CODEX PLANETARIUS

Proposed Water Quantity Standards for *Codex Planetarius*

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About *Codex Planetarius*

Codex Planetarius is a proposed system of minimum environmental performance standards for producing globally traded food. It is modeled on the *Codex Alimentarius*, a set of minimum mandatory health and safety standards for globally traded food. The goal of Codex Planetarius is to measure and manage the key environmental impacts of food production, acknowledging that while some resources may be renewable, they may be consumed at a faster rate than the planet can renew them.

The global production of food has had the largest impact of any human activity on the planet. Continuing increases in population and per capita income, accompanied by dietary shifts, are putting even more pressure on the planet and its ability to regenerate renewable resources. We need to reduce food production's key impacts.

The impacts of food production are not spread evenly among producers. Data across commodities suggest that the bottom 10-20% of producers account for 60-80% of the impacts associated globally with producing any commodity, even though they produce only 5-10% of the product. We need to focus on the bottom.

Once approved, *Codex Planetarius* will provide governments and trade authorities with a baseline for environmental performance in the global trade of food and soft commodities. It won't replace what governments already do. Rather, it will help build consensus about key impacts, how to measure them, and what minimum acceptable performance should be for global trade. We need a common escalator of continuous improvement.

These papers are part of a multiyear proof of concept to answer questions and explore issues, launch an informed discussion, and help create a pathway to assess the overall viability of *Codex Planetarius*. We believe *Codex Planetarius* would improve food production and reduce its environmental impact on the planet.

This proof-of-concept research and analysis is funded by the Gordon and Betty Moore Foundation and led by World Wildlife Fund in collaboration with a number of global organizations and experts. For more information, visit www.codexplanetarius.org

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Abstract

Codex Planetarius is a proposed set of environmental production standards for application to the global trade of agricultural commodities. The intent is to establish minimum acceptable levels of environmental protection with a focus on performance rather than practice across a range of measures, including habitat and biodiversity loss, greenhouse gas emissions (GHG) emissions, soil health, and water. This paper outlines considerations for a *Codex* water use standard that at the present time focuses on the condition of the water sources used, rather than farm-level water productivity, due to a lack of adequate information at the farm level. A focus on the condition of water sources aligns the standard with a range of sustainability considerations including the avoidance of natural resource depletion and related ecosystem damage and promotes collective action to create a sustainable water balance. A focus on water sources will also help to supplement farm-level metrics when they become available in the future because farm-level metrics based on water productivity do not in themselves ensure the sustainability of the water sources. The current proposal is based therefore on a standard that promotes a goal of maintaining dynamically stable or increasing water supplies for both human communities and freshwater ecosystems: *All blue water used in food production will be extracted from sources that are not depleted from over-extraction.*

Meeting this standard will require two levels of assessment and action: (1) if the water source is experiencing ongoing depletion, water consumption must first be reduced to a level that balances consumption with replenishment, resulting in stabilization of the water source; and (2) if the stabilized level of depletion does not adequately provide for environmental flows in affected rivers, additional reduction of water consumption must be achieved to attain ecological sustainability. The paper outlines specific indicators to evaluate compliance to this standard with an emphasis on the importance of long-term monitoring of groundwater levels and river flows and ensuring that these remain stable or increase over time, fluctuating within natural ranges, and are sustained at a level that supports environmental flow needs. It also outlines real-world examples of this approach from France, the USA, and Australia to illustrate the impact of over-extraction, the need for sustainable water management, and measurement and trend considerations for *Codex*. An appendix outlines how the standard can be modified once acceptable farm-level productivity metrics can be developed.

Conceptual Foundations

Global Water Cycle

One of the first things grade school students are taught about water is the "water cycle." The water cycle is usually portrayed as a pictorial diagram showing how water moves on the Earth's surface and through its atmosphere **(see Figure 1, page 8)**. **Figure 2 (page 8)** provides quantification of the flows of water through the global water cycle. Of all the water that falls from the sky as precipitation (rain or snow), nearly two-thirds is quickly evaporated from soils or transpired by plants (both wild and cultivated); this is commonly referred to as "green water." The remaining one-third of precipitation ends up as "blue water" that moves through rivers, lakes, and underground aquifers (groundwater). The *Codex* standard proposed here relates only to blue water use.

Presently, humans are extracting a little more than 4,000 cubic kilometers (=4,000 billion cubic meters or BCM) of blue water each year (Figure 2).[1] This represents ~10% of the blue water that replenishes rivers, lakes, and aquifers each year.[2] That would seem to be a modest impact on the water cycle, but it's not appropriate to assess our impacts on the water cycle from a global perspective because our impacts on the planet's water sources are highly localized.

Water is Local

Unlike human impacts on the atmosphere and climate, in which an individual's or business' greenhouse gas emissions are dispersed into the atmosphere and contribute to global climate change, our individual or community's impacts on water tend to be highly localized, primarily affecting nearby water sources, and the degree of impact varies among individual water sources. This is because the blue water sources on our planet are largely discrete and separated from each other, and the nature of our impacts differs from source to source depending on the volume of our extractions and the rate at which each source is being replenished. Rivers and lakes are separated by catchment (watershed) divides, and aquifers are replenished within discrete recharge areas. When we extract water from a particular blue water source, the impacts of our water diversions usually do not affect other sources. One important exception is the case in which water from another water source is being imported into the local basin; in this situation, both the local water source as well as the source from which water is being imported will need to be assessed.

It may be helpful to consider the analogy of blue water sources (rivers, lakes, aquifers) as bathtubs **(Figure 3, page 9)**. The quantity of water moving through a river or residing in a lake or aquifer at any given time is generally dependent upon how much water is entering the water source (faucet) and how much is being lost due to evaporation and human extractions (the drain). This balance between gains and losses is the crux of sustainable water management; when losses exceed gains, the water source will be depleted, i.e., the level of tub water will go down.

Direct and Indirect Uses of Water

The water used by any individual or business unit for domestic purposes or a business operation (i.e., an area of farmland or a manufacturing plant) is typically drawn from only a very small number of the many thousands of blue water sources around our planet; in most cases, water users depend upon a single local water source. For example, a city or dairy located in Arizona (US) is not going to use water from the Congo River in Africa, because while it may be physically possible to transport Congolese water to Arizona, the cost would be prohibitively expensive. Instead, each water user is going to utilize only those water sources that are physically accessible and affordable to use. This tends to connect water users with water sources that are quite local, such as a nearby river or aquifer. When additional water is being imported into a local basin, the condition of the water source(s) from which water is being imported will need to be assessed as well.

The geographic scope of a water user's impact can expand greatly when considering the virtual water embedded in consumer goods or supply chain inputs. For example, a dairy may depend upon feed crops grown far away, hence the water use impacts of the dairy need to include both the water consumed at the dairy as well as the water consumed in producing the feed crops. If the water sources affected by this virtual water transport ('indirect' water) can be identified, they can be evaluated in the same manner as suggested above for 'direct' water uses such as domestic purposes or manufacturing operations, i.e., as 'multi-local' (or multiple bathtub) impacts. Water use standards can be applied both to direct use of water, as well as indirect use.

Unsustainable Water Use in Farming Regions

Many farming regions around the globe became highly vulnerable to water shortages in the latter half of the past century as they became reliant on every cubic meter of the annually replenished water supply, i.e., the outflow of the bathtub drain approached, and in many places exceeded, the rate of replenishment (faucet). Farmers then began experiencing recurring shortages when droughts reduced the replenishment of rivers and lakes, and water levels in reservoirs and aquifers dropped.[4]

Climate change began further reducing the replenishment of rivers, lakes, and aquifers in recent decades, leading to accelerated depletion. Even 'dryland' farmers previously dependent only on rainfall to water their crops have begun to experience increasingly serious 'green water' shortages, causing many to begin irrigating their crops for the first time.

Farmers have generally not adapted well to these recurring shortages, meaning they have not lowered their consumptive use to the degree needed to balance replenishment and consumption for long-term sustainability. As a result, nearly three-fourths of irrigated farming is exposed to water shortages[5] and more than one-quarter of the world's irrigated food production today relies on unsustainable groundwater extraction.[6] In 2018, more than 13,000 irrigated farms encompassing nearly 623,000 ha in the United States reported interruptions in irrigation supplies that impacted crop yields. Due to water shortages in 2021 and 2022, farmers in the Central Valley of California — one of the most productive agricultural regions in the world — had their water deliveries cut by 43%, resulting in the fallowing of more than 304,000 ha (10% of farmland), direct economic losses of US$1.7 billion and the loss of 12,000 farm jobs. The North China Plain — one of China's most important agricultural regions — has experienced one of the most serious cases of large-scale overexploitation of a water source. In the past 60 years, the region's groundwater levels have dropped continuously at a rate of 0.5–2 meters per year.[7]

Sustainability Definitions and Implementation Challenges

Defining Sustainability

The concept of sustainability gained a lot of traction in 1987 when the United Nations' Brundtland published its report on Our Common Future, in which sustainability was defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

There are now many derivatives of this sustainability concept including the following:

- **Oxford Dictionary:** "the ability to be maintained at a certain rate or level, i.e., 'the sustainability of economic growth;' avoidance of the depletion of natural resources in order to maintain an ecological balance."
- **Merriam-Webster Dictionary:** "of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged."
- **Cambridge Dictionary:** "the quality of causing little or no damage to the environment and therefore able to continue for a long time."

There have also been numerous efforts to characterize sustainability with respect to water use. For instance, water expert Peter Gleick defined sustainable water management as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it."[8] With reference to groundwater use, Brian Richter and Melissa Ho of the World Wildlife Fund offered this vision for groundwater sustainability in agriculture: "Our use of groundwater in the short term must not jeopardize its future availability for human use, nor its continued sustenance of freshwater ecosystems… We need to monitor and manage our groundwater use such that aquifer levels and exchanges between groundwater and surface waters remain dynamically stable and resilient, especially in the face of climate change."[9]

In essence, when each of the above definitions of sustainability are translated to water management, they suggest that the water levels in lakes or aquifers should not decline over time, and river flows should not be depleted. We need to maintain, and in many cases restore, the volume of water in the bathtub to a level that supports ecological functions and greatly reduces the risks of water shortages.

Implementation Approaches and Challenges

There have been many efforts to operationalize the concept of sustainable water management.

United Nations

The United Nations adopted a suite of Sustainable Development Goals in 2015 that includes Target 6.4: "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity." Target attainment was initially assessed solely based on improvements in water-use efficiency, measured as the ratio of dollar value added by each unit of additional water use. Unfortunately, such a measure offers very little insight into whether progress is being made to "ensure sustainable withdrawals" because there is no direct evaluation of the status of the blue water sources being exploited. However, in 2019 an important indicator (6.4.2) was integrated into assessments of Target 6.4.[10] Indicator 6.4.2 involves an evaluation of "water stress" that incorporates consideration of environmental flows by calculating water stress (%) as the ratio of total freshwater withdrawn by all economic sectors divided by the difference between the total renewable freshwater resources and the environmental flow requirements, multiplied by 100. To determine an 'acceptable' level of water stress, the guidance for indicator 6.4.2 suggests that countries should first determine the current "Ecological Management Class" of each river, ranging from grades 'A' (natural) to 'E' (seriously modified), and then adopt the water stress level appropriate for the existing management class. It should be noted that while this approach may protect the existing condition of rivers, it does not require restoration of rivers that are already heavily depleted (i.e., management classes C-E), except for rivers in the 'E' class which are required to be restored to at least a 'D.'

European Union

In 2000, the European Union adopted a "Water Framework Directive" that set standards and monitoring requirements for the more than 110,000 blue water sources in its member countries. For rivers and lakes, the standards for achieving "high ecological status" are focused on maintaining "undisturbed" conditions: "There are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydro-morphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions." This would imply that river flows and lake levels have remained unaltered from historic conditions. In contrast, the Directive's standards for a high rank for groundwater state that: "The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction." In other words, the level of water in the bathtub is not declining. As of 2021, only 37% of blue water sources in the EU were ranked with good status, even though the implementing act called for achieving good status in all water sources by 2015.

Water Stewardship Certification

Similarly, the approach taken in developing an "International Water Stewardship Standard" by the Alliance for Water Stewardship (AWS) requires certification applicants to articulate their plan for achieving a "sustainable water balance" within each of the entity's water-supply catchments. The AWS defines sustainable water balance as "…the condition whereby ongoing water use in the catchment has no long-term negative impact on the natural environment and legitimate water users. It is typically assessed on an annual timescale. For a sustainable balance, total net water abstractions do not exceed natural replenishment of water bodies, while also ensuring water bodies maintain viable flows and water levels to sustain themselves, and the species that depend on them, in a healthy condition. A condition where outflows are consistently larger than inflows is a non-sustainable water balance." Importantly, the AWS provides detailed guidance and tutorials on data collection and analysis needed to evaluate whether a sustainable water balance has been achieved. At the end of 2023, the AWS had certified 274 business operations in 62 countries.

Science Based Target Network

The Science Based Targets Network is a civil-society and science-led initiative founded in 2019 by a group of global non-governmental organizations (NGOs) who have come together to help collectively define what is necessary for companies and cities to do "enough" to stay within Earth's limits and meet society's needs. Drawing from the best available science on ecological thresholds and societal needs, the guidance produced by the network helps companies comprehensively quantify their environmental impacts across their operations and value chains and then move to precise and credible action at landscape-level. The network has developed a guidance document to support companies in their efforts to achieve the science-based targets.

Local and state governments

Additionally, many local and state/provincial governments striving to manage water sustainably have imposed formal limits or "caps" on the volume of allowable extractions or the level/elevation at which a blue water source needs to be maintained. Wright and others (2025[11]) reviewed nearly 50 case studies from around the globe and concluded that more than 40% of the cases assessed appear to be achieving their sustainability targets. The authors offered six recommendations to help ensure success in setting and administering a sustainability limit, each of which will be pertinent in implementing the *Codex Planetarius* standard proposed herein as discussed below:

- Clearly state the purpose of the cap and its intended outcomes;
- Ensure that the cap is defined in easily understood quantitative terms, and can be applied to individual water users;
- Acknowledge that if water use already exceeds available water supplies, implementing a moratorium on new uses will not be adequate to achieve sustainable levels of water use;
- Prioritize transparent and honest communication regarding the anticipated impacts and benefits of the cap, especially if water-use reductions are required;
- Plainly define how caps will be implemented and success will be evaluated by ensuring that necessary monitoring mechanisms are in place; and
- Verify the implementing entity has the legal authority to enforce the cap.

A Proposed *Codex Planetarius* Standard for Water Quantity

One of the key findings from the Wight, et. al., paper cited above is that water sustainability initiatives are most effective when they measure performance by individual water users as well as the condition of the water source being used. This helps to reveal how individual actions accumulate to influence the condition of the water source. For example, a farmer-centered metric could set a benchmark level of water productivity that must be achieved, with the hope that the water-use behaviors of less productive farmers could eventually be improved to the benchmark level. Water productivity can be measured as revenue earned per unit of blue water used, or as the volume of crop produced per unit of blue water used. This would help to ensure that water is being used carefully and is generating an optimal level of farm revenue or crop production, and it would presumably also benefit the condition of water sources.

However, improvements in water productivity do not in themselves ensure the sustainability of a water source, for various reasons. For example, a primary means of increasing farm water productivity is to apply irrigation water more efficiently — such as by shifting from flood irrigation to drip irrigation — but efficiency-based programs have been harshly criticized around the globe because in most instances the water conserved through greater irrigation efficiency is simply used to grow more crops, which ironically often leads to higher levels of water consumption and no improvement in the condition of the water source being used (this irony is known as the "irrigation efficiency paradox"[12]). For this reason, water productivity metrics must always be accompanied by metrics reflecting the condition of the water source.

Unfortunately, the data and analysis needed to set appropriate farm-level benchmark targets for individual crops in each hydroclimatic region around the globe do not yet exist. **Figure 4 (page 9)** illustrates the farm water processes that would need to be quantified in evaluating a farmer's water performance. Properly evaluating a farmer's water productivity will require not just estimates of how much water crops are consuming ('beneficial consumption' in Figure 4) but also how much water is being 'wasted' to non-beneficial consumption.

When additional information about regional irrigation practices becomes available — such as the percentage of farms using flood irrigation vs. sprinkler or drip irrigation — some reasonable estimates of the non-beneficial consumption associated with each irrigation practice can be made based on 'irrigation efficiency ratios, i.e., the ratio of beneficial to total consumption (beneficial + non-beneficial). However, mapping of irrigation practices exists for only a limited number of regions at this time.

Lastly, another hurdle in implementing a farm-based performance metric is the challenge of setting an appropriate level of water-use performance. The proper way to do this requires an extensive benchmarking exercise such as was performed by Marston, et. al., (2020)[13] for the USA **(Figure 5, page 10)**, in which a distribution of water productivity is developed for each crop within each climatic region, and a standard is then set for 'high' performance, such as at the "Top 25th percentile" of all producers of the crop. However, such an exercise requires extensive and accurate local data on crop yields. In the Marston, et. al., analysis, the researchers were able to use county-level data on crop yields provided by the US Department of Agriculture, which are available only in a few other regions in the world.

Given shortcomings in our ability to set farm-level metrics, the water quantity standard proposed here focuses solely on the condition of the water sources being used:

All blue water used in food production will be extracted from sources that are not depleted from over-extraction.

Justification

Maintaining dynamically stable or increasing water supplies at a level supportive of environmental flows is crucial to the long-term health and sustainability of both human communities and freshwater ecosystems. When water sources are being diminished from over-extraction, less renewable water is available to support food production and aquatic life, and what remains can become increasingly difficult to access for human use.

For instance, as groundwater levels fall, the electricity cost of pumping the water from deeper levels can become prohibitive or wells can go completely dry. Seepage of water from aquifers is also a critically important source of water for rivers, wetlands, and lakes, and as groundwater levels drop the discharge into these water sources will decrease.

Sustaining adequate normal or low flows in rivers is of great ecological and economic importance. The amount of water moving through a river determines the depth of water, which can enable or impair the ability to divert water into irrigation canals. The amount of water moving through a river also dictates the volume of habitat available for aquatic organisms and access to water for terrestrial animals, and it influences water temperature, oxygen, and other aspect of water chemistry that determine which species can exist in a river.

The proposed standard is strongly aligned with the sustainability definitions presented above because it focuses on avoiding depletion of a natural resource and, where necessary, restoring water levels to arrest damage to ecosystems.

The huge advantage of a standard focused on water sources is that it motivates collective action, because farmers using a non-sustainable water source would need to work together to reduce consumption to the point that the water source comes back into an ecologically sustainable balance.

Metrics for Evaluating Compliance with Standard

Meeting this standard will potentially require two levels of assessment and action: (1) if the water source is experiencing ongoing depletion, water consumption must first be reduced to a level that balances consumption with replenishment, resulting in stabilization of the water source; and (2) if the stabilized level of depletion does not adequately provide for environmental flows, additional reduction of water consumption must be achieved to attain ecological sustainability. The specific indicators, measurement approaches, and data sources relevant to the two levels of action are described below.

Halting Depletion of Water Sources

Metric 1.1 Groundwater levels remain stable or increase over time, fluctuating within natural ranges of interannual variation (i.e., driven by climate variability) but not indicating downward trends.

- **Indicator:** Trend in interannual water table elevation or depth to groundwater
- **Measurement:** Water table elevation or depth to groundwater values are being collected by many governmental agencies at individual monitoring wells, in meters or feet. While even a few years of data can begin to reveal trends, wells that have been measured for at least 10 years and continue to be measured are strongly preferred for evaluating compliance with the *Codex Planetarius* standard. The well(s) selected for evaluation must be from the same aquifer that is being used for agricultural production and located as close as possible to the farms of interest.
- **Alternative measurement:** For water sources that are not being measured presently, hydrologic (groundwater) simulation models can be used to estimate trends in aquifer levels. However, such models require specialized expertise to operate, or to extract model outputs for a specific water source. This approach would likely necessitate

partnership agreements with groundwater modeling teams to provide the desired trends.

- **Default calculation:** 10+-year linear trend in annual values, calculated within Excel spreadsheet.
- **Data sources (measurements taken at groundwater monitoring wells):** Both global and country- or state-specific databases are available as described below.

Global database: Groundwater monitoring data are available for many countries and aquifers through the Global Groundwater Monitoring Network (GGMN) that was recently supplemented by a research team that spent years compiling and curating a dataset of 170,000 monitoring wells. For about half of these wells, the responsible authorities, data owners or data providers have given approval to share them through the GGMN. In this online viewer, users can browse over regions of interest, visualize the trend indicators, and consult the monitoring data charts. The GGMN is a participative, web-based network of networks, set up to improve quality and accessibility of groundwater monitoring information and subsequently our knowledge on the state of groundwater resources. GGMN is a UNESCO program, implemented by IGRAC and supported by many global and regional partners.

Examples of country-specific (state, provincial, or national) databases:

Canada

- **Alberta (57 sites):** http://environment.alberta.ca/apps/GOWN/#
- **Saskatchewan (69 sites):** https://www.wsask.ca/water-info/ground-water/observation-well-network/

United States

- https://dashboard.waterdata.usgs.gov/app/nwd/?region=lower48&aoi=default

Mexico

- https://sigagis.conagua.gob.mx/rp20/

(Note: Unfortunately, very few data are available for groundwater wells in Mexico)

Metric 1.2 River baseflows (groundwater discharges into rivers) or low flows remain stable or increase over time, fluctuating within natural ranges of interannual variation (i.e., driven by climate variability) but not indicating downward trends.

- **Indicators:** Interannual trends in annual 7-day and 30-day (or monthly) low flow periods.
- **Measurement:** Daily mean streamflow values are being collected by governmental agencies at hundreds of thousands of streamflow monitoring stations around the globe, in cubic meters per second (cms) or cubic feet per second (cfs). While even a few years of data can begin to reveal trends, rivers that have been measured for at least 10 years and continue to be measured are strongly preferred for evaluating compliance with the *Codex Planetarius* standard. For *Codex* assessment, the selected river monitoring station(s) should be located within the watershed being used for farm production and located as close to the water diversion point(s) as possible.
- **Alternative for unmeasured water sources:** For water sources that are not being measured presently, hydrologic simulation models can be used to estimate trends in river levels. However, such models require specialized expertise to operate, or to extract model outputs for a specific water source. This approach would likely necessitate partnership agreements with modeling teams to provide the desired trends.
- **Data processing:** Daily river flow values can be processed with the Indicators of Hydrologic Alteration software (IHA)[14] to calculate lowest 7-day and 30-day mean values in each year. Alternatively, simple linear trends can be assessed using daily or monthly values within an Excel spreadsheet.
- **Default calculation:** 10+-year linear trend based on annual values of 7-day and 30-day low flows; trends calculated within IHA software or Excel spreadsheet.
- **Data sources (measurements taken at streamflow monitoring stations):** Both global and country-specific databases are available as described below.

Global database

- **Global River Discharge Database** - This site contains a compilation of monthly mean river discharge data for over 3,500 sites worldwide.

Examples of country-specific (state, provincial, or national) databases:

- **Canada (691 sites):** https://wateroffice.ec.gc.ca/search/historical_e.html=
- **United States (>1,000 sites):** https://maps.waterdata.usgs.gov/mapper/index.html
- **Mexico (>300 sites):** https://sih.conagua.gob.mx

Examples of Assessments for Metrics 1.1 and 1.2

Examples of indicator evaluations for both a groundwater well and a river monitoring station are provided below.

Groundwater example (Metric 1.1): Beauce Aquifer, France. The Beauce Aquifer lies southwest of Paris and is one of the largest aquifers in France. Agriculture is the main user of groundwater in the region. Nearly 80% of farms in the area use groundwater to produce cereals and high-value vegetables. Irrigation increased by 50% during 1988-2000 because of increased demand for summer cash crops. The wetland of la Conie began to be impacted by falling groundwater levels in response to the rapidly increasing pumping, creating conflict between environmental groups, farmers, and the state. In response to concerns over the falling aquifer level, a stakeholder group of farmers and state authorities signed an agreement in March 1995 called the "Beauce Aquifer Charter," allowing the state to put a volumetric limit on withdrawals of groundwater and creating an aquifer monitoring system to maintain water levels in the wetland and environmental flows for the rivers in the basin.[15] These restrictions showed early signs of recovery but it has been hard to maintain a dynamically stable aquifer level **(Figure 6, page 10)**. Both the long-term graph and the recent 10 years indicate declining water levels. Therefore, Metric 1.1 is not being met.

River example (Metric 1.2): Arikaree River, Nebraska (USA). The Arikaree River winds its way through the shortgrass plains of eastern Colorado before joining the Republican River near Haigler, Nebraska. Historically, the river has supported great plant and animal diversity, including important habitats for a variety of Great Plains fish species. However, in recent decades many small-grain farms have become established. These farms access water from shallow alluvial (sandy) aquifers; when the water level in these aquifers is lowered from groundwater pumping, less groundwater discharges into the Arikaree as baseflow. **Figure 7 (page 11)** reveals severe recent declines in both the 7-day and 30-day low flows; in this instance, Metric 1.2 is not being met. Arresting this downward trend and allowing river levels to recover will require reductions in groundwater pumping to bring extractions back into balance with aquifer (and river) replenishment.

Restoring River Levels to Ecologically Sustainable Levels

Metric 2.1 River flows are maintained or restored to the targeted environmental flow level as specified by local assessments or the Science Based Targets Network (SBTN).[16]

- **Default Indicator:** Average monthly river flows. However, when locally derived environmental flow targets have been set, the specific flow parameters used in the e-flow prescription should be used.
- **Measurement:** See description for Metric 1.2 above.
- **Alternative for unmeasured water sources:** Use the model-based approach described in Hogeboom, et. al., (2020)[17] to determine whether monthly environmental flow requirements are being met. The SBTN has created guidance and an online tool for assessing compliance, as reflected in the 'percent reductions' in water consumption needed to meet environmental flow targets. If the percent reduction is greater than zero for any month, environmental flow requirements are not being met.
- **Data processing:** When daily river flow values are available, they can be processed with the Indicators of Hydrologic Alteration software (IHA)[18] to calculate monthly flows (or other e-flow parameters) in each year. When measured flows or locally derived environmental flow targets are not available, use the model-based approach of Hogeboom, et. al., (2020) and the SBTN online tool to assess compliance with environmental flow requirements.
- **Default calculation for measured water sources:** The multi-year average monthly flow is compared with locally derived environmental flow targets whenever such science-based e-flow targets have been developed; if locally derived flow targets are based on parameters other than average monthly flows, the prescribed parameters should be used. When measured flows or locally derived environmental flow targets are not available, use the model-based approach of Hogeboom, et. al. (2020) and the SBTN online tool to assess compliance with environmental flow requirements.
- **Data sources (measurements taken at streamflow monitoring stations):** Both global and country-specific databases are available as described for Metric 1.2 above.

Example of Assessment for Metric 2.1

The example below illustrates how the Hogeboom, et. al., (2020) approach and the SBTN online tool can be used to evaluate compliance with environmental flow requirements anywhere in the world. One output of the SBTN online tool is the provision of estimates for how much reduction in water consumption would be needed to attain monthly environmental flow targets.

River example: Lower Murray River, Australia. The Murray-Darling Basin in southeastern Australia is the most important agricultural area in Australia, supporting both domestic consumption as well as substantial export trade, particularly with Asian countries. The basin is a major producer of fruits, nuts, wine grapes, and vegetables. Locally derived environmental flow targets have been developed by the Murray Darling Basin Authority, based on parameters including base flows, small pulse flows, and large-scale flood flows. A recent assessment determined that none of these environmental flow targets were presently being met, and therefore Metric 2.1 would not be met.[19]

However, if these locally derived environmental flow targets had not been available, compliance with Metric 2.1 could be evaluated using the SBTN online tool. **Figure 8 (page 11)** illustrates how to obtain monthly reduction targets for the Lower Murray River portion of the Murray-Darling Basin.

As can be seen in **Figure 9 (page 11)**, the Lower Murray River basin (ID 505007 3410) is meeting its environmental flow requirements in nine of twelve months, but reductions in consumptive water use ranging from 6-25% will be required in other months to meet Metric 2.1. The primary reason that environmental flows are not being met in January through March is because of irrigated agriculture, as this is the heart of the irrigation season in this part of Australia. Much, if not all, the necessary reduction in water consumption will need to come from the agricultural sector.

Appendix: Alternative Approaches for Setting a Water Use Standard

A variety of approaches were considered for this water use standard in *Codex Planetarius*. Two alternative approaches are briefly summarized here.

Setting Basin Caps on Water Use

As discussed previously, a recent study by Wight and others[20] evaluated the efficacy of setting 'caps,' or limits, on water use as a means for attaining water sustainability. These caps typically set a limit on the total volume of water that can be withdrawn or consumed from a water source or alternatively set a level or elevation at which the water source must be maintained. The volume of allowable water use by each individual water user must then be allocated.

The attractiveness of a cap approach is that if the cap is properly set at a level that sustains adequate environmental flows, and if the cap is regularly monitored and enforced, it can achieve the same outcomes that Metrics 1.1 and 1.2 are designed to achieve.

However, the process of setting caps can be quite challenging politically, requiring strong leadership and meaningful engagement by the water users that will be regulated by the cap. The authority for cap implementation is usually a governmental entity or basin/aquifer authority. The governing entity will need to commission a scientific/technical study to set the cap at a level that prevents water depletion and sustains adequate environmental flows. The study will also need to set limits on the volume of water to be allocated to each water user.

It is important to note that setting a cap does not obviate the need to evaluate water source conditions as set out in Metrics 1.1 and 1.2, however. Regular evaluations of river flows and aquifer levels are needed to verify that the cap has been set at a level protective of the water source and environmental flows.

Setting Farm-level Benchmarks for Individual Crops

The challenges of implementing a metric based on benchmarked performance by each farmer have been discussed previously, i.e., the data needed to determine the water productivity of individual farms is not yet available. However, technological advancements — specifically, advancements in remote sensing — may enable estimation of farm-level water productivity in the future.

Already, remote sensing is being used in the western USA to estimate water consumption at the farm level using a technology known as "Open ET." It is hoped that this technology can soon become available over a much broader geography. Other remote sensing techniques such as NDVI (normalized difference vegetation index) are being tested for use in estimating crop yields. At some point in the not-too-distant future it may be possible to use these technologies to estimate water productivity for individual farms, i.e., water consumed per unit of crop yield. This would enable inclusion of a farmer-based metric in the *Codex Planetarius* standard. ■

Peer Reviewers

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Figures

Figure 1. The global water cycle (Source: NASA)

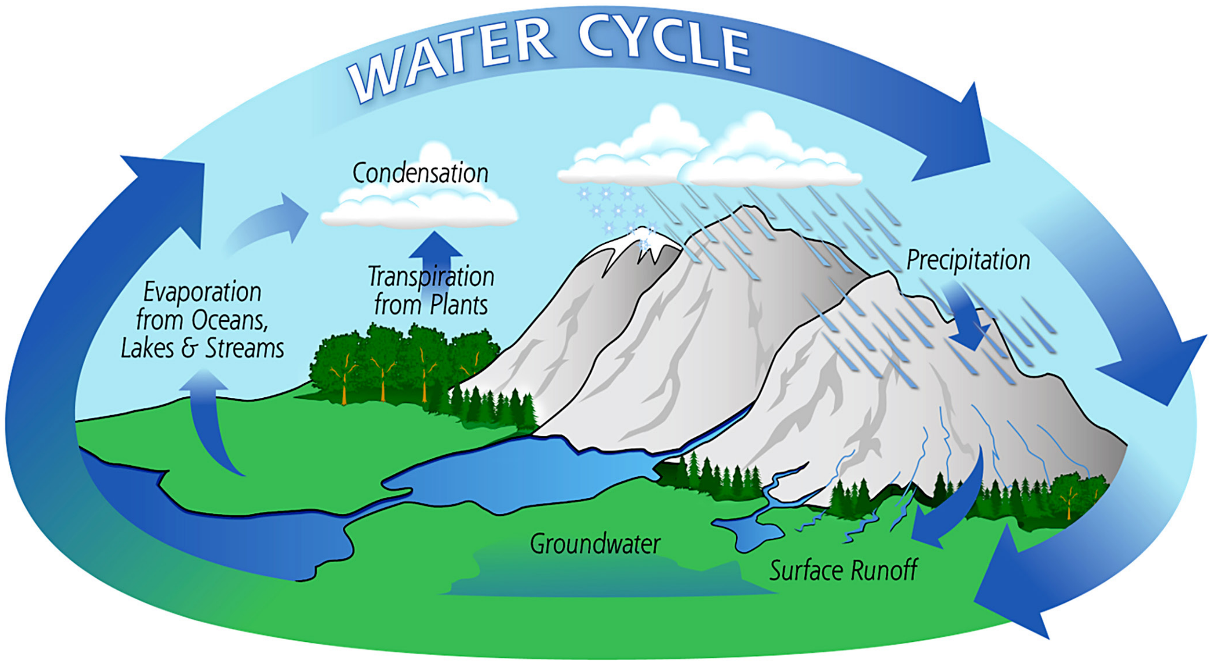

Figure 2. Quantification of the global water cycle. BCM = billion cubic meters = 1 cubic kilometer. Percentages shown represent the proportion of annual precipitation. Nearly two-thirds (62%) of all irrigation water is extracted from rivers and lakes, and the remaining 38% is pumped from aquifers.[3] *(Source: Brian Richter with Jason Pearson/Truth Studio)*

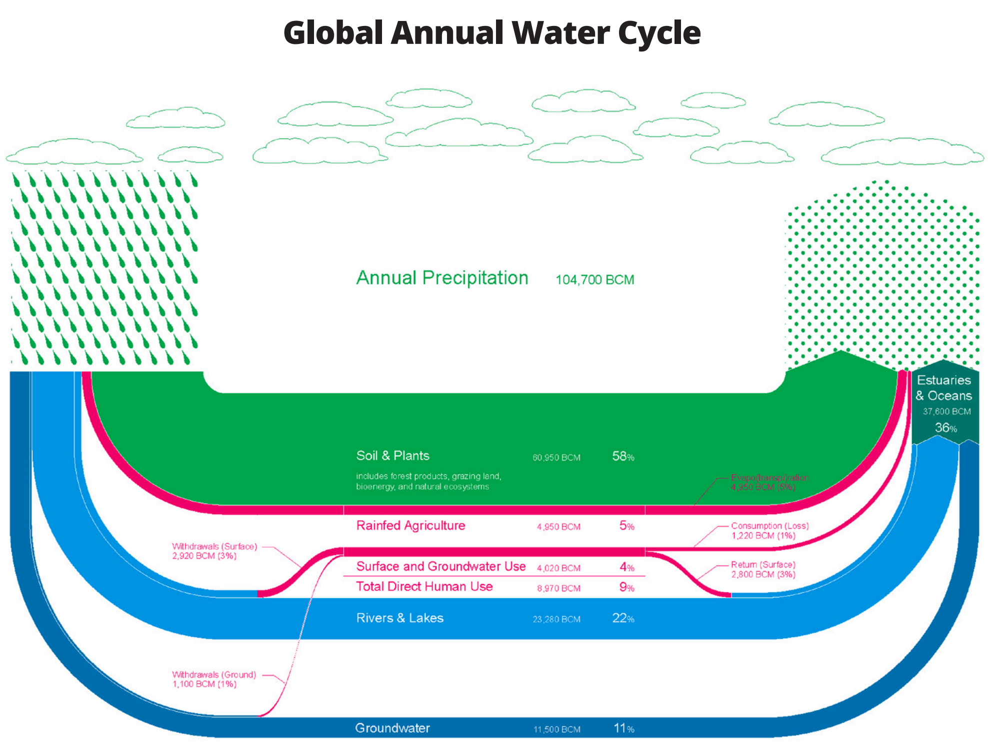

Figure 3. Each blue water source (river, lake, aquifer) can be perceived as a bathtub. The faucet represents replenishment of the water source deriving from rain or snow inputs, runoff from the catchment area, wastewater returned after human uses, importation of water from other blue water sources, or desalination inputs. The drain represents losses of water from the blue water source due to both natural losses (evaporation, plant transpiration, leakage into the ground) and anthropogenic extractions. When the rate of water flowing out the drain becomes greater than the rate of replenishment, the water level in the tub drops. The depletion of blue water sources is the focal issue of the proposed *Codex Planetarius* standard for water quantity described herein. *(Source: Niki Belkowski, The Markets Institute/WWF-US)*

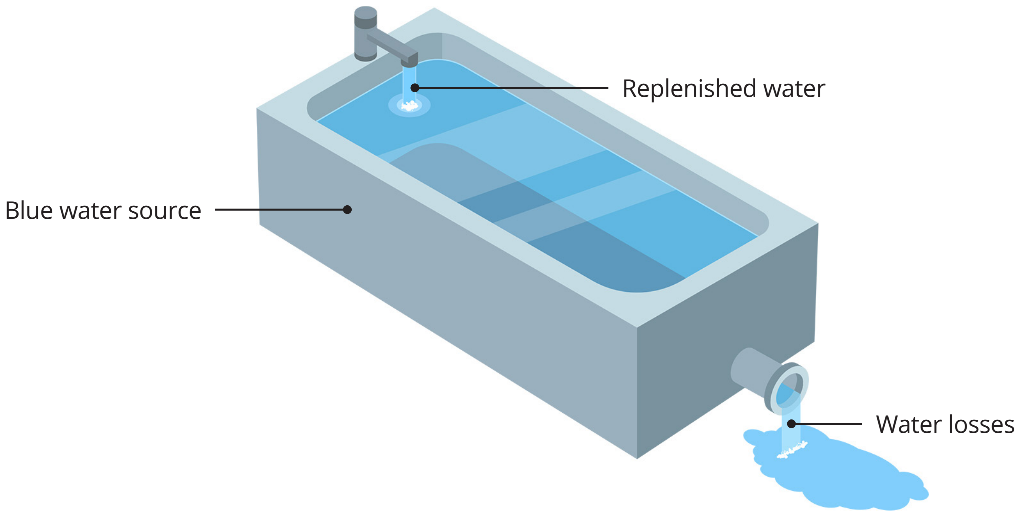

Figure 4. Illustration of the primary pathways of water flow in irrigated agriculture. Efforts to determine the total volume of water consumed on an individual farm would need to account for the volumes of water represented by each of the arrows in this diagram. *(Source: Richter, et. al., (2017). Used with permission.)*

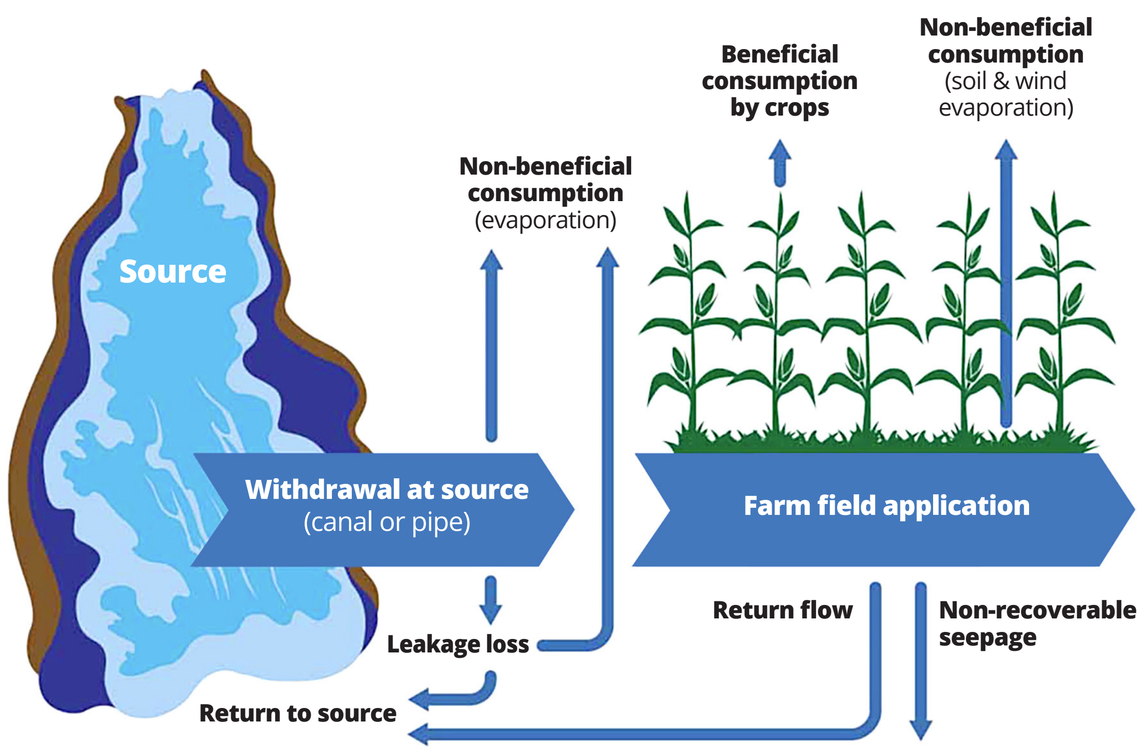

Figure 5. Illustration of the concept of 'benchmarking' among water users (such as farmers growing corn in a specific climatic region). The ratio of water consumption divided by crop yields (units of production) for each farm are arranged in a sequence from low- to high-water productivity, and a standard is set at a selected benchmark level, such as the "Top 25%." *(Source: Marston, et. al. (2020). Used with permission.)*

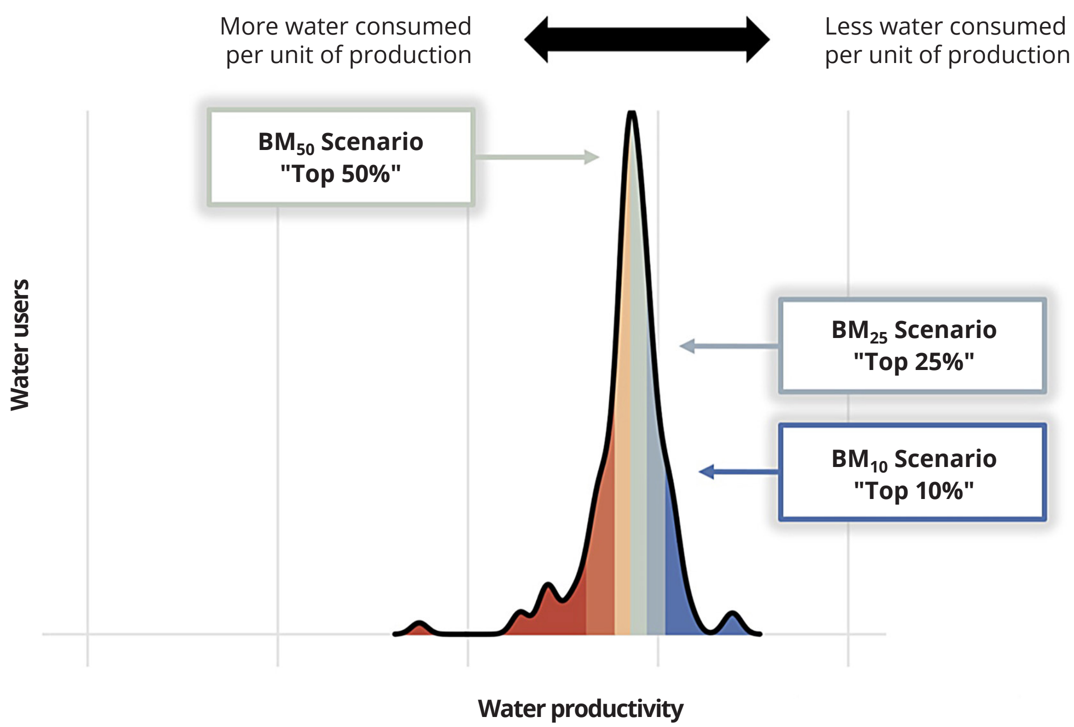

Figure 6. Depth to Groundwater (in meters) measured in a monitoring well located at Épieds-en-Beauce in the Beauce Aquifer of France. A cap on groundwater pumping volumes was instated in 1995 (left graph), and it appeared to have a positive impact for a few years. However, the trend over the period since the cap was established continues to be declining (right graph), meaning that this area would not qualify as meeting Metric 1.1 until the cap level can be adjusted to stabilize the aquifer. *Data from GGMN.*

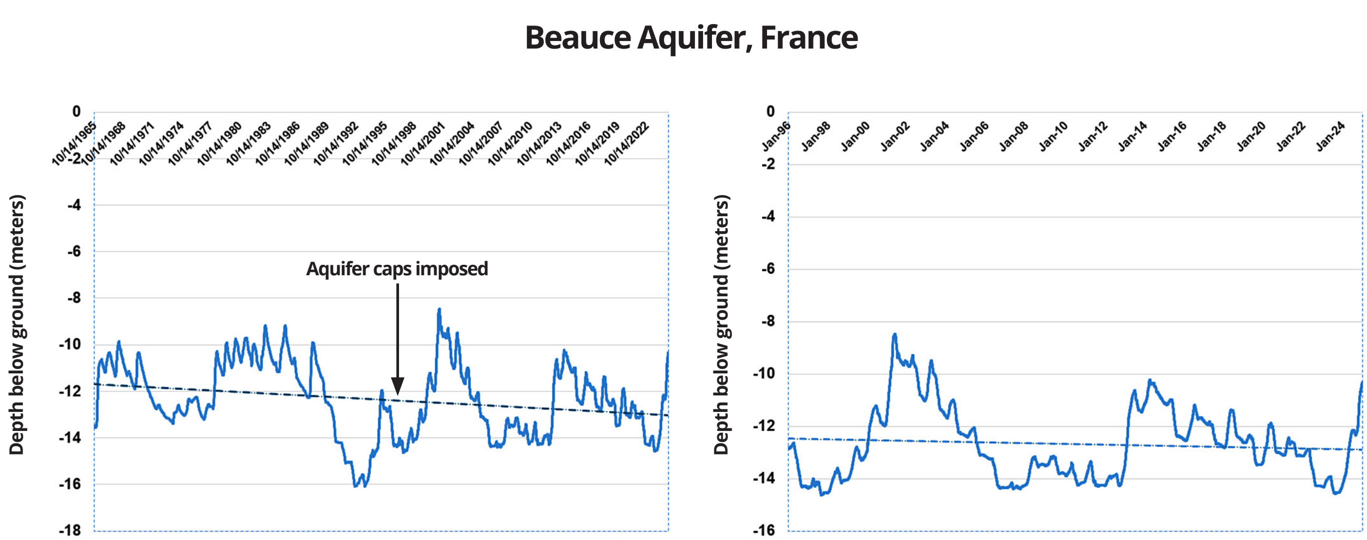

Figure 7. River low flows (in cubic feet per second) measured at a monitoring station near Haigler, Nebraska (USA). *Data from US Geological Survey.*

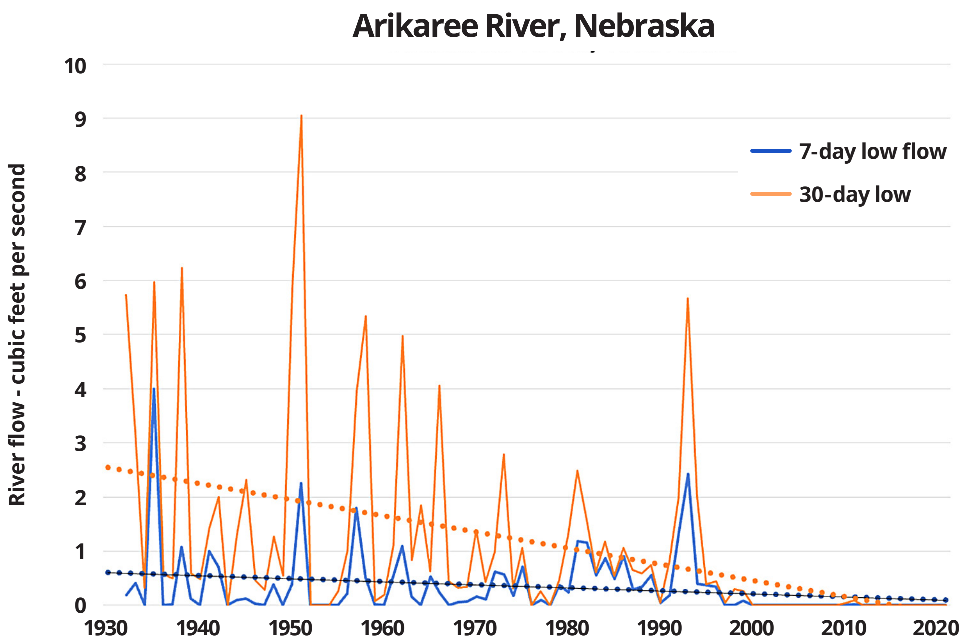

Figure 8. Example use of SBTN online tool to extract estimates of needed reduction in water consumption for each month of the year to meet environmental flow requirements.

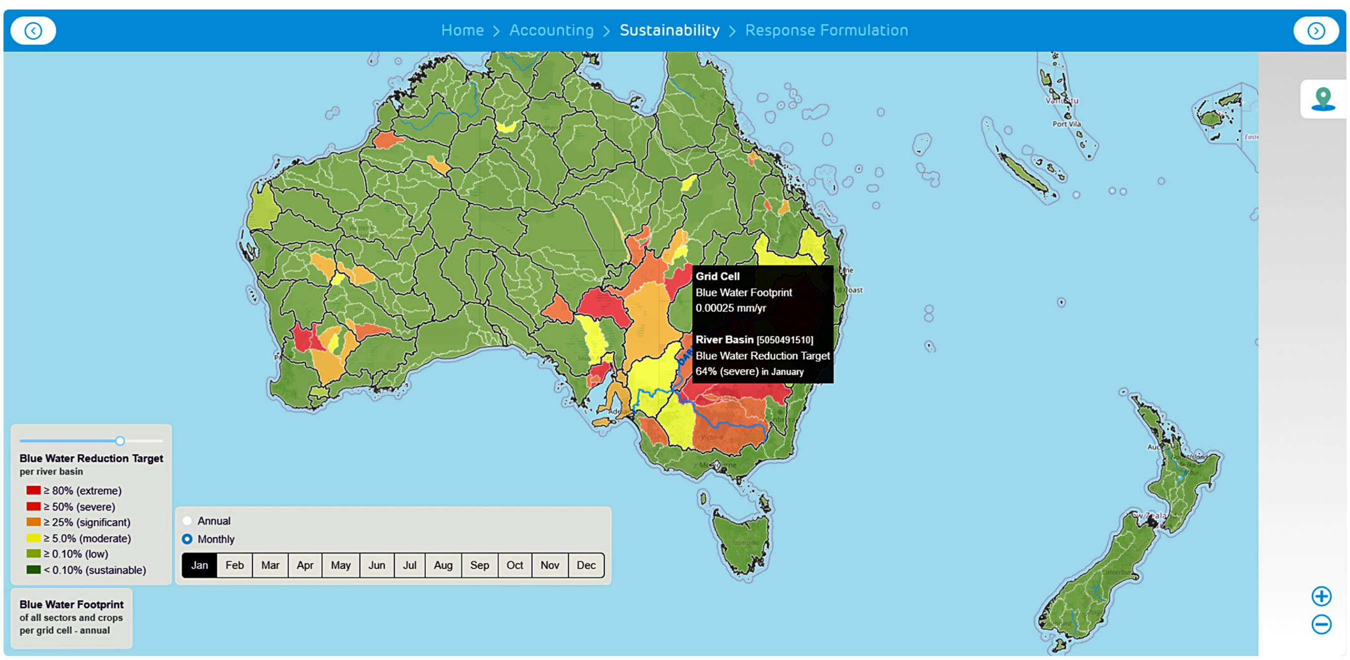

Figure 9. Necessary monthly reductions in water consumption are summarized here.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
% reduction	19	25	6	0	0	0	0	0	0	0	0	4

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