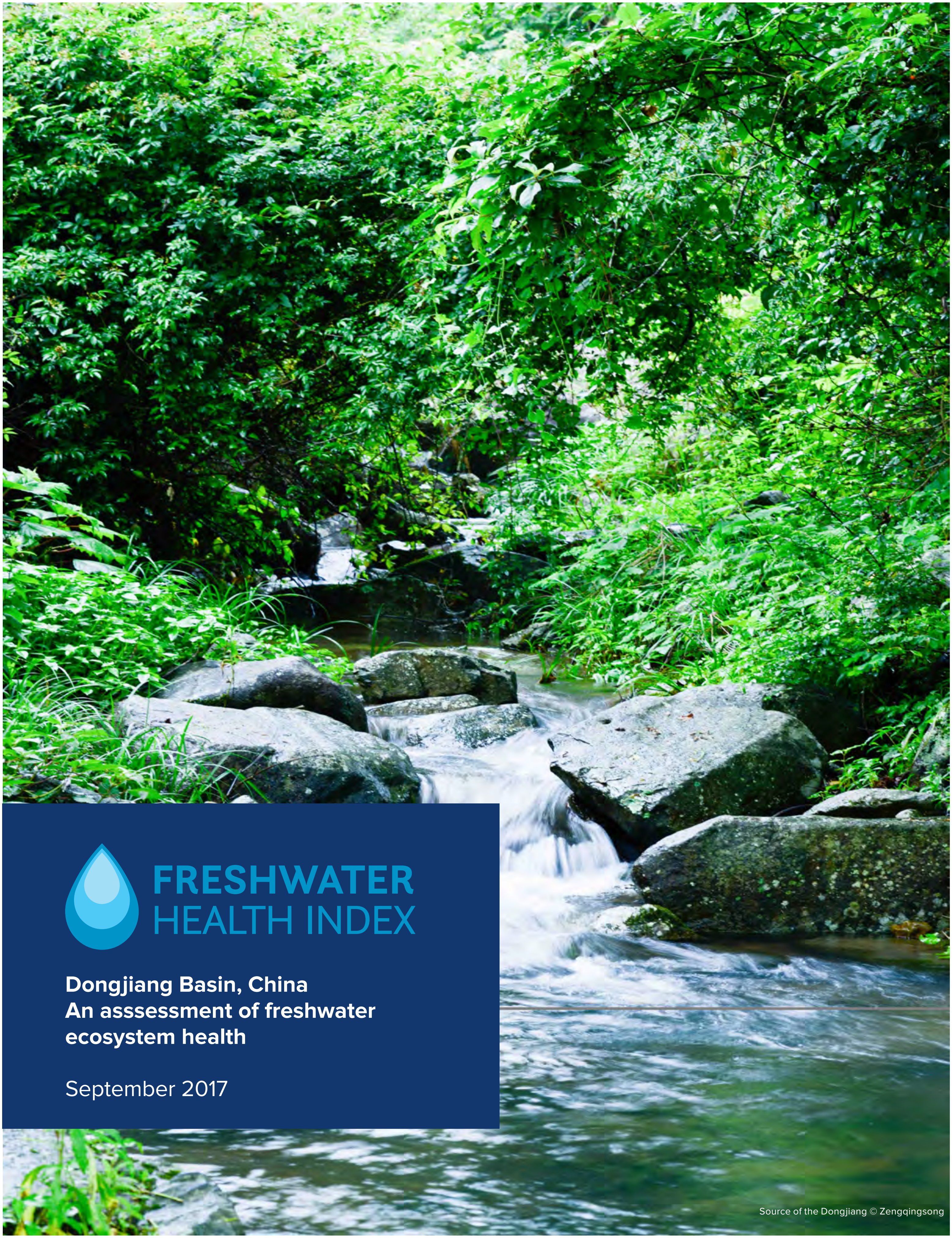

FRESHWATER HEALTH INDEX

Dongjiang Basin, China
An asssessment of freshwater ecosystem health

September 2017

Source of the Dongjiang © Zengqingsong

ACKNOWLEDGMENTS

We would like to thank all of the participants in our stakeholder forums for their time and insightful feedback in this testbed application of the Freshwater Health Index. Researchers from Sun Yat-sen University, South China University of Technology and the Pearl River Hydraulic Research Institute contributed their expertise and data to calculate many of the indicators and validate results. IUCN's South China program office capably coordinated these institutions and marshaled dozens of energetic volunteers to assist at both forums as well.

We would also like to acknowledge the contributions of our Science Working Group, (www.freshwaterhealthindex.org/science-working-group), which provided the initial conceptual and technical guidance to develop the Freshwater Health Index.

Finally, we are immensely grateful to our dedicated financial supporters, without whom we could not have realized the success of the Freshwater Health Index. Thank you to the Victor and William Fung Foundation Limited, Borrego Foundation, Flora Family Foundation, Betty and Gordon Moore, and Starwood Foundation.

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DONGJIANG BASIN, CHINA

EXECUTIVE SUMMARY

The Dongjiang is the primary water source for more than 40 million people in southern China. Despite its relatively small size, the basin is facing multiple — and often conflicting — freshwater needs. In the late 1950s, dams were built to provide flood control and hydropower, but currently water allocation and water quality have emerged as top priorities. Socioeconomically, there is a substantial disparity between the rural upstream communities and the urban areas in the delta, where per capita GDP is at least 10 times greater. This provides an impetus to relocate industries further upstream and maximize the productive use of land, both of which would bring short-term economic development but threaten water-related ecosystem services, such as the availability and quality of water downstream.

To help decision-makers assess trade-offs and set priorities for the Dongjiang's future, a consortium led by Conservation International and IUCN applied the Freshwater Health Index, a pioneering tool for assessing basin health in three components: ecosystems, water services, and governance. Working with partners from Sun Yat-Sen University, South China University of Technology and the Pearl River Water Resource Commission, a team of experts measured 11 key indicators, with 25 sub-indicators, scaled from 0-100 for ease of interpretation. Stakeholders from national, provincial and local governments as well as industry, academia and civil society provided input and helped identify top priorities. This is the first ever comprehensive look at freshwater health in the Dongjiang basin, and it provides several insights for further analysis or possible policy action.

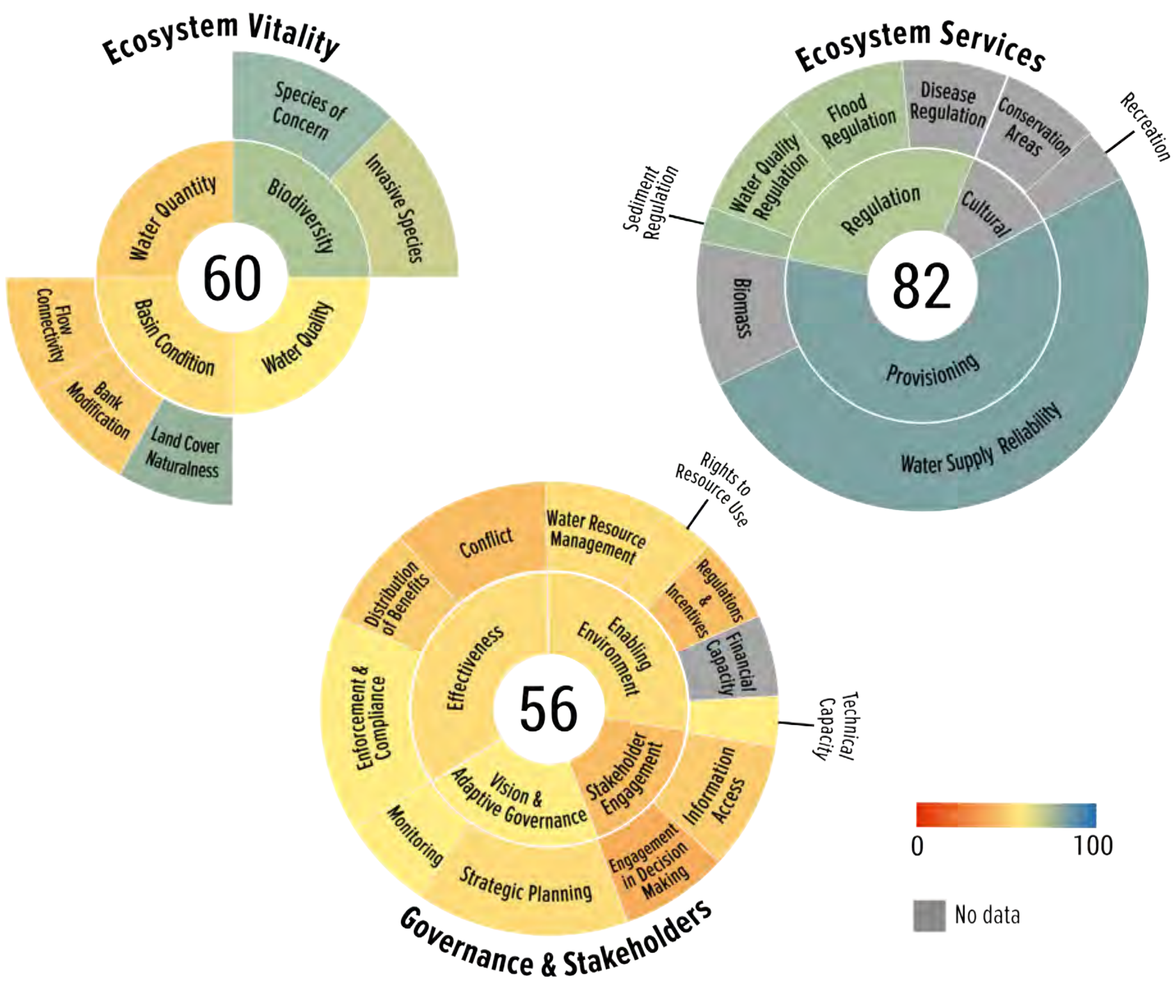
KEY RESULTS

- The Governance & Stakeholders component, which received the lowest score (56), should be treated as a priority within the basin. Strengthening underlying governance issues is a critical first step as decision-makers work to meet increasing water demand, improve water quality and adapt to climate change impacts.
- Ecosystem Vitality received a score of 60, indicating moderate health for the land, waterways and aquatic life in the basin. As the basin is heavily urbanized and has already been altered (e.g., through the construction of dams and reservoirs), there is likely a limit to how much this score can improve. Instead, focus should be on making targeted improvements and ensuring that the score does not decline.
- Ecosystem Services received the highest overall score (82) of the three components, indicating that the basin is presently meeting stakeholders' needs quite well. Water provisioning, rated most important among stakeholders, scored highest, whereas services that reduce hazards (such as floods) and maintain water quality scored more moderately.
- Pressures on the basin's ecosystems include flow and channel modification, which are primarily disruptive to fish and other aquatic life. But local declines in water quality, particularly from municipal wastewater and urban runoff, threaten both aquatic life and water supply. The lowest score for Water Quality Regulation was recorded at the downstream station of Boluo.

- Land cover is presently in moderate health (75), but lower scores in the upstream area south of the Fengshuba Reservoir reflect additional pressure from agricultural runoff. Similarly, Sediment Regulation scored 73, and although stakeholders do not perceive it as a major concern, areas above the Xinfengjiang and Baipenzhu reservoirs scored lower, which indicates threatened water quality and possibly the capacity of the reservoirs.
- Enforcement & Compliance received the highest score (60) in the Governance & Stakeholders component, but this was offset by a low score for Water-related Conflict (48), which was identified as the major concern. Incentives & Regulations also received a low score (47), which could be improved by incorporating additional tools such as eco-compensation for watershed services, which is under consideration.

CONCLUSIONS & NEXT STEPS

Overall, the Dongjiang basin is presently meeting the needs of the population depending on it, as reflected in the high score for Ecosystem Services. The lower score for



XUNWU © WENCHUN

Ecosystem Vitality indicates that human needs are being met at the expense of the local ecology, which may constitute an acceptable trade-off, but may also be an area where residents demand improvements in the future. **Responding to changing demands as well as a changing climate will be challenging, however, given the current governance system.** Increasing concerns about water quality near municipal intake points is just one example of where quantity and quality monitoring should be more integrated. This information should be made more accessible to stakeholders, and forums for local and cross-province engagement should be encouraged.

To stay on top of these issues and monitor progress, **we recommend re-assessing freshwater health in the basin within three years**. Local partners including Sun Yat-Sen University, South China University of Technology and the Pearl River Hydraulic Research Institute are now familiar with the methods and are capable to leading future assessments. stakeholder groups who participated in this first assessment through the workshops should continue to be engaged and provide feedback, but also be expanded to include even more participation from local government and industry.

We identified a few data gaps that should be addressed prior to a subsequent assessment. Although groundwater is not a substantial source in the basin, the overall picture is not complete without better data on its availability, use and quality. Despite the Dongjiang basin not being as biologically rich as the other parts of the Pearl River, local monitoring of biodiversity would be useful to prevent additional species loss. And given the importance of improving water governance in the basin, **it will be useful to identify financial needs, in terms of the gap between proposed budgets and actual allocations in water resource management sectors**.

Stakeholders in the Dongjiang basin expressed a strong interest in exploring future changes via scenarios. These scenarios include future economic development — increased urbanization and industrial relocation to upstream areas of Huizhou and Heyuan — as well as climate change, which may create more frequent extreme events (e.g., floods and droughts) in the basin. Thus, **an immediate next step would be to develop detailed scenarios with stakeholders and model these scenarios to evaluate changes** in specific Ecosystem Vitality and Ecosystem Services indicators. This will help stakeholders identify undesirable trade-offs and possible synergies, and help them begin setting quantitative targets for safeguarding the Dongjiang's health.

1. BACKGROUND

The Dongjiang River is one of the main tributaries of the Pearl River system in southern China. Although it is the smallest tributary in terms of basin area and annual average discharge, it is the primary water source for over 40 million residents, concentrated in the world's largest urban agglomeration in the Pearl River Delta. Dependent communities include the city of Hong Kong, which is located outside of the basin but procures approximately 80% of its municipal raw water supply from the Dongjiang. As the Pearl River Delta industrialized and then urbanized, the demands on the Dongjiang changed as well. Beginning in the late 1950s, dams were constructed primarily to provide flood control and hydropower, but at present, flood regulation and hydropower are lower order concerns, while water allocation among the cities, and water quality are priorities.

The Dongjiang Basin River Authority was created in 2008 to implement plans for water allocation, manage both quantity and quality, and coordinate the various stakeholder groups relying on the Dongjiang. Socioeconomically, there is a substantial disparity between the rural upstream communities (which are in Jiangxi province) and the urban areas in the delta — per capita GDP is at least 10 times greater downstream. Therefore, in addition to maximizing benefits from the Dongjiang, there is an impetus to manage the pressures to relocate industries further upstream as well as expand the mining sector, both of which would bring economic development but seriously threaten water supplies. To help stakeholders in the Dongjiang basin assess current conditions and begin planning for the future, we applied the Freshwater Health Index to measure health along three dimensions: Ecosystem Vitality, Ecosystem Services, and Governance & Stakeholders.

2. ECOSYSTEM VITALITY: INDICATOR AND SUB-INDICATOR RESULTS

The Ecosystem Vitality component of the Freshwater Health Index measures the integrity and functioning of the ecosystems — streams, rivers, wetlands, and forests — within the basin. Healthy ecosystems are fundamental to providing clean water, fish, protection from floods, and a variety of other benefits that people rely on in the Dongjiang basin. The four major indicators within the Ecosystem Vitality component measure: water quantity, water quality, basin condition, and biodiversity. Data come primarily from official government sources and are presented at the sub-basin or municipality scale, where possible, to show how and where the indicator scores vary within different parts of the basin.

When combining the four major indicators, the **Dongjiang basin receives an overall score of 60 for Ecosystem Vitality.** This suggests moderate ecosystem health — but as the detailed results below indicate, some indicators score better than others. It should be noted that the Dongjiang basin is already heavily urbanized, and its water resources have been modified (through dams and reservoirs) to meet demands for hydropower, water supply, and flood protection. There is likely a limit to how much these scores can improve without compromising the basin's ability to provide benefits to the 40 million people who depend on it. Therefore, **emphasis should be placed on ensuring that these scores do not decline, and further analysis of how improvements in ecosystem vitality, through conservation interventions, could also benefit ecosystem service delivery**. It should also be noted that stakeholders did not weight the Ecosystem Vitality indicators, so each indicator is given an equal weight by default, and it is not possible to infer particular preferences, as can be done for Ecosystem Services and Governance & Stakeholders indicators.

ORANGE TREES IN XUNWU © IUCN

2.1 Water Quantity

The Water Quantity indicator simply measures the amount and flow of water through the basin, including surface and groundwater. Ecosystems depend on seasonal patterns of water in the basin, and in many places, people have also come to depend on seasonal fluctuations in water quantity. Changing this natural pattern is often a consequence of modern development (e.g., building dams to regulate periods of flooding and drought), so it represents a trade-off with meeting human needs. However, these alterations can also have negative consequences for aquatic biodiversity and people who are accustomed to a natural flow pattern. Water Quantity is measured through two sub-indicators: Deviation from Natural Flow and Groundwater Storage Depletion. **The Dongjiang basin has a Water Quantity score of 51,** but that is based solely on the score for Deviation from Natural Flow, since groundwater storage data were not available.

2.1.1 Deviation from Natural Flow

Deviation from Natural Flow measures the degree to which current surface water flows have shifted from historic, natural flows (that is, pre-development). Reservoirs, agriculture and land-use change affect the timing and volume of surface water flows, which in turn, affect aquatic life and the availability of freshwater services downstream. Water resources have traditionally been managed to smooth out seasonal variability — reducing flood damages and/or ensuring adequate supplies — and so some deviation from natural conditions may be necessary to continue meeting human demands. **Deviation from Natural Flow received a score of 51 for the Dongjiang basin.** The relatively low score reflects the operation of three large reservoirs in the basin, in addition to numerous small ponds, reservoirs and micro-hydropower stations that modify water flow patterns from natural conditions. The operation policy of the main reservoirs is controlled by demand for water supply, flood protection and hydropower generation, respectively. These key benefits to people represent a trade-off with biodiversity (by decreasing stream connectivity and limiting habitat), sediment, and water quality impacted by the deviation (which may require additional costs for either dredging or flushing).

Table 1. Freshwater Health Index Indicators

Major indicators	Sub-indicators
ECOSYSTEM VITALITY	
Water Quantity	Deviation from Natural Flow
	Groundwater Storage Depletion
Water Quality	Suspended solids in surface water
	Total nitrogen in surface and groundwater
	Total phosphorous in surface and groundwater
	Indicators of major concern
Basin Condition	Bank Modification
	Flow Connectivity
	Land Cover Naturalness
Biodiversity	Species of Concern
	Invasive & Nuisance Species
ECOSYSTEM SERVICES	
Provisioning	Water Supply Reliability
	Biomass for Consumption
Regulation & Support	Sediment Regulation
	Water Quality Regulation
	Flood Regulation
	Disease Regulation
Cultural & Aesthetic	Conservation & Cultural Heritage
	Recreation
GOVERNANCE & STAKEHOLDERS	
Enabling Environment	Water Resource Management
	Rights to Resource Use
	Incentives & Regulations
	Financial Capacity
	Technical Capacity
Stakeholder Engagement	Information Access
	Engagement in Decision-making Process
Vision & Adaptive Governance	Strategic Planning & Adaptive Governance
	Monitoring & Learning Mechanisms
Effectiveness	Enforcement & Compliance
	Distribution of Benefits
	Water-related Conflict

2.1.2 Groundwater Storage Depletion

Groundwater Storage Depletion is a measure of the changes in the availability of water stored in aquifers. While primary stakeholders in the basin (municipal water suppliers) rely almost exclusively on surface water to meet water supply needs, groundwater abstraction is increasingly occurring both to meet industrial production of bottled water and to cover demand that exceeds cities' surface water allocations[1]. **Currently, however, the data required to estimate the scope of groundwater extraction and use is unavailable. This is identified as an important knowledge gap.**

2.2 Water Quality

Water Quality in the Ecosystem Vitality category refers specifically to the pollutant concentrations compared to thresholds needed to sustain biodiverse aquatic ecosystems. Independent of the direct impacts on human health and safety, pollution can harm aquatic life directly and also upset ecological balance by, for example, triggering harmful algal blooms. It is assessed based on monitored levels of four water quality parameters considered crucial for "good" ecological health of freshwater ecosystems. **Water Quality received a score of 61 for the Dongjiang Basin, indicating moderate quality. Agricultural and urban runoff appear to be the key sources of pollutants for the basin, so this indicator has potential for improvement in line with recent efforts to intercept and remediate pollution from these sources.**

2.3 Basin Condition

Basin Condition measures the extent of physical modifications to both land cover (e.g., forests converted to agriculture) and stream and river channels (e.g., building dams or widening channels) — all of which can impact the flow and quality of water as well as habitat for aquatic life. When combining these three factors — Bank Modification, Flow Connectivity, and Land Cover Naturalness — **the Dongjiang has a Basin Condition score of 56, which signifies poor health.** Considering the high population density and human dependence on the river, it will be challenging to substantially improve upon this score, so **emphasis should be placed on stabilizing it by restoring the most degraded sub-basins**.

2.3.1 Bank Modification

Bank Modification measures what is known as floodplain (lateral) connectivity. Lateral connectivity affects how the streams reach land and thus how materials such as nutrients and sediments are exchanged. Changes to this pattern, either through channelization or inundation through impoundments, affect the suitability for native vegetation and wildlife (including spawning fish and water birds), the biogeochemistry of the streams, as well as the extent of floodplains. **The Dongjiang has a Bank Modification score of 49, reflecting that lateral connectivity has been heavily altered due to urbanization and the need for flood control.** Improving this score, by re-creating natural stream banks would benefit the basin's wildlife and potentially recreational values, but must be weighed against the potential decline in current benefits.

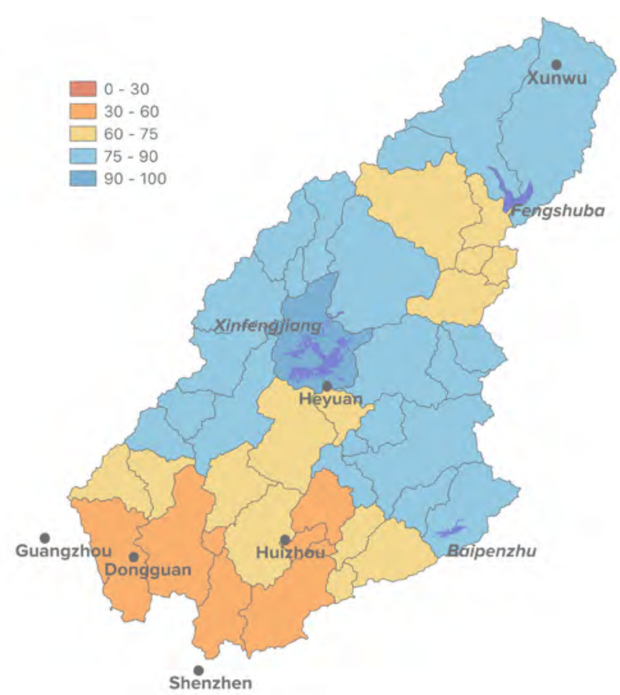
2.3.2 Flow Connectivity

Longitudinal or flow connectivity, also known as fragmentation, is particularly important to the movement of aquatic life such as fish, but also affects the flow of materials. It is affected by natural obstructions such as waterfalls, and engineered structures such as dams and weirs. Decreased longitudinal connectivity can negatively impact fish migration and reproduction, and may prevent sediment and other nutrients from being delivered downstream to the delta. **The Dongjiang has a score of 48 for flow connectivity, reflecting the presence of the three major dams and smaller weirs in the stream network.** However, a closer inspection of the actual passability of all of the structures built in the river network (especially small dams and barriers) is warranted. For example, the use of fish ladders may improve the connectivity score.

2.3.3 **Land Cover Naturalness**

Land Cover Naturalness measures how much the land has been changed from its natural, undisturbed state. Forests and wetlands are natural buffers that regulate the flow and quality of water. When they become degraded or are converted to agricultural or urban use, it changes the landscape's ability to regulate the water cycle. **The Dongjiang basin has a present Land Cover Naturalness score of 75, signifying good health overall.** The map in Figure 1 shows how this varies across the basin, where the lowest scores are, not surprisingly, in the delta, where urbanization is concentrated. There is also a high concentration of cultivated land in the upstream area, just below Fengshuba reservoir, leading to lower scores there. Importantly, the landscape is relatively undisturbed in the sub-basins containing the three main reservoirs, with highest values for Xinfengjiang reservoir.

Figure 1. Land Cover Naturalness in the Dongjiang Basin



2.4 **Biodiversity**

Biodiversity refers to the population status and trends of animal and plant species that live directly in or next to waterways. Declines in native species or increases in non-native ("invasive") species both are used as indicators of a deteriorating ecosystem. Moreover, aquatic biodiversity is often positively associated with fisheries and cultural services such as recreation. The biodiversity indicator is divided into two components: 1) Species of Concern, which focuses primarily on threatened or otherwise locally-important species, and 2) Invasive & Nuisance species. When combined, **the Dongjiang basin has a Biodiversity score of 73**, suggesting moderate health. However, this is also a subject where official and up-to-date data are lacking, so **investment in local campaigns to update data on biodiversity is needed**.

2.4.1 **Species of Concern**

Species of Concern measures threatened aquatic or riparian species in the basin — their proportion relative to the total species diversity as well as population trends. Declining species diversity (and declines within the threatened sub-population) is an early warning sign for ecosystem deterioration and can correspond to declines in benefits to people, such as fishing. **The Dongjiang basin has a score of 76 for Species of Concern.** Three species each of frogs and turtles in the basin are presently listed as threatened and constitute half of the list of threatened species (which include fish, dragonflies and crabs as well). While this suggests moderately good health for the basin overall, and is likely in better condition than the Xijiang and Beijiang, it should also be noted that local information is lacking, but most historical assessments indicate that threatened species' populations are declining.

2.4.2 **Invasive & Nuisance Species**

Invasive Species refers specifically to alien (non-native) species introduced into the ecosystem, either intentionally or accidentally, which are able to out compete or pose a threat to native species. Increasing populations of invasive species place added pressure on native species, degrade ecosystems and can negatively impact the economy and human health. **The Dongjiang basin's Invasive & Nuisance Species sub-indicator was assessed at 70.** This assessment focused exclusively on invasive aquatic species, of which three have been documented (Nile tilapia, water cabbage and water hyacinth). However, there are also abundant invasive species found in the riparian zone, which potentially impact habitat for native amphibians and reptiles as well as water quality.

3. ECOSYSTEM SERVICES: INDICATOR AND SUB-INDICATOR RESULTS

The Ecosystem Services component of the Freshwater Health Index measures the range of water-related benefits — from drinking water to hydroelectric power to protection from floods — provided by a freshwater ecosystem. These benefits, often provided in place of or as a complement to human-made infrastructure, are a way of connecting people to the natural ecosystems that they depend on. Ecosystem services are often classified according to how people experience them, and this is reflected in our three major indicators: Provisioning (goods taken from ecosystem), Regulation & Support ('background' processes that occur in ecosystems) and Cultural & Aesthetic (experiences people 'take' from ecosystems). Data for these indicators come from official sources including statistical yearbooks and, in the case of sediment regulation, modeled data. Cultural services are generally difficult to quantify, and data are not routinely collected. In the case of the Dongjiang, we have identified it as a data gap for this assessment, but recommend collecting basic data for future assessments.

When combining the three major Ecosystem Services indicators, **the Dongjiang basin receives an overall score of 82**. This suggests that the basin is presently fulfilling stakeholders' well-being needs, though there is variation among the specific services. This is also a partially complete score, since we lacked data on Cultural Services as well as Disease Regulation. It is also worth noting that these indicators and sub-indicators were weighted by stakeholders, revealing a clear preference for provisioning services from the basin (twice as high as that for regulating), as was expected, but also showed comparatively high weights on flood regulation and water quality regulation services.

3.1 **Provisioning**

Provisioning looks at the physical outputs — primarily water and fish — that freshwater ecosystems provide for people. These outputs from the ecosystems are critical inputs into economic development and are fundamental to food and water security. The Provisioning indicator is divided into two sub-indicators: Water Supply Reliability (relative to demand) and Biomass for Consumption. **Since biomass data were not available, the Provisioning score (86) was based entirely on Water Supply Reliability, which stakeholders weighted as being five times more important than fish and other biomass from the river**.

3.1.1 **Water Supply Reliability**

Water Supply Reliability looks at the ability to meet water demand from various sectors, at all locations, with respect to the total amount of water available. This includes minimum amounts of water for ecological maintenance, known as environmental flows. Decreases in reliability correspond to water insecurity, ecological degradation or unsustainable consumption of groundwater to compensate for surface water shortages. **Water Supply Reliability received a score of 86 for the Dongjiang basin, indicating good overall health.** In the districts where allocations were insufficient to meet demand (Guangzhou, Shenzhen and Heyuan), the shortfalls were modest. However, with most of the surface water in the basin already allocated and the freshwater ecosystem fairly modified to leverage this resource (see Deviation from Natural Flow and Channel Modification scores in Ecosystem Vitality), there is limited ability to meet increases in demand. Therefore, options, including groundwater exploitation, improved recycling of wastewater, diversion of water from outside the basin, water rights trading and desalination may be considered to meet future demand or increase flexibility in light of climate change-induced variability.

3.1.2 **Biomass for Consumption**

Biomass for Consumption measures the fish, wild food and other materials people harvest from freshwater ecosystems. While angling and small-scale fishing are present in the upstream sections of the Dongjiang, no evidence is currently found of pockets of local populations heavily dependent on the stream as a food source, and no official records are available that document subsistence fishing or otherwise. Therefore, **this sub-indicator was not calculated for the Dongjiang**.

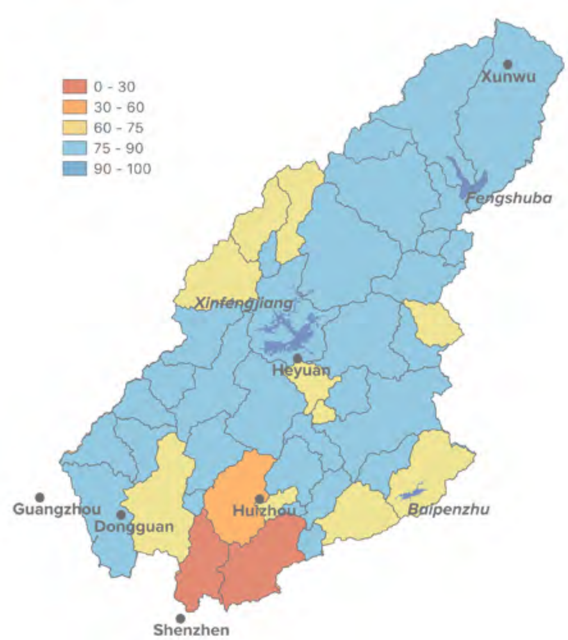
3.2 **Regulation & Support**

Regulation refers to the natural processes that support water supply and fisheries (e.g., by keeping water clean and flowing) and offer protection from floods and other hazards. Water resource development decisions frequently overlook the natural processes that help regulate water in an ecosystem, but replacing these "free" services with built infrastructure can be expensive. The Regulation & Support indicator comprises four sub-indicators: Sediment Regulation, Water Quality Regulation, Flood Regulation and Disease Regulation. Overall, **the Dongjiang has a score of 73 for regulating services**, with little variation among the sub-indicator scores. This indicates moderate health, but it is deserving of closer monitoring because of the close linkages to land use — further urbanization, large-scale agriculture and mining activities will create more stress on these regulating services.

3.2.1 **Sediment Regulation**

Sediment Regulation measures the ability of the ecosystem to moderate the flow of sediments from land to streams and deposit it in floodplains or outlets downstream. Too much sediment flowing downstream can compromise reservoirs' ability to retain sufficient quantity of water, or degrade water quality, while too little sediment delivered downstream deprives aquatic life and agricultural lands of critical nutrients. **The Dongjiang basin receives a score of 75 for Sediment Regulation.** The score is relatively high for the basin, with hot spots for erosion mostly near the urban areas downstream (Figure 2) where it may be less of a concern since it nourishes the delta. Erosion further upstream in Heyuan and above the Xinfengjiang and Baipenzhu reservoirs could be more problematic due to their impact on water quality, therefore monitoring of actual sediment deposition in these areas is recommended, along with monitoring of sediment excavation from the river beds, which are not well captured in modeled data.

Figure 2. Sediment Regulation in the Dongjiang Basin



3.2.2 **Water Quality Regulation**

Water Quality Regulation refers specifically to the ecosystem's ability to moderate pollution concentrations relative to human health standards. Ecosystems naturally filter and break down many water pollutants, but their capacity can easily be outstripped by the volume of pollutants released by human activity. For the Dongjiang, we included dissolved oxygen, biological oxygen demand, ammonium-N, chemical oxygen demand, fecal coliforms and heavy metals (zinc, copper, lead, cadmium). **The Dongjiang basin received a score of 72 for Water Quality Regulation, indicating moderate health.** The scores reflect recent successful efforts to improve water quality in the basin for human requirements. However, scores were lowest at the downstream station of Boluo (64), indicating that the river's buffering capacity between Xiacun and Boluo is being stressed and warranting closer monitoring. Comparing these with Water Quality scores in Ecosystem Vitality, controlling non-point sources of pollution presents itself as a strategy for overall further improvement.

3.2.3 **Flood Regulation**

Flood Regulation is the ability of the ecosystem to reduce the volume of flood runoff by slowing the timing of peak flows downstream and/or absorbing flood waters (e.g., in wetlands). Floods are one of the costliest natural disasters, and intact forests and wetlands can help reduce the level of this hazard and keep people and property out of harm's way. Flood Regulation here measures the exposure of people and property to floods. **The Dongjiang basin receives a score of 73 for Flood Regulation, indicating moderate health.** Stakeholders weighted Flood Regulation as an Ecosystem Service of major importance (10% higher than Water Quality Regulation) despite the fact that flood risk has substantially decreased in the past several decades, due to construction of levees, embankments and other flood protection works in the Dongjiang basin. Again, this trade-off is reflected through the Basin Condition, Biodiversity and (at this stage not calculated) Cultural sub-indicator scores. Therefore, this is likely to be an issue of continuing concern despite the lowered risk, since climate change may increase storm intensity.

3.2.4 **Disease Regulation**

Freshwater ecosystems play an important role in transmitting and containing pathogens and vectors associated with several common diseases, such as dengue, malaria, Cryptosporidium and schistosomiasis. These diseases are a leading cause of hospitalizations worldwide, and their risk to people increases with human modifications to freshwater ecosystems (e.g., dam construction, pollution). While records of water-associated diseases prevalent in the Dongjiang basin are likely to exist in the health sector, no centralized database could be identified and, thus, **access to the data required to calculate this sub-indicator was not available**. However, we recommend collecting these data and including a calculation for this sub-indicator, particularly as stakeholders assigned it a weight nearly as high (within ~10%) of Water Quality Regulation.

3.3 **Cultural & Aesthetic**

Cultural services refer to the non-material benefits people experience from freshwater ecosystems, such as their aesthetic beauty, recreational opportunities and cultural or spiritual fulfillment. These cultural services are linked to physical, emotional and mental health benefits as well as economic development opportunities (such as eco-tourism) — and freshwater ecosystems in particular are often associated with a society's cultural identity. Stakeholders assigned the lowest weight to this indicator, suggesting that it is presently of low importance relative to the Provisioning and Regulating services.

MATI RIVER IN XUNWU © LIUXINZHONG

The Cultural & Aesthetic indicator comprises two sub-indicators based on the two components of the experiential value of freshwater ecosystem services that can be quantified: Conservation & Cultural Heritage, and Recreation. Conservation and Cultural Heritage measures the degree to which freshwater ecosystems are being preserved for their cultural significance. Areas may be conserved in order to maintain ecological integrity and biodiversity or because of more direct ties to regional cultural heritage. Recreation refers to the time that people spend engaging in water-related recreational activities, such as fishing, hiking, boating, or enjoying waterfront scenery.

Currently, suitable data are not available in the basin, so **we recommend developing a protocol and collecting more specific data on both conservation and recreation in the Dongjiang basin, so that these services can be better monitored in light of growing interest in water-based recreation and likely future pressures for economic development**. Conservation & Cultural Heritage was weighted more than twice as important as recreation and, thus, would be a top priority for measurement.

4. GOVERNANCE & STAKEHOLDERS: INDICATOR AND SUB-INDICATOR RESULTS

The Governance & Stakeholders component of the Freshwater Health Index evaluates the structures (such as regulations) and processes by which people make decisions related to water resources. In contrast to Ecosystem Vitality and Ecosystem Services indicators, where data are routinely collected and measurement methods are commonplace, measuring governance is an emerging area without standardized approaches. The issues are also more subjective, meaning that peoples' perception is a valid source of information. To collect this information, we administered a survey to a large group of stakeholders from the Dongjiang basin. These stakeholders were primarily government officials (from provincial and local levels) and researchers with detailed knowledge of governance issues in the Dongjiang basin. It should be noted that the stakeholders who participated also strongly recommended that this survey be extended, perhaps in a simplified form, to a wider cross-section of stakeholders in the basin, to better reflect local (e.g., county level) conditions and provide more useful information on water governance in the basin.

When combining these results, **the Dongjiang basin has an overall Governance & Stakeholders score of 56**. This is the lowest performing set of indicators for the basin, which is not surprising considering that **improving water governance is a global challenge. Improving this score should be a top priority for decision-makers in the**

basin, particularly given the expected future increases in water demand and climate change-induced variability. Fortunately, the detailed assessments below provide insight into where and how such improvements could be made.

4.1 Enabling Environment

The Enabling Environment refers to the policies, regulations, market mechanisms and social norms that are in place to help govern and manage freshwater resources. Collectively, these determine what rights and assets are protected within a basin (e.g., the decision to cap total water withdrawals from the Dongjiang to safeguard the ecosystem), as well as how they are managed in the face of competition and conflict. When combining the five sub-indicators below, **the Dongjiang basin has a score of 53 for Enabling Environment**. This suggests a need for improvement, which may involve national as well as regional and local stakeholders.

4.1.1 Water Resource Management

Water Resource Management measures the degree to which institutions are responsible for performing functions such as intra-basin coordination, planning and development of infrastructure, mobilizing financial resources and protecting ecosystems. Water Resource Management is a complex set of tasks, typically involving multiple public agencies and other stakeholders. Weak coordination among these groups can lead to inefficient, inequitable or ineffective outcomes. **The Dongjiang basin received a score of 57 for Water Resource Management.** Within the Enabling Environment group, this sub-indicator received the highest weighting from stakeholders, suggesting it is their top priority. Scores were higher for coordination, infrastructure development, and finance mobilization, but lower for protecting and conserving ecosystems. Therefore, **improving the rules and guidelines surrounding conservation priority-setting and implementation would strengthen the overall water resource management framework in the basin**.

4.1.2 Rights to Resource Use

Rights to Resource Use measures the clarity of rights to water and water-related resources. Clear and enforceable rights, whether they are formal or informal (e.g., communal rights), are important for the efficient use of freshwater resources and for their equitable distribution throughout the basin. **The Dongjiang basin received a score of 57 for Rights to Resource Use.** Among the different categories of rules, stakeholders gave water pollution and land use the lowest scores, whereas rules pertaining to water use, allocation and fisheries scored comparatively higher. It should also be noted that stakeholders weighted this sub-indicator low – less than half of Water Resource Management – suggesting it is a lower priority.

4.1.3 Incentives & Regulations

Incentives & Regulations refer to the availability of different management instruments, such as impact assessments or financial incentives, that can be applied to encourage human activity with minimal negative impact on water and related environmental resources. In principle, a greater diversity of effective management instruments means more flexibility to devise solutions and, in turn, produce efficient responses. **The Dongjiang received a score of 47 for Incentives & Regulations, the lowest score for the Enabling Environment category.** This reflects the present emphasis on top-down regulatory approaches to water resource management in the basin. Individual scores for impact assessments and land-use zoning were comparatively higher than those for financial incentives, market-based schemes and honorary recognition programs. While it is possible for regulatory mechanisms to be wholly effective in safeguarding the basin's resources, **additional tools under consideration for the Dongjiang (payments to upstream communities for watershed services and tradeable water rights) would provide added flexibility and potentially more efficient and equitable mechanisms**.

4.1.4 **Financial Capacity**

Financial Capacity measures the extent to which necessary investments are being made to support water resource development and protection. Water resource infrastructure (e.g., dams, treatment plants) has high costs, and while economic instruments such as water pricing or pollution charges can be applied so that consumers or users (including individuals and corporations) help offset these costs or fund additional measures. Public investment may be necessary to ensure adequate financing for safeguards, ecosystem protection and remediation. **Financial Capacity was not assessed for the Dongjiang basin, since data on budgets were not easily obtained.**

4.1.5 **Technical Capacity**

Technical Capacity refers to the adequacy of the workforce, in terms of number, skill level and training opportunities, to fulfill technical functions related to water resource management — and not necessarily the level of technology that is in use. Even with sufficient Financial Capacity, a shortage of technical skills, such as environmental engineering, can hinder the effective and sustainable development of water resources. **Technical Capacity received the highest individual score within this category (59), with a slightly lower score for training opportunities compared to workforce numbers and skill level.** Improving training opportunities may become more important as technical staff address emerging issues of concern such as climate change. However, stakeholders also assigned Technical Capacity the lowest weight within this category, suggesting that it is a lower priority than improving Financial Capacity, for example, which was weighted 50% higher.

4.2 **Stakeholder Engagement**

Stakeholder Engagement refers to all the ways that stakeholders interact with one another within the basin, and the degree of transparency and accountability surrounding these interactions. While Stakeholder Engagement is carried out in different ways around the world, it is generally regarded as a key principle of good water governance to ensure that the full range of concerns is considered before major decisions are taken, to avoid potential conflicts and to ensure equitable distribution of benefits. The Stakeholder Engagement indicator is divided into sub-indicators on Information Access and Engagement in the Decision-making Processes. **Overall, Stakeholder Engagement in the Dongjiang basin received a score of 47, the lowest of the major indicators.** Stakeholders assigned this indicator the lowest weighting, suggesting it is only half as important, for example, as measures of Effectiveness.

4.2.1 **Information Access**

Information Access measures the accessibility of data on water quantity, water quality, resource management and development. Even in cases where data are collected routinely, if they are not available to interested stakeholders for research or analysis, decisions may be considered less transparent. Access to data also helps communities hold policymakers accountable (e.g., to determine that a particular policy or project is delivering the intended benefits).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Information Access received an overall score of 50 for the Dongjiang basin. This suggests stakeholders are approximately 50% satisfied with the information pertaining to water resource management in the basin. Information transparency (how it was obtained) scored the lowest, while the highest marks were given for information application (decision-makers routinely use all available information).

4.2.2 Engagement in Decision-making Process

This sub-indicator measures the scope of stakeholders' involvement in some aspect of decision-making processes, and the degree to which they have a voice in the cycle of policy and planning. While there are different levels of "suitable" engagement, increased participation is generally associated with improved information transfer, more targeted and equitable plans and policies, improved transparency and accountability, and reduced conflict. **Engagement in Decision-Making Processes received a score of 44, the lowest among all sub-indicators in the Governance & Stakeholders component.** Scores were roughly equivalent for stakeholder notification, ability to provide comment prior to decisions, and responsiveness to stakeholder input. However, stakeholders also assigned a weight approximately 20% lower than that for Information Access and suggested that active stakeholder participation was not a customary feature of water resource management in the basin, or in China more generally.

4.3 Vision & Adaptive Governance

This indicator measures the capacity to collect and interpret information, and then use that information to set policies, develop plans for the basin and adapt to changing circumstances. Effective water resource management requires flexible yet integrated forms of governance in order to deal with the sometimes rapidly changing conditions in a basin and the uncertainty associated with climate change and other emerging challenges. Therefore, strategic planning is an important aspect and is one of the sub-indicators here, but so are the monitoring and learning mechanisms in place, which allow strategic plans to be updated and adapted as circumstances change. **The Dongjiang basin received an overall score of 59 for Vision & Adaptive Governance, the highest among major indicators in the Governance & Stakeholders component, but still an area highlighted as a concern.**

4.3.1 **Strategic Planning & Adaptive Management**

This sub-indicator measures the degree to which comprehensive strategic planning (i.e., accounting for land and water use and infrastructure development) takes place within the basin. Having comprehensive plans, with well-defined objectives and long-term resource development priorities, can help establish a vision for sustainably meeting freshwater needs. But importantly, these plans need to be able to be adjusted as circumstances change or as new information becomes available. **Strategic Planning & Adaptive Management received a score of 60, the highest among all sub-indicators in Governance & Stakeholders.** Scores for developing a shared vision and strategic planning were about 20% higher than the score for adaptive management framework, suggesting that the ability to adapt is an area most in need of improvement here. It is also worth noting that stakeholders assigned a high weight to this sub-indicator, suggesting it is more than twice as important as Monitoring & Learning Mechanisms.

4.3.2 **Monitoring & Learning Mechanisms**

This sub-indicator refers to the quality and use of physical, chemical and biological monitoring of water resources in the basin to guide policy and planning processes. Ideally, decisions about water resource management are based on sound data and information, but this requires collecting such information (which entails costs) and making this information understandable to decision-makers. **The Dongjiang basin received a score of 58 for this sub-indicator.** Water quantity monitoring (e.g., streamflow and discharge) received the highest marks (equivalent to a 70), while biological & ecological monitoring received the lowest score (equivalent to a 42). This was also reflected in the need to rely on global data for the Biodiversity indicator under Ecosystem Vitality, in the absence of official, locally-collected data pertaining to biodiversity in the Dongjiang basin.

4.4 **Effectiveness**

Effectiveness refers to the outcomes from water-related policies and investment decisions: Are they in fact achieving what they were intended to do? Around the world, there is often a gap between policy and practice, between what is expected based on a complex decision and what actually occurs. This major indicator and its sub-indicators attempt to evaluate whether decisions are having the intended effects. **The Dongjiang basin received a score of 54 for this sub-indicator, suggesting room for improvement in closing this gap between policy and practice.** Stakeholders also assigned this indicator the highest weight out of any within Governance & Stakeholders, noting their concern with seeing results on the ground.

4.4.1 **Enforcement & Compliance**

This sub-indicator measures the degree to which laws are upheld and agreements are enforced. An “enforcement gap” can reflect either insufficient regulatory capacity or a lack of accountability, both of which undermine the effectiveness of laws and policies. **The basin received a score of 60 for Enforcement & Compliance, the highest among sub-indicators in this group.** This sub-indicator also received the highest weight among the sub-indicators in the group, suggesting that stakeholders rate it more than twice as important as Distribution of Benefits (from water resources). Among the specific topics, enforcement of water use (surface and groundwater) and flow guidelines were scored highest, whereas enforcement of water quality, water-use efficiency, and land use as it impacts waterways all scored lower.

4.4.2 **Distribution of Benefits**

Distribution of Benefits refers to the impacts of decisions about water resource management, with special attention to different segments of society: rural, urban, migrant workers and those without local registration, and those employed in resource-dependent sectors, such as fishermen. Water-related ecosystem services are, by their nature, unevenly distributed across a basin, and so actions must be taken (such as developing reservoirs and water distribution networks) to ensure that the resources are equitably distributed. **The Dongjiang basin received a score of 50 for this sub-indicator. Urban dwellers received a comparatively higher score and resource-dependent communities the lowest score, with other groups in between.** This perceived disparity also has a geographic component, as the majority of the urban population resides in the downstream delta region, whereas the rural and resource-dependent communities are further upstream, which has prompted consideration of "eco-compensation" as a way to enhance the share of benefits upstream residents enjoy from a healthy Dongjiang basin. **Workshop participants recommended that this particular topic be assessed with a much larger cross-section of stakeholders in the basin, to obtain a more representative depiction of how well the basin is meeting needs.**

4.4.3 **Water-related Conflict**

Tensions among stakeholders are expected when there is competition for scarce resources such as water. Tension that escalates into legal battles or even violent conflict prevents agreement and therefore can delay or undermine decisions taken within the basin. Here, we restrict the consideration to conflicts over water allocation, access, pollution, diversion or infrastructure development. **Water-related Conflict in the Dongjiang basin received a score of 48, which is the lowest score of the Effectiveness group.** This score was brought down by an extremely low score for conflicts over water quality and downstream negative impacts (32), suggesting that **addressing water quality conflicts in the Dongjiang should be a high priority**, whereas conflicts over water quantity, rights, access and infrastructure siting were all viewed as less problematic.

5. CONCLUSION

Results for the Dongjiang basin generally met expectations, where Ecosystem Services scores suggest good health, while Ecosystem Vitality and Governance & Stakeholders scored lower. The Ecosystem Vitality score, in the lower range of moderate health, indicates that human needs are being met at the expense of the local ecology, which may constitute an acceptable trade-off, but may also be an area where residents demand improvements in the future. At present, the basin's water governance, which has been evolving and will continue to with the appointment of a River Chief (*he zhang*), will need to improve. Responding to changing demands within the basin (growing urban populations, shifting agriculture and industrial relocations) as well as a changing climate will be challenging. Increasing concerns about water quality near municipal intake points is just one example of where quantity and quality monitoring should be more integrated, and where having improved local and cross-province engagement is necessary.

Water Quality received the highest weight among Regulation & Support services, reflecting stakeholders' concerns with deteriorating water quality in the basin, something that has received significant attention from local governments[2] with the establishment of additional monitoring stations and the introduction of ‘polluter pays’ systems. And while the Water Quality indicator suggested moderate health for human consumption purposes, fecal coliform levels were regularly higher than the threshold at all four monitoring stations, a result of unregulated discharges of municipal waste. With the growing industrialization of the mid-stream sections, and the potential for climate change to exacerbate the basin’s water pollution problems, water quality monitoring and standards require further attention.

Overall, the Governance & Stakeholders component included the lowest performing indicators — no sub-indicator scored above 60 — suggesting that this should be a priority area of concern for the Dongjiang basin. **New institutional arrangements, such as upstream compensation for environmental stewardship, are being discussed in the basin, but underlying governance problems may need to be addressed before instituting new mechanisms.** The weighting revealed that stakeholders consider outcomes (“Effectiveness”) twice as important as Stakeholder Engagement. Therefore, the low scores for Information Access (50) and Engagement in Decision-making (44) are likely of secondary concern when compared to Conflict (48). The low score for Conflict reflects increasing tension over water quantity and quality in the basin. And the emphasis stakeholders placed on Effectiveness also underscores their interest in understanding implementation gaps, particularly at local levels of governance. An even more localized assessment of water governance was called for in the basin and could help identify areas that might be lagging in terms of policy implementation.

The assessment also highlighted issues for further analysis or data collection. While stakeholders primarily rely on surface water to meet their needs, groundwater is also increasingly being used in some parts of the basin, and so we highlight groundwater monitoring as a key knowledge gap, given that it could be increasingly important in meeting water demand in the future. The overall water quantity picture is not complete without better data on the availability, use and quality of groundwater in the basin.

Despite the Dongjiang not being as biologically rich as the other parts of the Pearl River, local monitoring of biodiversity would still be useful to prevent the loss of additional species. It is also worth noting that current water allocations include environmental flows, but these minimum flow requirements have little input from biological requirements and are instead designed to prevent sea water intrusion from the Pearl River delta. This points to another knowledge gap: biomonitoring and linking the biological state of the river system to resource management concerns. The current water allocation limit may need revision to ensure that ecological flow requirements are safeguarded at all points in the basin.

The sub-indicator scores for Flood and Sediment Regulation highlight the trade-offs of river infrastructure development. While floods were historically a frequent natural disaster in the Dongjiang basin, channelization of the downstream segments and reservoir storage have substantially reduced flood risk. However, these modifications have impacted the sediment dynamics of the system, and in addition, increases in urbanization in the region have led to increased riverbank dredging to meet demand for gravel and related construction material. This has been associated with a drop in river bed level and an expected weakening of the flood levees[3]. Monitoring of these processes should be ongoing to provide a clearer understanding of the trade-offs.

Given the importance of improving water governance in the basin, it will also be useful to identify financial needs, in terms of the gap between proposed budgets and actual allocations in water resource management sectors. Importantly, an assessment of financial capacity should cover infrastructure needs (water supply development, distribution networks and wastewater treatment), but also investments in ecosystem conservation and rehabilitation, along with monitoring and enforcement.

Stakeholders in the basin expressed a strong interest in exploring future changes via scenarios, to better understand, visualize and discuss the possible trajectories for the basin's health. These scenarios include future economic development (increased urbanization and industrial relocation to upstream areas of Huizhou and Heyuan) as well as climate change, which may create more frequent extreme events (floods and droughts) in the basin. Thus, a next step would be to develop detailed scenarios with stakeholders and model these scenarios with a suite of hydrologic, quality, hydraulic, soil loss and allocation models to evaluate changes in specific Ecosystem Vitality and Ecosystem Services indicators relative to this initial baseline assessment. This will also help stakeholders identify undesirable trade-offs and possible synergies, and begin setting targets for improving the Dongjiang's health.

ENDNOTES

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2 Lee, F. and T. Moss (2014). "Spatial fit and water politics: managing asymmetries in the Dongjiang River basin." International Journal of River Basin Management 12(4): 329-339.

3 Liu, Huaixiang, Yongjun Lu, and Zhaoyin Wang (2012), GIS Approach Of Inundation Analysis In The Dongjiang (East River) Drainage Area." Procedia Environmental Sciences 12 (ICESE 2011): 1063–70. doi:10.1016/j.proenv.2012.01.388.

APPENDIX: METHODOLOGY FOR SELECT INDICATOR CALCULATIONS

Full documentation of the Freshwater Health Index methods is available in the FHI User Manual, which can be accessed through the website (freshwaterhealthindex.org). Below we provide details on how the methods were applied, and the data sources used, to produce the Dongjiang basin assessment.

ECOSYSTEM VITALITY

Deviation from Natural Flow

Observed discharge data from 4 gauging stations (Longchuan, Lingxia, Lantang, and Boluo) over the period 2001-2010 is compared with modeled discharge data (to simulate 'natural' conditions) generated by South China University of Technology, using the Amended Annual Proportion of Flow Deviation indicator (AAPFD) [Gehrke et al., 1995; Gippel et al., 2011]. The AAPFD gives a score, the higher the number the greater the alteration. This score was transformed and normalized to a 0-100 range, with 100 being no deviation from the natural flow regime. The basin wide deviation from natural flow regime score was the weighted arithmetic mean of the scores from the four locations, based on mean annual discharge.

Water Quality

Water Quality is assessed based on monitored levels of four water quality parameters considered crucial for "good" ecological health of freshwater ecosystems. These are: Total Suspended Solids (TSS), Total Phosphorous (TS) and Total Nitrogen (TN) with DO as an indicator of major concern. Threshold values were derived from the Class III of Environmental Water Quality Standard established by Ministry of Health; and is available for all parameters except TSS which we derived using historical baseline. The available water quality data for the five years of sampling (2010 to 2014) from 2 stations is compared against the thresholds using a modification of the CCMW Water Quality Index (CCMW WQI) method [Canadian Council of Ministers of the Environment, 2001]. The Index incorporates three elements: scope - the number of variables not meeting water quality objectives; frequency — the number of times these objectives are not met; and amplitude — the amount by which the objectives are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality) which we use as the FHI score.

Bank Modification

The channelization of the stream network and modification of land use in the riparian zone was evaluated by data extracted from examining satellite imagery. A score was assigned for each sub-basin, ranging from 0 (almost no modification visible in the riparian corridor) to 1 (nearly all of the corridor is modified). The basin score is a weighted geometric mean of the sub-basin scores, using river network length as the weighting.

Flow Connectivity

The Dendritic Connectivity Index (DCI) [Cote et al., 2009] was used to assess river channel fragmentation caused by dams. We assumed the passability of all dams in the basin for fish in either direction to be zero. The DCI is then calculated as a function of the length of river fragments (i.e., the unobstructed network between two obstructions) compared to the total length of the river network.

Land Cover Naturalness

We used land cover data from the GlobeLand30 dataset for the year 2010, available at http://glc30.tianditu.com. Land cover types were assigned scores ranging from 0-100 based on the following criteria: degree of naturalness, degree of human management of the water cycle to maintain this land cover, degree of pollution emissions, and vegetation characteristics. Naturalness was then calculated on a per pixel (30m resolution) basis and then the mean value is the basin score. Zonal statistics were then calculated for sub-basins at the HydroBasins Level 08 to depict intra-basin variation.

ECOSYSTEM SERVICES

Water Supply Reliability

Water Supply Reliability compares both the demand and supply of freshwater by the various sectors and actors in the Dongjiang basin. Estimate for supply is based on allocation to each city/county assigned by the Dongjiang River Basin authority, while demand is estimated from actual withdrawal information available for each, by sector (industrial, agriculture, municipal, ecological) for the period 2010-2015. The indicator uses information for where, how frequently and by how much supply allocation fell short of demand to estimate the value of this indicator; ranging between 0 (low reliability) to 100 (high reliability).

Sediment Regulation

Soil erosion and sediment transport are process regulated by rainfall-runoff and stream flow. Currently, estimates of sediment trapped by the reservoirs as well as in-channel erosion, extraction (by mining/dredging) and deposition are not available. However, changes to erosion risk driven by land cover change have been modeled for the basin by Lai et al. (2016) and used to calculate the indicator. The median erosion rate (15t/ha/yr) of Level II (mild erosion) specified by the Ministry of Water Resources in China is used as the threshold to estimate where in the basin, how frequently and by how much modeled soil erosion exceeded this threshold.

Water Quality Regulation

Nine water quality parameters of concern for human usage (DO, BOD-5, NH4-N, COD, Zn, Cu, Pb, Cd, fecal coliforms) were measured at 4 monitoring stations (Boluo, Heyuan, Lingxia, Xiacun) over the period 2009-2016. These data were used against the threshold established for Class II waters by Ministry of Health to calculate the index, measuring at which monitoring station, how frequently and by how much water quality thresholds are violated.

Flood Regulation

Flood damage estimates from 12 sites in the basin (Boluo, Dongguan, Gaopu, Guayingzhou, Haixi, Heyuan, Huizhou, Ma'an, Sijie, Silong, Simahe, Tonghu, Zengbo) over the period 2011-2015 were used to estimate where in the basin, and how frequently, floods were experienced.

GOVERNANCE & STAKEHOLDERS

Values for Governance & Stakeholders indicators were determined qualitatively and were elicited via survey methods — a 49-question survey using a Likert-type 5-point scale (https://www.diaochapai.com/survey2482012) was administered in Chinese to participants at the first stakeholder workshop in November 2016. In total, 32 participants, representing local, provincial and national governments, research & academia, business & industry, and civil society organizations took the survey. Scores were averaged within "modules" where each module related to a sub-indicator and included 3-6 questions. These averages (on the 1-5 scale) were then normalized to a 0-100 scale.

WEIGHTING

Major and sub-indicator weights for the Ecosystem Services and Governance & Stakeholders components were elicited from stakeholders using a two-level Analytic Hierarchy Process. The 32 workshop participants were asked to make a series of pairwise comparisons (e.g., do you consider "Water Provision" or "Biomass such as fish" to be more important?) and then rate the strength of their preferences. Numeric weights were then calculated using a balanced scale in the BPMSG AHP online system (http://bpmsg.com/academic/ahp.php) and the mean value of the group was used as the final weight. These weights were applied when combining sub-indicators into major indicator scores, and when combining major indicators into component scores.

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