Coconino Plateau Watershed Partnership

Water-Related Ecosystem Services Assessment

Phase II

FINAL REPORT

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Water-Related Ecosystem Services Assessment, Phase II
Final Report, September 2020

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Cover photo: Lockett Meadow landscape with pond, photo via www.goodfreephotos.com

AMP Insights
Executive Summary

The Coconino Plateau Watershed Partnership (CPWP) contracted for the completion of a Water-Related Ecosystem Services Assessment (ESA) as part of a broader effort to develop a framework for sustainable water management on the Coconino Plateau. The ESA focuses on the ecosystem services provided by surface water and groundwater resources of the Coconino Plateau, and specifically their importance and relative trends in their function, to help inform future water management decisions. The effort was conducted in two phases, with this report representing the culmination of Phase 2 work, which included 1) definition of the study area; 2) selection and description of assessment methods and metrics; and 3) a baseline assessment of the current state of selected services and recommendations for future study.

With regards to defining the study area, the Consulting Team recommended that the CPWP area of interest serve as the primary “study area,” but that indicators and associated metrics be selected at the geographic scale that best reflects the condition of the ecosystem service (as it is most relevant to the Coconino Plateau and area of interest), through the lens of stakeholder concerns, and making use of available information. It was recognized that in many cases, data would not be available at a spatial level that matched the boundaries of the study area. It was also recognized that in some instances, index sites might be chosen that lie outside of the study area, in order to reflect specific conditions associated with a given ecosystem service and connected stakeholder concerns.

As requested in the scope of work for the ESA, the focus of this effort was to identify indicators and metrics that were based on existing available data (rather than those that would require additional data to be collected) and that were accessible and replicable by CPWP members and stakeholders.

Commonly used indicators and metrics for assessment of water-related ecosystem services were derived from seminal literature and meta-analyses on the topic. In order to adequately address stakeholder concerns and the unique nature of the Coconino Plateau, additional indicators also were considered that were not found in the seminal literature reviewed, or that were adapted from these and other sources. In total, over 70 potential indicators were identified, and while all of these related in some way to the stakeholder concerns expressed in Phase 1, some were judged to be more feasible or more meaningful to assess.

Based on the goals of this effort, twenty-nine indicators were selected—covering a broad cross section of the water-related ecosystem services of the Coconino Plateau and key stakeholder concerns. These indicators were then populated to create a baseline assessment to describe the current status of water-related ecosystem services and any identifiable trends in their function.

A few of the notable trends identified through this assessment include:

- declining water levels in Lake Powell;
- recent decreases in total water use in Coconino and Navajo Counties even as populations have increased;
- increases in the number of wells in the study area, but decreases in the rate at which they are being added;
- apparent declines in select index wells’ groundwater levels and in summer (June) flow at certain stream gages and index springs;
increases in wildfire frequency, but also sustained forest restoration efforts; and
steady increases in visitation and visitor spending in Coconino County.

A number of significant data gaps also were identified. It is recommended that the CPWP continue to monitor and update the indicators and potentially pursue further data development or analysis in specific cases. It is also recommended that future planning for water sustainability build on this understanding of the multiple ways that the freshwater ecosystems of the Coconino Plateau region benefit humans and their communities; evaluate potential impacts on these services when considering water management alternatives; and identify opportunities for strategies that sustain and improve ecosystem service function.
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Acronyms

ADWR  Arizona Department of Water Resources
ADEQ  Arizona Department of Environmental Quality
AF    Acre-Feet
AMA   Active Management Area
AOT   Arizona Office of Tourism
APP   Aquifer Protection Permit
BLS   Below Land Surface
CEC   Contaminants of Emerging Concern
CPWP  Coconino Plateau Watershed Partnership
CWA   Clean Water Act
CWS   Community Water System
ESA   Ecosystem Services Assessment
GPM   Gallons Per Minute
HUC   Hydrologic Unit Code
MA    Millennium Ecosystem Assessment
NARGFM Northern Arizona Regional Groundwater-Flow Model
NF    National Forest
NP    National Park
NWIS  National Water Information System
PDO   Pacific Decadal Oscillation
PWSS  Public Water System Supervision
SDWA  Safe Drinking Water Act
SDWIS Safe Drinking Water Information System
SEAP  Springs Ecological Assessment Protocol
SIP   Springs Inventory Protocol
SNOTEL Snow Telemetry
SSI   Springs Stewardship Institute
SWE   Snow Water Equivalent
TAC   Technical Advisory Committee
TMDL  Total Maximum Daily Load
USGS  United States Geological Survey
1 Introduction

The Coconino Plateau Watershed Partnership (CPWP) contracted for the completion of a Water-Related Ecosystem Services Assessment (ESA) as part of a broader effort to develop a framework for sustainable water management on the Coconino Plateau. The ESA focuses on the ecosystem services provided by surface water and groundwater resources of the Coconino Plateau, and specifically their importance and relative trends in their function, to help inform future water management decisions.

The ESA effort was conducted in two phases and comprised five tasks:

- Task 1: Identification of the ecosystem services to be evaluated
- Task 2: Review of existing data
- Task 3: Definition of the services study area
- Task 4: Selection and description of assessment methods and metrics
- Task 5: Current state of selected services and future study

In Phase 1, Global Water Policy Consulting and H2O Consulting completed Task 1 and Task 2 of the ESA. In Task 1, CPWP stakeholders were interviewed in order to identify the water-related ecosystem services to be assessed. Seven priority stakeholder concerns were identified, and these concerns were linked to water-related ecosystem services. In Phase 1 Task 2, an annotated bibliography was generated identifying existing data sources available to assess the identified ecosystem services.¹

This Phase 2 report details the completion of the three remaining tasks. After reviewing the conclusions of the Phase 1 work, it describes the definition of the study area for the assessment; the methods and metrics selected to assess the identified ecosystem services, including specific indicators and associated metrics that were identified; and then, applying those metrics, it describes the current state of the identified water-related ecosystem services, including identification and discussion of trends. Finally, the report makes recommendations related to future study.

2 Water-Related Ecosystem Services

The Millennium Ecosystem Assessment (MA) was a multi-national, multi-stakeholder effort conducted under the oversight of the United Nations. Its objective was to “to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being” (Alcamo 2003). It is widely recognized as one of the seminal efforts to assess both ecosystem services and their interactions with human populations.

¹ Two reports were prepared describing the work completed and conclusions reached in Phase 1 of the ESA, covering Task 1 and Task 2 respectively (K. A. Russo and Masek Lopez 2018; Masek Lopez and Russo 2019). These reports will be referred to hereafter in this document as the “Phase 1 Reports.”
The Millennium Ecosystem Assessment definition of ecosystem services is as follows:

“Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.” (Alcamo 2003)

Ecosystem services encompass “the direct and indirect contributions of ecosystems to human well-being.” They are a useful concept for connecting people to the natural world and can “help make visible the key role of ecosystem functioning and biodiversity to support multiple benefits to humans” and thus contribute to more sustainable management of ecosystems (Grizzetti et al. 2016). Ecosystem services assessments offer a trans-disciplinary “lens” for looking at systems, rather than a specific management framework. Water-related ecosystem services derive from the world’s freshwater ecosystems, including rivers, lakes, floodplains, wetlands, riparian areas, and connected groundwater systems; a water-related ecosystem services assessment focuses on the various benefits to humans of these freshwater systems. (Martin-Ortega, Gordan, and Khan 2015; Grizzetti et al. 2016)

3 Review of Phase 1: Identifying Ecosystem Services for Evaluation

As further described in the Phase 1 ESA reports prepared for the CPWP, Global Water Policy Consulting was tasked with identifying the water-related ecosystem services to be evaluated through this assessment, which was accomplished through a series of interviews with key stakeholders. For more information on interview methods and results, please see the Phase 1 Task 1 Report. From the interviews, Global Water Policy Consulting identified seven key stakeholder concerns as follows. Each concern is also described in more detail in the Phase 1 Reports. The stakeholder concerns are listed here in order of relative priority or importance to stakeholders, as assessed by Global Water Policy Consulting. (K. Russo 2020)

1. The groundwater system and groundwater flow
2. Wildfire protection
3. Infrastructure needs: water supply, water resources monitoring
4. The effects of climate change
5. Water reuse
6. Assessment of tourism and recreation benefits and impacts
7. Protection of springs and seeps

Based on these stakeholder concerns, ecosystem services were recommended for assessment in Phase 2. Table 1 below is the original table of stakeholder concerns and associated ecosystem services included in the ESA Phase 1 Reports, linking identified stakeholder concerns to associated ecosystem services.
### Table 1. CPWP Stakeholder Concerns & Related Ecosystem Services (From ESA Phase 1 Report)

<table>
<thead>
<tr>
<th>Stakeholder Concern</th>
<th>Ecosystem Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Flow</td>
<td>Provisioning: Drinking Water, Water for Env. Flow</td>
</tr>
<tr>
<td></td>
<td>Regulating: Groundwater Recharge</td>
</tr>
<tr>
<td>Wildfire Protection</td>
<td>Regulating: Flood Protection, Erosion Prevention, Water Purification, Drinking Water</td>
</tr>
<tr>
<td></td>
<td>Regulating: Water Purification</td>
</tr>
<tr>
<td>Climate Change</td>
<td>Regulating: Climate Change Adaptation and Disaster Risk Reduction, Carbon Sequestration</td>
</tr>
<tr>
<td></td>
<td>Regulating: Water Purification, Groundwater Recharge, Recreation, Water for Non-Drinking Purposes, Drinking Water</td>
</tr>
<tr>
<td>Tourism and Recreation</td>
<td>Provisioning: Drinking Water, Water for Non-Drinking Purposes, Water for Env. Flow</td>
</tr>
<tr>
<td></td>
<td>Cultural: Recreation/Tourism</td>
</tr>
<tr>
<td>Springs</td>
<td>Provisioning: Water for Env. Flow</td>
</tr>
<tr>
<td></td>
<td>Regulating: Maintaining Wildlife Populations and Habitats</td>
</tr>
<tr>
<td></td>
<td>Cultural: Spiritual</td>
</tr>
</tbody>
</table>

As the first step of Phase 2, the Consulting Team reviewed the Phase 1 Reports and deliverables.

Based on this review, the Consulting Team proposed a number of adjustments to the organization of the stakeholder concerns and ecosystem services identified in the Phase 1 Reports in order to best align with the focus of the Phase 2 assessment. In addition to making some minor adjustments to the labeling of ecosystem services, the Consulting Team proposed that several of the identified ecosystem services were potentially relevant to additional stakeholder concern categories beyond those originally identified, and so should be noted as linked to those concerns. The Consulting Team also recommended that a few items that were initially identified as ecosystem services might be more usefully treated as drivers or indicators in the context of the Phase 2 assessment.²

The adjusted list of ecosystem services was then reorganized around the ecosystem services themselves, noting which stakeholder concerns were connected to each service. Table 2 is the reorganized version in which information is categorized by ecosystem service as opposed to stakeholder concern. Table 2 was discussed with the Technical Advisory Committee (TAC) at its January 2020 meeting and served as the starting point for the Phase 2 assessment.

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² In particular, the Consulting Team recommended that groundwater recharge be considered a driver of freshwater supply and thus an influencer of other water-related ecosystem services, rather than itself being considered an ecosystem service or benefit provided by the freshwater ecosystem; and that climate change (one of the identified stakeholder concerns) be linked as a driver to all of the other water-related ecosystem services, rather than be associated with carbon sequestration or climate change adaptation and risk mitigation, neither of which are themselves significant services provided by the freshwater ecosystem.
### Table 2. CPWP Stakeholder Concerns & Related Ecosystem Services (Reorganized)

<table>
<thead>
<tr>
<th>Category</th>
<th>Ecosystem Service</th>
<th>Stakeholder Concern(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning</td>
<td>Drinking Water</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
</tr>
<tr>
<td></td>
<td>Water for Non-Drinking Purposes</td>
<td>Groundwater, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
</tr>
<tr>
<td></td>
<td>Water for Env. Flow</td>
<td>Groundwater, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
</tr>
<tr>
<td>Regulating</td>
<td>Flood Protection</td>
<td>Wildfire Protection, Climate Change</td>
</tr>
<tr>
<td></td>
<td>Water Purification</td>
<td>Wildfire Protection, Infrastructure, Climate Change, Water Reuse</td>
</tr>
<tr>
<td></td>
<td>Erosion Prevention</td>
<td>Wildfire Protection, Climate Change</td>
</tr>
<tr>
<td></td>
<td>Maintaining Wildlife Populations &amp; Habitats</td>
<td>Climate Change, Springs</td>
</tr>
<tr>
<td>Cultural</td>
<td>Recreation/Tourism</td>
<td>Climate Change, Water Reuse, Tourism/Rec</td>
</tr>
<tr>
<td></td>
<td>Spiritual</td>
<td>Climate Change, Springs</td>
</tr>
</tbody>
</table>

It should be noted that although the focus of the assessment was on the particular ecosystem services identified through Phase 1 (rather than on the stakeholder concerns themselves), that assessment was completed through the lens of the stakeholder concerns, as those concerns were described in the Phase 1 Reports.

It is also useful to note that the names and divisions of particular ecosystem services categories and subcategories (for example, dividing “drinking water” from “water for non-drinking purposes”) follow terminology that is widely used in the ecosystem services literature. (See, for example, Grizzetti et al. 2016.)

### 4 Study Area

Ecosystem services operate at varied and multiple scales, and therefore, ecosystem services assessments can be undertaken at varying scales, from the very local to the national, continental, or global scale. Water-related ecosystem services assessments are sometimes, but not always, conducted at the scale of an individual watershed or groundwater basin. (Martin-Ortega et al. 2015)

The CPWP has previously defined its geographical area of interest based on the CPWP’s participants and the geographical reach of their shared water-related concerns. In particular, the area of interest has evolved to encompass its current area in north central Arizona through a series of water supply studies completed by the Arizona Department of Water Resources, the US Bureau of Reclamation, and local partners over the last several decades—including most recently a feasibility study that was initiated but not completed, to assess possible pipeline projects to provide Colorado River water to communities within the region (US Bureau of Reclamation 2016).

In the absence of plans for such a pipeline, the CPWP has committed itself to developing a proposed framework for sustainable water management on the Plateau, with a goal of ensuring adequate water supplies for the future while preserving the health of the Coconino Plateau environment (Coconino Plateau Watershed Partnership 2020). This ESA is intended to inform such a framework.
With this context in mind, the Consulting Team worked with the CPWP and TAC to define a study area specifically for the ESA. The following sub-sections describe the CPWP area of interest, the geographic scale of key water-related ecosystem services, and the selected study area for the purposes of this effort. After considering multiple possible approaches to defining the ESA study area, the Consulting Team recommended using the current CPWP area of interest as the study area—but assessing various services and indicators at different geographic scales, including those that encompass areas outside of the study area.

4.1 CPWP Area of Interest in Context

As noted above, the CPWP’s area of interest is based on its participants and their shared water-related interests and concerns. The area of interest is a unique and diverse area that is not defined by any one geographic, hydrologic, socioeconomic, or jurisdictional feature. It is bounded by the Colorado River through the Grand Canyon to the north and northwest; roughly by the Aubrey Cliffs to the west; by the divide between the Coconino Plateau and Verde groundwater basins to the southwest; roughly, but not entirely, by the Mogollon Rim to the southeast; and by the border of the Hopi Reservation to the east.

Thus, the area of interest is not coterminous with political boundaries. It includes parts of three counties: Coconino (encompassing 55% of the county’s land area), Navajo (17% of county land area), and Yavapai (<1% of county land area). It includes all or part of the land of four Native American Reservations (the Hualapai, Havasupai, Hopi and Navajo Reservations); portions of two National Forests (the Kaibab and the Coconino); and several National Park Service units, including the southern portion of Grand Canyon National Park (see Figure 1).
The CPWP area of interest—while encompassing the Coconino Plateau and the Coconino Plateau groundwater basin—is also hydrologically complex and does not align directly with hydrologic boundaries.

Indeed, precipitation that falls on the San Francisco Peaks—which, just north of Flagstaff, are the high point within the area of interest and of the state of Arizona—contributes runoff to tributaries of both the Little Colorado River and the Verde River, streams that flow towards opposite ends of the state and of the Lower Colorado River Basin. Overall, runoff within the area of interest contributes flow to the Little Colorado River, the Colorado River, and the Verde River and to tributaries of each of these significant waterways that flows within or along the boundaries of the area of interest. (Bills, Flynn, and Monroe 2007; Waring, Gwendolyn L. 2018)

Surface water flows within the area of interest are influenced not only by precipitation within that area, but by groundwater availability in large, complex, and interconnected regional aquifers—and by other broad influences within and across watersheds including, in the case of the Colorado River, hydrologic and policy drivers encompassing a basin that spans seven US states and regions of northern Mexico.

Geologically, the Coconino Plateau is a sub-province of the much larger Colorado Plateau—but the area of interest extends somewhat beyond this boundary. There are two regional groundwater systems on the Coconino Plateau: the C aquifer and Redwall-Muav aquifer. Groundwater discharge from the
Coconino Plateau feeds streams and rivers on the Plateau and along its borders, providing base flow (year-round flow derived from groundwater) to those streams and rivers. Groundwater discharge also provides flow to hundreds of springs and seeps across the region. The area of interest also encompasses a significant portion of the Little Colorado River groundwater basin and a small portion of the Verde groundwater basin, each of which is also a significant source of groundwater that discharges to area streams, rivers, and springs. (Bills, Flynn, and Monroe 2007; Arizona Department of Water Resources 2009a; 2009b; 2009c; US Bureau of Reclamation 2016)

To help illustrate this hydrologic context, Figure 2 locates the CPWP area of interest relative to local watersheds, at the HUC-8 scale. Figure 3 depicts the CPWP area of interest relative to groundwater basin boundaries as defined by the Arizona Department of Water Resources (ADWR).³

³ It is worth noting that even the groundwater basin boundaries defined by ADWR do not represent absolute hydrologic divides, given the complexity of the local geology and overlap and interconnection among regional aquifers. The CPWP’s “groundwater map,” available on its website, is a useful depiction of the overlapping lateral extent of regional aquifers underlying the area of interest (Coconino Plateau Watershed Partnership 2015).
At the outset of its analysis, the Consulting Team considered the various boundaries illustrated above along with several other sets of boundaries (for example, “Planning Areas” defined by ADWR [Arizona Department of Water Resources n.d.]) to consider alternatives for expanding the boundaries of the ESA study area beyond that of the CPWP area of interest to further encompass hydrologic and/or political features that are likely to be associated with water-related ecosystem services.

For example, the Consulting Team, with input from the TAC, considered that the study area could be expanded to include all of the Navajo Reservation, Grand Canyon National Park, and the Hualapai Reservation; expanded to include all of Coconino and Navajo Counties; or expanded to include the entirety of each groundwater basin or watershed that is touched by the area of interest. It could alternatively be adjusted on a finer scale to include specific additional watersheds, chapters of the Navajo Nation (for example), or other geographical units that are potentially relevant to specific stakeholder concerns or ecosystem services. The study area could also be contracted so as to focus, for example, on only the Coconino Plateau groundwater basin, or that basin plus a hydrologic “buffer” intended to also capture areas of discharge from the groundwater basin.

Each option assessed through this initial analysis, however, would have either significantly expanded or significantly truncated the study area relative to the CPWP’s traditional area of interest—or would have had the effect of expanding the scope of assessment of all services based on considerations related to a
specific service. Such an approach to defining a revised, fixed study area, therefore, was not recommended.

4.2 Scale of Ecosystem Services

As recognized in the Millennium Ecosystem Assessment, ecosystem services assessments should be conducted at a scale and across a geographic domain appropriate to the processes or phenomena being examined. At the same time, there is rarely if ever an ideal scale that best describes all processes or ecosystem services being assessed, and the scale of “observation” (or at which data is available) is rarely identical to the scale at which a physical or social process takes place. Furthermore, it is important to consider the “scale at which social decision making occurs, with which people can relate, and on which they can act....” (Alcamo et al. 2003)

To further consider the best approach for selecting a study area for this assessment, the Consulting Team prepared a matrix to more precisely identify ecosystem services to be assessed; the overall geographic impact of each ecosystem service; and the likely relevant geographic impact for the purposes of this study, to best reflect stakeholder concerns and available data (see Appendix A).

Specifically, this matrix included a column describing the overall geographic impact of the relevant ecosystem service; a handful of key “measurable characteristics” connected with the ecosystem service; and the likely (anticipated) geographic scale of information associated with these features. For some, multiple potential scales were listed and ranked as “ideal,” “possible,” or “more likely.”

While this matrix was not meant to comprehensively catalog all possible measurable characteristics of an ecosystem service, all available potential metrics, or all types of available information, it was intended to highlight the different spatial scales at which relevant information, needed to develop meaningful indicators and associated metrics, could be measured.

The information assembled and considered in the study area matrix made clear that the scale of the ecosystem services themselves and their impact do not in all cases align with the scale of the available information about those services. It was also evident that the appropriate geographic scale for assessment would need to vary depending on the particular ecosystem service and the indicators and associated metrics used to assess it.

4.3 Recommended Approach

Based on the foregoing analysis, the Consulting Team recommended using multiple geographic scales to assess the selected ecosystem services—a recommendation that is consistent with best practices in ecosystem services assessment. Using multiple scales can allow “individual ecological and social processes to be assessed at the scale at which they operate and to be linked to processes at different scales and levels of social organization.” It can also allow for the assessment to take into account the scale or level of dialogue and decision making about the relevant resources. (Alcamo et al. 2003)

Accordingly, after consultation with the TAC, the CPWP area of interest was adopted as the “study area” for the assessment. This is the area that has been the focus of CPWP attention, collaboration, and dialogue for many years, and was the area used to define stakeholders and stakeholder concerns for the first phase of this assessment. It defines a relevant level of dialogue and decision making.
The Consulting Team also recommended that indicators and associated metrics be selected and assessed at the geographic scale that best reflects the condition of the ecosystem service (as it is most relevant to the Coconino Plateau and area of interest), through the lens of stakeholder concerns, and making use of available information. It was recognized that in many cases, data would not be available at a spatial level that matched the boundaries of the study area. It was also recognized that in some instances, index sites might be chosen that lie outside of the study area, in order to reflect specific conditions associated with a given ecosystem service and connected stakeholder concerns.

5 Selecting Ecosystem Service Indicators and Metrics

This section provides an overview of the methods used for selecting appropriate indicators and associated measures/metrics to be used to a) assess the current state of the water-related ecosystem services selected by the CPWP in Phase 1; and b) track changes and trends in these water-related ecosystem services over time.

5.1 Definitions

For the purposes of this effort, definitions from the United Nations Environment Programme World Conservation Monitoring Centre publication on developing ecosystem service indicators are used:

- “Ecosystem service indicators are information that efficiently communicates the characteristics and trends of ecosystem services, making it possible for policymakers to understand the condition, trends and rate of change in ecosystem services.”
- “Measure (or measurement): Actual measurement of a state, quantity or process derived from observations or monitoring.”
- “Metric: a set of measurements or data collected and used to underpin each indicator.” (Brown et al. 2014)

More simply, an indicator refers to an overarching idea, while measures and metrics are then used to explain various traits or conditions of the indicator. For example, “freshwater supply” is an indicator, while some measures and metrics used to describe freshwater supply might be a) acre-feet (AF) available by source (i.e., AF of groundwater or surface water per year); b) AF available to people per year; c) percentage change over time of AF available to people; or d) deviation of AF available in any given year from an identified long-term average.

5.2 Indicator Identification

As provided for in the scope of work for the ESA, the focus of this effort was to identify indicators and metrics that could be assessed using existing available data (rather than those that would require additional data collection) and that would be accessible and replicable by CPWP members and stakeholders. Another objective in selecting indicators and metrics was to identify, where possible, those that would both (a) allow identification of any evident historic trends in ecosystem function; and (b) allow for ongoing monitoring of trends in ecosystem service function in the future. The focus, therefore, was on finding indicators that convey meaningful information based on available and regularly collected data.
An initial round of research, however, sought to catalog a much more comprehensive list of possible indicators relevant to stakeholder concerns expressed in Phase 1, regardless of their ability to meet these criteria. This approach was chosen for several reasons:

- to provide an overview of water-related ecosystem service indicators commonly used in the literature and base subsequent work on that foundation. Appendix B contains a list of possible indicators derived from seminal literature about ecosystem services indicators (including Berghöfer and Schneider 2015; Bergkamp and Cross, n.d.; Brown et al. 2014; Grizzetti et al. 2016; Layke et al. 2012; Nania and Cozzetto 2014; UN Environment 2017);
- to create a comprehensive list of indicators for future reference and/or application; and
- to highlight the differences between “ideal” and “applicable” indicators for the purposes of this effort.

In order to adequately address stakeholder concerns, additional potential indicators were added to the list that were not found in the seminal literature reviewed, or that were adapted from these and other sources. These additional indicators sought primarily to address the relatively unique nature of the Coconino Plateau with regard to its dependence on groundwater as a primary water source—and/or to best capture an ecosystem service’s relevance to an identified stakeholder concern.

For each indicator, the following categories of information also were included in the catalog of possible indicators:

- Ecosystem service category – defined as provisioning, regulating, or cultural.
- Ecosystem service sub-category – included to better differentiate the contributions of each category and match them to the ecosystem services identified in Phase 1.
- Associated stakeholder concern(s) – defined as groundwater, wildfire protection, infrastructure, climate change, water reuse, tourism/recreation, and springs; based on the stakeholder concerns connected to each service as illustrated in Table 2 above.
- Classification – classified based on the conceptual framework of Grizzetti et al. (2016), in which indicators represent capacity (potential of the ecosystem to provide the ecosystem service), flow (actual use of the service), and/or social benefit (human value derived from use of the service). An additional category was added—driver—that represents external variables that have the potential to affect the capacity, service flow, or benefit of the ecosystem in question.
- Potential measure(s)/metric(s) – potential ways in which data and information could be used to describe the indicator.

In total, over 70 potential indicators were identified (see Appendix C). While all of the identified possible indicators related in some way to the stakeholder concerns expressed in Phase 1, some were judged to be more feasible or more meaningful to assess than others. Identified indicators differed by a) the level of public data available for indicator measures and metrics within the study area; b) the level of effort necessary to regularly update the status and trends of the indicators; and c) the relevance of the indicators to the area of interest and identified stakeholder concerns.

### 5.3 Selected Indicators and Metrics

From the large list of potential indicators, a recommended list of indicators was created with a focus on selecting those that: a) strongly related to key stakeholder concerns; and b) could likely be measured using publicly available data that is collected and updated at regular intervals, and in a way that is easily...
accessible and replicable. The TAC reviewed a draft version of the recommended indicator list at their April 2020 meeting. Feedback from the TAC was incorporated into a revised list of recommended indicators. This revised list was presented to the CPWP at their May 2020 meeting along with a narrative description of each indicator that included:

- Indicator type – defined as direct or proxy. Indicators may relate directly or indirectly (i.e., a proxy indicator) to the ecosystem service of interest. Proxy indicators, while not direct representations of the indicator of interest, are often used in cases where a direct measure of the indicator is not available.
- Recommended measure(s)/metric(s)
- Recommended spatial scale
- Frequency of measurement (i.e., how often measurements are taken or datasets are updated)
- List of potential data sources for populating recommended measure(s)/metric(s)

The final list of selected indicators for assessing water-related ecosystem services in the study area, along with the associated metrics for each, includes further iterative revisions based on both comments from the TAC and additional research by the Consulting Team (see Table 3).
<table>
<thead>
<tr>
<th>Ecosystem Service - Subcategory</th>
<th>Indicator</th>
<th>Measure/Metric</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning - General</td>
<td>Regional climate variability</td>
<td>Winter precipitation (in)</td>
<td>Index sites</td>
</tr>
<tr>
<td></td>
<td>Reservoir levels</td>
<td>Reservoir storage volume (% full)</td>
<td>Index reservoirs</td>
</tr>
<tr>
<td></td>
<td>Well levels</td>
<td>Well depth to water (ft)</td>
<td>Index wells</td>
</tr>
<tr>
<td></td>
<td>Human population</td>
<td>#</td>
<td>Counties and Flagstaff</td>
</tr>
<tr>
<td></td>
<td>Total water demand</td>
<td>Volume (AF)</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Water source dependence</td>
<td>Volume by source (% of total)</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Groundwater demand</td>
<td>Volume (AF)</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Groundwater wells</td>
<td>Total wells (#), exempt wells (#)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Surface water demand</td>
<td>Volume (AF)</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Reclaimed water</td>
<td>Volume (AF)</td>
<td>Index water providers</td>
</tr>
<tr>
<td>Drinking Water</td>
<td>Residential water use</td>
<td>Volume (AF)</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Population served by water supply type</td>
<td># and %</td>
<td>Counties</td>
</tr>
<tr>
<td></td>
<td>Households without access to complete plumbing facilities</td>
<td># and %</td>
<td>Counties</td>
</tr>
<tr>
<td>Water for Non-Drinking Purposes</td>
<td>Non-residential water use by sector</td>
<td>Volume (AF and % of total)</td>
<td>Counties</td>
</tr>
<tr>
<td>Water for Environmental Flow</td>
<td>Stream flow</td>
<td>Median June flow (cfs)</td>
<td>Index streams</td>
</tr>
<tr>
<td></td>
<td>Spring flow</td>
<td>Median June flow (cfs)</td>
<td>Index springs</td>
</tr>
<tr>
<td>Regulating - General</td>
<td>Landcover change</td>
<td>Landcover type (acres)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Wildfire frequency</td>
<td>Incidents (#); extent (acres)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Forest restoration</td>
<td>Area treated (acres)</td>
<td>National Forests</td>
</tr>
<tr>
<td>Water Purification</td>
<td>Drinking water quality</td>
<td>SDWA exceedences (# of violations)</td>
<td>Index water providers</td>
</tr>
<tr>
<td></td>
<td>Impaired waters</td>
<td>#</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Monitoring for uranium mining</td>
<td>Active uranium mines (#); monitoring wells per active uranium mine (#)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Reclaimed water quality</td>
<td>Class of reclaimed water released by wastewater treatment facilities (Class A,B,C)</td>
<td>Index facilities</td>
</tr>
<tr>
<td>Wildlife Populations &amp; Habitats</td>
<td>Endangered species</td>
<td>Endangered/threatened species (#); endangered/threatened aquatic species (#)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Stream habitat</td>
<td>Impaired streams (#)</td>
<td>Study area</td>
</tr>
<tr>
<td></td>
<td>Spring habitat</td>
<td>Surveys (#); Avg. extent of data (1-10)</td>
<td>Study area</td>
</tr>
<tr>
<td>Cultural</td>
<td>Rec/tourism visitors</td>
<td>#</td>
<td>Index sites</td>
</tr>
<tr>
<td></td>
<td>Direct spending by non-resident rec/tourism</td>
<td>$</td>
<td>County</td>
</tr>
</tbody>
</table>
Given that all recommended indicators, and associated measures and metrics, were used in order to describe the current status of water-related ecosystem services in the area of interest, relevant indicator-specific information is included in Section 6 below.

6 Baseline Conditions and Trends

Using the recommended indicators, the Consulting Team conducted a baseline assessment within the identified study area to describe the current status of water-related ecosystem services and any identifiable trends in their function, as described in the following sections. The description of baseline conditions and trends is divided into a discussion of the identified provisioning ecosystem services; the regulating services; and the cultural services.

6.1 Provisioning Services: Baseline Conditions and Trends

Three provisioning ecosystem services were identified for assessment in Phase 1: water for drinking; water for non-drinking purposes; and water for environmental flow. Provisioning services are often among those where the benefit of an ecosystem to humans is most direct and visible. In this case, the three identified provisioning services reflect that the freshwater ecosystems of the Coconino Plateau region provide people with the water itself that is needed to drink and thus sustain human life; the water that is used for other household purposes and to, for example, grow crops, water livestock, fuel business and industry and facilitate energy production (all examples of “water for non-drinking purposes”); and, finally, water for “environmental flow”—that is, the water that flows in rivers, streams, springs, and other water-dependent features and supports all types of life dependent on water in this region.

The three identified provisioning ecosystem services strongly connect to each one of the stakeholder concerns identified through interviews in Phase 1. For example, stakeholders’ concern about groundwater flow and availability—the top identified concern—no doubt derives from groundwater’s centrality in the study area as a source of water for drinking, non-drinking purposes, and as the base flow of rivers, streams, and springs in and near the study area. Taking each of the other stakeholder concerns in turn, concerns about wildfire protection connect to the potential for wildfires and post-wildfire flooding to interfere with the quantity and quality of available drinking water. Infrastructure concerns expressed by stakeholders included concerns about the availability of infrastructure to provide drinking water throughout the study area; climate change concerns relate in large part to how climate change may affect the provision of water for consumption and in the environment. Concerns about water reuse also relate to concerns about how we use available water resources for these provisioning purposes; the “tourism and recreation” concern included consideration of how tourism impacts water demand for drinking and non-drinking purposes; and, finally, stakeholders’ concern about spring protection includes concern about whether water for environmental flow in those springs will continue to be available in the future.

Because of the centrality of the identified provisioning services—as well as their interaction with regulating and cultural services—a broad variety of indicators were selected to assess different aspects of the function of these services.

The following subsections, organized around each identified indicator, begin with consideration of indicators that are broadly relevant to all three provisioning ecosystem services. These are labeled as
“general” provisioning indicators and relate primarily to freshwater supply and demand—factors that are of central importance to the provisioning services, but are also difficult to measure directly within the study area. Discussion then proceeds to consideration of indicators more specific to water for drinking, water for non-drinking purposes, and water for environmental flow, respectively.

Provisioning – General: Regional Climate Variability

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs

Recommended measure: Annual winter precipitation (inches)

Spatial scale: Index sites

Frequency of measurement: Annually

Proxy for: Freshwater supply

Regional climate variability was selected as a proxy indicator for freshwater supply. More specifically, such variability represents an external environmental driver of freshwater supply, given that climate variability influences temperature and precipitation patterns and thus water availability. Potential metrics that could be used to track climate variability within the study area include temperature, Pacific Decadal Oscillation (PDO), Snow Water Equivalent (SWE), annual precipitation, annual winter precipitation, and/or annual snowpack. With the exception of PDO, which is measured on its own scale, and temperature, all identified measures/metrics could be presented as inches annually.

Based on a review of relevant literature and data the recommended measure of regional climate variability is annual winter precipitation, measured in inches. Winter precipitation is considered to be a key driver of groundwater recharge—and thus the sustainability of the freshwater supply—in the Coconino Plateau region. Furthermore, summer precipitation, while important to forests and other vegetation, is less relevant to long-term water availability as evaporation frequently exceeds summer precipitation in the area of interest. (Bills, Flynn, and Monroe 2007)

The National Water and Climate Center administers an automated snow telemetry (SNOTEL) network “composed of over 800 automated data collection sites located in remote, high-elevation mountain watersheds in the western US” that monitor snowpack, precipitation, temperature, and other climatic conditions (National Water and Climate Center 2020).

Four SNOTEL sites were identified within the study area—Snowslide Canyon (elevation – 9730 ft), Fry (elevation – 7200 ft), White Horse Lake (elevation – 7180 ft), and Mormon Mountain (elevation – 7500 ft). These high-elevation sites were selected as index sites given the importance of winter precipitation for groundwater recharge. These sites can be viewed on an interactive map on the National Water and Climate Center website. (National Water and Climate Center 2020)

In addition, “Flagstaff Area” (elevation – ~7000 ft), as defined by NOAA National Weather Service Forecast Office (2020), was selected. With the exception of Snowslide Canyon (1998-present), all SNOTEL sites have data from 1981-present, while Flagstaff Area data are available back to 1980.

All data are presented by water year—with a water year defined as starting in November of the previous year and ending at the end of October for the listed year. (For example, the water year 2000 begins November 1, 1999 and ends October 31, 2000).
As seen in Figure 4, all index sites follow a relatively similar pattern across the time frame considered, however, winter precipitation in the Flagstaff Area is consistently lower than at the other four index sites.

**Figure 4. Annual Winter Precipitation at Index Sites**

Over the period of record for which data are available, there is not a clearly observable trend in annual winter precipitation.

Other research indicates that climate is changing in northern Arizona, potentially leading to hotter and drier conditions (Meadow et al. 2018). Monitoring annual winter precipitation at select index sites is a way to observe potential associated trends in the availability of winter precipitation to contribute to groundwater recharge in the study area.

**Provisioning – General: Reservoir Levels**

*Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Storage volume (% full)*

*Spatial scale: Index reservoirs – Lake Powell and Lake Mary*

*Frequency of measurement: Annually*

*Proxy for: Surface water supply*

Surface water supply is relevant to the availability of water for both drinking and non-drinking purposes within the study area. (Note that surface water flowing in rivers, streams, and springs is more specifically addressed in the section on environmental flow below.)

Given the difficulty in estimating total surface water supply from all sources, the indicator “reservoir levels” was selected as a proxy indicator for surface water supply. Potential measures/metrics identified include capacity (AF), storage volume (AF or % of capacity filled), reservoir depth (ft), or overdraft—
withdrawal minus inflow (AF or %). Based on a review of relevant literature and data, the recommended measure for reservoir levels is storage volume (expressed as percentage of reservoir capacity filled).

There are numerous reservoirs, lakes, and stockponds in the study area. The two primary reservoirs relied upon for water supply within the study area are Lake Powell (managed by the US Bureau of Reclamation) and Lake Mary (managed by the City of Flagstaff) (Arizona Department of Water Resources 2009a; 2009b; 2009c). These two reservoirs were therefore selected as index sites for measuring and tracking reservoir levels.

Water from Lake Powell is relied upon by the City of Page for municipal supply, is delivered to the community of LeChee within the Navajo Nation, and has also historically been used by the Navajo Generating Station, a coal-fired power plant within the study area that was closed in 2019. Water levels in Lake Powell are one of the triggers (along with relative levels in Lake Mead) to determine how much water is released in a given year from Glen Canyon Dam, affecting both flows through the Grand Canyon and the availability of Colorado River water for use in Arizona and other Lower Colorado River Basin states, along with hydropower generation (US Secretary of Interior 2007). Water levels in Lake Powell are thus an important indicator not only of water supply within the study area but in the state and region.

Upper Lake Mary provides water to the City of Flagstaff, which is among the largest demand centers within the study area (Coconino Plateau Watershed Partnership 2015). On average, Flagstaff has historically obtained about 30% of its water supply from Upper Lake Mary, with other supplies coming from wells and springs (City of Flagstaff - Water Services Divisions 2018). Lake Mary is also a recreational amenity within the study area.

Lake Powell data are reported as AF of storage (Bureau of Reclamation 2020), while Upper Lake Mary data are reported as the percent of total capacity filled (City of Flagstaff - Water Services Divisions 2018). Both datasets include monthly data, which were converted to average annual values. In order to present data for both reservoirs in consistent units, Lake Powell data also were converted to percent of total capacity filled (see Figure 5).

**Figure 5. Percent of Total Capacity Filled (1995-2018)**

![Graph showing the percent of total capacity filled for Lake Powell and Lake Mary from 1995 to 2018. The graph demonstrates fluctuations in capacity filling over the years, with peaks and troughs indicative of water availability and usage. Lake Powell and Lake Mary are represented by distinct lines, allowing for comparison.]
As shown in Figure 5, water levels in Lake Powell have declined substantially in the last 25 years, with the reservoir going from over 75% full in 1995 to below 50% full in 2018. This decline has been attributed to a combination of factors, including increased demand throughout the Colorado River Basin; decreases in inflow to the river system based on patterns of drought and long-term climate variability; as well as the “overallocated” state of the Colorado River and the nature of the governing operating guidelines, which seek to balance water levels in Lake Powell and Lake Mead, even as both reservoirs decline. (US Bureau of Reclamation 2012)

These reservoir declines create substantial water supply, economic, and environmental risks in Arizona and the Lower Colorado River Basin (US Bureau of Reclamation 2012), and were the impetus for the recent enactment of the Colorado River Drought Contingency Plan (US Bureau of Reclamation n.d.). They are also anticipated to drive discussions in upcoming renegotiation of the 2007 Interim Guidelines that govern Colorado River shortages and the operations of Lakes Powell and Mead (US Bureau of Reclamation n.d.). The declines observed in Lake Powell thus represent declines in water availability that can impact the study area directly (e.g., by affecting flows in Grand Canyon and those water users who rely on Colorado River water—as well as those tribes that seek recognition of water rights to the Colorado River) and more indirectly (e.g., by affecting broader federal and state water policy and economics).

Provisioning – General: Well Levels

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs
Recommended measure: Well depth to water (ft)
Spatial scale: Index wells
Frequency of measurement: Approximately annually
Proxy for: Groundwater supply

Groundwater is a key water supply in the study area. As described in subsequent sections on water demand, most water providers in the study area rely on groundwater to meet residential demand, and “self-supplied” residential demand is also met primarily with groundwater. As also discussed below, groundwater provides base flow to the numerous rivers, streams, seeps, and springs whose flow originates as discharge from the area’s aquifers. “Groundwater flow” and its future availability to serve various purposes—including human consumption and provision of ecological and cultural benefits—was the top stakeholder concern identified in Phase 1 of the ESA.

The groundwater supply in the study area comes primarily from three large aquifers termed the N Aquifer, the C Aquifer, and the R-M Aquifer. While water in these aquifers appears to be a blend of water from different sources and with different residence times in the aquifers, it is believed that much of the area’s groundwater is “fossil” groundwater that was deposited in a different geologic age and is not readily recharged or replenished. One approximation of an annual water budget for the Coconino Plateau suggests that at least in some years with low precipitation, natural recharge is zero. Therefore, while the area’s groundwater supply is often considered to be relatively ample, it is also finite. The same study showed a net loss in groundwater storage over the Coconino Plateau region and noted that “existing gaps in hydrologic data make it difficult to predict with any degree of certainty the sustainability of the water supply for either natural or anthropogenic water demands.” (Bills, Flynn, and Monroe 2007)
Hydrologic models are especially valuable in predicting how groundwater supply may change over time given different possible scenarios. The Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and Alluvial Basin Aquifer Systems of Northern and Central Arizona (NARGFM) was first developed in 2010 and has since been modified on multiple occasions to address specific questions related to groundwater in northern Arizona. The CPWP has built on the NARGFM model to begin to assess specific scenarios related to groundwater flow and resources in the region. The CPWP’s modeling projects how projected future groundwater use may impact saturated aquifer thickness, depth to groundwater, and environmental flow at different sites of interest to the CPWP. (Matrix New World Engineering, Southwest Groundwater 2020)

The total volume of available groundwater supply within the study area (or in the underlying regional aquifers) is not, however, a number that is readily and precisely measurable so that it can be easily tracked on an annual or other relatively short-term basis for purposes of the ESA. Nor is comprehensive reporting or tracking of groundwater supply and demand data required throughout the study area, meaning that data are not available to track inputs and outputs to the aquifer systems on an annual or other short-term basis. In contrast, for example, in the state’s active management areas, major hydrologic inflows and outflows are reported and tracked on an annual basis to assess whether the aquifer is at “safe yield” or otherwise meeting its management goal.

In the absence of direct measures of total groundwater supply, proxy measures can be used to help assess and track groundwater supply within the study area over these shorter time periods. Possible proxy indicators and metrics for groundwater supply could include modeled or measured water levels in wells, saturated aquifer thickness at different sites, groundwater recharge (natural and artificial), overdraft (withdrawal minus recharge), or a measurement of mechanisms and tools available to achieve groundwater sustainability, such as the “groundwater sustainability index” developed by Pandey et al. (2011). Data are not readily available to assess many of these potential “proxy” indicators.

Based on data availability, water levels in index wells—wells with depth to groundwater measurements monitored by ADWR or the USGS—were selected to provide an indicator of total groundwater supply—or groundwater supply available to humans. ADWR’s “index well” set, a subset of wells from ADWR’s Groundwater Site Inventory wells, are typically visited once each year by field staff to obtain long-term records of groundwater level fluctuations. USGS also regularly monitors certain wells within the study area.

Index wells were chosen from the ADWR and USGS data sets based on data availability and location, with a focus on providing as much geographic coverage of the study area as possible (see Figure 6). The selection of index wells was also guided by reference to wells initially identified by the TAC in a prior effort to identify measurable sites in the study area; location in regards to proximity to population centers (cities/towns and Native American reservations); and location within ADWR-defined groundwater basins. The period of record for groundwater level monitoring was used to refine this list (see Figure 6 and Table 4).

Notably, there is a striking absence of regularly measured USGS or ADWR index wells in the northern or western portions of the study area—including in areas close to the Hualapai and Havasupai Reservations or near the western end of Grand Canyon National Park, as well as areas of the Navajo Nation and near Page—with most candidates for index sites clustering closer to Flagstaff and Sedona.
Figure 6. Location of Index Groundwater Wells
<table>
<thead>
<tr>
<th>Study ID</th>
<th>Agency</th>
<th>ADWR Reg_ID/USGS Site ID</th>
<th>Reason for Selection</th>
<th>Depth to Groundwater (Rounded average over period of record)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 1</td>
<td>ADWR</td>
<td>606205</td>
<td>Near Flagstaff, Verde River groundwater basin</td>
<td>1,160</td>
</tr>
<tr>
<td>Well 2</td>
<td>ADWR</td>
<td>637392</td>
<td>Forest Service land near Flagstaff, Little Colorado River groundwater basin</td>
<td>1,310</td>
</tr>
<tr>
<td>Well 3</td>
<td>ADWR</td>
<td>606195</td>
<td>Near Flagstaff, Little Colorado River groundwater basin</td>
<td>620</td>
</tr>
<tr>
<td>Well 4</td>
<td>ADWR</td>
<td>649814</td>
<td>Located near the center of the study area, National Park land, furthest north ADWR index well in the CPWP</td>
<td>1,590</td>
</tr>
<tr>
<td>Well 5</td>
<td>ADWR</td>
<td>649813</td>
<td>Forest Service land near Flagstaff, Little Colorado River Groundwater Basin</td>
<td>1,960</td>
</tr>
<tr>
<td>Well 6</td>
<td>ADWR</td>
<td>631803</td>
<td>Near Sedona, just outside CPWP</td>
<td>460</td>
</tr>
<tr>
<td>Well 7</td>
<td>ADWR</td>
<td>522853</td>
<td>Near Sedona, inside CPWP</td>
<td>10</td>
</tr>
<tr>
<td>Well 8</td>
<td>ADWR</td>
<td>529209</td>
<td>Near Williams</td>
<td>400</td>
</tr>
<tr>
<td>Well 9</td>
<td>ADWR</td>
<td>613880</td>
<td>In Coconino Plateau groundwater basin</td>
<td>90</td>
</tr>
<tr>
<td>Well 10</td>
<td>USGS</td>
<td>355254112054901</td>
<td>Period of record &amp; location in NW Coconino Plateau groundwater basin in Kaibab National Forest and nearest Grand Canyon National Park</td>
<td>940</td>
</tr>
<tr>
<td>Well 11</td>
<td>USGS</td>
<td>351214111022101</td>
<td>Period of record &amp; location in SE corner of Navajo Reservation</td>
<td>330</td>
</tr>
<tr>
<td>Well 12</td>
<td>USGS</td>
<td>355023110182701</td>
<td>Location on Hopi Reservation and far eastern part of the CPWP</td>
<td>450</td>
</tr>
<tr>
<td>Well 13</td>
<td>USGS</td>
<td>360217111122601</td>
<td>On Hopi Reservation</td>
<td>200</td>
</tr>
<tr>
<td>Well 14</td>
<td>USGS</td>
<td>360734111144801</td>
<td>Nearest Tuba City</td>
<td>30</td>
</tr>
</tbody>
</table>

The index wells selected have depths to groundwater that do not exceed 2,000 ft, and nearly 70% of these have depths to groundwater less than 1,000 ft—both measured as below land surface (BLS). The records for these index wells are not consistent across wells nor across years, skipping multiple years and taking place in different months of the year. As a result, depth to groundwater levels were averaged by calendar year and the resulting values do not allow for the easy determination of a visual trend without the aid of a linear trendline. Many of the index wells appear relatively stable, but there are a select few that are experiencing declining water levels (see Figure 7).
The index wells appearing to experience declining groundwater levels are well numbers 1, 3, and 12, associated respectively with Forest Highlands in the Coconino water-bearing zone, Lake Mary in the Coconino water-bearing zone, and Keam’s Canyon in a confined water-bearing zone (see Table 5).

**Table 5. Wells with Discernable Trends in Depth to Groundwater**

<table>
<thead>
<tr>
<th>Study ID</th>
<th>Agency</th>
<th>ADWR Reg_ID/USGS Site ID</th>
<th>Year of First Measurement</th>
<th>Year of Last Measurement</th>
<th>Increase in Depth to Groundwater (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 1</td>
<td>ADWR</td>
<td>606205</td>
<td>1963</td>
<td>2018</td>
<td>38</td>
</tr>
<tr>
<td>Well 3</td>
<td>ADWR</td>
<td>606195</td>
<td>1962</td>
<td>2018</td>
<td>81</td>
</tr>
<tr>
<td>Well 12</td>
<td>USGS</td>
<td>355023110182701</td>
<td>1970</td>
<td>2020</td>
<td>181</td>
</tr>
</tbody>
</table>

Further hydrogeologic assessment would be required to evaluate whether the observed declines in well levels in these locations are representative of trends in the surrounding area; such assessment is
recommended in conjunction with local water planning and continued regional evaluations of groundwater supplies and sustainability. Continuing to monitor index wells should provide an indication of whether and where broader trends in aquifer levels might require further attention and evaluation. In the future, index wells could also be linked to specific points in the CPWP’s hydrologic model in order to translate water levels in the index wells into a value representing the percent saturated thickness of the aquifer in those locations. Continuing to update hydrologic modeling and periodically comparing modeled to actual conditions is also likely to be a valuable way for the CPWP to continue to evaluate groundwater supply and sustainability of use.

Provisioning – General: Human Population

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs
Recommended measure: Population (#)
Spatial scale: Coconino County, Navajo County, Yavapai County and City of Flagstaff
Frequency of measurement: Annually
Proxy for: Total demand

In addition to water supply, human water demand is a central ecosystem services indicator of relevance to the provisioning ecosystem services. Human population, measured as number of individuals, is an important driver of water demand and was selected, therefore, as a proxy indicator for overall demand (to accompany more direct measures of demand described in subsequent sections).

The Arizona Commerce Authority creates state-, county- and place-level population estimates on an annual basis (1980-present). Data were obtained for Coconino County, Navajo County, Yavapai County and City of Flagstaff (see Figure 8). Although less than 1% of Yavapai County is within the study area (and only 0.18% of the study area is within Yavapai County), Yavapai County was included for this metric, to show the substantial contrast among neighboring counties.

**Figure 8. Population (1980-2018)**

While all four areas have seen relatively steady growth across the time frame shown, Yavapai County has the highest total growth factor (see Table 6)—almost double that of both Coconino and Navajo
Counties. The growth rate in Flagstaff—whose population comprises a little less than half of the total Coconino County population—is higher than that of the county as a whole.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Coconino County</th>
<th>Navajo County</th>
<th>Yavapai County</th>
<th>Flagstaff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019 to 1980 total growth factor</td>
<td>1.9</td>
<td>1.7</td>
<td>3.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

It should be noted that while human population is an important driver of water demand, water demand need not necessarily increase along with population. Because of conservation, improved efficiencies, water or land management actions, changes in area economies or uses of water, and other factors, certain water providers, metropolitan areas, and even states as a whole have seen decreases in total water use even as population increases. This is sometimes referred to as a “decoupling” of water demand from population growth.

**Provisioning – General: Total Water Demand**

*Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Volume (AF)*

*Spatial scale: County*

*Frequency of measurement: Every five years*

Overall human water demand (or use) is an important indicator for the provisioning ecosystem services, representing both the flow of the service (use of the water to benefit humans) and a “draw” on the system; trends in demand are important for evaluating strategies for future sustainability.

Despite the importance of the data, total water use is not regularly tracked at the study area level. Indeed, the State of Arizona does not generally require comprehensive reporting or monitoring of water use, at least in areas outside of active management areas (AMAs). While community water systems (CWSs) are required to file annual water use reports, most other sectors and individual water users are not required to report their water use. Further, data about water use on Native American

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4 A community water system is defined as a water system that serves 15 or more service connections used by year-round residents, or that serves 25 or more year-round residents who use water for drinking, cooking, bathing and cleaning (Arizona Department of Water Resources 2020a).
The USGS Water Use Data for the Nation (USGS 2020a) dataset was therefore used to estimate total water use by county as a proxy for total water demand in the study area. This dataset tracks water use by sector (public supply, domestic, commercial, industrial, mining, irrigation, livestock, and thermoelectric) at the county-scale on a five-year timestep with the most recent dataset issued for water use in 2015.

Although data has been reported in some areas of the United States since 1950, data for Arizona is only available from 1985 onward, and data collection (both naming conventions and thoroughness of water use reporting) has varied among different compilations. Consumptive use is measured in some of the years of data, however, the most consistent measure of water use across the years of data is diversion data. As such, the information presented here represents volumes diverted for use rather than consumptive use. Because of the year-to-year variability, the long-term trend in water use represented by data from 1985-2015 is of greater significance to this effort than the data from any individual year.

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5 Information about water demand on Native American Reservations can sometimes be obtained directly from a tribal government; through specific studies including those connected to federal projects or assessments; or through documentation connected to tribal water rights, claims, adjudication, or settlements. Because numerous tribal water rights in Arizona remain unresolved—including several significant rights for members of the CPWP—tribal water use information may in certain cases be sensitive or confidential.

6 Initially, the Consulting Team had recommended using data from water provider reports (annual CWS reports filed with ADWR and annual private water company reports filed with the Arizona Corporation Commission) to assess total demand from water providers as another “proxy” metric for total demand—and as a source of data for other demand-related indicators. While water provider data were anticipated to be particularly valuable because they could be specifically filtered to include only those providers within the study area (versus the county-level data available from USGS), it was ultimately determined to be an unreliable source of information for these purposes. The data were an incomplete representation of total demand because of the substantial demand left out (i.e., water use by other sectors, “self-supplied” water use, and demand on Native American Reservations). Data points must be individually extracted from multiple years of annual reports for each provider, as there is not a public database that catalogs the information. Most importantly for this effort, there proved to be substantial variability in the availability, format, and completeness of specific water provider reports over the years, making it difficult, if not impossible, to glean information that is representative of the study area as a whole or to identify trends over time.
In 2015, water use in Coconino County totaled approximately 42,700 AF and in Navajo County totaled approximately 56,300 AF. Total water demand in both Coconino and Navajo Counties increased between 1985 and 2000, and then decreased between 2000 and 2015. Coconino County’s 2015 water use is only slightly higher than its use in 1985; Navajo County’s 2015 water use is somewhat lower than its use in 1985. Comparing the trends shown in Figure 9 to those in Figure 8 above shows that water use in both counties has been declining in recent years, despite increases in population. Overall, demand has been higher in Navajo County than in Coconino County, though population has been higher in Coconino County over this time period.

The CPWP has created a “demand map” that is another useful source of information about human water demand in the study area, showing water provider demand for population centers within and approximate to the study area. In addition to aggregating information from water provider reports, the CPWP obtained estimates of demand associated with demand centers on Native American Reservations, making the dataset a particularly unique resource. The map, which shows 2015 demand and is anticipated to be updated for 2020, is another valuable product that the CPWP can use in tracking trends in water demand, especially if resources continue to be available to update the map going forward.7

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7 For the sake of context and comparison, study area demand as documented in the 2015 CPWP demand map (excluding demand centers outside of the study area) totals approximately 78,000 acre-feet. Because this estimate relies in part on water provider reports, it does not reflect all “self-supplied” demand within the study area.
Provisioning – General: Water Source Dependence

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs
Recommended measure: Volume by source (% of total)
Spatial scale: County
Frequency of measurement: Every five years

An important indicator related to the provisioning ecosystem services is water source dependence (i.e., reliance on groundwater versus surface water versus reclaimed water). Reliance on each type of water source has different potential implications for ecosystem service function and sustainability.

For example, although groundwater is recharged to a small degree within the study area, much of the region’s groundwater is considered to be a finite and non-renewable supply. Surface water can derive from groundwater supplies, but is also fed by annual precipitation, and so a portion of it can be considered renewable (although subject to seasonal, annual, and longer-term variability). Groundwater and surface water come with different infrastructure and quality considerations. In the CPWP region some groundwater requires very deep wells for access. Use of surface water usually requires diversion, delivery, and/or storage structures, potentially including dams, ditches, and/or reservoirs. This can be at a very large scale (as in the Colorado River and Lake Powell) or a much smaller scale (as in small private irrigation ditches). Surface water can require more treatment before use for potable purposes.

Geographic availability of groundwater and surface water also differs within the study area, with groundwater generally more broadly available—whereas there are only significant stretches of continuously flowing surface water in a few places on the Colorado Plateau. Groundwater and surface water are also treated differently under Arizona state law. In general, use of surface water in Arizona requires an appropriative water right. Groundwater usage is largely unregulated outside of Arizona’s AMAs, including within the study area. This generally also means that it is difficult to initiate a new surface water use without transfer of an existing water right (because many rivers and streams are considered to be fully appropriated, and a new water right cannot interfere with an existing, “senior” use), and thus surface water use is not expected to significantly increase on the whole. In contrast, groundwater use can be expected to continue to increase as demands increase, absent deliberate management or conservation measures or additional regulation.

Use of reclaimed water also comes with distinct considerations, including those related to infrastructure, treatment, and water quality. Reclaimed water is often considered a particularly valuable water source especially in contexts of scarcity, because its use avoids increasing use of water from other sources. Of course, its availability depends on the availability of the original source of water that is used and retreated—and there are unique water quality considerations and requirements associated with reclaimed water.

Data for the water source dependence indicator were sourced from the USGS data set of water use by sector and county (USGS 2020a). This data set shows not only relative reliance on surface water, groundwater, and reclaimed water, but also reliance on public versus “self-supplied” water sources.

As shown in Figure 10 below, Coconino County relies on surface water for the majority of its total use (approximately 60%), whereas Navajo County is almost entirely supplied by groundwater (85% of use).
In both counties, the majority of total water use is self-supplied rather than part of public supply. Reclaimed water currently only accounts for only a small percentage of supply across the two counties.

**Figure 10. Source of Water Supply by County**

It is important to recognize that the majority of surface water use and self-supplied water is used for thermoelectricity (Coconino County only), irrigation, or livestock. As further discussed in sections below, residential demand is largely dependent on groundwater within both counties and within the study area.

Figure 10 also illustrates an increased reliance on public water supplies between 1985 and 2015 for both counties—and in Coconino County a relative increase in reliance on groundwater versus surface water, while Navajo County has become relatively more reliant on surface water.

**Provisioning – General: Groundwater Demand**

*Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Volume (AF)*

*Spatial scale: County*

*Frequency of measurement: Every five years*

Human groundwater demand is an important indicator related to all three provisioning services. It represents the amount of groundwater used by people for drinking and non-drinking purposes. The rate of human use of groundwater also affects long-term supply availability, for direct human use and for environmental flow in rivers, streams, and springs—and also therefore ultimately affects the functioning of other regulating and cultural ecosystem services in the study area.

Groundwater demand could in theory be measured directly as volume (AF) or percent of total demand or approximated by measures such as volume of groundwater use reported by water providers, number of wells, or number of wells accessing specific aquifers. Given the relative importance of this indicator—and yet the difficulty in establishing a total volume directly—two measures were chosen in order to understand different aspects of groundwater demand. The first of these is groundwater demand by county.

Data from USGS highlight that groundwater demand by county is substantially higher in in Navajo County (averaging around 66,000 AF/year) and lower in Coconino County (averaging approximately
22,000 AF/year)—consistent both with Navajo County’s higher total demand and higher groundwater dependence.

USGS data also breaks out groundwater demand by sector. Public supply makes up the sector with the greatest demand in Coconino County, with irrigation being a more prominent sector for groundwater demand in Navajo County (see Figure 11). (USGS 2020a)

![Groundwater Demand by County and Sector](image)

Note: Public supply includes deliveries to domestic, commercial, and industrial uses.

Increasing groundwater demand from 1985 to 1990 tracks with population trends for these years, however, despite population in these counties continuing to increase, groundwater demand has decreased in the early 2000s. Data show that groundwater demand for irrigation and for livestock/aquaculture has tended to decrease, alongside industrial demand in Navajo County. Demand from public supply has increased somewhat in both counties over the period of record.

Provisioning – General: Groundwater Wells

*Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Wells (#), Exempt wells (#)*

*Spatial scale: Study area*

*Frequency of measurement: Annually*

*Proxy for: Groundwater demand*

An additional proxy indicator for groundwater demand that can be measured specifically for the study area is the number of groundwater wells as maintained in ADWR’s Wells55 dataset (Arizona Department of Water Resources 2020b).

ADWR’s record of wells represents those that have been registered with the agency, as required upon drilling a new well. ADWR does not generally track whether wells are in use, or the volume of water that they are pumping. There are also reasons that new wells may be drilled that don’t represent an increase in demand; for example, a utility may need multiple wells due to lower production rates; or a well in a rural area could be an indication of water availability, versus a home that relies on water hauling because of lack of water, a high depth to water that makes a well cost-prohibitive, or low water quality. It is nevertheless likely meaningful to track trends in the number of wells in the study area over time, as overall, new wells may often represent a new groundwater demand.
The current number of production wells in the study area, as extracted from the Wells55 database excluding wells used for monitoring and environmental purposes, is 3,271. Of these, approximately 66% are “exempt” wells (those with the capacity to pump 35 gallons per minute [gpm] or less), supporting the USGS data indicating that self-supplied water is an important aspect of water source dependence in the area (see Figure 12). (Arizona Department of Water Resources 2020b)

**FIGURE 12. NUMBER OF TOTAL PRODUCTION WELLS AND EXEMPT WELLS BY YEAR**

The trend depicted in Figure 12 makes clear that large-scale human reliance on groundwater is relatively new, with fewer than 100 wells documented in the study area as of 1950 and more than 3,000 by 2018. Although the number of wells continues to increase, it is also important to note that the rate at which new wells are being installed is itself decreasing and has recently returned to a rate similar to the pre-1970 rate of increase (see Figure 13).⁸

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⁸ The Consulting Team is unaware of a reason for the sharp increase in number of wells in 1970, and at the time of writing had not received a response to an inquiry to ADWR to learn if the increase could reflect a change in data collection processes or requirements.
Provisioning – General: Surface Water Demand

*Related stakeholder concern(s):* Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs

*Recommended measure:* Volume (AF)

*Spatial scale:* County

*Frequency of measurement:* Every five years

Surface water demand is another indicator related to all three provisioning ecosystem services. Surface water demand could be measured, for example, as a total volume (AF) by county, a volume as reported by water providers, and/or by a count or measure of surface water diversions or claimed surface water rights. The recommended measure is volume (AF) of reported surface water use by county.

Surface water demand data also were sourced from the USGS water use data by county (USGS 2020a). In Coconino County, surface water demand averages approximately 30,000 AF/year, whereas, in Navajo County, it averages just over 7,000 AF/year over the observed period. Surface water demand in Coconino and Navajo Counties is primarily used by very few sectors – public supply and thermoelectric in Coconino, irrigation and livestock & aquaculture in Navajo (see Figure 14).
The large thermoelectric use in Coconino County over this time period can be attributed to Navajo Generating Station, as discussed further in the section on non-residential water use below. Variability in surface water use for irrigation and livestock purposes may reflect variability in surface water availability in the years of measurement. Surface water that is available within the study area—especially local surface water, as opposed to that diverted from Lake Powell—is very sensitive to interannual variability and drought (US Bureau of Reclamation 2016; Bills, Flynn, and Monroe 2007).

Provisioning – General: Water Reuse

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs

Recommended measure: Volume (AF)

Spatial scale: Index water providers

Frequency of measurement: Annually

Water reuse was itself one of the key concerns identified by stakeholders in Phase 1. Its prevalence could theoretically be measured as the volume of water reused in the study area (AF), percent of water demand or water provider demand met with reclaimed water, percent of available reclaimed water that is reused (for the study area or a provider), number and/or percent of providers reusing water, volumes or percentages of water reused for different purposes, volume of direct potable reuse, the number and percent of providers with the capacity to treat to an identified water quality standard, or the number and/or the percent of providers reusing water who meet an identified standard of water quality, among others.

Two metrics were at first recommended: 1) number of water providers in the study area reusing water; and 2) percent of water provider demand in the study area that is met using reclaimed water. After further research, however, it was ascertained that while this information could potentially be reported at a study-area level for the year 2015 using data already compiled by CPWP for its demand map in that year, the data are not available to track these metrics over time study area-wide. As an alternative, the final recommended metric is to track water reuse (as a volume in AF) for the few major water providers in the study area for whom data are available.
Data about water reuse were sourced from water provider reports—specifically, community water system reports made by water providers to ADWR. As previously noted, this documentation does not include reports about water supply and water use on Native American Reservations.

Data for this metric were therefore obtained by starting with the water provider information already compiled by the CPWP for its 2015 demand map and identifying providers reusing water within the study area. According to this information (which relied on CWS reports as well as additional information from other sources), eight providers met a portion of their demand using reclaimed water in 2015 (see Table 7).

### Table 7. Water Providers Using Reclaimed Water Within the Study Area (2015)

<table>
<thead>
<tr>
<th>Providers using reclaimed water</th>
<th>2015 reclaimed water demand (AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagstaff</td>
<td>1921</td>
</tr>
<tr>
<td>Page</td>
<td>722</td>
</tr>
<tr>
<td>Williams</td>
<td>265</td>
</tr>
<tr>
<td>Sedona</td>
<td>154</td>
</tr>
<tr>
<td>Grand Canyon Village</td>
<td>118</td>
</tr>
<tr>
<td>Pinewood/Munds Park</td>
<td>106</td>
</tr>
<tr>
<td>Tusayan</td>
<td>83</td>
</tr>
<tr>
<td>Forest Highlands</td>
<td>47</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3416</strong></td>
</tr>
</tbody>
</table>

Starting with this information showing the prevalence of documented water reuse in 2015 among water providers in the study area, index providers were selected in order to assess trends going forward from 2015. Because they were both the most significant users of reclaimed water as of 2015, and providers for whom CWS reports were consistently available, the City of Flagstaff and the City of Page were chosen as index providers for this metric.⁹

Between 2015 and 2019, Flagstaff’s annual reclaimed water use averaged 1,907 AF, with a high of 2,189 AF in 2017, and represented an average of 26% of the total water delivered to customers by the City of Flagstaff. Water reuse in Page during the same timeframe averaged 821 AF per year, or an average of 42% of the water delivered by the City of Page (see Figure 15).¹⁰

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⁹ The City of Sedona operates a municipal wastewater reclamation facility, but receives delivery of potable water from a private water company, Arizona Water Company. Arizona Water Company’s CWS reports, therefore, do not document volumes of Sedona reclaimed water or how that water is used. CWS reports do not appear to be available on an annual basis for the City of Williams over the period considered.

¹⁰ An apparent anomaly in the 2018 data for the City of Page was adjusted to correct what appeared to be a typo in the CWS report, by which total treated effluent was added to the effluent reuse volume, yielding an effluent reuse number that was higher than the total available effluent.
Overall, water reuse data proved to be difficult to access for multiple facilities and water providers and over multiple years. Wastewater facility information is housed at the Arizona Department of Environmental Quality (ADEQ), and water provider information is housed at ADWR. Neither agency maintains a public database of the reported information, and individual reports are not available from ADEQ without a specific records request. Given stakeholders’ interest in this topic, the CPWP may wish to consider whether there are ways to improve the ease with which this information can be tracked broadly within the study area—for example by working with the state agencies to enhance data accessibility, or by working with interested Partnership members or other organizations to track the information at a more local level.

Provisioning – Drinking Water: Residential Water Use

*Related stakeholder concern(s):* Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs

*Recommended measure:* Volume (AF)

*Spatial scale:* County

*Frequency of measurement:* Every five years

Water for drinking is clearly one of the most essential benefits that humans obtain from freshwater ecosystems. Residential, or domestic, water use is an important indicator of drinking water demand. Although residential water use encompasses more than just water for drinking—it typically includes water for multiple household purposes—it is often the closest available measure of water used for drinking and it therefore was selected as an indicator.

Residential water use could theoretically be measured directly by volume, percent of total demand, population supplied, or gallons per capita. Based on a review of relevant literature and data, water for “domestic use”—defined by USGS as potable and non-potable water provided to households by a public water supplier (domestic deliveries) and self-supplied water use—is the recommended measure for this indicator.
Residential water use was estimated using the USGS Water Use Data for the Nation publicly supplied and self-supplied domestic water use categories (USGS 2020a) for both Coconino and Navajo Counties (see Figure 16).

**Figure 16. Domestic Water Use from Public and Self-Supply (1985-2015)**

Across the counties domestic water use has been increasing relatively steadily over the time period 1985-2015 with the exception of what appears to be a sharp decline experienced in Navajo County in 1995. The increasing trend over time mirrors trends in population in these counties (see Figure 8).

**Provisioning – Drinking Water: Population Served by Water Supply Type**

*Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Population served by water supply type (# and %)*

*Spatial scale: County*

*Frequency of measurement: Every five years*

The relative reliance of an area’s population on different drinking water sources is another useful indicator. The USGS (2020) tracks population served by water supply type—that is, public supply versus domestic self-supplied and public supplies deriving from groundwater versus surface water. Data are available at the county level every five years starting in 1985, as depicted in Figure 17 for Coconino and Navajo Counties.

The majority of the population in both counties has historically used publicly supplied groundwater. Only Coconino County has any substantive population served by publicly supplied surface water.

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11 The Consulting Team was unable to confirm the reason for this apparent decline.
Provisioning – Drinking Water: Households without Access to Complete Plumbing Facilities

Related stakeholder concern(s): Groundwater Flow, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs

Recommended measure: Households without access to complete plumbing facilities (# and % of total)

Spatial scale: County

Frequency of measurement: Annually

Proxy for: Population without access to improved water source(s)

When considering water for drinking as an ecosystem service, access to drinking water is also a key indicator. The issue of access to drinking water was one that was specifically identified by stakeholders as a concern within the study area (included as an “infrastructure” concern in the Phase 1 Reports). Stakeholders noted that parts of the study area do not have adequate infrastructure to provide households with readily available drinking water.
The population with and without access to improved water sources for drinking could be measured by total number of people with and without access to improved water sources or average distance from primary water source. In an effort to select an indicator for which regularly tracked information was available, the proxy indicator “households without access to complete plumbing facilities” was selected.

The US Census American Community Survey (2020) collects annual data on whether households have access to complete plumbing facilities, defined as having all three of the following: hot and cold running water, a flush toilet and a shower/bathtub (Raglin 2015). County-level data were downloaded for Coconino and Navajo Counties for all available years (see Table 8).

**Table 8. Occupied Households without Access to Complete Plumbing Facilities**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconino</td>
<td>1,792</td>
<td>1,305</td>
<td>2,250</td>
<td>1,547</td>
<td>1,837</td>
<td>1,594</td>
<td>1,804</td>
<td>1,462</td>
<td>1,482</td>
</tr>
<tr>
<td>Navajo</td>
<td>3,090</td>
<td>2,042</td>
<td>2,579</td>
<td>2,664</td>
<td>2,582</td>
<td>2,128</td>
<td>1,958</td>
<td>2,063</td>
<td>2,445</td>
</tr>
</tbody>
</table>

Multiplying the 2018 household estimates by average household size results in an estimate of total persons lacking access to full plumbing facilities (see Table 9).

**Table 9. Estimated Persons Lacking Full Plumbing Facilities**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconino</td>
<td>2.7</td>
<td>3,972</td>
<td>2.7%</td>
</tr>
<tr>
<td>Navajo</td>
<td>3.1</td>
<td>7,531</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

Figure 19 shows the estimated percentage of occupied housing units lacking complete plumbing facilities by county. In 2018, Coconino County and Navajo County occupied housing units lacking complete plumbing facilities represented 3.1% and 7.1% of total occupied housing units, respectively. These numbers are notably high—as a point of comparison, in 2018 the percentage of occupied housing units lacking complete plumbing facilities the Arizona and the United States were 0.66% and 0.38%, respectively.
As mentioned previously, this is a proxy indicator for access to improved water sources and ideally a more direct measure would be available. As an example, in their recent report Nania and Cozzetto (2014) estimated that between 25-40% of the population on the Navajo Reservation must haul water to meet every day needs.

**Provisioning – Water for Non-Residential Purposes: Water Use by Sector**

*Related stakeholder concern(s): Groundwater Flow, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs*

*Recommended measure: Volume (AF and % of total)*

*Spatial scale: County*

*Frequency of measurement: Every five years*

Water use by sector is an indicator that helps to describe “water for non-drinking purposes.” Water use by sector could be measured in volume (AF) of use per sector, volume (AF) for all non-drinking uses, or percent of total demand per use. A review of the literature and available data suggest that the best metrics are acre-feet of non-residential water use by sector and percent of total reported demand.

Data on water use by sector measured in volume (AF) of use per sector are sourced from the USGS dataset of Water Use Data for the Nation (USGS 2020a). Although the magnitude of water use for non-residential purposes is different in Coconino County versus Navajo County (about 25,000 AF and 42,000 AF respectively in 2015), each county appears to have experienced an overall trend toward decreasing non-residential water use from 1985-2015 (see Figure 20).
The greatest use of water for non-residential purposes is the thermoelectric sector in Coconino County and irrigation and livestock/aquaculture uses in Navajo County. The decreasing trend in non-residential water use is driven primarily by decreases in water use for livestock & aquaculture and irrigation in Coconino County and irrigation and industrial use in Navajo County (see Figure 21).

Coconino County’s substantial thermoelectric water use over the period of record can be largely attributed to the Navajo Generating Station, a coal-fired power plant whose operation ceased in 2019. Typically, the plant had used approximately 20,000 AF of Colorado River water from Lake Powell each year. The future use of that water (a portion of Arizona’s “Upper Basin” apportionment) is unresolved at this time. (Pyper 2019; Shea 2019)

Observed decreases in mining and industrial water use in Navajo County are at least partially explained by the discontinuation of a slurry line that had been used to slurry coal from Black Mesa 273 miles to a power plant in Laughlin, Nevada beginning in 1968, using as much as 7,000 AF of groundwater annually. When Peabody Energy discontinued use of the slurry pipeline in 2006, industrial water use from the N aquifer—which underlies the Hopi and Navajo Reservations—was reduced by approximately 70 percent. Up until that point, withdrawals by Peabody Energy had accounted for 60-75% of total withdrawals from that aquifer. (USGS 2016)
Provisioning – Water for Environmental Flow: Stream Flow

Related stakeholder concern(s): Groundwater Flow, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs
Recommended measure: Median June flow (cfs)
Spatial scale: Index streams (in study area nearby areas of interest)
Frequency of measurement: Annually (as available)

Rivers, streams, seeps, and springs provide essential habitat in the arid study area; play an essential role in supporting species diversity; have national significance; are a critical aspect of Grand Canyon National Park operations and of other attractions for residents and visitors in the region; and are linked to important components of Native American culture (Bills, Flynn, and Monroe 2007; L. E. Stevens, Jenness, and Ledbetter 2020). Stream flow of index streams was selected as an indicator of environmental flow to support these resources.

Stream flow can be measured by flow rate in cfs. Measurements could include daily or monthly flow, peak flow, average seasonal flow, or median flow during a summer month. The metric selected was median June flow as an approximation of base flow (Schenk, Jenness, and Stevens 2018).

Stream flow information is available from the National Water Information System (NWIS) maintained by the USGS for certain streams in and near the study area with gages or other regular surface water field measurements (USGS n.d.). Index sites were selected with guidance from TAC members, based on data availability, geographic location, and connection to resources and stakeholder concerns in the study area.

Even for streams with a relatively long history of gaged flow data, most records are not continuous. Table 10 shows selected index streams and the years for which the identified USGS gage was active in June, allowing for a calculation of median June flow.

### Table 10. Index Streams

<table>
<thead>
<tr>
<th>Stream ID #</th>
<th>USGS Gage #</th>
<th>Years Active in June</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>09398000</td>
<td>1906; 1917-1919; 1929-1933; 1936-1972; 2006</td>
<td>Chevelon Creek near Winslow, AZ</td>
</tr>
<tr>
<td>3</td>
<td>09404115</td>
<td>1996-1997; 2001-2008; 2012-2020</td>
<td>Havasu Creek above the mouth near Supai, AZ</td>
</tr>
<tr>
<td>4</td>
<td>09402300</td>
<td>1990-1992; 2003-2020</td>
<td>Little Colorado River above the mouth near Desert View, AZ</td>
</tr>
<tr>
<td>5</td>
<td>09401260</td>
<td>1977-2020</td>
<td>Moenkopi Wash at Moenkopi, AZ</td>
</tr>
<tr>
<td>6</td>
<td>09504420</td>
<td>1982-2020</td>
<td>Oak Creek near Sedona, AZ</td>
</tr>
<tr>
<td>7</td>
<td>09504000</td>
<td>1918-1921; 1965-1994; 1996-2020</td>
<td>Verde River near Clarkdale, AZ</td>
</tr>
<tr>
<td>8</td>
<td>09505800</td>
<td>1965-2020</td>
<td>West Clear Creek near Camp Verde, AZ</td>
</tr>
</tbody>
</table>

Figure 22 shows historical median June flow for the selected index streams between 1950 and 2020, at the gage sites identified in Table 10. Figure 23 separates the higher- from lower-flow streams to show the data at a scale that is easier to discern. It also shows linear trend lines for each data set.
While the data vary in terms of consistency, period of record, and variability, there does appear to be evidence of a downward trend in median June streamflow at the selected gage sites on Wet Beaver
Creek near Rimrock (#1 above), Havasu Creek near the mouth (#3 above), the Verde River near Clarkdale (#7 above), and West Clear Creek near Camp Verde (#8 above). There is not a discernible trend in flows at Oak Creek near Sedona (#6 above). While the trend lines potentially show slight increases in flow at Chevelon Creek (#2 above) and the Little Colorado River (#4 above), it is difficult to draw conclusions given the long gaps in recorded data. Data at Moenkopi Creek are also hard to interpret, as the stream—whose median June flow is often close to zero during the period of record—also appears to be very flashy during the month of June.

While these flow data by themselves would require further interpretation in order to draw firm conclusions, they do indicate the potential that the baseflow of several significant streams that rely on discharge from the study area may be in decline, and thus warrant further attention as well as continued tracking over time. This conclusion is consistent with other research showing modeled or measured declines in baseflow in regional streams and projecting additional future declines (Garner et al. 2013; Matrix New World Engineering, Southwest Groundwater 2020; Bills, Flynn, and Monroe 2007).

Provisioning – Water for Environmental Flow: Spring Flow

Related stakeholder concern(s): Groundwater Flow, Infrastructure, Climate Change, Water Reuse, Tourism/Recreation, Springs
Recommended measure: Flow (cfs)
Spatial scale: Index springs (in study area and nearby areas of interest)
Frequency of measurement: Annually (as available)

Springs have been described as keystone ecosystems—“small points on the landscape that are disproportionately diverse and ecologically interactive, for both wildlife and human uses” (Schenk, Jenness, and Stevens 2018). Water flow is critical to the unique and uniquely valuable ecosystems supported by springs. Aspects of the ecological health of springs could be measured in a number of ways, for example as represented in the Springs Stewardship Institute (SSI) Springs Inventory Protocol (SIP) and Springs Ecological Assessment Protocol (SEAP). These include measures of flow/discharge (cfs); water quality (e.g., temperature, pH, specific conductance, total alkalinity, and dissolved oxygen concentration); geomorphic change; percent cover by native and non-native species and vegetation change through time; macroinvertebrate species composition and density; and vertebrate species composition and density. The SEAP also allows for calculation and monitoring of an overall ecological health score and for scores in six categories (aquifer and water quality, site geomorphology, habitat and microhabitat array, site biota, human uses and influences, and administrative context under which the spring is managed). Each category is scored on the basis of five to eight subcategories that are ranked on a 0-6 scoring scale (L. Stevens, Springer, and Ledbetter 2016). These indicators also are considered below in the “Wildlife Populations and Habitat” section of this document.

The ideal measure of environmental flow in the context of springs is a direct measure of spring flow in cfs—for example, a median or mean flow level on an annual basis or for a particular time of year. Few springs are monitored this regularly, however, and measurements of flow, if made repeatedly, are sometimes measured at different times of year, making trend detection difficult. In general, SSI notes that “[m]any of the variables used in trend detection at springs ecosystems are influenced by seasonality. Therefore, caution is warranted when attempting to draw conclusions based on comparison among a small number of repeated site visits. Some variables may not be appropriate monitoring metrics at some springs or spring types.” (L. Stevens, Springer, and Ledbetter 2016)
With these constraints recognized, the selected metric for spring flow is nonetheless median June flow (cfs) at index springs—including springs within the study area, and those outside the study area that are chosen for their relevance to the study area and stakeholder concerns.

Possible index springs were chosen with guidance from the TAC by identifying sites with potentially available flow data (from gages or regular field measurements) and that represent a range of geographic, ecologic, and hydrologic contexts. From this set of possible index sites, five were selected based on data availability.

Data were sourced from the National Water Information System (NWIS) maintained by the USGS (USGS n.d.) and the Salt River Project (SRP), which provided data in response to a request made through its Watershed Connection program (Salt River Project n.d.).

In general, springs flow data proved to be limited. Within the USGS data set, actively monitored springs are limited to fewer than ten sites within the study area, although inactive sites are numerous. Both types of sites are limited in regard to the data recorded during field measurements and the frequency of those measurements, with one or fewer measurements per year not uncommon.

More information on springs in Arizona is contained in the Springs Online Database under the SSI of the Museum of Northern Arizona (Springs Stewardship Institute n.d.). Publicly available data for the springs, however, are also limited, in that, for a large proportion of the springs the public data is locational only. Although flow is one of the data points intended for collection, much of these data are sensitive and therefore require special permissions from the data owner(s), based on the land unit and research project. Additionally, according to SSI staff, regular flow measurements are available for very few springs in the database.

Even among the index springs identified, few have an extended history of gaged flow data, and not all records are continuous. Table 11 shows selected index springs and the years for which data are available for June, allowing for a calculation of median June flow.

<table>
<thead>
<tr>
<th>Spring ID #</th>
<th>Data Source or USGS Gage #</th>
<th>Years Active in June</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9399000</td>
<td>1906; 1936-1982; 2006</td>
<td>Artesian Spring SE of Winslow</td>
</tr>
<tr>
<td>2</td>
<td>9404110</td>
<td>1996-2019</td>
<td>Havasu Spring west of Grand Canyon Village</td>
</tr>
<tr>
<td>3</td>
<td>9401265</td>
<td>2005-2019</td>
<td>Pasture Canyon Spring(s) near Tuba City/Moenkopi</td>
</tr>
<tr>
<td>4</td>
<td>Salt River Project</td>
<td>2007-2019</td>
<td>Bubbling Spring/Page Springs</td>
</tr>
<tr>
<td>5</td>
<td>Salt River Project</td>
<td>2011-2013; 2015-2018</td>
<td>Sterling Spring</td>
</tr>
</tbody>
</table>

Figure 24 shows historical median June flow for the selected index springs between 1950 and 2020, at the gage sites identified in Table 11. Figure 25 separates the higher- from lower-flow springs to show the data at a scale that is easier to discern. It also shows linear trend lines for each data set.
Though the periods of record are not long, there appears to be evidence of a downward trend in median June spring flow at both Havasu Spring (near Supai on the Havasupai Reservation) and Sterling Spring (in the northeastern portion of the Verde groundwater basin). For the other index springs, flows appear to be stable, increasing, or unknown based on the small amount of data available.

The Phase 1 ESA report recommends working with the SSI staff to identify a discrete set of appropriate index springs in the study area; it also notes that once indicator springs have been identified, data should be acquired from the SSI database, but that this data acquisition will incur a fee to cover SSI staff time. If further resources are available in the future, it could be valuable to pursue this recommendation in order to assess whether other springs not identified through the present effort might make appropriate index sites for further tracking of spring flow, or of other attributes of ecological health as discussed further in the “Wildlife Habitat and Populations” section.

Given the importance of springs to stakeholders and their centrality in the region’s freshwater ecosystem—and yet the paucity of readily accessible data—it also may be advisable in the future to devise and track a measure of available spring-flow monitoring capacity itself, or to support efforts to enhance that capacity.

6.2 Regulating Services: Baseline Conditions and Trends

Four “regulating” ecosystem services were identified for assessment within the study area: flood protection, erosion control, water purification, and maintenance of wildlife habitat and populations.

Flood protection describes the ability of an ecosystem to regulate and manage the flow of water during periods of high rainfall or snowmelt in a way that minimizes the extent and severity of inundation. Soil erosion control is typically thought of in the context of terrestrial ecosystems and their ability (or lack thereof) to prevent soil erosion caused by wind and/or water.

With regards to these two ecosystem services, stakeholders specifically expressed concern about flooding and erosion in the study area as a result of catastrophic wildfires and the associated loss and degradation of forest land and ecosystem function. Because of this, indicators were developed to measure the primary “driver” of flooding and erosion in the study area—catastrophic wildfires, as well as changes in landcover.

Water purification refers to the ability of the freshwater ecosystem to provide water of a certain quality. Stakeholders mentioned concerns about the quality of reclaimed water, including the presence of contaminants of emerging concern (CECs) in water that is reused or returned to the environment, and generally about public perceptions connected to water reuse. They also mentioned concerns about the availability of monitoring infrastructure to monitor water quality, with particular attention paid to monitoring of the potential water quality impacts of uranium mining. There are also overall concerns about water quality, especially as climate change potentially causes declining water levels, and concerns about both the quantity and quality of water after a high-intensity fire. Based on these concerns and available data, indicators were selected that focus on drinking water quality; reclaimed water quality; monitoring of active uranium mines; and surface water quality in the environment.

Water is a necessary component for almost all sources of life on earth—in the study area, aquatic species such as the humpback chub are not only directly dependent on streamflow for survival, but are also endemic to the area. Other species, such as birds, rely on the streams and springs of the study area...
for water, and as breeding and nesting habitat. In an arid environment like the study area, changes in the timing or flow of water in springs and streams have the potential to significantly impact the species that rely on this water. Indicators related to “wildlife populations and habitat” were chosen to reflect the importance of water in supporting the diversity of life within the study area.

Regulating – General: Landcover Change

*Related stakeholder concern(s): Wildfire, Climate Change*

*Recommended measure: Landcover type (acres)*

*Spatial scale: Study area*

*Frequency of measurement: As available (every 2-3 years)*

*Proxy for: Erosion prevention and flood protection*

Landcover change, as it informs the extent of, and change in, the built environment and natural ecosystems, is a proxy indicator for erosion prevention and flood protection. The metric selected to assess landcover change is acres of landcover by type, measured using data sourced from the National Landcover Database (The Multi-Resolution Land Characteristics (MRLC) consortium 2020).

Land use data were extracted using the CPWP boundary to acquire information specific to the study area. In the CPWP three categories of land use make up approximately 97% of land area for each year of data available (i.e., 2001, 2004, 2006, 2008, 2011, 2013, and 2016): shrub/scrub land (67%), evergreen forest (15%), and herbaceous land (15%) (see Figure 26). The majority of the remaining 3% of land area (“Other” in Figure 26) is made up primarily of barren land (1.7%) and developed open space (0.6%), as well as much smaller areas of developed land of low, medium, and high intensity; woody wetlands; emergent herbaceous wetlands; deciduous forest; open water; mixed forest; and hay/pasture land uses.

![Figure 26. Land Cover in the CPWP Study Area](image)

From 2001 to 2016, evergreen forest land cover in the study area decreased by approximately 70,000 acres (6%) while developed space increased by a total of 5,800 acres: developed open space increased by approximately 2,200 acres (5%), developed low intensity by 1,500 acres (9%), developed medium
intensity by 1,600 acres (23%), and developed high intensity by 520 acres (34%). Excluding the
shrub/scrub, herbaceous, and open water categories of land cover, all other categories of natural
ecosystem land cover decreased, but by minimal acreage overall.

Regulating – General: Wildfire Frequency

Related stakeholder concern(s): Wildfire, Climate Change
Recommended measure: Incidents (#) and extent (acres)
Spatial scale: Study area
Frequency of measurement: Annually
Proxy for: Erosion prevention and flood protection

Wildfire can induce a large amount of erosion—including through post-wildfire flooding—and, as such,
wildfire frequency and extent can be used as a proxy indicator of the regulating ecosystem services of
erosion prevention and flood protection. Many datasets have been compiled to present accurate real-
time and historic wildfire occurrences.

This analysis pulls from the Historic Fire Database, a collaboration of NASA and Idaho State University,
which compiles fire perimeters from the US Forest Service, Bureau of Land Management, USGS, National
Interagency Fire Center, as well as state authorities. Although the database’s record goes back to 1950,
it should be noted that reporting by the authorities from which the database is sourced may not be
entirely consistent across agencies or over time (NASA and Idaho State University GIS Training and
Research Center 2020). Some sizes of fires may be excluded as a result of the underlying authorities’
reporting guidelines, but this is also often the case for other databases maintained for historic wildfire
records, such as the GeoMAC Historic Wildfire Perimeter dataset maintained by the US Forest Service
(Kuenzi 2020).

For the CPWP study area, wildfire frequency and fire size have been increasing from 1950 to 2018 with a
dramatic trend in fire size becoming apparent in the 1990s and 2000s (see Figure 27). This trend follows
that of wildfire trends across the western US and is a result of changes in fuel loads and climatic
conditions (Davis and Weber 2018).

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12 Categories of developed land are based on the intensity of development as determined by impervious surface
extent: “Developed, open space” (less than 20 percent impervious surface), “Developed, low intensity” (20-49
percent impervious surface), “Developed, medium intensity” (50-79 percent impervious surface), and “Developed,
high intensity” (80 percent or more impervious surface).
Regulating – General: Forest Restoration

*Related stakeholder concern(s): Wildfire, Climate Change*
*Recommended measure: Area treated (acres)*
*Spatial scale: Index sites - National Forests (Apache-Sitgreaves, Coconino, Kaibab and Tonto)*
*Frequency of measurement: Annually*
*Proxy for: Erosion prevention and flood control*

Forest restoration represents actions taken to reduce the risk of wildfire, such as forest thinning and prescribed burns. Such actions decrease not only the risk of wildfire, but of post-wildfire flooding and erosion, while enhancing groundwater recharge and surface water quality. Measurements could include, for example, measures of forest density, acres treated, or costs avoided—including costs of losses that encompass not only structural damage but other costs such as decreased housing prices post-fire and flooding (Mueller et al. 2018). The recommended measure is number of acres treated at index sites—specifically, the Apache-Sitgreaves, Coconino, Kaibab, and Tonto National Forests.

The Four Forest Restoration Initiative, part of the broader Collaborative Forest Landscape Restoration Program, includes Apache-Sitgreaves, Coconino, Kaibab and Tonto National Forests (US Forest Service 2020a). Data on acres treated to reduce risk of catastrophic fire are reported annually for all four forests combined and are currently available for 2010-2018.

As seen in Figure 28, over 750,000 acres (defined as unique acres because multiple treatments could occur on the same acre) have been treated. This represents approximately 8% of the total acres contained within these four forests.
### Regulating – Water Purification: Drinking Water Quality

**Related stakeholder concern(s):** Wildfire Protection, Infrastructure, Climate Change, Water Reuse

**Recommended measure:** Safe Drinking Water Act exceedances (\# of violations)

**Spatial scale:** Index public water providers

**Frequency of measurement:** Annually

The ability of the freshwater ecosystem to provide water of sufficient quality for different purposes can be considered through various water quality indicators and metrics. Drinking water quality, the first of several selected such indicators, could be measured, for example, by the presence or concentration of various constituents of interest or concern; compliance with relevant water quality regulatory standards; or the cost to treat source water for various purposes. The recommended metric is number of violations of Safe Drinking Water Act (SDWA) standards in a selected set of public water supply systems within the study area.

Counts of and types of violations of Safe Drinking Water Act standards can be an indicator of the water purification ecosystem service, as the number and types of violations provide information as to what contaminants exist in the local environment and what may be coming back into water sources from drinking water facilities. Detailed water quality data for individual (non-tribal) water providers is available from the ADEQ. (Arizona Department of Environmental Quality 2020e)

Five index water providers were chosen to represent the drinking water quality indicator for the CPWP study area: City of Flagstaff, City of Williams, City of Page, Grand Canyon National Park (Grand Canyon Village), and Arizona Water Company – Sedona. These five water systems are the principal water providers for large communities in the study area, report water quality data to ADEQ, and cover a substantial portion of municipal demand within the study area. (Coconino Plateau Watershed Partnership 2015)

Drinking water violations by the index water providers have been kept at relatively low rates from 2000-2019, with the exception of the years 2001, 2004, 2013, and 2016 for the City of Flagstaff and Arizona Water Company-Sedona (see Figure 29). The most frequent analyte violation for the City of Flagstaff, Page, Williams, and Grand Canyon National Park is chlorine, whereas the most frequent analyte
violation for Arizona Water Company-Sedona is DEHP – an organic compound commonly added to plastics (Agency for Toxic Substances and Disease Registry 2020; Arizona Department of Environmental Quality 2020e). The peaks in 2001, 2004, and 2013 for Arizona Water Company-Sedona were driven by DEHP, TCDDs,\textsuperscript{13} and polychlorinated biphenyls (PCBs), respectively, though violations from other analytes were also well represented. For the spikes in violations for the City of Flagstaff, turbidity was a large contributor in 2004, but over 30 different analyte violations were nearly equally represented in the 2016 spike. (Arizona Department of Environmental Quality 2020e)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure29.png}
\caption{Safe Drinking Water Standard Violations by Index Water Providers (2000-2019)}
\end{figure}

In the future, additional tribal water providers could be added to the set of index providers for whom drinking water quality is tracked. Under the Tribal Public Water System Supervision (PWSS) program, the US EPA collects drinking water compliance data to determine compliance with SDWA on Native American Reservations. EPA stores this information in the Safe Drinking Water Information System (SDWIS), which contains information about public water systems and their violations of EPA’s drinking water regulations (US EPA 2015a). Data might be tracked, for example, for the Tuba City, Polacca, Havasupai Village, and Peach Springs public water systems (US EPA n.d.). It should be noted, however, that the data are likely not directly comparable to that tracked by ADEQ.

\textsuperscript{13} TCDDs is the abbreviation for 2,3,7,8-Tetrachlorodibenzo-p-dioxin and related compounds, a carcinogen that is a byproduct of chlorophenols, hexachlorophene, and herbicides.
Regulating – Water Purification: Impaired Water Bodies

Related stakeholder concern(s): Wildfire Protection, Infrastructure, Climate Change, Water Reuse
Recommended measure: Impaired waters (#)
Spatial scale: Study area (including Lake Powell and Colorado River on boundary of study area)
Frequency of measurement: Every two years
Proxy for: Surface water quality

Surface water quality in the environment could be measured in a variety of ways including dissolved oxygen levels; pH, total nitrogen; the presence or concentration of various other constituents of interest or concern; treatment costs; or exceedances (violations) of relevant regulatory standards, among others. The recommended metric is the number of impaired waters (those that do not meet state water quality standards) within the study area.

The number of impaired water bodies within the study area is a useful proxy indicator for surface water quality as the type of impairment can inform how stakeholders can and should interact with specific water bodies in regard to use and reuse. The Arizona Department of Environmental Quality has Clean Water Act assessment maps for impaired surface waters for 2018 and 2020. Within the study area there are both impaired and “not attaining” lakes and streams. Both impaired and not attaining water bodies do not meet Clean Water Act standards—which are based on specific uses identified for the particular water body—but impaired water bodies require development of total maximum daily load (TMDL) requirements whereas not attaining water bodies do not. (Arizona Department of Environmental Quality 2020b)

As of 2020 there are five impaired or not attaining lakes and streams within the study area. The cause of the impairment in the lakes is cited as mercury in fish tissues, whereas the impairment for the streams results from exceeding allowable E. coli and selenium levels (Arizona Department of Environmental Quality 2020c; 2020d). From 2018 to 2020, no lakes were delisted or added to the impairment list, and while no streams or rivers were delisted, the Colorado River was added as an impaired water body due to excessive selenium levels (see Table 12). Although the Paria River is primarily outside of the study area, it was included here because of its direct connection to the Colorado River and intersection with the border of the study area.

<table>
<thead>
<tr>
<th>Type of Water Body</th>
<th>Impaired Water Bodies</th>
<th>Not Attaining Water Bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2018</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lakes</td>
<td>Lake Powell</td>
<td>Lake Mary (Upper and Lower)</td>
</tr>
<tr>
<td>Streams</td>
<td>Paria River</td>
<td>Oak Creek</td>
</tr>
<tr>
<td><strong>2020</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lakes</td>
<td>Lake Powell</td>
<td>Lake Mary (Upper and Lower)</td>
</tr>
<tr>
<td>Streams</td>
<td>Colorado River, Paria River</td>
<td>Oak Creek</td>
</tr>
</tbody>
</table>

While water bodies impaired by E. coli are generally indicators of the recreational value of a water body—as the impacts typically manifest in humans through freshwater recreation or fish consumption—selenium has the potential to cause reproductive impairments in aquatic species and influence mortality in both aquatic species and water fowl (EPA 2020; USGS 2020b; 2020c). Selenium is an irritant to humans at certain concentrations and durations of exposure. Extended periods of exposure or high
enough concentrations of selenium can cause gastro-intestinal irritation, respiratory irritation, and potentially a disease called selenosis that results in hair loss, nail brittleness, and neurological abnormalities, though the concentrations required for the manifestation of these health impacts are rarely seen outside of a workplace environment (Agency for Toxic Substances and Disease Registry 2003).

Lake Powell, the Colorado River, and the Paria River require TMDL development and subsequent plans and restrictions may impact how water from these sources can be used.

This metric may need to be revisited in the future, as new federal Clean Water Act (CWA) rules that went into effect during the summer of 2020 are anticipated to change how and where state water quality standards apply in Arizona. This may result in a significant “gap” in water quality protection for some waterways that have traditionally been subject to CWA requirements. (Arizona Department of Environmental Quality n.d.)

Regulating – Water Purification: Monitoring for Uranium Mining

Related stakeholder concern(s): Wildfire Protection, Infrastructure, Climate Change, Water Reuse
Recommended measure: Active uranium mines (#) and monitoring wells per active uranium mine (#)
Spatial scale: Study area
Frequency of measurement: Annually
Proxy for: Groundwater quality

Groundwater quality was of interest to stakeholders—especially as related to the potential threat to groundwater quality posed by uranium mining in the study area. Groundwater quality could be measured by, for example, NO3 levels, arsenic levels, occurrence of pesticides, levels of trace metals, uranium levels, # of exceedances (violations) of pertinent regulatory standards, treatment costs, or monitoring infrastructure/capability, among others. TAC members also recommended considering a metric reflecting groundwater that is unavailable for use because of its poor quality. While at present, there does not appear to be readily available data to make this measurement on a quantitative basis, it may be information that the CPWP would like to pursue in the future.

ADEQ collects groundwater quality data across the state. (Arizona Department of Environmental Quality n.d.) It appears, however, that the agency does not regularly monitor the basins within the study area. (See Towne & Jones, 2016, showing locations of ADEQ Ambient Groundwater Sampling, and noting no sampling in the Coconino Plateau groundwater basin and limited sampling in the Little Colorado River groundwater basin.) USGS also monitors groundwater quality across the state, although again the number of sites in which quality is regularly measured within the study area appears to be limited (USGS n.d.).

Based on data availability, the specific stakeholder concerns at issue, and the nature of potential threats to groundwater quality in the study area (see, e.g., Northern Arizona Council of Governments, 2002), the recommended indictor and metric is intended to specifically reflect the ability to monitor the impact of active uranium mining on groundwater resources. The recommended measure is a count of active uranium mines in the study area, plus a ratio of associated monitoring wells per active uranium mine in the study area.
The *Directory of Active Mines in Arizona: FY 2019*, a joint product of the Arizona Mine Inspector’s Office and the Arizona Geological Survey, characterizes active mines in the state as of 2019 (Arizona Geological Survey 2019). The associated map includes a layer that specifically identifies uranium mines.\(^\text{14}\) Canyon Mine, which is within the study area, is the only active uranium mine in the state as of 2019.

Information about associated monitoring wells should typically be found in the aquifer protection permit (APP) for the mine. APPs can be requested from ADEQ by facility. (Arizona Department of Environmental Quality n.d.) Information about water quality monitoring for Canyon Mine is compiled in Grand Canyon Trust’s report on that mine (Reimondo 2020). As of this writing, ADEQ had also assembled information about permitting for Canyon Mine on its website. An individual APP has not in the past been required for Canyon Mine, but as of September 2020, ADEQ requested that the mine operators apply for such a permit going forward. (Arizona Department of Environmental Quality 2020f) Currently, a single deep production well installed by the mine operators is monitored for water quality, as is a shallower USGS observation well close to the mine (Reimondo 2020).

**Table 13. Uranium Mines and Associated Monitoring Wells per Mine**

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon Mine</td>
<td>2</td>
</tr>
</tbody>
</table>

Although past uranium mining and its impact on water quality was not specifically articulated in the Phase 1 Reports as a concern, another possible future indicator to consider in relation to uranium mining impacts on the quality of groundwater in the study area would be a count of abandoned uranium mines within the study area (US EPA 2016a), progress towards clean-up, or a measure of contamination in nearby groundwater (US EPA 2016b). It is not clear, however, whether data for these metrics would be readily and publicly available on a regular basis in order to monitor trends. The US EPA estimates that there are more than 500 abandoned uranium mines on Navajo Nation lands, which have contaminated some local groundwater supplies. With other federal agencies, the EPA has issued two five-year plans addressing clean-up of these sites. (US EPA 2016c)

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\(^{14}\) While this is the first directory of active mines since the Arizona Dept of Mines and Mineral Resources released Directory of Active Mines in Arizona (2007), information should be available on an annual basis in the future; the directory states that the product is “the first in an ongoing, annual production between the Arizona Geological Survey and the Arizona State Mine Inspector’s Office.”
Regulating – Water Purification: Reclaimed Water Quality

Related stakeholder concern(s): Wildfire Protection, Infrastructure, Climate Change, Water Reuse

Recommended measure: Class of reclaimed water produced (A, B, C)

Spatial scale: Index wastewater treatment plants

Frequency of measurement: Annually

Reclaimed water quality was a concern noted by stakeholders, specifically in the context of water reuse. Some stakeholders articulated concern about the presence of CECs in reclaimed water. Others were concerned about public perceptions of reclaimed water quality, and the influence of those perceptions on opportunities for water reuse. Specific interest was also expressed in treating water for direct potable reuse.

Reclaimed water quality could be measured by the level or type of treatment of that water, by assessment of its suitability for use for different purposes, by the presence or levels of various constituents, by compliance with regulatory standards, or by the frequency or level of water quality monitoring, for example. The metric selected was class of reclaimed water produced by select index wastewater treatment facilities within the study area.

Reclaimed water is defined by Arizona state law as water that has been treated or processed by a wastewater treatment plant or an on-site wastewater treatment facility to meet certain standards. It can then be directly reused for certain allowable uses depending on the quality of the water. Class of reclaimed water (A+, A, B+, B, or C) is defined by ADEQ regulations based on protection of public health and groundwater quality. (Arizona Department of Environmental Quality 2017)

Under ADEQ classifications, Class A+ reclaimed water is wastewater that has undergone the most treatment (including secondary treatment, filtration, nitrogen removal treatment, and disinfection). At the other end of the spectrum Class C water has undergone the least treatment (minimal secondary treatment with or without disinfection). Whereas Class A and A+ reclaimed water may be directly reused for purposes that include, for example, irrigation of food crops, recreational impoundments, or snowmaking, Class B and B+ water may not be used for those purposes but may be used, for example, for golf course irrigation or dust control purposes. Allowable uses of Class C reclaimed water are more limited and include such uses as pasture or livestock watering for non-dairy animals. (Arizona Department of Environmental Quality 2020a)

Index wastewater treatment plants were selected based on an identification of those wastewater facilities within the study area with the most significant capacity and treatment volume according to available information (Northern Arizona Council of Governments 2002; Arizona Department of Water

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15 Also sometimes termed “compounds” of emerging concern, CECs are substances that have been released to, found in, or have the potential to enter water supplies. They are often found in trace or very low concentrations and are unregulated by the U.S. EPA. Some have been found to have a detrimental effect on fish and other aquatic wildlife, and/or to bioaccumulate in animals higher in the food chain. (US EPA 2015b; USGS, n.d.)
Resources 2009a; 2009b; 2009c).\textsuperscript{16} Data about the class of reclaimed water produced by these facilities was provided by ADEQ upon request (Savarirayan 2020). Because wastewater treatment facilities located on Native American Reservations do not report reclaimed water quality to ADEQ, no such facilities were included among the index sites.

Of the six index wastewater treatment facilities considered, four produce Class A+ reclaimed water. One produces Class A, and one produces Class B+ (see Table 14).

**Table 14. Class of Reclaimed Water Produced by Index Wastewater Treatment Facilities**

<table>
<thead>
<tr>
<th>Wastewater Treatment Facility</th>
<th>Reclaimed Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Flagstaff - Wildcat Hill WWTP</td>
<td>A+</td>
</tr>
<tr>
<td>City of Flagstaff - Rio de Flag Water Reclamation Facility</td>
<td>A+</td>
</tr>
<tr>
<td>City of Sedona Wastewater Reclamation Plant</td>
<td>A+</td>
</tr>
<tr>
<td>City of Page</td>
<td>A+</td>
</tr>
<tr>
<td>USDOI NPS - Grand Canyon NP - South Rim WWTP</td>
<td>A</td>
</tr>
<tr>
<td>City of Williams</td>
<td>B+</td>
</tr>
</tbody>
</table>

Although historic information about reclaimed water quality is not readily available, continuing to track the class of reclaimed water produced by facilities in the study area could allow for observation of changes over time.

In the future the CPWP may want to also consider looking at a metric specifically related to CECs, given stakeholders’ interest in this topic. Sampling for certain CECs is required by the US EPA for water systems of a certain size under the Unregulated Contaminated Monitoring Rule (US EPA 2015c). However, because there are not regulatory standards that apply to CECs, it would require care and potentially specialized expertise to identify metrics that meaningfully communicate how CECs may impact ecosystem service function within the study area.\textsuperscript{17}

Development of an indicator and metric related specifically to public perception of reclaimed water and its quality might also be helpful to CPWP stakeholders, given their identification of this issue in Phase 1. Evaluation and tracking of such an indicator would likely require gathering new data about public perceptions within the study area.

\textsuperscript{16} Capacity and treatment volumes for wastewater treatment facilities do not generally appear to be cataloged in Arizona in a regularly updated, readily accessible source. (ADEQ data on wastewater treatment plants is available on request.) However, the Arizona Water Blueprint produced by Arizona State University’s Kyl Center for Water Policy, and first released during the writing of this report, does map wastewater treatment plants and includes the “design capacity” for some of the mapped facilities. It may be a useful source for cataloguing facilities within the study area in the future. (Arizona State University Kyl Center for Water Policy 2020)

\textsuperscript{17} Flagstaff and Sedona have both sampled and evaluated CEC levels within their water systems and provide data on their websites (City of Flagstaff n.d.; 2018; Carollo 2014).
Regulating – Wildlife Populations and Habitats: Endangered Species

Related stakeholder concern(s): Climate Change, Springs
Recommended measure: Endangered/threatened species total (#) and aquatic (#)
Spatial scale: Study area
Frequency of measurement: Annually
Proxy for: Wildlife populations

Based on data availability, the indicator endangered species was selected as a proxy measure for wildlife populations. Number of endangered species could be measured within an area, or the same could be measured for a particular species type; alternatively, population numbers could be measured for a particular species. Based on available data, the recommended measure is total number of endangered/threatened species within the study area and number of threatened/endangered aquatic species.

The count of endangered species is a useful proxy indicator for wildlife populations and habitats as it provides insight into what types of critical habitats are degraded, to what extent, and what efforts are being made to protect or improve them. Counts of endangered species were extracted from the US Fish and Wildlife Service’s Information for Planning and Consultation tool and indicate that there are 19 total threatened and endangered species in the CPWP study area, of which six are aquatic species (see Table 15). (US Fish & Wildlife Service 2020)

<table>
<thead>
<tr>
<th>Species (Common Name)</th>
<th>Status</th>
<th>Aquatic (Yes/No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black-footed Ferret</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>California Condor</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Mexican Spotted Owl</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>Southwestern Willow Flycatcher</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Yellow-billed Cuckoo</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>Northern Mexican Gartersnake</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>Kanab Ambersnail</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Brady Pincushion Cactus</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Fickeisen Plains Cactus</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Navajo Sedge</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>San Francisco Peaks Ragwort</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>Sentry Milk-vetch</td>
<td>Endangered</td>
<td>No</td>
</tr>
<tr>
<td>Welsh’s Milkweed</td>
<td>Threatened</td>
<td>No</td>
</tr>
<tr>
<td>Apache Trout</td>
<td>Threatened</td>
<td>Yes</td>
</tr>
<tr>
<td>Gila Chub</td>
<td>Endangered</td>
<td>Yes</td>
</tr>
<tr>
<td>Humpback Chub</td>
<td>Endangered</td>
<td>Yes</td>
</tr>
<tr>
<td>Loach Minnow</td>
<td>Endangered</td>
<td>Yes</td>
</tr>
<tr>
<td>Razorback Sucker</td>
<td>Endangered</td>
<td>Yes</td>
</tr>
<tr>
<td>Spikedace</td>
<td>Endangered</td>
<td>Yes</td>
</tr>
</tbody>
</table>

There are other measures of wildlife populations or habitat that could enhance or replace this indicator, such as acres of critical habitat over time; acres of riparian habitat; miles of perennial streams; or population surveys of an indicator species for the region. These indicators were not pursued as publicly available data on a well-studied indicator species that characterized the region or informed habitat...
quality within the region were not readily identifiable. Nor are there regularly updated data sets related
to riparian habitat acreage or perennial stream miles. Additionally, specific information on critical
habitat condition or extent and population surveys are not widely available for threatened or
endangered species, in order to help protect the populations and their habitats from malicious intent.

Regulating – Wildlife Populations and Habitats: Spring Habitat

Related stakeholder concern(s): Climate Change, Springs
Recommended measure: Surveys (#) and average extent of data (1-10)
Spatial scale: Study area
Frequency of measurement: Annually

Springs play a critical role in supporting wildlife populations and habitats, especially in arid areas. As
described previously in the spring flow section, aspects of the ecological health of spring habitat could
be measured in a variety of ways, including measures of flow/discharge (cfs); water quality (e.g.,
temperature, pH, specific conductance, total alkalinity, and dissolved oxygen concentration);
geomorphic change; percent cover by native and non-native species and vegetation change through
time; macroinvertebrate species composition and density; and vertebrate species composition and
density. As described further below, the Springs Ecological Assessment Protocol (SEAP) also allows for
calculation and monitoring of an overall ecological health score. (L. Stevens, Springer, and Ledbetter
2016)

For the purposes of this effort, the recommended measures deal primarily with the level of data that is
available for each spring habitat, rather than the habitat quality itself. The level of data available by
spring is itself informative as it underscores a lack of available information required to evaluate and
monitor other aspects of spring habitat and ecological health for a multitude of springs on the Plateau.
There are two measures of data availability on springs that were provided by SSI: the number of surveys
and the average extent of data (EOD) by spring. EOD is a measure of the number of categories of data
that are recorded during a spring survey and ranges from 1-10 to reflect the ten categories of data
collected during a survey, including information on microhabitats, soil, flow, flora, and fauna (Springs
Stewardship Institute 2020).

As documented in SSI’s Springs Online database and reported to the study team, there are a total of 975
springs within the study area. Of these, 55% are on tribal land, 24% on National Park Service land, and
15% on US Forest Service land, with the remainder on private, state, county, or other federal land.
Twenty-seven percent of the springs recorded by SSI within the study area are on Hopi Tribal land, 23% are
within Grand Canyon National Park, and 17% are on land within the Navajo Nation. (Jenness, Jeff
2020)

SSI provided locational and other more detailed information about 681 springs in the CPWP study area
for this assessment (some springs were omitted from the dataset provided to the study team due to
privacy issues) (Jenness, Jeff 2020). Of these springs, nearly 500 have not been surveyed or are missing
an entry for the number of surveys. The great majority of the remaining springs have been surveyed
only a handful of times (see Figure 30).
Figure 30. Number of Surveys by Spring in the CPWP Study Area

Note: Data excludes springs that were omitted from the data set provided by SSI based on privacy/confidentiality concerns.

Of those springs that have been surveyed, the majority of springs have average EODs of less than five, such that, on average, during spring surveys data were collected for fewer than half of the potential data categories. Spring surveys and average EOD vary by geography. Springs in the eastern portion of the study area near Tuba City are primarily un-surveyed, but those that are surveyed have a high level of data collection. In contrast, a large number of springs in the Flagstaff area have been surveyed, but with low average levels of EOD. The springs in the northwest are more variable in both survey status and EOD (Figure 31).
SSI also produces the Springs Ecosystem Assessment Protocol, which allows for the calculation and monitoring of an overall ecological health score and for scores in six categories (aquifer and water quality, site geomorphology, habitat and microhabitat array, site biota, human uses and influences, and administrative context under which the spring is managed) for each surveyed spring. Each category is scored on the basis of five to eight subcategories that are ranked on a 0-6 scoring scale. (L. Stevens, Springer, and Ledbetter 2016)

These data were provided by SSI by individual survey, however, given the study timeline and the data manipulation needed to arrive at a SEAP score by spring, this was not a measure that could be analyzed for the purposes of this assessment. It is, however, a measure that could be analyzed in the future, for either the springs in the study area for which sufficient information is available, or for a set of selected “index” springs.

In general, SSI notes that long-term studies of springs and springs habitat are rare and highly context specific (L. Stevens, Springer, and Ledbetter 2016), as is reflected in the data presented above. Further analysis and monitoring of spring health could be of interest to the CPWP and its members, given the significance of springs in the area’s ecosystems and their importance to stakeholders as a concern identified in the first phase of this assessment.
Regulating – Wildlife Populations and Habitats: Impaired Streams

Related stakeholder concern(s): Climate Change, Springs
Recommended measure: Impaired streams (#)
Spatial scale: Study area (including Lake Powell and Colorado River on boundary of study area)
Frequency of measurement: Every two years
Proxy for: Habitat quality

Stream habitat health or resilience could be measured by, for example, species diversity or abundance, acres of habitat type, or acres restored, as a few examples. Despite the centrality of rivers, streams, and riparian habitat in supporting wildlife in Arizona, however, very little replicable data representing the health of aquatic or riparian habitat or tracking populations in the study area or broader region appear to be available on an ongoing basis.

Due to these data limitations, the recommended metric for stream habitat is the number of impaired streams (those that violate state water quality standards) within the study area as a proxy for habitat quality for aquatic species, as impairment and the cause of impairment can inform whether the habitat is suitable for native species’ survival. As described previously in the section on surface water quality, the ADEQ has Clean Water Act assessment maps for impaired surface waters. Within the study area there are both impaired and not attaining streams and rivers. Both impaired and not attaining water bodies do not meet Clean Water Act standards, but impaired water bodies require TMDL development whereas not attaining water bodies do not (Arizona Department of Environmental Quality 2020b). Impairment in the streams and rivers results from exceeding allowable E. coli and selenium levels (Arizona Department of Environmental Quality 2020c; 2020d). From 2018 to 2020 no streams or rivers were delisted, but the Colorado River was added as an impaired water body due to excessive selenium levels (see Table 16).

<table>
<thead>
<tr>
<th>Year</th>
<th>Impaired Water Bodies</th>
<th>Not Attaining Water Bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>Paria River</td>
<td>Oak Creek</td>
</tr>
<tr>
<td>2020</td>
<td>Colorado River, Paria River</td>
<td>Oak Creek</td>
</tr>
</tbody>
</table>

While water bodies impaired by E. coli are generally indicators of the recreational value of a water body—as the impacts typically manifest in humans through freshwater recreation or fish consumption—selenium has the potential to cause reproductive impairments in aquatic species and influence mortality in both aquatic species and water fowl. (EPA 2020; USGS 2020b; 2020c)

As also noted in the section on surface water quality, this metric may need to be revisited in the future, as new federal Clean Water Act rules change how and where water quality standards apply in Arizona.

6.3 Cultural Services: Baseline Conditions and Trends

Arizona is a popular destination for local and international visitors alike. The Arizona Office of Tourism (AOT) tracks visitor information by region of the state, and while the CPWP area of interest does not align exactly with any AOT region, the Northern Region, which includes Coconino, Navajo, and Apache Counties is similar. In 2018, the AOT estimated that Northern Arizona had 8.3 million domestic overnight visitors. This estimate does not include international visitors or day-trips. Ninety-three percent of these
visitors came for leisure (as opposed to business) and 61% were non-residents of Arizona. These visitors contributed over $2 billion in direct spending and supported almost 20,000 jobs in the region. (Arizona Office of Tourism 2018)

Water is an important component of many recreation and tourism sites in Arizona and, more specifically, the study area of interest—from the Colorado River in Grand Canyon to Havasu Creek on the Havasupai Reservation, to Oak Creek in Slide Rock State Park. In addition, visitors, particularly overnight visitors, are users of the local water resources—from drinking water to the water used to wash linens after their departure.

In addition to values connected to recreation and tourism, water and water sources in the region also provide cultural ecosystem services connected to cultural identity, heritage values, spiritual services, inspiration, and aesthetic appreciation.

Cultural – Recreation/Tourism: Visitors

Related stakeholder concern(s): Climate Change, Water Reuse, Tourism/Recreation
Recommended measure: Number of recreation/tourism visitors
Spatial scale: Index sites – Slide Rock State Park, Grand Canyon National Park, Coconino and Kaibab National Forests
Frequency of measurement: Annually or every five years
Proxy for: Non-resident water demand

The indicator recreation/tourism visitors was selected as both a direct measure of visitation and a proxy indicator for water demand by non-residents. For the former, focusing the indicator on only water-related recreation and tourism would be ideal, but review of literature and data suggests that this would not be possible at the spatial scale of the study area, though it could be possible at index sites.

The recommended measures are the number of recreation/tourism visitors annually at two index sites—Slide Rock State Park and Grand Canyon National Park—and every five years for Coconino and Kaibab National Forests.

One of the more recognizable water-related recreation/tourism locations in the study area is Slide Rock State Park. The Arizona Office of Tourism (2020) has annual State Park visitor data available starting in 2014. From 2014 to 2018, visitation to Slide Rock State Park has increased steadily (see Figure 32).
The most recognized and visited attraction in the study area, the Grand Canyon, also encompasses freshwater ecosystems and recreation (including everything from Colorado River rafting, backcountry recreation in reliance on springs as a water source, to overall enjoyment and appreciation of the life supported by water in a desert ecosystem). The National Park Service has tracked annual visitors to Grand Canyon National Park since 1919 (see Figure 33).

The US Forest Service (2020b) provides estimates of visitors to National Forests every five years. Table 17 includes visitor estimates for Coconino and Kaibab National Forests for years in which data were available.

**Table 17. Estimated Annual Site Visits to Coconino and Kaibab National Forests**

<table>
<thead>
<tr>
<th>Site Visits</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconino NF</td>
<td>5,541,000</td>
<td>4,715,000</td>
<td>5,057,000</td>
</tr>
<tr>
<td>Kaibab NF</td>
<td>276,000</td>
<td>757,000</td>
<td>496,000</td>
</tr>
</tbody>
</table>
Visitor estimates were also requested from the Arizona Snowbowl, as this is a site where water is used for winter recreation and reclaimed water is used for snowmaking, which began in 2012. Annual visitor estimates were not available, however, personal communication with Snowbowl staff indicates that 1) annual visitation was highly variable prior to 2012—from 3,000 to 206,000 individuals per year; and 2) since 2102, when snowmaking began, visitation has increased and also been more consistent—averaging approximately 210,000 individuals per year. (Murray 2020)

Cultural – Recreation/Tourism: Direct Spending from Recreation/Tourism

Related stakeholder concern(s): Climate Change, Water Reuse, Tourism/Recreation

Recommended measure: Direct spending (defined as “destination spending” in the Dean Runyan and Associates reports)

Spatial scale: County

Frequency of measurement: Annually

Direct spending associated with recreation/tourism was selected as a measure of the contribution to and importance of recreation and tourism to the local and regional economy.

Direct spending data are available at the county level in the annual report “Arizona Travel Impacts” produced by Dean Runyan Associates, a firm that produces detailed annual travel impact estimates for Arizona at both the state and county level. In the most recent published report, data are available from 2010-2018. It should be noted that the study methodology states that:

“Visitors are defined as persons that stay overnight away from home, or travel more than fifty miles one-way on a non-routine trip. Only the expenditures related to specific trips are counted as visitor spending. Other travel related expenditures such as the consumption of durable goods (e.g., recreational vehicles or sporting equipment) or the purchase of vacation homes are not considered.” (Dean Runyan Associates 2019)

Figure 34 shows direct visitor spending in constant 2019 dollars for Coconino and Navajo Counties. In 2018, direct visitor spending in Coconino County, the county that represents the majority of the study area, was over $1.5 billion. It is also notable that travel-generated tax revenue per household in Coconino County is more than double that of any other county in Arizona—an estimated $2,970 per household in 2018.
Cultural – Other

Related stakeholder concern(s): Climate Change, Springs

In addition to recreation and tourism, the Millennium Assessment identified five other categories of cultural ecosystem services including cultural identity, heritage values, spiritual services, inspiration, and aesthetic appreciation (Millennium Ecosystem Assessment 2005). Spiritual services were identified through Phase 1 of the assessment as being connected with stakeholder concerns, and in particular with climate change and springs. It is clear, however, that water and water sources in the study area support all of these categories of cultural services for Native Americans, other local residents, and visitors to the area. Some sites within the study area—the Grand Canyon most demonstrably—also have “non-use” value to people locally, nationally, and internationally who value the place, its existence, and its stewardship outside of direct visitation or other “use” of the place or resource.

While cultural ecosystem service values are widely recognized, they are less integrated into the ecosystem services framework than many other service types, and there are fewer established models and methods for assessment. This may be because they “are often characterized as being ‘intangible,’ ‘subjective,’ and difficult to quantify in biophysical or monetary terms” (Daniel et al. 2012). In addition, as the Millennium Ecosystem Assessment (2005) notes, “cultural and amenity services are entirely determined by human perceptions of their environment.” Such a statement suggests that direct involvement of the individuals who value and benefit from these services is critical to understanding the connection between humans and the ecosystem.

In the context of the study area, there are a number of well-documented water-related cultural ecosystem services. The Grand Canyon, for example, is a World Heritage site, in part because of its exceptional natural beauty and diversity of ecosystems (UNESCO World Heritage Centre n.d.). As noted in the Phase 1 ESA Reports, water resources of the Coconino Plateau are of great interest to scientists and educators. A nationwide survey demonstrated a “willingness” to pay for protection of backcountry springs in Grand Canyon based on attributes including accessibility, suitability as a back country water source, suitability as habitat for species of concern, aesthetics, and significance to Indigenous Nations (Mueller, Lima, and Springer 2017).
In 2016 the Bureau of Reclamation identified as many as 43 federally recognized tribes with potential traditional, historical, cultural, or religious ties to Glen and Grand Canyons (US Bureau of Reclamation and National Park Service 2016). Springs, streams, and wetlands in and around Grand Canyon are highly valued by some tribes based on the connections of these waters to the tribes’ identity, history, beliefs, and culture (US Bureau of Reclamation and National Park Service 2016; Complaint for Declaratory Judgment and Injunctive Relief, Havasupai Tribe v. Anasazi Water Co. 2017; Yeatts and Harned 2015). The same is true of other area waters, including those in the Verde watershed (see, for example Randall, Vincent E. and Coder, Chris 2018). The San Francisco Peaks—a visible center of orogenic precipitation and snow, and a site of reclaimed water use—are sacred to at least thirteen Native American Tribes (“Sacred Land Film Project” 2020). In addition to these and other well-known examples, there are countless additional sites and cultural services that may not be well known or well documented. To adequately address the range of cultural values associated with water-related ecosystem services, a thoughtful, well-designed, and participatory stakeholder-driven process would be most appropriate.

Initially, the Consulting Team had recommended developing an index to assess the “level of protection” of a handful of sites with recognized cultural and spiritual value, in order to include a quantitative indicator for cultural/spiritual ecosystem services within this assessment. An assessment of the level of protection could include a scale for evaluating how well-protected these sites are in terms of their land base, water quantity/flow, and water quality.\(^{18}\)

While some meaningful generalizations can be made to help define a scale for “level of protection,” however, there are likely to be important differences among stakeholders in terms of their ideas about how to define these different “levels,” and also about appropriately representative indicator sites. Thus while the initially proposed indicator (“level of protection of water-related cultural sites”) may still be valuable for the CPWP to pursue in the future, ensuring an adequate level of stakeholder engagement in designing the metric would require an effort outside of the scope and timeline for this assessment, and potentially require development or collection of data that is not presently publicly available.

Given the degree of cultural importance of water-related and water-dependent places and resources in the study area, the CPWP may wish to further pursue these issues in the future.

7 Conclusions and Recommendations

Freshwater ecosystems convey numerous benefits to the people and communities within the study area. The indicators and metrics developed as part of this effort were designed to describe these benefits—also known as ecosystem services—in their current (and in some cases historical) state and also allow for tracking of changes and trends in these water-related ecosystem services over time.

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\(^{18}\) An assessment such as this could take into consideration, for example, that within the study area generally there is not state regulation of groundwater withdrawals, nor a widely applicable mechanism to protect rivers, streams, springs, or other water-based sites from depletion; and that regulations related to water quality are variable and in flux, with new federal Clean Water Act regulations taking effect in the summer of 2020, for example. This regulatory environment plays out in different ways with regard to different services and sites within the study area, based on factors that include land ownership and status, land use, and the status of state and federal water rights, to name a few.
To that end, a baseline assessment using selected indicators and metrics was completed by the Consulting Team to assess the current status of water-related ecosystem services and any identify any notable trends in their function.

In terms of provisioning services notable highlights from the baseline assessment are as follows:

- Although other research indicates that the climate in northern Arizona is becoming hotter and drier (Meadow et al. 2018), this does not currently translate into a recent, observable trend in winter precipitation, which is critical to groundwater recharge in the study area.
- Water levels in Lake Powell have declined substantially since the late 1990s, representing a decline in surface water availability from this source, which could potentially impact the study area and its water users.
- Total groundwater supply in the study area is not easily measured or tracked directly. Of fourteen selected index wells, three showed declining water levels. Continuing to monitor index wells could provide an indication of whether and where broader trends in aquifer levels might require further attention and evaluation.
- As the population has increased within the study area, so has domestic demand. At the same time, however, total water demand has decreased since 2000. The decrease in total water demand stems from sectors other than domestic water use, which has been increasing in both Coconino and Navajo counties since 1995.
- Coconino County relies on surface water for the majority of its total use (approximately 60%), whereas Navajo County is almost entirely supplied by groundwater (85% of use). In both counties, the majority of total water use is self-supplied rather than part of public supply. A large portion of Coconino County’s recently reported surface water use can be attributed to the Navajo Generating Station, whose operations were terminated in 2019. Residential water use in both counties is largely sourced from groundwater.
- Well data suggest that large-scale human reliance on groundwater is relatively new, with fewer than 100 wells documented in the study area as of 1950 and more than 3,000 by 2018. While the number of wells in the study area continues to increase, the rate of increase has itself declined in recent years.
- The greatest use of water for non-residential purposes is the thermoelectric sector in Coconino County and irrigation and livestock/aquaculture uses in Navajo County.
- Eight water providers met a portion of their demand using reclaimed water in 2015, with the Cities of Flagstaff and Page being the largest users of reclaimed water.
- In 2018, Coconino and Navajo County occupied housing units lacking complete plumbing facilities represented 3.1% and 7.1% of total occupied housing units, respectively. In contrast, in 2018 the percentage of occupied housing units lacking complete plumbing facilities the Arizona and the United States were 0.66% and 0.38%, respectively.
- The baseflow of several significant streams that rely on discharge from the study area may be in decline, and thus warrant further attention as well as continued tracking over time. While flow data are available for very few springs, flow in two of five index springs may also be in decline.

Notable highlights from the baseline assessment of regulating ecosystem services are as follows:

- Evergreen forest land cover in the study area has decreased by approximately 70,000 acres (6%) from 2001-2016. Developed land cover has increased across all levels of intensity by a more modest number of acres (approximately 11,600 acres), but this acreage represents large
percentage increases in two specific developed land categories: developed open space (5% increase) and high intensity development (34% increase).

- In recent years both the frequency and the size of wildfires are on a dramatic upward trend within the study area. Forest restoration has been undertaken on an annual basis in the study area since at least 2010, with a primary goal of reducing fuel loading in preparedness for wildfires.

- Safe Drinking Water Act violations from 2000-2019 have been relatively low for the index providers analyzed, with the exception of four notable years (2001, 2004, 2013, and 2016) during which the count of violations was higher for the City of Flagstaff and the Arizona Water Company-Sedona.

- ADEQ performs limited continuous groundwater quality monitoring in the study area, and there are only two groundwater monitoring wells associated with the one active uranium mine in the study area.

- Reclaimed water quality in the study area is generally high among the wastewater facilities with the most significant capacity and treatment volume; of six index facilities, four produce Class A+ reclaimed water, one produces Class A, and one produces Class B+.

- There are 19 total endangered and threatened species of flora and fauna in the study area, of which six are aquatic species.

- In 2020, there were two “impaired” and one “not attaining” streams within the CPWP based on state water quality standards.

- There are close to 1,000 documented springs within the study area, but the majority have not been surveyed or have been surveyed only a handful of times; long-term studies and monitoring of springs and spring habitat are both rare and context-specific, despite their importance as “keystone ecosystems.”

In terms of cultural services, notable highlights from the baseline assessment are as follows:

- Recreation and tourism in the study area has been increasing consistently in the parks considered (Slide Rock State Park and Grand Canyon National Park) and has been variable in the national forests (Kaibab and Coconino National Forests). In recent years there have been more than six million annual visitors to Grand Canyon National Park.

- From 2009-2018 direct visitor spending in Coconino County has been increasing steadily, while visitor spending in Navajo County has been relatively static over that timeframe. In 2018, direct visitor spending in Coconino County was over $1.5 billion. Travel-generated tax revenue per household in Coconino County is more than double that of any other county in Arizona—an estimated $2,970 per household in 2018.

- Water and water sources in the study area support services including cultural identity, heritage values, spiritual services, inspiration, and aesthetic appreciation.

It is important to note several data-related limitations of the study:

- As the goal of this study was to develop indicators that could be populated using existing, regularly reported, publicly available data, this type of data was used in the baseline assessment. No primary data collection occurred nor were all potentially relevant point-in-time studies used or cited.

- Existing, publicly available data reported with regular frequency were not available for all desired or “optimal” indicators or metrics. As such, proxy indicators or less-optimal metrics were used for some ecosystem services.
Not all data used were available at the spatial scale of the study area. For example, data for many indicators were available at the county level. As mentioned previously, the study area includes parts of three counties, none of which aligns neatly with the study area: Coconino (encompassing 55% of the county’s land area), Navajo (17% of county land area), and Yavapai (<1% of county land area).

In some cases, data needed to populate an indicator were tracked by multiple agencies/organizations (e.g., water quality for tribal versus non-tribal water providers); at different temporal scales (e.g., well data); and/or using different measurements (e.g., gallons versus AF or water year versus calendar year), among other data inconsistencies—making it difficult, in some cases, to provide adequate and/or meaningful results.

Based on lessons learned, the following are recommendations of ways to expand and improve this effort in the future:

- Continue to monitor and update the indicators as new data become available.
- Consider creating a dashboard or database in which to collect data and present findings in a standardized fashion.
- Periodically reevaluate stakeholder concerns and consider whether they merit the addition or adjustment of any selected indicators.
- Modify indicators used as new or improved data become available to focus on direct, as opposed to proxy, measures.
  - For example, county-level data measuring the percentage of occupied housing units lacking complete plumbing facilities was used as a proxy indicator for access to improved water sources. Ideally, a more direct measure of the population in the study area without sufficient access to water would be available.
  - The “endangered species” indicator is a proxy measure for wildlife populations and habitat, and if data became available, could be replaced with population counts for an indicator species or set of species. More regular and comprehensive monitoring of riparian habitat or perennial stream miles could also allow for a meaningful and more direct measurement of water-dependent habitat.
- The importance of certain stakeholder concerns, ecosystem services, and/or indicators may warrant continued or additional investment in or advocacy for data collection or analysis, especially where there are significant data gaps. For example:
  - Further hydrological assessment could be undertaken to evaluate whether observed declines in well levels are representative of trends in the surrounding area. Index wells could also be linked to specific points in the CPWP’s hydrologic model in order to translate water levels in the index wells into a value representing the percent saturated thickness of the aquifer in those locations. In some parts of the study area, there is a notable absence of regularly monitored wells, which CPWP members may wish to address.
  - Continued hydrologic modeling and periodic comparison of modeled to actual conditions (including projected versus actual demands) will likely be a valuable way for the CPWP to continue to assess groundwater supply and sustainability of use, including potential impacts on aquifer levels and flows in springs and streams.
  - Although the flow and future availability of groundwater for multiple uses and purposes was the top stakeholder concern identified in Phase 1 of the ESA, there is not a comprehensive system or state requirement for reporting water use in the study area. Continuing to invest in updates to the CPWP “demand map” is a potentially valuable
way for the Partnership to track trends in water demand at the water provider and community level.

- In the future, the CPWP may wish to pursue collection of information specifically related to CECs or to public perceptions of reclaimed water, especially if interest in direct potable water reuse remains high. Given stakeholders’ interest in water reuse more generally, CPWP also may wish to consider whether there are ways to improve the ability to track reuse information more broadly within the study area.

- Given the importance of springs to stakeholders and their centrality in the region’s freshwater ecosystem—and yet the paucity of readily accessible data about spring flow—it may be advisable in the future to devise and track a measure of available spring-flow monitoring capacity, or to undertake efforts to increase that capacity; further evaluation of ideal index springs could also be of value. Further assessment and monitoring of spring habitat and ecological health may also be of interest to the CPWP and its members.

- A participatory, stakeholder-driven process may be warranted to more wholly represent the variety of water-related cultural ecosystem services in the study area.

In future planning for water sustainability on the Coconino Plateau, it is important to consider the broad range of ecosystem services provided by the area’s freshwater ecosystems, and to evaluate the possible impacts on these services in considering different water management alternatives. This ecosystem services assessment should support such efforts, as well as education about the multiple roles of water in benefitting people on the Plateau and in the surrounding region. Continuing to monitor and update indicators should help the Partnership, its members, and other stakeholders to understand and anticipate significant trends in the function of water-related ecosystem services and to identify opportunities for strategies that yield multiple benefits in terms of the sustained or improved function of these services.
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### APPENDIX A: Study Area Matrix: Geographic Scale of Ecosystem Services

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<tr>
<th>Ecosystem Service</th>
<th>Ecosystem Service Subcategory</th>
<th>Stakeholder Concerns</th>
<th>Geographic Scale of Ecosystem Service</th>
<th>Key Measurable Characteristics</th>
<th>Geographic Scale of Information</th>
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<tbody>
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<td><strong>Provisioning</strong></td>
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<td>All</td>
<td>Regional aquifers, plus some surface water sources, Service flow defined by population centers</td>
<td>Water used for drinking</td>
<td>Ideal Study area. Possible: Planning area or county</td>
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<tr>
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<td></td>
<td></td>
<td>Residential use</td>
<td>More likely: Index cities, water companies, reservations</td>
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<tr>
<td>Water for Non-Drinking Purposes</td>
<td>Groundwater, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Regional aquifers, plus some surface water sources, Service flow defined by diffuse demand</td>
<td>Water used for non-drinking purposes</td>
<td>Ideal Study area. Possible: Planning area or county</td>
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<td></td>
<td>Water use by sector (i.e., ag, industry, etc.)</td>
<td>More likely: Index cities, water companies, reservations</td>
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<tr>
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<td></td>
<td></td>
<td>Water reuse</td>
<td>Ideal Study area. More likely: Index city or cities</td>
</tr>
<tr>
<td>Water for Env. Flow</td>
<td>Groundwater, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Watershed (i.e., rivers &amp; streams) and springs - connection to large regional aquifers</td>
<td>Water for env. flow</td>
<td>Ideal Study area. More likely: Index streams and springs</td>
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<td>Streams</td>
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<td>Flood Protection</td>
<td>Wildfire Protection, Climate Change</td>
<td>Watershed, floodplain</td>
<td>Flood risk</td>
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## APPENDIX B: Indicator Frequency in Literature Reviewed

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<td></td>
<td>Cultural site use</td>
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<tr>
<td></td>
<td>Species of importance</td>
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</tbody>
</table>
## APPENDIX C: Potential Indicators and Associated Measures/Metrics

<table>
<thead>
<tr>
<th>Ecosystem Service - Subcategory</th>
<th>Indicator</th>
<th>Stakeholder Concern(s)</th>
<th>Classification</th>
<th>Measure/Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning: Drinking Water</td>
<td>Water used for drinking</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Flow</td>
<td>AF, population (#), gallons per capita, % Δ over time, deviation from long-term avg</td>
</tr>
<tr>
<td></td>
<td>Residential water use</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Flow</td>
<td>AF, % of total demand, population (#), gallons per capita, % Δ over time</td>
</tr>
<tr>
<td></td>
<td>Population experiencing water stress</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Benefit</td>
<td>#: % of total, % Δ over time, deviation from long-term avg</td>
</tr>
<tr>
<td></td>
<td>Population w/o improved water source(s)</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Benefit</td>
<td>#: % avg distance from primary water source, water hauling co. use, community water station use</td>
</tr>
<tr>
<td></td>
<td>Supply from protected sources</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Flow</td>
<td>% population inside active management area</td>
</tr>
<tr>
<td></td>
<td>Residential water costs</td>
<td>Groundwater, Wildfire Protection, Infrastructure, Climate Change, Water Reuse, Tourism/Rec, Springs</td>
<td>Benefit</td>
<td>$/AF, % Δ over time</td>
</tr>
<tr>
<td></td>
<td>Resilience of supply to climate change</td>
<td>Climate change adaptation plans (#) or % of water service providers with a plan</td>
<td>Flow</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX C continued: Potential Indicators and Associated Measures/Metrics

<table>
<thead>
<tr>
<th>Ecosystem Service - Subcategory</th>
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<tbody>
<tr>
<td><strong>Provisioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water for Non-Drinking Purposes</td>
<td>Water used for non-drinking purposes</td>
<td>Groundwater, Infrastructure, Climate Change</td>
<td>Flow</td>
<td>AF, % Δ over time, deviation from long-term avg</td>
</tr>
<tr>
<td></td>
<td>Water use by sector</td>
<td>Water Reuse, Tourism/Rec, Springs</td>
<td>Flow</td>
<td>AF, AF for all uses, % of total demand, % Δ over time, deviation from long-term avg</td>
</tr>
<tr>
<td></td>
<td>Water costs by sector</td>
<td></td>
<td>Flow</td>
<td>$/AF, % Δ over time</td>
</tr>
<tr>
<td></td>
<td>Non-drinking water source(s) dependence</td>
<td></td>
<td>Flow</td>
<td>AF or % for surface water &amp; groundwater, % self-supplied, onsite water harvesting, reclaimed use</td>
</tr>
<tr>
<td>Water for Env. Flow</td>
<td>Water for env. flow</td>
<td>Groundwater, Infrastructure, Climate Change</td>
<td>Flow</td>
<td>AF, % of total supply, riparian acres, perennial stream miles</td>
</tr>
<tr>
<td></td>
<td>Dependence on groundwater</td>
<td>Water Reuse, Infrastructure, Climate Change</td>
<td>Flow</td>
<td>% of flow from groundwater</td>
</tr>
<tr>
<td></td>
<td>Spring flow</td>
<td>Water Reuse, Tourism/Rec, Springs</td>
<td>Flow</td>
<td>average flow (cfs), average depth (ft), modeled spring flow response to demand/climate</td>
</tr>
<tr>
<td></td>
<td>Stream flow</td>
<td></td>
<td>Flow</td>
<td>peak or base flow (cfs), depth (ft), rainfall/runoff relationships, modeled stream response</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>Landcover</td>
<td>Groundwater, Wildfire, Infrastructure, Climate Change</td>
<td>Capacity</td>
<td>acres by type, % of type, % Δ over time</td>
</tr>
<tr>
<td></td>
<td>Wildfire frequency</td>
<td>Water Reuse, Infrastructure, Climate Change</td>
<td>Flow</td>
<td>frequency (#), extent (acres), % of total forest, % Δ over time, deviation from long-term avg</td>
</tr>
<tr>
<td></td>
<td>Forest resilience</td>
<td>Water Reuse, Tourism/Rec, Springs</td>
<td>Capacity/Driver</td>
<td>condition, acres restored, avoided costs, willingness to pay, Δ housing prices</td>
</tr>
<tr>
<td><strong>Flood Regulation</strong></td>
<td>Flood risk</td>
<td>Wildfire Protection, Climate Change</td>
<td>Flow</td>
<td>acres, % of total, population, # events, $ assistance, cost avoidance, frequency in burn areas</td>
</tr>
<tr>
<td></td>
<td>Floodplain storage capacity</td>
<td>Wildfire Protection, Climate Change</td>
<td>Capacity</td>
<td>days of river discharge floodplain can store</td>
</tr>
<tr>
<td><strong>Water Purification</strong></td>
<td>Surface water quality</td>
<td>Wildfire Protection, Climate Change</td>
<td>Capacity</td>
<td>phosphate concentration, oxygen, turbidity, salinity levels, # regulations, compliance, monitoring</td>
</tr>
<tr>
<td></td>
<td>Groundwater quality</td>
<td>Wildfire Protection, Climate Change</td>
<td>Capacity</td>
<td>NO3, pesticides, trace metals, arsenic, uranium, # of regulations, compliance, monitoring</td>
</tr>
<tr>
<td></td>
<td>Drinking water quality</td>
<td>Wildfire Protection, Climate Change</td>
<td>Flow</td>
<td>SDWA compliance, levels of analytes</td>
</tr>
<tr>
<td></td>
<td>Reclaimed water quality</td>
<td>Wildfire Protection, Climate Change</td>
<td>Flow</td>
<td>treatment level, end uses, levels of constituents, compliance with reg standards, monitoring</td>
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<tr>
<td></td>
<td>Nutrient concentration</td>
<td>Wildfire Protection, Climate Change</td>
<td>Flow</td>
<td>nutrient load, nutrient retention, sedimentation</td>
</tr>
<tr>
<td></td>
<td>Water treatment costs</td>
<td>Wildfire Protection, Climate Change</td>
<td>Benefit</td>
<td>$/AF for treatment costs, $/AF of avoided costs, % Δ over time</td>
</tr>
<tr>
<td><strong>Regulating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion Prevention</td>
<td>At-risk soil</td>
<td>Wildfire Protection, Climate Change</td>
<td>Capacity</td>
<td>acres, % of total acres, population (#), % Δ over time</td>
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<tr>
<td></td>
<td>Erosion regulation</td>
<td>Wildfire Protection, Climate Change</td>
<td>Capacity</td>
<td>instream sedimentation, erosion rate, stream channel movement, channel aggradation/degradation</td>
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<tr>
<td>Wildlife Populations &amp; Habitats</td>
<td>Spring resilience</td>
<td>Climate Change, Springs</td>
<td>Capacity</td>
<td>flow/dischage (cfs), water quality, ecological health score, monitoring capacity</td>
</tr>
<tr>
<td></td>
<td>Species abundance</td>
<td>Climate Change, Springs</td>
<td>Capacity</td>
<td>species protected (# and % of total), macroinvertebrate &amp; vertebrate species composition &amp; density</td>
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<tr>
<td></td>
<td>Habitat change</td>
<td>Climate Change, Springs</td>
<td>Flow</td>
<td>geomorphic change, percent native/non-native species cover, vegetation % over time</td>
</tr>
<tr>
<td></td>
<td>Stream resilience</td>
<td></td>
<td>Capacity</td>
<td>flow (annual/seasonal, peak/base), water quality, temperature</td>
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<tr>
<td></td>
<td>Species abundance</td>
<td></td>
<td>Capacity</td>
<td>species (#), population (#), species protected (# and % of total), biodiversity index, Δ over time</td>
</tr>
<tr>
<td></td>
<td>Habitat change</td>
<td></td>
<td>Flow</td>
<td>acres by habitat type, % Δ over time, acres restored, perennial stream miles</td>
</tr>
<tr>
<td></td>
<td>Non-native species abundance</td>
<td></td>
<td>Capacity</td>
<td>species (#), population estimates by species (#), % Δ over time</td>
</tr>
<tr>
<td></td>
<td>Endangered species</td>
<td></td>
<td>Capacity</td>
<td>number (total or by species/habitat type), population of indicator species (#)</td>
</tr>
</tbody>
</table>
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<tbody>
<tr>
<td>Recreational/Tourism</td>
<td>Water-based rec/tourism visitors</td>
<td>Benefit, % of total visitors, % change over time, visitors by water-related activity (%)</td>
<td>Benefit</td>
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<tr>
<td></td>
<td>Rec/tourism visitors</td>
<td>Benefit, % change over time, visitors by water-related activity (%)</td>
<td></td>
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<tr>
<td></td>
<td>Water-based rec by residents</td>
<td>Benefit, % of population, % change over time, by water-related activity (%)</td>
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<tr>
<td></td>
<td>Water-based recreation sites</td>
<td>Flow, % change in visitors (%)</td>
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<tr>
<td></td>
<td>Resilience of flows at key recreation sites</td>
<td>Flow, # days</td>
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<td></td>
<td>Costs/benefits of water-based rec/tourism</td>
<td>Benefit, $, % change over time (real dollars)</td>
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<td>Direct spending by non-resident rec/tourism</td>
<td>Benefit, $, % change over time (real dollars)</td>
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<td></td>
<td>Jobs created by non-resident rec/tourism</td>
<td>Benefit, % of total jobs, % change over time</td>
<td></td>
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<tr>
<td></td>
<td>Earnings from non-resident rec/tourism</td>
<td>Benefit, $, % change in total earnings (%)</td>
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<tr>
<td></td>
<td>Tax revenue from non-resident rec/tourism</td>
<td>Benefit, $, % change in total revenue (local), $ per capita</td>
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<tr>
<td></td>
<td>Total economic impact rec/tourism</td>
<td>Benefit, $, % change in total revenue, $ per capita</td>
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<td></td>
<td>Home value</td>
<td>Benefit, hedonic pricing analysis, median home value ($)</td>
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<tr>
<td></td>
<td>Water use by rec/tourism-related industries</td>
<td>Flow, AF, gallons per visitor, % change over time</td>
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<tr>
<td>Cultural</td>
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<tr>
<td>Other</td>
<td>Cultural sites with water component</td>
<td>Flow, # perceived quality of sites, water level changes at sites, level of protection</td>
<td>Flow</td>
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<td>Cultural site use</td>
<td>Benefit, # of users by type (e.g., tribes, recreators, tourists), % change over time</td>
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<tr>
<td></td>
<td>Key surface water features</td>
<td>Flow, # perceived quality of sites, % change from long-term average, water level changes at sites</td>
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<tr>
<td></td>
<td>Species of importance</td>
<td>Flow, % of populations (%)</td>
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</tr>
</tbody>
</table>