name, area, elevation, and feature type.

Other General Data

ADWR. 2009. **Arizona Water Atlas Section 2.2 – Little Colorado River Basin**. Arizona Department of Water Resources (ADWR) website accessed December 22, 2018, http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/CentralHighlands/documents/volume_5_VRB_final.pdf ◄◄◄

This section of the Arizona Water Atlas provides information about the Coconino Plateau Basin, including the following:

- Topography
- Land ownership
- Climate – meteorological stations and Annual Precipitation
- Surface water – streamflow, flood ALERT, reservoirs and stockponds, runoff, perennial/intermittent streams, major springs,
- Groundwater – major aquifers, well yields, estimated natural recharge, estimated water in storage, number of index wells, last water-level sweep, groundwater flow, depth to water in selected wells,
- Water quality – well, mine, or spring sites that have exceeded water quality standards, lakes and streams with impaired waters, effluent dependent reaches,
- Water demand,
- Effluent generation, and

- Water adequacy determinations

Information that is useful for the ecosystem services assessment includes data for the Coconino County and Hopi Reservation portions of the Little Colorado River Basin. The only drawback of the Arizona Water Atlas volumes is that the information is somewhat dated, since they were published in 2009.

ADWR. 2009. **Arizona Water Atlas Section 5.5 – Verde River Basin**. Arizona Department of Water Resources (ADWR) website accessed December 22, 2018, http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/CentralHighlands/documents/volume_5_VRB_final.pdf ◄◄◄

This section of the ADWR Water Atlas contains the same types of data as Section 2.2 – Little Colorado River Basin (see above). Information that is useful for the ecosystem services assessment includes data for the Sycamore Canyon watershed and Oak Creek watershed portions of the Verde River Basin.

ADWR. 2009. **Arizona Water Atlas Section 6.1 – Coconino Plateau Basin**. Arizona Department of Water Resources (ADWR) website accessed December 22, 2018, http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/WesternPlateau/documents/Volume_6_COP_final.pdf ◄◄◄

This section of the ADWR Water Atlas contains the same types of data as Section 2.2 – Little Colorado River Basin (see above). The entire mapped area has information that is useful for the ecosystem services assessment. The designated major springs should be considered during Phase 2 of the ecosystem services assessment as potential long-term monitoring sites for water sustainability.

ADWR. 2015. **Final Hydrographic Survey Report for The Hopi Indian Reservation - In re The General Adjudication of the Little Colorado River System and Source**. Arizona Department of Water Resources (ADWR), 161 p.◄◄

The Arizona Department of Water Resources (ADWR) prepared this Final Hydrographic Survey Report (Hopi HSR) to address water rights claimed by the Hopi Tribe and the United States on the Tribe's behalf, for use on the Hopi Reservation. The report describes the surface water and groundwater resources of the Hopi Reservation based on ADWR investigation.

ADWR. 2018. **GIS Data and Maps**. Arizona Department of Water Resources (ADWR) website accessed December 10, 2018, https://new.azwater.gov/gis ◄

The data on this website was developed by the Arizona Department of Water Resources to give the public access to the Department's vast store of GIS and tabular data. Some if the data sources are discussed elsewhere in this report. Here is the list of all data sources.

Current GIS data available

- Irrigation Districts
- Irrigation Non-Expansion Areas
- Irrigation Grandfathered Rights
- Surface Water Filings
- Statements of Claimant
- Surface Watershed
- Strategic Vision
- Municipal Service Areas.

Tabular data (which contain location coordinates for building a GIS file)

- Groundwater Site Inventory (GWSI)
- Statement of Claimant Data
- Surface Water Data
- Wells 55 Registry

Interactive online searchable data and maps

- Assured and Adequate Water Supply
- Community Water Systems
- GWSI

ALRIS. 2012. **Geologic Formations**. Arizona Land Resource Information Services dataset accessed via AZ Geo Clearinghouse, July 2018, https://azgeo.az.gov/AZGEO/datasets/geologic-formations (Use search term "geologic".) ◄

This dataset includes polygons that represent the geologic formations. The data was created to serve as base information for use in GIS. The shapefile includes geology ID, frequency, age, and area.

ASLD. 2018. **External GIS Links**. Arizona State Land Department website viewed December 10, 2018, https://land.az.gov/mapping-services/alris/links ◄

The Arizona State Land Department provides links to some additional sources of GIS data. This "Links" webpage includes links to state and federal repositories with publicly available GIS data. Examples of data sources, not otherwise covered in this annotated bibliography but that may be useful for the ecosystem services assessment include the following:

<u>Online Mapping</u>

- ASLD Parcel Viewer
- GEO MAC Wildland Fire Support

<u>Other Data Resources</u>

- TIGER/Line Files US Census Bureau
- Arizona Department of Water Resources Hydro data for Arizona
- Arizona Department of Environmental Quality Records Center

AZGS. 2018. **Bibliography of Arizona Geology.** Arizona Geological Survey website accessed October 22, 2018, http://azgs.arizona.edu/azgeobib ◄◄◄

This searchable online database provides a wealth of detail about geology In Arizona. It can be searched by area, basin, watershed, and keyword. As an example of search results, Sharon Masek Lopez conducted a search using *area* – Oak Creek Canyon, *basin* – Verde River, *watershed* – Verde River, and *keyword* – hydrology. Search results revealed four documents:

Owen-Joyce, S.F. and Bell, C.K. 1983. *Appraisal of water resources in the Upper Verde River area, Yavapai and Coconino Counties, Arizona*. ◄◄

Levings, G.W. 1980. *Water resources in the Sedona area, Yavapai and Coconino Counties, Arizona* ◄◄

McGavock, E.H. 1968. *Basic ground-water data for southern Coconino County, Arizona* ◄

Feth, J.H. 1954. *Preliminary report of investigations of springs in the Mogollon Rim region, Arizona* ◄

These examples are all seminal works that are fundamental to our understanding of the hydrology of Oak Creek Canyon and the Verde watershed. However, most of the materials in the Bibliography of Arizona Geology are dated and might be superseded by later reports for which they are references. For Phase 2 of the ESA, Sharon Masek Lopez recommends conducting a thorough literature search using the Bibliography of Arizona Geology. Appendix A shows additional search results of 30 reports found using Area - Coconino Plateau, Basin - (none), Watershed - Colorado River, Little Colorado River, Verde River, and Keyword - aquifer, hydrogeology, and hydrology.

AZGS. 2018. **The Geologic Map of Arizona.** Arizona Geological Survey website accessed October 22, 2018, http://data.azgs.az.gov/geologic-map-of-arizona/ ◄

This interactive online map shows geologic units, unit contacts, quaternary faults, high-angle faults, detachment faults, and thrust faults. The map can only be viewed online and is not downloadable, which limits its usefulness.

Coston, Natalie. 2010. **Statistical Examination of Water Data in the Coconino Plateau for Use as Sustainability Indicators**. Northern Arizona University for the Coconino Plateau Watershed Partnership Technical Advisory Committee's (CPTAC) Sustainable Water Management Subcommittee. CPWP website accessed October 8, 2016, http://www.cpwac.org/SWBreports/coston2010.pdf ◄

Northern Arizona University (NAU) undergraduate student Natalie Coston ran statistical analyses of both raw and transformed water data for the CPWP. Datasets included precipitation and snowfall for Flagstaff Airport and Arizona Climate Division 2, SNOTEL data, stream flow for Wet Beaver Creek and Oak Creek, depth to groundwater at the Lake Mary well field wells, and Pacific Decadal Oscillation (PDO) index values for north

Pacific Ocean sea surface temperatures. A table summarized the results. The conclusion was that linear trend analyses yielded no significant findings for these datasets. Different data transformations and/or more sophisticated statistical analyses may be necessary to derive sustainability indicators from precipitation, streamflow, and groundwater level data.

Appendices are available on via a link on the password-protected website "Links to TAC and Sustainable Water Management Subcommittee reference material", https://www.cpwac.org/sustain.htm. Request password from Ron Doba.

Sharon Masek Lopez recommends reanalysis of PDO vs. precipitation and streamflow data. She found a significant relationship between September through December PDO index and Verde River flood magnitudes January through March. (Masek Lopez, SR, DE Anderson, and AE Springer. 2007. *Teleconnection of Verde River Geomorphology and Cottonwood-Willow Community with North Pacific Climate Patterns - The Pacific Decadal Oscillation.* Poster presentation, Twenty-First Meeting of the Arizona Riparian Council). PDO might provide predictive power for reservoir management. Also, in terms of gauging climate change, long-term trends in PDO should be evaluated.

Homer, C.C., Huang, L., Yang, B., Wylie and M. Coan. 2004 **National Land Cover Database, Land Cover - Superzone Five.** Desert Landscape Conservation Cooperative website accessed October 2018, https://dlcc.databasin.org/datasets/b6d86efd53ed4444a1f43ee310b1043c ◄◄

This raster dataset portrays land cover for the National Land Cover Database (NLCD) mapping superzone five, covering most of Arizona, western New Mexico, and small parts of Utah, Colorado, and Texas. The shapefile includes land cover type and count.

Navajo Nation. 2003**. Navajo Nation Drought Contingency Plan 2003**. Navajo Nation Department of Water Resources, 157 p. ◄◄◄

This Contingency Plan provides guidance to the Chapters and the federal agencies to take appropriate action to minimize drought impacts. It includes useful data about climate, precipitation, lakes and reservoirs, wells, and various types of water use. Although this report is dated, it could serve as a good platform for renewed discussions about water infrastructure needs for the western Navajo Nation.

NPS. 2018. **Integrated Resource Management Applications (IRMA) Portal**. National Park Service (NPS) website accessed December 22, 2018, https://irma.nps.gov/Portal/ ◄◄

The Integrated Resource Management Applications (IRMA) Portal provides easy access to National Park Service applications that manage and deliver resource information to parks, partners and the public. IRMA includes the following applications:

The Data Store - Find and download documents and datasets about natural and cultural resources in the parks.

AQWebPortal (Aquarius Web Data Portal) - Search and view continuous water quality and quantity data from NPS monitoring locations.

NPSpecies - Get species lists with the occurrence and status of species in more than 300 NPS national parks

STATS (Park Visitor Use Statistics) - Retrieve comprehensive graphs, reports, and statistics on historic, current, or forecasted park visitor use

PEPC (Planning, Environment & Public Comment) - Website that provides for public involvement in the NPS planning process, with links to planning and environmental documents used to guide park management

SRTS (Survey Request Tracking System) - Submit an OMB Information Collection request for conducting a social science survey at a national park and monitor the approval process

As examples of quick searches, the term "spring" for Grand Canyon National Park returned 166 results, and the term "water quality" for Walnut Canyon National Monument returned 65 results. Many item overlap both lists, including monitoring protocols and regional reports. For Phase 2 of the ecosystem services assessment, a thorough search should be conducted in IRMA for Grand Canyon springs data.

NRCS. 2018. **Geospatial Data Gateway**. USDA Natural Resources Conservation Service website accessed December 12, 2018, https://datagateway.nrcs.usda.gov/ ◄◄

The Geospatial Data Gateway (GDG) provides access to a map library of over 100 high resolution vector and raster layers in the Geospatial Data Warehouse. It is the One Stop Source for environmental and natural resources data, at any time, from anywhere, to anyone. It allows you to choose your area of interest, browse and select data, customize the format, then review and download. This service is made available through a close partnership between the three Service Center Agencies (SCA); Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA) and Rural Development (RD). Examples of data types available for Coconino County include: census, climate, LiDAR/DEM, place names, geology political boundaries, hydrography, hydrologic units, natural color ortho imagery, soils, topography and transportation. Data layers are ordered online. A link to a zip file is sent to the email address that you provide. The layers available at the Geospatial Data Gateway could provide fundamental baseline data for analysis within the ecosystem services assessment.

USGS. 2018. **Black Mesa Monitoring Program, Interactive Data Map**. U.S. Geological Survey website access September 21, 2018. https://az.water.usgs.gov/projects/BlackMesaMonitoringIMap/imap.html ◄◄

This interactive map contains spring, well, and surface water monitoring sites, primarily associated with the N Aquifer, and located within the Hopi Reservation and Black Mesa region. Data include well water levels, spring discharge, streamflow, and water quality. The interactive map contains descriptions of available data types for each site and links to the NWIS Web Interface for download of the data. Because this dataset is useful for multiple ecosystem service types (e.g. provisioning – water for drinking, industrial water use, regulating – water quality), it is listed here under "Other General Data."

USGS. 2018. **NLCD 2011 Land Cover Conterminous United States**. Raster data file. U.S. Geological Survey website accessed December 11, 2018, https://catalog.data.gov/dataset/nlcd-2011-land-cover-conterminous-united-states ◄◄

This GIS raster dataset depicts landcover for the conterminous United States. The raster for Arizona can be downloaded using a link on the website listed. The National Land Cover Database products are created through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium, which is a partnership of several federal agencies (www.mrlc.gov). Land cover types include the following:

Unclassified
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/scrub
Herbaceous
Hay/Pastures
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands

Inspecting the raster data, there appear to be some misinterpretations of land cover, especially in in mixed use areas. However, the data may be useful for water balance modeling purposes, since it extends across the full area of interest. The same data is also available from the Bureau of Reclamation's Conservation Planning Atlases. In the atlases, the land cover raster is clipped to the Southern Rockies and Desert Landscape Conservation Cooperative boundaries. These atlases are described in the "Regulating Services - Federal Projects and Programs" section below.

PROVISIONING ECOSYSTEM SERVICES

Drinking Water

Water Supply Data

ACC. 2018. **Water Company Annual Reports AND Water-Sewer Company Annual Reports**. Arizona Corporation Commission Utilities Division, website accessed October 8, 2018 https://www.azcc.gov/Divisions/Utilities/Annual%20Reports/water.asp ◄◄◄

Water company annual reports to the Arizona Corporation Commission include details about private water company operations. Details about water pumping, storage, delivery, and maintenance amounts are very useful. These number can often be used to assess system efficiency and leakage losses. Unfortunately, the reports are not all equally complete. Some water companies do a better job of providing extensive data. Some companies do not report that should. For the ecosystem services assessment, the annual reports could be evaluated to identify systems where efficiency could be improved, such as by repairing leaks, converting to wastewater reuse for landscaping, encouraging xeriscape, or promoting other water conservation measures.

ADWR. 2018. **Community Water System (CWS) Annual Reports**. Search ADWR's Imaged Records, CWSDoc, System Name, Annual Report Year. Website accessed October 8, 2018, https://infoshare.azwater.gov/docushare/dsweb/HomePage ◄◄◄

"Community water system" refers to any water system that has 15 or more service connections (hook-ups) or serves 25 or more people. (Water systems that serve less than 15 service connections or 25 people are considered private water systems and are not regulated by ADEQ or ADWR.) Through annual reports submitted by the water system owners, ADWR's InfoShare website provides detailed information about community water systems.

Each annual report form provides information about water system management, wells and/or surface water used, volume of water withdrawn and delivered, and the quantity delivered to various types of system connection (resident single or multi-family, commercial, turf, and other). These reports are very useful because they indicate water demand. To access annual reports, select "CWSdoc" in the Imaged Record drop down menu, enter the System ID or Name (as discovered using the interactive map listed above), select an annual report year, and designate the document type as "Annual Report."

ADWR. 2018. **Community Water Systems (CWS) Interactive Map**. Website accessed October 8, 2018, http://gisweb2.azwater.gov/cws ◄◄

This interactive map is a good way to identify community water systems in the CPWP area of interest. Once the systems are identified, then the ADWR Imaged Records can be queried for the annual reports. (See *ADWR. 2018. Community Water System (CWS) Annual Reports* above for instructions on querying images records.)

City of Flagstaff. 2018. **Report to the Water Commission, Year 2018 - Water, Wastewater, Reuse and Stormwater Annual Report, Including Historical Data and Graphical Trends**. City of Flagstaff Water Services Division Annual Report, May 14, 2018. 69 p. https://www.flagstaff.az.gov/DocumentCenter/View/58067/2018-Report-to-Water-Commission ◄◄◄

This is the most up to date report on City of Flagstaff water resources. It includes great historical data as well as current numbers for water supply, water use, and anticipated future water demand. The report provides details about city wells, Lake Mary, Inner Basin springs and wells, climate monitoring, reclaimed water, stormwater management, water conservation, Red Gap Ranch, and more. The City's report to the water commission will be a key reference in the Phase 2 ecosystem services assessment.

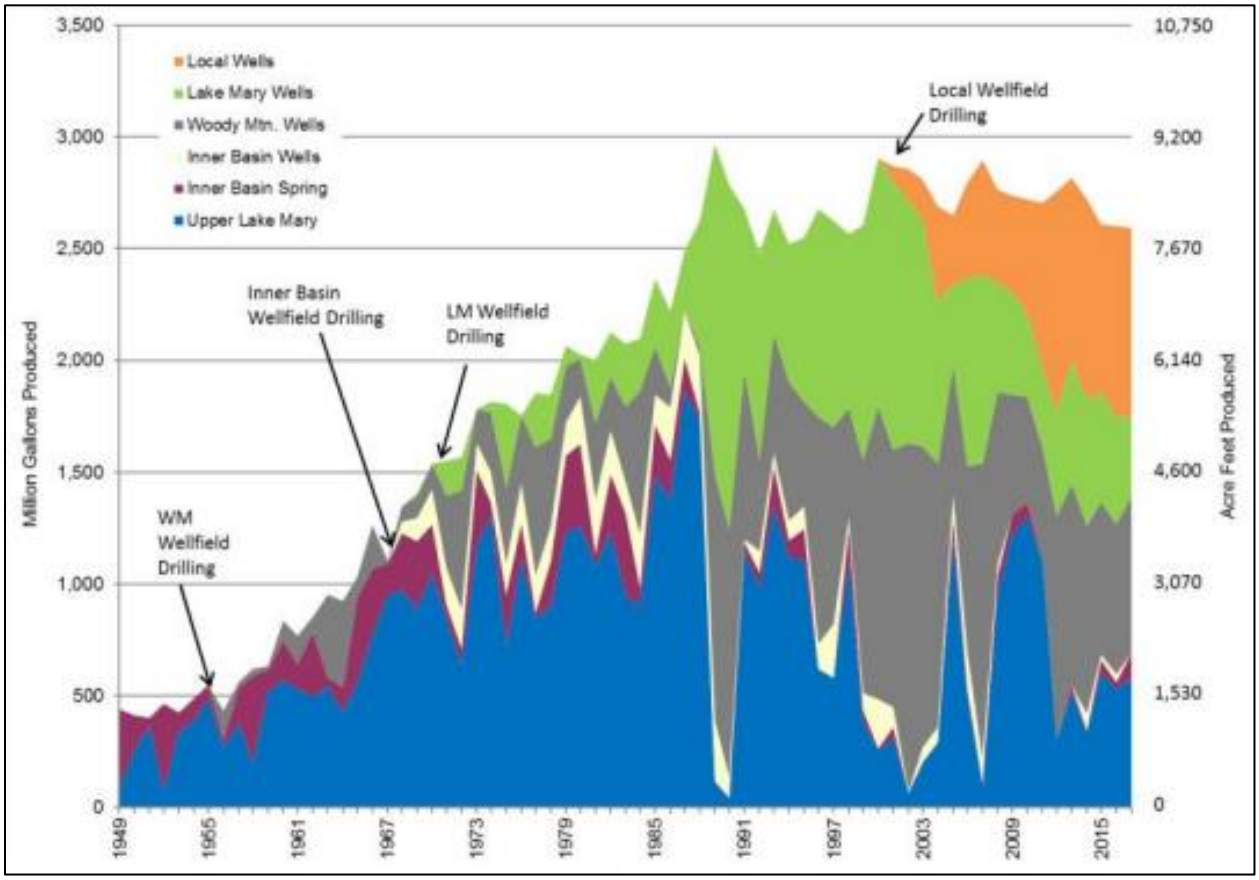

Figure 3. City of Flagstaff Water Sources - 1949 through 2017 (from Report to the Water Commission, Year 2018).

Stakeholders are concerned about wastewater reuse. Concerns include both the benefits and the potential impacts from wastewater reuse. Multiple water-related ecosystem services are affected by wastewater reuse, including the following:

Provisioning:	consumptive and non-consumptive water uses (benefit)
Cultural:	recreation (benefit)
Regulating:	habitat support (benefit),
	groundwater recharge (benefit), and
	water quality (potential impact).

Below, Table 2 provides data on Flagstaff's wastewater reuse delivery. See also the water quality section of this report for discussion of potential impacts of wastewater reuse.

Table 2. ***City of Flagstaff Reclaimed Water Direct Delivered in 2017*** *(City of Flagstaff's Report to the Water Commission Year 2018 - Water, Wastewater, Reuse and Stormwater Annual Report, page 9. See Water Supply Data section above for citation.)*

Recipient Categories	**Acre-Feet**	**Notes**
Golf Courses	926	Pine Canyon 288 AF, Continental 638 AF
Manufacturing	141	
Municipal parks, schools	137	
Commercial	105	
Northern AZ University	144	
Construction	77	reclaimed hydrant meters & standpipes
Residential	1	
Snowbowl	329	427 AF Nov '17 – Feb '18 ski season
Total Direct Delivered	**1,860**	
Discharged to Rio De Flag	4,517	Not included in total direct delivered

City of Flagstaff. 2018. **Water Resources**. Chapter Six in Flagstaff Regional Plan 2030. 20 pages. City of Flagstaff website accessed November 28, 2018, https://www.flagstaff.az.gov/DocumentCenter/View/48421/VI-Water-Resources?bidId= ◄◄◄

This report contains much useful data about City of Flagstaff water supply and water use. It provides information about water sources and how they will be used to meet future water demand. It also discusses surface water, including stormwater management and the Rio de Flag Flood Control Project.

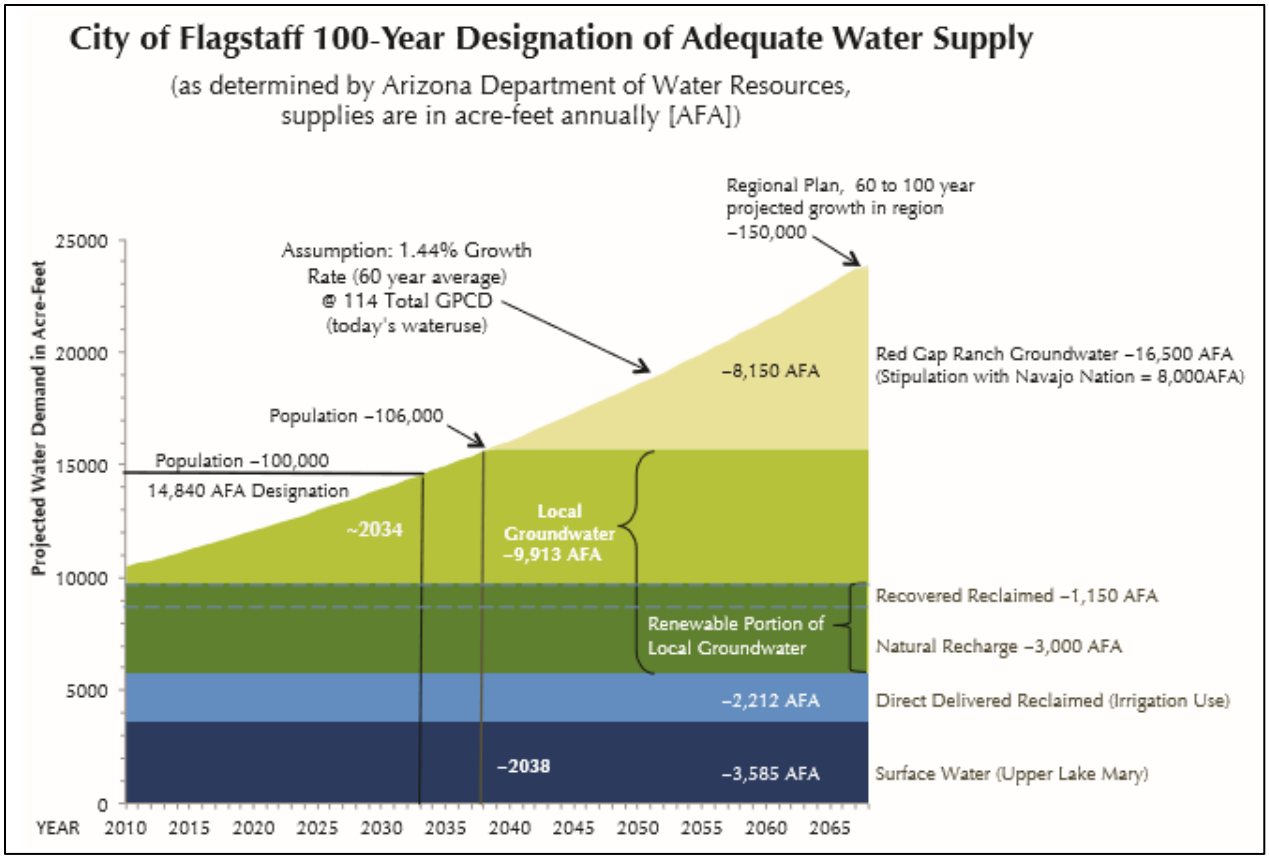

Figure 4. City of Flagstaff projected water demand through 2070 and how demand will be met (from "Water Resources", Chapter Six in Flagstaff Regional Plan 2030).

Navajo Access Workgroup. 2010. **Project Summary: Mapping of Water Infrastructure and Homes Without Access to Safe Drinking Water and Basic Sanitation on the Navajo Nation**. Prepared by Navajo Access Workgroup, charge by the multi-agency Federal Infrastructure Task Force to Increase Access to Safe Drinking Water and Basic Sanitation in Indian Country, 22 p. ◄◄

The data collection effort was conducted primarily by IHS and EPA, with support from other entities, including the Centers for Disease Control and Prevention (CDC), the Navajo Tribal Utility Authority (NTUA), the Navajo Public Water Systems Supervision Program, the Navajo Division of Community Development, and the Navajo Department of Water Resources (DWR). All data used for this mapping project were secondary data collected by other entities for different purposes, so data accuracy and completeness are difficult to estimate. These data should only be used at the pre-planning level.

Navajo Nation. 2011. **Draft Water Resource Development Strategy for the Navajo Nation**. Navajo Nation Department ff Water Resources, 114 p. ◄◄

This document details the lack of adequate domestic and municipal water, which is the greatest water resource problem facing the Navajo Nation. It includes proposed regional

and local water supply projects as well as rehabilitation and development of local irrigation and livestock water systems. The report provides maps of wells in the various aquifers. It also describes surface water resources.

WRDC. 2011. **Water Resources Development Commission (WRDC) Final Report, Volume I**. Arizona Department of Water Resources (ADWR) website accessed December 22, 2018, https://infoshare.azwater.gov/docushare/dsweb/Get/Document-7649/WRDC_Vol_I.pdf ◄◄

In 2010, the Arizona State Legislature passed House Bill 2661 that established the Water Resources Development Commission (WRDC). The WRDC was given the task of assessing Arizona's demand for water and the supplies available to meet those demands for the next 25, 50, and 100 years. The commission's final report Volume 1 presents findings of the Water Supply and Demand Committee and the Finance Committee and provides recommendations with regards to data analyses and further studies and evaluations.

WRDC. 2011. **Water Resources Development Commission (WRDC) Final Report, Volume II - Water Resources Development Commission Environmental Working Group Arizona's Inventory of Water-Dependent Natural Resources**. Arizona Department of Water Resources (ADWR) website accessed December 22, 2018, https://infoshare.azwater.gov/docushare/dsweb/Get/Document-7650/WRDC_Vol_II.pdf ◄◄

Volume 2 of the WRDC Final Report conveys the findings of the Environmental Working Group. It provides a new tool to evaluate the relationship between the state's waters and the environmental resources those waters support. The report is organized by groundwater basins. It discusses potential risks to water-dependent natural resources and provides recommendations.

Well Water Levels and Other Well Data

Arizona Department of Water Resources provides three sets of GIS data regarding wells: GWSI Sites, Index Wells, and Well Registry (Wells 55). These datasets can be accessed online via the ADWR website https://gisdata-azwater.opendata.arcgis.com/

ADWR. 2018. **Groundwater Site Inventory (GWSI).** Arizona Department of Water Resources website accessed October 12, 2018, https://gisweb.azwater.gov/waterresourcedata/gwsi.aspx ◄◄◄

GWSI provides groundwater level data for scientific use. Reported water levels have been collected by ADWR and USGS staff. These data are useful for evaluating trends in groundwater levels.

ADWR. 2018. **Index Wells.** Arizona Department of Water Resources website accessed October 12, 2018, https://gisdata-azwater.opendata.arcgis.com/datasets/c2f49270336244c4891e06f4a6b9fba9_0 ◄◄◄

Index wells are a subset of all GWSI sites. Approximately 1,700 wells are designated as "Index" wells statewide out of over 43,700 GWSI sites. Typically, index wells are visited once each year by ADWR field staff to obtain a long-term record of groundwater level fluctuations. In the CPWP area of interest there are 28 index wells, which provide good snapshots in time of water levels. Sixteen of these are pumping wells; twelve are unused for water supply and serve as observation wells. These observation wells are very valuable for monitoring aquifer trends, because the water level data are not confounded by drawdown due to pumping.

ADWR. 2018. **Well Registry Web (Wells 55 Database).** Arizona Department of Water Resources website accessed October 12, 2018. https://gisweb.azwater. gov/waterresourcedata/wellregistry.aspx ◄◄

Wells 55 provides well location and ownership. The records may include geologic data, well construction, initial water level, historic pumping data, associated water rights information, and well status. Location coordinates can be erroneous because of the historic use of a cadastral system. A shapefile of all Arizona Wells 55 locations was downloaded and clipped to the CPWP area of interest. Wells 55 can be a good source of initial water levels and can help provide an understanding of hydrogeology, but it lacks later water level data for assessing trends.

Macy, Jamie P., and Jon P. Mason, J.P. 2017. **Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2013–2015.** U.S. Geological Survey Open-File Report 2017–1127, 49 p. https://doi. org/10.3133/ofr20171127 ◄◄

This is a periodic report for U.S. Geological Survey monitoring of well levels, streamflow, and water quality associated with the N Aquifer on the Navajo and Hopi Indian Reservations. (This reference is also listed in the "*Water Quality*" section of this report.)

Marley, Bob, Bob Newcomer, and Nat Nutongla. 2004. **C-Aquifer Exploration Near Moenkopi, Arizona**. Poster by Bob Marley, Tetra Tech EMI, Albuquerque, NM Bob Newcomer, Golder Associates Inc., Albuquerque, NM and Nat Nutongla, Hopi Water Resources Program, Kykotsmovi, AZ Moenkopi for The Hopi Tribe. (Not available online. See files delivered with this report.) ◄

This poster includes geophysical data, downhole photos, a major ion chemistry piper diagram, and descriptive narrative to describe hydrogeologic attributes and water quality of the Moenkopi C Aquifer Well. It can provide insight into the challenges of tapping C Aquifer water for water supply on Navajo and Hopi Lands.

Navajo Nation. 2018. **Navajo Nation Wells.** GIS point shapefile provided by Navajo Nation Senior Hydrologist Carlee McClellan, June 2018. ◄◄◄

This shapefile includes 1019 data points for western Navajo Nation wells, including the Coconino Plateau Watershed Partnership area of interest. Because much of the well data were acquired by Navajo Nation from USGS, the shapefile also shows some wells on Hopi lands and lands west and south of the Navajo Nation. Shapefile attributes include:

Well No.	Aquifer	Well Use
Coordinates	Static Water Level	Location
Watershed number	Well Name	Data Source
Date completed	USGS ID	Operator
Elevation	Well Type	
Depth	Well Status	

This shapefile can be used to identify wells of interest. Additional data can be found in hard copy files at the Navajo Nation Water Resources Department, Water Management Branch in Window Rock. Contact Senior Hydrologist Carlee McClellan (cmcclellan@navajo-nsn.gov) for additional information.

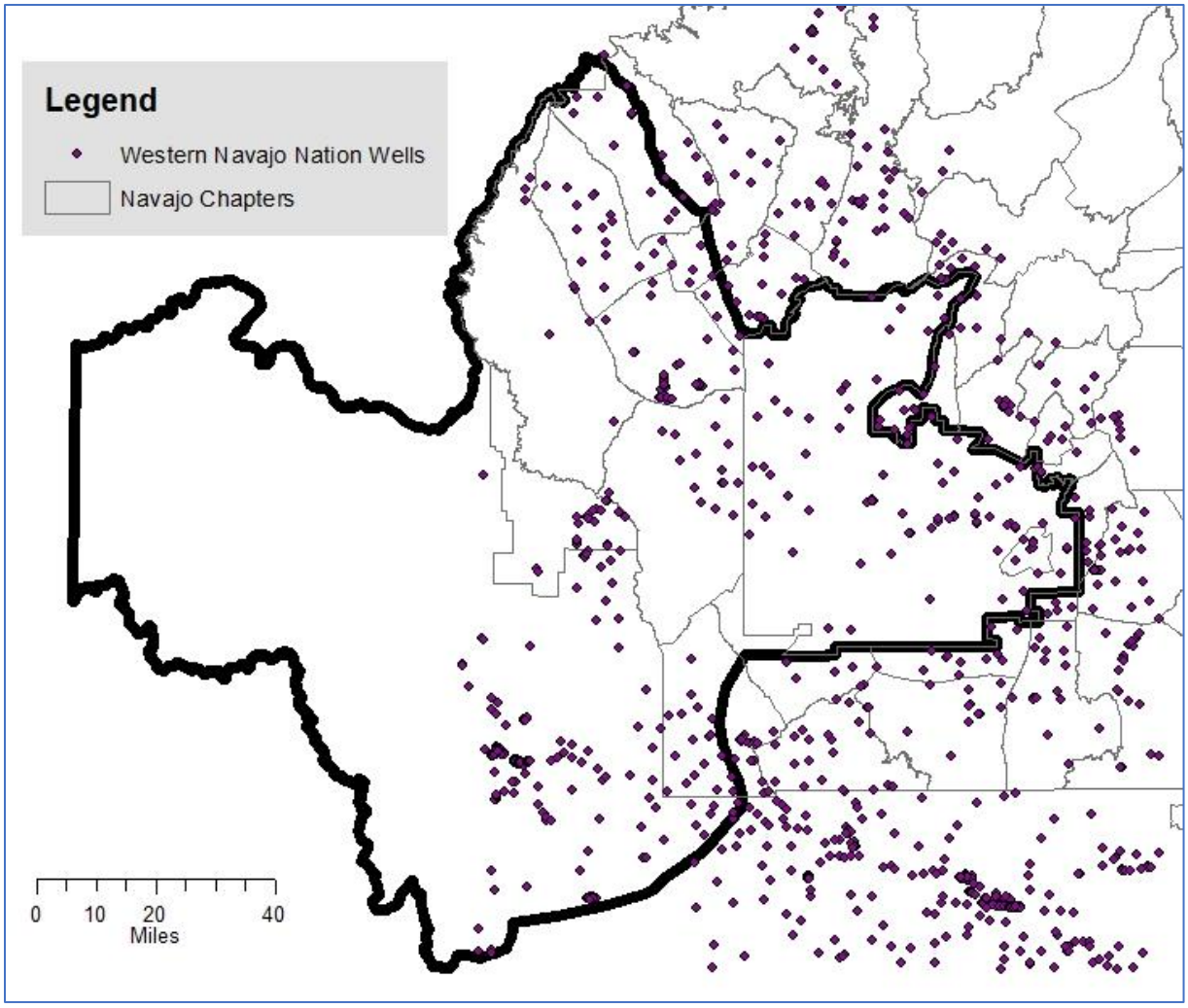

Figure 5. Wells in the Western Navajo Nation and surrounding areas (Map generated in ArcMap by Sharon Masek Lopez, using shapefile provided by Navajo Nation Water Resources Department).

Navajo Nation. 2018. **Navajo Well Data**. Personal communication from Carlee McClellan, Navajo Nation Water Resources Department, to Sharon Masek Lopez, June 2018 in Window Rock. ◄◄◄

Sharon Masek Lopez visited the Navajo Nation Water Resources Department, Water Management Branch in Window Rock in June 2018. She met Senior Hydrologist Carlee McClellan. Carlee showed Sharon the extensive collection of well data for wells on the Navajo Nation. These are hard copy files housed in fire-proofed filing cabinets at the Water Management Branch. The individual files include well construction data, geologic information, pump test results, and maintenance records. Some of these files date back many decades.

The majority of wells on the Navajo Nation are stock watering wells outfitted with windmills. Most of these were installed by Bureau of Indian Affairs in the mid-20th

Century. These wells are intended for livestock watering, but residents in remote parts of the reservation often haul drinking water from them. On the Navajo Nation there are also municipal water supply wells, monitoring wells, and other types of wells. Oil and gas wells are more common in the eastern Navajo Nation; there are none in the Coconino Plateau Watershed Partnership (CPWP) area of interest.

To access hard copy Navajo Nation well data, contact Carlee McClellan (cmcclellan@navajo-nsn.gov). Carlee recommended the U.S. Geological Survey's online National Water Information System (NWIS) database as the most readily available data source for wells on the Navajo Nation.

Tetra Tech. 2004. **Completion Report for Water Supply Well No. MC-1 (Moenkopi C Aquifer Well)**. Tetra Tech for The Hopi Tribe Water Resources Program. 15 p. (Not available online. See files delivered with this report.) ◄◄

To provide municipal water supply to the villages of Upper Moenkopi and Lower Moencopi, The Hopi Tribe contracted to construct and pump-test a C Aquifer well in 2003-2004. Tetra Tech's report details the geology, well construction, aquifer properties, and water quality of the C Aquifer well. In 2011, a reverse osmosis treatment plant was constructed to treat high total dissolved solids in water pumped from this well and water deliveries to the villages began. Because little data exists for the C Aquifer north of Cameron, Tetra Tech's report is valuable for characterizing the C Aquifer.

USGS. 2018. **NWIS – National Water Information System – Web Interface**. USGS website accessed May 2018, https://waterdata.usgs.gov/nwis/ ◄◄◄

The National Water Information System (NWIS) includes water resources data for surface water, groundwater, springs, and the atmosphere. The NWIS Mapper is a quick way to see data sites (https://maps.waterdata.usgs.gov/mapper/index.html). Sites may be active or inactive. NWIS is a fundamentally important data source for the ecosystem services assessment.

Wells – NWIS wells data are especially good for tribal lands. For other areas, GWSI and Wells 55 data are more complete (Fig. 6). For this Phase 1 ecosystem services assessment (ESA), well water levels and spring elevations from NWIS were combined with well water level elevations from GWSI and Wells 55 to generate a data interpolation surface for the R Aquifer (Figures 7). A similar interpolation was conducted to represent the C Aquifer using GWSI well water level data and one Hopi C Aquifer well water level. (Figures 8).

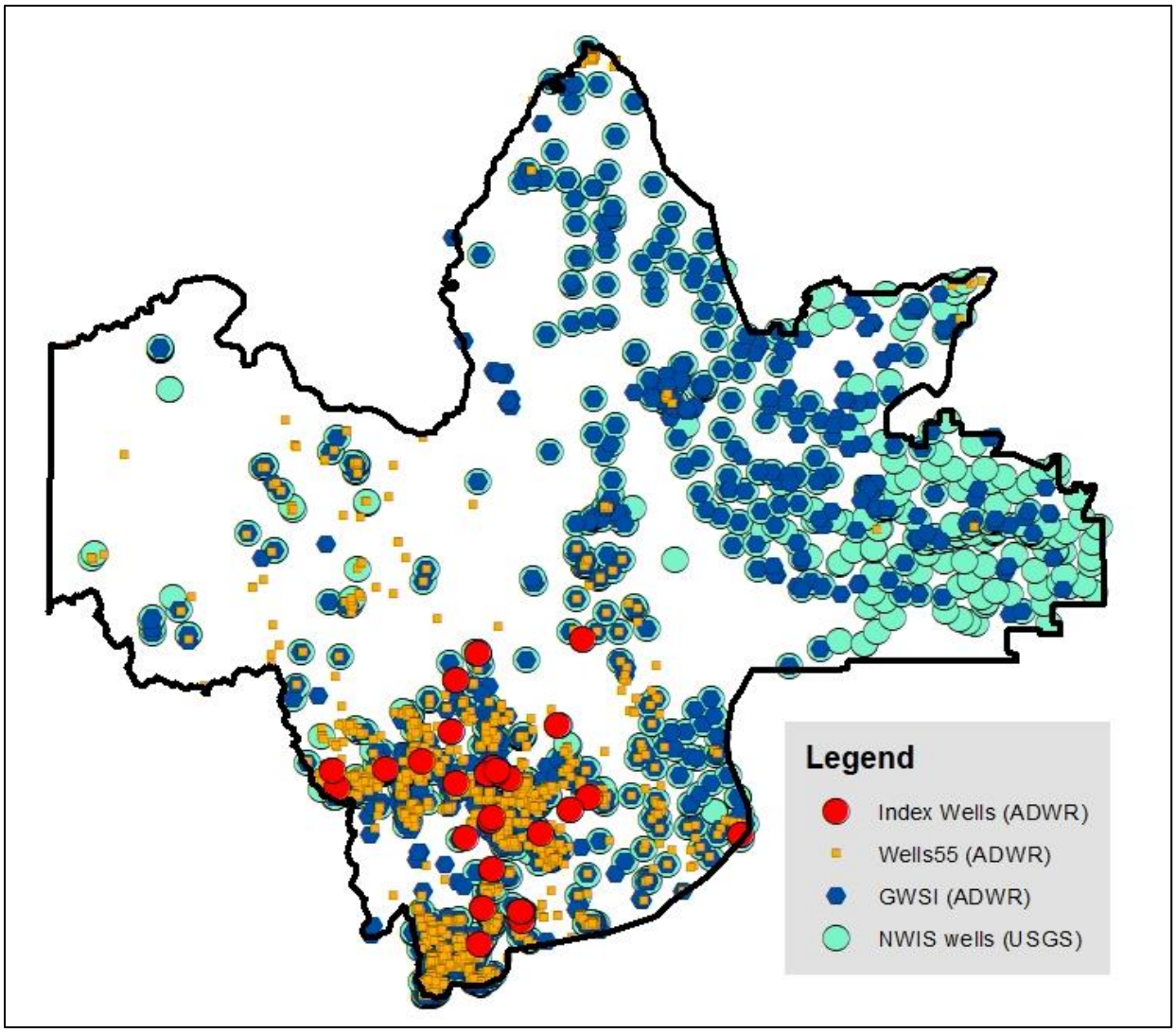

Figure 6. Well data points – ADWR (Wells 55, GWSI) and USGS (NWIS). (Map generated in ArcMap by Sharon Masek Lopez.)

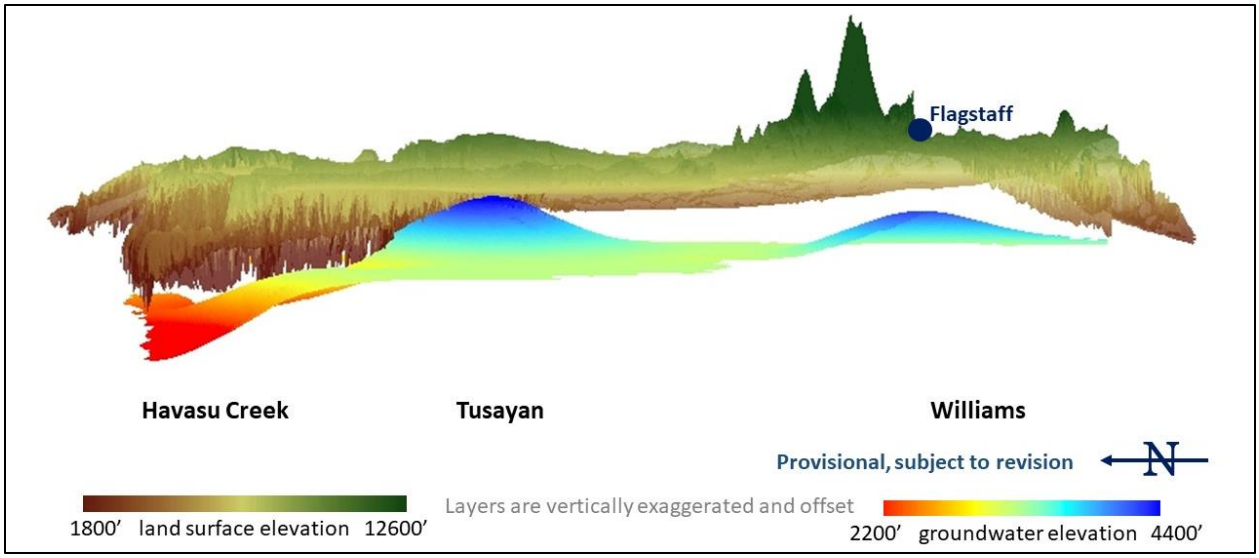

Figure 7. R Aquifer three-dimensional representation. (This is a data interpolation surface generated in ArcMap by kriging well water levels and spring elevations. The surface is displayed three-dimensionally in ArcScene. Image generated by Sharon Masek Lopez.)

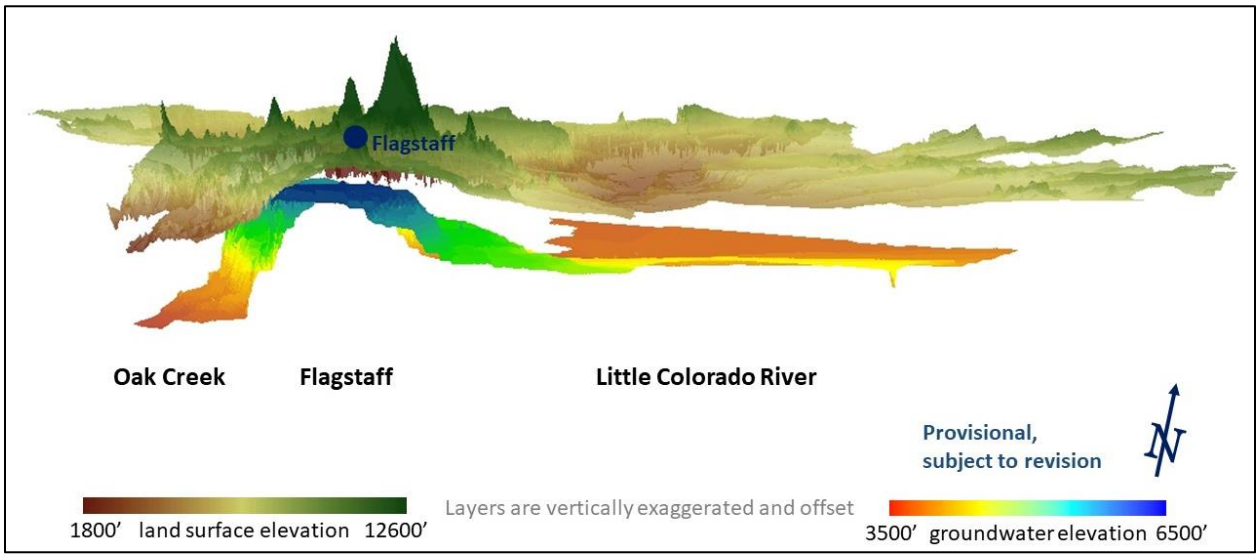

Figure 8. C Aquifer three-dimensional representation. (This is a data interpolation surface generated in ArcMap by kriging well water levels. The surface is displayed three-dimensionally in ArcScene. Image generated by Sharon Masek Lopez.)

Groundwater Characterization and Modeling

AMEC. 2012. **Final Groundwater Modeling Impact Analysis, City of Flagstaff - Water Resource Sustainability Study, Coconino County, Arizona**. Submitted by AMEC Environment & Infrastructure, Inc. to City of Flagstaff, July 12, 2012. Volume 1, 80 p, Volume 2 (figures), 110 p. (Not available online. See files delivered with this report.) ◄◄◄

As part of efforts to update their Designation of Adequate Water Supply (AWS), the City of Flagstaff commissioned a study to quantify current water supplies and make projections about how to meet water needs over the next 100 years. Adapting the Northern Arizona Regional Groundwater Flow Model (NARGFM), AMEC Environment & Infrastructure, Inc. (AMEC) generated a groundwater flow model for the Flagstaff and Red Gap Ranch (RGR) areas. The model-calibrated simulation presented in the report covers the period from 1910 through 2010 (the "transient calibration period"). The 100-year predictive simulations presented in this report span the period from 2010 through 2110. Two scenarios were modeled. Scenarios 1 and 2 simulated annual potable demands of 8,411 af/yr and 22,985 af/yr respectively and predicted C and R Aquifer drawdowns within a 10-mile radius of Flagstaff and RGR.

Because stakeholders have a strong interest in understanding groundwater flow and potential effects of pumping on springs, this modeling report merits close examination during Phase 2 of the Ecosystem Services Assessment.

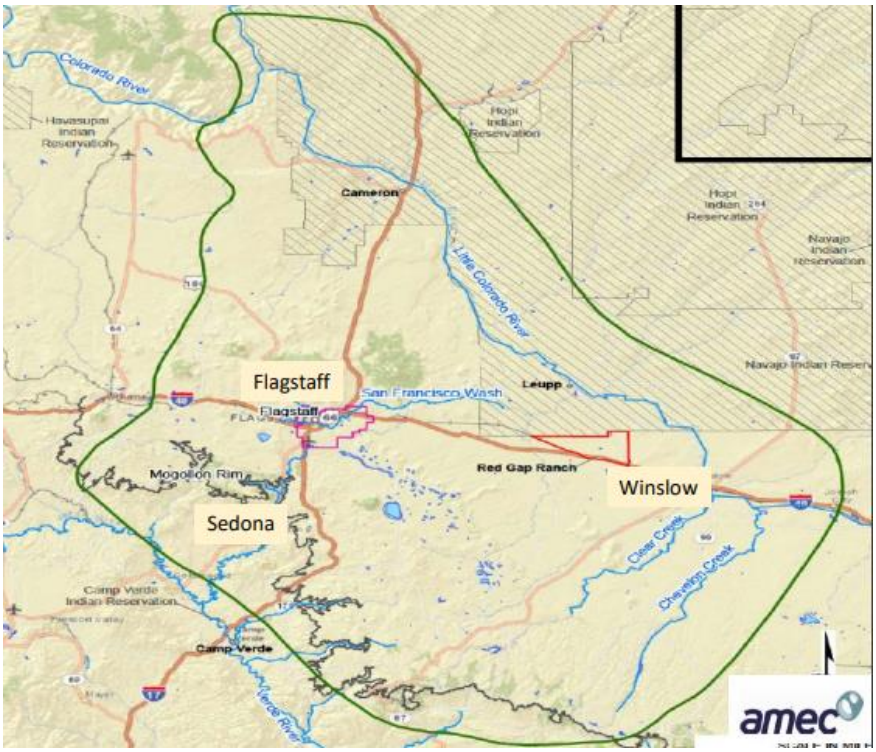

Figure 9. Groundwater model boundary for Water Resource Sustainability Study, Coconino County, Arizona (AMEC 2016).

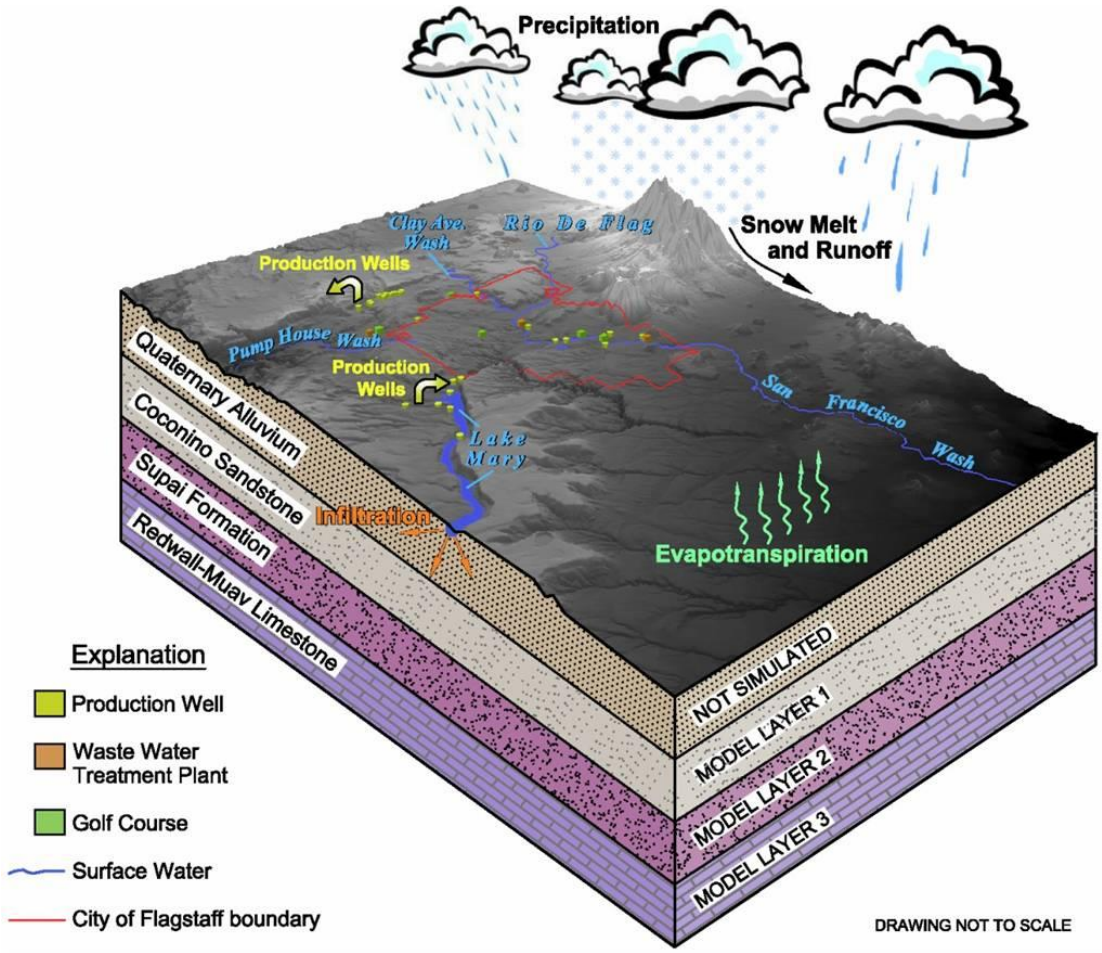

Figure 10. Conceptual diagram for detailed area of study of AMEC model for City of Flagstaff. (https://www.flagstaff.az.gov/2266/2012-Water-Sustainability-Study).

Bills, Donald J., Margot Truini, Marilyn E. Flynn, Herbert A. Pierce, Rufus D. Catchings, and Michael J. Rymer. 2000. **Hydrogeology of the Regional Aquifer near Flagstaff Arizona, 1994-1997**. USGS website viewed October 15, 2018, https://pubs.er.usgs.gov/publication/wri004122 ◄◄

This study characterized the C Aquifer in the Flagstaff area using remote sensing, geologic mapping, ground-penetrating radar, seismic methods, resistivity, well and spring inventories, borehole geophysics, well and aquifer tests, and water chemistry data. This is a good foundational document to understand the C Aquifer.

Brown, C.R., and Macy, J.P. 2012. **Groundwater, surface-water, and water-chemistry data from C-aquifer monitoring program, northeastern Arizona, 2005–2011**. U.S. Geological Survey Open-File Report 2012–1196, v.1.1, 38 p. U.S. Geological Survey (USGS) website accessed December 15, 2018, https://pubs.usgs.gov/of/2012/1196/ ◄◄

As part of an ongoing aquifer monitoring program, for thirty-five C Aquifer wells water levels were measured and water quality was tested. Fifteen wells ranged from about -0.2 to about -0.5 percent change in water level. For historical water-level data, changes in water levels were greatest around pumping centers, as indicated by a -97.0 feet for the Lake Mary 1 Well, which represents a -16.5 percent change from 1962 to 2005. The authors also tested water quality and examined streamflow records for Chevelon and Clear Creek.

Clear Creek Associates. 2018. **Well Siting Study Report Flagstaff, Arizona**. Prepared for City of Flagstaff by Clear Creek Associates, Scottdale, Arizona. 148 p. (Not available online. See files delivered with this report.) ◄◄

Clear Creek Associates, LLC conducted a well siting investigation to identify multiple favorable locations to be considered for installation of municipal water supply wells in the future. Sites investigated fell within a five-mile buffer around the City boundary. Hydrogeologic conditions within the Study Area were thoroughly assessed based on literature review, fracture trace analysis, and field reconnaissance. From the hydrogeologic conditions, a prioritization matrix was created and then refined by additional geophysical surveys, which resulted in the recommendations for siting future wells.

Hart, Robert J John J. Ward, Donald Bills, and Marilyn E. Flynn. 2002. **Generalized Hydrogeology and Ground-water Budget for the C Aquifer, Little Colorado River Basin, and Parts of the Verde and Salt River Basins, Arizona and New Mexico**. U.S. Geological Survey Water Resources Investigation Report 02-4026, 45 p. ◄

Groundwater budget components for the C Aquifer were evaluated using measured or estimated discharge volumes. Discharge from the C aquifer is estimated to be 319,000 acre-feet per year.

Hoffmann, J.P., Bills, D.J., Phillips, J.V., and Halford, K.J.. 2006. **Geologic, hydrologic, and chemical data from the C aquifer near Leupp, Arizona**. U.S. Geological Survey Scientific Investigations Report 2005–5280, 42 p. ◄◄

This report presents data and analyses from a study in support of a Federal effort to evaluate the C aquifer. Data collected for this investigation pertain to well construction, geology, aquifer tests, and water chemistry at three sites within the study area south and southwest of Leupp.

Leake, S.A., Hoffmann, and Dickinson, J.E. 2005. **Numerical ground-water change model of the C aquifer and effects of ground-water withdrawals on stream depletion in selected reaches of Clear Creek, Chevelon Creek, and the Little Colorado River, northeastern Arizona**: U.S. Geological Survey Scientific Investigations Report 2005-5277, 29 p. ◄◄◄

Groundwater modeling was conducted using two scenarios with differing withdrawal rates that were run for a 101-year period that included 51 years of withdrawals followed by 50 years of no withdrawals. The maximum streamflow depletion rate for all reaches in the scenario with the greatest withdrawal rates was computed to be about 0.6 cubic foot per second. The depletion rate was highest in lower Clear Creek, the reach that is closest to the well field.

Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F. 2011. **Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and Alluvial Basin Aquifer Systems of Northern and Central Arizona.** U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p. USGS website accessed October 9, 2018, https://pubs.usgs.gov/sir/2010/5180/ ◄◄◄

This report details the Northern Arizona Regional Groundwater Flow Model (NARGFM), which covers a broad area of the Colorado Plateau and Verde River watershed, including the CPWP area of interest. The website provides the report and groundwater modeling files. The "NARGFM Data Sets and Programs" link prompts the download of a zip package containing files used for the model (49.5 MB). Recommendation: Convert the model output files to GIS format for use in the Phase 2 Ecosystem Services Assessment. The City of Flagstaff's consultant Nathan Miller at Matrix Neworld may be able to assist in the file conversion.

Pool, D.R. 2016. **Simulation of groundwater withdrawal scenarios for the Redwall-Muav and Coconino aquifer systems of northern and central Arizona**. U.S. Geological Survey Scientific Investigations Report 2016–5115, 38 p. http://dx.doi.org/10.3133/sir20165115 ◄◄◄

The Northern Arizona Regional Groundwater Flow Model was used to estimate the hydrologic changes, including water-level change and groundwater discharge to streams and springs, that may result from future changes in groundwater withdrawals in and near the Coconino Plateau Water Advisory Council study area. The simulated period represented 2006 through 2105.

- Scenario 1 assumed no major changes in groundwater use except for increased demand based on population projections.
- Scenario 2 assumed that a pipeline will provide a source of surface water from Lake Powell to areas near Cameron and Moenkopi that would replace local groundwater withdrawals.
- Scenario 3 assumed that the pipeline would extend to the Flagstaff and Williams areas, and would replace groundwater demands for water in the area.

Scenario 1 simulated the most change in groundwater discharge for the Little Colorado River below Cameron and for Oak Creek above Page Springs where declines in discharge of about 1.3 and 0.9 cubic feet per second (ft^3/s), respectively, were simulated.

Southwest Groundwater Consultants. 2015. **Red Gap Ranch – Leupp Water Resources Environmental Assessment Groundwater Flow Model**. Prepared by Southwest Groundwater Consultants, Inc. for City of Flagstaff. 153 p. Coconino Plateau Watershed Partnership website accessed December 22, 2018, http://www.cpwac.org/generalfiles/RGRL%20Groundwater%20Flow%20Model.pdf ◄◄◄

This report describes the development of a groundwater flow model for the City of Flagstaff's Red Gap Ranch potential well field. The focus of the groundwater modeling effort was to assess the impact of proposed water withdrawals from the future well field on baseflow in the Little Colorado River, Clear Creek and Chevelon Creek and, in particular, those portions of the creeks noted by the USF&WS as habitat for the threatened Little Colorado spinedace. This study is important to review as part of the ecosystem services assessment, because it addresses potential impacts to stream baseflow.

USGS. 2011. **Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and Alluvial Basin Aquifer Systems of the Northern and Central Arizona**. U.S. Geological Survey website accessed October 14, 2018, https://pubs.usgs.gov/sir/2010/5180/ (See website's right sidebar to download zip file of model files). ◄◄◄

This is the Northern Arizona Groundwater Flow Model (NARGFM). It is a numerical flow model (MODFLOW) of the groundwater flow system in the primary aquifers in northern Arizona that was developed to simulate interactions between the aquifers, perennial streams, and springs. The model simulates predevelopment conditions that are assumed to be steady state, followed by nine transient stress periods that encompass the period 1910–2005. The model can be used by resource managers to examine the hydrologic consequences of various groundwater development and climate change scenarios for regions that are sub-basin or larger in area.

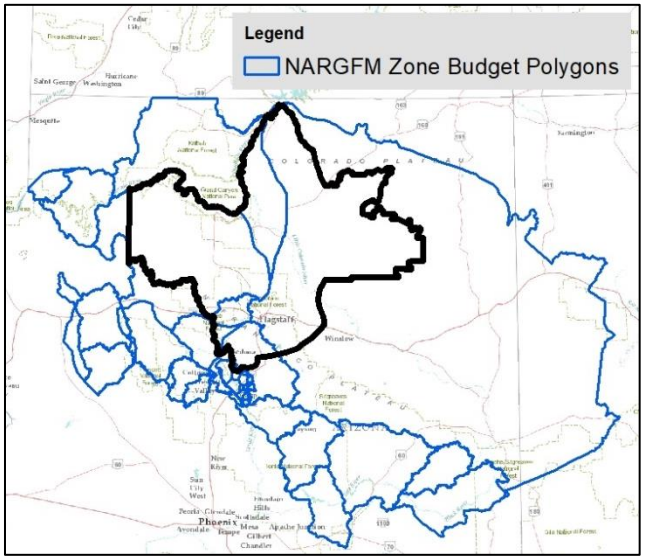

Figure 11. Northern Arizona Regional Groundwater Flow Model zone budget polygons overlain on the Coconino Plateau Watershed Partnership area of interest. (Map generated in ArcMap by Sharon Masek Lopez.)

Wilson, Eric, 2000. **Geologic framework and numerical flow models of the Coconino Plateau Aquifer, Grand Canyon, Arizona**. Northern Arizona University M.S. Thesis. 72 p. Available at NAU Cline Library. ◄◄◄

Wyatt, Clinton J.W., Frances C. O'Donnell, and Abraham E. Springer. 2015. **Semi-Arid Aquifer Responses to Forest Restoration Treatments and Climate Change**. Groundwater, 53 (2) 207–216. ◄◄◄

The purpose of this study was to develop an interpretive groundwater-flow model to assess the impacts that planned forest restoration treatments and anticipated climate change will have on large regional, deep (>400m), semi-arid aquifers in north central Arizona.

Zhu, Chen. 2000. **Estimate of recharge from radiocarbon dating of groundwater and numerical flow and transport modeling**. Water Resources Research, 36 (9) 2607-2620.

A case study of the N Aquifer showed that recharge estimates were within the bounds determined by chloride mass balance but are significantly higher than previous estimates derived from the Maxey-Eakin method. ◄

Water Supply Studies

YCWAC. 2011. **Central Yavapai Highlands Water Resources Management Study Phase II Water Resources Inventory Report**. Yavapai County Water Advisory Council, 59 p. ◄

The Central Yavapai Highlands Water Resource Managements Study (CYHWRMS) was an appraisal level study funded through a cost share agreement among the Bureau of Reclamation (Reclamation), the Arizona Department of Water Resources (ADWR) and the Yavapai County Water Advisory Committee (WAC). It contains useful data for the Oak Creek Watershed portion of the Coconino Plateau Watershed Partnership area of interest.

NPS. 2018. **Transcanyon Water Distribution Pipeline Grand Canyon National Park Environmental Assessment**. National Park Service (NPS) website accessed December 21, 2018, https://parkplanning.nps.gov/document.cfm?parkID=65&projectID=52237&documentID=91131 ◄

This environmental assessment evaluates alternatives for continued provision of water from the north side of the Colorado River to the south rim of the Grand Canyon. Most of the document addresses areas outside the Coconino Plateau Watershed Partnership area of interest. However, it does provide some useful background data about water treatment and distribution infrastructure on the south rim.

USBR. 2002. **Grand Canyon National Park Water Supply Appraisal Study**. Prepared by U.S. Bureau of Reclamation for Grand Canyon National Park, 50 p. USBR website viewed October 24, 2018, https://www.usbr.gov/lc/phoenix/reports/ncawss/allfiles/10_grandcanyon.pdf ◄◄

The Bureau of Reclamation conducted this appraisal study to develop potentially viable alternatives that would provide a treated water supply to the North and South Rims of Grand Canyon National Park through the year 2050.

USBR. 2013. **Central Yavapai Highlands Water Resources Management Study**. Yavapai County Water Advisory Committee website accessed October 15, 2018, http://www.yavapai.us/bc-wac/cyhwrms ◄◄

The Central Yavapai Highlands Water Resources Management Study (CYHWRMS) was an appraisal level study initiated by local communities in Yavapai County to assess future water supply and demand. Existing demands and population (2006) were defined and projected to 2050. Future demands (2050) were compared with supply scenarios to identify future unmet demands. Alternatives were developed to provide water for unmet demand; these alternatives were evaluated for viability. A federal interest in regional water resources planning was established. The study area includes Cornville and Sedona. Data for those areas could inform Phase 2 of the ecosystem services assessment.

USBR. 2016. **North Central Arizona Water Supply Feasibility Study**. U.S. Bureau of Reclamation website accessed October 9, 2018, https://www.usbr.gov/lc/phoenix/programs/NCAWSFS/NCAWSFStudy.html ◄◄◄

The focus of this study potential use of Lake Powell to augment water supply via pipeline delivery system options. The alternatives pursued included a mainstem ”Western Navajo Pipeline” from Lake Powell to Cameron, with spur lines to Keams Canyon and to Bitter to meet Navajo and Hopi tribal demands only. Appendix D Steady State Hydraulic Modeling files are available on request from Jeff Riley, Engineering Division Manager at the USBR Phoenix Area Office (623-773-6457, jriley@usbr.gov). The file sizes are large and will need to be sent via flash drive, external hard drive, or CD.

Sharon Masek Lopez had a phone conversation with Jeff Riley and Doreen Song of USBR. They discussed the North Central Arizona Water Supply Feasibility Study and how it could inform the CPWP ESA. Jeff and Doreen thought that the geologic information could be useful, as well as the potential community water demands that were projected into the future. Jeff emphasized that the project would supply water only for municipal and industrial uses, not agricultural use. However, he said that Navajo water sources are stressed in August and September when stockponds can be dry and lack of wind makes windmill tanks dry also. During these times, water haulers tap municipal supplies. Stress on municipal supplies can cause them to run out. He gave the example of water hauling

at Dilkon that exhausts the supply and causes ranchers to drive to Winslow for water. The NCAWS pipeline would provide flexibility in the system and reduce stock watering stress on municipal water supplies.

This report is important for addressing the stakeholder concern about underserved households within the CPWP area of interest. There are many homes in the western Navajo Nation that are without water service.

Water for Non-Drinking Purposes

See also data sources in the General Data section near the beginning of this document, especially discussion of industrial water use, irrigation, and stockwatering in chapters of the Arizona Water Atlas.

Irrigation

ADWR. 2000. **Chapter 3.4 Irrigation Uses, Verde River Watershed Study.** Arizona Navigable Stream Adjudication Commission website viewed October 15, 2018, http://www.ansac.az.gov/UserFiles/PDF/02232015/X057_SRP-ADWRandWatersedInfo/Arizona%20Department%20of%20Water%20Resources,%20Verde%20River%20Watershed%20Study%20(2000).pdf ◄◄

Chapter 3.4 of this report provides data about irrigation water uses in the Oak Creek Watershed. This data may be useful for determining impacts on ecosystems services from agricultural irrigation diversions.

City of Flagstaff. 2011. **City of Flagstaff Reclaim Distribution System with Reuse Sites**. Map. City of Flagstaff website accessed December 22, 2018, https://www.flagstaff.az.gov/DocumentCenter/View/14247/Reclaim-Master-Map-as-of-8-12-2011?bidId= ◄◄

This map shows routes of reclaimed water pipes in Flagstaff. Because the pipeline to Snowbowl is privately owned, it is not shown on the map. The map may be useful for ecosystem services assessment, if paired with wastewater reuse delivery volumes (*see City of Flagstaff. 2018. Report to the Water Commission, Year 2018* in the Water Supply Data section of this report).

Kampfe, Robert. 2018. **Requesting irrigation data from golf course turf managers or superintendents**. Personal communication of Bob Kampfe, retired golf course turf manager, and Sharon Masek Lopez. ◄

To learn irrigation rates for golf courses throughout the Coconino Plateau Watershed Partnership area of interest, retired golf course turf manager Bob Kampfe recommends going directly to each golf course and asking to talk with the turf manager or golf course superintendent. Water use to irrigate turf varies by season, temperature (elevation),

and grass type. Because golf course grass is short-cropped, course managers sometimes use additional water to ensure overcoming plant stress. The turf manager would be the best source of data on water use. Hopefully, through a friendly and open exchange that includes discussion about how informed water resources management might benefit golf courses, managers will be willing to share data. Because this could be a pleasant but somewhat time-consuming process, it might best be assigned to a student intern or volunteer.

Masek Lopez. 2018. **Upper Oak Creek Irrigation Ditches and Homesteads**. Unpublished map produced by H_2O Consulting for Sedona Heritage Museum. (Not available online. See files delivered with this report.) ◄◄

This PDF of a GIS-generated map portrays 24 currently-operating or historic irrigation ditches in the Red Rock area (Red Rock Loop Road), Sedona, and Oak Creek Canyon. The PDF file is scalable PDF file, so zoom in to see details. Sharon Masek Lopez and her associate Melissa Dyer mapped these ditches during Spring-Summer 2018 as part of a history investigation funded by a museum donor. The full data archive includes 24 historical summaries, investigation field notes (16 field investigations), notes and/or transcripts from informant interviews (22 interviews), water rights documents, other historic source documents, and over 2,000 photographs. The map and history archives could be useful to understand agricultural water use of upper Oak Creek.

Mueller, Julie M. Wes Swaffar, Erik A. Nielsen, Abraham E. Springer, and Sharon Masek Lopez. 2013. **Estimating the value of watershed services following forest restoration**. Water Resources Research,49: 1773–1781. doi:10.1002/wrcr.20163. ◄

Through contingent valuation (an ecological economics tool), researchers used a survey to determine Verde Valley irrigation water users' willingness to pay (WTP) for forest restoration that could benefit water availability. They found a positive and statistically significant WTP within their sample of $183.50 per household, at an aggregated benefit of more than $400,000 annually for 2,181 irrigators.

Industrial Water Use

See also General Data and Water Supply Studies sections of this report for data on water demand for industrial water use.

ADWR. 2009. **Arizona Water Atlas – Eastern Plateau (Vol. 2), Central Highlands (Vol. 5), and Western Plateau (Vol. 6) Planning Areas**. ADWR website viewed October 15, 2018, http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm ◄◄

The Arizona Water Atlas includes Industrial Water Use, which encompasses irrigation of golf courses using surface water, groundwater, and/or reclaimed water. The atlases may be useful in calculating water demand for golf courses and golf communities. In the

three volumes of the atlas, tables provide information about water adequacy determinations, including listings of golf courses and golf communities for which determinations have been made. These could serve as a guide for requesting more detailed information from the ADWR Assured and Adequate Water Supply Section (assuredadequate@azwater.gov, 602. 771.8599).

Stock Watering

ADWR. 2009. **Arizona Water Atlas – Eastern Plateau (Vol. 2), Central Highlands (Vol. 5), and Western Plateau (Vol. 6) Planning Areas**. ADWR website viewed October 15, 2018, http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm ◄◄

This water atlas reference is repeated from the Industrial Water Use section of this report. The three Arizona Water Atlas volumes also provide data on reservoirs and stockponds. This includes:

- Small Reservoirs (greater than 15-acre-feet and less than 500 acre-feet capacity,
- Other Small Reservoirs (between 5 and 50 acre-feet capacity), and
- Stockponds (up to 15 acre-feet capacity), from water right filings.

These data could help estimate total water demand for stockwatering in the CPWP area of interest.

External Water Use

Paterson, Willa, Richard Rushforth, Benjamin L. Ruddell, Megan Konar, Ikechukwu C. Ahams, Jorge Gironás, Ana Mijic, and Alfonso Mejia. 2015. **Water Footprint of Cities: A Review and Suggestions for Future Research**. Sustainability, 7: 8461-8490. doi:10.3390/su7078461◄

This scientific journal article discusses water footprint for use assessing cities' water resources use. Water footprint a conceptual framework that addresses direct and indirect uses of water from both local and external sources. Water footprint includes blue water (surface water and groundwater), green water (moisture in the soil-water evapotranspired through plants and soils), and grey water (water necessary to assimilate waste flows).

Rushforth, Richard and Benjamin Ruddell. 2013. **Trade in and valuation of virtual water impacts in a city: A Case Study of Flagstaff, Arizona**. Poster presented at American Geophysical Union Fall Meeting. Abstract available at http://adsabs.harvard.edu/abs/2013AGUFM.H11O..04R ◄

Using the Embedded Resource Accounting (ERA) framework, researchers examined the network of embedded water flows created through the trade of goods and services and economic development in Flagstaff, Arizona. They associated these flows with the

creation of value in sectors of the economy. Flagstaff has an external water footprint of 53,996 acre-feet of water. That is the amount of water used in other places to generate and supply goods are services that are sold in Flagstaff. The majority (84%) of this external water use is agricultural water for food production.

Water for Environmental Flow

Spring Discharge and Surface Water Flow

See also Springs Stewardship Institute Geodatabase and Springs Online database in the "*Maintaining Wildlife Populations and Habitats – Springs"* section of this report below.

City of Flagstaff. 2018. **Upper Lake Mary Watershed Monitoring Program**. Fact Sheet. City of Flagstaff website accessed December 29, 2018. https://az-flagstaff4.civicplus.com/DocumentCenter/View/56342/fact-sheet?bidId= ◄◄

Seven observational watersheds have been instrumented within the Upper Lake Mary Watershed to collect data for use in evaluating hydrologic effects of 4FRI forest restoration treatments. Flowtography and pressure transducers were installed in 2014 and 2015 to gauge surface water discharge. Also, three precipitation gauges have been placed in three of the seven watersheds. Salt River Project (SRP) maintains the gauges and collects and stores the data on contract to City of Flagstaff which owns the data. These data could be used to model soil and forest structure effects on surface water discharge and water availability to the Upper Lake Mary reservoir. Data are available by request to City of Flagstaff. Contact Water Resources Manager Erin Young at eyoung@flagstaffaz.gov or (928)213-2405.

Dunn, Cindy. 2018. **Page Springs Discharge Monitoring**. Personal Communication to Sharon Masek Lopez. ◄◄◄

Sharon Masek Lopez spoke with Page Springs Hatchery Program Manager Cindy Dunn on October 12, 2018. Cindy expressed that Salt River Project (SRP) had formerly monitored spring discharge of Cave Spring and Page Spring that provide water to the Page Springs Fish Hatchery and downstream irrigators. However, SRP monitoring has lapsed and now Arizona Game and Fish Department (AGFD) maintains the gauges for those two springs. This spring discharge data is an important monitor of aquifer response to human water demand and potential impacts to the aquatic and riparian ecological communities. Cindy Dunn can be reached at 928.451.5354 or cdunn@azgfd.gov to discuss how to acquire the AGFD spring discharge data.

Leake, Stanley A. and Jeanmarie Haney. 2010. **Possible Effects of Groundwater Pumping on Surface Water in the Verde Valley, Arizona**. U.S. Geological Survey Fact Sheet 2010–3108, 4 p. ◄◄◄

The USGS and The Nature Conservancy working collaboratively published this fact sheet. Usint the Northern Arizona Regional Groundwater Flow Model, they evaluated potential groundwater pumping effects on surface water and riparian areas.

SRP. 2018. **SRP Flowtography**. Brochure provided by Salt River Project Water Measurement Division. See also online description at https://www.watershedconnection.com/projects/flowtography ◄◄

Salt River Project's Flowtography™ is a method of recording stream depth using time-lapse photography and an event gauge located in the thalweg (deepest part of the channel) of a surveyed stream channel cross-section. Water depth is recorded by the camera at 15-minute intervals, including at night. Photo images are transmitted via satellite or cellular network, as well as manually downloaded. In the office, water depth is read from the image and used along with channel metrics to calculate stream discharge. Typically, pressure transducers provide a secondary measurement for flow at each site.

Within the CPWP area of interest, SRP has installed and maintains Flowtography™ gauges and pressure transducers to measure surface water discharge at fourteen sites on the Kaibab and Coconino National Forests:

- 4 Middle Sycamore observational watersheds
- 2 Lower Sycamore observational watersheds
- 7 Upper Lake Mary observational watersheds
- 1 Newman Canyon gauge, near its confluence with Upper Lake Mary

Thirteen of these sites are observational watersheds that were selected to evaluate hydrologic effects of the Four Forest Restoration Initiative (4FRI) forest thinning treatments. NAU identified the observational watersheds to represent varying intensities of thinning treatment, including three control watersheds.

There are six observational watersheds located south of Williams in the Sycamore Canyon watershed. They range in size from about 400 to 1600 acres. Also, SRP has installed and maintains 11 precipitation gauges within these observational watersheds. SRP retains its Flowtography and precipitation data collected in the Sycamore observational watersheds as confidential and proprietary, so these data are not publicly available.

Forest restoration treatments have not yet occurred at the observational watersheds. An eight-year (plus or minus one year) calibration period is in effect prior to treatments. However, because there is broad variability in pre-treatment conditions across the observational watersheds, the calibration period data could be used to ask and answer many research questions regarding hydrologic effects of edaphic (soils related) factors and forest structure. Modeling would be most robust if the SRP data were combined

with City of Flagstaff data from observational watersheds west of Upper Lake Mary. SRP collects, maintains, and houses these data and images in corporate servers under contract with Flagstaff, but the data is owned by the City.

This report's author, Sharon Masek Lopez, recommends that Coconino Plateau Watershed Partnership Technical Advisory Committee members discuss the possibility of paying to acquire SRP's datasets collected in Sycamore Canyon observational watersheds. Once acquired, the datasets could be made available to researchers to model hydrologic response to forest restoration practices.

SRP. 2018. **SRP Snowtography**. Brochure provided by Salt River Project Water Measurement Division. See also online description at https://streamflow.watershedconnection.com/Content/pdf/SRPSnowtography.pdf ◄◄

SRP Snowtography™ is a method for recording snow depth, snow duration, and environmental conditions over time using time-lapse photography focused on an event gage. The panoramic view of the surrounding landscape provides Four-Season Image Monitoring™. Images are transmitted via a satellite or cellular network, as well as manually downloaded.

SRP has established an array of nine snowtography stations along an elevational gradient in the vicinity of Stoneman Lake Road (Figure 12) for use in informing reservoir operations. Although this set of snow gauges is slightly outside the CPWP area of interest, it will provide perhaps the best monitoring in northern Arizona for changing snowfall and snowpack retention in response to climate change. Therefore, it could provide critical data for sustainable water resources management. As with the Flowtography data, SRP is currently retaining its Snowtography data and elevational vegetation survey data from these sites as confidential and proprietary.

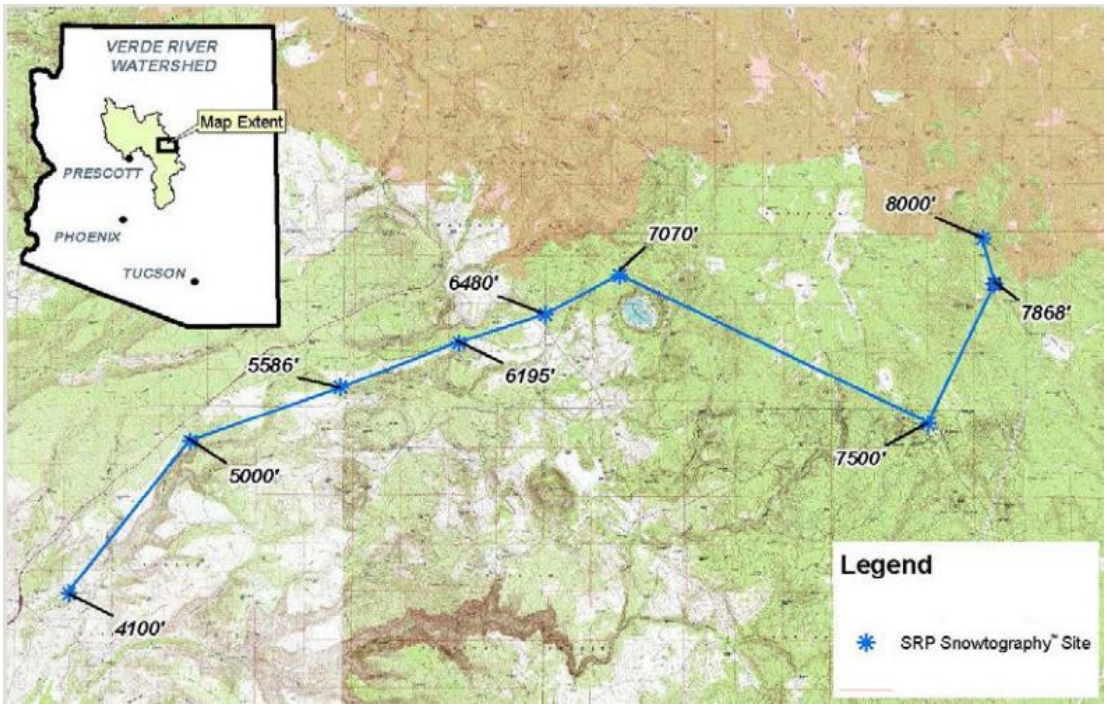

Figure 12. Salt River Project Snowtography™ elevational gradient near Stoneman Lake Road. (Map provided by Salt River Project.)

SRP. 2018. **Watershed Connection**. Salt River Project (SRP) website accessed October 13, 2018 https://streamflow.watershedconnection.com/ ◄◄

WatershedConnection.com is a website launched by Salt River Project (SRP) in 2017 to replace WatershedMonitor.com. It provides real-time data about hydrological and meteorological conditions for gauging stations maintained by SRP. In the CPWP area of interest, SRP gauge sites include the following:

- *JD Cabin near Williams* – precipitation gauge, 1989 to present ◄◄
- *Oak Creek near Sedona* (USGS gauge), streamflow 1981 to present, precipitation 1985 to present, ◄◄ (data available through NWIS)
- *Sterling Springs* – spring discharge as streamflow gauge at outflow of Sterling Springs Fish Hatchery, 2010 to present, and ◄◄◄
- *Bubbling Ponds* – spring discharge as a streamflow gauge, 2006 to present. ◄◄◄

Because these data are reported in real time and the online archive is only available for the past year, a data request must be made to SRP to access the older archival data. Make data requests through the website.

USFS. 2018. **Forests to Faucets**. U.S. Forest Service website accessed October 18, 2018, https://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml. ◄

The USDA Forest Service *Forests to Faucets* project provides GIS modeling and mapping of the continental United States to identify areas most important to surface drinking water. The GIS database addresses the role forests play in protecting these areas and the extent to which these forests are threatened by development, insects and disease, and wildland fire. This assessment provides information that can identify areas of interest for protecting surface drinking water quality.

Forests to Faucets promotes the idea of valuing drinking water as an ecosystem service. However, index values for importance of watersheds to drinking water appear heavily weighted by population served (e.g. water source areas for Phoenix received higher index values). For this reason, the indices might have limited value for the CPWP ecosystem services assessment.

USGS. 2018. **NWIS – National Water Information System – Web Interface – Surface Water**. USGS website accessed May 2018, https://waterdata.usgs.gov/nwis/sw ◄◄◄

The National Water Information System (NWIS) includes water resources data for surface water, groundwater, springs, and the atmosphere. The NWIS Mapper is a quick way to see data sites (https://maps.waterdata.usgs.gov/mapper/index.html). Sites may be active or inactive. NWIS is a fundamentally important data source for the ecosystem services assessment.

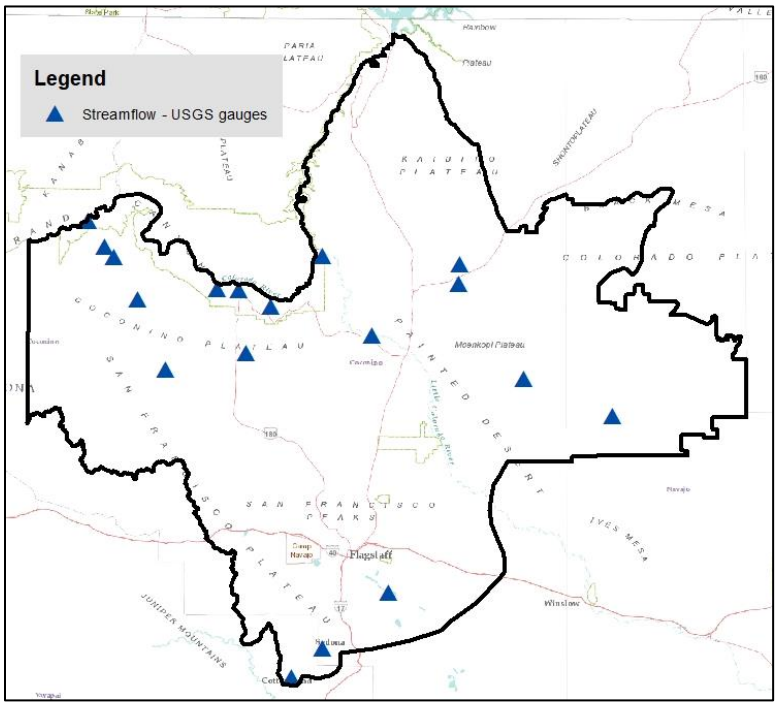

Figure 13. USGS streamflow gauging stations. (Map generated in ArcMap by Sharon Masek Lopez.)

Streamflow – The map at the left show USGS Steamflow Gaging sites, data for which is available online through the National Water Information System (NWIS). This is the most reliable and accessible source of streamflow data.

(See also NWIS springs data described and mapped in the *Maintaining Wildlife Populations and Habitats - Springs* section.)

Fisheries

AGFD. 2009. **Statewide Fish Management Team**. Arizona Game and Fish Department (AGFD), 54 p. ◄

The Watershed-based Fish Management Process (WFMP) provides a systematic, data-driven process that accommodates socio-political concerns, includes public involvement, and facilitates the development of fisheries management plans at various scales. This report provides recommendation of the Statewide Fish Management Team.

AGFD. 2018. **Arizona's Online Environmental Review Tool (ERT)**. Arizona Game and Fish Department (AGFD) website viewed October 15, 2018, https://azhgis2.esri.com/ ◄◄

Through this tool, the Arizona Game and Fish Department's Heritage Data Management System (HDMS) and Project Evaluation Program (PEP) work together to provide current, reliable, objective information on Arizona's plant and wildlife species locations and status. This environmental review and project planning website was developed and intended for the purpose of screening projects for potential impacts on resources of special concern. Users agree to the terms of use for the website. The information can be used to guide preliminary decisions and assessments of proposed land and water development, management, and conservation projects statewide, while incorporating fish and wildlife resource needs or features. The ERT is a good tool for locating basic data about species of concern for the ecosystem services assessment, with the caveat that data are more complete for sensitive species and sparse for non-sensitive species.

AGFD. 2018. **Fish survey data annual reports for selected creeks**. Acquire from individual Arizona Game and Fish Department (AGFD) fisheries biologists listed below. ◄

Per AGFD Fish Special Chuck Benedict and Wildlife Habitat Specialist Hannah Griscom, much of AGFD's ongoing fish survey data are in annual reports and nowhere else. These data are not publicly distributed and were not gathered together for Phase 1. If the fish survey data are deemed necessary for Phase 2 of the ecosystem services assessment, the consultant may obtain the data by reaching out to the following AGFD fisheries biologists:

- Oak Creek - Matt Rinker
- Sycamore Canyon - Matt Chmiel
- Lakes and reservoirs - Chuck Benedict

The AGFD Flagstaff office phone number is 928.774.5227.

Because fish presence and abundance depend on many factors, not the least of which are stocking, fishing pressure, and predation (especially of native fish by sports fish), fish survey data do not make good indicators of sustainable water resources management.

AGFD. 2018. **HabiMap**. AGFD website viewed October 15, 2018, http://www.habimap.org/ ◄

HabiMap is a user-friendly, web-based data viewer intended to make information contained within the State Wildlife Action Plan available to anyone interested in Arizona's wildlife for planning purposes. However, HabiMap is being phased out. Instead, project planners can use the Environmental Review Tool (ERT) to access sensitive species wildlife and plant data needed for environmental clearances. ERT incorporates HabiMap.

AGFD. 2018. **Heritage Data Management System (HDMS).** Arizona Game and Fish Department (AGFD) website viewed October 15, 2018, https://www.azgfd.com/wildlife/heritagefund/ ◄◄◄

HDMS information is available so Arizonans can make prudent decisions weighing future development, economic growth, and environmental integrity. HDMS is an AGFD data management system, available to the public on a limited basis through the Environmental Review Tool and more completely by data request. Requests can be sent to HDMS Program Coordinator Sabra Tonn by e-mail at stonn@azgfd.gov. Sabra's phone number is 623.236.7618.

This HDMS is part of a global network of more than 80 Natural Heritage Programs and Conservation Data Centers. HDMS has "element occurrences"[1] and "point observations" for plants and wildlife. Species data readily available on the HDMS website typically includes a three to seven-page species abstract and a map of species points observations, element occurrences, and predicted species range. Sometimes photos are included.

Fish species are included in the HDMS. However, the HDMS fish data do not reflect ALL of the fish surveys that have been completed, because some of those data are housed in individual fisheries biologist's records. Ranges of fish in a watershed can expand and contract quite a bit based on fluctuating river conditions, so AGFD generally refers to a species either occurring or not occurring in an entire watershed/subwatershed. Endangered and sensitive species datasets are more extensive than for non-sensitive species, especially after translocations or a change in management.

[1]An Element Occurrence (EO) is an area of land and/or water in which a species or natural community is, or was, present.

USFWS. 2014. **Gila River Basin Native Fish Program - Native Aquatic and Semi-Aquatic Species of the Gila River Basin.** U.S. Fish and Wildlife Service (USFWS) website viewed October 23, 2018, https://www.usbr.gov/lc/phoenix/biology/azfish/nativespecies.html ◄◄

In consultation with USFWS, U.S. Bureau of Reclamation operates the Gila River Basin Native Fish Program. This program was established as mitigation, after the Central Arizona Project (CAP) canals transported nonnative species that have impacted native fish since the mid-1990s. Located at the USBR Phoenix Area Office, Bill Stewart is the

program manager. Oak Creek and Sycamore Creek are in Bill's area. Bill can be contacted at 623.773.6252 or WStewart@usbr.gov. Sharon Masek Lopez spoke with him October 2, 2018.

The webpage cited here contains links to information about multiple aquatic and semi-aquatic species, including species status, distribution, and recovery plans. This is good background information for the ecosystem services assessment. Once species of interest are identified, the ESA Phase 2 consultant could follow up with USFWS and USBR to obtain specific datasets.

USFWS. 2018. **National Wild Fish Health Survey Database**. U.S. Fish and Wildlife Service (USFWS) website viewed October 15, 2018, https://ecos.fws.gov/wildfishsurvey/database/page/intro ◄

The USFWS National Wild Fish Health Survey Database (NWFHSDb) has been available to the public since September 2001. The database contains data on pathogen occurrence in free-ranging (wild) populations of fish. This data is collected via the National Wild Fish Health Survey, initiated in 1996 as a collaborative effort among U.S. Fish & Wildlife Service National Fish Health Centers and stakeholders such as tribes, states, and the aquaculture industry. The database is part of an effort to create an information system that will be a valuable tool for the management, protection, and recovery of aquatic ecosystems.

The NWFHSDb consists of two distinct components: 1. an internal database maintained and utilized by the Fish Health Centers for entering, tracking, and reporting data, and 2. a publicly accessible website. Data from each Fish Health Center is available on the website for display and download. The Region 2 Fish Health Center that serves Arizona is located in Pinetop, AZ. Contacts are John C. Thoesen, Phil Hines, and Jason Woodland at 928-367-1902.

Fish health data might be useful in the ecosystem services assessment as indicative of climate change effects on aquatic ecosystem health. However, this approach would need to be discussed in more depth with USFWS fisheries biologists.

Young, Erin. 2018. **Francis Short Pond Fish.** Personal communication to Sharon Masek Lopez, November 29, 2018. ◄

City of Flagstaff Water Resources Manager Erin Young provided information via email to Sharon Masek Lopez regarding fish at Frances Short Pond, which is supplied by reclaimed water from the City. A City water resources intern interviewed the Arizona Game and Fish Department (AGFD) office and was told that Francis Short Pond is the most popular fishing lake in the area. (Erin recommended asking AGFD for data from any fishing venues in northern Arizona). Information that the intern gathered from AGFD included the following:

"Thousands of anglers visit this lake every year, with estimates from Arizona Department of Fish and Game (ADFG) putting the total number of angling days at around 12,000. AZDFG also believes that a single angler day generates around 111 dollars for the community. That means that Francis short is generating 1,332,000 dollars every year just in fishing."

Young, Kirk L., E. Patricia Lopez, David B. Dorum. 2001. **Integrated Fisheries Management Plan for the Little Colorado River Watershed**. Arizona Game and Fish Department (AGFD), Phoenix. 194 p. ◄◄

The purpose of this plan is to provide fisheries personnel with a practical management decision tool. The plan provides site-specific (reach-level) management recommendations needed to meet AGFD's native fish and sportfish mandates. AGFD Wildlife Habitat Specialist Hannah Griscom thinks the species distribution models for fish are probably pretty good. They can be scaled to different watershed Hydrologic Unit Code (HUC) levels.

Aquaculture

Aquaculture is defined as the rearing of aquatic animals or the cultivation of aquatic plants for food. Three Arizona Game and Fish Department (AGFD) fish hatcheries and one private trout farm (Rainbow Trout Farm) produce fish within the CPWP area of interest. AGFD facilities include Pages Springs Fish Hatchery, Bubbling Ponds Fish Hatchery, and Sterling Spring Fish Hatchery. The Rainbow Trout Farm and all three AGFD facilities use spring discharge for hatching and rearing fish. They all discharge water to Oak Creek. Because the fish are raised for sport fishing and not exclusively for food, it is debatable whether these four facilities constitute aquaculture. Rainbow Trout Farm has a "no catch and release" policy. Customers pay for every fish caught, and every fish caught is cleaned for use as food. Therefore, the trout farm might be considered aquaculture.

Sharon Masek Lopez reached out to the Rainbow Trout Farm in Oak Creek Canyon to ask about the volume of fish produced annually; see entry below. Sharon also spoke with AGFD fish biologists Cindy Dunn who manages the Page Springs Hatchery and Dave Fox who manages the Sterling Springs Hatchery. Fish production at the hatcheries is highly variable from year to year and statistics are not readily available.

Of the thousands of fish that the state hatcheries produce at Oak Creek, most are distributed to streams and lakes throughout Arizona and some occasionally are sent out of state. Conversely, at times AGFD purchases fish from out-of-state hatcheries to stock lakes and streams in Arizona. Therefore, there is no direct correlation between hatchery production within the CPWP area of interest and fish available for food within the area of interest. In other words, the import and export of the aquaculture ecosystem services makes it very difficult to quantify

those services. Therefore, aquaculture would not make a good indicator of sustainable water resources management.

Gokey, Lydia. 2018. **Rainbow Trout Farm Fish Production**. Personal communication with Sharon Masek Lopez, December 12, 2018. ◄

Sharon Masek Lopez had a telephone conversation with Lydia Gokey, Manager of the Rainbow Trout Farm (928.282.3379). Lydia has been the manager for a year. She said she was disappointed to find that previous managers did not collect data and maintain records on fish production. Rainbow Trout Farm uses spring water for their trout rearing facilities and commercial fishing ponds. Downstream of the fish ponds, there are settling ponds, and the clarified water discharges to Oak Creek. They use no antibiotics in their operation, so it is okay to discharge to the creek. Each year the trout farm receives 100,000 eggs from a business in Washington state. They receive eggs every couple of months and continually have fish in different stages of growth.

This year Rainbow Trout Farm lost about 10,000 fish to otters. They tried unsuccessfully to live-trap the otters. (The otters took the bait but managed to not get caught.) So, the trout farm put electric fence around the raceways and eventually the otters left the area.

Concerning Water Rights

Some stakeholders interviewed by Dr. Kira Russo expressed interest in seeing a database assembled of water rights, showing dates of appropriation that indicate junior and senior rights. Although this may be useful information for some stakeholders, there are probably tens of thousands of surface water right claims within the Coconino Plateau Watershed Partnership area of interest, and compiling such a database would be an enormous task far beyond the scope of an ecosystem services assessment. For those interested in researching surface water right claims, summary data and the claims themselves are available from the Arizona Department of Water Resources online at https://new.azwater.gov/surface-water/queries. Queries can be made by:

- applicant name,
- surface water permit or certificate of water right,
- watershed,
- township, range, and section,
- type of surface water filing, or
- instream flow filings.

A good place to start searching for water rights claims may be to query for a Surface Water Report by Section, Township and Range. This report lists surface water filings and associated information within a section(s), township and range.

Adams, E. Charles. 2007. **Hopi Use and Development of Water Resources in the Little Colorado River Drainage Basin of Arizona: An Archaeological Perspective to 1700**. Prepared for The Hopi Tribe in Conjunction with Adjudication of Little Colorado River Water Rights by E. Charles Adams, Ph. D. Archaeological Research & Consulting Services. 152 p. ◄

REGULATING ECOSYSTEM SERVICES

Water Regulation - Groundwater Recharge

Because precipitation and variable climate conditions greatly influence groundwater recharge, climate data and climate change adaptation are addressed in this section. Geology, topography, landcover, and edaphic factors also influence groundwater recharge; some of these data sources were listed in the General Data section at the start of this report. The climate data listed in this section also apply to the next section "*Climate Change Adaptation and Disaster Risk Reduction*."

Climate Data

There are many sources of climate data. Different agencies and organizations collect, compile, and model climate data. Below are data sources relevant for CPWP. Be aware that some data may use WBAN (Weather-Bureau-Army-Navy) five-digit station identifiers. The WBAN identifier is used by NOAA's National Center for Environmental Information (NCEI) for digital data storage and general station identification purposes.

CoCoRaHS. 2018. **Community Collaborative Rain, Hail & Snow Network.** CoCoRaHS, Colorado State University, Fort Collins, Colorado website accessed August 2018, https://cocorahs.org/Stations/ListStations.aspx ◄◄

The CoCoRaHS network is a community-based network of volunteers working together to measure and map precipitation. The network originated at Colorado State University and is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF). Network locations are available online from the CoCoRaHS website. The saved shapefile, generated from a CSV file provided by Arizona State Climatologist Nancy Selover, includes site name, latitude, longitude, elevation, and precipitation for August 2018. Data for other months is available through the CoCoRaHS website.

Crimmins, Michael A., Daniel B. Fergusun, Jeremy L. Weiss, and Holly Faulstich. 2015. **Hopi Climate – An Overview to Support Drought Monitoring and Management**. University of Arizona, Climate Assessment for the Southwest (CLIMAS), 9 p. ◄◄

Data from two long-term weather stations on and around the Hopi Reservation were used to climate extremes that may be expected in the region. The report addresses

temperature and precipitation, aridity, paleoclimate variability, and short- and long-term drought.

Hereford, R. 2007**. Climate variation at Flagstaff, Arizona - 1950 to 2007**. U.S. Geological Survey (USGS) Open-File Report 2007-1410, 17 p. USGS website accessed December 22, 2018, https://pubs.usgs.gov/of/2007/1410/of2007-1410.pdf ◄◄

This report, written for the nontechnical reader, interprets climate variation at Flagstaff as observed at the National Weather Service (NWS) station at Pulliam Field (or Airport), a first-order weather station staffed by meteorologists. The report may be useful in the Phase 2 ecosystem services assessment in addressing stakeholder concerns about climate change.

Navajo Nation. 2018. **Navajo Nation Weather Stations and Precipitation Gauges.** Shapefiles provided by Navajo Nation Water Resources Department, Water Management Branch, Window Rock, Arizona. ◄◄◄

These two shapefiles show the locations of weather stations and precipitation gauges on the Navajo Nation. The locations are clipped to the CPWP area of interest with a buffer extending eastward to provide additional stations that could help improve potential data interpolation. For Navajo Nation weather and precipitation data contact Senior Hydrologist Carlee McClellan (cmcclellan@navajo-nsn.gov) at Navajo Nation Water Resources Department, Water Management Branch.

PRISM. 2018. **PRISM Climate Group Datasets.** Oregon State University PRISM Climate Group, Corvallis, Oregon website accessed June 2018, http://prism.oregonstate.edu/ ◄◄

PRISM datasets are high-resolution spatial climate data for the United States. They include max/min temperature, dewpoint, and precipitation. PRISM is a set of monthly, yearly, and single-event gridded data products of mean temperature and precipitation, max/min temperatures, and dewpoints. These raster data are spatially interpolated from point data. The table is a summary of the datasets available in Coconino and Yavapai counties. The table includes 30-year normal, annual values, single-month values, monthly values, and daily values of seven different measurements. PRISM is useful for evaluating spatial variability of climate.

Selover, Nancy. 2018. **Arizona Weather and Precipitation Stations**. Comma separated text file provided by State Climatologist Nancy Selover. ◄◄◄

State Climatologist Nancy Selover provided a comma separated text file with the location coordinates of all weather stations and precipitation gauges in Arizona. This text file was converted to a shapefile and clipped to the CPWP area of interest. Dr. Selover provided the following descriptions of the various climate data sources:

- **CoCoRaHS** – The Community Collaborative Rain, Hail & Snow Network is a citizen science network for precipitation only. Since the network's stations are located in people's yards and manually operated, there are few remote locations.
- **COOP** - The Cooperative Observer Program stations form the largest network. Overseen by the National Weather Service, observers at these stations record daily maximum and minimum temperature, plus precipitation. Each station observer collects data at the same time every day, although not all stations have data collected at the same time as other stations. For example, many station observers record data at 5 p.m. every day; others record at 7 a.m., or 8 a.m., noon, or so forth. Each station's daily data covers the 24 hours preceding its time of observation. Each observer maintains their regular time of observation.
- **NCEI** - The National Centers for Environmental Information in Asheville, NC is the repository for all the NOAA climate data.
- **NWS** - The National Weather Service operates first order and/or airport stations. They keep hourly data and include temperature, precipitation, dew point, wind speed and direction, and barometric pressure. There are many fewer stations in this network. These stations also get their daily maximum and minimum temperature and precipitation data reported, just like the other stations.
- **PRISM** is a climate modeling program that interpolates climate data between data collection stations. Operated by Oregon State University, PRISM stands for Parameter-elevation Regressions on Independent Slopes Model. PRISM utilizes data from RAWS, COOP, and all other National Weather Service stations (described above). PRISM also ingests the CoCoRaHS data daily (described above).
- **RAWS** - Remote Automated Weather Stations are operated by BLM and the U.S. Forest Service. They collect hourly data like the National Weather Service first order station, primarily for fire conditions (temperature, dew point, solar radiation, precipitation, wind speed and direction, fuel moisture and fuel temperature.) Those data are available through WRCC for Arizona. RAWS sites are located in more remote areas, typically at higher elevations in the watershed and forests.
- **WRCC** - The Western Regional Climate Center typically only gives monthly data, not daily. Those same stations' daily data can be pulled from NCEI.

WRCC. 2010. **Cooperative Observer Program (COOP).** Western Regional Climate Center (WRCC), Station Metadata, Reno, Nevada website access September 2018, https://wrcc.dri.edu/Monitoring/Stations/station_inventory_show.php?snet=coop&sstate=AZWebsite ◄◄

The Cooperative Observer Program is a network of volunteers that take daily weather observations. General information about the program is available at https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/cooperative-observer-network-coop. The COOP program is run through the

National Weather Service. The saved shapefile includes county, station name, latitude, longitude, elevation, and beginning and end date of data collection.

WRCC. 2018. **Remote Automated Weather Stations (RAWS) Network, Arizona: Station Data Inventory Listings**. Western Regional Climate Center website accessed July 2018, https://wrcc.dri.edu/Monitoring/Stations/station_inventory_show.php?snet=raws&sstate=AZ ◄◄◄

RAWS is a network of automated weather stations run by the U.S. Forest Service (USFS) and Bureau of Land Management (BLM) and monitored by the National Interagency Fire Center (NIFC). RAWS is mainly used to observe potential wildfire conditions, but it also contributes information for research applications. (See also RAWS website https://raws.nifc.gov/.) RAWS stations are often located in remote areas, particularly in national forests. The WRCC website lists Arizona network locations available online. A shapefile was generated which includes station name, elevation, latitude, and longitude.

WRCC. 2018. **Snow Telemetry (SNOTEL).** Western Regional Climate Center (WRCC) Station Metadata, Reno, Nevada website access July 2018, https://wrcc.dri.edu/Monitoring/Stations/station_inventory_show.php?snet=snotel&sstate=AZ ◄◄◄

The Snow Telemetry (SNOTEL) network includes stations located in remote, high-elevation mountain watersheds and monitor snowpack (snow depth, snow water equivalence), precipitation, temperature, and other climatic conditions. This network is part of the Snow Survey and Water Supply Forecasting Program that is administered by the Natural Resources Conservation Service (NRCS) National Water and Climate Center. Network locations are available online from WRCC. The saved shapefile includes site name, latitude, longitude, elevation, and start and end date of the station. Along with automated SNOTEL data, there are also manually collected data from snow courses.

Climate Change Adaptation and Disaster Risk Reduction

See also Greater Flagstaff Forest Partnership (GFFP) and Flagstaff Watershed Protection Project (FWPP) citations in the *Wildfire Protection* section in this report below. The main purpose of GFFP and FWPP forest thinning efforts is to reduce wildfire hazard in the wildland-urban interface. However, because the treatments also improve forest health, they help with climate change adaptation by making the forest less water-stressed and more resilient.

City of Flagstaff. 2012. **City of Flagstaff Resiliency and Preparedness Study.** City of Flagstaff website accessed October 22, 2018, https://www.flagstaff.az.gov/DocumentCenter/View/38841/City-of-Flagstaff_Resiliency-and-Preparedness-Study_May_2012?bidId= ◄◄

The City conducted the Resiliency and Preparedness Study to better understand how the impacts of local climate changes will directly affect City operations. Potential climate impacts were identified and vulnerability rankings were assigned for the following City operations: emergency services, energy, forest health, public health, stormwater, transportation, and water. Recommendations were made for climate adaptation and resiliency.

Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K. Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, and B.H. Udall. 2018. **Southwest.** In Impacts, Risks, and Adaptation in the United States: **Fourth National Climate Assessment**, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1101–1184. doi: 10.7930/NCA4.2018.CH25, https://nca2018.globalchange.gov/chapter/southwest ◄◄◄

The "Southwest" chapter of the "Fourth National Climate Assessment" is a sobering document. We can anticipate within the next fifty years that Arizona will become warmer, we will see more rain and less snow, and there will be more frequent extreme storm events and potentially higher severity and larger wildfires. These climate change effects will undoubtedly affect the hydrologic balance, bringing added uncertainty to water resources management. Implementing adaptation measures and emissions reduction actions are recommended, especially for indigenous peoples who rely on ecosystems that could be disrupted by climate change effects.

Mawdsley, Jonathan and Rachel Lamb. 2013. **Climate-Change Vulnerability Assessment for Priority Wildlife Species, Navajo Nation**. Prepared for the Navajo Nation Department of Fish and Wildlife (NNDFW) in collaboration with the H. John Heinz III Center for Science, Economics and the Environment, Washington DC, 49 p. https://www.indianaffairs.gov/sites/bia.gov/files/assets/public/pdf/idc2-060731.pdf ◄

The Navajo Nation Department of Fish and Wildlife (NNDFW) and the H. John Heinz III Center for Science, Economics and the Environment jointly developed a climate-change vulnerability assessment for priority wildlife and plant species and habitats on the Navajo landscape. The priority species and habitats included in this analysis were identified by the entire staff of NNDFW through a structured planning process. Animal and plant species were discussed, including salt cedar (Tamarix spp). This vulnerability assessment provides a conceptual framework for further climate adaptation planning on the Navajo landscape within an adaptive management context.

Nania, Julie, Karen Cozzetto, et al. 2014. **Considerations for Climate Change and Variability Adaptation on the Navajo Nation.** University of Colorado, Boulder, 212 p. https://www.indianaffairs.gov/sites/bia.gov/files/assets/public/pdf/idc2-060732.pdf ◄

This report provides information to the Navajo Nation and its communities for use in climate change and climate variability adaptation. It includes a synopsis of available information on climate changes currently being observed in the Southwestern United States and on the Navajo Reservation and introduces potential future climate changes in the Southwest. Nine key resource sectors are addressed: water, farming, range, health, tourism, biodiversity, forest, community infrastructure, and energy. For each sector information includes: 1) an introduction to the resource, 2) potential climate change and variability impacts on that resource, 3) an assessment of legal, political, economic, and other vulnerability and adaptive capacity factors that may contribute to or lessen impacts, 4) some potential adaptation strategies; and 5) an initial survey of funding options to facilitate adaptation planning and implementation efforts.

NOAA. 2018. **ThreadEx – NOAA Long-Term Station Extremes For America.** National Oceanic and Atmospheric Administration (NOAA) website viewed October 22, 2018, http://threadex.rcc-acis.org/ ◄◄

ThreadEx is a project designed to address the fragmentation of station information over time due to station relocations. Its purpose is to calculate daily extremes of temperature and precipitation. Since weather and precipitation stations are sometimes relocated, records from the various locations are *"threaded"* together to give a long-term continuous record from which extremes can be identified. These data are useful for assessing changes in the occurrence of extreme weather events and increasing temperature that are predicted with climate change.

O'Donnell, Frances C., William T. Flatley, Abraham E. Springer, and Peter Z. Fulé. 2018**. Forest restoration as a strategy to mitigate climate impacts on wildfire, vegetation, and water in semiarid forests**. Ecological Applications, 28(6) 1459–1472. ◄

This research was conducted on the North Kaibab. However, the concepts and findings are applicable to the CPWP area of interest. Researchers estimated that climate-induced vegetation changes will result in annual runoff declines of up to 10%, while restoration may reduce or reversed this decline.

USFS. 2018. **Four Forest Restoration Initiative (4FRI) Geospatial Data**. U.S. Forest Service (USFS) website accessed December 22, 2018, https://www.fs.usda.gov/main/4fri/gis ◄

The Four Forest Restoration Initiative (4FRI) is the largest forest restoration effort of its kind. Nearly 2.4 million acres of the Kaibab, Coconino, Apache-Sitgreaves and Tonto National Forests are being identified for a landscape-scale assessment to improve forest health and sustainability. The goals of the 4FRI are to 1) accelerate large restoration efforts to support natural fire regimes, healthy diverse forests and rangelands, and abundant populations of native plants and animals; 2) facilitate community fire protection and preparedness; and 3) enhance local economies through the use of excess trees.

This website provides links to geospatial data associated with 4FRI, including:

- 4FRI project boundary maps
- Task Orders of the Phase One Stewardship Contract
- 4FRI Projects Map
- Record of Decision web map
- All geospatial data from the 1st EIS – boundaries, vegetation and prescribed fire treatments, roads, spring restoration, and stream channel restoration.

Through restoration treatment effects on water balance, 4FRI will have significant impacts on several water-related ecosystem services, including Climate Change Adaptation and Disaster Risk Reduction.

Maintaining Wildlife Populations and Habitats

There are several classes of databases that compile information on flora, fauna, and habitats. Arizona Game and Fish has HabiMap, Environmental Review Tool (ERT), and Heritage Data Management System (HDMS), which were described above in the Fisheries section of this document, also apply to this section on Maintaining Wildlife Populations and Habitats. Various federal agencies have conducted assessments or have ongoing monitoring programs, such as the U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS) and U.S. Bureau of Reclamation (USBR). Specimen collections at museums and from other scientific endeavors are reliable data sources but may be dated (e.g. Integrated Digitized Biocollections**,** SEINet). Databases that make use of citizen science phone apps (e.g. NatureServe, iNaturalist, eBird) are up to date but tend to include redundant reports, and the reporting can be skewed by observer bias compared with scientific surveys. Each wildlife and habitat dataset has something valuable to offer. Some may be more strategically useful for the CPWP ecosystem services assessment than others.

Arizona Game and Fish Department (AGFD) Data Sources

AGFD. 2018. **Arizona's Most-Valued Hunting and Fishing Locations v.1.0**. Arizona Game and Fish Department (AFGD) website viewed December 28, 2018, http://azgfd.maps.arcgis.com/apps/MapSeries/index.html?appid=72ef284e22ab441b81c72472409c5d24&autoplay ◄

This online map conveys results of the Sportsmen's Value Mapping (SVM) Project. For this project, 7,500 randomly selected Arizona hunters/anglers were contacted and 1200 respondents mapped their most valuable hunting and fishing spots. In the Coconino Plateau Watershed area of interest, Upper Lake Mary and Mormon Lake are highly valued for waterfowl, cold water fish and warm water fish. In addition, Oak Creek Canyon is highly valued for cold water fish.

AGFD. 2018. **Environmental Review Tool (ERT)**, Arizona Game and Fish Department website accessed October 19, 2018, https://azhgis2.esri.com/ ◄◄

The ERT is on online mapping and report tool used primarily for project planning purposes where environmental clearances are needed. Users log in and create a project by drawing a polygon or uploading a shapefile. A report can be downloaded using the "generate report" tab on the project page. In the map viewer, maps can also be generated for export as image files, but data cannot be downloaded as GIS files. Data points are not available, because most of the data are for sensitive species. Instead, HabiMap predictive models provide distribution maps of potential occurrence. For more specific data and for GIS layers, a data request must be made to HDMS.

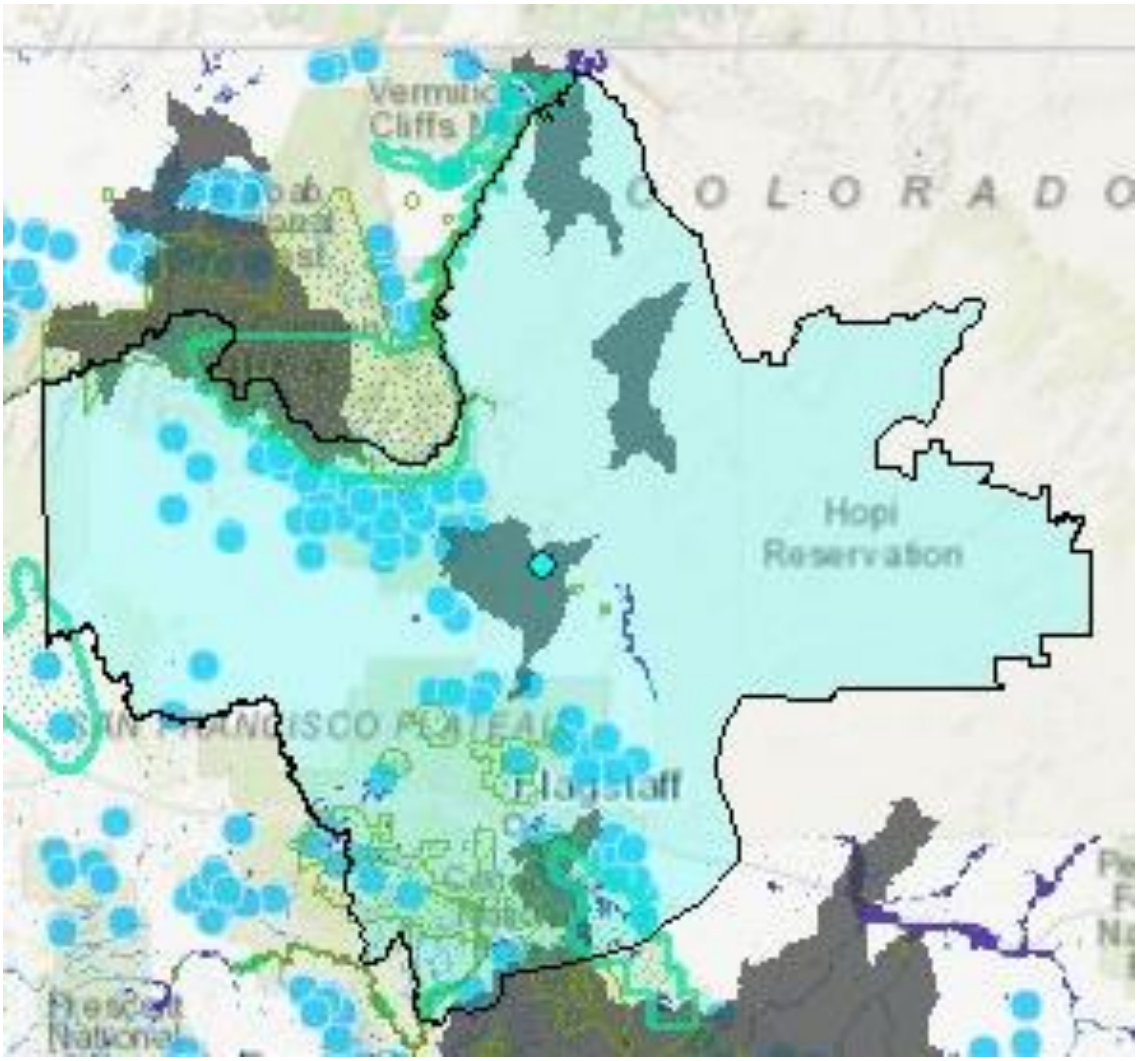

Figure 14. Example of a map generated by the Environmental Review Tool (ERT). Blue outlined polygons – Important Bird Areas. Solid grey pixels – Northern Leopard Frog distribution. Dark blue pixels – high riparian value. Blue dots – wildlife waters.

AGFD. 2018. **HabiMap.** Arizona Game and Fish Department website accessed October 19, 2018, http://www.habimap.org/ ◄

HabiMap is composed of predictive models that show the likely distribution of species. It is being incorporated into and replaced by ERT. Use ERT instead.

AGFD. 2018. **Heritage Data Management System (HDMS).** Arizona Game and Fish Department website accessed October 19, 2018, https://www.azgfd.com/wildlife/heritagefund/ ◄◄◄

Heritage Data Management System **(**HDMS) is a state-wide central repository of site-specific data on special status species. This is a clearinghouse for rare species information; data come from many sources including federal, state, and tribal agencies, museums and herbaria, academia, literature, Heritage Grant reports and sightings from knowledgeable individuals. It is a dynamic database with data being added and corrected daily. HDMS has information about the taxonomy, ecology, biology and status of all vertebrates and many rare plants and invertebrates in Arizona. HDMS is part of a global network of more than 80 Natural Heritage Programs and Conservation Data Centers. A presentation that provides a good description of the Arizona's HDMS can be found at the website (viewed October 18, 2018) https://defenders.org/sites/default/files/publications/overview_of_arizona_heritage_data_management_system.pdf

Once a report and map have been generated using the Environmental Review Tool, additional detail may be found on the HDMS website by using the species lists. Distribution maps and biological abstracts are available for species. Additional data and GIS layers can be requested from the HDMS. Landowner permission is needed to acquire point data. Requests can be made to Program Director Sabra Tonn (stonn@azgfd.gov, 623.236.7618).

After extensive conversations with AGFD biologists, for the purposes of the ecosystem services assessment, the author of this report, Sharon Masek Lopez, recommends that HDMS data requests focus on macroinvertebrates and obligate wetland plants that are associated with springs. Other plant and animal species have too many confounding variables affecting presence/absence and abundance data.

Federal Projects and Programs

Stortz, Sasha, Clare Aslan, Tom Sisk, Todd Chaudhry, Jill Rundall, Jean Palumbo, Luke Zachmann, and Brett Dickson. 2018. **Natural Resource Condition Assessment: Greater Grand Canyon Landscape Assessment.** Natural Resource Report. NPS/GRCA/NRR—2018/1645. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2253268 ◄◄

The Greater Grand Canyon Landscape Assessment (GGCLA) used a trans-boundary, collaborative, and spatial approach to assess resources across an analysis area determined by watersheds rather than administrative boundaries. The effort included both natural and cultural resources in the region. There was extensive tribal outreach and engagement to address the ethnographic importance of natural resources.

This is a useful data source for wildlife and habitat data for the Grand Canyon, but it is also a good source for cultural data. [See related LCI 2013 reference in "Spiritual, Inspirational, and Symbolic Appreciation" section of this report.]

Stortz, Sasha. 2018. **Data Gallery - Greater Grand Canyon Landscape Assessment**. USBR DataBasin website accessed October 25, 2018, https://databasin.org/galleries/8ce8106a09d7492fb491667358512b1d ◄

This online data gallery provides supporting materials for the Greater Grand Canyon Landscape Assessment, which is a coordinated assessment effort of Northern Arizona University's Landscape Conservation Initiative and Grand Canyon National Park. This data gallery provides fundamental ecological data for Grand Canyon National Park. However, the data layers mainly focus on terrestrial ecosystems; there is a lack of data about springs and seeps. Therefore, the data gallery has limited use for the water-related ecosystem services assessment.

Folders and files in the data gallery are as follow:

- Administrative Boundaries – Watersheds, Map Extent, Land Management, Geographic Areas, GGCLA Analysis Area
- Landscape – Ecological Integrity, Biorichness, Fire Regime Condition Class
- Prioritization – Priority Areas Below the Rim, Priority Areas Above the Rim
- Stessors – Tour Overflights, Cheatgrass Occurrence Probability
- Visitor Experience – Wilderness Character, Visitor Use by Backcountry Unit, Recreational Resources, Natural Sound Level, Natural and Anthropogenic Sound Level, All-sky Light Pollution Rio, Change in Acoustic Environment
- Wildlife – River Avifauna, Mountain Lion Habitat Quality, Mule Deer Habitat Quality, Mule Deer Habitat Connectivity, Bighorn Sheep Habitat Quality, Bighorn Sheep Habitat Connectivity.

USBR. 2018. **Conservation Planning Atlas.** U.S. Bureau of Reclamation Southern Rockies Landscape Conservation Cooperative (LCC) and Desert LCC websites accessed October 22, 2018, https://srlcc.databasin.org/ AND https://dlcc.databasin.org/ ◄◄

The LCC Conservation Planning Atlases provide platforms to access and integrate geospatial data sets, maps, and information for use in analysis and conservation planning. A search tool can be used to find datasets for plant and animal species, ecology, landcover, and many more themes. There is a large amount of GIS data

available, but much of it is not applicable to a water-related ecosystem services assessment for the Coconino Plateau Watershed Partnership area of interest. For locations south of the Mogollon Rim, search the Desert LCC Conservation Planning Atlas. For locations north of the Mogollon Rim, search the Southern Rockies Conservation Planning Atlas.

USFS. 2018. **Oak Creek Watershed Restoration Environmental Assessment**. Coconino National Forest website accessed October 22, 2018, https://www.fs.usda.gov/nfs/11558/www/nepa/107958_FSPLT3_4396936.pdf ◄

The Oak Creek Watershed Restoration Environmental Assessment is a programmatic environment assessment (EA) that covers multiple watershed improvement projects. On page 50, "Table 9. Determinations for Forest Service sensitive species" provides a list of sensitive aquatic and riparian wildlife species within the project areas. The list includes lowland leopard frog, desert sucker, Sonoran sucker, roundtail chub, California floater, Page springsnail, a mayfly, and a caddisfly. These species might make good indicators of sustainable water resources management in the ecosystem services assessment.

USFWS. ____. **Comprehensive Assessment & Monitoring Program (CAMP).** U.S. Fish and Wildlife Service (USFWS), *reference not found, source not rated*.

A U.S. Bureau of Reclamation fisheries biologist recommended looking at data in the U.S. Fish and Wildlife Service Comprehensive Assessment and Monitoring Program (CAMP). A search was conducted, but no CAMP information could be found for Arizona.

USGS, ADEQ, and AGFD. 2007**. Ecological Assessment of Streams in the Little Colorado River Watershed, Arizona, 2007**. U.S. Geological Survey (USGS), Arizona Department of Environmental Quality (ADEQ), and Arizona Game and Fish Department. 42 p. ◄◄

As part of the Regional Ecological Monitoring and Assessment Program grant project, the ecological condition of the Little Colorado River (LCR) watershed was assessed based on the biological, chemical, and physical habitat data collected from 30 randomly selected wadeable perennial stream locations within the LCR basin. A large proportion of the assessed LCR stream length was found to be in most disturbed condition with respect to biotic indicators of ecological condition. The most pervasive stressors observed were non-native aquatic vertebrate species, non-native crayfish, and habitat integrity.

Natural History Collections

iDigBio. 2018. **Integrated Digitized Biocollections**, iDigBio website viewed October 19, 2018, https://www.idigbio.org/portal/ ◄◄◄

The Integrated Digitized Biocollections (iDigBio) is a national resource for Advancing Digitization of Biodiversity Collections (ADBC) funded by the National Science

Foundation. Through ADBC, data and images for millions of biological specimens are being made available in electronic format for the research community, government agencies, students, educators, and the general public. This database would likely be a good source for baseline data for those species that are determined to be important for the ecosystem services assessment.

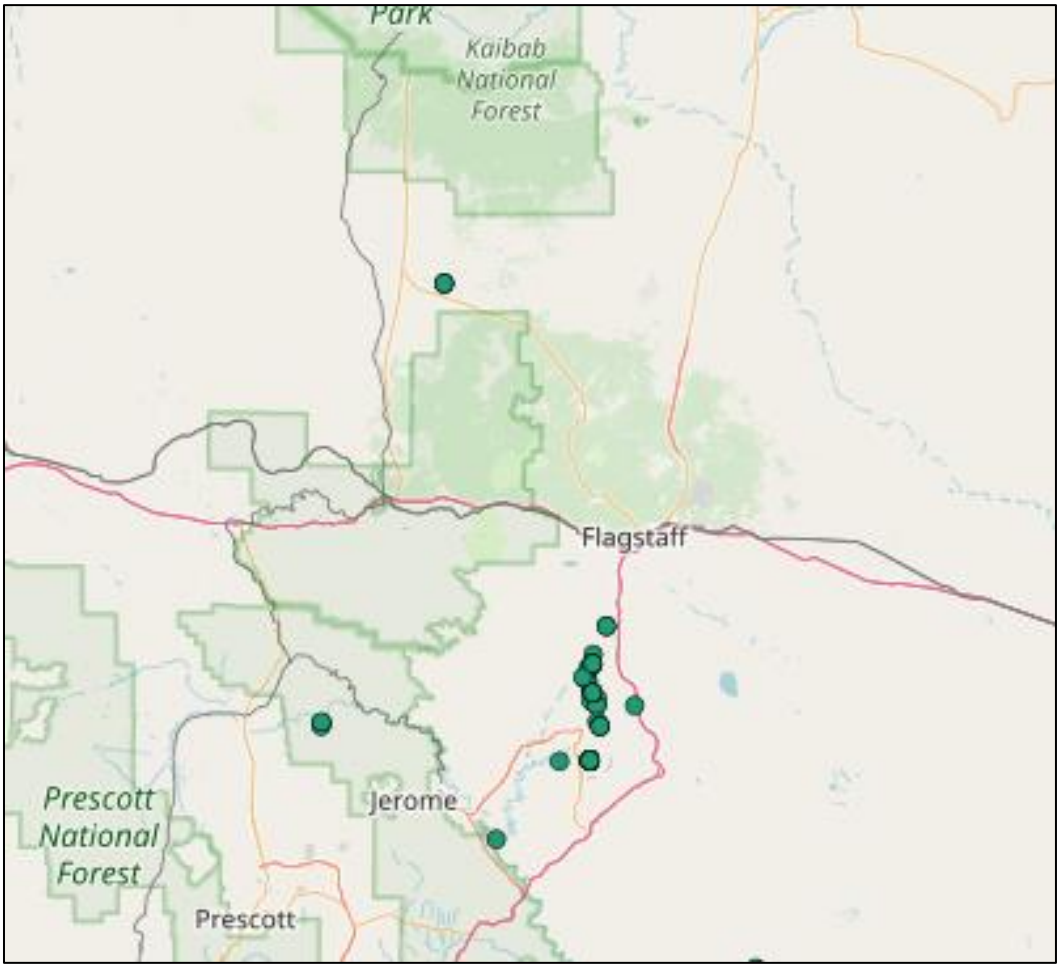

Figure 15. Example map output from iDigBio – Narrow-headed garter snake (Thamnophis rufipunctatus) museum specimen collection points.

SEINet. 2018. **SEINet – Arizona – New Mexico Chapter.** Southwestern Environmental Information Network (SEINet) website accessed October 19, 2018, http://swbiodiversity.org/seinet/index.php ◄◄◄

Supported by the National Science Foundation, the Southwestern Environmental Information Network (SEINet) is a fully integrated portal network for plant data. It is a suite of data access technologies and a distributed network of collections, museums, and agencies that provide environmental information. The Arizona-New Mexico Chapter is one of ten regional North American portals, each of which represents a unique perspective of the research community. The Southwest portal sponsors are Arizona

State University and University of New Mexico Herbarium. Data from all projects within the network are configured to access a single shared database.

Sharon Masek Lopez recommends that the consultant who completes Phase 2 of the ecosystem services assessment speak with ecologist Dr. Larry Stevens (Springs Stewardship Institute) and botanist Glenn Rink (Far Out Botany). Ask for recommendations on reference materials regarding wetland plants. Also, ask them for a discrete list of obligate wetland plant species that would serve as the best indicators of wetland/spring health in north central Arizona. Particular attention should be given to plants that are sensitive to hydrologic conditions (as opposed to sensitivity to other stressors such as grazing pressure). Occurrences and collections of these plants as recorded in SEINet could serve as baseline data for long-term monitoring to gauge water resources management impacts on springs and wetlands.

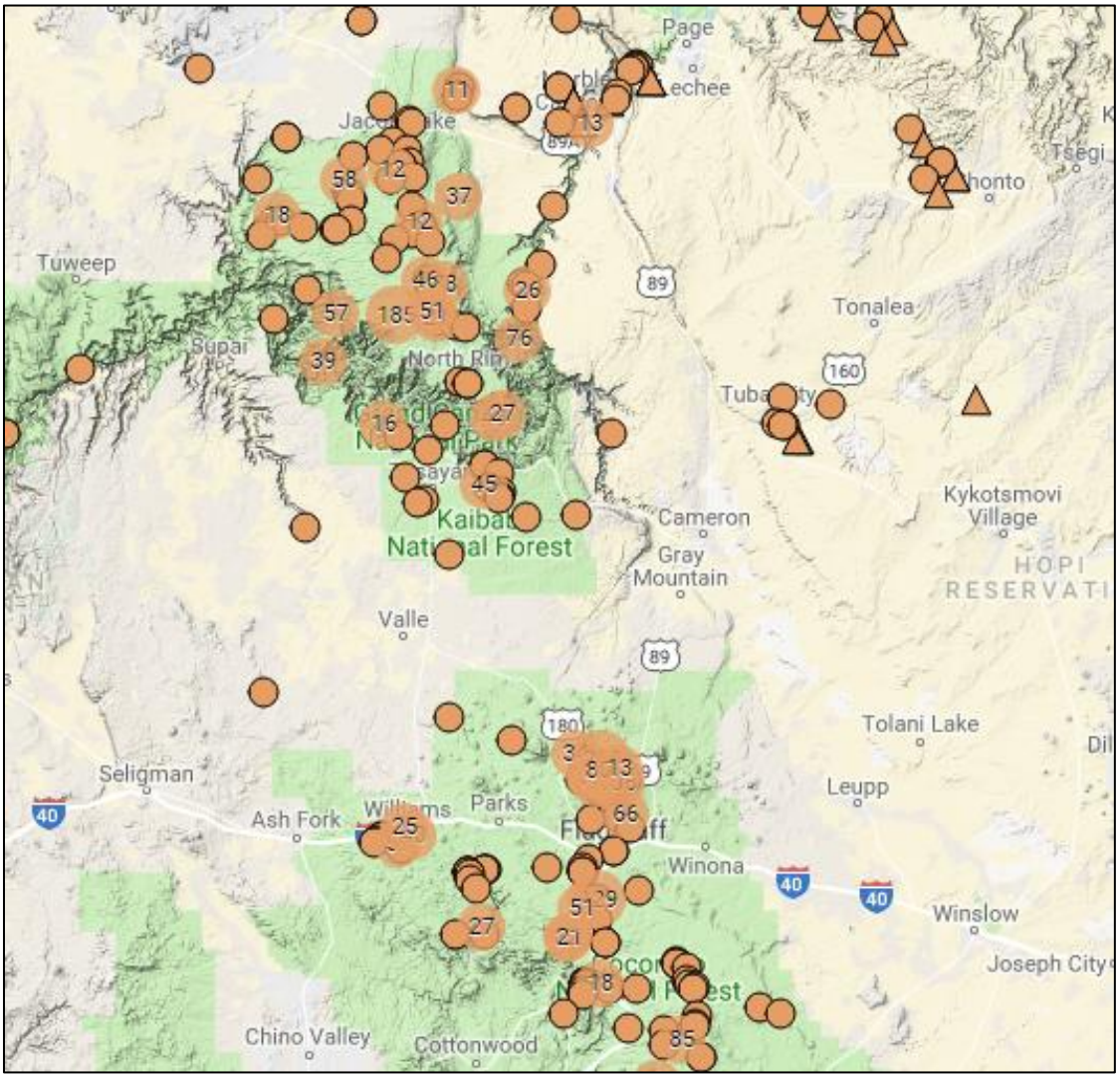

Figure 16. Example map output from SEINet – Observations and collections of sedge (Carex spp.), an obligate wetland plant.

Citizen Science Data Portals

eBird – See "Birds" section below.

iNaturalist. 2018. **iNaturalist**. Website accessed October 22, 2018, https://www.inaturalist.org/ ◄

iNaturalist is an online platform for recording, sharing, and discussing nature observations. The number of observations worldwide is mind-boggling. There are almost 400,000 observers worldwide and nearly 14 million observations including over 182,000 species. However, searching for species just in the CPWP area of interest proved challenging. The map shows many observations, especially around Flagstaff and the Grand Canyon, but it is not clear how to sort the data and most data are for non-water-related species. This report's author, Sharon Masek Lopez, asked Marci Madsen Fuller about iNaturalist. Her husband Terry Fuller is a frequent contributor to iNaturalist. Marci and Terry responded, "iNaturalist is kind of spotty....not very comprehensive yet," as compared to other online citizen science databases like eBird.

TNC. 2018. **NatureServe**. The Nature Conservancy website accessed October 19, 2018, http://www.natureserve.org/ ◄

Founded by The Nature Conservancy, the NatureServe Networks collect data about imperiled species and entire ecosystems and provide data visualizations and analyses to guide conservation decision making. A quick search on invertebrates for Arizona revealed almost exclusively entries for tiger beetles, which are an apparently popular taxa for citizen scientists. Meanwhile, there were no entries for narrow-headed garter snakes. Unfortunately, this database seems to have limited application for the CPWP ecosystem services assessment, because of the narrow bands of interest among the contributors.

Birds

Audubon. 2018. **Audubon Christmas Bird Count**. National Audubon Society website accessed October 23, 2018 https://www.audubon.org/conservation/science/christmas-bird-count ◄

The Audubon Christmas Bird Count (CBC) is the nation's longest running community science bird project. Seasonality, of course, affects results in the CBC. A search of the database for yellow-billed cuckoos in Arizona yields a result of "none found". Obviously, this is because in December the cuckoos, which nest in Arizona riparian areas, have migrated south for the winter. A conversation with a bird biologist is recommended to discuss which wintering bird species are good indicators of sustainable water resources management. Most likely waterfowl will be on that list. Perhaps tracking waterfowl at

the Anderson Mesa IBA through the CBC would be a good way to determine climate change and forest management effects on lake-dependent waterfowl.

AZ IBA. 2018. **Arizona Important Bird Areas**. Arizona Important Bird Areas website accessed October 23, 2018, http://aziba.org/?page_id=38 ◄

The Important Bird Area (IBA)is a global program founded by BirdLife International the 1980's. The Arizona IBA Program was established in 2001 and is co-administered by Audubon Arizona and the Tucson Audubon Society. The Arizona Important Bird Areas Program is a field-oriented, community-engaged, science-based and conservation-focused program to benefit Arizona's bird populations of greatest conservation concern, and other native biodiversity, and their most critical habitats and sites. The program is citizen-science oriented and utilizes data sources such as e-Bird, Christmas Bird Counts, Breed Bird Survey Data as well as data collected by agencies such as Arizona Game and Fish, the Forest Service and the National Park Service.

In the CPWP area of interest there are two IBAs with data relevant to a water-related ecosystem services assessment (see Figure 14):

- ***Anderson Mesa IBA,*** lake complex supports migratory waterfowl - https://www.audubon.org/important-bird-areas/anderson-mesa-coconino-national-forest and
- ***Lower Oak Creek IBA***, riparian birds - https://www.audubon.org/important-bird-areas/lower-oak-creek

Riparian obligate bird species might make good indicators of sustainable water resources management. However, as discussed with AGFD Wildlife Habitat Specialist Hannah Griscom, there are many factor affecting bird populations, and there could be significant lag between hydrologic change and riparian vegetation change affecting riparian-obligate bird species. Therefore, datasets for IBAs have limited utility for the ecosystem services assessment.

Corman, Troy E. and Edwin A. Juarez. 2017. **Arizona Coordinated Bird Monitoring Program Progress Report: 2006-2012.** Arizona Game and Fish Department (AGFD), Technical Report 296, Phoenix, AZ, 90 p. ◄◄

This report was recommended by AGFD biologists, especially pages 17 to 22 - Colonial Waterbird Nest Survey. In Arizona, colonial nesting aquatic birds include white-faced ibis and several species of herons, egrets, cormorants, and grebes. Changing water levels and prey availability influence the annual occurrence and number of nesting waterbirds. Hence, changing water levels of lakes and reservoirs in the CPWP area of interest might impact nesting waterbirds, making them good indicators of water-related ecosystem services.

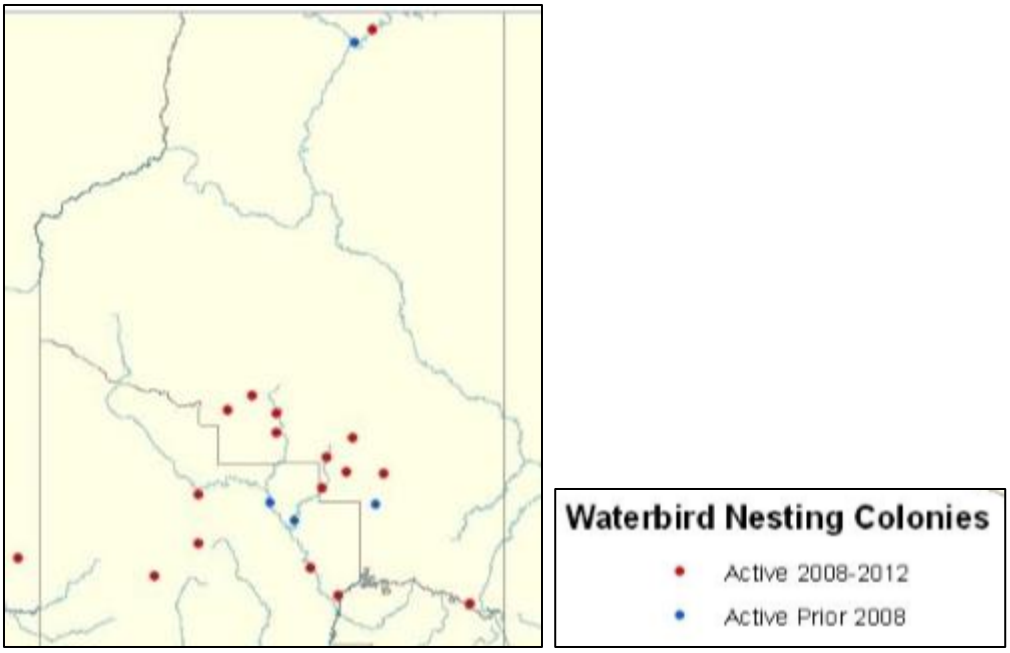

Figure 17. Nesting waterbirds in Coconino County and adjacent parts of Yavapai County.

Also, in the Corman and Juarez (2017) report, is a Riparian Breeding Bird Survey on pages 43 to 45. Riparian communities and aquatic habitats comprise less than 2% of the total land area in the arid western United States, yet they are considered the most productive, ecologically diverse, and threatened habitats in Arizona. Due to extensive loss and alteration of riparian habitat, a significant number (47 species or 32%) of birds listed as Arizona's Species of Greatest Conservation Need (SGCN) regularly nest in riparian areas. For the ecosystem services assessment it is recommended that the consultant identify the SGCN within that CPWP area of interest that nest in riparian areas. Datasets for these species could be examined to see if one or more species might serve as a good indicator of sustainable water resources management.

eBird. 2018. **eBird**. Audubon and the Cornell Lab of Ornithology website accessed October 23, 2018, https://ebird.org/home ◄

eBird is the world's largest biodiversity-related citizen science project, with more than 100 million bird sightings contributed each year by eBirders around the world. eBird data document bird distribution, abundance, habitat use, and trends through checklist data collected within a scientific framework. Birders enter when, where, and how they gathered data, and then fill out a checklist of all the birds seen and heard during an outing. An eBird free mobile app allows offline data collection. The website provides many ways to explore and summarize data. The eBird database could be searched for sensitive riparian-obligate bird species to inform the ecosystem services assessment. However, birds are affected by many factors of which water resources management is just one. Therefore, other taxa more closely associated with changes in water availability would likely make stronger indicators in the ecosystem services assessment.

Hunter, William C., Robert D. Ohmart, and Bertin W. Anderson 1987**. Status of Breeding Riparian-Obligate Birds in Southwestern Riverine Systems**. Center for Environmental Studies, Arizona State University, 9 pages. ◄

This document is dated, but it has a useful table the lists the riparian-obligate bird species in the Southwest.

RMBO. 2010. **Monitoring the Birds of Coconino, Kaibab and Prescott National Forests: 2010 Field Season Report.** Rocky Mountain Bird Observatory (RMBO) website accessed October 23, 2018, https://birdconservancy.org/wp-content/uploads/2014/06/CNF_KNF_PNF_2010_field_season_report.pdf ◄

Point counts are one of several methods used to inventory and monitor bird populations. A point count is a tally of all birds detected by sight and sound by a single observer located at a fixed position during a specified period of time (i.e., 3 min.). Arizona Game and Fish Department biologists recommended the U.S. Forest Service point count data for birds for use in the ecosystem services assessment. This 2010 point count report was found online. In Coconino National Forest, field technicians conducted 624 point counts, detecting 5,447 birds of 119 species throughout the Forest between May 2 and July 2, 2010. In Kaibab National Forest, field technicians conducted 546 point counts, detecting 5,282 birds of 102 species throughout the Forest between May 19 and July 5, 2010.

For the ecosystem services assessment, if point count data are to be used, it is recommended that the consultant talk with the forest biologists about riparian-obligate bird species, such as certain warblers, and filter the dataset for those species.

Insects

Deviche, Pierre. 2018. **Arizona Dragonflies.** Pierre Deviche website accessed October 24, 2018, http://azdragonfly.org/ ◄◄◄

This web site presents photographic documentation on odonate species that have been officially recorded in Arizona. It is an excellent resource for naturalists and citizen scientists who add to the record of dragonfly and damselfly sightings. If Pierre Deviche were open to it, Arizona Dragonflies might make a good platform from which to organize volunteer odonate surveys across the CPWP area of interest. If observations are paired with voucher specimens logged into Symbiota Collections of Arthropods Network (SCAN), potentially an effective monitoring program could be established. Odonates could serve as key indicators of sustainable water resources management.

SCAN. 2018. **Symbiota Collections of Arthropods Network (SCAN)**. SCAN website accessed October 23, 2018, http://scan-bugs.org/portal/ ◄◄◄

The Symbiota Collections of Arthropods Network (SCAN) serves specimen occurrence records and images from over 100 North American arthropod collections for **all** arthropod taxa. A search for order Trichoptera (caddisflies) in Arizona returned the map in Figure 18.

There appear to be ample historic collections of aquatic macroinvertebrates in the CPWP area of interest. In discussions with AGFD Wildlife Habitat Specialist Hannah Griscom, she recommended that aquatic macroinvertebrates may serve as one of the better indicators of sustainable water resources management, because of their reliance on free-flowing water. It is recommended that the SCAN database be paired with the SSI database during the ecosystem services assessment to identify taxa with a sufficient number of data points to assess longitudinal trends and inform future monitoring data collection.

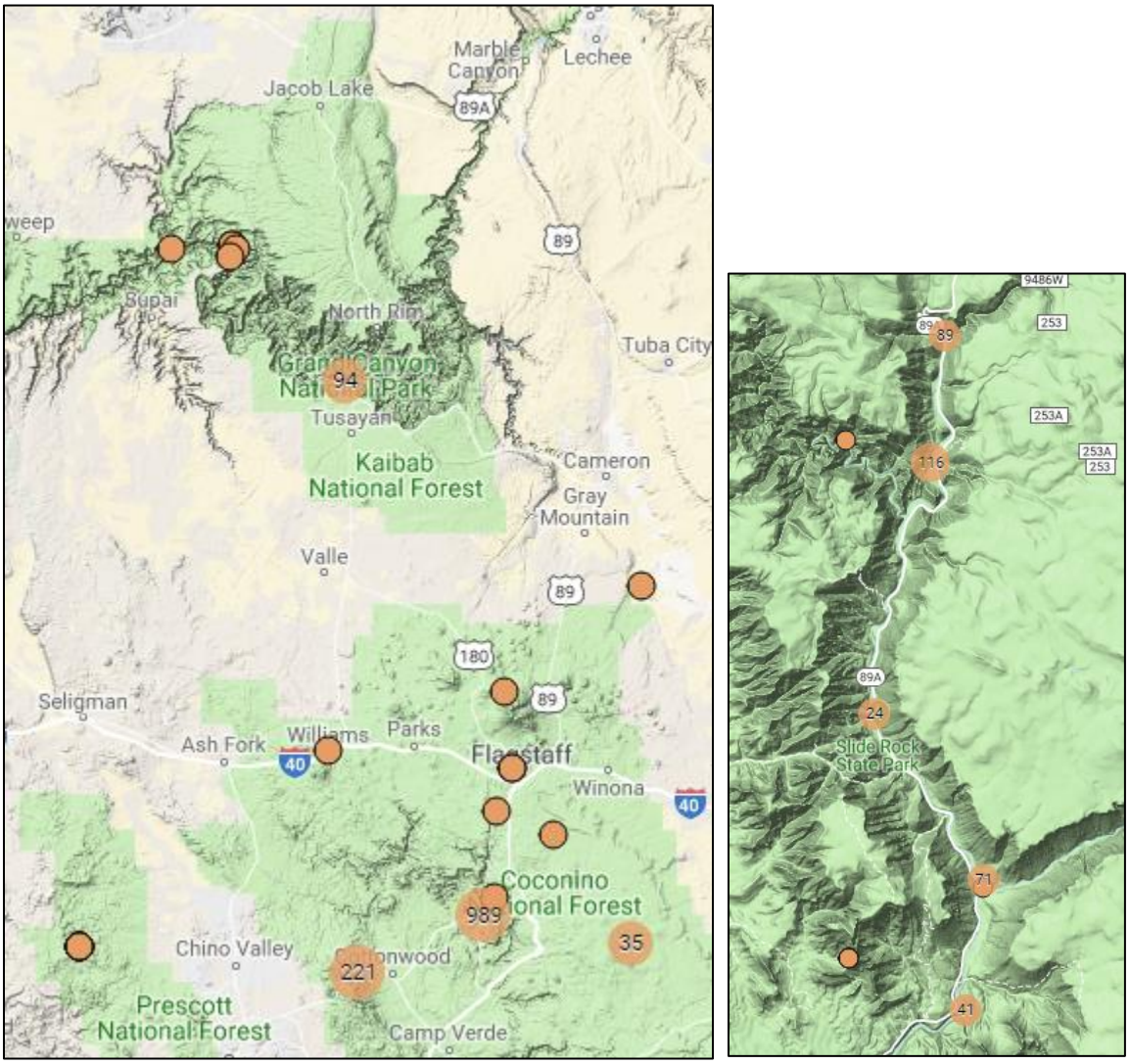

Figure 18. SCAN results for "Trichoptera" (caddisfly) higher taxonomy search in Arizona. Map is zoomed to CPWP area of interest. To the right is detail for Oak Creek Canyon.

UA. 2018. **Odonata Central**. University of Alabama Museums website accessed October 23, 2018, https://www.odonatacentral.org/index.php/PageAction.get/name/HomePage ◄◄◄

Odonata Central is designed to make available what is known about the distribution, biogeography, biodiversity, and identification of order Odonata (dragonflies and damselflies) in the Western Hemisphere. It makes use of relational databases to dynamically generate maps, checklists, and accompanying data for dragonflies and damselflies. The initial distribution data used on the site are based on the North American Dot Map Project, a project initiated by Nick Donnelly and involving more than 100 contributors from the Odonata community with the goal of accurately documenting the distributions of all North American species. There are 54 distinct species of Odonates in Coconino County. Because odonates by nature are absolutely dependent on open water and healthy aquatic macroinvertebrate populations as prey base, this database may be a very useful for the ecosystem services assessment. It could be a valuable tool, especially if it paired with observations by the Springs Stewardship Institute (Dr. Larry Stevens).

Springs

Adams, Eric A. 2005. **Determining ephemeral spring flow timing with laboratory and field techniques: Applications to Grand Canyon, Arizona**. Northern Arizona University M.S. Thesis. 80 p. Available at NAU Cline Library. ◄◄

Adams, E.A, S.A. Monroe, A.E. Springer, K.W. Blasch, D.J. Bills. 2006. **Flow Timing of South Rim Springs of Grand Canyon, Arizona, Using Electrical Resistance Sensors**. Ground Water, 44:630-641. doi:10.1111/j.1745-6584.2006.00223.x ◄◄

Crossey, Laura J., Tobias P. Fischer, P. Jonathan Patchett, Karl E. Karlstrom, David R. Hilton, Dennis L. Newell, Peter Huntoon. Amanda C. Reynolds, Goverdina A.M. de Leeuw. 2006. **Dissected hydrologic system at the Grand Canyon: Interaction between deeply derived fluids and plateau aquifer waters in modern springs and travertine.** Geology, 34 (1) 25-28. ◄◄

This brief article provides a Piper diagram of water chemistry of Grand Canyon springs, including Havasu Spring and Blue Spring, which are within the Coconino Plateau Watershed Partnership area of interest. The Piper diagram shows mixing trends between the epigenic (meteoric) and endogenic (deeply derived) end members. The previously unrecognized deeply derived waters, issuing along faults, contribute excess

CO_2 and explain the volume and location of travertine deposits and the geochemical variability among springs.

Crossey, L.J., K.E. Karlstrom, A.E. Springer, D. Newell, D.R. Hilton, T. Fischer. 2009. **Degassing of mantle-derived CO2 and He from springs in the southern Colorado Plateau region–neotectonic connections and implications for groundwater system**. Geological Society of America Bulletin., 121:1034-1053. doi: 10.1130/B26394.1. ◄◄

Crossey, L.C., K.E. Karlstrom, R. Dorsey, J. Pearce, E. Wan, L.S. Beard, Y. Asmerom, V. Polyak, R.S. Crow, A. Cohen, J. Bright, and M.E. Pecha. 2015. **Importance of groundwater in propagating downward integration of the 6–5 Ma Colorado River system: Geochemistry of springs, travertines, and lacustrine carbonates of the Grand Canyon region over the past 12 Ma**. Geosphere, 11 (3) 660–682. doi:10.1130/GES01073.1 ◄

Researchers applied multiple geochemical tracers ($^{87}Sr/^{86}Sr$, [Sr], $\delta^{13}C$, and $\delta^{18}O$) to waters and carbonates of the lower Colorado River system to evaluate its paleohydrology over the past 12 Ma. Modern springs in Grand Canyon reflect mixing of deeply derived (endogenic) fluids with meteoric (epigenic) recharge. Havasu Spring and Blue Spring, within the Coconino Plateau Watershed Partnership area of interest, were evaluated as part of this study.

Fuller, C.C., Cain, D.J., Croteau, M-N., Barasch, D.A., Beisner, K.R., Stoliker, D.L., and Schenk, E.R. 2018. **Biogeochemical data of water, sediments, periphyton, and macroinvertebrates collected from springs in and near Grand Canyon National Park, Arizona**. U.S. Geological Survey data release, https://doi.org/10.5066/P9CR6GCW OR https://www.sciencebase.gov/catalog/item/5b735cf1e4b0f5d5787c61c0 ◄◄◄

The U.S. Geological Survey is studying uranium and associated trace element bioaccumulation in aquatic invertebrates across a gradient of dissolved uranium concentrations in spring outflow pools and creeks in the Grand Canyon and adjacent watershed. This data release makes available data from sampling campaigns in April 2016 and in April 2017. Data collected include: 1) major ion, trace element and dissolved organic carbon in surface waters of spring outflow pools and streams; and 2) concentrations of uranium and other trace elements in bed sediment, periphyton, and larva of aquatic insect taxa.

Ingraham, Neil L., Kim Zukosky, and David K. Kreamer. 2001. **Application of Stable Isotopes to Identify Problems in Large-Scale Water Transfer in Grand Canyon National Park**. Environ. Sci. Technol., 35:1299-1302. ◄

Researchers measured stable isotopes of south rim springs at Grand Canyon and compared them with Roaring Spring to determine impacts from Roaring Spring water delivered to the south rim. Whether by percolation from the sewage discharge at the

Clearwell Overflow or by a leak in the transcanyon pipeline, the researchers observed that perhaps up to half of the water discharging at Indian Garden Spring ultimately originates as North Rim water, indicating that anthropomorphic forces have impacted this spring.

Kessler, James A. 2002. **Grand Canyon Springs and the Redwall-Muav Aquifer: Comparison of Geologic Framework and Groundwater Flow Models**. Northern Arizona University M.S. thesis. 122 p. Available at NAU Cline Library. ◄◄◄

Kobor, Jeremy. 2004. **Simulating water availability in a spring-fed aquifer with surface water/groundwater flow models, Grand Canyon, Arizona**. Northern Arizona University M.S. Thesis. 125 p. Available at NAU Cline Library. ◄◄

Mueller, Julie M., Ryan E. Lima, and Abraham E. Springer. 2017**. Can environmental attributes influence protected area designation? A case study valuing preferences for springs in Grand Canyon National Park**. Land Use Policy, 63: 196-205. ◄◄◄

Researchers estimated nonmarket values of springs within Grand Canyon National Park using a Choice Experiment (CE). They conducted a nationwide online survey to determine willingness to pay (WTP) to protect backcountry springs and attributes including; accessibility, suitability as a backcountry water source, suitability as habitat for species of concern, aesthetics, and significance to indigenous nations.

Choice experiment is one of a number of ecological economics instruments used to estimate the value ecosystem services. Such value estimation is useful to inform decision-making and sometimes to establish payment for ecosystem services systems. Phase 2 of the CPWP Ecosystem Services Assessment will not go so far as valuing ecosystem services. However, if the CPWP TAC were interested in that next step, the Mueller et al. (2017) paper is a good example of how to go about valuing services.

NPS. 2018. **Grand Canyon springs hydrology & ecology database**. National Park Service (NPS) database. (Usefulness is not rated, because the National Park Service is not currently releasing the database to the public.)

This database has been developed by the National Park Service and partners. It contains data regarding springs along the South Rim of the Grand Canyon, on Havasupai and Hualapai tribal lands, and on national forest, state, and private lands. Pending water rights litigation or settlement proceedings, the data cannot be released at this time. NPS Water Resources Division's Groundwater Hydrologist Paula Cutillo (paula_cutillo@nps.gov) did provide a recent scientific paper, Tobin etal. 2018; see citation below. Per Paula Cutillo, inquiries about springs data availability can be made to Grand Canyon National Park Science and Resource Management Division Chief Jeanne Calhoun (jeanne_calhoun@nps.gov, 928.638.7750).

If this database were available it would be highly valuable for the ecosystem services assessment. Sharon Masek Lopez recommends that the CPWP TAC open a dialogue with Jeanne Calhoun to see if some data could be released for the assessment.

SSI. 2018. **Springs Online**. Springs Stewardship Institute website viewed October 15, 2018 http://springstewardshipinstitute.org/about-the-database/ ◄◄◄

Developed in 2010 by Jeri Ledbetter, Dr. Larry Stevens, and Dr. Abraham Springer, Springs Online offers a user-friendly interface and uses simple methods to enter, retrieve, and analyze springs inventory data. The database is easily accessible to landowners, land managers, conservation organizations, researchers, and the public, furthering the institute's mission to provide quality information regarding springs. The springs online database has multiple tabs for each spring, which include: General, Description, Surveys, Polygons, Georeferencing, Geomorphology, SPF, EOD, History, and Admin. Extensive data can be found within the Survey tab. For a full explanation about the database, view the database tour movie via a link at the bottom of the database manual webpage (http://springstewardshipinstitute.org/database-manual-1).

SSI. 2018. **Springs Stewardship Institute (SSI) Geodatabase**. Data available by request. ◄◄◄

The Springs Stewardship Institute has a vast database of spring hydrology, ecology, and cultural data. Much of this data is privacy protected and requires permissions from the data owners (tribes, private land owners, federal and state land management agencies). The privacy protections are generally in place to protect sensitive sites from disturbance.

SSI conducts two levels of spring inventories:

Level 1 General Reconnaissance is the beginning level survey of a spring site. After a brief, 15- to 20-minute visit, surveyors record georeference data and access directions, photograph the source and the surrounding microhabitat, and note the basic features of the spring's ecosystem (biota and flow). Level 1 helps in identifying the distribution of springs across a landscape, as well as determining the level of need for more rigorous inventories.

Level 2 SIP and SEAP is a detailed inventory of the springs ecosystem. Surveyors describe baseline physical, biological, and administrative variables. Using standardized spreadsheets, surveyors record geomorphology, soils, geology, solar radiation, flora, fauna, water quality, flow, and any additional georeference data. They then record a thorough assessment of the site's condition and any potential risks to the spring system. The data collected during Level 2 is complex, consisting of two parts: a Springs Inventory Protocol (SIP) and a Springs Ecological Assessment Protocol (SEAP). However, all of the data is interrelated - contributing to the quality of the relational database.

Sharon Masek Lopez requested a GIS shapefile of spring locations from SSI. All non-sensitive locations were provided (Figures 19 and 21). Altogether there are 1,033 springs in the CPWP area of interest, of which 740 have publicly available data. (Many springs are sensitive, and permission must be sought to acquire data). Survey has been completed at 373 springs, some with multiple surveys, for a total of 1,120 surveys. Some surveys are extensive and others are very basic.

For the Phase 2 ecosystem services assessment, Sharon recommends that the consultant work with the Springs Stewardship Institute to identify a discrete set of springs that would make good monitoring points for ecological impacts from changes in R and C Aquifer discharge. Once these indicator springs have been identified, data should be acquired from the SSI database for those springs. Data acquisition will incur a fee to cover SSI staff time.

Ideal indicator springs will have SIP and SEAP already completed, repeated ecological surveys, and a long-term record of spring discharge. Pairing the SSI data with U.S. Geological Survey spring monitoring data will be important to optimize the physical and chemical data in the National Water Information System (NWIS) together with the SSI data.

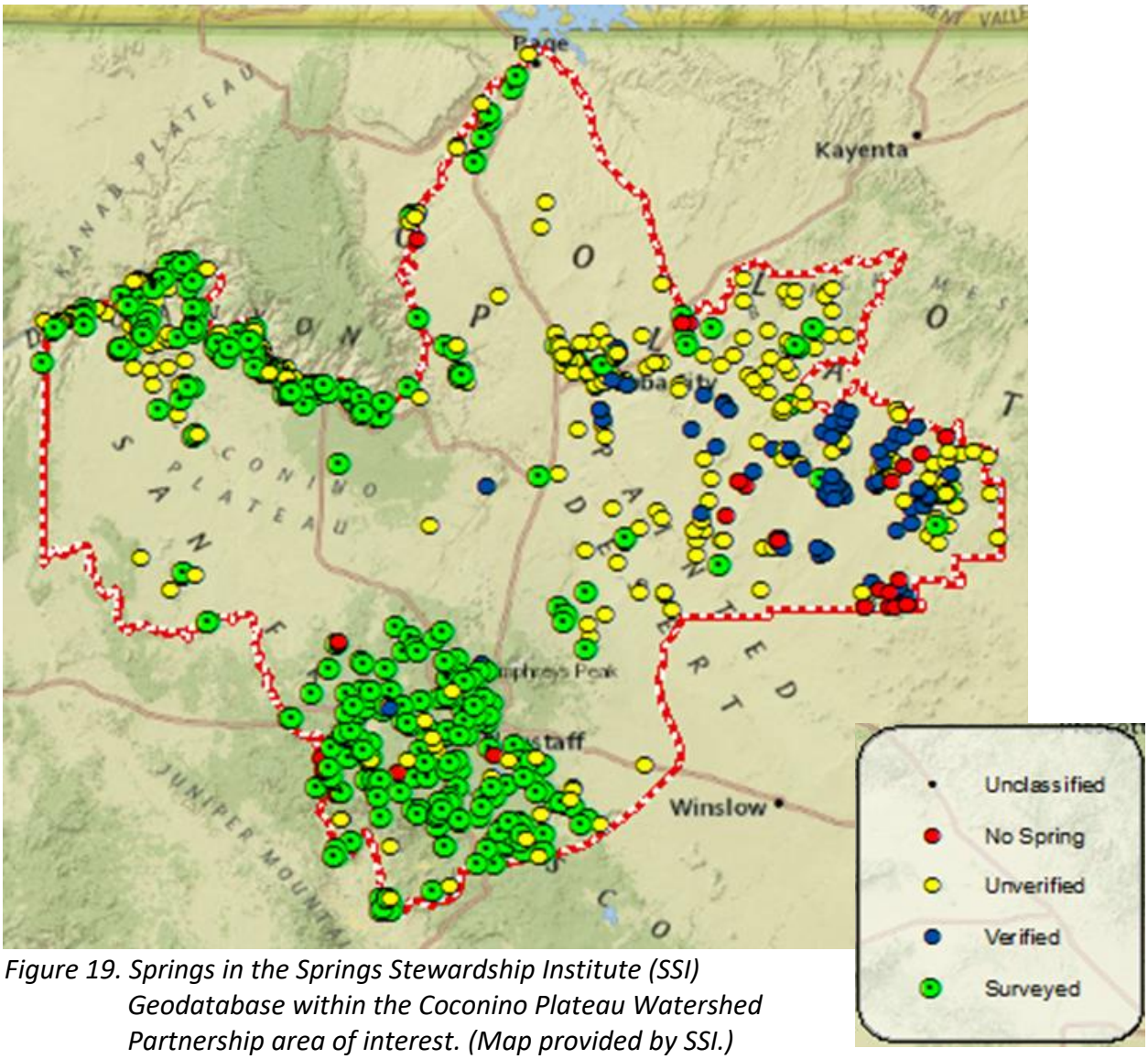

Figure 19. Springs in the Springs Stewardship Institute (SSI) Geodatabase within the Coconino Plateau Watershed Partnership area of interest. (Map provided by SSI.)

Tobin, Benjamin W., Abraham E. Springer, David K. Kreamer, and Edward Schenk. 2018. **Review: The distribution, flow, and quality of Grand Canyon Springs, Arizona (USA).** Hydrogeol J, 26:721–732. https://doi.org/10.1007/s10040-017-1688-8 ◄◄◄

There are approximately 750 spring in Grand Canyon, many seasonal and some perennial. Most flow from the karstic Redwall-Muav aquifer and show seasonal patterns in flow and water chemistry indicative of variable aquifer porosities, including conduit flow. Tracer techniques and water age dating indicate a wide range of residence times for many springs, supporting the concept of multiple porosities. Aquifer recharge throughout the region is dominated by snowmelt that either diffusely recharges or flows into large sinkholes that feed the two underlying aquifers. The complex response and

residence times indicate that springs respond quickly to storm events but are a combination of young and older waters.

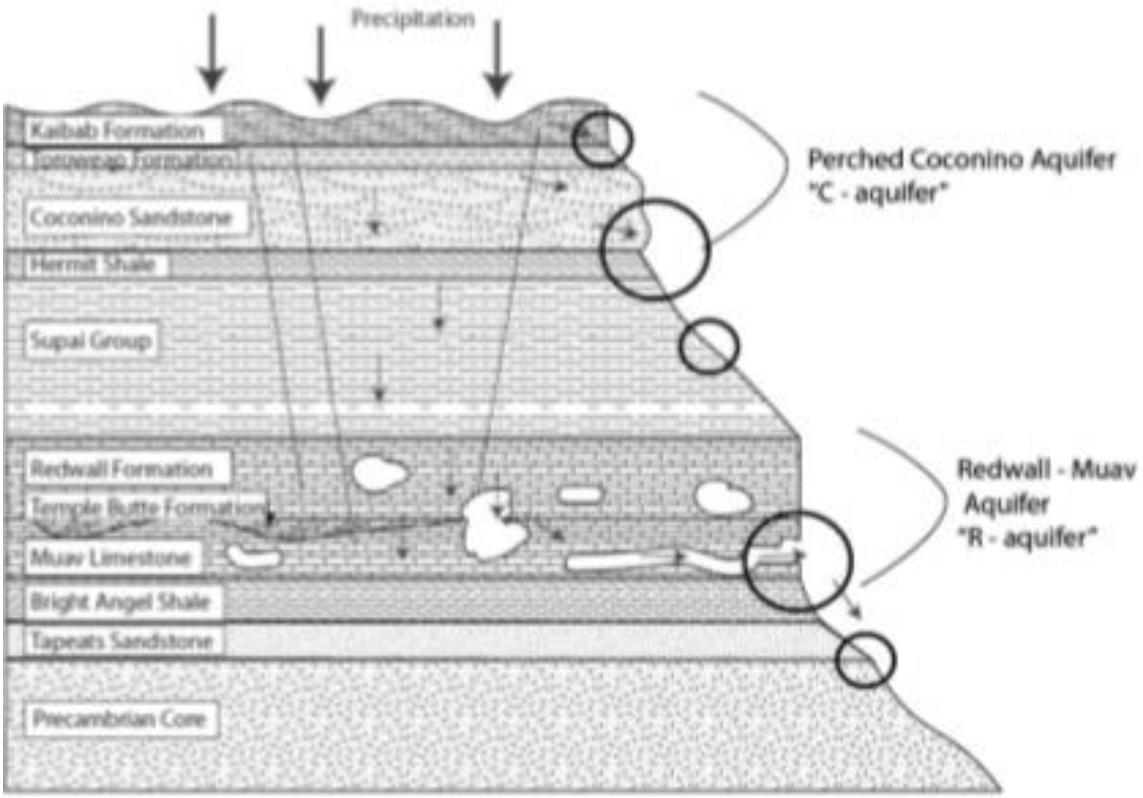

Figure 20. Hydro-stratigraphic column representing the relative location of springs and aquifers in Grand Canyon. Near vertical lines represent fractures and locations of likely vertical transport of water. Large circles represent dominant location of springs, while smaller circles represent location of additional locations of springs. (Tobin et al. 2018)

USGS. 2018. **NWIS – National Water Information System – Web Interface**. USGS website accessed May 2018, https://waterdata.usgs.gov/nwis/ ◄◄◄

The National Water Information System (NWIS) includes water resources data for surface water, groundwater, springs, and the atmosphere. The NWIS Mapper is a quick way to see data sites (https://maps.waterdata.usgs.gov/mapper/index.html). Sites may be active or inactive. NWIS is a fundamentally important data source for the ecosystem services assessment.

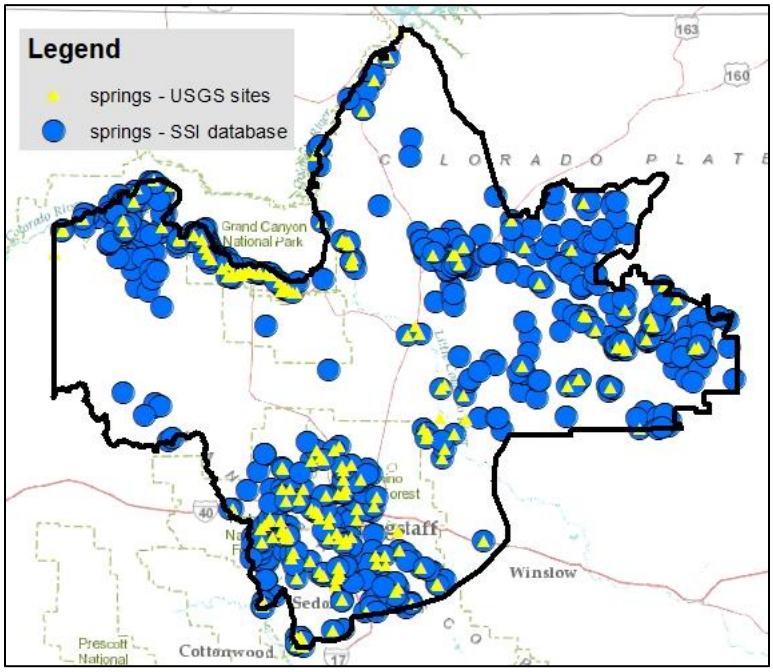

Figure 21. Springs data points in the Springs Stewardship Institute (SSI) and National Water Information System (NWIS) databases.

Springs – NWIS lists 236 springs in the CPWP area of interest, which is far few than the Spring Stewardship Institute lists (Figure 21). However, NWIS includes data on aquifer geology and spring elevation, which may be more reliable than the SSI data. Therefore, it is recommended to use the datasets in tandem.

Flood Protection

AFWS. 2018. **Integrated Live Data Map, Arizona Flood Warning System.** AFWS website accessed October 23, 2018, http://www.afws.org/gmap/gmap.html ◄◄

In 1979, the Arizona Legislature authorized funds to create the Arizona Flood Warning Office (ADWR originated in June of 1980). The Flood Warning fund was used to support the Arizona offices of the U.S. Geological Survey (USGS) in maintaining their stream flow gages, and the National Weather Service (NWS) in improving flood prediction. Following the 1993 floods, ADWR's role expanded in 1994 into the Arizona Flood Warning System. The online interactive map compiles ALERT data from throughout Arizona.

ALERT is an acronym for "**A**utomated **L**ocal **E**valuation in **R**eal **T**ime" and refers to a National Weather Service format developed in the 1970s for transmission of hydrometeorological data from remote sensors via radio in real-time. The City of Flagstaff and Yavapai County Flood Control District operate ALERT networks within the CPWP area of interest. Saved ALERT data could be used to evaluate rainfall/runoff relationships to determine trends potentially associated with climate change or land management practices (e.g. forest restoration).

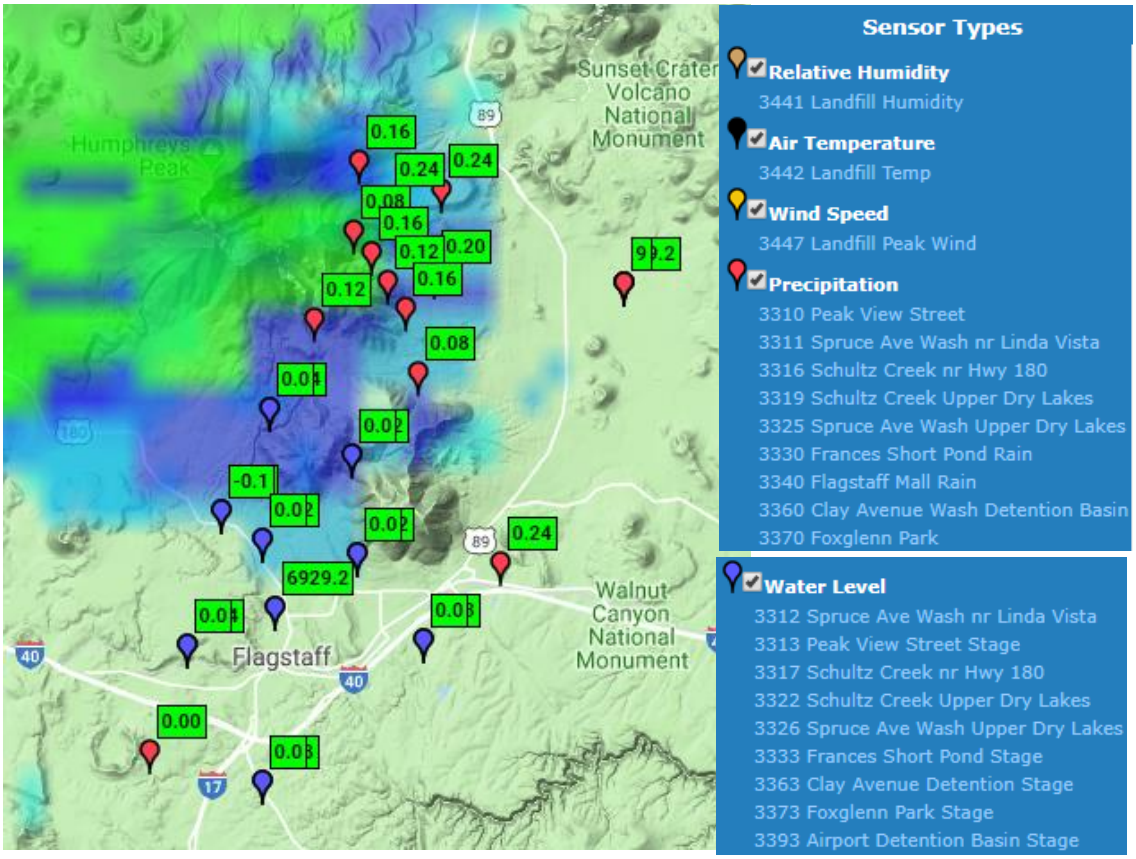

Figure 22. Flagstaff ALERT Network gauging stations, 3:20 p.m. October 23, 2018.

Coconino County. 2015. **Coconino County Multi-Jurisdictional Hazard Mitigation Plan**. Coconino County, Flagstaff, Arizona,203 p. http://www.coconino.az.gov/DocumentCenter/View/8916/Coconino-County-MJMHMP_20101?bidId= ◄◄◄

This plan includes hazard risk profiles for the following hazards: dam failure, drought, earthquake, **flood**, hazardous materials incidents, sever wind, transportation accidents, wildfire, and winter storm.

JE Fuller. 2018. **Real time weather and water level data, Flagstaff**. JE Fuller website viewed October 23, 2018, http://www.jefullerdata.com/ADWR/Flagstaff/mapfs.html ◄◄

Engineering firm JE Fuller, on contract to the City of Flagstaff, operates a small network of radio-telemetered gauges that transmit rainfall and streamflow information in real time (as it occurs). The primary function of these gauges is to monitor and document severe rainfall and flooding events and to make this information available to emergency responders. The JE Fuller Flagstaff office contacts are Joe Loverich (joe@jefuller.com), Cory Helton (cory@jefuller.com), and Ian Sharp (ian@jefuller.com). The office phone is (928)214-0887.

MacDonald, Christopher. 2018. **Terrestrial Ecological Unit Inventory - Hydrologic Soils Groups**. Personal communication to Sharon Masek Lopez, December 6, 2018. ◄◄◄

See full description in "Erosion Prevention" section below.

The Terrestrial Ecological Unit Inventory is an important data resource that should be considered during the Phase 2 Ecosystem Services Assessment. It may by integral to follow-on modeling efforts to identify priority sites for forest restoration to reduce post-wildfire flooding hazard, which is a top concern of CPWP stakeholders.

Yavapai County. 2018. **Yavapai County Flood Control District**. YCFCD website accessed October 23, 2018, http://weather.ycflood.com/ ◄◄

The Yavapai County Flood Control District (YCFCD) operates a network of automated precipitation and streamflow gauges as part of the ALERT system. Figure 23. Shows the gauge locations within the CPWP area of interest. These gauges can play a role in addressing the stakeholder concerns about post-wildfire flooding impacts.

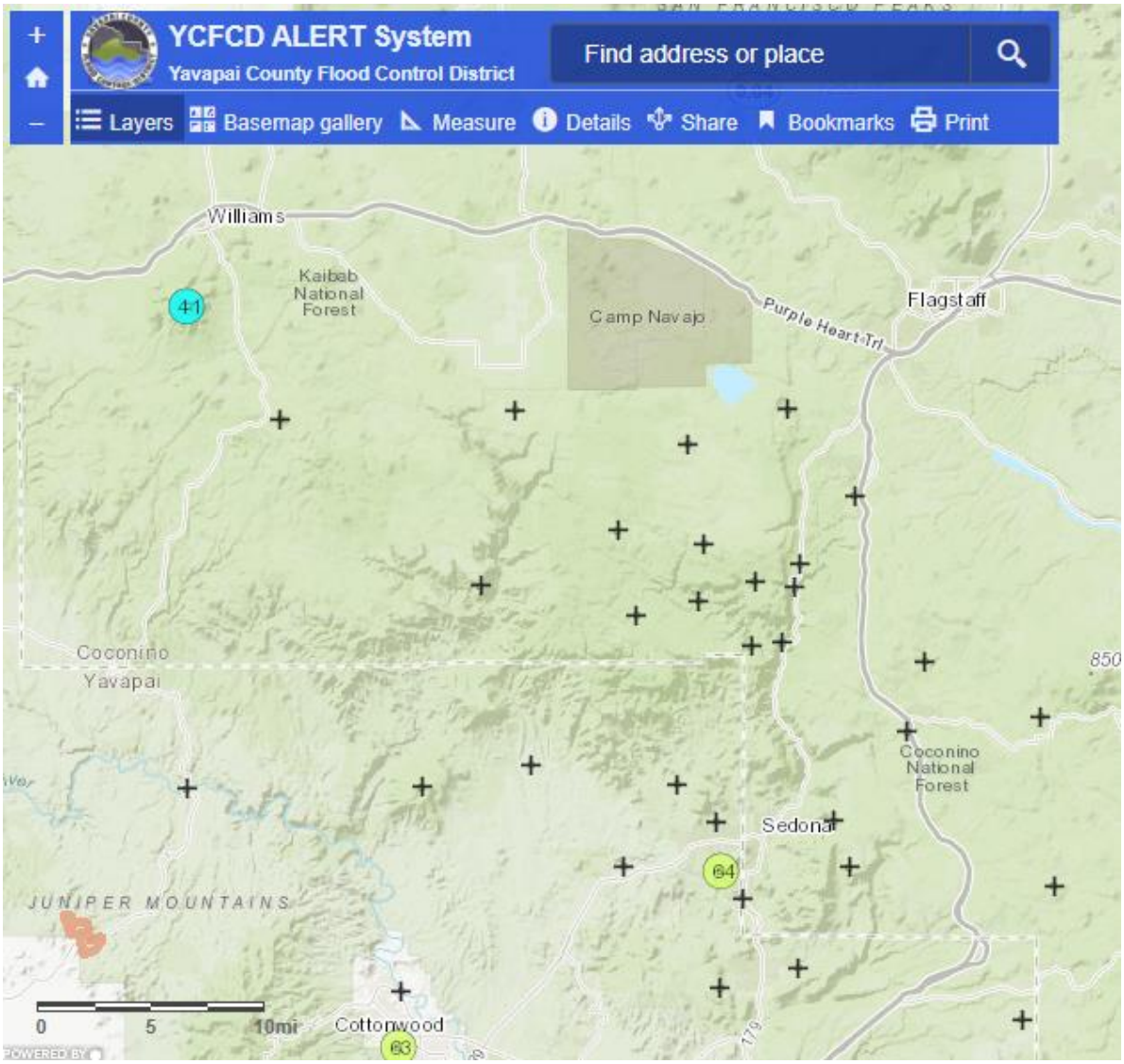

Figure 23. Yavapai County Flood Control District (YCFCD) gauges located within the CPWP area of interest.

Flooding-Related Reports

Civiltec and JE Fuller. 2016. **Fort Valley Initial Engineering Assessment.** Coconino County website accessed October 23, 2018, http://www.coconino.az.gov/1455/Fort-Valley-IEA ◄◄

FLO-2D was used for the combined hydrologic and hydraulic modeling for the 2-, 5-, 10-, 25-, 50- and 100-year, 24-hour storm events in the Fort Valley area. The results of the modeling supersede previous studies and should be used as best available data until subsequent studies are approved by the County.

Loverich, Joseph B., Ann M. Youberg, Michael J. Kellogg, and Jon E. Fuller. 2017. **Post-Wildfire Debris-Flow & Flooding Assessment: Coconino County, Arizona.** Arizona Geological

Survey website accessed October 23, 2018, http://repository.azgs.az.gov/sites/default/files/dlio/files/nid1727/ofr-17-06_v1_cococty.pdf ◄◄◄

The Coconino County Post-Wildfire Debris Flow and Flooding Assessment identified areas that are at risk for flooding and debris flows in the aftermath of a reasonable-scenario wildfire. The study consisted of a countywide reconnaissance-level evaluation, and more detailed planning-level evaluation of post-fire flood and debris flow hazards for two pilot study areas in Fort Valley and the City of Williams.

This report can provide insight to address stakeholder concerns about post-wildfire flooding.

Mueller, Julie M., Ryan E. Lima, Abraham E. Springer, and Erik Schiefer. 2018. **Using Matching Methods to Estimate Impacts of Wildfire and Post-wildfire Flooding on House Prices**. American Geophysical Union (AGU) Water Resources Research, 10.1029/2017WR022195

Researchers used a matching approach (ecological economics tool) to estimate the impact of wildfire and post-wildfire flooding on house prices, including flood risk covariates, for neighborhoods downstream of the Schultz Fire. ◄

Floodplain Mapping

Coconino County. 2018. **Coconino County Floodplain Viewer**. Coconino County website accessed October 23, 2018, https://gismaps.coconino.az.gov/floodplain/ ◄◄

Coconino County GIS provides this view of floodplain mapping. Use Internet Explorer to access the viewer (it does not display using Chrome). The source data for the county's floodplain viewer comes from FEMA's National Flood Hazard Layer (NFHL); see FEMA (2018) below for details. This mapping will play an important role in addressing stakeholder concerns about post-wildfire flooding. Sharon recommends that the consultant who conducts the Phase 2 ecosystem services assessment download necessary data from the FEMA National Flood Hazard Layer.

FEMA. 2018. **National Flood Hazard Layer (NFHL)**. Federal Emergency Management Agency (FEMA) website accessed December 17, 2018, https://www.fema.gov/national-flood-hazard-layer-nfhl ◄◄◄

The National Flood Hazard Layer (NFHL) is a geospatial database that contains current flood hazard data. FEMA provides flood hazard data to support the National Flood Insurance Program. Information can be used to better understand flood risk and type of flooding. The simplest way to access NFHL flood hazard data is through FEMAs Map Service Center at https://msc.fema.gov/portal/home.

Yavapai County. 2018. **Yavapai County Floodplain Mapping**. Yavapai County website accessed October 23, 2018, http://gis.yavapai.us/Flood/ ◄◄◄

Yavapai County GIS data online provides this view of floodplain mapping. The website was functioning well when it was viewed. This mapping will be useful to address flooding concerns in lower Oak Creek watershed within the Coconino Plateau Watershed Partnership area of interest.

Water Purification

Water Quality

Other than regarding wastewater reuse, water quality did not arise as a top concern of Coconino Plateau Watershed Partnership stakeholders. Therefore, most of the data sources in this section have a low usefulness ranking for the Phase 2 Ecosystem Services Assessment.

ADEQ. 2018. **Water Quality Layers, ADEQ eMaps**. Arizona Department of Environmental Quality website accessed September 21, 2018, https://gisweb.azdeq.gov/arcgis/emaps/ ◄

Arizona Department of Environmental Quality's eMaps is an interactive GIS web mapping application for visualizing environmental information in Arizona. It contains surface water sample sites, stream reaches designated as Outstanding Arizona Waters, stream reaches and lakes assessed for compliance with the State's water quality standards, and waters which are on the state's 303(d) list of impaired waters.

- Lakes Assessed 2016
- Streams Assessed 2016
- Surface Water Sampling Sites

Macy, Jamie P., and Jon P. Mason, J.P. 2017. **Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2013–2015.** U.S. Geological Survey Open-File Report 2017–1127, 49 p. https://doi. org/10.3133/ofr20171127 ◄◄

This is a periodic report for U.S. Geological Survey monitoring of well levels, streamflow, and water quality associated with the N Aquifer on the Navajo and Hopi Indian Reservations. (This reference is also listed in the "*Well Water Levels and Other Well Data*" section of this report.)

NWQMC. 2018. **Water Quality Portal.** National Water Quality Monitoring Council website accessed September 21, 2018, https://www.waterqualitydata.us/portal/ ◄

The Water Quality Portal is a database sponsored by the U.S. Geological Survey, the U.S. Environmental Protection Agency, and the National Water Quality Monitoring Council to provide water quality data collected by over 400 state, federal, tribal, and local agencies in one location. It integrates water quality data from the USGS National Water

Information System (NWIS), the EPA STOrage and RETrieval (STORET) Data Warehouse, and the USDA ARS Sustaining The Earth's Watersheds – Agricultural Research Database System (STEWARDS). USGS biological data comes from the BioData Retrieval system, which includes biological community and physical habitat data collected by USGS scientists from stream ecosystems. Queries of this database for the CPWP area obtained datasets from USGS, EPA, the National Park Service, Arizona Department of Environmental Quality, Hopi Tribe, Hualapai Tribe, and Navajo Nation.

OCWC. 2012. **Improvement Plan for Oak Creek Watershed, Arizona**. Oak Creek Watershed Council website viewed October 14, 2018, https://oakcreekwatershed.org/images/PDFfiles/FINAL_OCWIP/15_OCWIP_9-12-12_Complete.pdf ◄

In 2011 and 2012, under the coordination of principal investigator Sharon Masek Lopez, Oak Creek Watershed Council staff and volunteers conducted an investigation of *E. coli* contamination of surface water. Besides creek water, stormwater runoff and springs were sampled to try to determine source areas of *E.coli*. Microbial source tracking for human DNA was conducted to evaluate potential water quality threats from leaking septic systems. This report provides a good background about *E. coli* contamination in the Oak Creek watershed and identifies problem areas to be addressed. Data tables are included. A set of fourteen potential watershed improvement projects are described.

USGS. 2018. **Black Mesa Monitoring Program, Interactive Data Map**. U.S. Geological Survey (USGS) website access September 21, 2018. https://az.water.usgs.gov/projects/BlackMesaMonitoringIMap/imap.html ◄◄

This interactive map contains spring, well, and surface water monitoring sites located within the Hopi Reservation and Black Mesa region. Data include well water levels, spring discharge, streamflow, and water quality. The interactive map contains descriptions of available data types for each site and links to the NWIS Web Interface for download of the data.

This citation is repeated. It also appears in the "Other General Data" section of this report.

USGS. 2018. **National Water Information System (NWIS).** U.S. Geological Survey website accessed September 21, 2018, https://waterdata.usgs.gov/nwis/qw ◄◄◄

The United States Geological Survey collects chemical, physical, and biological properties of water, sediment, and tissue samples throughout the nation. Data are stored in the National Water Information System. The NWIS site contains time-series data for gage height, streamflow, groundwater level, precipitation, physical and chemical properties of water, and water use, as well as discrete sample data for water, sediment, and biological samples.

Because the NWIS database includes so many different types of water data, the NWIS citation is repeated throughout this report. It also appears in the following report sections:

- Well Water Levels and Other Well Data
- Spring Discharge and Surface Water Flow
- Springs

NWIS includes discharge and water quality data for springs in the Coconino Plateau Watershed Partnership (CPWP) area of interest. As discussed in the "Springs" section of this report, NWIS physical and chemical data are very important for pairing with Springs Stewardship Institute data to address springs that may be impacted by R and C Aquifer drawdowns, which is one of the top concerns of CPWP stakeholders.

Wastewater Reuse – Water Quality Concerns

Reclaimed wastewater by its nature is not an ecosystem service, because it is generated by human activities. However, reuse of reclaimed wastewater can impact ecosystem services. Kandulu et.al. (2017) evaluated wastewater reuse in comparison with water augmentation options by assessing impacts to ecosystem services. For the urban area of Adelaide, Australia, water reuse was found to impact four ecosystem services, including 1. provisioning food and fiber, 2. salinity levels, 3. climate regulation and 4. water quality regulation.

For the Coconino Plateau Watershed Partnership area of interest, ecosystem services affected by wastewater reuse may include water quality regulation (regulating), groundwater recharge (regulating), recreation (cultural), and consumptive and non-consumptive water use (provisioning). Because stakeholder concerns regarding wastewater reuse seem to center around water quality issues, literature and datasets regarding Contaminants of Emerging Concern (CECs) are placed in this Regulating Services - Water Purification section of the report. See related wastewater reuse data in the Provisioning Services section of the report:

- Water Supply - City of Flagstaff water reuse delivery volumes and
- Irrigation - Map of reclaimed water distributions system.

City of Flagstaff. 2015. **Flagstaff City Manager's CEC Advisory Panel Preliminary Data Report September 14, 2015**. City of Flagstaff website accessed December 21, 2018. https://www.flagstaff.az.gov/DocumentCenter/View/47860/Staff-preliminary-data-report-sept-14-2015-2?bidId= ◄

Recognizing the importance of the Contaminant of Emerging Concern (CEC) issue, Kevin Burke, Flagstaff's previous City Manager, organized an advisory panel of 12 local, state, and nationally recognized researchers, scientists, and industry professionals to help understand what CECs mean to Flagstaff. The panel evaluated the status of CECs in Flagstaff reuse water based on monitoring data. Compounds in Flagstaff's water supplies are found in the part per billion level (microgram per liter) and part per trillion level (nanogram per liter), whereas regulatory standards require that water supplies are

required to be extensively tested for metals and inorganic contaminants, among others, mostly at the part per million level (milligram per liter).

City of Flagstaff. 2018. **Compounds of Emerging Concern (CECs): What are they… and should I be worried?** City of Flagstaff website accessed December 14, 2018, https://flagstaff.az.gov/3926/Compounds-of-Emerging-Concern ◄

This website gives a general explanation about Contaminants of Emerging Concern (CECs) and directs readers to additional resources.

City of Flagstaff. 2018. **Flagstaff City Manager's CEC Advisory Panel Final Report - January 9, 2018**. City of Flagstaff website accessed December 14, 2018, https://www.flagstaff.az.gov/DocumentCenter/View/56693/CEC-Panel-Report---Final-November-2017 ◄◄◄

This final report provides a summary conclusion to the five-year collaborative work conducted by the Flagstaff City Manager's CEC Advisory Panel. The Research Subcommittee has collected thousands of data points across Flagstaff and other municipal water systems, in Arizona and elsewhere, over a two-year period. Flagstaff water samples from 20 locations were analyzed for up to 96 CECs, including caffeine, 17-beta estradiol, triclosan, and N-Nitroso-dimethylamine (NDMA), which were specifically recommended by the panel. Initial results did not identify any increased risks associated with the Flagstaff reclaimed water as compared to other analyzed water re-use systems. The highest concentrations of CECs are shown in Table 3.

Table 3. Highest concentrations of Contaminants of Emerging Concern (CEC) detected in water sampled by City of Flagstaff. (Excerpted from "Flagstaff City Manager's CEC Advisory Panel Final Report - January 9, 2018")

CEC Constituent	# of Samples Collected	# of Samples with detections	Lowest Concentration Detected	Range of Detected Concentrations (2011–2015)	Units[1]
Raw Groundwater (2014–2015)					
Acesulfame-K [2]	8	1	ND	20	ng/l
Fluoxetine [3]	8	1	ND	24	ng/l
Raw Surface Water (2011-2015)					
4-nonylphenol [4]	3	1	ND	380	ng/l
Flumequine [5]	3	1	ND	630	ng/l
Oxolinic Acid [5]	3	1	ND	420	ng/l
Treated Surface Water (2011-2015)					
4-nonylphenol	4	2	ND	110-200	ng/l
Flumequine	4	2	ND	330-480	ng/l
Oxolinic Acid	4	2	ND	231-310	ng/l

Potable Water Distribution System (2010-2015)					
4-nonylphenol	11	1	ND	260	ng/l
Flumequine	11	5	ND	34-290	ng/l
Oxolinic Acid	11	2	ND	231-310	ng/l
Chlorinated Reclaimed Source Water (2010–2015)					
Acesulfame-K	4	3	ND	580 - 1300	ng/l
Amoxicillin [5] (semi-quantitative)	4	2	ND	10,000 - 14,000	ng/l
Azithromycin [5]	4	1	ND	1500	ng/l
Flumequine	4	2	ND	530 - 600	ng/l
Iohexal [6]	4	2	ND	81 - 910	ng/l

[1] ng/l = parts per billion, ppb

[2] artificial sweetener

[3] pyschiatric medication

[4] degradation product of nonionic surfactants

[5] antibiotic

[6] contrast media or dyes for X-ray imaging

Erosion Prevention

MacDonald, Christopher. 2018. **Terrestrial Ecological Unit Inventory - Hydrologic Soils Groups**. Personal communication to Sharon Masek Lopez, December 6, 2018. ◄◄◄

Kaibab National Forest Soils and Watershed Program Manager Christopher (Kit) MacDonald talked with Sharon Masek Lopez over the phone. They discussed many difference aspects of how soils affect the hydrologic cycle and, in turn, how soils are affected by management practices and fire in northern Arizona forests. Kit had commented during his interview with Dr. Kira Russo that he was concerned about potential impacts on soil productivity from prescribed fire and managed wildfire. High heat under burn piles can result in high soil burn severity, i.e. damage soil structure, biota, and nutrients. (Kit's comment constitutes the only comment made by a stakeholder about a supporting ecosystem service.)

Kit recommends using the Terrestrial Ecosystem Unit Inventory, and in particular the designations of Hydrologic Soil Group, as a means of identifying locations at risk of soil erosion due to fire, management practices, or extreme storm events. Hydrologic Soil Groups C and D have the highest risk for soil erosion, because these soils contain clayey or rocky restrictive layers or are located in flat areas. These conditions slow the downward infiltration of water. Low infiltration can cause the soil column to fully

saturate, resulting in rapid runoff that makes soil susceptible to erosion. Low infiltration, soil saturation, and rapid runoff also contribute to flooding hazard.

Kit reported that the Forest Service has a set of tables as database (.dbf) files that can be joined or related to the TEUI GIS data to populate the attributes table. Hydrologic Soil Group is included in these tables. Without the tables, useful data cannot be easily extracted from the TEUI data layer. Kit can provide the tables, but he did make them available prior to completing this report. Perhaps the data tables can be acquired from the USFS Geospatial Technology and Applications Center in Salt Lake City, UT (https://www.fs.fed.us/gstc/).

The Terrestrial Ecological Unit Inventory (TEUI) is an important data resource that should be considered during the Phase 2 Ecosystem Services Assessment. It may by integral to follow-on modeling efforts to identify priority sites for forest restoration to reduce post-wildfire flooding hazard, which is a top concern of CPWP stakeholders.

Stempniewicz, Victoria A. 2014. **Evaluating Erosion Risk Mitigation Due to Forest Restoration Treatments Using Alluvial Chronology and Hydraulic Modeling**. M.S. Thesis, Northern Arizona University, 169 p. ◄◄◄

The study evaluated the potential benefits of Flagstaff Watershed Protection Project forest restoration treatments for reducing flooding hazard generated in the Schultz Creek watershed, a major tributary of the Rio de Flag. Alluvial chronology was used to study the recent geologic history of Schultz Creek. Hydraulic modeling predicted how peak flood flow magnitudes and stored sediment could be affected by severe wildfires. During the Phase 2 Ecosystem Services Assessment, this thesis should be closely examined in addressing stakeholder concerns about post-wildfire flooding.

USFS. 2014. **Draft Slide Fire Burned Area Emergency Response Report - Coconino National Forest, June 24, 2014**. U.S. Forest Service, 213 p. ◄

This report details the Burned Area Emergency Response (BAER) team's assessment of the Slide Fire. It includes the burn severity, identification of values at risk, and recommendations for emergency stabilization treatments designed to reduce the risk to life, property, natural and cultural resources associated from post fire storm events.

USFS. 2018. **Coconino National and Kaibab National Forest Terrestrial Ecologic Unit (TEU) Land Type**. GIS layers. U.S. Forest Service (USFS) Region 3 Geospatial Data websites accessed December 15, 2018,

Coconino National Forest:

https://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5209303

Kaibab National Forest:

https://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5209305

◄◄◄

The purpose of this GIS feature class is to provide an inventory of the various ecotypes on the national forests. Terrestrial Ecological Units (TEU) are mapped units of land within which ecological structure, function, capabilities, responses, and management opportunities and limitations can be predicted. Currently there are significant gaps in potential natural vegetation, geology, and/or geomorphology data sets on many Forest Service units.

As discussed above in "MacDonald 2018", hydrologic soil group data can be found in database (.dbf) files that attribute the TEU layers. Together, the attribute files and the GIS layer provide important information for assessing soil erosion and flooding hazards in the Coconino Plateau Watershed Area of interest.

USFS. 2018. **Results of WEPP model assessment of upland roads and roads in riparian areas proposed for decommissioning.** In Oak Creek Watershed Restoration Environmental Assessment, Coconino National Forest website accessed October 22, 2018, https://www.fs.usda.gov/nfs/11558/www/nepa/107958_FSPLT3_4396936.pdf ◄

Coconino National Forest Hydrologist Amina Sena assessed potential sediment yield from road segments proposed for decommissioning on the Red Rock Ranger District. For the assessment, she used the Forest Service Water Erosion Prediction Project (WEPP) model (https://forest.moscowfsl.wsu.edu/fswepp/). Because erosion related to roadways was not recognized as a top concern of stakeholders during interviews, the usefulness of this report is ranked low.

See also the "Oak Creek Watershed Restoration Environmental Assessment, Coconino National Forest" description in the "Federal Projects and Programs" section of this report.

USFS. 2018.**TEUI Geospatial Toolkit.** U.S. Forest Service (USFS) website accessed December 15, 2018, https://www.fs.fed.us/eng/rsac/programs/teui/about.html ◄◄◄

The Terrestrial Ecological Unit Inventory Geospatial Toolkit (TEUI Toolkit) was developed and is maintained by the USFS Geospatial Technology and Applications Center in Salt Lake City, UT. The TEUI Toolkit is an ArcGIS AddIn that assists users in mapping and analyzing landscapes using geospatial data. The Toolkit was designed to accelerate the TEUI mapping process but can also be used for a variety of other natural resource mapping efforts. The Toolkit utilizes both continuous and discrete raster data (e.g., slope, aspect, elevation), polygon data (e.g., map units), and point data (e.g., soil pedon or vegetation plots) to calculate zonal statistics and display the results in both a tabular and graphical format.

For the CPWP Ecosystem Services Assessment Phase 2, Sharon Masek Lopez recommends the consultant work with the USFS Geospatial Technology and Applications Center to obtain all the necessary files to map soils with hydrologic soil groups C and D on the Kaibab and Coconino National Forests. Mapped hydrologic soil groups could be

used to model priority forest restoration areas to protect against soil erosion and subsequent water quality and aquatic habitat impacts.

Carbon Sequestration

Finkral, A.J. and A.M. Evans. 2008. **The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest**. Forest Ecology and Management, 255 (7) 2743-2750. ◄

An unintended consequence of fire suppression has been the increased storage of carbon in ponderosa stands. Thinning treatments reduce standing carbon stocks while releasing carbon through the combustion of fuel in logging machinery, burning slash, and the decay of logging slash and wood products. These reductions and releases of stored carbon must be compared to the risk of catastrophic fire burning through the stand and releasing large quantities of carbon to the atmosphere to more fully understand the costs and benefits – in carbon terms – of forest restoration strategies.

Rasmussen, Craig. 2006. **Distribution of soil organic and inorganic carbon pools by biome and soil taxa in Arizona**, Soil Science Society of America Journal Abstract – Pedology. 7 (1) 256-265. ◄

The objectives of this study were to quantify soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks in Arizona biomes. Biome distribution was extracted from the Arizona Gap Analysis Project spatial vegetation dataset (GAP), while soil C data were extracted from the Arizona State Soil Geographic Dataset (STATSGO) at a scale of 1:250 000, and the western Yavapai County Soil Survey Geographic Dataset (SSURGO) at a scale of 1:24 000. Raster based soil C estimations incorporate the spatial distribution and areal land cover of each soil type within a biome, providing a more accurate representation of soil C stocks.

Wildfire Protection

FWPP. 2018. **Flagstaff Watershed Protection Project Monitoring Plan.** FWPP website accessed October 24, 2018, http://flagstaffwatershedprotection.org/wp-content/uploads/2018/04/FWPP-Monitoring-Report-update-2018.pdf ◄◄

This monitoring plan report provides a synopsis of wildfire-protection-related studies in the Flagstaff area, including:

1. Studies that are planned/underway/complete
2. Studies that are needed to address knowledge gaps in order to answer voters' questions, and
3. Potential and future studies and funding opportunities.

The Flagstaff Watershed Protection Project (FWPP) developed four Capacity Monitoring Frameworks: 1) Fire Behavior, 2) Hydrologic Response, 3) Socioeconomic, and 4) Other Ongoing/Potential Monitoring Projects.

Sharon Masek Lopez recommends that the consultant for the Phase 2 Ecosystem Services Assessment meet with Greater Flagstaff Forest Partnership (GFFP) Coordinator Anne Mottek Lucas (mottekconsulting@gmail.com, 928.310.8102) and determine which completed studies or ongoing monitoring have the greatest utility for addressing the stakeholders' concerns about post-wildfire flooding.

GFFP. 2018. **Community Wildfire Protection Plan (CWPP).** Greater Flagstaff Forest Partnership (GFFP) website accessed December 14, 2018, http://gffp.org/community-wildfire-protection-plan-cwpp/ ◄◄

The Greater Flagstaff Area Community Wildfire Protection Plan (CWPP) was jointed developed by Greater Flagstaff Forest Partnership (GFFP) and the Ponderosa Fire Advisory Council (PFAC), which represents local fire departments and fire districts. In 2005, the Arizona State Forester, Coconino County, and City of Flagstaff approved the plan that covers a 939,736-acre area centered on Flagstaff. Working closely with U.S. Forest Service staff and the Northern Arizona University Forest Ecosystem Restoration Analysis (Forest ERA) program, the CWPP was designed to address specific goals, objectives and principles. The primary goals of the CWPP are to educate and involve the public, implement forest treatments to reduce wildfire threat and improve forest health in a prioritized manner, and utilize FireWise building techniques and principles.

GFFP. 2018. **Greater Flagstaff Forest Partnership Forest Treatments Map 2014**. Greater Flagstaff Forest Partnership (GFFP) website accessed December 18, 2018, http://gffp.org/wp-content/uploads/2018/01/GFFP_Treatment_Map_2014.pdf ◄◄

To reduce wildfire hazard, Greater Flagstaff Forest Partnership (GFFP) **and collaborators** like the City of Flagstaff, Arizona Department of Forestry & Fire Management and Coconino National have worked together to implement on-the-ground forest treatments around the City of Flagstaff. This map shows all forested areas around Flagstaff that were thinned up through 2014, as part of the Community Wildfire Protection Plan (CWPP).

Pyrologix. 2017. **Region 3 Risk Assessment Results GeoDatabase.** FSIM model developed by Pyrologix LLC for the U.S. Forest Service. (Not available online. See GIS files provided with this report.) ◄◄◄

This geodatabase presents results of FSIM modeling for U.S. Forest Service Region 3 (Arizona, New Mexico, West Texas). The database was provided to Sharon Masek Lopez by Northern Arizona University School of Forestry Ph.D. student Jesse Young via Google Drive, at the request of Professor Dr. Andrea (Andi) Thode. FSIM is a model used to

estimate the burn probability and variability in fire behavior across large landscapes. This FSIM model output was generated by Pyrologix LLC for the U.S. Forest Service Region 3.

Sharon Masek Lopez spoke with Joe Scott of Pyrologix LLC who completed the FSIM fire hazard modeling. Of the various GIS layers available, Joe recommended the “likelihood of fire” (a.k.a. burn probability) and the “fire intensity” results (a.k.a. conditional flame length) as the most useful for gauging potential impacts to water resources. Together, these two metrics express fire hazard. The layers for Highly Valued Resource or Assets (HVRA), such as infrastructure, transmission lines, oil and gas pipelines, and oil and gas wells, should be useful to address stakeholder concerns about risks due to potential wildfire.

This geodatabase would be very useful for addressing CPWP stakeholder concerns about wildfire and post-wildfire flooding. For future inquiries about geodatabase updates, contact USFS Fire Ecologist Tessa Nicolet (tnicolet@fs.fed.us, 928.474.7978).

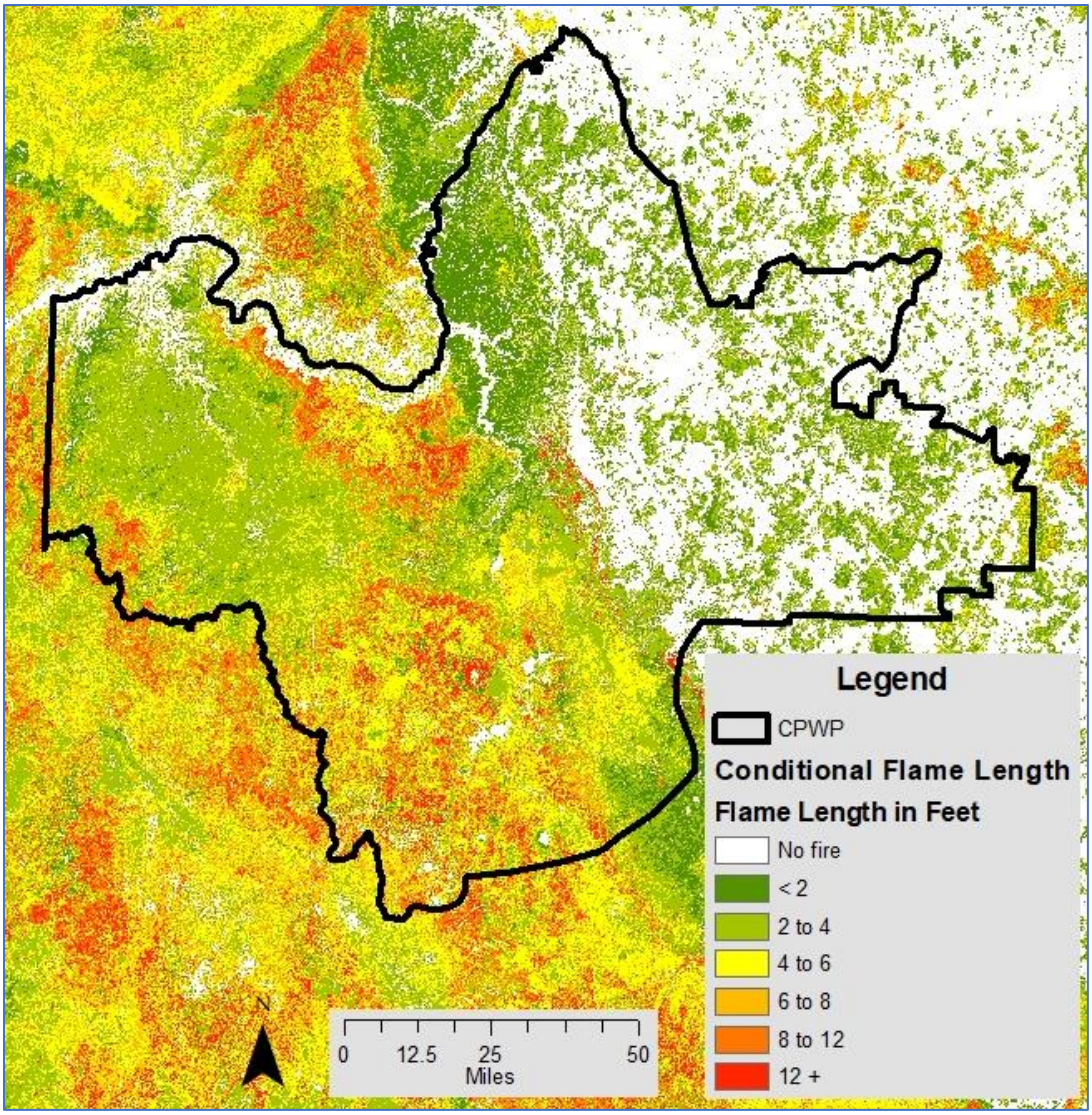

Figure 24. USFS Region 3 Wildfire Hazard Modeling – Flame Length

USDA and USDI. 2014. **LandFire Data Products Distribution Table**. LandFire website accessed October 18, 2018, https://www.landfire.gov/version_comparison.php ◄◄◄

LandFire, Landscape Fire and Resource Management Planning Tools, is a shared program between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, providing landscape scale geo-spatial products to support cross-boundary planning, management, and operations. The LandFire database contains a wealth of data used for fire modeling throughout Alaska, Hawaii, and the conterminous United States (CONUS). Unfortunately, there does not seem to be a way to query the database for a particular area of interest, so it is necessary to download data for the entire CONUS and then clip it. Be aware that download times are long and the files eat up storage space. For CPWP's purposes, perhaps the most recently available (2014) fuel loading model would be the most useful

for gauging wildfire hazard. However, other forest condition data, such as forest canopy bulk density, forest canopy base height, forest canopy cover, also may be useful to evaluate forest health and wildfire hazard.

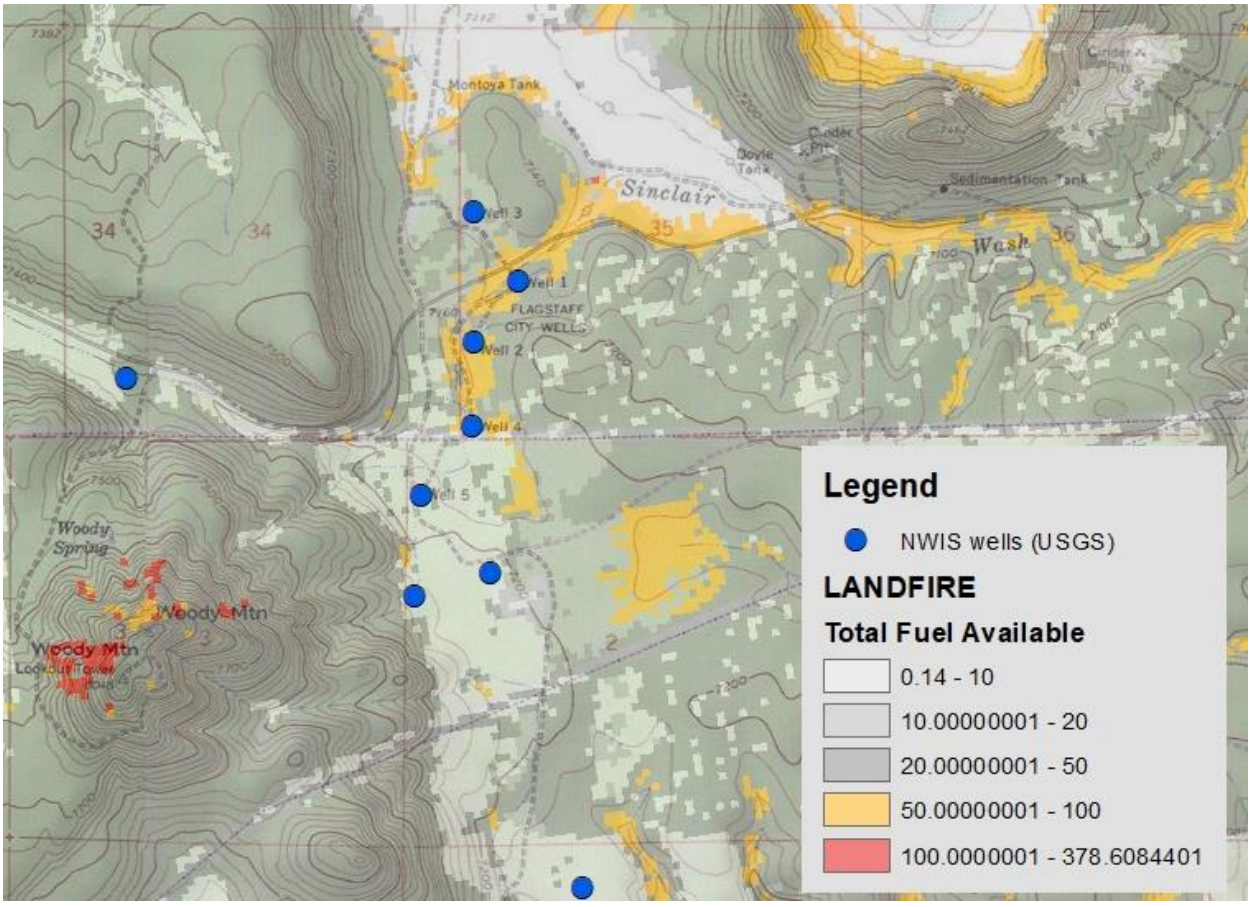

Figure 25. LandFire map of fuel availability in the vicinity of the City of Flagstaff's Woody Mountain Well Field. Notice fuel loading in the north half of wellfield along Sinclair Wash.

CULTURAL ECOSYSTEM SERVICES

Recreation/Tourism

In the Coconino Plateau Watershed Partnership area of interest, it is difficult to obtain basic data on recreation, such as number of visitors to area lakes and springs. In Phase 2 of the ecosystem services assessment, the CPWP Technical Advisory Committee should discuss how vital such data are for sustainable water resources planning. If the data are critical, then the Phase 2 consultant should work closely with Arizona Game and Fish department to obtain water-related recreation data for use in the ecosystem services assessment.

AOT. 2018. **Arizona State Park Visitation.** Arizona Office of Tourism (AOT) website accessed December 16, 2018, https://tourism.az.gov/state-park-visitation ◄◄◄

Two tables are available from this Arizona Department of Tourism website. The first table provides state park visitation in 2018. The second table provides visitation for the years 2003 through 2013. Slide Rock State Park year-to-date visitation in September 2018 was 403,433 people, a 6.6% increase over 2017. The monthly total for September was 44,773 visitors, which was a 14.1% increase over 2017.

Red Rock State Park is operated as a nature preserve and environmental education. The park does not allow recreating in Oak Creek and, hence, has much lower visitation than Slide Rock. Red State Park year-to-date visitation in September 2018 was 62,834 people, a 6.1% increase over 2017. The monthly total for September was 5,924 visitors, which was a 1.9% decrease compared to 2017.

Slide Rock State Park visitation has a large economic impact on Coconino County, and it relies on Oak Creek streamflow. Therefore, park visitation will serve as an important indicator in the ecosystem services assessment.

AOT. 2018. **Northern Region 2017 Year-end Data Review**. Arizona Office of Tourism (AOT) website accessed December 16, 2018, https://tourism.az.gov/sites/default/files/documents/files/AOT-NorthernPresentation2018_Final.pdf ◄◄◄

This report provides tourism statistics for Coconino, Navajo, and Apache Counties. 43 million people visited Arizona's northern region in 2017.To request a breakdown of the data for Coconino County, Sharon Masek Lopez reached out to the Arizona Office of Tourism, including Director of Research Colleen Floyd (cfloyd@tourism.az.gov, 602.364.3716) and Research Manager Kari Roberg (kroberg@tourism.az.gov, 602.364.4158).

Sharon Masek Lopez reached out to AOT Director of Research Colleen Floyd to request a breakdown of northern Arizona regional data by county and City of Flagstaff (Table 4). According to AOT, visitors spent $342 million in "Food Service" in 2017 in Coconino County. AOT also provided data on water-related tourism in the northern region (Table 5).

Table 4. Northern Arizona Annual Hotel Occupancy in 2017. Data provided by Arizona Office of Tourism, source: Smith Travel Research (STR).

Geography	**Demand[1]**	**Occupancy (%)[2]**
Apache County, AZ	194,634	0.52
Coconino County, AZ	3,162,151	74.83
Flagstaff, AZ	1,464,248	75.13
Navajo County, AZ	627,488	54.88

[1] Demand is room nights sold.

[2] Occupancy is percentage of total available rooms.

Table 5. Water recreation in Arizona's Northern Region (Coconino, Navajo, and Apache Counties) by domestic overnight visitors in 2017. Data provided by Arizona Office of Tourism, source: Longwoods International.

Activity	% of Visitors, 2017
Beach/waterfront	2.9%
Boating/sailing	3.3%
Fishing	5.0%
Rafting	3.0%
Swimming	11.4%
Waterpark	2.6%

Friends of the Verde River recently joined the Coconino Plateau Watershed Partnership in December 2018. This means that the CPWP area of interest might expand for the Phase 2 Ecosystem Services Assessment. If so, it is recommended that the Phase 2 consultant gather water recreation data for Yavapai County from AOT. Contact Director of Research Colleen Floyd at cfloyd@tourism.az.gov or (602)364-3716.

AZ Central. 2016. **Sedona tourism triples over the last decade**. February 5, 2016 news article. AZ Central website accessed December 16, 2018. https://www.azcentral.com/story/travel/road-trips/2016/02/05/sedona-tourism-triples-decade/79870460 ◄

According to the U.S. Forest Service, in 2015, nearly 3 million people visited the Red Rock Ranger District of the Coconino National Forest. The Forest Service counted visitors at the district's visitor center, heritage sites, Oak Creek Vista, Fossil Creek, and several other areas including camping sites and trails. Nearly 2 million of the visitors came to enjoy the hiking trails in and around Sedona.

City of Flagstaff. 2018. **Flagstaff Water Consumption (Past 5 Years)**. Pie chart posted on Flagstaff City Council Woman Jamie Wheelan's FaceBook page, November 28, 2018. ◄

This pie chart shows the relative water consumption for different water uses in Flagstaff. Notice that hotels and motels account for 6% of Flagstaff's water use. This provides a rough estimation of tourism-related water use, but does not incorporate other tourism-related water use such as for restaurants and retail stores.

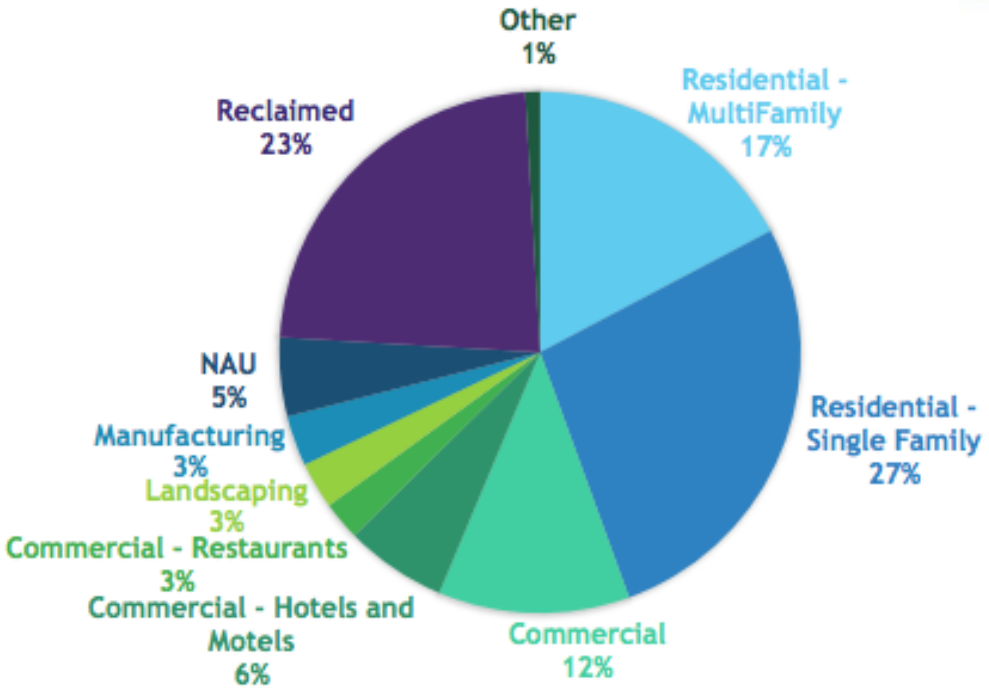

Figure 26. Flagstaff water consumption (Past 5 Years), water use sector as percent of total.

FCVB. 2018. **2017-2018 Visitor Profile**. Presentation slides accessed December 14, 2018 through the Flagstaff Convention and Visitor Bureau (FCVB) webpage, https://www.flagstaffarizona.org/visitorprofile/ (A copy of the presentation was also provided by Erin Young, City of Flagstaff.) ◄◄◄

According to the Flagstaff Convention and Visitor Bureau, 5.5 million people visited Flagstaff from July 2017 through June 2018. Of these visitors, 30% came from Arizona, 57% came from other U.S. state, and 13% were international. 74% were overnight visitors, and the average length of stay was 3 days. Average party size was 3.2 people. Traveling to the Grand Canyon was the top reason for visiting Flagstaff (68%). Other popular reasons were Route 66 nostalgia (34%), hiking or walking trail (32%), and Lowell Observatory (32%). Arizona Snowbowl accounted for 10% of visits. While here, downtown Flagstaff was the most popular activity (44%).

These data might be useful for estimating tourism water use. Especially if the visitation numbers are paired with published estimates of water use, such as Gössling et al. 2012, a reasonable estimate of water use might be determined.

FCVB. 2018. **Flagstaff Convention and Visitor Bureau FY 2018 Annual Report and FY 2019 Marketing Plan.** Flagstaff Convention and Visitor Bureau (FCVB) website accessed December 14, 2018, https://www.flagstaffarizona.org/get-connected/about-fcvb/reports/ ◄◄◄

Fedler, Anthony. 2014. **2013 Economic Impact of Fishing in Arizona.** Conducted for the Arizona Game and Fish Department by Responsive Management™, 34 p. http://dev-fishaz.pantheonsite.io/wp-content/uploads/2016/08/Fedler-2013-Economic-impact-of-fishing-in-Arizona.pdf ◄

This report is concerned with data gathered on fishing-related expenditures in Arizona during 2013. it uses these expenditure data to produce an analysis of the 2013 economic impact of fishing in Arizona. Fishing involves many externalities (e.g. fish in lakes are often stocked from sources outside the area). Also, stakeholders did not consider fishing as a top concern. For these reasons, the economic impact of fishing in Arizona was given a low usefulness rating for the ecosystem services assessment.

Gössling, Stefan, Paul Peeters, C. Michael Hall, Jean-Paul Ceron, Ghislain Dubois, L Vergne Lehmann, and Daniel Scott. 2012. **Tourism and water use: Supply, demand, and security. An international review.** Tourism Management 33, 1-15. ◄◄◄

Gössling et al. (2012) evaluated tourism-related water use for many countries throughout the world. The research paper estimated water use per tourist per day in the United States at 300 liters (79 gallons).

Visitation data for the entire CPWP area of interest are not available. However, by applying Gössling's U.S. daily tourist water use value to parts of the CPWP where visitation numbers are available, annual tourism water use can be estimated (Table 6).

Table 6. Estimated tourism water use in the Coconino Plateau Watershed Partnership area of interest, based on 79 gallons of water use per U.S. tourist per day, from Gössling et al. (2012).

Place	Tourists per year (million)	Water Use (acre-feet)
Sedona	3.1[a]	800
Flagstaff	5.5[b]	1,300
Grand Canyon	6.3[c]	1,500
Approximate total	14.8	3,600

[a] Sedona Chamber of Commerce and Tourism Bureau

[b] Flagstaff Convention and Visitors Bureau

[c] National Park Service

To examine tourism water demand at various places throughout the Coconino Plateau Watershed Partnership area of interest, Sharon Masek Lopez recommends that the consultant for the Phase 2 Ecosystem Services Assessment compare 1. the Coconino County and Flagstaff hotel occupancy numbers provided by AOT, 2. hotel occupancy numbers provided by Sedona Chamber of Commerce and Tourism Bureau, and 3. Grand Canyon National Park visitation numbers. Apparently, Grand Canyon National Park

visitation is a major driver for tourist visits in the region and, hence, a major factor in tourism water demand.

Stakeholders expressed strong interest in tourism-related water demand. Given the complexity and uncertainty involved in estimating tourist numbers, the authors of this report recommend that the Coconino Plateau Watershed Partnership Technical Advisory Committee (CPWP TAC) determine how necessary it is to have a complete and precise accounting of tourism water use or whether an estimate is sufficient.

If a precise accounting of tourism water use is desired, in Phase 2 of the CPWP Ecosystem Services Assessment, Sharon Masek Lopez recommends the CPWP TAC work closely with municipalities and water companies, to seek out more precise data on water use for hotels, restaurants, and water-related recreation. This might entail compiling water and/or waste water volumes for hotels and restaurants from water and waste-water service records. Because such a data compilation would be somewhat tedious and laborious, perhaps the task is well suited for a student intern.

NPS. 2018. **Grand Canyon National Park Annual Visitation 1919 to Present**. National Park Service (NPS) website accessed December 16, 2018, https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Annual%20Park%20Recreation%20Visitation%20(1904%20-%20Last%20Calendar%20Year)?Park=GRCA ◄◄◄

Grand Canyon National Park received following number visitors in the past five years:

2011	4,298,178
2012	4,421,352
2013	4,564,840
2014	4,756,771
2015	5,520,736
2016	5,969,811
2017	6,254,238

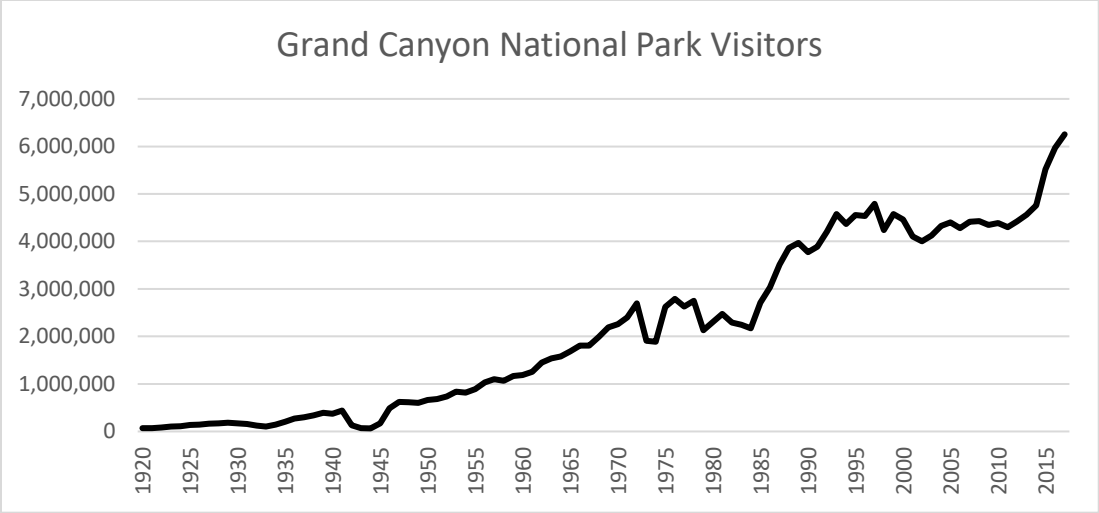

Figure 27. Grand Canyon National Park visitors 1920 to 2017 (National Park Service).

Given the sharp rise in park visitation since 2011, this report's authors recommend the CPWP discuss with Grand Canyon National Park projections of future visitation. Projected park visitation is important information for the ecosystem services assessment and CPWP's planning to meet long-term regional water demand.

NPS. 2018. **Flagstaff Area National Monuments Visitation**. Data tables downloaded from the Integrated Resource Management Applications (IRMA) and provided by National Park Service Natural Resource Specialist Paul Whitefield. ◄◄

These data tables provide annual visitor numbers from the beginning of each monument through 2017. Included are Wupatki, Sunset Crater, and Walnut Canyon National Monuments.

SCCTB.2018. **17/18 Annual Report**. Sedona Chamber of Commerce & Tourism Bureau (SCCTB) website accessed December 16, 2018, https://sedonachamber.com/wp-content/uploads/2015/08/Annual_Report_2018.pdf ◄

This annual report provides statistics on the economic impact of tourism in Sedona. It includes tourism-related sales, tourism-related sales tax revenue, and the Sedona Chamber of Commerce & Tourism Bureau operational budget to promote Sedona as a destination. Unfortunately, it does not provide the total annual visitors or data on hotel occupancy and number of restaurant patrons.

Sharon Masek Lopez followed up by contacting SCCTB CEO Jennifer Wesselhoff to fill in some missing details for quantifying tourism-related water use. See "Wesselhoff" citation below.

SCCTB. 2018. **Our Community.** Sedona Chamber of Commerce & Tourism Bureau (SCCTB) website accessed December 16, 2018, https://sedonachamber.com/our-community/ ◄

Sedona is visited by nearly 3 million tourists each year.

Tucson Audubon Society. 2013. **Economic Contributions of Wildlife Viewing to the Arizona Economy: A County-Level Analysis**. Water Resources Research Center (WRRC) website viewed December 28, 2018, https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/TAS_Economic%20Contributions%20of%20Wildlife%20Viewing%20to%20the%20Arizona%20Economy.pdf ◄◄

This report assesses the 2011 economic contributions of watchable wildlife recreation in Arizona, statewide, by county and by specific types of activity. Direct spending by both residents and non-residents for wildlife watching was analyzed, along with the multiplier effects of that spending. Total retail sales value for Coconino County was $48,192,790, which supported a 747 full and part time jobs for a total of $26,255,976 in salaries and wages. State and local tax revenue was $5,334,997, while federal tax revenue was $6,008,591,

Wesselhoff, Jennifer. 2018. **Tourism Data for Sedona to Inform Water Planning**. Personal communication from Sedona Chamber of Commerce & Tourism Bureau (SCCTB) CEO Jennifer Wesselhoff to Sharon Masek Lopez via email, December 17, 2018. ◄◄◄

Sedona Chamber of Commerce & Tourism Bureau (SCCTB) CEO Jennifer Wesselhoff responded to a data request from Sharon Masek Lopez. Jennifer provided a "Sedona Fun Facts" handout generated by SCCTB, a report on hotel occupancy trends from Smith Travel Research (STR), and some additional findings of SCCTB.

STR is a company that provides data benchmarking, analytics and marketplace insights for the hospitality industry. Jennifer shared an STR report that shows hotel occupancy and average daily rates for the last 18 months in Sedona. These data are for a select number of Sedona hotels that subscribe to the STR service. SCCTB extrapolates the STR data to estimate occupancy for all 4,000 rooms in the Sedona area.

SCCTB estimates the annual number of visitors to Sedona based on hotel performance data, general day-trip assumptions, and visitor profile data from past survey efforts. By using lodging performance information and relationships to timeshare and other overnight accommodations (occupancy rates, average party size, length of stay, etc.), SCCTB estimated that **Sedona hosted approximately 3.1 million visitors in 2017**. Day visitors accounted for 40%, while 60% stayed overnight. SCCTB research shows that 73% of Sedona visitors participate in dining during their stay.

Data provided by SCCTB can be used during the Phase 2 Ecosystem Services Assessment to help estimate tourism-related water demand, which was a top concern expressed by CPWP stakeholders during interviews.

Intellectual – Education and Research

Water resources of the Coconino Plateau Watershed Partnership area are certainly of great interest to scientists and educators. Using the Northern Arizona University's Cline Library search tools, a scientific publications search yielded the results in Table 7. Of course, not all search results are relevant, but the results do indicate the level of research interest in different parts of the CPWP area of interest.

Table 7. Number of scientific papers returned in searches regarding the Coconino Plateau Watershed Partnership (CPWP) area of interest. Northern Arizona University Cline Library search tools were used, including Web of Science and Academic Search Complete. ◄

Search words	Web of Science Results	Academic Search Complete Results
Oak Creek AND Arizona	25	358
Navajo AND water	187	4,890
Hopi AND water	45	1.818
Flagstaff AND water	39	3,787
Coconino Plateau AND water	1	125
Grand Canyon AND springs	97	6,214

Spiritual, Inspirational, and Symbolic Appreciation

Regarding spiritual appreciation of water, specific data are typically not available, due the sensitive nature of traditional cultural knowledge. Therefore, for the ecosystem services assessment, there may need to be a broad treatment of Native American cultural values in Grand Canyon and throughout the CPWP area of interest.

Berger, Todd. 2008. **Reflections of Grand Canyon Historians: Ideas, Arguments, and First-Person Accounts.** Grand Canyon Association, Grand Canyon, Arizona. 224 p. ◄◄

According to Hopi Tribe Archaeologist Mike Yeatts, on page 29 of this book, there is discussion of the Hopi salt pilgrimage, clans, cultural properties, and below the rim.

LCI. 2013. **Greater Grand Canyon Landscape Assessment – Cultural TWG Meeting Summary.** Northern Arizona University Landscape Conservation Institute (LCI) website accessed October 24, 2018, https://nau.edu/lci/greater-grand-canyon-landscape-assessment-documents/ ◄◄

The first meeting of the Greater Grand Canyon Landscape Assessment (GGCLA) Cultural Technical Work Group (TWG) was held on April 23rd, 2013. Meeting notes include information about the following:

- archaeological resources of Grand Canyon National Park,
- identified cultural landscapes,
- ethnographic resources,

- data and databases,
- other data sources, and
- indicators of condition of ethnographic resources.

It was noted that critical tribal involvement for identifying ethnographic resources and landscapes had not been forthcoming, due to reluctance to divulge sensitive knowledge. Also, Grand Canyon itself is a traditional cultural property (TCP) for all traditionally associated tribes, and that encompasses everything within the canyon.

[See related Stortz et al. (2018) reference in the "Maintaining Wildlife Populations and Habitats – Federal Projects and Programs" section of this report.]

USBR and NPS. 2016. **Glen Canyon Dam Long-Term Experimental and Management Plan FEIS - Tribal Resources Technical Information and Analysis**. Argonne National Laboratory website accessed October 24, 2018, http://ltempeis.anl.gov/documents/final-eis/vol2/Appendix_I-Tribal.pdf ◄◄

This cultural analysis is centered around water resources. It includes assessment regarding riparian areas, wetlands, trout management, Lake Powell water levels, and access to culturally important sites and resources. The URL to access the full EIS is http://ltempeis.anl.gov/documents/final-eis/.

Yeatts, Michael. 2018. **Tribal values of Grand Canyon water and natural resources.** Personal communication from Michael Yeats to Sharon Masek Lopez. (Not available online. See files delivered with this report.) ◄

On October 11, 2018, Sharon Masek Lopez interviewed The Hopi Tribe's archaeologist Michael Yeatts regarding tribal values of Grand Canyon water and natural resources. Two pages of notes were collected. Several resources listed in this section were recommended by Mike Yeatts.

Aesthetic Appreciation

Padget, Martin. 2013. **Hopi Film, the Indigenous Aesthetic and Environmental Justice: Victor Masayesva Jr.'s *Paatuwaqatsi – Water, Land and Life*.** Journal of American Studies, 47 (2) 363-384. ◄

This journal article reviews a film by a Hopi film maker that addresses the Hopi aesthetic in relation to water. Masayesva's film documents a 1,650-mile run made by Hopis from their home villages in Northern Arizona to Mexico City in early 2006 to commemorate the closing of the Black Mesa Pipeline that withdrew water from the N Aquifer to slurry coal to the Mohave Generating Station along the Colorado River for over 30 years. The article reviews Masayesva's filmmaking career to date and considers his core idea of the indigenous aesthetic.

CONCLUSIONS AND RECOMMENDATIONS

Through the interview process, Dr. Kira Russo identified the seven most important concerns of Coconino Plateau Watershed Partnership stakeholders. These concerns are as follows:

1. **Groundwater Flow** - Continued assessment of groundwater flow to inform decision-making for sustainable long-term groundwater use that ensures sufficient water for environmental flows and springs ecosystems,
2. **Wildfire Protection** - Protection against catastrophic fire and subsequent flooding,
3. **Infrastructure Needs** - Identification of water supply and water monitoring infrastructure needs,
4. **Climate Change** - Effects of climate change on water availability for natural systems and human use, especially a) changes in seasonality (e.g. more rain, less snow, earlier spring), b) increased occurrence of extreme weather events, and c) prolonged drought due to temperature increases,
5. **Water Reuse** - Further assessment of water reuse on the Coconino Plateau, including a strong interest in treating for direct potable reuse,
6. **Tourism and Recreation** - Assessment of tourism economic benefits balanced with costs of additional water demand, and
7. **Springs** – How groundwater use, wildfire, forest health, climate change, and tourism affect spring discharge and spring ecosystem health.

Based on findings from comping datasets for Task 2 of the ecosystem services assessment, Sharon Masek Lopez makes the following recommendations to the CPWP Technical Advisory Committee.

Groundwater Flow

To address groundwater flow, consider data for the following ecosystem services:

- Drinking Water (Provisioning),
- Water for Environmental Flow (Provisioning), and
- Groundwater Recharge (Regulating).

Well Water Levels, other well data, and groundwater models may be used to characterize groundwater flow. Figures 7 and 8 are examples of three-dimensional depictions of groundwater that may be easier for lay audiences of decision-makers to understand than technical reports. For the Phase 2 ecosystem services assessment, it is recommended to convert various groundwater model outputs to GIS files that can be displayed in this fashion. The Phase 2 consultant should work closely with the CPWP Technical Advisory Committee members to identify future groundwater modeling objectives and areas of interest.

Wildfire Protection

To address the hydrologic benefits of wildfire protection, consider data for the following ecosystem services:

- Flood Protection (Regulating),
- Erosion Prevention (Regulating),
- Water Purification (Regulating), and
- Drinking Water (Provisioning).

The Greater Flagstaff Forest Partnership and the Flagstaff Watershed Protection Project have made great progress in recent years thinning forest in the wildland urban interface according to Community Fire Protection Plans. These efforts have benefited from robust fire hazard modeling, such as LandFire and FSIM. The USFS Terrestrial Ecosystem Survey data also provides extensive data about soils and vegetation, which have a great bearing on post wildfire erosion and flooding.

It is recommended that the Phase 2 consultant work closely with U.S. Forest Service professionals to optimize the use of existing fire hazard modeling and identify priority forest restoration areas. Once identified, the Coconino Water Advisory Council could advocate for early treatment. Emphasis should be on avoiding high severity fire:

- To protect water supply infrastructure (e.g. wellheads and the power grid to water supply wells),
- To safeguard watersheds of surface water reservoirs that provide drinking water to cities,
- To reduce post-wildfire flooding hazard that would cause costly damages to personal property, and
- To reduce erosion and sedimentation that could damage aquatic ecosystems.

Much of this analysis has likely already been done through the Four Forest Restoration Initiative (4FRI) and other forest planning processes. It is important to have discussions early and often with Forest Service professionals to ensure that ecosystem services assessment is a synergistic net benefit to both the Forest Service and the Coconino Plateau Watershed Partnership members.

The CPWP may want to consider investing in ecohydrologic research that has been started through a collaboration of Coconino and Kaibab National Forests, the City of Flagstaff, Salt River Project, and Northern Arizona University. There is much to be gained from a deeper understanding of how forest restoration treatments affect hydrologic balance.

Infrastructure Needs

To address infrastructure needs for water supply and water monitoring, consider data for the following ecosystem services:

- Drinking Water (Provisioning),
- Water for Non-Drinking Purposes (Provisioning),
- Water for Environmental Flows (Provisioning),
- Water Purification (Regulating).

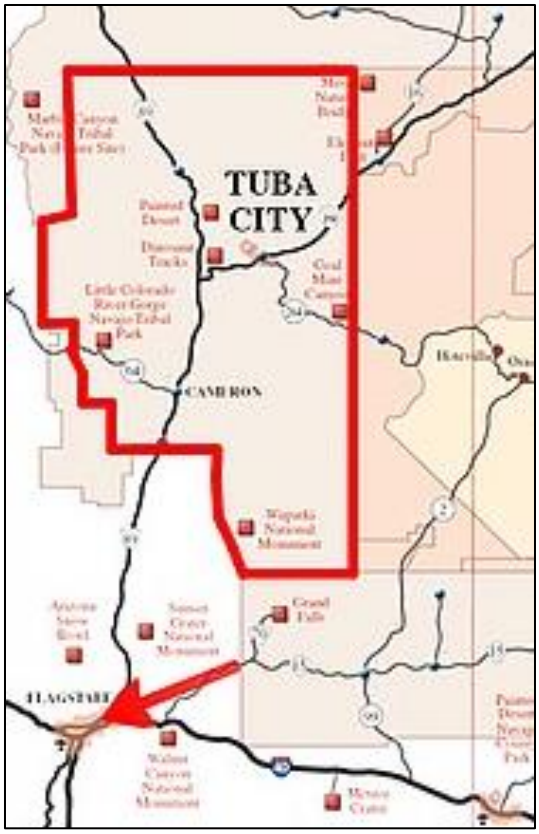

Figure 28. Map of the former Bennett Freeze Area (red outline).

The focus of concern about infrastructure should be on homes in the western Navajo Nation and on Hopi lands that do not have water service. Bureau of Reclamation's North Central Arizona Water Supply Feasibility Study provides water demand data. The Navajo Access Workgroup's 2010 document identifies the number of home sites in each chapter that are without water service. During the Phase 2 assessment, it is recommended that the consultant and CPTAC make a request to Indian Health Services (with Navajo Nation Department of Water Resources approval) for GIS maps showing home sites that are without water service.

Many unserved homes are within the Bennett Freeze area (Figure 28). This is partly due to the development freeze, imposed by Bureau of Indian Affairs from 1966 to 2009. Another factor is the lack of good quality groundwater. Both the C Aquifer and alluvial water tend to be brackish in this area. Practical and cost-effective water treatment technologies are needed. The alternative is to run pipelines from locations with good quality water. Because homesites are spread far apart, water resources planners are challenged to find cost-effective solutions.

Climate Change

To address the challenges of climate change, consider data for the following ecosystem services:

- Climate Change Adaptation and Disaster Risk Reduction (Regulating) and
- Carbon Sequestration (Regulating).

Human-caused climate change is happening. The recently released "Fourth National Climate Assessment" is sobering. Arizona can anticipate warmer conditions, changes in timing and form of precipitation (more rain, less snow), and increased incidence of severe weather between

now and 2070. These effects of climate change, combined with population growth, will pose significant water resources management challenges. Climate change will make it even more critical to balance the water needs of the natural environment with human water use, which is the goal of ecosystem service assessment.

Wastewater Reuse

To address the hydrologic benefits and water quality challenges of wastewater reuse, consider data for the following ecosystem services:

- Water Purification (Regulating),
- Groundwater Recharge (Regulating),
- Recreation (Cultural),
- Water for Non-Drinking Purposes (Provisioning), and
- Drinking Water (Provisioning).

Based on City of Flagstaff wastewater reuse delivery volumes (Table 2), 65% of reclaimed water deliveries in Flagstaff was used to irrigate turf in 2017. Turf includes golf courses, parks, and public school and Northern Arizona University grounds and playing fields. Most reclaimed water (71%) is not delivered at all; 4,517 acre-feet of reclaimed water was discharged to the Rio de Flag in 2017. There is great capacity to put reclaimed water to higher uses or to optimize groundwater recharge.

The Coconino Plateau Watershed Partnership should have discussions with City of Flagstaff about the City's vision for future reclaimed water use. Data within this report can help inform those discussions. Given that it is unlikely the portion used for golf courses will grow substantially, where does the City want to devote its capacity for wastewater reuse? How would City of Flagstaff prioritize the following uses:

- Groundwater recharge via ponds or injection wells,
- Rio de Flag green belts (also a means of groundwater recharge),
- Direct potable use,
- Industrial use, and/or
- Other uses?

Contaminants of emerging concern (CEC) (e.g., pharmaceuticals, endocrine disrupting compounds, personal care products, pesticides, algal toxins) must be part of any discussions about future wastewater reuse. The City of Flagstaff has tested for CECs in surface water, water supply well water, water distribution system water, and wastewater. Although the CEC concentrations in all water supply-associated samples were not elevated compared to other cities of this size throughout the United States, they were present. The presence of CECs may cause the public to have concerns about potential environmental and human health effects.

Of the water types tested for CECs in Flagstaff, groundwater displayed the lowest concentrations of CECs. This may reflect the land's natural filtering capacity. The limited evidence seems to show that CEC's may be attenuated greatly during hundreds of feet of infiltration from the land surface to the C aquifer. The public might find this reassuring and prefer groundwater recharge over direct potable reuse, especially if they cannot be assured that CECs are removed through treatment prior to water delivery. The lack of drinking water standards for CECs complicates public acceptance of direct potable reuse and may lead to the desire for additional treatment (USBR 2016).

In the Coconino Plateau Watershed Partnership area of interest, data on CECs are limited. Therefore, it is recommended that the Phase 2 consultant conduct a thorough literature search to inform water reuse recommendations in the ecosystem services assessment. Also, it is recommended that City of Flagstaff continue to regularly test for CECs in water supply wells nearest to the wastewater plant discharge points to gauge whether increasing concentrations are reaching the screened intervals of the wells.

Tourism and Recreation

To address economic benefits and the water management challenges of recreation and tourism, consider data for the following ecosystem services:

- Drinking Water (Provisioning),
- Water for Non-Drinking Purposes (Provisioning),
- Water for Environmental Flow (Provisioning), and
- Recreation/Tourism (Cultural).

The CPWP Technical Advisory Committee should have a discussion about objectives of applying tourism data to water resources management. Precise and extensive data on tourism-related water use is probably not practical to acquire. Assumptions must be made to generate better estimates.

Water companies have confidentiality rules. They cannot release water delivery data by customer (e.g. individual hotels or restaurants). However, commercial water use is reported to ADWR. As one stakeholder has pointed out, nearly all commercial enterprise in Sedona is tourism-related. Therefore, commercial water use numbers for Sedona, along with estimates of the annual number of visitors, could be used to generate assumptions about water use per tourist per day. These calculations would be a refinement of the Gössling et.al. (2012) estimated per tourist water use per day for the United States of 79 gallons per day.

Another alternative for estimating tourism-related water use is to approach hotels, motels, and restaurants and ask them directly for water use data from their water service billing. Many will probably not want to participate, but if enough did participate, then there would be clear data for generating better estimates of tourism-related water use. Because gathering such data

would be a laborious task, it is recommended to assign it to a student intern. Some thought should be put into how to incentivize participation.

Springs

Because springs are hydrologically and ecologically sensitive to the groundwater flow system, wildfire, climate change, and recreation, they integrate many of the CPWP stakeholders' concerns. To address springs, consider data for the following ecosystem services:

- Water for Environmental Flow (Provisioning),
- Groundwater Recharge (Regulating), and
- Maintaining Wildlife Populations and Habitats (Regulating).

In Phase 2 of the ecosystem services assessment (ESA), it is recommended that a discrete set of springs be selected to serve as indicators of the effects of water management practices. Springs should be selected that discharge from the R Aquifer, C Aquifer, and N Aquifers and from the perched water in a band from Mormon Lake north to Fort Valley and west to Parks.

For the Phase 2 ecosystem services assessment, Sharon Masek Lopez recommends the consultant work with the Springs Stewardship Institute to identify the discrete set of springs that would make good monitoring points for ecological impacts from changes in aquifer discharge, especially the R Aquifer and C Aquifer. Ideal indicator springs will have SIP and SEAP already completed, repeated ecological surveys, and a long-term record of spring discharge. Pairing the SSI data with U.S. Geological Survey spring monitoring data will be important to optimize the physical and chemical data in the National Water Information System (NWIS) together with the SSI data.

Ms. Masek Lopez further recommends that the consultant who completes the Phase 2 ESA speak with ecologist Dr. Larry Stevens (Springs Stewardship Institute) and botanist Glenn Rink (Far Out Botany). Ask these ecologists for recommendations on reference materials regarding wetland plants and ask them to generate a discrete list of obligate wetland plant species that would serve as the best indicators of wetland/spring health in north central Arizona. Particular attention should be given to plants that are sensitive to hydrologic conditions (as opposed to other stressors such as grazing pressure). Occurrences and collections of these plants as recorded in SEINet could serve as baseline data for long-term monitoring to gauge water resources management impacts on springs and wetlands.

Similarly, talk with Dr. Stevens about macroinvertebrates species that could make the best indicators of spring health. To search for baseline macroinvertebrate data, use the databases to gather macroinvertebrate data:

- Integrated Digitized Biocollections (iDigBio),
- Heritage Data Management System (HDMS),
- Symbiota Collections of Arthropods Network (SCAN),

- Arizona Dragonflies, and
- Odonata Central.

Use the macroinvertebrate data, along with data from Fuller et al. 2018 and Dr. Steven's recommendations, to select representative springs across the CPWP area of interest for long term monitoring.

While this task 2 was being completed, National Park Service Groundwater Hydrologist Paula Cutillo (personal communication) informed Sharon Masek Lopez that the agency has extensive data concerning Grand Canyon springs hydrology and ecology, including data from Havasupai and Hualapai lands. However, the NPS will not release this data, because it might be used in the near future for water rights litigation. In Phase 2, it is recommended that the consultant prepare for a formal request that the CPWP TAC and/or WAC could submit to the National Park Service to obtain Grand Canyon springs data relevant to ecosystem services assessment.

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This concludes the Phase 1 Ecosystem Services Assessment Task 2 report, including annotated bibliography and recommendations. References and Appendices follow.

References

NOTE: LITERATURE AND ARTICLES MAY BE REQUESTED FROM THE LEAD AUTHOR

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APPENDICES

Four appendices accompany this report. They were delivered to the Coconino Plateau Watershed Partnership via flash drive.

NOTE: LITERATURE AND ARTICLES MAY BE REQUESTED FROM THE LEAD AUTHOR

Appendix A. Search results from the Bibliography of Arizona Geology using keys words "aquifer", "hydrology", and "hydrogeology"

Appendix B. Literature and data files described in the annotated bibliography

Appendix C. GIS files and a GIS map package for all GIS data gathered for Task 2

Appendix D. Metadata for selected GIS files