WORLD RESOURCES INSTITUTE

Working Paper

AQUEDUCT WATER RISK FRAMEWORK

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EXECUTIVE SUMMARY

Awareness around the physical, regulatory and reputational water risks to companies and their investors is on the rise; and robust, comparable and comprehensive data is needed to help assess these water-related risks. In response to this demand, the World Resources Institute (WRI) Markets and Enterprise Program developed the Aqueduct Water Risk Atlas, a comprehensive and publicly available global database and interactive mapping tool that provides information on water-related risks worldwide. The Aqueduct Water Risk Atlas provides a set of indicators that capture a wide range of variables, and aggregates them into comprehensive scores using the Water Risk Framework. Companies can use this information to prioritize actions, investors to leverage financial interest to improve water management, and governments to engage with the private sector to seek solutions for more equitable and sustainable water governance. This working paper describes the Water Risk Framework, the indicators it includes, and the methodology used to combine them into aggregated, comprehensive risk scores.

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Disclaimer: *Working papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues. Most working papers are eventually published in another form and their content may be revised.*

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INTRODUCTION

The Aqueduct Water Risk Atlas (Aqueduct) is a comprehensive and publicly available global database and interactive mapping tool that provides information on water-related risks worldwide. Aqueduct makes use of 12 global indicators to inform companies, investors, and other audiences about geographic exposure to water-related risks. By using Aqueduct's water risk maps, companies can evaluate their exposure to external water risks and contextualize water use information; investors can identify water issues threatening their portfolio; and public-sector decision makers can better understand water security and its role in economic growth.

The first part of this working paper provides information on how the 12 global indicators are grouped into a framework. The second part defines each category of the framework and its indicators. The third part highlights the methodology used to combine the indicator values into aggregated risk scores. The document concludes with lessons learned and recommendations for future research.

Background

Global water use has been growing at more than twice the rate of population in the last century.[1] Water scarcity already affects every continent, and the United Nations estimates that by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity; two-thirds of the world population will be under stress conditions; and water withdrawals will increase by 50 percent in developing countries and 18 percent in developed countries.[2] For companies, access to water could constrain growth, particularly for those in water-intensive sectors, or with operations, markets, and/or supply chains in water-stressed areas.[3] Water shortages have already constrained economic growth in China, Australia, India, and parts of the United States. More than half (53 percent) of the Global 500 companies that responded to the Carbon Disclosure Project's (CDP) *CDP Global Water Report 2012* survey had experienced detrimental water-related business impacts, with associated financial costs for some companies as high as US$200 million.[4]

Information on company water-related data is infrequently disclosed[5] and few companies have access to comprehensive data on their suppliers' water context and performance. This lack of data is of particular concern because, for many corporations, most of their water footprint is embedded in their supply chain.[6] Many tools are emerging to help companies understand the complex nature of water risk; however, there remain significant inconsistencies and gaps in how these tools measure and report geographic water risk. For example, much of the water supply and demand information in the public domain is provided at major watershed and country levels, and lacks the level of granularity needed to accurately characterize the water context at a given location. Additionally, geographic water-risk data is often provided in its raw form with little interpretation to help nontechnical audiences understand the results. In response to these challenges, the World Resources Institute (WRI) Markets and Enterprise Program (MEP) developed the Aqueduct Water Risk Atlas to provide an easy-to-use and publicly-available global database and mapping tool of highly-granular water risk information. By quantifying, mapping, and informing on water-related risks, this project aims to:

- Help companies and investors evaluate and disclose geographic water risks;
- Help public-sector actors better understand water security; and
- Supply high-quality metrics and maps for analysis and to other information providers.

WATER RISK FRAMEWORK

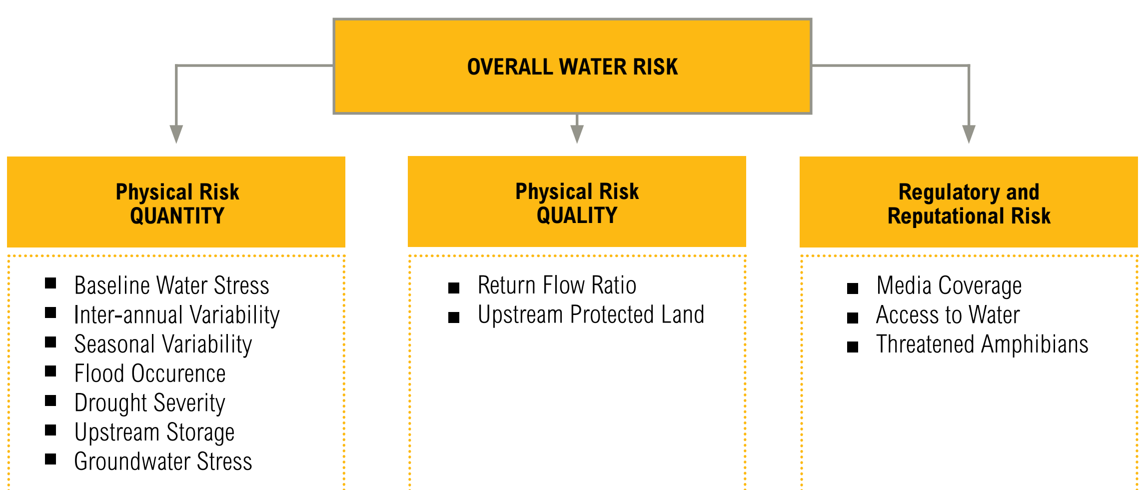
Global water scarcity is clearly an important emerging risk; however, it threatens stakeholders differently, depending on their exposure to the risks and their resilience to the risks' impacts. For example, the resilience to drought of different municipalities across the Okavango River Basin in Africa varies based on their practices to mitigate naturally occurring risks (e.g. conservation incentives and infrastructure). Likewise, two water-intensive companies operating in similar locations may face different levels of reputational risk during a water shortage depending on their level of engagement in corporate water stewardship. For example, a company might gain reputational benefits and reduce its dependency on local water sources by recycling its wastewater, thus leaving more available water for local farmers. However, regardless of their level of engagement in sustainable water practices, neighboring companies face the same external water context and will benefit from understanding and assessing water-related risks.

In response to growing concerns from the business community around water scarcity, water quality problems, and climate-related impacts, as well as increasing demand and competition for freshwater,[7] WRI grouped the 12 global indicators in the Aqueduct Water Risk Atlas into a Water Risk Framework (Figure 1) based on current literature and research. This framework organizes indicators into categories of risk that allow the creation of a composite index that brings together multiple dimensions of water-related risk into comprehensive aggregated scores. By providing consistent scores across the globe, the Aqueduct Water Risk Atlas enables rapid comparison across diverse aspects of water risk.

Composite Index

Single indicators have been used widely over the years in water resources and economic policy.[8] However, the growing need to better understand the interaction of multiple water-related risks has increased the demand for composite indicators that capture multiple and diverse issues in a single metric. For example, the Human Development Index led to the creation in 2001 of the Water Poverty Index (WPI), an integrated index for water management.[9] The WPI then served as a basis for the Canadian government to develop the Canadian Water Sustainability Index,[10] as well as for the creation of the Climate Vulnerability Index[11] and Water Vulnerability Index.[12] Other water-related composite indexes include the Environmental Performance Index,[13] the Adaptive Capacity Index for water resources systems,[14] the Watershed Sustainability Index,[15] and the cumulative incident threat indexes for human water security and biodiversity.[16] Each of these indexes addresses water or environmental sustainability from a different perspective. However, at the time the Aqueduct Water Risk Framework was developed, there was no index in the public domain that evaluated the exposure of companies and investors to water-related risks.

Figure 1 | **Water Risk Framework**



Framework

The Aqueduct Water Risk Framework seeks to fill this void by providing information on geographic water risks, incorporating the latest research, data, and hydrological modeling techniques. Aqueduct complements existing tools, builds on other water-related indexes, and reflects state-of-the-art indicators and current thinking on water-related risks. Specifically, this approach complements other corporate water tools by providing comprehensive and aggregated water-risk scores, and mapping the results in a way that is easy for corporate and investor audiences to understand. The indicators in the Water Risk Framework were selected based on data availability, pilot studies, and expert consultation. An advisory group of over 20 experts from the private and public sectors, as well as from academia and nongovernmental organizations was convened to guide and review the Water Risk Framework.

The Aqueduct Water Risk Framework enables users to study indicators individually or collectively, as well as to quantify and compare a variety of multidimensional water-related measures. Indicators are grouped into three categories of water risks to business based on definitions provided by Ceres.[17]

- **Physical Risks: Quantity:** Physical risks related to quantity are defined as the exposure to changes in water quantity (e.g. droughts or floods) that may impact a company's direct operations, supply chains and/or logistics. Physical water risks also refer to the disruption of needed electric power due to water issues because many electricity sources require water for cooling (e.g. nuclear or coal plants) or for generation (hydropower).

- **Physical Risks: Quality:** Physical risks related to quality are defined as the exposure to changes in water quality that may impact a company's direct operations, supply chains, and/or logistics.

- **Reputational and Regulatory Risks:** Reputational risks are defined as potential conflicts with the public regarding water issues that can damage a company's image or result in the loss of the company's license to operate in a community. Reputational risks are particularly common in developing countries where infrastructure and/or regulation may not be sufficient to provide all users with access to safe and reliable drinking water supplies. Regulatory risks are defined as the exposure to the impacts of water-related regulations on a given company. As physical and reputational pressures increase, many local and national governments are responding with more stringent water policies. If unanticipated, these regulatory changes can prove costly to companies and, in some cases, limit industrial activities in particular geographic areas.

The framework approach allows users to obtain an aggregated score for overall water risk, as well as for each of the three categories described above. As a result, the information provided is relevant not only to water-intensive companies interested in physical, regulatory, and reputational risks, but also any other water user interested in better understanding and characterizing the complexities of the geographic water context.

The selected indicators capture measures of likely exposure to risk representative of each category of water risk, and were chosen based on: (1) their relevance to major water users, (2) data availability in the public domain, and (3) the ability to generate detailed sub-basin scale maps globally.

The framework, indicators, and methods described in this document were tested in collaboration with basin experts on six key river basins: the Murray-Darling in Australia, the Yellow and Yangtze in China, the Orange-Senqu in Southern Africa, the Colorado in the United States, and the Mekong in South-East Asia. The results and metadata for these pilot tests are available for download at the project website (www.wri.org/aqueduct).

WATER RISK INDICATORS

To develop many of the indicators in the Water Risk Framework, two measures of water supply were required: *total blue water* and *available blue water*. Total blue water approximates natural river discharge, and accounts for all within-basin and accumulated upstream natural runoff. Available blue water is an estimate of surface water availability and is computed from total blue water by removing all upstream consumptive uses.

This section describes each category of water risk and the indicators they include.

Figure 2 | **Physical Risk: Quantity Indicators**

Physical Risk
QUANTITY

- Baseline Water Stress
- Inter-annual Variability
- Seasonal Variability
- Flood Occurence
- Drought Severity
- Upstream Storage
- Groundwater Stress

Physical Risks: Quantity

Physical risks related to quantity are defined as the exposure to changes in water quantity (e.g. droughts or floods) that may affect a company's direct operations, supply chains and/or logistics.[18] Having an adequate and reliable water supply is a growing concern among the business community worldwide; it can have a direct impact on a company's supply chain, operations, productivity, and overall growth. For example, in 2011 Levi Strauss became rapidly aware of physical risks related to water availability when floods in Pakistan and parched fields in China destroyed crops and sent cotton prices soaring.[19] Also in 2011, floods in South-East Asia forced Honda and Toyota to stop all production in Thailand,[20] driving Toyota Motor Corp. to produce 30 percent fewer vehicles than initially planned at its Japanese plants.[21] That same year, droughts in the United States drove companies like Gap to cut its profit forecast by 22 percent.[22] Aqueduct captures a measure of these water risks related to quantity by means of seven indicators: baseline water stress, inter-annual variability, seasonal variability, flood occurrence, drought severity, upstream storage, and groundwater stress (Figure 2).

Baseline Water Stress

Baseline water stress is the annual water withdrawals divided by the mean of available blue water. Baseline water stress measures the level of competition for available water, and estimates the degree to which freshwater availability is an ongoing concern.[23]

Baseline water stress and similar withdrawal-to-availability indicators are widely used in scientific and policy literature to identify regions experiencing water stress.[24] This indicator accounts for total water withdrawals in the numerator, measuring the actual level of water demanded in a local area and hence the level of competition and need for alternative water sources if supply is not sufficient. The denominator measures available blue water, accounting for the accumulative impact of consumptive water withdrawals on water availability. Areas with baseline water stress values above 20 percent may begin to experience risks from stress to the environment,[25] competing water uses, and natural variations in supply. A threshold of 40 percent water use relative to supply signifies severely water-stressed conditions.[26] Water risks to business that could result from such a scenario include: growing conflicts between competing water users; difficulties and delays in obtaining or renewing water allocation and use permits; or increasing costs associated with new water restrictions and the demand for new, alternative, and more costly water sources. For example, Freeport-McMoRan, one of the world's largest producers of copper, gold, and molybdenum, is investing US$300 million to construct a desalination plant and pipeline near the Pacific Ocean to meet long-term water supply needs at one of its mines.[27]

Inter-annual Variability

Inter-annual variability is the coefficient of variation of the annual total blue water. The coefficient of variation is the standard deviation divided by the mean, a commonly used calculation to measure the fluctuations in river discharge. Inter-annual variability represents a measure of the unpredictability of supply, and is an important explanatory variable when analyzing shared water use from an economic and international relations perspective in transboundary river basins.[28]

A higher variability means more variation of freshwater renewable supply between different years. In the absence of adequate water storage and governance mechanisms, high inter-annual variability may threaten business operations due to insufficient or unreliable access to water supplies during dry years. In 2012, Anglo American reported financial impacts of approximately US$83 million as it sought to decrease the environmental risk and production time loss caused by high variability in precipitation.[29]

Seasonal Variability

Seasonal variability is the coefficient of variation between the mean total blue water for each of the 12 months of the year. Seasonal variability complements inter-annual variability by providing information on water supply variability within a year.

Water use practices in areas of high seasonal variability (e.g., areas with both monsoon rains and extended dry periods) are often long adapted to local climate. However, as demand increases, water users may need to seek alternative sources of water during dry times of the year. In the absence of adequate water storage and governance mechanisms, withdrawals during dry months may lead to groundwater depletion and potential conflicts among users. Situations of this type can threaten business operations with unpredicted halts in water-related process (e.g. production, cooling, distribution) and higher operating costs associated with additional storage and recycling requirements. For example, seasonal drought in Kluang, Malaysia resulted in production curtailments costing Kimberly-Clark US$2 million.[30]

Flood Occurrence

Flood occurrence is the number of large floods reported over a given time period. The number of floods recorded provides a measure of the physical risk and disruption potential directly related to too much water.

The disruption potential of frequent floods is exacerbated in areas where water management institutions are unable to adequately prevent or manage the impacts of flooding in a given watershed.[31] In the absence of natural storage, flood control infrastructure, or appropriate flood management response plans, events of this nature can disrupt business operations due to staff, operational, or supply-chain disruption. For example, in 2010, Sasol Limited suffered production losses of approximately US$15.6 million due to flooding of a portion of the Sasol Synfuels plant.[32] Furthermore, exposure to flooding can result in an increase in costs due to high insurance rates, property damage, or remediation costs.

Drought Severity

Drought severity estimates the average magnitude of droughts and is the mean of the lengths of droughts multiplied by the dryness of all droughts that have occurred in an area. Drought is defined as a contiguous period in which soil moisture remains anomalously low; dryness is the average number of percentage points by which soil moisture drops below a defined threshold; and length is the duration of the drought in months.

Areas frequently exposed to droughts may rely heavily on management and infrastructure to help mitigate the strong variability in water supply. In regions where management regimes or infrastructure are not in place, or the duration and severity of droughts exceeds institutional capacity, major water users are more vulnerable. For example, The Southern Company reported a US$200 million loss during the 2008 drought in the United States because hydroelectric power generation dropped by 50 percent.[33] Severe droughts can cripple economies and impact companies by disrupting production and cooling and distribution processes, as well as supply chains and agricultural production.

Upstream Storage

Upstream storage is the total upstream storage capacity divided by the mean total blue water. Upstream storage measures the capacity to buffer variability in water supply, and provides a measure of supply resilience for a geographic area.[34]

Upstream storage measures how well equipped an area is to buffer supply variability and increase reliability of water supplies, and has been used in academic literature as an indicator of regional socioeconomic water resource stress[35] and of supply-driven water vulnerability.[36] Higher ratios indicate higher resilience to changes in water availability, and lower vulnerability to water scarcity and floods. Currently, industrial water withdrawals account for about 16 percent of global water demand, and are projected to reach 22 percent by 2030.[37] This sharp increase in demand makes access to stored water a priority for many water-dependent companies, particularly in areas with high inter-annual and seasonal variability. Thus, acknowledging the potential risk of not having access to stored water is essential when evaluating the overall water-related business risk of an area. It should be noted that this indicator does not take into account the negative impacts of reservoir construction on hydrological and ecological processes.

Groundwater Stress

Groundwater stress indicates widespread stress of groundwater resources, and is computed by dividing the groundwater footprint (GF) by the area of the aquifer. The GF is the ratio of the average annual abstraction of groundwater over the recharge rate, minus the groundwater contribution to environmental stream flow, times the area of interest.[38] Thus, by dividing the GF by aquifer area we obtain the water balance between aquifer inflows and outflows and the ratio of groundwater demand to sustainable supply.

Groundwater supplies water to billions of people, as well as to irrigated agriculture and major industrial users, and strongly influences the health of many ecosystems. Research indicates that humans are overexploiting groundwater in many large aquifers, especially in Asia and North America. Furthermore, estimates indicate that about 1.7 billion people live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat.[39]

Groundwater stress ratios above one indicate where unsustainable groundwater consumption could affect groundwater availability and impact groundwater-dependent surface water and ecosystems.[40] Water-intensive companies that rely on stressed aquifers are likely to face increased competition and more stringent regulations around abstraction rates. Furthermore, situations of this type can drive businesses to seek alternative and often more costly sources of water. Data limitations and poor understanding of the available supply of local groundwater sources make this aspect of critical importance when assessing the geographic context of water.

Figure 3 | **Physical Risk: Quality Indicators**

Physical Risk
QUALITY

- Return Flow Ratio
- Upstream Protected Land

Physical Risks: Quality

Physical risks related to quality are defined as the exposure to changes in water quality that may impact a company's direct operations, supply chains and/or logistics.[41] High-quality process water is essential to many industrial production systems. In 2012, 20 percent of the Global 500 companies responding to the *CDP Global Water Report 2012* survey disclosed risks in their direct operations related to declining water quality. Companies in basins with poor water quality may require additional investment and operational costs for pretreating and monitoring influent water. Additionally, poor water quality may lead to the disruption of companies' operations and production. For example, in 2007 Intel and Texas Instruments required more than 11 billion gallons of ultrapure water for the production of silicon chips.[42] Because of its dependency on high-quality water, JPMorgan estimated that a water-related shutdown at a Intel or Texas Instruments facility could result in US$100 to US$200 million in lost revenue during a quarter.[43] The entire beverage industry requires access to high-quality freshwater to maintain the quality and safety of its products.[44] Aqueduct uses two indicators to measure the risk of not having access to high-quality water: return flow ratio and upstream protected land (Figure 3).

Return Flow Ratio

Return flow ratio is all upstream nonconsumptive use divided by the mean of available blue water. Return flow ratio measures the percent of available water previously used and discharged upstream as wastewater.

This indicator measures a region's dependence on its wastewater treatment infrastructure to ensure acceptable water quality. In the absence of adequate treatment infrastructure, businesses and other major water users will face higher operational costs, driven by the requirement for additional or alternative influent treatment mechanisms; require more stringent monitoring of influent and effluent water quality; and/or need to seek alternative sources of water. The risk posed by a high return flow ratio can be mitigated in areas with operating wastewater treatment plants and effective natural systems.

This indicator is most applicable to water users that depend on surface water sources, rather than to users that rely largely on groundwater sources.

Upstream Protected Land

Upstream protected land is the percentage of total blue water that originates in protected areas. Protected areas include large unmodified or slightly modified areas, set aside to preserve their natural condition and protect biodiversity and geological/geomorphological features, large-scale ecological processes, and particular species or habitats.[45] Ecosystem services provided by many of these natural landscapes include freshwater storage, flood protection, and nutrient recycling. Runoff originating in protected areas is less likely to be polluted by anthropogenic sources and thus contributes to maintaining downstream water quality.

Lower values indicate regions where a smaller proportion of the upstream watershed is under protection. Companies and other major water users in areas with low values of upstream protected land must be cognizant of potential water quality issues and contamination from upstream anthropogenic sources.

Regulatory and Reputational Risks

Businesses thrive in stable regulatory environments, whereas unpredictable changes in regulation or policy can prove costly to companies. Regulatory water risks arise when an unexpected change in a water-related law or regulation increases a business' operating costs, reduces the attractiveness of an investment, or changes its competitive landscape.[46] Uncertainty in regulatory change that could affect water allocations, the price of water, the number of permits available for siting or withdrawals, or wastewater discharge requirements, can impact a company's capacity to develop strategic growth plans, signify large cost increases, and cause disruption of operations and supply chains. For example, South African Coal Mining Holdings announced it planned to close its operations at Umlabu driven in part by delays in obtaining a water license without which the mining operations could not begin.[47] Similarly, Exelon recently announced that it would retire its nuclear plant in the U.S. state of New Jersey 10 years earlier than planned due to the potential cost—over US$800 million over the remaining life of the plant—of having to meet more stringent water permitting conditions.[48]

Reputational water risks, conversely, refer to companies' exposure to criticism, potentially leading to a loss of customers or investors due to perceptions about their decisions, actions, or impacts on freshwater resources and ecosystems and the communities that depend on them.[49] Reputation is one of a corporation's most important assets and also one of the most difficult to protect.[50] In 2012, 15 percent of the respondents to *CDP Global Water Report* disclosed risks of reputational damage in their direct operations. Community opposition and perceived or real inequalities in water use can appear quickly and have severe impacts on business operations; furthermore, governments in emerging economies are becoming more and more responsive to community demands. Situations of these types can affect business profoundly, in some cases resulting in the loss of a company's license to operate, as PepsiCo and Coca-Cola bottlers experienced in Kerala, India or as Manhattan Minerals and Meridian Gold did in Latin America.[51] Aqueduct captures measures of the exposure to regulatory and reputational risks with the following three indicators: media coverage, access to water, and threatened amphibians (Figure 4).

Figure 4 | **Regulatory and Reputational Risk Indicators**

Regulatory and Reputational Risk

- Media Coverage
- Access to Water
- Threatened Amphibians

Media Coverage

Media coverage is the percentage of all media articles on water scarcity and/or pollution in an area. The number of media reports covering water pollution and water scarcity concerns reflects the level of media and public awareness about water and about how companies are handling this resource.[52] Understanding the level of public awareness around water issues can help gauge potential social conflicts and concerns that could translate into reputational risks to companies and other major water users.

Reputational risks have been widely recognized in literature and by subject-matter experts as one of the primary corporate risks stemming from a company's relationship to water. This risk is manifested through tensions and conflicts around access to water or the degradation of water resources.[53] Higher levels of media coverage indicate higher levels of social awareness around water, and in turn higher likelihood of social tension and opposition should business use, or be perceived to use, water in an inequitable or unsustainable way. Local conflicts can damage image, translate to litigation costs, and cause employee or supply-chain disruption.[54]

Access to Water

Access to water is the percentage of population without access to improved drinking water sources. An improved drinking-water source is defined as one that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with fecal matter.[55]

Higher values indicate areas where people have less access to safe drinking-water sources, and consequently challenges maintaining equitable use of water resources. In parts of the world with low access to and inequitable use of water, companies, particularly those that might put at risk the availability or quality of the resource, are faced with the risk of local or international community opposition. These types of risks are particularly common in developing countries where infrastructure and/or regulation may not be sufficient to provide all users with access to safe and reliable drinking water supplies.[56]

Threatened Amphibians

Threatened Amphibians measures the percentage of freshwater amphibian species that are classified as threatened by the International Union for Conservation of Nature and Natural Resources (IUCN). Amphibians are sensitive to disruption to their natural ecosystems and thus serve as a proxy for ecosystem health and vulnerability.

Areas with more threatened and vulnerable freshwater ecosystems are more likely to see increased regulations around the use of freshwater over time, particularly for those responsible for major water withdrawals and wastewater discharges. Higher values of threatened amphibians indicate more fragile freshwater ecosystems that may experience increased regulatory risk.

DATA SELECTION

To calculate the value of the indicators and ensure the integrity of the results, WRI is committed to using the most robust global datasets in the public domain. WRI acknowledges the limitations of global datasets and, therefore, underwent a comprehensive data selection process in consultation with external experts. Consultation was carried out with subject-matter experts to seek advice on the selection of datasets, as well as detailed information on the limitations and anomalies of the data. The selection process includes the following steps:

- Step 1: Literature review of similar initiatives, studies, and water-related research projects.
- Step 2: Identification of data sources in the public domain with global coverage that are widely recommended by subject-matter experts.
- Step 3: Comparative analysis of all identified data sources and evaluation based on the granularity, time frame covered, publication date, and source.
- Step 4: Selection of data sources based on results of the comparative analysis and expert feedback.

AGGREGATION AND RISK SCORING

As data sources are identified, WRI calculates and maps the 12 indicators globally. The calculation and mapping process varies from indicator to indicator, driven by spatial resolution, data specifications, and methodology.

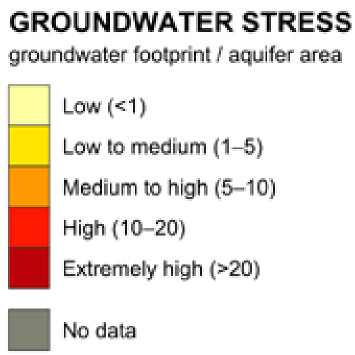
Once indicators are calculated, users can view the results individually or aggregate them into composite risk scores. The methodology to aggregate indicators into composite scores is described below.

Setting Thresholds

The first step in aggregation is to place all indicators on a comparable scale. This step is achieved by normalizing indicators over a set of thresholds, which are chosen to divide indicators into five categories. For example, the groundwater stress indicator is divided into five categories based on the ratio of groundwater abstraction to recharge rates (Figure 5).[57]

For each indicator, thresholds are determined using existing literature, governmental or intergovernmental guidelines, the range and distribution of indicator values, and expert judgment. For example, for baseline water stress, WRI's thresholds reflect thresholds for withdrawal-to-availability indicators established in the scientific literature.[58]

Figure 5 | **Threshold Values of Groundwater Stress**



Normalizing Results and Scoring

All indicator values are then mapped to thresholds and normalized to a score between 0–5, such that scores of 0–1 correspond with the lowest category, and scores of 4–5 correspond with the highest category. The general function for mapping indicators whose thresholds are on a logarithmic scale (e.g. baseline water stress) is:

$$\min\left(5, \max\left(0, \left(\frac{\ln(r) - \ln(t_1)}{\ln(base)} + 1\right)\right)\right)$$

where r is the raw value, t_1 is the lowest category's upper threshold and *base* is the rate of increase between thresholds. Values greater than five or less than zero are truncated to remain within the range of 0–5. Similarly, the general function for mapping indicators whose thresholds are on a linear scale is:

$$\min\left(5, \max\left(0, \left(\frac{r - t_1}{diff} + 1\right)\right)\right)$$

where *diff* is the difference between thresholds. Different functions may be used to meet irregular thresholds.

The threshold method of indicator normalization has several advantages and one distinct disadvantage. Foremost, it creates clear categories, and enables scores to be matched to guidelines. Relative to purely mathematical or statistical methods of normalization, thresholds are unaffected by extreme values. They allow for comparison even when using new sources of data. However, the disadvantage is that the scoring of indicators, whether based on established guidelines or statistical distributions, is subjective. By defining thresholds, WRI assigns meaning to specific indicator values. To maintain transparency in the process WRI clearly displays the relationship between raw values and categories and enables users to access unnormalized data.

Setting Indicator Weights

Once indicator thresholds and scores have been established, weights must be assigned to each indicator based on its level of importance and relevance. Since exposure to different risks varies, users are able to modify the weighting of each individual indicator. WRI acknowledges that users may benefit from guidance on how to set weights and therefore provides preset weighting schemes and the option for users to adjust the value of each indicator weight.

There are five distinct weights for each indicator, and indicators may also be ignored completely by removing them from the calculation. These weights, or descriptors of importance, are translated into an exponential scale for calculation (Table 1). An exponential scale is preferred over a linear scale due to human tendency to categorize intensity by orders of magnitude of difference.[59]

Table 1 | **Indicator Weighting Scale**

IMPORTANCE	EXPONENT	WEIGHT
Very low	2^0	1
Low	2^1	2
Medium	2^2	4
High	2^3	8
Very high	2^4	16

The indicator weighting capability enables users to create customized risk profiles. To increase transparency, users are allowed to view aggregated scores that reflect their specific risk exposure. Alternatively, users that do not require this level of specificity will be able to apply default preset weights for specific industry sectors. The Aqueduct Water Risk Atlas offers 10 preset indicator weighting profiles (Table 2). These profiles were developed based on information provided in corporate water disclosure initiatives and input from water experts to reflect the particular risks and challenges faced by each water-intensive industry sector.

Table 2 | **Preset Indicator Weighting Profiles**

WEIGHTING PROFILES	
Default	Agriculture
Food & Beverage	Chemicals
Electric power	Semiconductor
Oil & Gas	Mining
Construction materials	Textile

Aggregating Indicator Values

To obtain estimates of the level of water-related risks, the Aqueduct Water Risk Atlas combines individual indicator results into aggregated risk scores for the three categories in the Water Risk Framework as well as for overall water risk.

To calculate aggregated risk scores, all indicator values under each category are combined by a weighted average. Specifically, the result for any specific category is the sum of the individual indicators within that category times their weights, divided by the sum of the weights of those indicators. Similarly, the score for overall water risk is the sum of all individual indicators times their weights, divided by the sum of all the weights. Indicators in regions for which there is no data are excluded from the weighted average for those regions.

That is, for each region *j:*

$$a_j = \frac{\sum x_{ij} w_i}{\sum w_i} \text{ for } i \text{ in } \{\text{all indicators where } x_{ij} \neq null\}$$

Where a_j is the weighted average, x_{ij} is the indicator score, and w_i is the indicator weight.

Since the weighted average pulls all indicator values toward the mean, the aggregated scores are rescaled to extend through the full range of values (0–5). This normalization is conducted to communicate the full range of relative risk values given the user's chosen weighting scheme. The final displayed score, s_j, is then computed as:

$$s_j = \left(\frac{a_j - \min(a)}{\max(a) - \min(a)} \right)$$

Displaying Results

The resulting values for indicators, categories, and overall water risk are hosted in a geographic information system (GIS) platform that enables the individual indicator and aggregated water risk scores to be color-coded and mapped across the entire world. The user can configure the Aqueduct Water Risk Atlas to map an individual indicator or combination of indicators based on preset or customized weights. The user can then export and share the personalized risk map as well as download data tables with the indicator, category, and overall water risk scores and absolute values for any location.

CONCLUSION

Awareness of the physical, regulatory, and reputational water risks to companies and their investors is on the rise;[60] and robust, comparable, and comprehensive data is needed to help assess these water-related risks. The Aqueduct Water Risk Framework provides a set of metrics that captures a wide range of variables, and aggregates complex results into comprehensive scores.

The selection of indicators and methods presented in this working paper is an inherently subjective process that creates value by simplifying complex phenomena. Although every effort has been made to create a robust and objective framework, the academic and professional discourse remains without a single best way to combine and compare diverse metrics into a composite index. Therefore, results, to some extent, reflect the judgment of the authors and expert advisors. However rich and rigorous the results produced, this exercise inevitably runs up against the limits of describing the complexity of water-related risks with a single number.

Although the Water Risk Atlas attempts to draw the most value out of existing water data, there is room for improving the framework by including more information on water quality and regulatory and reputation risks. Barriers, such as inconsistent availability of robust and comparable data, and the unwillingness of governments to share water data, hamper the collection of consistent global water-quality information.[61] In a similar way, the complex and qualitative nature of regulatory and reputational drivers of risk complicate researchers' ability to create consistent and robust metrics. Research is underway to develop new measures of these water-related risks.

Finally, the Aqueduct Water Risk Atlas provides comparability across the globe acting to highlight areas of potential concern. These global metrics and associated maps can help identify water-related risks, and provide a picture of how they vary spatially across regions, countries, or continents. However, to understand the complete picture of the conditions on the ground, further study must evaluate each area's infrastructure and policy and management practices that might mitigate the identified water-related risks.

WRI plans to continue to improve the indicators and aggregation methodology. We welcome comments and suggestions from interested parties. For more information on the Aqueduct Water Risk Framework and associated maps please visit: www.wri.org/aqueduct.

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