An Assessment of Water Sustainability Indicators for the Colorado River Basin

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By

Ray Quay, Josephine Godwyll, and Dave D. White

Decision Center for Desert City

Julie Ann Wrigley Global Institute of Sustainability

Arizona State University

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Introduction

Water is essential to human settlements because water is needed for many of the basic functions of human settlement. Basic human needs include direct consumption, hygiene, and cooking. Water is also part of the basic systems that support human settlement including food production, transportation, and recreation as well more complex needs within fire suppression, manufacturing, and power production. Lastly, human settlements are dependent on their supporting environmental systems which also require water. Thus, an essential concept of water sustainability over the long-term water supply cannot be lower than water demand needed to sustain human settlement and environmental needs. Over time, systems and external factors that influence them change, and institutions must adapt as conditions of supply and demand change to keep supplies at least equal to or more than demand.

The water rights allocated for the Colorado River Basin exceed that which can be allocated for a normal water flow year and are significantly over allocated for long-term drought and climate change. In order to maintain sustainable water systems in the basin, practices and policies will have to be initiated to manage supplies and demands in order to adapt to changing conditions over time. Such policies are based on the interaction between complex urban and environmental systems such as the economy, personal attitudes, neighborhood social dynamics, water and sewer infrastructure, natural riparian habitats, natural and altered watershed hydraulics, natural climate and weather systems, and government regulations. These systems are not static, but each are complex adaptive systems that change over time and our ability to understand each of these systems and their relationships is limited. Thus, estimating the current state of these interactions is difficult and predicting their future state is close to impossible. Yet, every time a new public policy is enacted to achieve some goal or solve some problem, it is an attempt to predict the impact this policy will have on the future state of these systems. The reality is that when policies are enacted and implemented there is no guarantee the result will be to increase water sustainability. Thus, evaluation is a critical aspect of planning for water sustainability. When we enact policy, we must also plan to assess the impact this policy had on water sustainability. This will require us to measure the current or estimate the future state of water sustainability.

When assessing the level and effectiveness of polices to enhance water sustainability, the outcomes of change we are ultimately interested in are the metrics of the policy implementation. Even though our goal is to enhance the state of water sustainability, in these cases our focus is to understand to what degree the changes in water sustainability can be attributed to the policy. Thus, such assessment will have three components.

How we assess water sustainability:

1) What was the state of water sustainability before the policy was implemented?

2) What is the state of water sustainability after the policy was implemented?

3) To what degree did the new policy contribute to the change (positive or negative) between the initial and new state of water sustainability?

To accomplish this, metrics that measure water sustainability will be needed. These metrics need to reflect not only the overall sustainability but also measures components of sustainability that are either related to or affected by water management policies. This is not as straight forward as it may seem. Water sustainability is not a static state for which one can measure the balance between supply and demand and declare that balance has been or has not been achieved. Human water needs are going to be defined in terms of quality of life and will be different for different people, different regions, at different points in time. Water supplies and demand are not static, changing over time and for different places. Water sustainability will be dynamic over time in terms of its definition and state. Assessing water sustainability requires a set of metrics that reflect multiple viewpoints and multiple aspects of sustainability that relate to a wide range of possible water management policies. To develop these metrics a definition of water sustainability is needed.

Defining Water Sustainability

Over the last 25 years, the concept of water sustainability has evolved from a simple aspect of supply being balanced with demand, to more complex and broader concepts. Hufschmidt and Tejwani (1993) in a UNESCO report defined water sustainability as, 'a set of activities that ensures that the value of the services provided by a given water resource system will satisfy present objectives of society without compromising the ability of the system to satisfy the objectives of future generations.' This is modeled around the Brundtland Commission report language (World Commission on Environment and Development 1987). This has been criticized as being too anthropogenic (Jones 2011) and later definitions included natural or environmental needs as well as human needs. The California Water Plan (2013) recently defined it as, “Water sustainability is the dynamic state of water use and supply that meets today’s needs without compromising the long-term capacity of the natural and human aspects of the water system to meet the needs of future generations.” (Department of Water Resources 2013)

Though these definitions reference natural or environmental systems, they are still primarily anthropogenic, focused on the balance between human water uses and supplies, and environmental and natural concerns defined as protecting natural resources primarily to meet human perceived needs such as recreation or water quality. They also do not cover the broader context of resource management suggested by Dixon and Fallon (1989) which would include management of storm waters, issues of social justice and characterizing it more as a process of managing systems for sustainability over a long, time frame. To broaden this scope of a water sustainability definition, the following is suggested:

> *Water sustainability is the long-term dynamic state of balancing water resources with human (economic, social, and health) and environmental needs without compromising the long-term capacity of the natural and human aspects of the water systems to meet the needs of future generations.*

This definition includes the common water sustainability concept of a balance between supply and demand. But this definition also covers other aspects of water sustainability related to storm water where the issue is managing water resources and human social systems to limit hazards to human settlement while not limiting the capacity of natural water systems. This definition includes a wide variety of the elements composing water resources and human needs. It includes how water is related to the economy, how it is important to social needs and systems, how it is important to human health. It also includes environmental needs and all the components of water resources which include the sources of water supply as well as the systems that sustain these supplies. Thus, any process that attempts to assess the state of water sustainability will have to encompass all of these elements.

Defining water sustainability Indicators

Our desire to assess the state of water sustainability is rooted in our desire to maintain it at a desirable level. Indicators can help us to understand not only a current assessment of water sustainability, but also how is it changing in relationship to what is desirable. A good indicator not only is one that helps with this assessment, but also provides insight into what is causing it to change, i.e. a problem, and how to fix the problem. It is not practical to expect any one indicator to be a sole assessor of water sustainability thus, a suite of indicators will be required. This suite of indicators will be more useful if they not only measure some aspect of water sustainability, but also if they are structured so it is easy to understand how they are interrelated to each other, and how they individually and collectively are related to our desired state of sustainability. Given the dynamics of our water systems and the wide breadth of uses for water, it is not likely that there can be just one viewpoint of water sustainability and its desired state. Thus, a good suite of water sustainability indicators must also be able to represent this range of viewpoints. Water sustainability indicators will be used by a wide a wide variety of people to make tactical and strategic decisions about a wide range of water issues. Effective indicators will need to:

- be credible to a wide range of public and private actors by telling a neutral unbiased but compelling story,
- be salient to the issues being considered by public and private agencies,
- be based on data sources and methods that are rooted in traditional water resources and community policy in order to be legitimate, and
- be accessible and easily understood by all actors, even those that are not experts.

Purpose

The purpose of this report is twofold:

1) Establish an annotated set of current academic and professional indicators that can be used to assess the water sustainability of the Colorado River Basin.
2) Identify the needs for professional development and academic research to further define and enhance an effective water sustainability indicator system for the Colorado River Basin.

Methodology

A set of indicators was compiled based on a literature review of indicator systems. A water sustainability framework was created based on a literature view of other frameworks. Each indicator was then assessed against this framework. The data sources used for each of the indicators were critically reviewed.

Indicator Identification

An initial set of indicators was compiled based on a literature review to identify existing relevant indicator systems. Table 1 lists the 22 systems identified. An initial list of water sustainability indicators were extracted from these indicator systems. These indicators were then characterized based on their attributes and a smaller set of indicators were identified based on combining similar indicators and choosing indicators most appropriate for the Colorado River Basin. Table 3 provides a basic list of the 208 final indicators and the Appendix includes a more descriptive list. The indicators were grouped into 10 topics, as listed in Table 2.

Table 1: Water Sustainability Indicator Systems Reviewed

	Indicator System	Brief Description	Agency
1.	UNESCO Water Quality Indicators	Indicators on freshwater quality at a global scale.	UNESCO
2.	World Water Assessment Program	World Water Development Report (WWDR4), *Managing Water under Uncertainty and Risk*.	UNESCO
3.	Colorado's Rivers Report Card	Indicators assessing the condition of eight rivers in Colorado.	Conservation Colorado
4.	Canadian Water Sustainability Index	Indicators for evaluating the well-being of Canadian communities with respect to fresh water.	Government of Canada Policy Research Initiative
5.	City of Phoenix Water Quality Indicators	Indicators that highlight array of factors that will influence water availability and water demand over the next 50 years.	City of Phoenix Water Services Department
6.	Colorado River Watch Network Water Quality Monitoring	Indicators for water quality monitoring in the Colorado River Basin.	Colorado River Watch Network
7.	Rural Sustainability Indicators: Outlook for Central America	Conceptual framework to develop and use water indicators.	CIAT/World Bank/UNEP Project
8.	Water Sustainability Resilience	Indicators that highlight resilience in water sustainability efforts for urban water sector.	Energy and Resources Group, University of California
9.	Chandler Water Resilience Score Cards	Indicators to measure extent of Chandler's resilience in water related issues.	ASU Kyl Center for Water Policy at Morrison Institute
10.	Indicators for improved water resources management	Indicators to measure water resource management.	UN Environment …

Indicator System	Brief Description	Agency
11. Indicator system for improved water quality	Indicator for measuring surface water quality in river basins.	Oliveira, R. E. S., Lima, M. M. C. L., & Vieira, J. M. (2007). An indicator system for surface water quality in river basins.
12. Minnesota Water Sustainability Indicators	Indicators to measure water sustainability in Minnesota.	Water Resources Center University of Minnesota
13. National Academies Critical Issues Indicators	Discussed indicators that measure water sustainability.	National Academy of Engineering
14. OECD environmental indicators	Reviewed indicators pertaining to water related environmental issues.	Organisation for Economic Co-operation and Development
15. RAND Adaptation Indicators	Indicators on adaptive use of the Colorado River in changing times.	RAND: Environmental, Energy, and Economic Development Program
16. California Water Sustainability Indicators	Indicators to measure water sustainability approach and processes in California.	UC Davis, DWR, USEPA
17. Water UK Sustainability Indicators	Indicators measuring water sustainability in the UK.	Water UK
18. Arizona Water Meter	Indicators comparing water conservation programs in 15 Arizona communities.	Water Resource Advocates
19. Risk and Vulnerability Indicators	Indicators highlighting water resource risk and vulnerability tendencies.	World Resource Institutes
20. Water Efficiency and Conservation Indicators	Indicators on laws and policies that pertain to water efficiency and conservation.	Alliance for Water Efficiency and Environmental Law Institute

Indicator System	Brief Description	Agency
21. Colorado River Basin; Demand and Supply Indicators	Indicators that measure demand and supply concerns on the Colorado River Basin.	U.S Department of the Interior December 2012 Bureau of Reclamation
22. Sustainable Water Management in the West	Colorado River Basin Water management indicators.	U.S Department of the Interior December 2012 Bureau of Reclamation

Table 2: Water Sustainability Indicator Topic Categories

ID	Category	Description
1	Water Supply	Related to various aspects of water supplied to meet human needs.
2	Water Demand	Related to the human use of water.
3	Economic and Financial	Related to how water supports local and regional economies.
4	Environmental	Related to the water needs of natural systems.
5	Disaster Management	Related to management of stormwater and droughts.
6	Climate Change	Related to the impact that climate change may have on water supply and demand.
7	Social Well-Being	Related to how water supports social and community systems.
8	Infrastructure/Water MGMT	Related to the infrastructure management systems needed to collect, store, and deliver water.
9	Energy	Related to the role water plays in energy production and the role energy plays in water treatment and delivery.
10	Legal - Governance	Related to the legal aspects of water use and management.

Table 3: List of Indicators Reviewed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
1	Total Withdrawal Upper Basin	Total amount of water removed from freshwater sources for use.	Water Demand	Measured/ Estimated	Region
2	Total Blue Water	Measured/estimated for each catchment. The accumulated runoff upstream of the catchment plus the runoff in the catchment.	Environmental	Measured/ Estimated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
3	Available Blue Water	Total amount of water available to a catchment before any uses are satisfied. Calculated as all water flowing into the catchment from upstream catchments plus the runoff in the catchment.	Water Supply	Measured/ Estimated	Watershed
4	Return Flow Ratio	Measures the percent of available water previously used and discharged upstream as wastewater.	Infrastructure/ Water MGMT	Measured/ Estimated	Region
5	Seasonal Variability	Measures variation in water supply between months of the year.	Water Supply	Calculated	Region
6	Drought Severity	Measures the average length of drought times the and the dryness of the droughts from 1901-2008.	Disaster MGMT	Calculated	Region
7	Baseline Water Stress	Measures total annual water withdrawals expressed as a percentage of the total annual available blue water.	Water Supply	Calculated	Region
8	Threatened Amphibians	Measures the percentage of freshwater amphibian species classified by IUCN as threatened.	Environmental	Measured/ Estimated	Region
9	Water Quality-Total Dissolved Solids	Measures the portion of solids in water that can pass through a filter of a specific pore size.	Environmental	Measured/ Estimated	Region
11	Water Quality-Electrical Conductivity	Measures how easily electricity passes through water.	Environmental	Measured/ Estimated	Region
12	Flood Occurrence	Number of floods recorded from 1985-2011.	Disaster MGMT	Reported	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
13	Media Coverage	Measures the percentage of media articles in an area on water-related issues.	Social Well-Being	Reported	Region
14	Upstream Storage	Measures the water storage capacity available upstream of a location relative to the total water supply at that location.	Infrastructure/ Water MGMT	Measured/ Estimated	Watershed
15	Index of non-sustainable water use	Comparison of total and agricultural water demands to renewable water supply indicating areas where non-sustainable practices may be occurring.	Infrastructure/ Water MGMT	Calculated	Watershed
16	Rural and urban population	Spatial distribution of total global population and the spatial extent and density of human settlements with 1,000 persons or more.	Economic	Reported	Global
17	Relative Water Stress Index	Domestic, industrial, and agricultural water demand per available water supply.	Water Demand	Calculated	National
18	Sources of contemporary nitrogen loading	Nitrogen loading onto the land mass and aquatic systems as a source for delivery to the coastal zone; a measure of potential water pollution.	Environmental	Measured/ Estimated	National
19	*Domestic and industrial water demand	Domestic and industrial water demand.	Water Demand	Measured/ Estimated	National
20	Impact of sediment trapping by large dams and reservoirs	Measures the residence time of water held in large reservoirs; sediment trapping efficiency of large reservoirs.	Infrastructure/ Water MGMT	Measured/ Estimated	National
21	Interannual Variability	Measures the variation in water supply between years.	Water Supply	Calculated	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
22	Coefficient of variation for climate moisture index	The CV index for the CMI is a statistical measure of variability in the ratio of plant water demand to precipitation. Useful for identifying regions with highly variable climates as potentially vulnerable to periodic water stress and/or scarcity.	Environmental	Calculated	Region
23	Water Reuse Index (WRI)	Consecutive water withdrawals for domestic, industrial, and agricultural water use along a river network relative to available water supplies as a measure of upstream competition and potential ecosystem and human health impacts.	Water Supply	Calculated	Region
24	Access to information, participation, and justice	Assessment of conditions with regard to access to information, participation, and justice in water decisions and on-going water reform process to give an indication of the inclusiveness of the reform process in water governance.	Legal	Surveyed	National
25	Assessing progress towards achieving the Integrated Water Resources Management target	Moving to a solution if IWRM requires a series of preliminary steps that can be monitored to show the progress toward meeting the target.	Infrastructure/ Water MGMT	Surveyed	Global

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
26	Total actual renewable water resources per capita; inflow from other countries (dependency ratio); proportion of total actual renewable freshwater resources withdrawn.	The theoretical maximum annual volume of water resources available in a country.	Water Supply	Measured/ Estimated	National
27	Groundwater development stress	Show to what extent current groundwater abstraction is or will be modifying the original groundwater regimes.	Water Supply	Calculated	Region
28	Dissolved Nitrogen	The sum of concentrations of dissolved inorganic nitrogen specifically nitrate and nitrite in water.	Environmental	Measured/ Estimated	Region
29	Trends in catchment projection	Percentage of land area set aside for protection over time.	Legal	Calculated	Region
30	Freshwater Species Population Trends Index	The Freshwater Living Plant Index Tracks changes in freshwater species found in temperate and tropical freshwater ecosystems since the baseline year of 1970.	Environmental	Calculated	Region
31	Agricultural GDP as a share of total GDP	The share of the country's GDP derived from agriculture.	Economic	Calculated	National
32	Irrigated land as a percentage of cultivated land	Area under irrigation as a proportion of total cultivated land.	Water Demand	Calculated	National
33	Proportion of renewable water resources used for irrigated agriculture	Agriculture water withdrawals as share of total water withdrawals.	Water Demand	Calculated	National

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
34	Land irrigation relying on groundwater	Groundwater use as share of total irrigation.	Infrastructure/ Water MGMT	Calculated	Global
35	Trends in industrial water use	Trends in industrial water withdrawals and consumption over the past 50 years.	Water Demand	Measured/ Estimated	National
36	Organic Pollution Emissions	Proportion of organic water pollution by industrial sector.	Environmental	Measured/ Estimated	National
37	Trends in ISO 14001 Certification	Number of companies that revived ISO 14001 certification; companies with this certification improve their water use efficiency and water productivity reduce pollution and pressure on the water resources and the environment.	Legal	Reported	Global
38	Risk and Policy Assessment	Assessment of the efficiency of public policies for flood mitigation in terms of actual impact on physical social and economic features of flood disasters.	Disaster MGMT	Surveyed	Global
39	Climate Vulnerability Index	Assesses human vulnerability in the context of global threats to water resources.	Disaster MGMT	Calculated	National
40	Water sector share in total public spending	Percentage of the national budget spent in water sector for expanding, rehabilitating, and maintaining water related infrastructures and improving water resources management and	Economic	Reported	National

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
		governance vis-a-vis other economic sectors.			
41	Comparison of actual to desired level of public investment in drinking water supply	Ratio of actual level to desired level of investment in drinking water supply.	Economic	Reported	National
42	Rate of operation and maintenance cost recovery for water supply and sanitation	Measures water fees actually collected as a percent cost of operation and maintenance in water supply and sanitation.	Economic	Reported	City
43	Water and sanitation charges as percentage of various household income groups	Shows how much water and sanitation charges constitute of various household income groups.	Economic	Reported	National
44	Population exposed to water stress	Population found in Relative Water Stress index set threshold.	Social Well-Being	Reported	National
45	Aquifer Declines	Number and capacity of basins with years-long overdraft.	Water Supply	Measured/ Estimated	Region
46	Baseline Water Stress	Total annual water withdraws regardless of purpose (industrial, agricultural, residential) as a total percent of the annual flow.	Water Demand	Calculated	Region
47	Benefits from Water Management	Equitable distribution of economic and health benefits from water management.	Social Well-Being	Surveyed; Reported	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
48	Completion of stewardship actions	The completion of restoration recommendations and key actions during implementation phase of the process.	Social Well-Being	Surveyed; Reported	State
49	Drought Resilience	Maximum severity of drought during which core water demands can still be met.	Disaster MGMT	Modelled	State
50	Ecological Footprint	Measure of the amount of biologically productive land and sea area required to meet the consumption and waste production patterns of a population or process.	Environmental	Calculated	State
51	Energy Requirements for Water Delivery	Energy required per unit of clean drinking water delivered to consumer.	Energy	Measured/ Estimated	State
52	Equitable Decision-Making Process	For water management diversity of participating organizations. Evaluating who is part of stakeholder and decision-making processes that affect the distribution movement and fate of water.	Social Well-Being	Surveyed	State
53	Flood Resilience	Maximum flood that can be experienced without exceeding a specified amount of damages.	Disaster MGMT	Calculated	State
54	Greenhouse Gas Emissions	GHG emissions from land/water management, industrial/commercial activities energy production or transportation.	Climate	Calculated	State
55	Groundwater Stress	Ratio of groundwater withdrawal relative to its	Water Supply	Calculated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
		recharge rate over a given aquifer.			
56	Historical Drought Severity	Measures the average length of drought times and the dryness of the droughts from 1901-2008.	Disaster MGMT	Measured/ Estimated	State
57	Historical Flooding Occurrence	Number of floods recorded from 1985-2011.	Disaster MGMT	Measured/ Estimated	State
59	Participation in local stewardship	Rates of local stakeholders to participate in local stewardship.	Social Well-Being	Surveyed	State
60	Potentially unhealthy water supply	Amount of people whose drinking water supply is potentially unhealthy.	Social Well-Being	Reported	State
61	Storm Resilience	Maximum storm intensity that can occur without causing more than some amount in damages.	Disaster MGMT	Modelled	State
62	Sustainable Water Usage	Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater	Water Supply	Measured/ Estimated	State
63	Water Demand	Total agricultural, residential and commercial water demand.	Water Demand	Measured/ Estimated	State
64	Water Footprint	Sum of water used directly or indirectly to produce goods and services consumed by humanity.	Economic	Calculated	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
65	Water Risk (WRI)	Risk scores were calculated and put in risk categories using scores for identified categories namely: 1. Baseline water stress 2. Interannual variability 3. Seasonal variability 4. Flood occurrence 5. Drought severity 6. Upstream storage 7. Groundwater stress 8. Return flow ratio 9. Upstream protected land 10. Threatened amphibians	Infrastructure/ Water MGMT	Calculated	State
66	Water Scarcity Index	Water scarcity is a function of water availability and water use. Represents the over-use of water in a region.	Water Demand	Calculated	Region
67	Water Travel Distance	Distance traveled for units of drinking and irrigation water.	Water Supply	Measured/ Estimated	Region
68	Affordable Water Prices	Percent of drinking water suppliers which have instituted an affordable.	Social Well-Being	Reported	State
69	Available Water	Total water available from natural and managed flows. Calculated as all water flowing into the catchment from upstream catchment plus any imports of water the catchment, minus upstream consumptive use plus runoff in the catchment.	Water Supply	Measured/ Estimated	Region
70	Earthquake Resilience	The maximum earthquake intensity that can occur without causing more than some amount (e.g. $20 million) in damages due to	Disaster MGMT	Modelled	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
		water infrastructure disruptions including levees.			
71	Forest Land Conversion	Total acreage of forest land converted over time.	Environmental	Measured/ Estimated	State
72	Managed Geomorphic Flows	Magnitude and timing of managed system flows suitable for native riparian habitats and geomorphic processes.	Environmental	Measured/ Estimated	Region
73	Non-potable water needs for agriculture	Proportion of agricultural non-potable water needs met with non-potable water.	Infrastructure/ Water MGMT	Measured/ Estimated	State
74	Percent recycled water	Use of recycled water as a percent total of water used.	Infrastructure/ Water MGMT	Measured/ Estimated	State
75	Protected aquifer recharge areas	Number of acres protected or enhanced in aquifer recharge areas.	Environmental	Measured/ Estimated	Region
76	Public support and awareness of water system protection	Amount of awareness the public holds regarding water system protection.	Social Well-Being	Surveyed	State
77	Residential water use and conservation	Average water use per household or per capita.	Water Demand	Measured/ Estimated	State
79	Percent water re-use	Volume of water re-used as a fraction of the total water used.	Infrastructure/ Water MGMT	Measured/ Estimated	State
80	Water shortage	Percent likelihood per year over the next 20 years of water shortage.	Water Supply	Modeled	State
81	Water storage and use	Years of average water use at current use levels represented by the current stored volume of water.	Water Supply	Measured/ Estimated	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
82	Index of Biotic Integrity	Index of biotic community composition and structure which respond to disturbance.	Environmental	Calculated	Region
83	Land subsidence	Both the absolute amount of lands that have subsided and the rate of change (positive or negative) in subsidence are important measures.	Environmental	Measured/ Estimated	State
84	Mercury in fish tissue	Measure of mercury in fish tissue. For mercury to increase in concentration in fish tissue it must be available in the environment (water and/or sediment) and methylated usually by bacteria in hypoxic/anoxic conditions.	Environmental	Measured/ Estimated	Watershed
85	Native fish habitat and flow	Sufficient and adequate direction of flows for maintaining historically present native fish.	Environmental	Measured/ Estimated	Watershed
86	Native fish community	Ratio of observed to expected native fish species in a waterbody or watershed.	Environmental	Measured/ Estimated	Watershed
87	Stream Condition Index	Biological index composed of indicators and metrics that represents the condition of benthic invertebrate communities living in streams and rivers.	Environmental	Calculated	Region
88	Trophic State Index	How eutrophic conditions are in a water-body. Excess algal growth can indicate eutrophic conditions and is the basis of the index.	Environmental	Calculated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
89	Water transfer benefit to local economies	Equitability of benefit realization for local economies in water-source and water-receiving regions due to water transfer.	Economic	Reported	City
90	Water transfer costs and benefits	Fiscal costs and benefit for local economy in water-source and water-receiving region due to water transfer.	Economic	Reported	Region
91	Abundance of key non-native species	Relative abundance trend of non-key native species.	Environmental	Measured/ Estimated	Region
92	Abundance trend of key indicator species at different life stages (i.e. Delta smelt Longfin smelt juvenile striped bass Chinook salmon all salmonid populations).	The well-being of regulated and culturally-important fish species is important to measure in order to understand ecosystem condition.	Environmental	Measured/ Estimated	Region
93	Amount of industrial pollutants released	Tons of industrial pollutants released and disposed into a watershed/region annually.	Environmental	Measured/ Estimated	Watershed
94	Fertilizer application rate	Rate of fertilizer applied per unit area.	Economic	Measured/ Estimated	Region
95	Groundwater nitrate	Concentration of nitrate in groundwater.	Environmental	Calculated	Region
96	Groundwater water quality index	Combination of general indicators to measure groundwater quality.	Environmental	Calculated	Region
97	Impervious Surface: Water Quality Index	Proportions of a watershed covered by impervious materials that prevent water from leaching directly into the soil.	Environmental	Calculated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
98	Periphyton cover and biomass	The amount and extent of cover of algae attached to the benthos and other underwater surfaces.	Environmental	Calculated	Watershed
99	Pollutant and bacteria index	Composed of indicators of chemical and bacterial pollution.	Environmental	Calculated	Watershed
100	Upstream protected lands	Measures the percentage of total water supply that originates from protected ecosystems.	Environmental	Measured/ Estimated	Region
101	Water treatment cost	Cost of water treatment.	Economic	Measured/ Estimated	State
102	Renewable Water Resources	Measures of the amount of water provided over time by precipitation in a region and surface groundwater flowing into the region.	Water Supply	Measured/ Estimated	Region
103	Water Delivery	Measures percent years of system vulnerability at the upper (Lee Ferry Deficit) and lower basin (Lake Mead Pool Elevation - below 1,000 ft msl) to determine what percent of years the basin will be vulnerable.	Water Supply	Modeled	Region
104	Electrical Power	Measures percent years of system vulnerability where the upper and lower basins will generate less than 4,450 GW/yr. for 3 consecutive years and Lake Mead pool elevation less that 1,050 feet msl.	Energy	Modeled	Region
105	Flood Control	Measures the critical river stage below Hoover Dam (amount of years that flow may be greater than 28,000 cubic feet per second).	Disaster MGMT	Modelled	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
107	Recreation	Measures 3 different areas: 1. Days less than current conditions with variable hydrology for Colorado River Boating; 2. Lake Powell Shoreline facilities (pool elevation less than 3,560 feet msl); 3. Lake Mead shoreline facilities (pool elevation less than	Economic	Modeled	Region
108	Ecological	Measures/projects Colorado percentage of years where Colorado river flow is less than targeted flow conditions and percentage of years where Hoover to Davis Dam flow experiences annual flow change greater than 845,000 AF.	Water Supply	Modeled	Region
109	Water Use	10-year running average from 1923-2006 and projections to 2063.	Water Demand	Modeled	Region
110	Water Supply	10-year running average from 1923-2006 and projections to 2063.	Water Supply	Modeled	Region
112	Specific Conductance	Measures the ability of water to pass an electrical current.	Environmental	Measured/ Estimated	Watershed
113	pH	Measures alkalinity or acidity concentration of a solution on a 0-14 scale.	Environmental	Measured/ Estimated	Watershed
114	Transparency	Measures how far light can penetrate a body of water.	Environmental	Measured/ Estimated	Watershed
115	Nitrates	Nitrate nitrogen in excess amounts can cause an increase in algae growth	Environmental	Measured/ Estimated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
		which eventually leads to decreases in dissolved oxygen.			
116	Stream Flow	Flow rate at which water moves through a river, creek, stream, etc.	Environmental	Measured/ Estimated	Watershed
117	E. Coli	Measured/estimated in number of colony-forming units per 100 mL.	Environmental	Measured/ Estimated	Watershed
118	Organic Solvents	Ratio of industrial solvent trichloroethylene in water	Environmental	Measured/ Estimated	Watershed
119	Hydrocarbon Contamination	Amount of hydrocarbons from leaking service station fuel tanks in water sites.	Environmental	Measured/ Estimated	Watershed
120	Pesticides	Pesticide contamination of wells.	Environmental	Measured/ Estimated	Watershed
121	Heavy Metals	Concentrations of heavy metal in groundwater, especially chromium.	Environmental	Measured/ Estimated	Watershed
123	Arsenic	Less than 10 ppb in specific wells.	Environmental	Measured/ Estimated	Watershed
125	Total gallons per capita	Total amount of water used per capita per day including system losses.	Water Demand	Measured/ Estimated	City
126	Residential GPCD	Residential GPCD by metered deliveries.	Water Demand	Reported	City
127	Salt River Project urban irrigation deliveries in Phoenix	Deliveries of non-potable canal water for landscape irrigation purposes in Phoenix from 2000-present.	Water Supply	Measured/ Estimated	City
128	Seasonal water use by category	Amount of water used (mgd) by single-family, multi-family, and non-residential consumers.	Water Demand	Measured/ Estimated	City

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
129	Average Monthly water bill for southwest cities	Cost per month for water bill by southwest city.	Economic	Reported	Region
130	Water Demand and Average Annual Temperature	Water demand (AF) per year and average annual temperature.	Economic	Measured/ Estimated	City
131	Water Demand and Annual Precipitation	Water demand (AF) and annual precipitation (In).	Water Demand	Measured/ Estimated	City
132	Rate Structure	Are rates uniform (flat) seasonal or inclining block rates? Inclining block rates are most effective at communicating value of water. Conservation-oriented price structure makes curve slope upward.	Economic	Reported	City
133	Conservation Measures	Raise community awareness and motivate residents to use water more effectively. Use 29 measures from ADWR's MNPCCP program to provide order and consistency.	Social Well-Being	Surveyed; Reported	City
134	Conservation Ordinances	Can impact the entire utility's customer base. Use a list recognized by ADWR's MNPCCP.	Water Demand	Surveyed; Reported	City
135	Funding for Conservation	Amount per capita spent on water conservation efforts.	Economic	Reported	City
136	Water Loss	Water saved by improving supply-side efficiency. Does the utility have an active leak detection and repair program?	Water Supply	Reported	City
137	Effluent Use	Re-use of liquid waste or sewage rather than	Infrastructure/ Water MGMT	Measured/ Estimated	City

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
		discharged into a stream or river.			
138	Groundwater Withdrawal	Total groundwater withdrawal as a % of safe yield estimates.	Water Supply	Measured/ Estimated	Region
139	Environment related Effluent	Wastewater discharge as a % of total stream flow.	Infrastructure/ Water MGMT	Calculated	Region
140	Agricultural Efficiency	Gallons per dollar of agriculture production per day.	Economic	Measured/ Estimated	State
141	Urban/Rural Efficiency	Gallons of water used per capita every day in Arizona.	Water Demand	Measured/ Estimated	State
142	Power Efficiency	Gallons per megawatt of power produced per day.	Energy	Measured/ Estimated	State
143	Surface Water	Withdrawal by water treatment plants as a % of stream flows.	Water Supply	Measured/ Estimated	State
144	Economy	Local water used for goods production as % of total water use.	Water Supply	Measured/ Estimated	City
145	Current Supplies	The city's demand for water as a percent of all readily available supplies.	Water Demand	Measured/ Estimated	City
146	Future Supplies	What is the city's capacity to meet increased future demand?	Water Demand	Modeled	City
147	Infrastructure management	Is the water infrastructure vulnerable to significant amounts of system loss?	Infrastructure/ Water MGMT	Modeled	City
148	Contingency Planning	Is surface water prioritized over the use of groundwater supply? Are recovery programs aquifer storage or other measures being taken to ensure against drought?	Infrastructure/ Water MGMT	Surveyed	City

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
149	Water Consciousness	Are residents and the city aware of water consumption and scarcity issues with water? Is the city promoting water-saving projects or boosting awareness?	Social Well-Being	Surveyed	City
182	State agency in charge drinking water conservation	Presence and enforcement of regulation for water consumption showerheads.	Legal	Surveyed	City
183	Water consumption regulation for toilets	Presence and enforcement of regulation for urinals.	Legal	Surveyed	City
184	Showerheads water consumption regulation	Presence and enforcement of federal standard for residential and commercial family-sized clothes washers requires a water factor (WF) of 9.5 or less.	Legal	Surveyed	City
185	Water consumption regulation for pre-rinse spray valves	Presence and enforcement of water consumption regulation for pre-rinse spray valves.	Legal	Surveyed	City
186	Mandatory building or plumbing codes	Presence and enforcement of mandatory building or plumbing codes.	Legal	Surveyed	City
187	Water loss regulation or policy	Presence and enforcement of water loss regulation or policy.	Legal	Surveyed	City
188	Conservation activities as part of water permitting process	Presence and enforcement of conservation activities as part of water permitting process.	Legal	Surveyed	City
189	Drought emergency plans	Presence and enforcement of drought emergency plans.	Legal	Surveyed	State
190	Conservation planning required	Requirement of conservation planning	Legal	Surveyed	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
	separate from drought plan	required separate from drought plan.			
191	Authority to approve or reject conservation plans	Established process and authority to approve or reject conservation plans.	Legal	Surveyed	State
192	Water conservation plans requirements	Frequency of required water conservation plans.	Legal	Surveyed	State
193	Planning framework or methodology	Presence of framework or methodology in applying for water use.	Legal	Surveyed	City
194	Implementation of conservation measures required	Presence and enforcement of conservation measures.	Legal	Surveyed	City
195	State funding for urban water conservation programs	Presence of state funding for urban water conservation.	Economic	Surveyed	State
196	Technical assistance for urban water conservation programs	Presence of technical assistance.	Legal	Surveyed	State
197	Does the state require volumetric billing	Volumetric billing required.	Legal	Surveyed	State
198	Percent of publicly supplied connections that are metered	Presence of publicly supplied connections that are metered.	Infrastructure/ Water MGMT	Surveyed	City
199	ET microclimate information for urban landscapes	Presence and consideration of microclimate information.	Water Demand	Surveyed	City
200	Per Capita Water use	Single family homes daily water consumption.	Water Demand	Measured/ Estimated	City
201	Average Flow	Average flow rate of water compared to historic flows of the river	Environmental	Measured/ Estimated	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
202	Water Quality	Amount of pollution, dissolved oxygen, and other foreign contaminants that threaten the quality of water on plants, animals, and humans.	Environmental	Measured/ Estimated	Region
203	Water Diverted out of Basin	Amount of water taken from the river and moved through canals or other vessels for human use.	Water Demand	Measured/ Estimated	Region
204	Major Dams	Number of dams that have an impact on water flow in Colorado River and its tributaries in Colorado.	Infrastructure/ Water MGMT	Measured/ Estimated	Region
205	Other Factors	Social and economic benefit from rivers such as fishing, rafting, and boating.	Social Well-Being	Measured/ Estimated	Region
206	Legal Authorization	Questions pertaining to whether or not legal authorization is for environmental transfers and whether the authorization of environmental rights is in any way restricted.	Legal	Measured/ Estimated	State
207	Protection of Environmental Water Rights	Legal and practical protection for water left upstream through environmental transfers.	Legal	Measured/ Estimated	State
208	Scope of environmental Water Rights	Assessed whether or not environmental water rights are subject to limitations that do not apply to other water rights and whether the state has financial resources and personnel dedicated to protecting streamflow and facilitating environmental water trans	Legal	Measured/ Estimated	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
209	Process for applying environmental water transfers	Compares administrative and judicial processes needed to approve environmental water transfers among the various states and assess whether the level of review is well tailored to the nature of the transfer.	Legal	Measured/ Estimated	Region
216	Total coliform bacteria	Measures the total amount of fecal coliform enterococcus bacteria and E. Coli bacteria in an area.	Environmental	Measured/ Estimated	Watershed
217	Turbidity	Measures the cloudiness or transparency of a body of water.	Environmental	Measured/ Estimated	Watershed
218	Salinity	Saltiness or dissolved salt content in a body of water.	Environmental	Measured/ Estimated	Watershed
219	Hydrogen Sulfide Concentration	Amount of hydrogen sulfide present in a body of water.	Environmental	Measured/ Estimated	Watershed
220	Inorganic water chemistry	Measures the amount of inorganic water nutrients organic water and total coliform bacteria in water.	Environmental	Measured/ Estimated	Watershed
221	Fish tissue chemistry	Measures if fish and other aquatic resources are safe to eat based off fish tissue. chemistry and fecal coliform bacteria in water.	Environmental	Measured/ Estimated	Watershed
222	Biological responses	Are aquatic populations communities and habitats protected from water and sediment toxicity?	Environmental	Measured/ Estimated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
223	Pollutant exposure	Are aquatic populations protected from pollutant exposure? Measured/estimated through organic and inorganic sediment chemistry total organic carbon fish tissue chemistry, turbidity, and inorganic and organic water chemistry.	Environmental	Measured/ Estimated	Watershed
224	Habitat	Are aquatic populations protected from living in a dangerous habitat? Measured/estimated by dissolved oxygen sediment grain size analysis sediment organic carbon electrical conductivity salinity hydrogen sulfide and ammonia levels.	Environmental	Measured/ Estimated	Watershed
225	Amount of debris and trash	Measures the amount of pollutants that damage the aesthetic conditions of the water.	Environmental	Measured/ Estimated	Watershed
226	Groundwater-Level Declines	Long-term declines in ground water levels occur when withdrawal exceeds recharge of an aquifer.	Water Supply	Measured/ Estimated	Watershed
227	Land subsidence	Settling or sinking of surface due to changing subsurface compositions.	Environmental	Measured/ Estimated	Region
228	Groundwater-Storage Reductions	Long-term declines in groundwater levels cause long-term reductions in groundwater storage. Estimated by using direct measurements coupled with remote modeling tools over time.	Water Supply	Measured/ Estimated	Watershed

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
229	Interconnected Surface-Water Depletions	Measure of surface water levels in streams, rivers, lakes, etc. coupled with groundwater levels of the same period.	Environmental	Measured/ Estimated	Region
230	Water-Quality Degradation	Determining changes in groundwater quality over time involves systematic monitoring of the constituents of concern coupled with understanding of the dynamics of the groundwater-flow system.	Environmental	Measured/ Estimated	State
231	Renewable Water Resources	Measures of the amount of water provided over time by precipitation in a region and surface groundwater flowing into the region.	Water Supply	Measured/ Estimated	Region
232	Water in the Environment	Amount of water remaining in the environment after human use.	Environmental	Measured/ Estimated	Region
233	Water Use Sustainability	Measures the degree to which water use meets current needs, while protecting ecosystems and the interests of future generations.	Infrastructure/ Water MGMT	Measured/ Estimated	Region
234	Quality of Water for human uses	Measures the quality of water used for drinking, recreation industry, and agriculture.	Environmental	Measured/ Estimated	Region
235	Quality of water for the environment	Measures the quality of water supporting flora and fauna, and related ecosystem processes.	Environmental	Measured/ Estimated	Watershed
236	Water Quality Sustainability	Composite measures of the degree to which water quality satisfies human and ecosystem needs.	Environmental	Measured/ Estimated	State

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
237	Withdrawal and use of water	Measures the amount of water withdrawn from the environment and the end use.	Water Demand	Measured/ Estimated	State
238	Human uses of water in the environment	Measures the extent to which people use water resources for waste assimilation, transportation, and recreation.	Economic	Measured/ Estimated	Region
239	Water-dependent resource use	Measures the extent to which people use resources like fish and shellfish that depend on water resources	Economic	Measured/ Estimated	Region
240	Human Health	Measures the extent to which human health may be affected by the use of water and related resources.	Social Well-Being	Measured/ Estimated	Region
241	Indices of Biological Condition	Measures of the health of ecosystems.	Environmental	Measured/ Estimated	State
242	Amount and Quality of living resources	Measures the productivity of ecosystems.	Environmental	Measured/ Estimated	State
243	Capacity and reliability of infrastructure	Measures the ability of infrastructure to meet and provide human and ecosystem needs.	Infrastructure/ Water MGMT	Measured/ Estimated	State
244	Efficacy of institutions	Measures the prevalence of legal and institutional frameworks in managing water and related-resources sustainably.	Legal	Surveys	State
249	Colorado River Basin supply and use	10-years average water supply and 10-year water use on a line chart from 1923-2006.	Water Supply	Measured/ Estimated	Region

ID	Indicator	Definition	Indicator Category	How Indicator Developed	Indicator Scope
250	Reconstruction of Colorado River flows at Lees Ferry, AZ	Annual values and a five-year moving average represented on a line chart.	Water Supply	Measured/ Estimated	Region
251	Dam Density	Density of medium to large dams per 0.5 x 0.5 degree grid cell.	Infrastructure/ Water MGMT	Modeled	Global
252	Disinfection Byproducts (Surface Water)	Organic by-products in surface water.	Environmental	Measured	City
253	Pharmaceuticals and Endocrine	Pharmaceutically active compounds in drinking water.	Environmental	Measured	City

Indicator Assessment

Though this report reviewed an extensive list of indicators across a broad range of topics, not all indicators will be useful for all assessments of water sustainability. The context of how the indicators is intended to be used will be an important consideration as to which indicators are best for that use. Each indicator has specific areas of water sustainability that they address, has limitations associated with the data used, often addresses a specific geographic scale which will affect the functionality for a specific use. To assist with matching indicators to the right context, an assessment of the indicators was done against the sustainability principles each indictor is related to, the general data sources of the indicator, and the general functionality of the indicators in general for different issue topics.

Sustainability Assessment

The intent of an indicator is to assess the current or past state of a system or program. In this case, we are focused on the state of water sustainability of the Colorado River Basin and the institutions and programs managing water in the Basin. The indicators in this report are intended to measure different aspects of water sustainability. Water sustainability is not a single concept, but rather based on a variety of concepts each of which may provide a different viewpoint based on the context of its use. To assess which aspect of water sustainability each indicator will be useful to assess, a water sustainability framework was developed that helps identify various aspects of sustainability related to water management.

Description

Sustainable resource management emphasizes the efficient distribution of resources over a period of time, based on equitable considerations across a variety of inter and intra generational stakeholders, bearing in mind its economic implications and effect on ecological systems (Milne, 1996; Devuyst, 2000). Sustainability frameworks draw on three main areas; the environment, society and economics, and all these areas overlap with one another (Tavanti, 2010). In water resource management, an assessment framework provides a structure for identifying and categorizing the key areas of concern which need to be explored and measured (Bertule et al, 2017). Several sustainability indicator frameworks have evolved for assessing water resource governance at a global level and drought sensitive regions.

Sources

The Sustainability Assessment Framework was derived from several sources that have either defined sustainability framework or suggested concepts that would be important for such a framework. Gibson, (2006) conducted an extensive analysis; synthesizing literature and case studies to establish key principles for sustainability assessment. Quirk and Stuart (Quirk & Stuart, 1980) suggest the Colorado River Basin has the history of being the single most important over-allocated resource in the arid West and review some key concepts about the sustainability of the Basin. Wiek & Larson, (2012) and Schneider, Bonriposi, & Graefe (2015) developed key features of sustainability from the perspective of water governance systems based on a literature analysis of publications on water governance. Other sources of literature synthesized included Ostrom, (2009) and (Pahl-Wostl, Conca, Kramer, Maestu, & Schmidt, 2013). Based on a review of these sources, seven key principles and the critical features for water governance were developed and are outlined in the Table 4 below.

Table 4: Sustainability Principles and Features

Principle Number	Principles from Gibson, (2006)	Key Features	Description	Source from which Key Features are Derived
1.	Social Ecological System Integrity	Water quality	Maintain or enhance water resources quality, avoiding pollution.	(Wiek & Larson, 2012)
		Pollution prevention	Prevent social and ecological pollution related to waste water.	(Wiek & Larson, 2012)
		Surface water flows	Maintain surface water flows to support social and ecological systems.	(Wiek & Larson, 2012)
		Aquifer protection	Ensure aquifers are not taxed beyond instability.	(Wiek & Larson, 2012)
		Water quantity	Coordinate water use and impacts within stipulated physical units.	(Wiek & Larson,2012)
2.	Resource Efficiency, Maintenance, Management	Water use reduction/efficiency	Reduce water use/enhancing water use efficiency.	(Wiek & Larson,2012)
		Water use recycling	Effluent water reuse.	(Wiek & Larson,2012)

		Water loss elimination	Eliminate water loss.	(Wiek & Larson,2012)
		Institutional management	Institution based water resource management related activity/information.	(Wiek & Larson,2012)
3.	Livelihood sufficiency and opportunity	Basic needs	Meet basic needs related to water.	(Schneider, Bonriposi, & Graefe, 2015)
		Recreation and enjoyment	Meet water related needs associated to recreation and enjoyment.	(Schneider, Bonriposi, & Graefe, 2015)
		Agriculture	Meet irrigation needs.	(Schneider, Bonriposi, & Graefe, 2015)
		Hydropower	Meet needs associated to hydropower.	(Schneider, Bonriposi, & Graefe, 2015)
		Secondary economic activities	Meet economic needs related to secondary use of water.	(Schneider, Bonriposi, & Graefe, 2015)
4.	Social ecological civility and democratic governance	Procedural justice normative frameworks	Make decisions governed by the rule of law.	(Schneider, Bonriposi, & Graefe, 2015)
		Procedural justice – transparency	Disclose relevant information to all parties who affect and are affected by water governance.	(Schneider, Bonriposi, & Graefe, 2015)
		Participation in decision making	Involve all groups who affect and are affected by water governance.	(Ostrom, 2009); (Wiek & Larson,2012)
5.	Inter-generational and intra-generational equity	Distributive justice – risk, cost and benefits	Equitable distribution of risks, costs and benefits equitably distributed across all present and future stakeholders.	(Schneider, Bonriposi, & Graefe, 2015)
		Equitable representation	Equitable representation based on geography, demography, and interest.	(Pahl-Wostl et al., 2013) (Wiek & Larson,2012)

		Cross generational representation	Representation of future generations through their guardians.	(Wiek & Larson,2012)
		Contextual justice- Adequate comparable capacities	Ensure water user groups have comparable capabilities to access and benefit from water.	(Schneider, Bonriposi, & Graefe, 2015)
6.	Interconnectivity from local, regional, to global scale	Interconnectivity ordinances and institutional requirements	Presence of ordinances/institutional requirements to guide actions at different points that influence other water related points on local, national, and global scale.	(Wiek & Larson,2012)
		Multiple scale resource impacts	Reduce or eliminate negative impacts between scales.	(Wiek & Larson,2012)
		Multiple scale stakeholder impacts	Recognize and coordinate among local and state stakeholders.	(Wiek & Larson,2012)
7.	Precaution and adaptability	Anticipate water shortages	Anticipate future water shortages.	(Wiek & Larson,2012)
		Mitigate water shortages	Mitigate future water shortages.	(Wiek & Larson,2012)
		Adapt to water shortages	Adapt water shortages and water quality problems.	(Wiek & Larson,2012)
		Capital	Material and financial capital which allows for exploitation and diversion when needed.	(Schneider, Bonriposi, & Graefe, 2015)
		Collaboration capacity	Ability to respond to water problems through formal and informal justification.	(Schneider, Bonriposi, & Graefe, 2015)

		Institutions and entitlements	Property rights, concessions, formal, and informal rules of water governance to respond to water shortage crises.	(Schneider, Bonriposi, & Graefe, 2015)
		Flood related disaster management	Resilience in flood related disasters.	(Hegger, Driessen, & Dieperink, 2014)

Indicators by Sustainability Framework

A total of 209 indicators were reviewed, analyzed, and categorized based on the principle and key features they represented. Table 5 lists the indicators by sustainability principle and feature.

Table 5: Indicators and Sustainable Principles and Features

Principle	Feature	Indicator ID	Indicator
1. Social Ecological System Integrity			
	Water Quality		
		9	Water Quality-Total Dissolved Solids
		11	Water Quality-Electrical Conductivity
		18	Sources of Contemporary Nitrogen Loading
		28	Dissolved Nitrogen
		36	Organic Pollution Emissions
		54	Greenhouse Gas Emissions
		82	Index of Biotic Integrity
		84	Mercury in Fish Tissue
		96	Groundwater Water Quality Index
		98	Periphyton Cover and Biomass
		99	Pollutant and Bacteria Index

Principle	Feature	Indicator ID	Indicator
		112	Specific Conductance
		113	pH
		117	E. Coli
		119	Hydrocarbon Contamination
		120	Pesticides
		121	Heavy Metals
		123	Arsenic
	Stream flows for wildlife and riparian areas		
		5	Seasonal Variability
		6	Drought Severity
		8	Threatened Amphibians
		21	Interannual Variability
		30	Freshwater Species population Trends Index
		45	Aquifer Declines
		54	Greenhouse Gas Emissions
		69	Available Water
		71	Forest Land Conversion
		72	Managed Geomorphic Flows
		85	Native fish habitat and flow
		86	Native fish community
	Ensuring aquifers are not taxed beyond instability		
		No Indicators	
	Pollution prevention		
		36	Organic Pollution Emissions
		50	Ecological Footprint
		93	Amount of industrial pollutants released
		94	Fertilizer application rate
		95	Groundwater nitrate
		118	Organic Solvents
		119	Hydrocarbon Contamination
		120	Pesticides
		139	Environment related Effluent
	Water Quantity		
		1	Total Withdrawal Upper Basin

Principle	Feature	Indicator ID	Indicator
		2	Total Blue Water
		3	Available Blue Water
		4	Return Flow Ratio
		7	Baseline Water Stress
		45	Aquifer Declines
		46	Baseline Water Stress
		102	Renewable Water Resources
		138	Groundwater Withdrawal
	Coordinated Water Use		
		No Indicators	
2. Resource Efficiency and Maintenance			
	Reducing Water use/Enhancing Water use Efficiency		
		15	Index of non-sustainable water use
		16	Rural and urban population
		17	Relative Water Stress Index
		77	Residential water use and conservation
		125	Total gallons per capita
		126	Residential GPCD
		127	Salt River Project urban irrigation deliveries in Phoenix
		128	Seasonal water use by category
		129	Average Monthly water bill for southwest cities
		132	Rate Structure
		133	Conservation Measures
		134	Conservation Ordinances
		137	Effluent Use
		140	Agricultural Efficiency
		141	Urban/Rural Efficiency
		143	Surface Water
		148	Contingency Planning
	Recycling Water		
		74	Percent recycled water
		79	Percent water re-use
	Eliminating water loss		
		136	Water Loss

Principle	Feature	Indicator ID	Indicator
	Extraction and Recharge Balance		
		4	Return Flow Ratio
		15	Index of non-sustainable water use
		22	Coefficient of variation for climate moisture index
		23	Water Reuse Index (WRI)
		55	Ground water Stress
	Water Coordination (laws, institutions for water management)		
		No Indicators	
3. Livelihood sufficiency and opportunity			
	Regional Development-Basic Needs		
		5	Seasonal Variability
		6	Drought Severity
		9	Water Quality- Total Dissolved Solids
		11	Water Quality- Electrical conductivity
		17	Relative Water Stress Index
		19	*domestic and industrial water demand
		21	Interannual Variability
		41	Comparison of actual to desired level of public investment in drinking water supply
		46	Baseline Water Stress
		49	Drought Resilience
		51	Energy Requirements for Water Delivery
		63	Water Demand
		113	pH
		121	Heavy Metals
		123	Arsenic
		145	Current Supplies
	Regional Development-Recreation and Enjoyment		
		5	Seasonal Variability
		6	Drought Severity

Principle	Feature	Indicator ID	Indicator
		19	domestic and industrial water demand
		21	Interannual Variability
		46	Baseline Water Stress
		49	Drought Resilience
		63	Water Demand
		145	Current Supplies
	Regional Development-Agriculture		
		5	Seasonal Variability
		6	Drought Severity
		9	Water Quality- Total Dissolved Solids
		11	Water Quality- Electrical conductivity
		17	Relative Water Stress Index
		18	Sources of contemporary nitrogen loading
		21	Interannual Variability
		33	Proportion of renewable water resources used for irrigated agriculture
		35	Trends in industrial water use
		46	Baseline Water Stress
		49	Drought Resilience
		63	Water Demand
		113	pH
		123	Arsenic
		145	Current Supplies
	Regional Development-Hydropower		
		5	Seasonal Variability
		6	Drought Severity
		49	Drought Resilience
		63	Water Demand
		142	Power Efficiency
		145	Current Supplies
	Regional Development-Secondary Economic Activities		
		6	Drought Severity
		17	Relative Water Stress Index

Principle	Feature	Indicator ID	Indicator
		21	Interannual Variability
		46	Baseline Water Stress
		49	Drought Resilience
		63	Water Demand
		145	Current Supplies
4. Socio-ecological civility & democratic governance			
	Access to Information		
		13	Media Coverage
		24	Access to information participation and justice
	Participation in Decision Making		
		76	Public support and awareness of water system protection
	Elicit full aspect of interests and perspectives		
		59	Participation in local Stewardship
5. Inter-generational and intra-generational equity			
	Distributive Justice (impact)-Dist J (impact)		
		No Indicators	
	Distributive Justice (benefit)- Dist J (benefit)		
		No Indicators	
	Distributive Justice (cost)- Dist J (cost)		
		No Indicators	
	Participatory justice (involvement)-		
		No Indicators	
	Procedural Justice - normative frameworks		
		No Indicators	
	Procedural Justice - Disclosure of relevant Info(Transparency)		
		No Indicators	
	Procedural Justice- Principles of impartiality (nondiscrimination		
		No Indicators	
	Contextual Justice-Adequate comparable capacities		
		No Indicators	
6. Interconnectivity from local to global scales			
	Presence of ordinances to guide actions at different points that influence other water related points on local, national and global scale		

Principle	Feature	Indicator ID	Indicator
		No Indicators	
	Reduce or Eliminate negative impacts between scales	No Indicators	
	Recognize and coordinate among local and state stakeholders	No Indicators	
7. Precaution and adaptability			
	Anticipate Future Water Shortages	5	Seasonal Variability
		6	Drought Severity
		7	Baseline Water Stress
		16	Rural and urban population
		17	Relative Water Stress Index
		19	*domestic and industrial water demand
		21	Interannual Variability
		56	Historical Drought Severity
		62	Sustainable Water Usage
		65	Water Risk (WRI)
		66	Water Scarcity Index
		80	Water shortage
		81	Water storage and use
		103	Water Delivery
		109	Water Use
		110	Water Supply
		145	Current Supplies
		146	Future Supplies
	Mitigate Future Water Shortages	6	Drought Severity
		49	Drought Resilience
		62	Sustainable Water Usage
		65	Water Risk (WRI)
		103	Water Delivery
		109	Water Use
		110	Water Supply
		146	Future Supplies
	Adapt water shortages and water quality problems		

Principle	Feature	Indicator ID	Indicator
		5	Seasonal Variability
		6	Drought Severity
	Material and Financial Capital		
		12	Flood Occurrence
	Collaborative Capacity		
		No Indicators	
	Institutions and entitlement		
		37	Trends in ISO 14001 Certification
		38	Risk and Policy Assessment
	Resource Efficiency		
		No Indicators	
	Learning Capacity		
		No Indicators	

Data Assessment

The data that an indicator is based on is important in an assessment of its credibility and legitimacy. Different data sources have characteristics that may limit their use for certain applications, either because of the physical or temporal context of how it will be used. A total of 28 data sources were identified for the 208 indicators assessed. Table 6 provides an analysis of each data source based on data type, time frame for which they were available to the public, identified advantages, the scope at which they are reported, limitations, and identified critiques.

Table 6: Indicator Data Assessment

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
USGS Surface Water Quality Data	Tests conducted on samples Data is updated every 24 hours (USGS 2016).	Free and available to the public	Available for national, state, county and hydrological unit levels	Much data exists for which documentation is limited. The USGS and EPA however agree that such data may still be useful and thus is not excluded from their systems (USGS 2016).	Available data in the past (e.g. 1990-1998), there is insufficient data to meet US EPA recommendations for determining water quality (Pope, Rosner et al. 2004).
USGS stream flow data	Flow data from gages relayed through satellite, telephone or radio telemetry Transmitted to USGS offices every 1 to 4 hours	Free and available to the public in real time	Available for national, state, county and hydrological unit levels	All real time data are provisional and subject to revision	Inadequate stream gage network results in information gap on key watersheds (Escriva-Bou, McCann et al. 2018)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
USGS Landsat Data	Satellite data	Free and available for immediate download	Global	Limited duty cycle which affects the amount of data that can be captured and downlinked to ground station network (Ober) Limited field reference data.	Like other Earth observation-based data, data is not always available in analysis ready format and may require preprocessing which could be a cumbersome process. ‘Analysis Ready Data’ is available for Landsat 1-5 MSS data but not available for initial releases because of the need for further processing and poor quality (Altaweel 2017).
USGS Groundwater Quality Data Water	Data transmitted from on-site automated recording equipment (USGS 2017)	Provisional data from various sites available daily	Selected sites across the US	Daily data from field samples are only provisional and accuracy has not been verified. Conditions like poor well construction and cement intrusion severely limit reliability of water quality data (GRADIENT Corporation 2013)	Cumbersome retrieval of discrete sample data. Data is large, complex and disaggregated from a variety of projects ranging from the national to watershed scales (USGS 2017)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
USGS Groundwater level data	Manual and automated measurements of the depth to water in wells (USGS 2018)	Provisional data from various sites available daily	Selected sites across the US	Daily data from field samples are only provisional and accuracy has not been verified.	Scarcity of well data in certain areas (Snyder 2008)
USGS Precipitation records	Continuous and intermittent data collected from precipitation gages and stations (USGS 2016)	Open data available to the public	Selected sites across the US	In many instances data available is not sufficient enough for the data correction processes to be applied (USGS 2016)	Data starting from October 2007 can be returned with a step however data not quality assured is limited to 120 days or less by local USGS water science centers.
USGS Water use Data	Estimated use of water from water use information reported by local, state and federal environmental agencies (Dieter, Maupin et al. 2018)	Available for public use	Available nationwide, reported at a county level	Data is reported, and details may be over or under reported by reporting agencies.	Available in 5-year intervals. Gap in data availability is a challenge Different methods used for data collection in different states.
BOR consumptive use and losses in Upper Basin	Data sourced from reports and ongoing programs (Bureau of Reclamation 2004)	Disaggregated data at state and tributary levels	Upper Colorado river basin	Data for 2006 to 2010 is provisional Data is reported, and details may be over or under reported by reporting agencies	Available in 5-year intervals. Gap in data availability is a challenge

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
BOR water accounting report	Flow data sourced from USGS, while water use data is sourced from reported data (Bureau of Reclamation 2018)	Available for public access and use	Lower Colorado river basin	Reported, data may be over or under reported by reporting agencies	Data available on an annual basis, not available for months and days (Bureau of Reclamation 2018)
. UN FAO Aquastat	Water withdrawal estimates data is reported at national levels Flow data obtained from tracking individual river points of international significance	Publicly available	National level, Not available for the US.	Reported data may be under or over reported	The absence of direct measurement and the complexity of assessment methods, makes reported figures not always reliable. These difficulties explain why such figures are not always available at country level (AQUASTAT 2016).

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
. City of Phoenix Water Quality Data	Data obtained from sample tests conducted each year (Water Services Department 2017; Water Services Department 2018)	Available to the public	Phoenix	Conducted and published each year, creating a one year data lag	Lack of legal limits on contaminants like chromium 6 and the absence of testing requirements in the past has resulted in data gaps on such contaminants (Sutton, 2010).
. Arizona Department of Water Resources Water supply, demand and use data	Supply and use data reported by utility system and well operators from water meters at the source and points of release Other data sources include data sourced from reports and surveys (Arizona Department of Water Resources 2018)	Measured data is asserted to provide a better approximation of water supply and use	Arizona		Metered data may report all water leaving the points of release as water use. Water lost through system and consumer leaks thereafter may be mistaken for water use. Data is self-reported with little review by ADWR staff. Most data is in raw text reports and not available as electronic data tables.

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
California Institute of Technology lake classification data	Amalgamation of contact sensed data and digitally processed multispectral scanner data acquired by aircraft and satellite (Blackwell and Boland 1979)	Complementary data to further evaluate contact sensed data	Selected Colorado lakes	The Landsat MMS was not specifically designed for water quality studies. There is a limited dynamic range with low resolutions. The predictive capabilities of the scanners are effectively reduced by the disparity between the range of their data.	Atmospheric variability both overtime and space adds variability to remotely sensed data (Altaweel 2017)
California Department of Water Resources Water	Supply and use data obtained from a variety of sources including water utilities and other water providers Other data sources include data sourced from reports and surveys (Department of Water Resources 2018)	Measured data is asserted to provide a better approximation of water supply and use.	California	Data is self-reported.	Metered data may report all water leaving the points of release as water use. Water lost through leaks thereafter may be mistaken for water use

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
. California department of fish and wildlife data	Field Surveys and retrospective population information obtained through reviews and species accounts in published literature and field study reports.	Appropriate for comparison with ongoing methodologies adopted in different publications and report	California	Relies heavily on already existing species accounts.	Seasonal timing of data collection may provide skewed representation (U.S. FIsh and Wildlife Service 2016)
. NASA Gridded population data	Population estimates are created by extrapolating the raw census estimates to a series of target years: 2000, 2005, 2010, 2015, and 2020. Both sets of estimates are proportionally allocated to raster cells (i.e., pixels) using a uniform areal-weighting	Data Quality Indicators data set can help a user determine if GPWv4 is appropriate to use for their study	Global	Limitations arise related to how current input population and boundary data are. Neither CIESIN nor NASA verifies or guarantees the accuracy, reliability, or completeness of any data provided.	In countries, or locations within countries, where the input units are quite large, the precision of individual pixels within those units is degraded. (Center for International Earth Science Information Network (CIESIN) 2017)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
	approach to produce the population surfaces. (Doxsey-Whitfield, MacManus et al. 2015)				
. National Center Environmental Information Basin Delineation data	Digital Elevation Model derivatives are used to estimate basin areas (United States Environmental Protection Agency 2017)	Models are available to the public	National	Taking drainage area estimates published by the USGS as a standard, there is a relative error (absolute values) in estimating drainage areas using both the 400-m and 30-m DEM derivatives	DEM-based drainage area estimates are less accurate for smaller basins (Eash, Barnes et al. 2018)
Dartmouth Flood Observatory flood data	Global Active Archive of Major Flood. Aggregated flood events from news, governmental, instrumental, and remote sensing sources and estimates the extent of flooding based on reports of affected regions. (Dartmouth Flood Observatory 2007)	Free and readily available to the public	National	Because this database combines different information source and cover 18 years, it cannot be totally consistent.	The question of data consistency is recursive with this kind of database. Media may over report or under report raising questions of data reliability (Dartmouth Flood Observatory 2007)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
Living planet report	Index value calculated with reference to baseline value derived from number of freshwater species estimated for 1970 (World Wildlife Federation 2016)	Report is free and readily available to the public	Global	Calculations are done taking each year as a unit for analysis. Index values related to specific seasons are not reported (World Wildlife Federation 2016)	
The Water Balance Model (WBM)	Hydrology model: Daily climate drivers of temperature and precipitation from NASA's MERRA to analyze effects of irrigation and reservoirs on the hydrological cycle (Livneh, Rosenberg et al. 2013)	Fast computational devices and availability of finer resolution input data	National	The parameter values in the WBM are assigned a priori and are not calibrated.	Uncertainties related to spatial scales (50km grids) which are too coarse for effect simulation to answer water science cycle questions (Wood, Roundy et al. 2011)
Global Reservoir and Dam (GRanD) Data-base	Compiling already available reservoir	Provides a single reservoir and dam database for the scientific community.	Global	Sets 0.1 km^3 as the minimum dam/ reservoir size that can be captured.	The database is missing key dams in certain areas which are less than the stipulated minimum size for capture (Lehner, Reidy Liermann et al. 2011)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
	and dam information, reported by institutions such as the FAO Aquastat and completing missing information from new sources or statistical approaches (Lehner, Reidy Liermann et al. 2011)				
Flood Disaster Preparedness Indices	Survey questionnaire	Provides single instrument for measuring state of infrastructure, mitigation plans, mitigation systems, evacuation plans, recovery plans, information and education, collaboration, and community strength (UN International-DHI Center on Water and Environment 2017)	Global	Questionnaires have limitations in the type of data that can be collected. Details like cultural, linguistic, meteorological differences are difficult to capture	Questionnaire demands localized understanding and knowledge. Responders may demonstrate some level of bias (UN International-DHI Center on Water and Environment 2017)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
OECD Income and Expenditure surveys	Survey questionnaire	Provides instrument to capture survey data on household expenditure on water supply and sanitation services of the households representing a given income bracket (Organisation for Economic Co-operation and Development 2008)	Global	Self - reported data could be over reported or under reported.	It does not consider other contributions of high cost water bills like water leakages (Organisation for Economic Co-operation and Development 2008)
Surface Water Ambient Monitoring Program Water Quality data	Calculated index	Provides index derived from indicators and metrics that represent the condition of benthic invertebrate communities living in streams and rivers (California Water Boards 2018)	California's surface waters	Inability to combine data sets from different programs. Differing data structures and field and laboratory methods has hindered effective progress towards meaningful interpretations of the data	Sites are not randomly selected, and this introduces bias into the results. A core set of indicators must be sampled synoptically at all sites to determine impacts to beneficial uses (California Water Boards 2018)

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
Alliance for Water Efficiency Survey	Survey questionnaire	Provides instrument for assessing presence of water conservation policies (Christiansen, Dickinson et al. 2012)	Nationwide	Self-reported data could be over reported or under reported. Information is now out of date as to status of states programs.	There is no guarantee that if a law is passed that it will be implemented well, nor if no law is passed that there is not implementation.
World Health Organization data on chemical and bacterial pollution	Calculated index	Provides index that measures chemical and bacterial pollution (Ashbolt, Grabow et al. 2001)	Global	A single indicator or range of indicators may not be appropriate for all varying contexts (Ashbolt, Grabow et al. 2001)	Water regulatory agencies are yet to come to terms with problems associated with the reliance on fecal indicator bacteria
Colorado River Watch Network Water Quality Data	Reported data	Open access to water quality data tested and reported by trained volunteers and reviewed and analyzed by CRWN (River Watch of Colorado 2018)	Colorado River basin at more than 150 sites between Big Spring and Matagorda Bay.	Site data is partly dependent on volunteer distribution	Reservations are expressed on volunteer-based data collection

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
National policies related to water	Data sourced from national documents on water policy	Open access and available as public records	National	Based on documented policies. Does not assess whether these policies are successfully enforced	Data gaps may exist for context based policies below the national level. Policies appropriate at the national scale may not necessary translate to local scales (Cash & Moser, 2000)
National Budget in relation to water	Reported data from national water and finance ministries	Available as public records	National	Reported data with cases of under reporting or over reporting information	Ambiguities exist on what should be considered as the desired level of investment which varies based on technology, kind of water source and number of people in each settlement (UNDESA,2012)
National Report on treaty commitments	Reported data	Available online to the public via FAO website	National	Estimated based on data sourced from water resource data sheets and water balance computational sheet (FAO ,2003)	Data is only available at the country level. Further estimates are required to appropriate to a lesser scale, which may further distort estimated data.

Data Sources	Type & Time Frame	Advantages	Scope	Limitations	Critiques
IUCN Red List of threatened amphibians	Assessment results from workshops, reviews and consistency checks from project staff, participants and experts	Assessments are available via website open to the public	Global	Assessments are considered to be out of date after ten years. Though a shorter time interval may be ideal, thousands of species captured in the list require considerable time and resources to update and thus makes it difficult to update at shorter intervals	The system for prioritizing some species over others have been critiqued owing to concerns of bias (Master,1991) The IUCN has in the past been critiqued for withholding information (Mrosovsky,1997). The need to enlist more taxonomic and geographical experts in order to expand its reach beyond the less than 2% of known coverage Rodrigues, et al (2006)

Functional Assessment

Indicators are intended to be used in practice and research for assessing the past, current and possible future state of water sustainability. Any indicator's data and content may make it more or less suited for different purposes and understanding this context is an important consideration when selecting indicators. The following examines some of the general strengths and weakness of the indicators based on their use under the 10 topic categories (See Table?).

Water Demand

Water sustainability is focused on the balance between supply and demand. This topic is related to the aspects of demand which are important to consider such as scale of water use, systems of water delivery, the users of water, and the efficiency of this water use. It covers about 10% of the indicators.

Scale

Most of the data used for the water demand indicators comes from either a city scale or a national scale, which is based on aggregated city level data. The availability of data at geographies smaller than a city or utility varies from city to city. Arizona has a state law that limits the ability of utilities to share data at a scale that would allow an individual's or business' water use to be identified. Water data that is reported at larger geographic scales for subcategories of demand, either by land use or physical and socio economic attributes are just averages and typically have a high variability among individual water users in a subcategory.

System

In the US there are a number of systems used to deliver water for consumption. For potable water there are two basic systems, 1) public and private utilities that deliver potable water via piped distribution systems and 2) private wells for which water is pumped and delivered directly to the user. The former systems are regulated by state and federal agencies which require submittal of reports on water production. Most of these systems have meters measuring the quantity and quality of water flow within the system and in the US most have meters at the point of delivery. These reports form the basis for most data we have on system level water demand and for the most part is fairly accurate. The regulation and oversite of the later private well systems varies widely from state to state and region to region. Some places there is no over site and in others there is a high level of oversite with requisite data collection. Thus, data for these systems is spotty. Many of these systems do not have meters and flow is often estimated on how long water flows through a valve and the size of the valve or how long a pump was operated. For all these systems, data collection is through self-reported data and thus is subject to human error.

Systems for delivery of water for irrigation primarily follow three types of systems, 1) water diverted directly a surface supply via dams, weirs, and/or ditches, 2) water delivered via canals, trenches and large low pressure pipes, and 3) direct delivery from wells in pipes or ditches. Rarely do these systems include meters, rather estimates of the amount of water used for system 1 and 2 are based on the weir flow calculations (length*Height*width*flow rate) using visual estimates of size and flow for a particular location and time. Estimates of water used for systems 3 (groundwater) are based on rate or flow for a pump and how long the pump was operated. These types of measurements are estimates and not as reliable as a meter because operational parameters can change widely over time and location.

Efficiency

Public Supply Efficiency

The metric Gallons Per Capita per Day is one of the most widely used measures of efficiency in the US for public water systems and domestic water use. Values for this metric in the US can range from as low as 30 to as high as several thousand. Sometimes this metric is based on housing unit or billed customer instead of persons. Though it is widely used, it does have some limitations that should qualify its use. This metric is based on two other metrics, a unit of users (people, housing units, employees, billed customers) and water use (monthly or annual). In order to be valid, these two sub metrics should be calculated for the same geographic area for the same period of time. This can make estimating these metrics difficult as follows:

1. Estimating population or occupied housing units at any point in time is difficult. The gold standard is the US Decadal Census. This census is the best source of data on occupied units and people, but it does have some limitations. It has a tendency to undercount in places with high recent immigrant populations and high turnover populations such as retirement, university and tourist communities. This is the preferred source of population estimates and works well for larger geographies, however, when the geography of water use does not match the census boundaries, population counts have to be extrapolated to match the geography of water use, which can often introduce error. Often population counts are needed for years other than US census years. In these cases, population can be estimated in a number of ways. It can be extrapolated from a trend using previous census data. It can be estimated using the number of occupied housing units and persons per household, using building records to add new housing built since the previous census, and the estimates of occupied units and persons per household from a previous census. These methods are all estimates and can be subject to error when rates of change for occupancy and persons per household are high.
2. Estimating water use is not that difficult, but how it is done and the definition of water use can vary from community to community. Some communities will use total water produced other will use billable water records. The first would include water lost in production or during delivery, that later will not. Some communities do not have all their users metered, so total production is the only estimate available. Some communities will include reclaimed water as produced water and or delivered water, others will not. Almost all water estimates are for annual use, which is divided by days in the year to give average daily use. However, this does not match the same temporal period.
3. One aspect of unit per gallons measures of efficiency is that the efficiency is associated with the unit. For example, in gallons per capita per day, the efficiency is focused on how efficient people are in using water. One complication with this is that the water use measured is not always just a result of the unit. For example, if I calculate GPCD using total water produced, not all of the water produced is for use by people who live in the community. Water produced that is used to produce a juice or a car, is not necessarily water used by those that live in the community. This can result in the GPCD for a community with just houses to be higher than a community with a lot of water using industry, even if it has the same houses as the first community. One response to this is to calculate separate efficiency metrics for residential and non-residential water use. This effectively makes the water use more aligned with the consuming unit. For utilities that meter their customers, this is often easy to do by classifying customer accounts as residential or non-residential.
4. Outdoor water use is a component of a communities total water use. How landscapes are managed can have an impact in outdoor water use, with some practices being more efficient than others, but management is not the only factor affecting outdoor water use, climate also has an impact. Some climatic zones are wetter than others, thus maintaining landscapes may require more or less water. In the US we have cultural norms about landscapes that include turf, such as golf courses, playing fields, parks and private yards. These landscapes in a dryer climate will require more water than in a wetter climate. In southern climates, particularly the dryer climates, they can also be enjoyed for more parts of the year, making these areas attractive tourist locations in the winter, which is a vital part of the economy.

These complications of estimating unit per use metrics makes comparing metrics across time and between communities problematic and very context relevant. Comparing metrics over time will be a function of how population is estimated in each year. Using different methods, such as census one year and an estimate based on housing units another, can result in deviations that are not the result of changes in efficiencies but rather over or under estimated population counts. Comparing metrics between different communities will be a function of how water use is defined and context specific characteristics of each community. Difference in unit per gallon measures may be a result of how water is defined, or the composition of actual users or water compared to units (residential and non-residential), rather than some difference in efficiency. These temporal and context sensitive factors should be accommodated when using this type of metric.

Agriculture Efficiency

Measuring agricultural efficiency is an elusive metric because of the wide context associated with agriculture irrigation and poorly articulated concepts of agriculture water consumption. Generally, the concept would be based on a metric of how much water is consumed for some unit of agriculture production. However, both of these metrics will vary based on context. In places where the water needs of an agriculture product cannot be satisfied by natural precipitation, then supplemental irrigation will be needed. In some cases, the total water consumed for production (natural plus irrigated) will be higher. Thus, the same agricultural product in a wetter climate will require less total consumed water irrigation than the same product in a dryer climate. Even within a region, soils can change the water needs of a crop making one location require more water than another.

Different crops and products require different amounts of water given the same climatic conditions, making efficiency a function of crop selection which is primarily driven by the changing economics agricultural product markets. Thus, there is no universal metric of agricultural water efficiency that can be used to compare efficiency across space and time.

Lastly, some of the water used for irrigation is not consumptive. Some is returned to aquifers or surface waters making it available to be used again. Some is evaporated, making it available again in some other regions.

However, there are metrics that can be used in context to assess agricultural efficiency. Data is available to understand the water needs of various crops under different evapotranspiration regimes so that the efficiency of different methods of irrigation under the same context can be assessed. Since US agriculture is essentially a business, agricultural income can be used as unit of production against water used to assess efficiency in terms of gallons per dollar of net income. Though this cannot account for climatic differences between regions, it can be used to account for markets and crop selections over time within a region. Regardless, agriculture indicators should be used with caution for comparisons across regions and economic cycles and accounting for consumptive and non-consumptive water use should be considered.

Water Supply

The other side or the supply and demand balance is water supply. This topic relates to indicators assessing the amounts and management of water supplies. The indicators under this topic account for just under 15% of all indicators with most addressing water supplies in total (i.e. total of all sources). of which are address some specific water source. There are five basic sources of water in the US, 1) surface water which consists of rivers and lakes/reservoirs, 2) ground water which can be withdrawn from aquifers, 3) sea water desalination which results from process of removing salt from ocean water, 4) reused water which comes from the reuse of collected wastewater from cities or farms, and 5) rain water which is collected before it has a chance to go into a stream or river.

Surface

In the US, there is a wealth of comprehensive information about surface water which is collected at a national level. Data for current and historical average and peak flows of most major rivers and streams is directly collected and made publicly available in standard data formats by the Dept. of Interior (Bureau of

Reclamation and USGS). Data about water levels and releases is available for all reservoirs managed by federal agencies, but is not as readily available for non-federal or private reservoirs.

Water quality data for rivers and streams near water treatment plant intakes and wastewater treatment plant outfalls is available from the EPA in a generally consistent format across all states. One limitation is that this data is reported to the EPA by state agencies, who receive the data from plant operators. Quality control of the data varies from state to state and there are known inconsistencies in some data sets.

Ground Water

Ground water metrics are subject to a number of considerations when using them as indicators. Ground water has three types of important metrics, the amount of recharge to aquifers, the amount of water stored in aquifers, and the amount of water removed from aquifers, natural and human withdrawal. Unlike surface water, in the US there are no national agencies that directly collect groundwater data comprehensively across the US. The USGS does conduct groundwater studies on specific aquifers throughout the country, but this does not represent a comprehensive coverage. Most groundwater data available is collected at a state level, and the type of data collected varies from state to state.

As far as human removal or pumping, some states do and some states do not require reporting of groundwater use. Some require reporting of ground water pumping only at certain levels of pumping or for certain purposes. Data collected will vary from just rates of withdrawal to water quality and well depth and water level data. In some cases, reporting is different for different geographic extents. Thus, data on groundwater pumping from one state may not be defined as the same in another state or even one community to another. Absolute volumes of groundwater pumping over time for one specific location using the same source of information are likely to be a valid metric. Comparison of volumes of groundwater pumping between communities or states should be done with caution based on the source of data and what groundwater pumping is being reported.

Data on groundwater storage and recharge is based on the availability of studies that have examined specific aquifers. Some aquifers have been highly studied including the use of test wells, others have very little of any data available. The USGS has done studies of specific aquifers around the country and have developed estimates of recharge rates, storage and natural and human withdrawal rates. Some states have agencies, such as the Arizona Department of Water Resources, that study and model specific aquifers within their states. Some states require reporting for new wells of depth to water and water production rates which can be used to monitor aquifer storage.

Effluent and Reclaimed

There is national and state data available on some of the reuse of wastewater, primarily from wastewater treatment plants. The EPA sets standards for the water quality of treated wastewater used for various purposes and does require reporting on the operations of treatment plants that produce effluent for reuse. However, data on the actual reuse of effluent, how much, when, and for what purpose, is not collected by the EPA through a reporting process. Reporting on this varies from state-to-state and often must be collected directly from the utility that is distributing the effluent for reuse.

Desalination

The removal of salt and other dissolved materials at a small scale is done simply by evaporating water in a confined space and then collecting the condensate. However, desalination at the scale needed for urban areas in the US is a highly technical process, normally done using reverse osmosis by forcing water under high pressure through semipermeable polymer membranes which block salt from passing through. This is an expensive capital and operational process requiring large amounts of power. These plants are highly metered and thus, estimates of production are readily available from the agencies operating the plants.

Rainwater/Storm Water Harvesting

There is very little data available on the use of rainwater harvesting. There are no national agencies that collect this data. Few states regulate the use of rainwater, Colorado being one of the exceptions thus, there is no required reporting of rainwater use. There have been some surveys that have estimated percent of people using rainwater, but no quantification of use.

Economic and Financial

This topic is related to indicators assessing how water supports local and regional economies, the financial aspects of water management, or the financial resource of individuals and covers just under 10% of the indicators. Most of the indicators in this category are targeted to a larger geographic scale and rely on directly reported data from global and national agencies which is generally based on national reporting requirements or are estimated based on reported data. Most are reporting on aspects of the economy. Some address impacts on individuals and families, most of these are reporting at a national level.

Environmental

This topic is related to the indicators that assess the water needs of natural systems and water quality. This represents the largest set of indicators, almost 30%. Most of the data used for these indicators are based on analyzed water samples or counts of animal and plant species and thus, will be accurate and reliable. Most are reported as part of a larger geographic scale assessments (State, Region, and Watershed), though in many cases actual data by sample site is available and can be used to do assessments at smaller geographic areas.

Disaster Management

This topic is related to indicators assessing management of storm water and droughts. This is one of the smaller topics, less than 5 percent, with about a third addressing drought and the rest focused on flooding. Almost all of the indicators are reporting at a state or regional level. Most of the storm water indicators are based on modeling and less reported data. Most of the drought indicators are calculated based on historical data on the length and severity of past droughts.

Climate Change

This topic is related to the impact that climate change may have on water supply and demand and only covers two indicators (1%), one assessing global threats to water supplies with a climate change emphasis and one assessing the green-house gas emissions from various activities including water management. Both are calculated based on data reported at national and state levels. There are some indicators under other topics that do include some aspect of climate change.

Social Well-Being

This topic is related to how water supports or impacts social and community systems including health, public and media awareness and engagement, social justice, political will, and fulfillment of social needs. This topic covers just over 5% of the indicators and most of these are at city, state and region scales. Most of these are based on surveys and reported data with some estimating number of people under different water related conditions. Such data will be subject to bias introduced through survey design and sampling, or the difficulties of defining geographic extents of water issues to estimate number of people affected.

Infrastructure/ Water MGMT

This topic is related to the infrastructure systems and their management needed to collect, store, treat and deliver potable and waste water. These indicators make up just under 10 percent of the indicators and cover a range of scales from city, to region, and state. Most of the indicators utilize data collected by agencies about system performance or physical attributes with some indicators estimating a level for the indicator using this data, i.e. the data collected does not directly measure the indicator. Given much of this data is system measurements it will be reliable and accurate. These generally fall into two groups, those related to the balance between water supply and demand, and those assessing the reuse of effluent.

Energy

Related to the role water plays in energy production and the role energy plays in water treatment and delivery, only two indicators were included. One addresses how much power can be produced with available water for hydro power and the other estimates how much power is used to treat and deliver water. There are no indicators for the efficiency of power.

Legal - Regulation, and Governance

This topic is related to the legal aspects of water use regulation and management. This topic includes about 10% of the indicators which are focused primarily on regulations and enforcement. Most of the data for these indicators is based on self-reported surveys. Such surveys can include bias as a result of survey design and sampling. The indicators primarily cover two geographic scales, local government regulations and enforcement, and state requirements for local governments.

What is Missing?

The realm of sustainability indicators is quite extensive. There are literally hundreds of sustainability indicator systems that range from a global system like the UN's Sustainable Development Goals to indicators included in individual cities' and organization sustainability plans. For this report, we limited our review of general sustainability indicator schemes and focused primarily on schemes that were primarily focused on water. We also limited our review primarily to schemes based in the United States. Thus, there were several indicator schemes that we did examine but did not include in this review. Some of the more notable ones are discussed briefly here.

UN Sustainable Development Goals Indicators

The UN's Sustainable Development Goals, adopted in 2015 (Assesmbly 2015), have become a world standard for global sustainability. The 17 goals cover a wide range of topics, two are dedicated to water issues, Goal 6 Clean Water and Sanitation, and Goal 14 Life Below Water, but Goal 3 Good Health and Well Being, Goal 4 Quality Education, Goal 11 Sustainable Cities and Communities, and Goal 12 Responsible Consumption and Production do mention water as an issue (Division for Sustainable Development Goals (DSDG) 2018). The UN has developed a set of indicators for these goals, 13 of which are related to water sustainability, 11 in Goal 6 and 2 in the other goals (Assesmbly 2017).

These indicators are primarily designed to assess sustainability in undeveloped countries. Half of the indicators are focused on provision of treated water and sewage and the remaining are general metrics with fairly subjective assessments of efficiency, supply environmental conditions. Most of these indicators are reflected in more detailed indicators included in this review.

Water Sensitive Cities Index

The phrase "Water Sensitive City" has been widely used in practice and the literature by a wide range of organizations and researchers. Much of this is a result of research and engagement done by Cooperative

Research Centre Water Sensitive Cities which is funded by Australia's Commonwealth Government's Cooperative Research Centre (CRC) Programme, which is equivalent to the United States National Science Foundation. The original concept developed by Brown and Wong who suggested that cities water sustainability could be represented in time by six city states, 'Water Supply City', the 'Sewered City', the 'Drained City', the 'Waterways City', the 'Water Cycle City', and the 'Water Sensitive City' based on three concepts of cities as water supply catchments, cities providing ecosystem services and cities comprising water sensitive communities. (Brown, Keath et al. 2009; Wong and Brown 2009). This framework was reviewed for use within the sustainability framework assessment but because it was more a state-based framework rather than a sustainability framework it was not used.

Later, an index was developed to assess what state a city was in which included indicators (Chesterfield, Urich et al. 2016). This concept has now been branded by the Cooperative Research Centre Water Sensitive Cities, who has developed a planning process for cities to transition to a higher water sensitive city state and tools, including an index assessment tool. These are now rapidly being adopted by cities in Australia and to some extent cities in Europe. Tracking down the index indicators without joining the CRC program proved to be difficult, because this seemed primarily an Australian tool it was not included in this review.

California Water Sustainability Indicators

As part of California's 2013 Water Plan Update, a California Water Sustainability Indicator framework (WSIF) was developed and tested. This framework had a massive set of indicators (1800) covering wide range of items related to water system conditions and their relationships to ecosystems, social systems, and economic systems sustainability (Shilling 2014). Most of these indicators were general in nature. Finding information about its application and more detail on the indicator system proved difficult because many of the URL links to supporting documents were broken. Given limited resources, this was initially abandoned as a source for indicators. After the initial list of indicators was developed and assessment started, a second version of a 2014 document was found that contains more detailed information about two pilot studies using the framework (Shilling 2014). Given the limited resources and late date this document was also not used. However, a great deal of work was done to compile the WSIF indicator list and there is a wealth of information in both documents about how indicators should be and can be developed. The second document contains a high level of detail about individual indicators used, the metrics, sources of data and calculations as applied to the pilot studies.

Conclusions and Recommendations

The water sustainability indicators collected and reviewed for this report cover a wide range of topics and geographic scales which provides a base that can be used to establish a set of water sustainability indicators for most contexts. However, these indicators do not represent a universal set that can be applied across all topics, geographic scales, and political contexts. Rather, different indicators will be best suited for different contexts. There are gaps in this list of indicators around certain sustainability principles as well as topics of interest which limit full application of the indicators. Lastly there are .limitations to some of the sources of data used to drive these indicators. Though certainly the list of indicators presented in this report provide an adequate basis for most policy efforts, these three limitations suggest that using them should be done with attention to how such limitations make affect the credibility, salience, and legitimacy of the indicators. Also, there is need to develop new indicators to fill gaps in indicators for certain topics and sustainability principles and to summarize the indicators where there is a large preponderance for a particular topic or sustainability principle.

Credibility, Salience, and Legitimacy,

The intent of using a sustainability indicator is to assess the state of a social or natural system and trigger decisions about actions required to make the system more sustainable. This requires that the indicator be effective in making a connection between knowledge and action. This is more likely to occur when the indicator is considered credible, salient, and legitimate by those who can take such action, i.e. decision makers (Cash, Clark et al. 2003; White, Wutich et al. 2010).

Credibility will be a function of how decision makers view the adequacy of the science and technical aspects of the indicator. This may be in part how well trusted are the agencies providing the data for or maintaining the indicator. It may also be a function of how well the indicator is documented and the adequacy of its science and technical arguments. A metric should be used in a manner that reflects the limitations and context of its data sources. This includes scale and temporal context. When metrics are compared, some level of allowance for accuracy of the metric should be applied. Comparison of a metric based on weir flow measurement should provide more leeway than a metric based on a meter measurement. Many of the metrics, particularly those for the Social-Being topic, are based on self-reporting surveys which can have significant credibility issues.

Salience will be a function of how relevant the indicator is to the current needs of the decision makers. This may be in part how well the indicator is linked to an action that is part of the decision maker's current policy agenda. This may suggest that indicator systems focused on specific aspects of water sustainability that match a regions or agencies issue may be more useful than a comprehensive set of indicators. Metrics should be functionally appropriate for the policy for which it is applied.

Legitimacy reflects the perception that the indicator was developed in a manner that reflects fair and reasonable treatment of the topic the indicators are focused on. This may be a result of how well the indicator system and its development respectfully and fairly represents the viewpoints across the range divergent values and beliefs of stakeholders engaged in the issue.

Gaps and Gobs in Indicator Context

Within this inventory of water sustainability indicators there are a number of areas where there are excesses and deficiencies within the indicator list. There are a significant number of environmental indicators, most of which are highly technical in nature though they are based on objective and reasonably accurate measures of environmental conditions. Presenting over 50 indicators to represent an environmental perspective is likely excessive, particularly given that many of these are highly technical and difficult to relate to what people perceive as water for the environment. However, there are a few indicators focused on specific aspects of the environment which may be appropriate in different locations if there is available data.

There are very few indicators related to water and energy. This may reflect the fact that in many regions, water consumed for power represents a relatively small percentage of total water consumption. This is particularly for most parts of the Colorado River Basin, though northern Arizona, southwest Wyoming, and northwestern parts of New Mexico do have some water consumed for power production. None of the power indicators reflect efficiencies of power production.

There are only about 5 indicators that address agricultural water use, most just look at agriculture water use as part of total regional demand. Only one addresses agriculture efficiency.

Surprisingly there are only two indicators addressing climate change directly, one on mitigation and one on vulnerability to generate threats to water, climate change being one.

The indicators for water supply and infrastructure management are well represented however within these there are some noted deficiencies. One is addressing groundwater. Though safe yield as an indicator for the sustainability of groundwater pumping is not inherently the most rigorous indicator, it is one that is conceptually easily understood. However, our ability to apply it comprehensively on a spatial basis is limited and thus, there are few indicators that successfully use it, creating a gap in the indicators of ground water sustainability.

The indicators for water demand are well represented in the indicator list however these indicators are either focused on overall water efficiency or residential efficiency measured against population. These indicators do not address the rich structure or water use by various categories of consumers, including within residential. There are only about 5 indicators that address agricultural water use, most just look at agriculture water use as part of total regional demand. Only one addresses agriculture efficiency.

There are a number of indicators that measure the status of environmental health and productivity, based on measurable factors such as water quality and species counts. However there are few indicators that measure the state of the ecosystem services that environmental features provide to human settlements. This includes air quality, heat, recreation, flood management and aesthetics.

Another gap is in the use of standards. This limits point in time assessments and leads people to compare indicator values across regions, which is often flawed due to the context of factors driving the issue being measured and variance in data used from one place to the next. The one exception to this is the water quality indicators for which there are numerous state and federal standards.

Having indicators that represent the full breadth of sustainability principles will be important to have legitimate indicator systems. The indicators identified here represent four of the seven major principles, however, three principles not well represented include, 4) Social Ecological civility and democratic governance, 5) Inter-generational and intra-generational equity, 6) Interconnectivity from local, regional to global scale have very few identified indicators, and Resource Efficiency Management. There are likely several reasons why there is less of a focus on metrics to assess water management based on these principles.

Scale: Management of water within most regions is more local than global. The vast majority of the public experience with water is primarily when people turn on their tap at home and when they pay their water bill. Most institutions involved in water management have customers defined by a specific geography. For institutions that manage at a regional scale, most of their customers are other institutions within their region. Management at the state level of water resources is primarily as a regulator, not as a water provider. Water resource management at a national level is centered primarily on specific federally managed infrastructure and flood plains, though water quality is nationwide. International water resource management is primarily only in cases where a specific resource, river or lake, is either split or crosses an international border. Thus, as the scale of water management in the use moves from local to global, there are fewer issues, people and institutions are involved.

Institutions: Management of water occurs primarily via institutions, which have a tendency to focus on their aspects of management and less so on others.

Technical versus Social/Governance: For the last 100 years, water management has been primarily a technical and financial issue. With a focus on what infrastructure needs to be built to deliver water and collect wastewater in a manner that meets federal water quality standards and how the infrastructure is financed. However, in the future technical solutions will be more limited and softer governance approaches, such as collaboration and value setting, will be needed.

Time Scale: The time scale of water management is more focused on financial cycles and less on the lifespan of infrastructure or social cycles.

Governance: Most governance of water management is done by existing established governance institutions. Each has established laws, policies, and processes that define and frame the democracy of water management thus, democratic processes are more focused on compliance and less on broad participatory engagement.

There are three trends that suggest that these three principles will play an important role in the future of the regions and thus, there is a need to expand indicators for these principles.

Efficiency: Improving the efficiency and technology of domestic and commercial indoor water fixtures has been driven by the federal standards adopted in 1992 (Environmental Policy Act, 1992) and subsequent amendments. Thus, the trend over the last 20 years of declining per capita water use has been primarily the result of technical changes not social changes but, we are beginning to reach the bottom of what can be achieved technically. If we are to continue this trend into the future, two things will need to occur, water use behavior will have to change, and outdoor water use will have to become more efficient. Both of these will require more involvement from water customers. As the curve of technology-based efficiency improvements begin to bottom out, people's behavior on how they use water will be the key to continuing declines in water use. This will require motivation that will likely be based on a high level of knowledge about water issues in general.

Water as a public resource: Over the last 100 years the development of the federal system of dams and canals for the Colorado River Basin created a system in which water was plentiful. Thus, concerns of how to use it were focused mostly on access to water, not what was the purpose of the water used. As we begin to approach the limits of Basin water, the focus will shift to the uses of water and as water becomes limited, communities will want to be sure that adequate water is available to achieve social and economic community goals. This will likely require decisions that trade-off between these goals, such as economic, equity, and quality of life. These are decisions that will have to be made by a public well-informed about water issues and these trade-offs.

Climate change: Climate change will unfold over a long-term, with slow change to possibly, hotter and drier regions. This long time frame is difficult for people to become concerned about current events and decisions but, there are several aspects of climate change that warrant attention now. Mitigation is now a critical issue because the horizon for no turning back progressive impacts is rapidly approaching. Future generations will have access to even fewer resources and policy options than today and actions now can protect options and reduce costs for future generations.

Recommendations

This review suggests that there are a number specific additional efforts needed to make the list of indicators presented here more applicable to a broader range of application contexts.

Data Needs

There is a need to develop more groundwater information related to the sustainability of ground water pumping. The data needed to estimate safe yield is difficult to obtain, if at all, and estimates of existing aquifer volumes in storage are even less available. Availability of data quantifying pumping at local levels various widely from state to state, though at very large scales NASA's Grace data can be used at large region and state levels and USGS Water Use by Supply data provides an estimate at the county level, though accuracy of this data also varies by region. Availability of data on rates of groundwater recharge also vary widely from one region to another, and are mostly dependent on where groundwater models, such as those done by the USGS, have been developed. Developing groundwater models for all regions of the Colorado River basin though desirable is not practical. There is a need to regional recharge models similar to global models but at higher resolutions to estimate recharge based on factors which can be tested for change over time. While these data efforts are underway further refinement of current groundwater indicators to make them more standardized proxies for safe yield should be done.

For most of the non-environmental indicators there is a need for standards to allow for evaluation of point in time indicators results and for comparison of indicators across time between places. Most of these standards will need to be value based thus there is a need for both basin wide standards development and localized standards development. Basin wide standards could be developed by a single agency based on sustainability principles with a review of key region stakeholders. Local standards will need to be more goal oriented with a process that local agencies can engage in to develop these standards.

New Indicators

To fill the gaps in indicators by topic and sustainability principle, a number of new indicators should be developed. These include:

1) More social indicators, particular social justice indicators and indicators centered around social values of water as well as impacts on future generations,
2) More governance indicators that address established concepts of soft governance such as institutional collaboration, knowledge sharing, and more distributed democratic decisions and actions,
3) More specific indicators of vulnerability to climate change impacts on water supply and demand,
4) More agricultural indicators to assess water efficiency across a number of production factors, such as net income, acres of product type, or core nutritional standards. These indicators should address issues of agriculture product export as opposed to local use in regards to water sources.
5) More power indicators to assess power production water efficiency across all forms of power production. These indicators should address issues of power exporting as opposed to local use in regards to water sources.
6) More indicators to assess a detailed view of efficiency across a wider range of urban water uses.
7) More indicators that assess the status and water efficiency of water related environmental services that benefit human settlement.
8) Indicators to measure the vulnerability or opportunities of water connections between local and global geographies.

Simplification

There is a need to develop meta indicators for several categories of indicators that have numerous individual indicators. Using a large set of indicators to reflect a single concept is difficult for people to comprehend current state and state changes over time and also difficult to support a single action when some indicators are high and some are low. Meta indicators could be devised that use multiple lower level to calculate a single value to reflect the state of a concept.

Appendix: Water Sustainability Indicators

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
1	Total Withdrawal Upper Basin	Total amount of water removed from freshwater sources for use	Total Withdrawal	World Resources Institute	Water Demand	Region	Quantitative	Precaution and adaptability; Social Ecological System Integrity
2	Total Blue Water	Measured/ Estimated for each catchment. The accumulated runoff upstream of the catchment plus the runoff in the catchment.	Total Blue Water	World Resources Institute	Environmental	Watershed	Quantitative	Precaution and adaptability; Social Ecological System Integrity
3	Available Blue Water	Total amount of water available to a catchment before any uses are satisfied. Calculated as all water flowing into the catchment from upstream catchments plus the runoff in the catchment	Available Blue Water	World Resources Institute	Water Supply	Watershed	Quantitative	Precaution and adaptability; Social Ecological System Integrity
4	Return Flow Ratio	Measures the percent of available water previously used and discharged upstream as wastewater.	Return Flow Ratio	World Resources Institute	Infrastructure/ Water MGMT	Region	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
5	Seasonal Variability	Measures variation in water supply between months of the year	Seasonal Variability	World Resources Institute	Water Supply	Region	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability; Social Ecological System Integrity
6	Drought Severity	Measures the average length of droughts times the dryness of the droughts from 1901-2008.	Drought Severity	World Resources Institute	Disaster MGMT	Region	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability; Social Ecological System Integrity
7	Baseline Water Stress	Measures total annual water withdrawals expressed as a percentage of the total annual available blue water.	Baseline Water Stress	World Resources Institute	Water Supply	Region	Quantitative	Precaution and adaptability; Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
8	Threatened Amphibians	Measures the percentage of freshwater amphibian species classified by IUCN as threatened	Threatened Amphibians	World Resources Institute	Environmental	Region	Qualitative	Social Ecological System Integrity
9	Water Quality- Total Dissolved Solids	Measures the portion of solids in water that can pass through a filter of a specific pore size.	Water Quality- Total Dissolved Solids	World Resources Institute	Environmental	Region	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
11	Water Quality-Electrical conductivity	Measures how easily electricity passes through water	Water Quality-Electrical conductivity	World Resources Institute	Environmental	Region	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
12	Flood Occurrence	Number of floods recorded from 1985-2011	Flood occurrence	World Resources Institute	Disaster MGMT	Region	Quantitative	Precaution and adaptability
13	Media Coverage	Measures the percentage of media articles in an area on water-related issues	Media Coverage	World Resources Institute	Social Well-Being	Region	Qualitative	Socio-ecological civility & democratic governance
14	Upstream Storage	Measures the water storage capacity available upstream of a location relative to the total water supply at that location.	Upstream Storage	World Resources Institute	Infrastructure/ Water MGMT	Watershed	Mixed	Resource Efficiency and Maintenance and Management
15	Index of non-sustainable water use	Comparison of total and agricultural water demands to renewable water supply, indicating areas where non-sustainable practices may be occurring	Index of non-sustainable water use	UNESCO	Infrastructure/ Water MGMT	Watershed	Quantitative	Resource Efficiency and Maintenance and Management
16	Rural and urban population	Spatial distribution of total global population and the spatial extent and density of human settlements with 1,000 persons or more	Rural and urban population	UNESCO	Economic	Global	Quantitative	Precaution and adaptability; Resource Efficiency and Maintenance and Management
17	Relative Water Stress Index	Domestic, industrial, and agricultural water demand per available water supply	Relative water stress index	UNESCO	Water Demand	National	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability; Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
18	Sources of contemporary nitrogen loading	Nitrogen loading onto the land mass and aquatic systems as a source for delivery to the coastal zone; a measure of potential water pollution	Sources of contemporary nitrogen loading	UNESCO	Environmental	National	Mixed	Livelihood sufficiency and opportunity; Social Ecological System Integrity
19	Domestic and industrial water demand	Domestic water demand , Industrial water demand	Domestic and Industrial water use	UNESCO	Water Demand	National	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability; Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
20	Impact of sediment trapping by large dams and reservoirs	Measures the Residence time of water held in large reservoirs; sediment trapping efficiency of large reservoirs.	Impact of sediment trapping by large dams and reservoirs	UNESCO	Infrastructure/ Water MGMT	National	Mixed	Resource Efficiency and Maintenance and Management
21	Interannual Variability	Measures the variation in water supply between years	Inter-annual variability	UNESCO	Water Supply	Region	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability; Social Ecological System Integrity
22	Coefficient of variation for climate moisture index	The CV index for the CMI is a statistical measure of variability in the ratio of plant water demand to precipitation. Useful for identifying regions with highly variable climates as potentially vulnerable to periodic water stress and/or scarcity	Coefficient of variation for climate moisture index	UNESCO	Environmental	Region	Mixed	Resource Efficiency and Maintenance and Management
23	Water Reuse Index (WRI)	Consecutive water withdrawals for domestic, industrial and agricultural water use along a river network relative to available water supplies as a measure of upstream competition and potential ecosystem and human health impacts	Water Reuse Index (WRI)	UNESCO	Water Supply	Region	Quantitative	Livelihood sufficiency and opportunity; Resource Efficiency and Maintenance and Management
24	Access to information, participation, and justice	Assessment of conditions with regard to access to information, participation, and justice in water decisions and on-going water reform process to give an indication of the inclusiveness of the reform process in water governance	Access to information, participation, and justice	UNESCO	Legal	National	Qualitative	Inter-generational and intra-generational equity; Socio-ecological civility & democratic governance
25	Assessing progress towards achieving the Integrated Water Resources Management target	Moving to a solution if IWRM requires a series of preliminary steps that can be monitored to show the progress toward meeting the target	Assessing progress towards achieving the Integrated Water Resources Management target	UNESCO	Infrastructure/ Water MGMT	Global	Qualitative	Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
26	Total actual renewable water resources per capita; inflow from other countries (dependency ratio); proportion of total actual renewable freshwater resources withdrawn.	The theoretical maximum annual volume of water resources available in a country.	Total actual renewable water resources	UNESCO	Water Supply	National	Quantitative	Resource Efficiency and Maintenance and Management
27	Groundwater development stress	Show to what extent current groundwater abstraction is or will be modifying the original groundwater regimes	Groundwater development stress	UNESCO	Water Demand	Region	Quantitative	Social Ecological System Integrity
28	**Dissolved Nitrogen	The sum of concentrations of dissolved inorganic nitrogen, specifically nitrate and nitrite in water	Dissolved Nitrogen	UNESCO	Environmental	Region	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
29	Trends in Catchment projection	Percentage of land area set aside for protection over time	Trends in Catchment projection	UNESCO	Legal	Region	Quantitative	Social Ecological System Integrity
30	Freshwater Species population Trends Index	The Freshwater Living Plant Index Tracks changes in freshwater species found in temperate and tropical freshwater ecosystems, since the baseline year of 1970	Freshwater Species population Trends Index	UNESCO	Environmental	Region	Mixed	Social Ecological System Integrity
31	Agricultural GDP as a share of total GDP	The share of the country's GDP derived from agriculture	Agricultural GDP as a share of total GDP	UNESCO	Economic	National	Quantitative	Resource Efficiency and Maintenance and Management
32	Irrigated land as a percentage of cultivated land	Area under irrigation as a proportion of total cultivated land	Irrigated land as a percentage of cultivated land	UNESCO	Environmental	National	Quantitative	Resource Efficiency and Maintenance and Management
33	Proportion of renewable water resources used for irrigated agriculture	Agriculture water withdrawals as share of total water withdrawals	Agriculture water withdrawals as share of total water withdrawals	UNESCO	Water Demand	National	Quantitative	Livelihood sufficiency and opportunity; Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
34	Land irrigation relying on groundwater	Groundwater use as share of total irrigation	Groundwater use as share of total irrigation	UNESCO	Infrastructure/ Water MGMT	Global	Quantitative	Interconnectivity from local to global scales; Social Ecological System Integrity
35	Trends in industrial water use	Trends in industrial water withdrawals and consumption, over the past 50 years	Trends in industrial water use	UNESCO	Water Demand	National	Mixed	Livelihood sufficiency and opportunity; Resource Efficiency and Maintenance and Management
36	Organic Pollution Emissions	Proportion of organic water pollution by industrial sector	Organic Pollution Emissions	UNESCO	Climate	National	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
37	Trends in ISO 14001 Certification	Number of companies that revived ISO 14001 certification; companies with this certification improve their water use efficiency and water productivity, reduce pollution and pressure on the water resources and the environment	Trends in ISO 14001 Certification	UNESCO	Economic	Global	Quantitative	Precaution and adaptability; Resource Efficiency and Maintenance and Management
38	Risk and Policy Assessment	Assessment of the efficiency of public policies for flood mitigation in terms of actual impact on physical, social, and economic features of flood disasters	Risk and Policy Assessment Indicator	UNESCO	Environmental	Global	Mixed	Precaution and adaptability
39	Climate Vulnerability Index	Assesses human vulnerability in the context of global threats to water resources	Climate Vulnerability Index	UNESCO	Climate	National	Mixed	Interconnectivity from local to global scales; Inter-generational and intra-generational equity
40	Water sector share in total public spending	Percentage of the national budget spent in water sector for expanding, rehabilitating, and maintaining water related infrastructures and improving water resources management and governance vis-à-vis other economic sectors	Water sector share in total public spending	UNESCO	Infrastructure/ Water MGMT	National	Quantitative	Interconnectivity from local to global scales
41	Comparison of actual to desired level of public investment in drinking water supply	Ratio of actual level to desired level of investment in drinking water supply	Ratio of actual to desired level of public investment in drinking water supply	UNESCO	Economic	National	Mixed	Livelihood sufficiency and opportunity; Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
42	Rate of operation and maintenance cost recovery for water supply and sanitation	Measures water fees actually collected as a percent cost of operation and maintenance in water supply and sanitation	Rate of operation and maintenance cost recovery for water supply and sanitation	UNESCO	Infrastructure/ Water MGMT	City	Quantitative	Resource Efficiency and Maintenance and Management
43	Water and sanitation charges as percentage of various household income groups	Shows how much water and sanitation charges constitute of various household income groups	Water and sanitation charges as percentage of various household income groups	UNESCO	Economic	National	Quantitative	Inter-generational and intra-generational equity
44	Population exposed to water stress	Population found in Relative Water Stress index set threshold	Population exposed to water stress	UNESCO	Social Well-Being		0	Interconnectivity from local to global scales
45	Aquifer Declines	Number and capacity of basins with years-long overdraft	Aquifer Declines	UC Davis Sustainability Indicators Group	Water Supply	Region	Mixed	Social Ecological System Integrity
46	Baseline Water Stress	Total annual water withdraws, regardless of purpose (industrial, agricultural, residential), as a total percent of the annual flow	Baseline Water Stress	UC Davis Sustainability Indicators Group	Water Demand	Region	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
47	Benefits from Water Management	Equitable distribution of economic and health benefits from water management	Benefits from Water Management	UC Davis Sustainability Indicators Group	Social Well-Being	Region	Qualitative	Inter-generational and intra-generational equity
48	Completion of stewardship actions	The completion of restoration recommendations and key actions during implementation phase of the process	Completion of stewardship actions	UC Davis Sustainability Indicators Group	Social Well-Being	State	Qualitative	Resource Efficiency and Maintenance and Management
49	Drought Resilience	Maximum severity of drought during which core water demands can still be met	Drought Resilience	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Mixed	Livelihood sufficiency and opportunity; Precaution and adaptability
50	Ecological Footprint	Measure of the amount of biologically productive land and sea area required to meet the consumption and waste production patterns of a population or process	Ecological Footprint	UC Davis Sustainability Indicators Group	Environmental	State	Quantitative	Social Ecological System Integrity
51	Energy Requirements for Water Delivery	Energy required per unit of clean drinking water delivered to consumer	Energy Requirements for Water Delivery	UC Davis Sustainability Indicators Group	Energy	State	Quantitative	Livelihood sufficiency and opportunity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
52	Equitable Decision-Making Process	For water management, diversity of participating organizations. Evaluating who is part of stakeholder and decision making processes that affect the distribution, movement, and fate of water.	Equitable Decision-Making Process	UC Davis Sustainability Indicators Group	Social Well-Being	State	Qualitative	Inter-generational and intra-generational equity
53	Flood Resilience	Maximum flood that can be experienced without exceeding a specified amount of damages	Flood Resilience	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Mixed	Precaution and adaptability
54	Greenhouse Gas Emissions	GHG emissions from land/water management, industrial/commercial activities, energy production, or transportation	Greenhouse Gas Emissions	UC Davis Sustainability Indicators Group	Climate	State	Quantitative	Social Ecological System Integrity
55	Ground water Stress	Ratio of groundwater withdrawal relative to its recharge rate over a given aquifer	Groundwater Stress	UC Davis Sustainability Indicators Group	Water Supply	Watershed	Quantitative	Resource Efficiency and Maintenance and Management
56	Historical Drought Severity	Measures the average length of droughts times the dryness of the droughts from 1901-2008.	Historical Drought Severity	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Quantitative	Precaution and adaptability
57	Historical Flooding Occurrence	Number of floods recorded from 1985-2011	Historical Flooding Occurrence	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Quantitative	Precaution and adaptability
59	Participation in local Stewardship	Rates of local stakeholders to participate in local stewardship	Participation in local Stewardship	UC Davis Sustainability Indicators Group	Social Well-Being	State	Mixed	Socio-ecological civility & democratic governance
60	Potentially unhealthy water supply	Amount of people whose drinking water supply is potentially unhealthy	Potentially unhealthy water supply	UC Davis Sustainability Indicators Group	Social Well-Being	State	Quantitative	Inter-generational and intra-generational equity
61	Storm Resilience	Maximum storm intensity that can occur without causing more than some amount in damages	Storm Resilience	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Mixed	Precaution and adaptability
62	Sustainable Water Usage	Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater	Sustainable Water Usage	UC Davis Sustainability Indicators Group	Water Supply	State	Quantitative	Precaution and adaptability; Social Ecological System Integrity
63	*Water Demand	Total Agricultural, residential, and commercial water demand	Water Demand	UC Davis Sustainability Indicators Group	Water Demand	State	Qualitative	Livelihood sufficiency and opportunity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
64	Water Footprint	Sum of water used directly or indirectly to produce goods and services consumed by humanity	Water Footprint	UC Davis Sustainability Indicators Group	Economic	State	Quantitative	Resource Efficiency and Maintenance and Management
65	Water Risk (WRI)	Risk scores were calculated and put in risk categories using scores for identified categories namely 1.Baseline water stress, 2.inter annual variability 3.Seasonal Variability 4. Flood Occurrence 5. Drought Severity 6.Upstream Storage 7.Groundwater stress 8.Return flow ratio 9.Upstream Protected Land 9. Threatened Amphibians	Water Risk	UC Davis Sustainability Indicators Group	Infrastructure/ Water MGMT	State	Qualitative	Precaution and adaptability
66	Water Scarcity Index	Water scarcity is a function of water availability and water use. Represents the over-use of water in a region	Water Stress Index	UC Davis Sustainability Indicators Group	Water Demand	Region	Mixed	Precaution and adaptability
67	Water Travel Distance	Distance traveled for units of drinking and irrigation water.	Water Travel Distance	UC Davis Sustainability Indicators Group	Water Supply	Region	Quantitative	Resource Efficiency and Maintenance and Management
68	Affordable Water Prices	Percent of drinking water suppliers which have instituted an affordable "lifeline" rate for low-income residential customers	Affordable Water Prices	UC Davis Sustainability Indicators Group	Social Well-Being	State	Mixed	Inter-generational and intra-generational equity
69	Available Water	Total water available from natural and managed flows. Calculated as all water flowing into the catchment from upstream catchment plus any imports of water the catchment minus upstream consumptive use plus runoff in the catchment	Available Water	UC Davis Sustainability Indicators Group	Water Supply	Region	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
70	Earthquake Resilience	The maximum earthquake intensity that can occur without causing more than some amount (e.g., $20 million) in damages due to water infrastructure disruptions, including levees	Earthquake Resilience	UC Davis Sustainability Indicators Group	Disaster MGMT	State	Mixed	Precaution and adaptability

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
71	Forest Land Conversion	Total acreage of forest land converted over time	Forest Land Conversion	UC Davis Sustainability Indicators Group	Environmental	State	Quantitative	Social Ecological System Integrity
72	Managed Geomorphic Flows	Magnitude and timing of managed system flows suitable for native riparian habitats and geomorphic processes	Managed Geomorphic Flows	UC Davis Sustainability Indicators Group	Environmental	Region	Qualitative	Social Ecological System Integrity
73	Non-potable water needs for agriculture	Proportion of agricultural non-potable water needs met with non-potable water.	Non-potable water needs for agriculture	UC Davis Sustainability Indicators Group	Infrastructure/ Water MGMT	State	Quantitative	Resource Efficiency and Maintenance and Management
74	Percent recycled water	Use of recycled water as a percent total of water used.	Percent recycled water	UC Davis Sustainability Indicators Group	Infrastructure/ Water MGMT	State	Quantitative	Resource Efficiency and Maintenance and Management
75	Protected aquifer recharge areas	Number of acres protected or enhanced in aquifer recharge areas	Protected aquifer recharge areas	UC Davis Sustainability Indicators Group	Environmental	Region	Mixed	Social Ecological System Integrity
76	Public support and awareness of water system protection	Amount of awareness the public holds regarding water system protection	Public support and awareness of water system protection	UC Davis Sustainability Indicators Group	Social Well-Being	State	Qualitative	Inter-generational and intra-generational equity; Socio-ecological civility & democratic governance
77	Residential water use and conservation	Average water use per household or per capita	Residential water use and conservation	UC Davis Sustainability Indicators Group	Water Demand	State	Quantitative	Resource Efficiency and Maintenance and Management
79	Percent water re-use	Volume of water re-used as a fraction of the total water used	Water re-use	UC Davis Sustainability Indicators Group	Infrastructure/ Water MGMT	State	Quantitative	Resource Efficiency and Maintenance and Management
80	Water shortage	Percent likelihood per year, over the next 20 years, of water shortage.	Water shortage	UC Davis Sustainability Indicators Group	Water Supply	State	Mixed	Precaution and adaptability
81	Water storage and use	Years of average water use at current use levels represented by the current stored volume of water.	Water storage and use	UC Davis Sustainability Indicators Group	Water Supply	State	Quantitative	Precaution and adaptability
82	Index of Biotic Integrity	Index of biotic community composition and structure, which respond to disturbance	Index of Biotic Integrity	UC Davis Sustainability Indicators Group	Environmental	Region	Mixed	Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
83	Land subsidence	Both the absolute amount of lands that have subsided and the rate of change (positive or negative) in subsidence are important measures.	Land subsidence	UC Davis Sustainability Indicators Group	Environmental	State	Mixed	Social Ecological System Integrity
84	Mercury in fish tissue	Measure of mercury in fish tissue. (for mercury to increase in concentration in fish tissue, it must be available in the environment (water and/or sediment) and methylated, usually by bacteria in hypoxic/anoxic conditions)	Mercury in fish tissue	UC Davis Sustainability Indicators Group	Environmental	Watershed	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
85	Native fish habitat and flow	Sufficient and adequate direction of flows for maintaining historically present native fish.	Native fish habitat and flow	UC Davis Sustainability Indicators Group	Environmental	Watershed	Qualitative	Social Ecological System Integrity
86	Native fish community	Ratio of observed to expected native fish species in a waterbody or watershed	Native fish community	UC Davis Sustainability Indicators Group	Environmental	Watershed	Quantitative	Social Ecological System Integrity
87	Stream condition Index	Biological index composed of indicators and metrics that represents the condition of benthic invertebrate communities living in streams and rivers	Stream condition Index	UC Davis Sustainability Indicators Group	Environmental	Region	Mixed	Social Ecological System Integrity
88	Trophic State Index	How eutrophic conditions are in a water-body. (Excess algal growth can indicate eutrophic conditions and is the basis of the index.)	Trophic State Index	UC Davis Sustainability Indicators Group	Environmental	Watershed	Qualitative	Social Ecological System Integrity
89	Water transfer benefit to local economies	Equitability of benefit realization for local economies in water-source and water-receiving regions due to water transfer	Water transfer benefit to local economies	UC Davis Sustainability Indicators Group	Economic	City	Qualitative	Inter-generational and intra-generational equity
90	Water transfer costs and benefits	Fiscal costs and benefit for local economy in water-source and water-receiving region due to water transfer	Water transfer costs and benefits	UC Davis Sustainability Indicators Group	Economic	City	Quantitative	Inter-generational and intra-generational equity
91	Abundance of key non-native species	Relative abundance trend of non-key native species	Abundance of key non-native species	UC Davis Sustainability Indicators Group	Environmental	Region	Quantitative	Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
92	Abundance trend of key indicator species at different life stages (i.e. Delta smelt, Longfin smelt, juvenile striped bass, Chinook salmon, all salmonid populations).	The well-being of regulated and culturally-important fish species is important to measure in order to understand ecosystem condition	Abundance trend of key indicator species at different life stages (i.e. Delta smelt, Longfin smelt, juvenile striped bass, Chinook salmon, all salmonid populations).	UC Davis Sustainability Indicators Group	Environmental		0	Social Ecological System Integrity
93	Amount of industrial pollutants released	Tons of industrial pollutants released and disposed into a watershed/region annually.	Amount of industrial pollutants released	UC Davis Sustainability Indicators Group	Environmental	Watershed	Quantitative	Interconnectivity from local to global scales; Social Ecological System Integrity
94	Fertilizer application rate	Rate of fertilizer applied per unit area.	Fertilizer application rate	UC Davis Sustainability Indicators Group	Economic	Region	Quantitative	Interconnectivity from local to global scales; Social Ecological System Integrity
95	Groundwater nitrate	Concentration of nitrate in groundwater	Groundwater nitrate	UC Davis Sustainability Indicators Group	Environmental	Region	Quantitative	Interconnectivity from local to global scales; Social Ecological System Integrity
96	Groundwater water quality index	Combination of general indicators to measure groundwater quality	Groundwater water quality index	UC Davis Sustainability Indicators Group	Environmental	Region	Mixed	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
97	Impervious Surface: Water Quality Index	Proportions of a watershed covered by impervious materials that prevent water from leaching directly into the soil.	Impervious Surface: Water Quality Index	UC Davis Sustainability Indicators Group	Environmental	Watershed	Quantitative	Social Ecological System Integrity
98	Periphyton cover and biomass	The amount and extent of cover of algae attached to the benthos and other underwater surfaces.	Periphyton cover and biomass	UC Davis Sustainability Indicators Group	Environmental	Watershed	Mixed	Social Ecological System Integrity
99	Pollutant and bacteria index	Composed of indicators of chemical and bacterial pollution.	Pollutant and bacteria index	UC Davis Sustainability Indicators Group	Environmental	Watershed	Mixed	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
100	Upstream protected lands	Measures the percentage of total water supply that originates from protected ecosystems	Upstream protected lands	UC Davis Sustainability Indicators Group	Environmental	Region	Quantitative	Interconnectivity from local to global scales; Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
101	Water treatment cost	Cost of water treatment	Water treatment cost	UC Davis Sustainability Indicators Group	Economic	State	Quantitative	Resource Efficiency and Maintenance and Management
102	Renewable Water Resources	Measures of the amount of water provided over time by precipitation in a region and surface groundwater flowing into the region	Renewable Water Resources	UC Davis Sustainability Indicators Group	Water Supply	Region	Mixed	Social Ecological System Integrity
103	Water Delivery	Measures percent years of system vulnerability at the upper (Lee ferry Deficit) and lower basin (Lake Mead Pool Elevation - below 1000ft Msl) to determine what percent of years the basin will be vulnerable	Water Delivery	US Department of Interior	Disaster MGMT	Region	Mixed	Precaution and adaptability
104	Electrical Power	Measures percent years of system vulnerability where the upper and lower basins will generate less than 4,450 GW/yr. For 3 consecutive years and Lake Mead pool elevation less that 1,050 feet msl.	Electrical Power	US Department of Interior	Energy	Region	Mixed	Precaution and adaptability
105	Flood Control	Measures the Critical river stage below Hoover Dam (amount of years that flow may be greater than 28,000 cubic feet per second)	Flood Control	US Department of Interior	Disaster MGMT	Region	Mixed	Precaution and adaptability
107	Recreation	Measures 3 different areas: 1. Days less than current conditions with variable hydrology for Colorado River Boating; 2. Lake Powell Shoreline facilities (pool elevation less than 3,560 feet msl); 3. Lake Mead shoreline facilities (pool elevation less than	Recreation	US Department of Interior	Social Well-Being	Region	Mixed	Precaution and adaptability
108	Ecological	Measures/projects Colorado percentage of years where Colorado river flow is less than targeted flow conditions and percentage of years where Hoover to Davis Dam flow experiences annual flow change greater than 845,000 AF	Ecological	US Department of Interior	Environmental	Region	Quantitative	Precaution and adaptability

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
109	Water Use	10-year running average from 1923-2006 and projections to 2063	Water Use	US Department of Interior	Water Demand	Region	Quantitative	Precaution and adaptability
110	Water Supply	10-year running average from 1923-2006 and projections to 2063	Water Supply	US Department of Interior	Water Supply	Region	Quantitative	Precaution and adaptability
112	Specific Conductance	Measures the ability of water to pass an electrical current.	Specific Conductance	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Social Ecological System Integrity
113	pH	Measures alkalinity or acidity concentration of a solution on a 0-14 scale.	pH	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
114	Transparency	Measures how far light can penetrate a body of water.	Transparency	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Social Ecological System Integrity
115	Nitrates	Nitrate nitrogen in excess amounts can cause an increase in algae growth, which eventually leads to decreases in dissolved oxygen.	Nitrates	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Social Ecological System Integrity
116	Stream Flow	Flow rate at which water moves through a river, creek, stream, etc.	Stream Flow	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Social Ecological System Integrity
117	E. Coli	Measured/ Estimated in number of colony-forming units per 100ml.	E. Coli	Colorado River Watch Network - Water Quality Monitoring	Environmental	Watershed	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
118	Organic Solvents	Ratio of industrial solvent trichloroethylene in water	Organic Solvents	City of Phoenix Water Services	Environmental	Watershed	Quantitative	Social Ecological System Integrity
119	Hydrocarbon Contamination	Amount of hydrocarbons from leaking service station fuel tanks in water sites	Hydrocarbon Contamination	City of Phoenix Water Services	Infrastructure/ Water MGMT	Watershed	Quantitative	Social Ecological System Integrity
120	Pesticides	Pesticide contamination of wells	Pesticides	City of Phoenix Water Services	Infrastructure/ Water MGMT	Watershed	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
121	Heavy Metals	Concentrations of heavy metal in groundwater, especially chromium	Heavy Metals	City of Phoenix Water Services	Infrastructure/ Water MGMT	Watershed	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity

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123	Arsenic	Less than 10 ppb in specific wells	Arsenic	City of Phoenix Water Services	Infrastructure/ Water MGMT	Watershed	Quantitative	Interconnectivity from local to global scales; Livelihood sufficiency and opportunity; Social Ecological System Integrity
125	Total gallons per capita	Total amount of water used per capita per day including system losses	Total gallons per capita	City of Phoenix Water Services	Water Demand	City	Quantitative	Resource Efficiency and Maintenance and Management
126	Residential GPCD	Residential GPCD by metered deliveries	Residential GPCD	City of Phoenix Water Services	Water Demand	City	Quantitative	Resource Efficiency and Maintenance and Management
127	Salt River Project urban irrigation deliveries in Phoenix	Deliveries of non-potable canal water for landscape irrigation purposes in phoenix from 2000-present	Salt River Project urban irrigation deliveries in Phoenix	City of Phoenix Water Services	Water Supply	City	Quantitative	Resource Efficiency and Maintenance and Management
128	Seasonal water use by category	Amount of water used (mgd) by single-family, multi-family, and non-residential consumers	Seasonal water use by category	City of Phoenix Water Services	Water Demand	City	Quantitative	Resource Efficiency and Maintenance and Management
129	Average Monthly water bill for southwest cities	Cost per month for water bill by southwest city	Average Monthly water bill for southwest cities	City of Phoenix Water Services	Economic	Region	Quantitative	Inter-generational and intra-generational equity; Resource Efficiency and Maintenance and Management
130	Water Demand and Average Annual Temperature	Water Demand (AF) per year and average annual temperature	Water Demand and Average Annual Temperature	City of Phoenix Water Services	Economic	City	Quantitative	Resource Efficiency and Maintenance and Management
131	Water Demand and Annual Precipitation	Water demand (AF) and annual precipitation (In)	Water Demand and Annual Precipitation	City of Phoenix Water Services	Water Demand	City	Quantitative	Resource Efficiency and Maintenance and Management
132	Rate Structure	Are rates uniform (flat), seasonal, or inclining block rates? Inclining block rates are most effective at communicating value of water. Conservation-oriented price structure makes curve slope upward	Rate Structure	Western Resource Advocates	Economic	City	Qualitative	Resource Efficiency and Maintenance and Management
133	Conservation Measures	Raise community awareness and motivate residents to use water more effectively. Use 29 measures from ADWR's MNPCCP program to provide order and consistency	Conservation Measures	Western Resource Advocates	Social Well-Being	City	Qualitative	Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
134	Conservation Ordinances	Can impact the entire utility's customer base. Use a list recognized by ADWR's MNPCCP	Conservation Ordinances	Western Resource Advocates	Economic	City	Qualitative	Resource Efficiency and Maintenance and Management
135	Funding for Conservation	Amount per capita spent on water conservation efforts.	Funding for Conservation	Western Resource Advocates	Disaster MGMT	City	Quantitative	Resource Efficiency and Maintenance and Management
136	Water Loss	Water saved by improving supply-side efficiency. Does the utility have an active leak detection and repair program?	Water Loss	Western Resource Advocates	Water Supply	City	Qualitative	Resource Efficiency and Maintenance and Management
137	Effluent Use	Re-use of liquid waste or sewage rather than discharge into a stream or river	Effluent Use	Western Resource Advocates	Infrastructure/ Water MGMT	City	Qualitative	Resource Efficiency and Maintenance and Management
138	Groundwater Withdrawal	Total groundwater withdrawal as a % of Safe Yield Estimates	Groundwater	WaterSim Sustainability Metrics	Water Supply	Region	Mixed	Social Ecological System Integrity
139	Environment Effluent	Wastewater discharge as a % of Total Stream Flow	Environment	WaterSim Sustainability Metrics	Infrastructure/ Water MGMT	Region	Quantitative	Social Ecological System Integrity
140	Agricultural Efficiency	Gallons Per Dollar of Agriculture Production Per Day	Agricultural Efficiency	WaterSim Sustainability Metrics	Economic	State	Quantitative	Resource Efficiency and Maintenance and Management
141	Urban/Rural Efficiency	Gallons of water used per capita every day in Arizona.	Urban/Rural Efficiency	WaterSim Sustainability Metrics	Water Demand	State	Quantitative	Resource Efficiency and Maintenance and Management
142	Power Efficiency	Gallons Per megawatt of power Produced Per day	Power Efficiency	WaterSim Sustainability Metrics	Energy	State	Quantitative	Livelihood sufficiency and opportunity
143	Surface Water	Withdrawal by water Treatment plants as a % of stream flows	Surface Water	WaterSim Sustainability Metrics	Water Supply	State	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
144	Economy	Local water used for goods production as % of total water use	Economy	WaterSim Sustainability Metrics	Water Supply	City	Mixed	Resource Efficiency and Maintenance and Management
145	Current Supplies	The city's demand for water as a percent of all readily available supplies	Current Supplies	Kyl Center Water Scorecards	Water Demand	City	Quantitative	Livelihood sufficiency and opportunity; Precaution and adaptability

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
146	Future Supplies	What is the city's capacity to meet increased future demand?	Future Supplies	Kyl Center Water Scorecards	Water Demand	City	Qualitative	Precaution and adaptability
147	Infrastructure management	Is the water infrastructure vulnerable to significant amounts of system loss?	Infrastructure management	Kyl Center Water Scorecards	Infrastructure/ Water MGMT	City	Qualitative	Precaution and adaptability
148	Contingency Planning	Is surface water prioritized over the use of groundwater supply? Are recovery programs, aquifer storage, or other measures being taken to ensure against drought?	Contingency Planning	Kyl Center Water Scorecards	Climate	City	Qualitative	Resource Efficiency and Maintenance and Management
149	Water Consciousness	Are residents and the city aware of water consumption and scarcity issues with water? Is the city promoting water-saving projects, or boosting awareness?	Water Consciousness	Kyl Center Water Scorecards	Social Well-Being	City	Qualitative	Resource Efficiency and Maintenance and Management
182	State Agency in charge Drinking Water conservation	Presence and enforcement of regulation for water consumption showerheads	State Agency in charge Drinking Water conservation	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
183	Water consumption regulation for toilets	Presence and enforcement of regulation for urinals.	Water consumption regulation for toilets	Alliance for Water Efficiency and Environmental Law Institute	Water Demand		0	Resource Efficiency and Maintenance and Management
184	Showerheads water consumption regulation	Presence and enforcement of federal standard for residential and commercial family-sized clothes washers requires a water factor (WF) of 9.5 or less.	Showerheads water consumption regulation	Alliance for Water Efficiency and Environmental Law Institute	Water Demand		0	Resource Efficiency and Maintenance and Management
185	Water consumption regulation for pre-rinse spray valves	Presence and enforcement of water consumption regulation for pre-rinse spray valves	Water consumption regulation for pre-rinse spray valves	Alliance for Water Efficiency and Environmental Law Institute	Water Demand		0	Resource Efficiency and Maintenance and Management
186	Mandatory building or plumbing codes	Presence and enforcement of mandatory building or plumbing codes	Mandatory building or plumbing codes	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
187	Water loss regulation or policy	Presence and enforcement of water loss regulation or policy	Water loss regulation or policy	Alliance for Water Efficiency and Environmental Law Institute	Infrastructure/ Water MGMT		0	Resource Efficiency and Maintenance and Management
188	Conservation activities as part of water permitting process	Presence and enforcement of conservation activities as part of water permitting process	Conservation activities as part of water permitting process	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
189	Drought emergency plans	Presence and enforcement of drought emergency plans	Drought emergency plans	Alliance for Water Efficiency and Environmental Law Institute	Infrastructure/ Water MGMT		0	Resource Efficiency and Maintenance and Management
190	Conservation planning required separate from drought plan	Requirement of conservation planning required separate from drought plan	Conservation planning required separate from drought plan	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
191	Authority to approve or reject conservation plans	Established process and authority to approve or reject conservation plans	Authority to approve or reject conservation plans	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
192	Water conservation plans requirements	How often are water conservation plans required	Water conservation plans requirements	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
193	Planning framework or methodology	Presence of framework or methodology in applying for water use	Planning framework or methodology	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
194	Implementation of conservation measures required	Presence and enforcement of conservation measures	Implementation of conservation measures required	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
195	State funding for urban water conservation programs	Presence of state funding for urban water conservation	State funding for urban water conservation programs	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
196	Technical assistance for urban water conservation programs	Presence of Technical assistance	Technical assistance for urban water conservation programs	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
197	Does the state require volumetric billing	Volumetric billing required	+ Does the state require volumetric billing	Alliance for Water Efficiency and Environmental Law Institute	Legal		0	Resource Efficiency and Maintenance and Management
198	Percent of publicly supplied connections that are metered	Presence of publicly supplied connections that are metered	Percent of publicly supplied connections that are metered	Alliance for Water Efficiency and Environmental Law Institute	Infrastructure/ Water MGMT		0	Resource Efficiency and Maintenance and Management
199	ET microclimate information for urban landscapes	Presence and consideration of microclimate information	ET microclimate information for urban landscapes	Alliance for Water Efficiency and Environmental Law Institute	Water Demand		0	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
200	Per Capita Water use	Single family homes daily water consumption.	Per Capita Water use	Energy and Resources Group	Disaster MGMT	City	Quantitative	Resource Efficiency and Maintenance and Management
201	Average Flow	Average flow rate of water compared to historic flows of the river	Flow	Conservation Colorado	Environmental	Region	Quantitative	Precaution and adaptability; Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
202	Water Quality	Amount of pollution, dissolved oxygen and other foreign contaminants that threaten the quality of water on plants, animals, and humans	Water Quality	Conservation Colorado	Environmental	Region	Mixed	Social Ecological System Integrity
203	Water Diverted out of Basin	Amount of water taken from the river and moved through canals or other vessels for human use	Water Diverted out of Basin	Conservation Colorado	Water Demand	Region	Quantitative	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
204	Major Dams	Number of dams that have an impact on water flow in Colorado River and its tributaries in Colorado	Major Dams	Conservation Colorado	Infrastructure/ Water MGMT	Region	Quantitative	Resource Efficiency and Maintenance and Management
205	Other Factors	Social and Economic benefit from rivers, such as fishing, rafting, and boating	Other Factors	Conservation Colorado	Social Well-Being	Region	Qualitative	Inter-generational and intra-generational equity
206	Legal Authorization	Questions pertaining to whether or not legal authorization is for environmental transfers and whether the authorization of environmental rights is in any way restricted.	Legal Authorization	Water in The West	Legal	State	Qualitative	Inter-generational and intra-generational equity
207	Protection of Environmental Water Rights	Legal and Practical protection for water left upstream through environmental transfers	Protection of Environmental Water Rights	Water in The West	Legal	State	Qualitative	Inter-generational and intra-generational equity
208	Scope of environmental Water Rights	Assessed whether or not environmental water rights are subject to limitations that do not apply to other water rights and whether the state has financial resources and personnel dedicated to protecting streamflow and facilitating environmental water trans	Scope of environmental Water Rights	Water in The West	Legal	State	Qualitative	Inter-generational and intra-generational equity
209	Process for applying environmental water transfers	Compares administrative and judicial processes needed to approve environmental water transfers among the various states and assess whether the level of review is well tailored to the nature of the transfer.	Process for applying environmental water transfers	Water in The West	Legal	Region	Qualitative	Inter-generational and intra-generational equity
216	Total Coliform bacteria	Measures the total amount of fecal coliform, enterococcus bacteria, and E. Coli bacteria in an area	Total Coliform bacteria	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity
217	Turbidity	Measures the cloudiness or transparency of a body of water	Turbidity	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
218	Salinity	Saltiness or Dissolved salt content in a body of water	Salinity	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity
219	Hydrogen Sulfide Concentration	Amount of hydrogen sulfide present in a body of water	Hydrogen Sulfide Concentration	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity
220	Inorganic water chemistry	Measures the amount of inorganic water, nutrients, organic water, and total coliform bacteria in water	Inorganic water chemistry	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity
221	Fish tissue chemistry	Measures if fish and other aquatic resources are safe to eat based off fish tissue chemistry and fecal coliform bacteria in water.	Fish tissue chemistry	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Social Ecological System Integrity
222	Biological responses	Are aquatic populations, communities, and habitats protected from water and sediment toxicity?	Biological responses	Surface Water Ambient Monitoring Program	Environmental	Watershed	Qualitative	Social Ecological System Integrity
223	Pollutant exposure	Are aquatic populations protected from pollutant exposure? measured/ estimated through organic and inorganic sediment chemistry, total organic carbon, fish tissue chemistry, turbidity, and inorganic and organic water chemistry	Pollutant exposure	Surface Water Ambient Monitoring Program	Environmental	Watershed	Mixed	Social Ecological System Integrity
224	Habitat	Are aquatic populations protected from living in a dangerous habitat? measured/ estimated by dissolved oxygen, sediment grain size analysis, sediment organic carbon, electrical conductivity, salinity, hydrogen sulfide, and ammonia levels.	Habitat	Surface Water Ambient Monitoring Program	Environmental	Watershed	Mixed	Social Ecological System Integrity
225	Amount of debris and trash	Measures the amount of pollutants that damage the aesthetic conditions of the water	Amount of debris and trash	Surface Water Ambient Monitoring Program	Environmental	Watershed	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
226	Groundwater-Level Declines	Long-term declines in ground water levels occur when withdrawal exceeds recharge of an aquifer	Groundwater-Level Declines	California SGMA	Water Supply	Watershed	Quantitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
227	Land subsidence	Settling or sinking of surface due to changing subsurface compositions	Land subsidence	California SGMA	Environmental	Region	Mixed	Social Ecological System Integrity
228	Groundwater-Storage Reductions	Long-term declines in groundwater levels cause long-term reductions in groundwater storage. Estimated by using direct measurements coupled with remote modeling tools over time	Groundwater-Storage Reductions	California SGMA	Water Supply	Watershed	Mixed	Livelihood sufficiency and opportunity; Social Ecological System Integrity
229	Interconnected Surface-Water Depletions	Measure of surface water levels in streams, rivers, lakes, etc. Coupled with groundwater levels of the same period.	Interconnected Surface-Water Depletions	California SGMA	Environmental	Region	Mixed	Social Ecological System Integrity
230	Water-Quality Degradation	Determining changes in groundwater quality over time involves systematic monitoring of the constituents of concern, coupled with understanding of the dynamics of the groundwater-flow system.	Water-Quality Degradation	California SGMA	Environmental	State	Mixed	Social Ecological System Integrity
231	Renewable Water Resources	Measures of the amount of water provided over time by precipitation in a region and surface groundwater flowing into the region	Renewable Water Resources	UC Davis Sustainability Indicators Group	Water Supply	Region	Mixed	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
232	Water in the Environment	Amount of water remaining in the environment after human use	Water in the Environment	UC Davis Sustainability Indicators Group	Environmental	Region	Quantitative	Social Ecological System Integrity
233	water use sustainability	Measures the degree to which water use meets current needs while protecting ecosystems and the interests of future generations	water use sustainability	UC Davis Sustainability Indicators Group	Water Demand	Region	Qualitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
234	Quality of water for human uses	Measures the quality of water used for drinking, recreation, industry, and agriculture	Quality of water for human uses	UC Davis Sustainability Indicators Group	Social Well-Being	Region	Qualitative	Livelihood sufficiency and opportunity
235	Quality of water for the environment	Measures the quality of water supporting flora and fauna and related ecosystem processes	Quality of water for the environment	UC Davis Sustainability Indicators Group	Environmental	Watershed	Qualitative	Social Ecological System Integrity

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
236	Water Quality Sustainability	Composite measures of the degree to which water quality satisfies human and ecosystem needs	Water Quality Sustainability	UC Davis Sustainability Indicators Group	Environmental	State	Qualitative	Social Ecological System Integrity
237	Withdrawal and use of water	Measures the amount of water withdrawn from the environment and the end use	Withdrawal and use of water	UC Davis Sustainability Indicators Group	Water Demand	State	Mixed	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
238	human uses of water in the environment	Measures the extent to which people use water resources for waste assimilation, transportation, and recreation	human uses of water in the environment	UC Davis Sustainability Indicators Group	Economic	Region	Qualitative	Resource Efficiency and Maintenance and Management
239	Water-dependent resource use	Measures the extent to which people use resources like fish and shellfish that depend on water resources	Water-dependent resource use	UC Davis Sustainability Indicators Group	Economic	Region	Qualitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
240	Human Health	Measures the extent to which human health may be affected by the use of water and related resources	Human Health	UC Davis Sustainability Indicators Group	Social Well-Being	Region	Qualitative	Livelihood sufficiency and opportunity
241	Indices of Biological Condition	Measures of the health of ecosystems	Indices of Biological Condition	UC Davis Sustainability Indicators Group	Environmental	State	Mixed	Social Ecological System Integrity
242	Amount and Quality of living resources	Measures the productivity of ecosystems	Amount and Quality of living resources	UC Davis Sustainability Indicators Group	Environmental	State	Mixed	Social Ecological System Integrity
243	capacity and reliability of infrastructure	Measures the ability of infrastructure to meet and provide human and ecosystem needs	capacity and reliability of infrastructure	UC Davis Sustainability Indicators Group	Infrastructure/ Water MGMT	State	Qualitative	Livelihood sufficiency and opportunity; Social Ecological System Integrity
244	Efficacy of institutions	Measures the prevalence of legal and institutional frameworks in managing water and related-resources sustainably	Efficacy of institutions	UC Davis Sustainability Indicators Group	Social Well-Being	State	Qualitative	Precaution and adaptability
249	Colorado River Basin Supply and use	10-years average water supply and 10-year water use on a line chart from 1923-2006	Colorado River Basin Supply and use	National Academy of Engineering	Water Supply	Region	Mixed	Resource Efficiency and Maintenance and Management; Social Ecological System Integrity
250	Reconstruction of Colorado River flows at Lees Ferry, AZ	Annual values and a five-year moving average represented on a line chart.	Reconstruction of Colorado River flows at Lees Ferry, AZ	National Academy of Engineering	Water Supply	Region	Quantitative	Livelihood sufficiency and opportunity; Resource Efficiency and Maintenance and Management

ID	Indicator	Definition	Metric	Original System	Category	Geographic Scale	Data Type	Sustainability Principles
251	Dam Density	Density of medium to large dams per 0.5 x 0.5 degree grid cell	Dam Density	UNESCO	Infrastructure/ Water MGMT	Global	Quantitative	Resource Efficiency and Maintenance and Management
252	Disinfection Byproducts (Surface Water)	Organic byproducts in surface water	Disinfection Byproducts (Surface Water)	City of Phoenix Water Services	Environmental		0	Inter-generational and intra-generational equity; Social Ecological System Integrity
253	Pharmaceuticals and Endocrine	Pharmaceutically active compounds in drinking water	Pharmaceuticals and Endocrine	City of Phoenix Water Services	Environmental		0	Inter-generational and intra-generational equity; Social Ecological System Integrity

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