Position Paper on Valuing Water in Bangladesh

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EXECUTIVE SUMMARY

In policy and investment decisions, the consideration of all benefits and costs related to water provides the foundation for sustainable water management and long-term socio-economic development. The absence of this consideration results in substantial misallocation of resources, which materializes in water resource management challenges which Bangladesh faces, such as localized severe groundwater over-abstraction and water shortages, surface water pollution and flooding.

Valuing water provides the basis for recognizing and considering all costs and benefits provided by water, including their economic, social and ecological dimensions (Bellagio Principles, 2017).

While valuing water is not equal to pricing of water, it can be a useful tool to determine equitable and incentivized pricing schemes for water. Internationally, valuing water has been prioritized as global action to achieve sustainable water resources management by the UN and the World Bank High Level Panel for Water, of which the Honorable Prime Minister of Bangladesh is a member.

Understanding the total economic value of water, i.e. the value to the economy, society and environment, can provide a basis to find strategic responses to Bangladesh's water resource challenges, such as:

- Optimizing water usage in the High Barind tract to reduce over-abstraction of groundwater;
- Identifying solutions to address Dhaka's falling groundwater levels;
- Providing guidance on managing multiple competing demands on the Halda River;
- Considering the water transfer from Jamuna to Buriganga River, to dilute pollution levels in and around Dhaka;
- Relieving Bhabodaho from water logging from rainfall and flooding events, caused by sediment build-up behind polders, which prevent saline intrusion.

The value of water can be assessed by choosing methods from three main water valuation approaches, which include:

- Revealed preference approach, which uses methods of observing peoples' behavior in markets where water is relevant;
- Cost-based approach, which infers the value of water based on costs incurred to mitigate damage, replace the ecosystem service or avoided costs if the ecosystem services are maintained;
- Stated preference approach, which uses methods to directly question stakeholders on their preferences around water.

The applicability of the methods to the Bangladeshi context and to specific sectors has been discussed during a multi-stakeholder workshop, held on November 2, 2017, in Dhaka. Based on this, and to provide concrete evidence of the importance of valuing water for Bangladesh, the valuing water approach is piloted in three case studies. These case studies include: **1)** Optimizing cropping patterns in Barind Tract, **2)** Addressing falling groundwater tables in Dhaka, and **3)** Balancing competing water demands in Halda River. Focussing on practicality, approaches, which can be executed with current data availability, were chosen. The ideal approaches, given data availability, are outlined and pathways on how to achieve these in future are suggested.

Currently, investment decisions in Bangladesh are made based on the Development Project Proforma/Proposals (DPP), following the guidelines provided by the Planning Commission of the Ministry of

Planning of the Government of Bangladesh.[1] A financial analysis is required to assess the profitability of the investment, i.e. the revenues, capital, operation and maintenance expenditures. Further, an economic analysis is required to assess the investment's impact on the wider economy, society and environment. However, the proposed approach to this analysis, using specified shadow prices, does not include the impact on water resources. Thus, the economic analysis **does not** consider e.g. the impact of new irrigation projects on falling groundwater tables, the impact of new industrial sites on additional point source pollution, or the impact of new urban developments on wetlands on lost flood retention potential, to name but a few. According to the guidelines, these impacts may be mentioned qualitatively, where identified.

With adopting valuing water as an integral part to policy making and investment decisions, Bangladesh can take a leading role in enabling sustainable water management, and thus sustainable long-term economic growth and equitable access to water for all.

> *To drive this initiative forward, the National Steering Board (NSB) of the Bangladesh Water Multi-Stakeholder Partnership (BWMSP) set up a High-Level Valuing Water Committee to lead this initiative. It is further supported by a Technical Valuing Water Committee. Jointly, and in cooperation with the Ministry of Water Resources, the Committees developed a Proforma for Study Proposal (PFS) on a Study to Develop Operational Shadow Prices for Water to Support Informed Policy and Investment Decision Making Processes. It was approved by the Ministry of Water Resources and is now being implemented by WARPO. This Position Paper provided the foundation for this work.*

[1] General Economics Division, Planning Commission of the People's Republic of Bangladesh (2014) Development Project Proforma/ Proposal (DPP) Manual – Instructions for Preparing Development Project Proposal). Part 1: Main Guideline.

CONTENTS

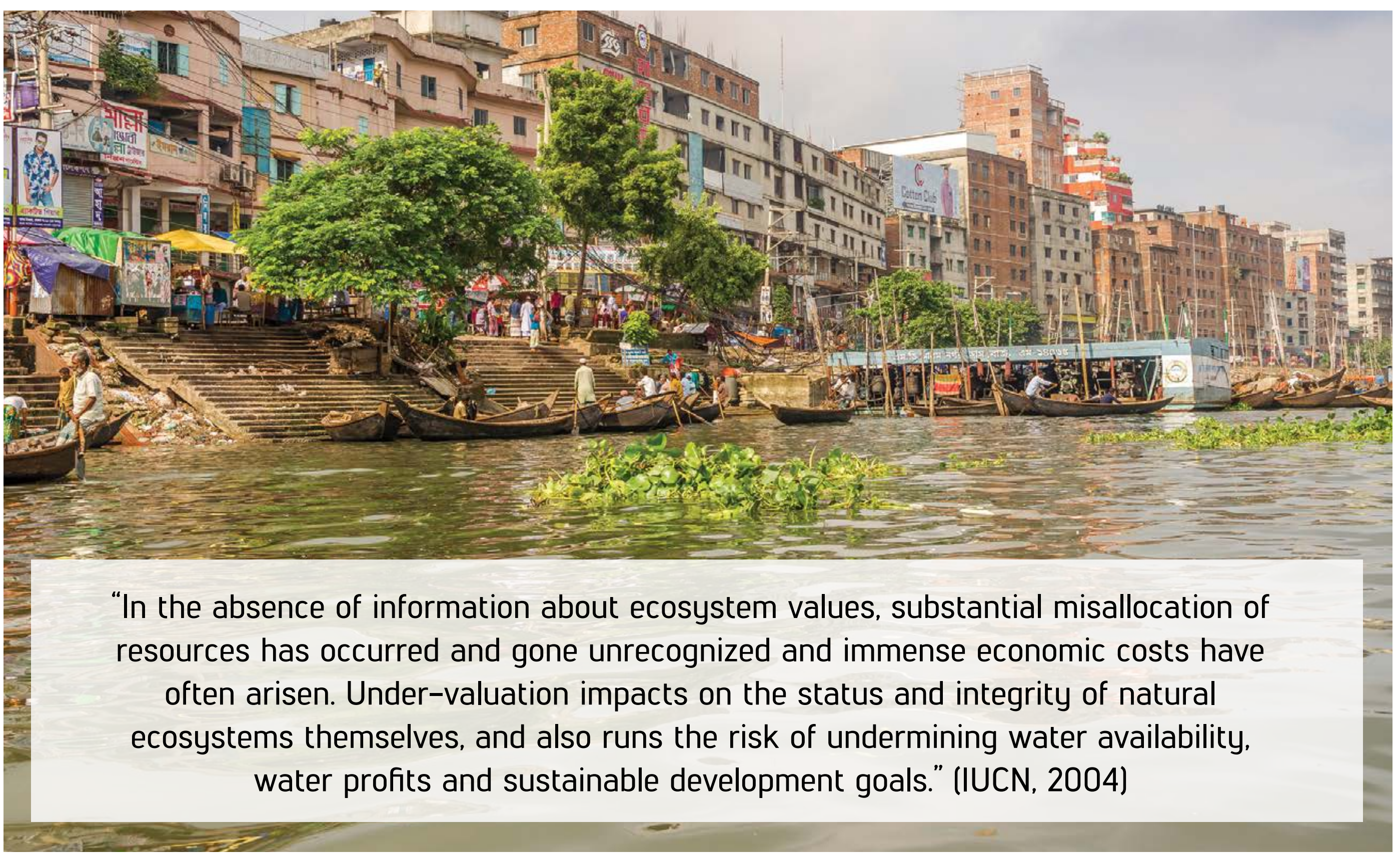
1. Vision on valuing water: Why is it important?

Valuing water provides the basis for recognizing and considering all benefits provided by water, including their economic, social and ecological dimensions (Bellagio Principles, 2017). The consideration of all benefits and costs related to water provides the foundation for sustainable water management and long-term socio-economic development.

To understand the full impact of, e.g., construction of a river barrage, the full costs and benefits need to be considered. These include the obvious consideration of the financial costs (capex, opex) of the barrage, and the benefits to the irrigators. However, further considerations need to be made to provide a full assessment on whether this investment really has the desired socio-economic impact. As such, the barrage may have an impact on the fish population, and thus an impact on the production and livelihood of the fishermen. Also, the captured sediment behind the barrage may have a negative impact on the agricultural land downstream leading to reduced yields, etc.

By considering these trade-offs, valuing water can help balance multiple uses and services provided by water in a sustainable and equitable manner and strengthen institutions and infrastructure. Thus, effective water management presents a transformative opportunity to convert risk to resilience, poverty to well-being, and degrading ecosystems to sustainable ones (Bellagio, 2017).

For Bangladesh, it is of particular importance as it is a densely populated active delta country, with multiple and increasing competing water demands, diminishing groundwater aquifers, increasingly polluted surface and groundwater bodies, and being vulnerable to climate change.



"In the absence of information about ecosystem values, substantial misallocation of resources has occurred and gone unrecognized and immense economic costs have often arisen. Under-valuation impacts on the status and integrity of natural ecosystems themselves, and also runs the risk of undermining water availability, water profits and sustainable development goals." (IUCN, 2004)

2. Developments on valuing water in Bangladesh

Internationally, valuing water has been prioritized as global action to achieve sustainable water resources management by the United Nations and the World Bank High Level Panel for Water, of which the Hon'ble Prime Minister of Bangladesh is a member.

In May 2017, the High-Level Panel for Water has drafted the "Bellagio Principles on Valuing Water," which seek to provide high-level guidance on the rationale for valuing water and on how to implement it in practice.

The principles are as follow:

- **Principle 1:** Consider the multiple values to different stakeholders in all decisions affecting water.
- **Principle 2:** To build trust, all processes to reconcile values need to be conducted in ways that are equitable, transparent and inclusive of multiple values. Trade-offs will be required, particularly in water scarce areas. Inaction today will lead to even greater trade-offs required in future.
- **Principle 3:** Value and protect all sources of water, including watersheds, rivers, aquifers and associated ecosystems for current and future generations.
- **Principle 4:** Promote education and public awareness about the essential role of water and its intrinsic value.
- **Principle 5:** Increase investment in institutions, infrastructure, information and innovation to realize the full potential and values of water.

Valuing water is now also prioritized by key stakeholders in Bangladesh, with the Bangladesh Water Multi-Stakeholder Partnership (BWMSP) driving the development of applicable methods for Bangladesh. The BWMSP includes high-level representatives from the government, private sector, NGOs, civil society and academia.

On June 25, 2016, the National Steering Board (NSB) approved a Concept Note on Economic Incentives for Sustainable Water Management in Bangladesh, which includes among others the importance of establishing methods for valuing water. Since then, the BWMSP and its Task Force (TF) have focused on the development of concrete proposals on valuing water. A Concept Note specifically on Valuing Water has been developed and presented in the Dhaka Water conference in July 2017.

To understand the applicability of key methods on valuing water to the Bangladeshi context, a multi-stakeholder workshop was organized on November 2, 2017. The discussed methods are outlined in Section 6, while their applicability was assessed for the agricultural, industrial and urban sectors in Bangladesh.

At this workshop, stakeholders agreed that water valuation holds a big potential to support addressing Bangladesh's water resource management challenges and that valuing water should be part of the process of taking strategic decisions. It was strongly suggested to start with a simple approach to valuing water, for which data are already available, and to then move on towards a more complex and holistic approach. It was found that the developed methods for Bangladesh have to be practical, rather than academic, even if this is at the cost of details and nuances, etc.

Taking the outcome of the stakeholder consultations into consideration and building on existing work done, this Position Paper on Valuing Water in Bangladesh illustrates how water can be valued for selected strategic decisions—suggesting a simple approach for now and a more holistic approach to target for the future.

Following the first draft of this position paper and acknowledging the importance of valuing water for Bangladesh, the BWMSP has chosen Valuing Water as one of its priority areas within its work stream on Water Governance and Sustainability and formed a High-Level Committee on Valuing Water chaired by, Principal Coordinator (SDG Affairs), Prime Minister's Office, GoB. The High-Level Valuing Water Committee (VWC) had its first meeting on August 12, 2018, in which it was decided to form a Technical Valuing Water Committee."

The High-Level Committee on Valuing Water requested the Planning Commission to re-examine the use of shadow prices for water in their economic analysis for investment decisions (DPP Manual) and submit a report with its findings to the High Level Valuing Water Committee. It concluded – and thus confirmed the findings of the Position Paper – that while shadow prices were used for other resources, the value of water is currently not considered in investment decisions in Bangladesh. It further outlined the need of determining the value of water and subsequently revising the DPP Manual and related assessment formats to integrate this consideration to investment decisions.

The High Level Valuing Water Committee found the requirement of a Study on Developing Operational Shadow Prices for Water to Support Informed Policy and Investment Decision Making Processes. Building on this Position Paper, the High Level Valuing Water Committee, with support of the Technical Valuing Water Committee, and in cooperation with the Ministry of Water Resources, developed the required Proforma for Study Proposal (PFS).

The project on Developing Operational Shadow Prices for Water to Support Informed Policy and Investment Decision Making Processes was approved by the Ministry of Water Resources and is now being implemented by WARPO. The HL-VWC and T-VWC continue to offer support and guidance as and when needed. The results of this study will be shared separately.

3. Strategic investment decision-making in Bangladesh today

Proposed (investment) projects need to be submitted to the competent authorities, following the steps and procedures required by the Development Project Proforma/ Proposal (DPP) Manual, provided by the General Economics Division (GED) from the Planning Commission of the Ministry of Planning of the Government of Bangladesh[2] (2014).

The project proposals require a financial and economic analysis of the proposed project, which includes three assessments: 1) Net Present Value (NPV), 2) Benefit-Cost Ratio (BCR) and Internal Rate of Return (IRR).[3]

However, while the DPP requires an economic analysis, in addition to the financial analysis, the value of water is not considered part of these analyses. However, it is expected to identify (qualitatively) the types of environmental impacts as part of the DPP.

The outcome of the financial and the economic analyses are bound to be different due to externalities and market imperfections which result in differences in 1) social and private benefit, 2) social and private costs, and 3) market distortions.

To facilitate the economic analysis—and thus to save time and resources—shadow prices are determined. Shadow prices shall reflect the economic price—rather than the market price—internalizing the wider economic impact beyond their direct financial impact.[4]

The DPP Manual offers shadow prices/conversion factors for multiple project types, such as for inputs and outputs of agricultural production, as well as for various installations of tube wells. However, while there are shadow prices/conversion factor for pumping, there are no such shadow prices for water itself.[5]

Thus, as an example, while the diesel costs for pumping may reflect the wider implications for the economy, the impacts on already over-exploited water resources are not considered in current decision-making processes when following the DPP Manual. Given falling groundwater levels and the importance of tube wells contributing to these, the current analyses may well contribute to the over-exploitation of resources, while aiming at optimizing the total economic outcome.

Determining methods for valuing water can support the inclusion of shadow prices for water into the established decision-making process, or even go beyond it.

[2] General Economics Division, Planning Commission of the People's Republic of Bangladesh (2014) Development Project Proforma/ Proposal (DPP) Manual – Instructions for Preparing Development Project Proposal). Part 1: Main Guideline.

[3] The financial analysis assesses the costs and benefits for the entrepreneur or agency undertaking the investment/project. The economic analysis assesses the wider costs and benefits of the investment/project for the entire society, including environmental, social and economic effects.

[4] In practice, conversion factors, i.e. the ratio of the accounting price to the market price, are listed in the DPP which are multiplied with market prices to thus determine the economic/shadow price.

[5] However, even if a shadow price for water were included, the existing shadow prices are based on the Master Plan Organization (MPO) from 1987. An update would be required in any case to reflect changes in the current socio-economic and environmental situation.

4. Potential strategic applications for valuing water in Bangladesh

As outlined above, understanding the value of water allows one to consider trade-offs and balance multiple uses and services provided by water to achieve long-term sustainable development. The value of water differs across regions, seasons, sectors and sources. This section briefly illustrates how valuing water can help to address some of Bangladesh's pressing water resource management challenges.

Southwest Bangladesh: Khulna, Sathkira and Bagerhat

Challenge: Increased shrimp farming in brackish waters has led to environmental degradation, including salinization of groundwater and freshwater ponds as well as degradation of agricultural lands. As a consequence, women from poorer households have to walk to get drinking water in the dry season. Rickshaws and water tankers are now supplying water at a cost. Shrimp ponds need to be changed from time to time, requiring new land, and leaving behind the old land unfit for agricultural production.

How Valuing Water can help: Currently the focus lies in maximizing short-term benefits from shrimp farming, not taking the value of water for other uses into account. Estimating the value of clean drinking water and non-saline groundwater for other purposes, such as agriculture, may show that shrimp farming comes at a considerable non-reversible long-term cost. Valuing water can support policy decisions making to meet the overall long-term socio-economic benefit.

Southwest Bangladesh – Bhabodaho

Challenge: Bhabodaho, under Abhoynagar Upazila in Jessore District, suffers from constant waterlogging, with citizens not being able to follow a regular life anymore, as they have to use boats for transport rather than walking. The waterlogging has been caused by the construction of polders as part of tidal river management. Polders prevent saline intrusion from the sea, however, due to sediments building up on the land side of the polders—carried by the river—the shore is now higher than the city—causing water logging during rainfall and flooding events.

How Valuing Water can help: Water can also have a negative value if it is causing harm. In this case the costs related to waterlogging, such as preventing leading a regular economic life with agriculture and transportation by boat rather than by foot can be estimated. This negative value (cost) can be compared to the cost of measures to address this water logging, such as dredging or sluices etc., to justify these measures.

Northeast – Sylhet/Greater Haor Basin

Challenge: This unique ecosystem is flooded during monsoon times. To be able to grow paddy rice before the monsoon arrives, (submersible) embankments have been constructed. These are designed such that the paddy fields will only be flooded after harvest by roughly mid-May. This year heavy rainfall upstream in India has caused flash floods earlier than expected—on 28 March 2017. Ninety percent of crops were destroyed. Further, fertilizers which were just applied to fields were washed into the river and killed the fish. One-sixth of Bangladesh's crops are produced in this area, resulting in increased rice prices and forcing Bangladesh to buy rice from Myanmar.

How Valuing Water can help: As in the case of Bhabodaho, water can have a negative value, as the flash flood is causing harm. Assessing the negative value (cost) of water from the destruction caused to fish and agricultural production, mitigative measures, such as heightening the inflatable embankments or moving towards crops with shorter growing season may be justified.

Jamuna Transfer:

Challenge: Buriganga River is heavily polluted—especially during the dry season. There are plans to transfer water from the Jamuna to dilute water pollution levels in and around Dhaka.

How Valuing Water can help: An assessment of tradeoffs among multiple water values which would be foregone in Jamuna River due to the transfer and the change in the value for water uses in the diluted Buriganga may give important insights. A holistic assessment considering issues such as reduction in fish production, increased flood risk, etc. is required to understand the long term implications and profitability of such infrastructure projects..

5. Definition and terms related to water valuation

There are many definitions of the value of water in literature and practice. In this Position Paper, the Total Economic Value (TEV) is defined as the sum of its use values and non-use values (IUCN, 2004). Thus, this definition includes the economic dimension, as well as the environmental, social and existence value of water.

TEV = Use values + non-use values

Where use values (also called economic value at times) include

- ***Direct values,*** i.e. outputs that can be consumed or processed directly, such as RMG, fish, rice, etc.
- ***Indirect values***, i.e. ecological services such as flood control, regulation of water flows, nutrient retention, etc.
- ***Option values,*** i.e. premium placed on maintaining resources and landscapes for future possible direct and indirect uses, some of which may be unknown today

And where non-use values (also called intrinsic values at times) include

- ***Existence values,*** i.e. intrinsic value of resources and landscapes, irrespective of its use, such as cultural, aesthetic, bequest significance, etc.

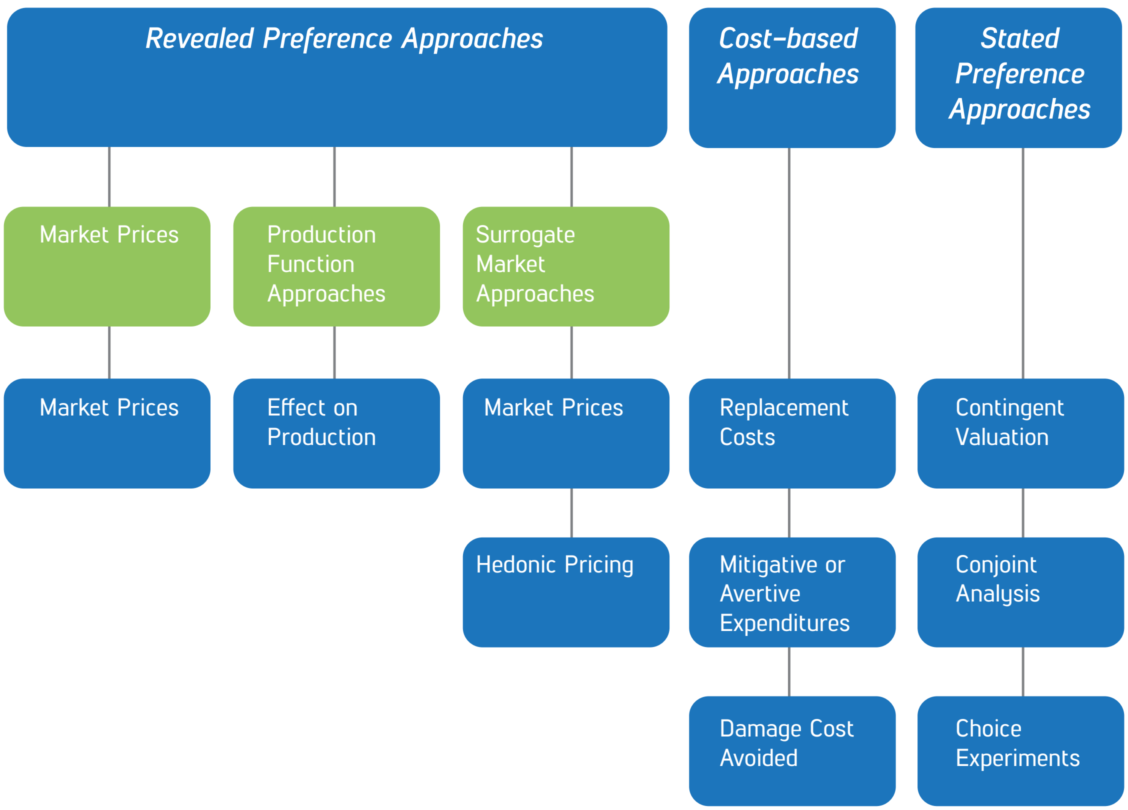
While it is relevant to define the components, which determine the total economic value of water, it is not always relevant to define all of these to address a particular water management issue.

In the past, most water valuations have focused on specific components of the total value of water—depending on the focus and aim or the water management issue which was to be addressed.

6. Overview of valuing water methods

The three main water valuation approaches include: 1) Revealed preference approach, 2) Cost-based approaches, and 3) Stated preference approach (Figure 1). A brief overview is provided below for the key methods grouped under these approaches. A concise overview of methods is available in Annex 1.[6]

Figure 1 Overview of Valuing Water Methods



Source: IUCN (2004)

6.1. Revealed preference methods

'Revealed preference approaches include methods of observing peoples' behavior in markets where water is relevant. They seek to reveal the value of water by analyzing the choices individuals/ organizations or governments make in given situations and are based on actual behavior. The most popular methods are introduced in the following.

Market price method

Data on the water price and water use are used to estimate the value of water. In a competitive and well-functioning market, the market price is determined by relative demand and supply of a good or service. In this case, it reflects the true scarcity of the good/ service and equates to its marginal value (IUCN, 2004).

[6] For more detailed insights, please refer, e.g., to "Value—Counting ecosystems as water infrastructure" by the International Union for Conservation of Nature (IUCN).

Market prices are used to estimate a point on the demand curve. Where there is sufficient variation in water prices, it is possible to statistically estimate the demand curve for water services. This reveals the value of a change in water use and does not depend on whether prices are: efficient or inefficient; administrative or market; positive or zero.

If water services are not priced in a market, it is possible to use the variation in the price of accessing water, such as pumping costs, to estimate the demand curve.

> ***For example,*** *the water demand function for tomatoes was estimated in Iran by using statistic and panel data. Based on this, the price elasticity of irrigation water is computed. This can be used to understand how a change in price, ceteris paribus, affects the quantity of water demanded by users.*

It is often said to be the 'simplest, most straightforward and commonly-used method for valuing water' (IUCN, 2004). However, the successful estimation of a demand curves requires that:

- Users can freely adjust their water use (shortages)
- Users are optimizing (behavioral economics)
- There are no substantial market failures (externalities)
- Data are available or can be collected
- There is sufficient variation in prices
- There are no prohibitive statistical challenges
- There is sufficient statistical expertise

Production function/residual value method

Water is used for many production processes, such as for agriculture or textile industry, as basic input. Thus, by assessing the impact on production by changing either the quantity or the quality of water on the production processes, the value of water can be estimated. This is possible even in absence of market prices for water.

For the production function method, the marginal contribution of each input to profits will be calculated by using multivariate techniques[7] By establishing a 'biophysical or dose-response relationship between ecosystem quality, the provision of particular services, and related production, including *effect on production methods*'[8], changes in output resulting from changes in water inputs are estimated. For this method, details of how the quality and quantity of water impacts output need to be known and a relatively large dataset is required to assess the impact in a statistically significant way.

A simpler approach is the residual value method, for which the costs of all inputs, except for water, are subtracted from the revenue of production. Assuming that water is a critical input for production, the net profits can be used to estimate the average value of water as an input, as this profit would be lost if water were not available.[9] For example, for rice production, data on crop income, crop yields, crop prices and water usage will be required. While this method is simpler to apply than the production function method, due to lower data and knowledge of production process requirements, it is limited by large differences in profitability between crop types and farm sizes.

> ***For example,*** *the value of the conservation of upland forests in Mantadia National Park in Eastern Madagascar in avoiding downstream flooding was assessed by understanding its contribution to agricultural production downstream. After establishing the relationship between land use change and downstream flooding, the impact on rice production from this flooding was assessed. It was found that the net present value for watershed protection from the establishment of the National Park was USD 126,700.*[10]

IN MADAGASCAR, THE IMPACT ON RICE PRODUCTION FROM DOWNSTREAM FLOODING WAS ASSESSED, AND THE NET PRESENT VALUE FOR WATERSHED PROTECTION FROM THE ESTABLISHMENT OF MANTADIA NATIONAL PARK WAS

USD 126,700

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[7] Striver (2008) Strategy and methodology for improved IWRM. Technical Brief No 3.

[8] IUCN (2004)

[9] Striver (2008) Strategy and methodology for improved IWRM. Technical Brief No 3.

[10] IUCN (2004) quoted: From Kramer, R.A., Richter, D.D., Pattanayak, S. and N. Sharma, 1997, Ecological and Economic Analysis of Watershed Protection in Eastern Madagascar, Journal of Environmental Management 49: 277–295.

Surrogate market prices method (hedonic pricing)

The absence or presence, or the quality and quantity of water, can influence the price for other goods and services. Thus, the value of water is sometimes reflected indirectly in people's expenditures.[11] The most common approach is to assess the difference in property prices in two locations, which differ with respect to water. Thus, if two blocks of land are identical except that one has access to water and the other does not, the difference in land prices would indicate the value of water. In practice, the blocks are likely to be different, so statistical approaches are needed to account for these differences.

> ***For example***, *hedonic pricing was used to assess the value of urban wetlands in Portland, Oregon in the United States of America. About 15,000 residential home sales were analyzed based on the property price, a variety of structural, neighborhood and environmental characteristics of the property and socio-economic characteristics of the buyer. Based on a regression analysis to estimate the hedonic price function for property prices and the construction of a willingness to pay (WTP) function for the size of the nearest wetland, it was shown that the proximity to the wetland and its size had a significant impact on property values.*[12]

Successfully implementing approaches based on observed prices in related markets requires that:

- The value of water is captured in related markets
- Data are available or can be collected
- There is sufficient variation in access to water
- There are no prohibitive statistical challenges
- There is sufficient statistical expertise

6.2. Cost-based methods

Cost-based methodologies infer the value of water based on costs incurred to mitigate damage, replace the ecosystem service or avoided costs if the ecosystem services are maintained. They key methods are introduced below.

Replacement cost method

The value of water can sometimes be estimated with reference to avoided costs or the cost of replacing a water-related service. The replacement can reflect the next best alternative to the foregone good or service or a man-made product, infrastructure or technology. The cost of the replacement can be taken as an estimate for the value of water. However, it can be difficult to find a 'perfect' alternative.

Mitigative or avertive expenditures

If the loss of a water service, or a decline in its quantity or quality, has negative effects, the costs of the required mitigation or aversion measures can be used to estimate the value of this water service. For example, the loss of a wetland upstream reduces the ability of the water system to purify itself, thus additional technologies for water purification may be required to achieve the same water quality status as before the wetland was lost.

Damage cost avoided

In cases where water ecosystems protect economically valuable assets, the damage cost resulting without this ecosystem can be used as an estimate for the value of this water ecosystem service. The value refers to the maximum willingness to pay in monetary terms to avoid a certain damage.

> ***For example***, *the lower shire wetlands in Malawi and Mozambique and the Barotse floodplain in Zambia cover a combined area of 1.5 mn hectares. Among other ecosystem services, the floodplains store water in the rainy season and thus avoid flooding downstream. A study assessed the avoided damage to infrastructure, land and settlements as well as production opportunities and found that the value of the flood attenuation for the two wetlands amounted to a present value of USD 3 million.*[13]

Successfully implementing cost-based approaches requires that:

- Users do not obtain water services from multiples sources
- The costs of replacement, mitigation or aversion measures or of resultant damage without the water ecosystem service are well known
- Data on costs are available or can be collected
- There is sufficient consistency and confidence in cost estimates at the scale of analysis
- There is sufficient statistical expertise

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[11] IUCN (2004).

[12] IUCN (2004). From Mahan, B.L., 1997, Valuing Urban Wetlands: A Property Pricing Approach, US Army Corps of Engineers Institute for Water Resources, Evaluation of Environmental IWR Report 97-R-1 Washington, DC

[13] IUCN (2004) quoted from Turpie, J., Smith, B., Emerton, L. and J. Barnes, 1999, Economic Valuation of the Zambezi Basin Wetlands, IUCN—International Union for Conservation of Nature

6.3. Stated preference method

In some cases, e.g. when potential policies, rather than actual policies, are assessed, or when non-use (passive) water values shall be assessed, market transactions cannot be used as a basis to estimate the value of water. In these cases, stakeholders can be questioned directly for their preferences, which then can be used as proxy for the value of the water service.

The most common stated preference approach is contingent valuation. Other stated preference methods include conjoint analysis and choice experiments. However, due to complex data needs and analyses, these are rarely applied.

Contingent Valuation (CV)

The value of water can be estimated based on the responses of users to hypothetical scenarios, which seek to elicit their willingness to pay (WTP) or willingness to accept (WTA) for specific water services. The surveys can either be open-ended survey, in which the respondent determines their own response, or dichotomous choice surveys, which offer choices for respondents.

***For example**, contingent valuation was used to assess the economic value of drought mitigation measures, such as upstream forest protection, for local farmers in Eastern Indonesia. Surveys were carried out which captured the farmers' socio-economic information and included questions on whether they would be willing to pay for drought protection measures, and if so how much. The survey included reminders on their constraints and substitution options. It was found that the mean WTP ranged between USD 2-3 per household, with farmers expecting higher profits from their rice sales and those being higher educated willing to pay more.* [14]

Conjoint analysis

Similarly to CV, the value of water can be estimated based on responses from users on different hypothetical situations which described using their characteristics or attributes. Respondents are asked to either rank them or choose between them, rather than stating their WTP or WTA.

Choice experiments

Similarly to CV, the value of water can be estimated based on the responses of users to choose between alternative proposed scenarios, such as policies. For example, a user could be asked whether he prefers large quantities of low quality water or small quantities of high quality water.

Successfully implementing stated preference approaches requires that:

- Users are able to understand the scenarios
- Users are able to formulate sensible responses
- Users are honest in their responses
- The surveys can be undertaken
- There is sufficient expertise in study design
- There is sufficient statistical expertise

[14] IUCN (2004) quoted from Pattanayak, S. and R. Kramer, 2001, Pricing ecological services: Willingness to pay for drought mitigation from watershed protection in eastern Indonesia, *Water Resources Research* 37(3): 771–778.

7. Applicability of these valuing water methods to Bangladesh

To understand the applicability of the methods introduced above to the Bangladeshi context, case studies were used across the industrial, urban and agricultural sectors to discuss the application of key methods. The workshop material can be found in Annex 3.

The following case studies were discussed:

- **Industry:** Water usage and discharge by textile industry in Dhaka
- **Urban:** Residential Apartment Complexes in Dhaka
- **Agriculture:** Rice Production in the Barind Tract

Table 1 below summarizes the applicability of the methods to the above-mentioned case studies.

Table 1: Response matrix to applicability of valuing water methods to Bangladesh

Methodology	Applicability to Bangladesh		
	Industry	Urban	Agriculture
Revealed Preference Market Prices	limited applicability	limited applicability	limited applicability
Revealed Preference Surrogate Market Price	not applicable	not applicable	limited applicability
Revealed Preference Production Function	applicable	not applicable	applicable
Cost-based	applicable	applicable	limited applicability
Stated Preference	applicable	applicable	applicable

Source: Stakeholder Consultation on 2 Nov 2017

Please note that further research is required to find a definite answer to the applicability of all methods to the Bangladeshi context.

- applicable
- limited applicability
- not applicable

Source: Dey et al. (2015)


TEXTILE INDUSTRY


RESIDENTIAL APARTMENT COMPLEXES IN DHAKA


RICE PRODUCTION

8. Applying valuing water methods in practice

The concrete application of valuing water methods are demonstrated in three pilot studies, including valuing water for agriculture, for industry and for ecosystem services. To date, valuing water has often been restricted in practice by the complexity of data needs and analyses. The following sections, describe the ideal methodology to valuing water for each of the three pilot studies. Acknowledging that data requirements do not allow for these advanced techniques at the moment, simpler approaches are proposed. While even the findings from the simpler approaches can be insightful for decision makers, they provide a good starting point to further refine the valuing water methodologies over the course of time.

Since the applications of valuing water are numerous, but resources to do these assessments are limited, the following considerations were used to prioritize pilot studies:

- **Relevancy:** Does the value of water relate to an important policy decision?
- **Sensitivity:** Does the value of water have the potential to change the policy decision?
- **Uncertainty:** Is the value of water currently poorly understood?
- **Knowledge:** Would a valuation study substantially reduce uncertainty about the value of water?
- **Cost:** How much would it cost to attain the results?

The three prioritized pilot studies are demonstrated below.

8.1. Pilot Study #1: Optimization of cropping patterns in High Barind Tract

In the High Barind Tract, falling groundwater levels and reduced surface water flow pose a threat to agricultural production—and thus to Bangladesh's food security and to the livelihood of the local farmers.

The Barind Tract has a comparatively higher elevation than the floodplains and thus remaining dry when the floodplains are flooded during monsoon. Besides a few small streams, this region is dependent on groundwater. The Barind Tract covers most parts of the greater Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, Joupurhat and Naogaon districts of Rajshai division. About 47% of the Barind area is classified as highland, 41% as medium highland and the rest as lowland. [15]

[15] Barind Tract, Bangladedia. http://en.banglapedia.org/index.php?title=File:BarindTract.jpg#filelinks. Last accessed 11 May 2018..

One of the drivers for the unsustainable agricultural production is that farmers to not consider the full value of water in their production considerations. While the price/cost of irrigation water to the farmers in many cases reflects the cost of supply, i.e. abstraction and distribution, it does not factor in the economic costs, e.g. the scarcity of water. [16]

Valuing agricultural water in the Barind Tract has a number of potential applications, including helping to better understand the benefits and costs of different mechanisms for allocating water between irrigators, such as:

- Open access
- Administrative allocation
- Administrative water prices
- Taxes and subsidies on outputs and non-water inputs
- Water markets

In addition to the aggregate benefits and costs it is also possible to estimate the distribution of benefits and costs between groups. Valuing water can help to design these mechanisms, for example by providing evidence on how to adjust input subsidies to meet government objectives.

8.1.1 Approach in ideal world

To estimate the value of water to agriculture in the Barind Tract it is necessary to quantify the value of water in different uses, how water is allocated across uses, and hydrological constraints. Understanding the mechanisms for allocating water is important because it determines how an increase in water availability would be distributed across users (or how a decrease would be rationed). This is relevant even when the allocation mechanism is not in question. Understanding the hydrological constraints is relevant since the starting point for water availability matters. All else equal, the greater the availability of water, the higher the total value of water and the lower the marginal value of water.

The economic component of the ideal approach captures the behavior of irrigators, such as whether to irrigate and what quantity of water to use. It also captures the benefits and costs of water use to irrigators. The hydrological component captures groundwater levels based on factors including recharge and abstraction. This is typically implemented through water balance equations and can be challenging in complex systems where the resource may be poorly understood. The hydrological component helps to ensure that the economic component is realistic, for example, that water use cannot exceed water availability.

The economic component needs to include the demand function for water by irrigators (either explicitly or implicitly) to capture the behavior of irrigators or the benefits and costs of water use. The demand function shows the quantity of water used at different prices, including the quantity demanded at zero price. The demand function can also be used to estimate the value of increasing or decreasing water use. The demand function can be modelled at different levels of aggregation from the individual level to the system level, with the appropriate level depending on the application.

There are a number of options for estimating demand functions, including:

- **Revealed preference (prices):** Collect data on actual water use and water prices (and other factors that affect water use) and estimate the demand function statistically. There are no direct volumetric data on water use, but there are ways of calculating it indirectly.
- **Production function:** Collect data on outputs such as rice and inputs such as water and estimate the production function statistically. To reduce estimation bias, it is sometimes possible to estimate the production function indirectly by exploiting the duality between the production and cost functions. The demand function can be derived from the production function (or cost function) and data on prices. Participants at the stakeholder workshop suggested that farm management surveys had been conducted and provide a potentially rich source of information on physical inputs and outputs as well as financial data.
- **Stated preference (contingent valuation):** Ask irrigators what quantity of water they would use at different hypothetical water prices and estimate the demand function statistically. Participants at the stakeholder workshop could not point to any existing stated preference studies, suggesting that new surveys would be required to implement stated preference options.

[16] Even within the Barind Tract there are differences in water availability between low and high Barind, resulting in different scarcity values of water.

Which option is most appropriate depends on the circumstances. If sufficient data were available, the revealed preference approach based on observed behavioral responses to water prices would likely be most appropriate. The ideal data set for this analysis would cover multiple irrigators over multiple time periods and have substantial variation in prices.

Irrespective of how user demand is estimated, the broader system model could be implemented using mathematical programming approaches. These approaches can be used to determine how water is allocated. In convex problems where non-linearities are particularly important non-linear programming and mixed integer programming (with piecewise linear approximations) can be used. Where dynamics are especially important dynamic programming can be used. Relevant examples of mathematical programming approaches include Ruhul et al. (1997), Alaya et al. (2003) and Tilahun (2002) (Box 1).

The approach set out above focuses on the value of water to agriculture. During the assessment, the social and environmental impacts need to be identified and included in the analysis.

Box 1: Determination of optimum crop mix for crop cultivation in Bangladesh (Alaya et al. 2003)

The study was motivated by objectives to improve the productivity of the agricultural sector in Bangladesh. A linear programming model was developed to maximise agricultural profits and determine the optimal combination of crops for different types of land. This is subject to several constraints, which include food demand, land availability and capital constraints. The study allowed for single, double and triple cropped lands with an annual cropping pattern. The results revealed that an annual contribution can be increased by 15,945 million Taka (1997). This provides a typical approach to agricultural programming models and shows the potential applicability to Bangladesh. Extending the approach to include water would be possible.

8.1.2 Approach for now

Given time and data restrictions, a simplified version of the production function approach—known as fixed proportions, or residual value method—was chosen.

As described in Section 0, the net profit for each hectare of agricultural land is calculated, excluding water costs. The net profit is estimated to reflect the value of water. This estimation is performed for each crop type. More details on the methodology, can be found in Annex 3.

The key economic equation is: $$\Pi = \sum_i N_i X_i \qquad (1)$$

where Π is total net benefit excluding water costs, N_i is the net benefit per hectare excluding water costs for land use i and X_i is the area of land use i. In this case, the land use refers to a possible production system which can be comprised of a number of crop rotations.

The net benefit per hectare excluding water costs can be disaggregated into:

$$N_i = R_i - M_i - L_i - K_i - D_i \qquad (2)$$

where R_i is the benefit of output per hectare for land use i, M_i is the materials and equipment cost per hectare for land use i, L_i is the labour cost per hectare for land use i, K_i is the capital cost per hectare for land use i, and D_i is the land cost per hectare for land use i.

All relevant benefits and costs should be included. If relevant costs are excluded, the value of water will be overstated (see Young 2005).

In this model, the area of land that can be allocated to different land uses is constrained by the available water resources, i.e. the sustainable recharge rate of the aquifer, and by the availability of suitable land. For this approach, it was also assumed that the prices of outputs and inputs other than water are fixed. This is an important limitation because the policies considered could affect prices, especially land prices.

Once the above is determined, it can be used to estimate the net benefit of an additional unit of water for different land uses and thus also of the total net benefit associated with incremental changes in water use across all land uses. The equations can be used to estimate the value of water to agriculture under the simplifying assumption that the allocation of water to different land uses is efficient (which may or may not approximately hold). This can be implemented through a linear programming approach where Π is maximized subject to the constraints above, i.e. available land and water resources.

8.1.3 Pilot study

This pilot study is intended as a first attempt—within given data availability—to provide an initial understanding of how valuing water can be used to support decisions addressing the challenges in the High Barind Tract area. Section 8.1.4 offers suggestions on how to further refine the analysis.

This pilot study has been based on underlying data and findings from an existing BRAC study (Dey et al., 2015), and was supplemented by additional data as indicated.[17] The study was conducted in five districts, namely, Rajshahi, Dinajpur, Rangpur, Bogra and Pabna. Besides secondary data, primary was collected through a survey covering 450 farm families from 90 farms from each upazila of the targeted district.

Dey et al. (2015) found that— due to overexploitation—the groundwater table has significantly declined over the last 30 years (1981-2011), ranging from -2.3 to -11.5 m. Figure 2 shows that Rajshahi district was affected the worst, followed by Pabna, Bogra, Dinajur and Rangpur. During this period the density of shallow and deep tube wells has increased 8.5 times, while the irrigated land only increased 1.6 times. Further, it was found that the average annual river water level and discharge has similarly declined from 20 m to 19 m and rom 90.8 to 56.9 m³/sec between 1981 and 2010 respectively.

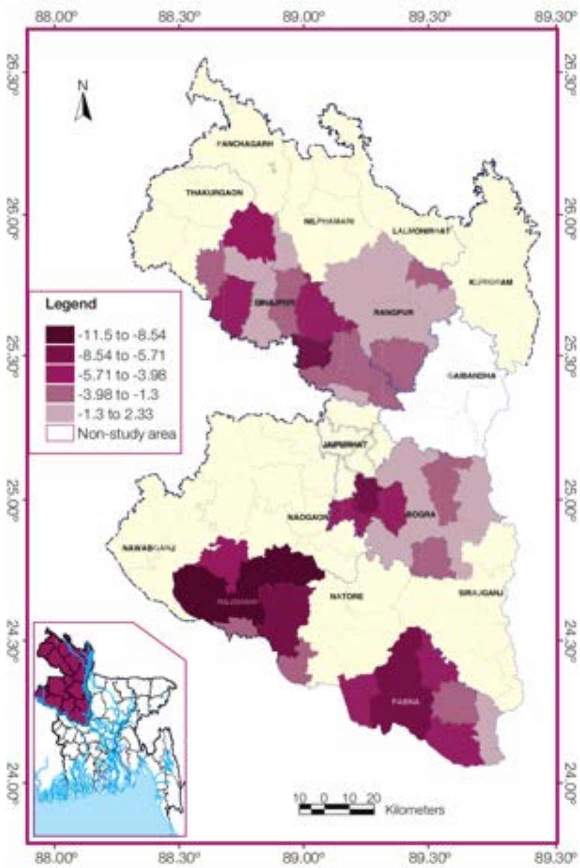
Between 1980/81 and 2000/01 the area in which Boro rice is grown has increased around 17 times, while that of the remaining ten major crops has increased three times. The increase in Boro area was highest in Rangpur, followed by Rajshahi, Dinajpur, Bogra and Pabna districts (Dey et al, 2015).

To gain a better understanding of the value of water in these target districts alternative crop choices in addition to boro rice—are assessed for their profitability and water requirements. The ten major crops in the target districts during boro season include wheat, potato, sugarcane, onion, eggplant, chilies, mustard, lentils and jute (Dey et al, 2015). Of these, sufficient information for the analysis for the target districts is available for five crops, namely, boro rice, wheat, potato, mustard and lentils. The further assessment was conducted for these five crops.

The following data were used to estimate equation (1) introduced on adjacent page:

- **Gross revenue (TK/Ha):** These data are available for targeted crops in the target districts from the study conducted by Dey et al. (2015). If no specific value was available for one specific target district, the average gross revenue across the remaining districts was taken.
- **Total costs (Tk/ha):** These data are available for all targeted crops in the target districts from the study conducted by Dey et al. (2015). If no specific value was available for one specific target district, the average total costs across the remaining districts was taken.
- **Total costs, excluding water resource costs (Tk/ha):** For this pilot study, water resource costs, such as water abstraction charges, are not are considered separately from total input costs. As the water resource costs are assumed to be comparatively small, it is not expected to influence the final result. However, when further refining the model, these should be analyzed separately.

Figure 2: Map of groundwater depletion in targeted districts (upazila basis)



Source: Dey et al. (2015)

[17] Dey et al. (2015). Environmental and Economic Sustainability of Groundwater for Irrigation: Implications for Ensuring Food Security in the North-West Region of Bangladesh. Research Monograph Series No. 62. BRAC Research and Evaluation Division. BRAC Center. Dhaka.

- **Water requirement (m³/ha).** These data were assessed for the target crops as follows:

    - **Water usage for boro rice:** The capacity of lifting water (m³/hr) by DTW and STW, the cost of lifting water per hour by DTW and STW (Tk/hr), as well as the overall percentage of type of fuel used for STWs was received from personal communication with the authors of Dey et al. (2015).[18] It was assumed that these parameters are the same across all districts. Based on total water lifted by STW and DTWs for boro rice production in the target districts and related costs, the actual water usage for boro production (m³/ha) for each target district was deducted.

    - **Water usage of wheat, potato and mustard:** Information on estimated net water requirements by crop were taken from Asaduzzaman et al. (2018).[19] Given that application efficiency is estimated at 80% and conveyance efficiency is equally estimated at 80%, an additional 40% of water requirement was added to the net water requirement to derive the gross water requirement.[20] The gross water requirement is thus comparable to the water lifted for boro rice. It is assumed that the water usage is the same across all target districts.

    - **Water usage for lentils:** As the net water requirement for lentils was not available in the mentioned sources, the green and blue water footprint was estimated.[21] As no data was available for Bangladesh, data from West Bengal (India) was taken as best proxy given the geographical proximity and similarity. As mentioned above, this value was adjusted to consider application and conveyance efficiencies. It is assumed that the water usage is the same across all target districts.

- **Total maximum area of cultivation, per district (ha):** The latest data (2010/11) on the area of cultivation of the targeted crops was used to delineate the maximum area of cultivation. This data was made available in personal communication with the authors of Dey et al. (2015).

- **Minimum area of cultivation for boro rice (ha):** Understanding the significance of boro rice production for national food security and farmers' livelihoods, the model is optimized within the constraint of retaining a minimum area for the cultivation of boro rice. The minimum area is defined by the average boro rice area cultivated between the years 1988-1991, i.e. the time after the irrigation boom took place.

- **Maximum area of cultivation per targeted crop (ha):** Given the differences in irrigation infrastructure required between boro rice cultivation and other crops, and potential complications of transforming only one part of a boro area into an area of the cultivation of other crops, the maximum area of cultivation per target crop is distinguished between boro and non-boro areas. The maximum boro rice cultivation area is based on the maximum historic production data between 1981-2011 for each district (personal communication with Dey et al, 2015). The maximum cultivation area for non-boro crops is based on the total current area of cultivation of each target district minus the average historic boro rice cultivation area between 1988-1991, i.e. the assumed minimum area of cultivation for boro rice, for each district.

- **Aquifer recharge available for irrigation (m³):** No conclusive estimate for the sustainable rate of aquifer abstraction has been found to date. However, given the above-mentioned evidence of falling groundwater tables, it is safe to assume that current abstraction rates are too high. Further, we have an estimate of the current water usage of the targeted crops in each district. Thus, for purpose of deriving a rough estimate for this pilot study and for showing the impact of changes to this abstraction rate, the analysis was conducted for a range of abstraction rates, i.e. 50%, 60%, 70%, 80%, 90% and 100% of the current abstraction rate for the five targeted crops.

As described in section 8.1.2, the optimal allocation of land use across the five target crops was assessed for each district to maximize net benefits, considering land and water constraints, as well as the chosen minimum area for boro cultivation. To provide a more differentiated picture, a scenario analysis with different water abstraction rates (as % of current abstraction) was conducted and contrasted to the status quo.

Assuming that the optimized allocation of land use is efficient, the value of water is estimated based on the marginal value of water for each production system. In other words, the marginal value of water is the incremental value that is achieved through additional output of each target crop based on one unit of water (Tk/m³). To gain a more differentiated assessment, this was done for each district

[18] Please note: DTW are generally powered by electricity, while STW can be either powered by diesel, electricity or both.

[19] Assaduzzaman, Delacamara, Restiani and Anik (2018). Economic Policy Incentives for Optimal Water Use in Agriculture and Industry in Bangladesh. 2030 Water Resouces Group. World Bank.

[20] M A Baqui (2014). Final Report of The Study for Collection of Data Related to Irrigation in 100 Upazilas of Bangladesh.

[21] Mekonnen, M.M. and Hoekstra, A.Y. (2010). The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands.

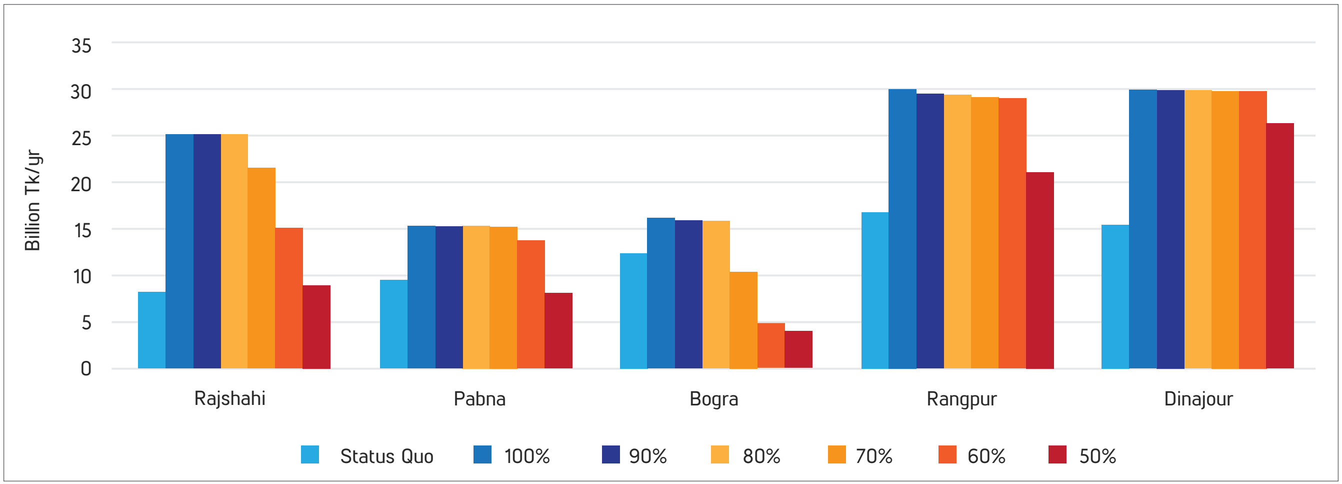
separately. The marginal value of water was also assessed for each crop separately.

Tentative Results[22]

Across all districts, the optimization of land use has led to an increase in total net benefits between 31% in Bogra and 205% in Rajshahi (see Figure 3). Further, it is interesting to see the impact of the total amount of water abstracted (as % of current water abstraction) on total net benefits. Figure 3 illustrates that the same net benefits (or marginally less) can be derived when only abstracting 80% of the current water abstraction for these five crops. For Pabna this even holds true when only abstracting 70% of current water abstractions, and for Rangpur and Dinajour only 60% of current water abstractions are required.

Figure 4 and Figure 5 below provide an overview of the allocation of land use between boro and non-boro crops, as well as the respective allocation of water usage. Today (status quo) the area cultivated by boro rice comprises between 63% in Dinajour and 79% in Rangpur. It is interesting to see that—when optimizing land use to maximize the total net benefit while considering water and land constraints—the total boro area does not exceed the set minimum area, as determined by the model (see details on minimum cultivation of boro

Figure 3: Total net benefits across scenarios (Tk/yr)



Note: The % values in the scenarios refer to the % water abstracted of total currently abstracted water for the five target crops

Figure 4: Boro Area as % of total cultivated area across scenarios

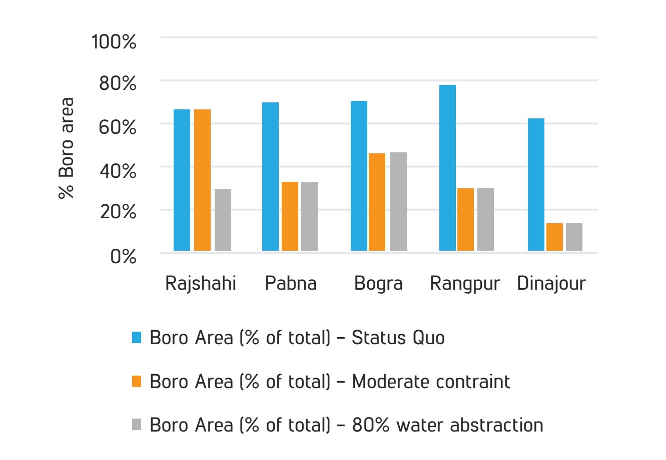
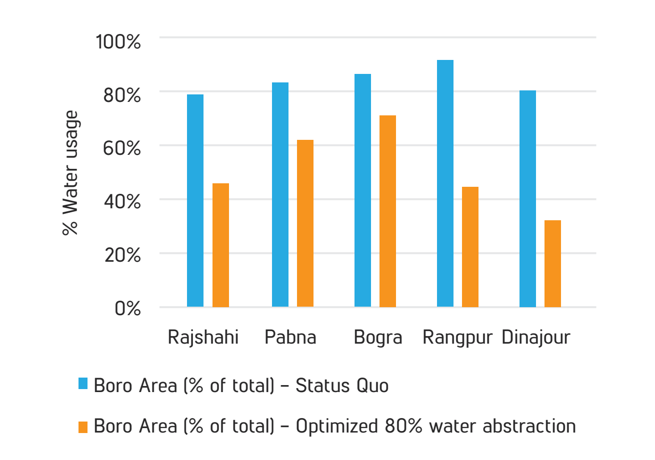


Figure 5: Boro water usage (% total) across scenarios



[22] The analysis and results are still subject to a peer review and to further refinement, as required.

area above). This shows that the other four crops provide greater net benefits than boro rice (see also Figure 7 to Figure 11 below). Figure 5 shows that today (status quo) boro rice requires between 80% and 90% of total water usage among the target crops. In the optimized model, this percentage is reduced to between 33% in Dinajour and 73% in Bogra.

Figure 6 below illustrates that the assessed marginal value of water on the production system level across the five target crops varies between 4.08 TK/m³ in Rajshahi and 6.79 Tk/m³ in Dinajour. Interestingly, the average pumping costs for water from deep tube wells (DTW) amounts to 0.69 Tk/m³ and from shallow tube wells (STW) 6.03 Tk/m³ (Dey et al, 2015). Given the distribution of DTWs and STWs, the average costs across pumping modalities for pumping water amounted to 0.96 Tk/m³ in Rangpur, 1.92 Tk/m³ in Pabna, 2.90 Tk/m³ in Dinajour, 3.10 Tk/m³ in Rajshahi and 3.87 Tk/m³ in Bogra.

Figure 7 to Figure 11 illustrate the net benefit per hector across land uses (tk/ha) and the net benefit per unit of water across land uses (tk/m³) and on a system level. Potato and lentils show the highest net benefit among all target crops, while boro rice shows the lowest in all target districts.

Figure 6: Marginal value of water across the production system (tk/m³)

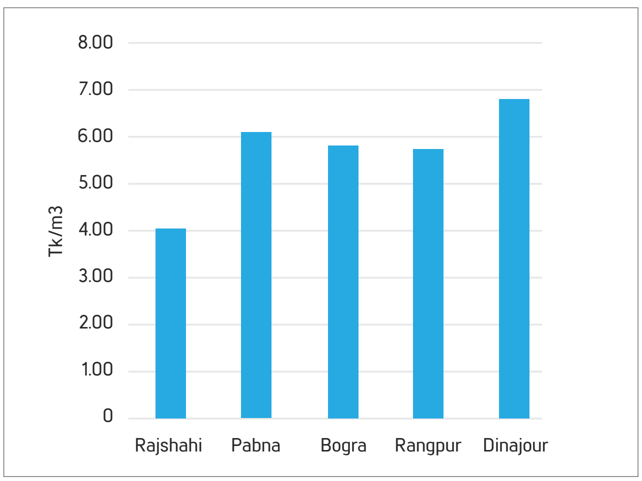


Figure 7 Rajshahi: Comparison of net benefit and marginal value of water per crop[23]

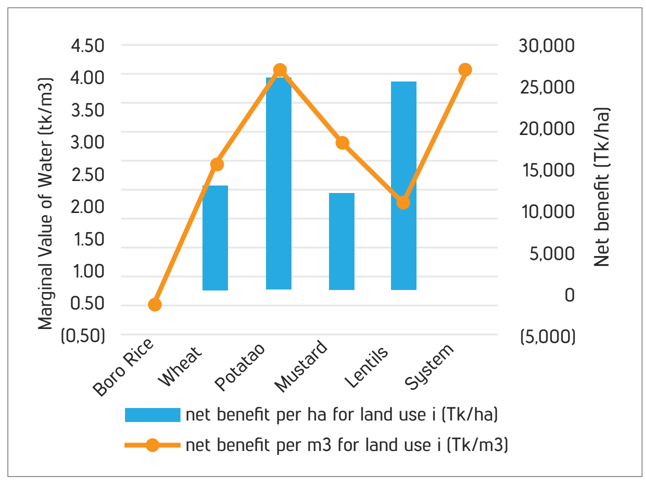


Figure 8 Pabna: Comparison of net benefit and marginal value of water per crop

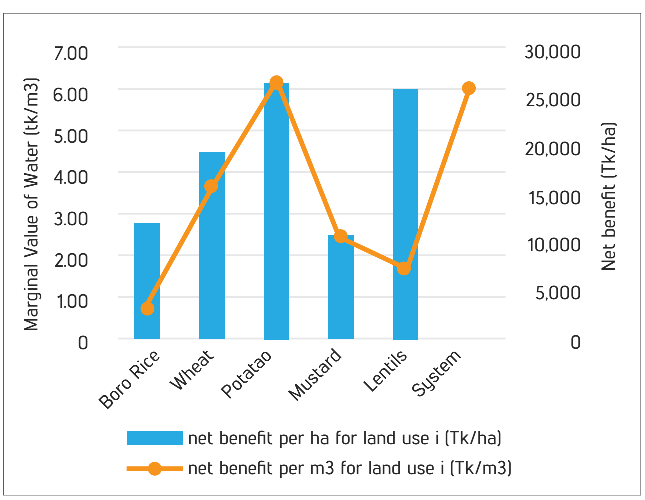
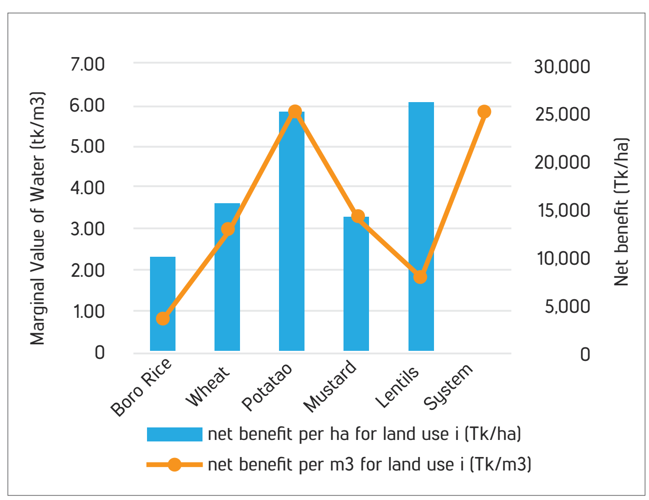


Figure 9 Bogra: Comparison of net benefit and marginal value of water per crop



[23] Please note that the net benefit for Boro rice is negative in Rajshahi district. We are currently cross-checking the underlying data with the authors of Dey et al. (2015).

8.1.4 The way ahead

To allow for a further refinement of the simplified approach, a discussion on the following questions is required:

- Which level of water abstraction can be considered as sustainable, i.e. what is the sustainable aquifer recharge rate? How can this be further detailed to district level?
- What is the realistic minimum area for boro rice cultivation, which should be considered in the model?

Figure 10 Rangpur: Comparison of net benefit and marginal value of water per crop

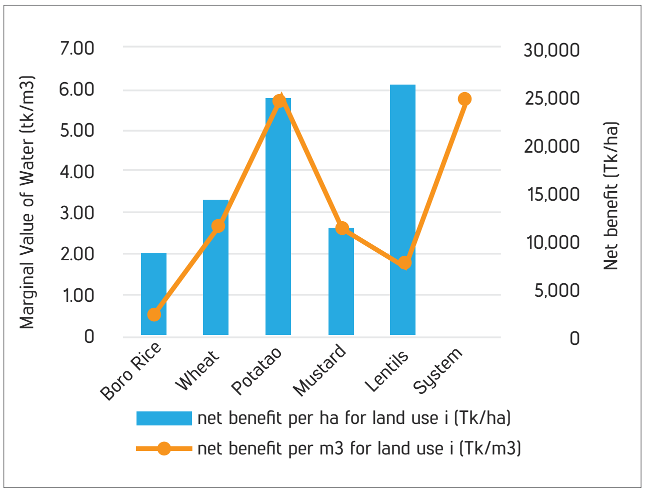
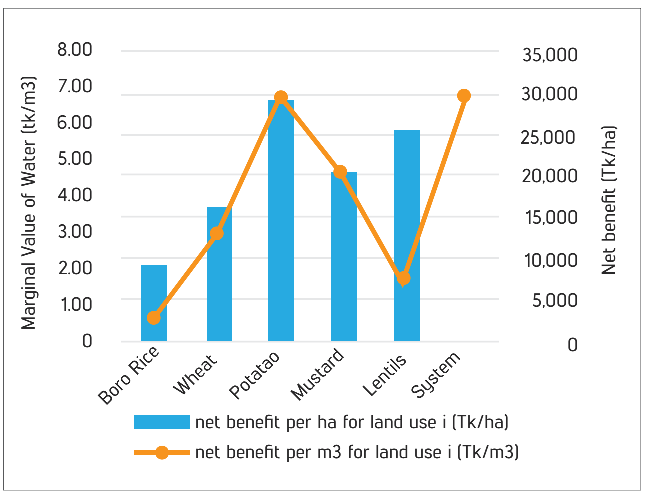


Figure 11 Dinajour: Comparison of net benefit and marginal value of water per crop



- In the optimization model, potato and lentils were the most profitable crops. Is there a market (domestic/international) for these products in case production increased significantly?
- How high are the water resource/abstraction costs (i.e. excluding irrigation costs)?

To achieve a more accurate estimate of the value of water in the Barind Tract, it is required to move towards the advanced methodology. For this, discussions with the respective units of the Government of Bangladesh, such as the Ministry of Agriculture, BMDA, Ministry of Environment etc. are required, to understand which data can be potentially collected as part of the overall data collection to ensure a sustainable application of this method.

8.2. Pilot Study #2: Addressing falling groundwater tables in Dhaka

Due to over abstraction of groundwater, the groundwater table in some locations in Dhaka is falling by 2 m annually. This is mainly driven by that fact that the true value of groundwater in and around Dhaka is not understood and the consequences of diminishing groundwater are not costed in the overall decision-making processes for business plans, abstraction licenses, or for city development plans.

It is possible to value a particular source of water, such as groundwater. This can be used to evaluate the benefits and costs of water demand reduction measures, such as water efficient technologies, and water supply augmentation measures, such as surface water transfers.

8.2.1 Approach in ideal world

In order to estimate the value of groundwater, it is necessary to understand how a reduction in groundwater availability would affect water use as well as water supplied from alternative sources.

The economic component should consider all users of water, such as households and industry, and their respective demands. It should also include the costs of all water sources, including alternatives to groundwater. This includes any constraints on the availability of water from alternative sources. For example, there could be relevant limits on the availability of acceptable quality of surface water, especially in the dry season. The hydrological component should encompass both management rules and physical processes such as stochastic groundwater recharge and surface water inflows.

Given the heterogeneity of water users in Dhaka, such as households, industry, commercial buildings, the method chosen for the estimation of the demand functions may differ for different users.

There are a number of methods, which can be used to estimate the water demand function:

- **Revealed preference (prices):** Collect data on actual water use and water prices (and other factors that affect water use) and estimate the demand function statistically. Participants at the stakeholder workshop suggested that there would not be sufficient variation in urban water prices to use them as a basis for estimating demand for households or industry.
- **Revealed preference (hedonic pricing):** Collect data on land prices and the determinants of land prices including access to water and estimate the relationship statistically. The concern amongst participants is that there would not be sufficient variation in access to water to lead to variation in land values, in which case hedonic pricing would not be applicable.
- **Production function:** Collect data on outputs and inputs such as water and estimate the production function statistically. The production function approach appears to be the most promising option for estimating demand by industry. Some participants from industry indicated that they have data available on their production processes and would be willing to share this data. However, there are questions as to whether these data would be sufficiently representative of industry in general in Dhaka. The production function approach does not apply to households since they do not have a production function.
- **Stated preference (contingent valuation):** Ask households/ water users what quantity of water they would use at different hypothetical water prices and estimate the demand function statistically. Stated preference approaches could be the best option for estimating the values for households in Dhaka. Participants indicated that a government survey is regularly conducted, which includes questions on willingness to pay, although whether this would be sufficient is unclear. Participants also noted the importance of including women in the surveys as they are typically responsible for obtaining water for the household.

Irrespective of how user demand is estimated, the broader system model should be dynamic, so that changes over time in the economy and hydrology are explicitly represented. Further, it would also be desirable if the model was spatially explicit, e.g. using a nodal structure, with each node having a water balance equation showing inflow and outflow at different points in time. During the assessment, the environmental and social values need to be determined and included into the model.

Monte Carlo simulation approaches are often applied to urban water problems. With these the impact of reduced groundwater availability can be simulated over a large number of future states of the world. The results can be expressed as a confidence interval rather than simply a point estimate for the value of groundwater. An example is provided in Box 2.

While the approach concentrates on water quantity, valuation techniques can be applied to inform decisions around water quality, which is a critical water management issue in Dhaka.

Box 2: Optimizing water supply headworks operating rules under stochastic inputs: Assessment of genetic algorithm performance (Cui et al. 2003)

This study combines genetic algorithms with Monte Carlo simulations in order to determine the least cost operation management plan of an urban water system, which consists of a number of interconnected reservoir systems. This process optimises the key operating rules for the complex system, with features including managing demand growth, stochastic reservoir inflow volumes, highly variable climatic conditions and various water management rules. Similar approaches are widely applied for supply augmentation planning and other aspects of urban water management and could be applied in Bangladesh.

8.2.2 Approach for now

Given time and data restrictions, a simplified modelling approach based on the replacement cost method was chosen. Taking the textile industry in and around Dhaka as an example, the approach assesses the costs and the profit implications to the textile industry for responding to less available groundwater. Possible responses include the substitution of groundwater with other water supply options, such as surface water, or the introduction water demand reduction measures. Both responses have a cost which can be used to estimate the value of groundwater to the textiles industry.

8.2.3. Methodology

For the textiles industry, there are costs associated with using less water, such as potentially reduced revenue from production, increased capex and opex associated with more water efficient technologies or costs associated with alternative sources of supply. Assuming that the textiles industry selects the least costly option, the net cost of reduced groundwater availability is the additional cost incurred for replacing groundwater minus the original cost of groundwater supply and can be expressed as:

$$N = min\ (V, A_i,..., A_i) - G \qquad (9a)$$

where N is the net cost of reduced groundwater availability (BDT/m³), V is the value of water to the textiles industry (BDT/m³), A_i is the cost of the i^{th} alternative source of water (BDT/m³), and G is the cost of groundwater (BDT/m³).

If there are no alternatives to replace groundwater (see Box 3) or the cost of this replacement exceeds the value of water to the textiles industry), production will not be profitable, and the net cost of reduced groundwater availability is:

$$N = V - G \qquad (10)$$

Box 3: Imperfect alternatives

In some cases, the alternatives to groundwater might be highly imperfect. For example, in the dry season the availability and quality of surface water might not be sufficient to substitute for groundwater in the textiles industry. Hence, in these parts of Bangladesh surface water would only be a substitute for part of the year.

There are no simple approaches for accounting for imperfect alternatives. In the case of surface water, Equation 9 could be evaluated for the dry season and wet season:

$$N = s_D\ (min(V, A_{1D},..., A_{1D}) - G) + s_W\ (min\ (V, A_{1W},..., A_{1W}) - G) \qquad (9b)$$

where s_D is the share of dry season months in a year and s_W is the share of wet season months in a year. However, this formulation assumes that there are no annual fixed costs associated with textiles production or alternative water sources and is not recommended partly because it will overstate the viability of alternative water sources that are only available for part of the year. As a result, the estimated value of groundwater would tend to be understated.

8.2.4. Pilot study

To illustrate the application of this methodology, a rough estimation was performed with publicly available information. The sample of textile companies considered in this analysis only includes those, which are listed at the Dhaka Stock Exchange and have factories in Greater Dhaka. Only considering listed companies allows the usage of validated profit data, which is an important data input for this assessment.

Please note that this analysis is only a very rough approximation intended to catalyse dialogue on the usability and applicability of valuing water in Bangladesh. Further analysis is required for a holistic assessment.

Overview of input data and assumptions

The following data were used for equation 9a introduced above:

- V, **the value of water to the textiles industry (BDT/m³):** The net profit after taxes was taken from the consolidated Annual Reports of the textile companies which are listed at the Dhaka Stock Exchange which have factories in Greater Dhaka. While the above method states that the cost for water should not be included in the profit estimate, it was found that in some cases it was not possible to separate the water-related costs from other costs. Further, it was found that—were a separation possible—these costs were minimal and thus would not significantly impact the analysis if left included. Thus, to ensure a consistent analysis across companies, it was decided to use the net profit after taxes, as stated in the Annual Report. Further, the total water required for each company is based on the production capacity stated in the annual report. The annual production capacity is multiplied with benchmark values on water requirements per ton for four key production processes in the textile industry (see Table 2).

Table 2: Overview of benchmark values on water requirements per process

Process	Water Usage (m³/ton)
Dyeing and Finishing	160
Denim Processing	110
Knit Composite	230
Washing plant	90
Spinning and weaving	*

Source: IFC/ Water PaCT
Note: * Hardly any water usage, not included in the analysis

- ***A_1*, the cost of the alternative source of water—surface water (BDT/m³):** While Dhaka WASA is supplementing groundwater with surface water to supply its municipal and industrial customers, the majority of industries—which mostly have their own groundwater bore wells—do not yet use surface water. To allow for a proxy of the additional cost required to substitute (parts of) groundwater with surface water, the current treatment and distribution costs provided by DWASA are considered. The cost is considered at 16 BDT/m³. This cost includes the distribution from the Water Treatment Plant (WTP) to Dhaka' main water distribution system. However, this cost estimate can be considered as too low as: 1) Companies within the boundaries of DWASA water supply would have to invest to connect to the main DWASA pipeline, and companies outside of DWASA water supply would have to invest in connection to the closest pipeline; and 2) If all companies within DWASA boundaries would switch to public water supply, DWASA would have to invest in expanding its water supply network to accommodate for the increased demand. Thus, this can be considered as an underestimation of the value of water.

- ***A_2*, the cost of the alternative source of water—reducing water demand by water efficiency measures (BDT/m³):** When considering the replacement cost of groundwater, water demand reduction measures also need to be considered. Based on the Benchmarking Study conducted by IFC/PaCT for its member textile companies, the average cost of water efficiency measures amount to 0.15 USD/m³ (12.43 BDT/m³). The percentage of water savings from total water usage depends on the water efficiency measure and on the factory specific context.

- ***A_3*, the cost of the alternative source of water—increasing supply with rainwater harvesting at factories (BDT/m³):** A further option for substituting groundwater is rainwater. As factories already have a water reservoir, this can be filled with rainwater during the wet season, reducing the pressure from groundwater. The benchmarking study conducted by IFC/PaCT found that the average costs for rainwater harvesting amounts to 0.08 USD/m³. The total groundwater usage saved depends on the existing water storage reservoir of the factories and on whether or not additional reservoirs would be built for this purpose.

- ***G*, the cost of groundwater (BDT/m³):** In most cases, factories pump the groundwater from their private bore wells and treat this water before using it for their processes. The benchmark study by IFC/PaCT states that the average pumping cost amounts to 1.7 BDT/m³ and the average treatment costs to 8 BDT/m³. It needs to be noted that the pumping and treatment cost vary with different locations based on the depth and quality of groundwater reserves.

Tentative Results

As stated in Box 3 on the previous page, surface water is an imperfect alternative when considering this substitute across an entire year, due to quality and quantity constraints during the dry season. As it would not be financially viable to operate a factory only during the wet season, it can be stated that the value of groundwater for the textile industry in Greater Dhaka tends towards the costs of not having an alternative and thus having to close or significantly reduce operations.

Area of Dhaka the Capital of Bangladesh.

When considering the option that there are no alternatives for groundwater, the value of groundwater for the textile industry differs per factory, which is illustrated in Figure 12 below. The values differ widely and range from 9 BDT/m³ to 234 BDT/m³.

However, it needs to be considered that alternatives to groundwater exist, such as substituting groundwater with harvested rainwater, substituting groundwater with surface water and reducing water demand by water efficiency measures. These options, however, only apply for a limited volume of total water required by the factories for rainwater harvesting and water efficiency improvements and for a limited time of the year for surface water volume.

Nevertheless, these options can be considered to reduce the pressure on groundwater reserves and thus have an impact on the net cost of reduced groundwater availability. Figure 13 provides an overview of the average net unit costs of reduced groundwater availability per option across the analysed factories. The values range between (-3.07) BDT/m³ for rainwater harvesting measures and 120 BDT/m³ in case there is no substitute, as illustrated below.

Figure 12: Net cost of reduced groundwater availability (Option: No alternative to groundwater)

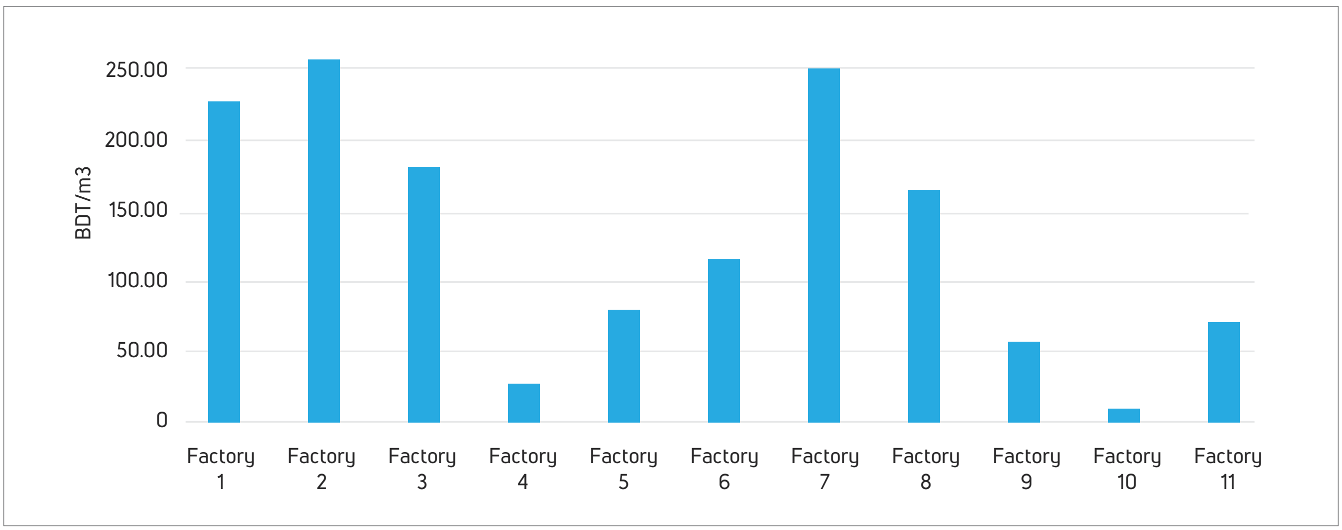
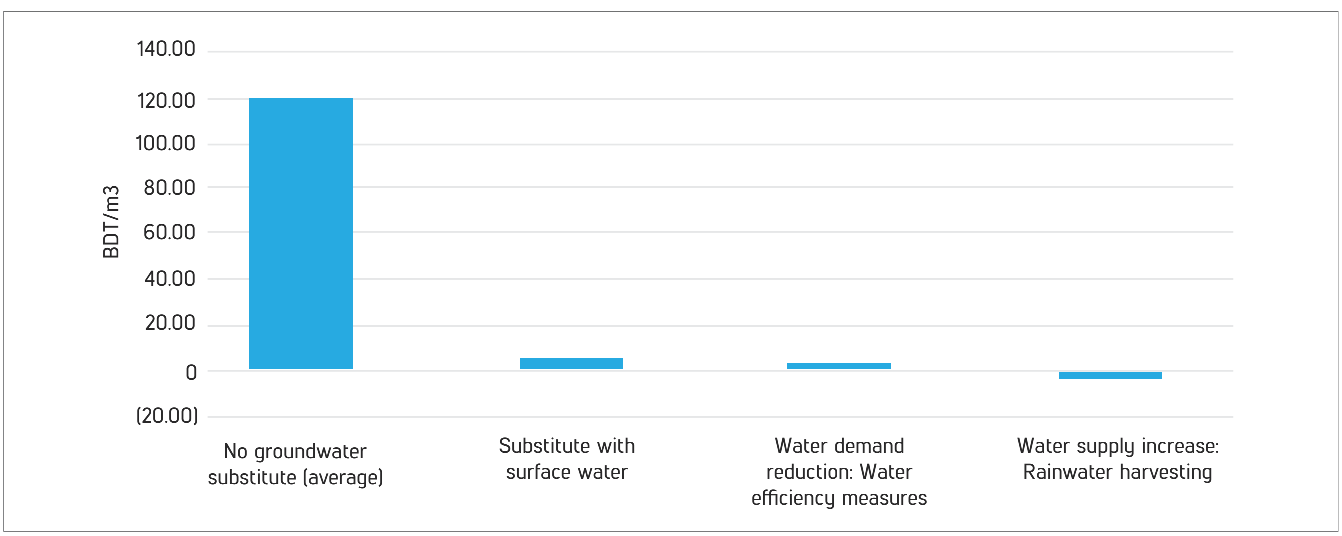


Figure 13: Net cost of reduced groundwater availability across replacement options



The overall year-round value of groundwater for the textile industry has to be estimated at factory level, as the options for substituting groundwater with surface water or harvested rainwater, as well as the water demand option by improving water use efficiency, are highly factory dependent. As an example, Table 3 provides the net cost of replacing groundwater by assuming a hypothetical set of options for a factory. If 15% of water can be saved from water efficiency improvements, 10% of water can be substituted with rainwater and surface water could be used for 30% of the year, then the net cost of substituting groundwater would amount to 55.91 BDT/m³.

Table 3: Hypothetical options for a factory and related net cost of replacing groundwater

Replacement Option	Impact of option on total water requirement (%)
Water efficiency	15%
Rainwater harvesting	10%
Surface water	30%
No option	45%
Net cost of reduced groundwater (BDT/m³)	55.91

To set this net cost into context, the industrial water price charged by Dhaka WASA—to the industries connected to and using its distribution system—was increased to 33.60 BDT/m³ in August 2017.[24]

Table 4: The average impact of net cost of replacing groundwater on net profit after taxes for sample textile companies

Option Chosen	
Industrial water usage (m³/yr)	17,248,010
Net profit after taxes	2,089,922,094
Option: Surface water substitute (100%)	
Additional cost (BDT)	108,662,463
% net profit after taxes	5%
Option: Hypothetical option mix (see Table 3)	
Additional cost (BDT)	964,257,219
% net profit after taxes	46%

Note: Please note that these values shall merely provide an insight into the magnitude of the costs, as the surface water substitute on its own is unlikely to be viable year-round and as the second option is based on a hypothetical scenario as was introduced in Table 3 above.

To set this value further into context, Table 4 shows that depending on the option chosen and possibility to substitute groundwater, the additional costs would range between 5% and 46% of net profits after taxes.

It needs to be highlighted that these estimates are based on a high-level assessment and on a limited sample size. It can be expected that the net cost of replacing groundwater—and thus the value of groundwater to the industries in Greater Dhaka—is very likely to increase with each of the suggested refinements stated below.

8.2.5. The way ahead

As in Pilot Study #1, it is required to move towards the advanced methodology to relax some of the stated assumptions and gain a better overall picture of the value of water for all users, including the environment. For this, discussions with the respective units of the Government of Bangladesh, such as the Ministry of Textiles, Ministry of Industry, BGMEA, IFC/PaCT, Ministry of Environment, etc. are required to understand which data can be potentially collected as part of the overall data collection to ensure a sustainable application of this method.

In the meantime, the approach of the simplified method can be improved in the following ways:

- Increase in sample size, which requires data on (validated) net profit after taxes and total water requirement per factory;
- Differentiate the costs of groundwater abstraction and treatment by industrial zone, considering differences in groundwater levels and quality;
- Further specify the costs for surface water provision, considering the costs of a) connecting factories within the DWASA territory to the main distribution lines; b) connecting factories outside the DWASA territory to the main distribution lines or to separate surface water pipelines; c) expanding the DWASA supply network to accommodate for the increased industrial water demand;
- Further specify the volumetric potential for substituting groundwater with harvested rainwater;
- Further specify the volumetric potential for reducing water demand by introducing water efficiency improvements.

[24] Source: http://www.newagebd.net/article/21203/dhaka-wasa-unilaterally-raises-tariff

8.3. Pilot Study #3: Balancing competing water demands of agriculture and fisheries in Halda River

Halda River provides the last natural spawning area for major Indian carp in Bangladesh, from which the fingerlings are distributed to carp production ponds in entire Bangladesh. Further, it is of economic importance due to farming from the Ruhi fish (sp. Labeo rohita) and it provides a habitat for the endangered Gangetic Dolphin.

Modifications in their water ecosystem have drastically reduced the carp eggs being laid, with impacts for carp production across Bangladesh. The previously meandering Halda River has been straightened to reduce transportation times across the river. Then, with intensifying agriculture. barrages were built to store irrigation water, mainly for the boro rice. The critical time for water storage coincides with the spawning period for the carps—the barrages impede the carp from travelling upstream and finding spawning areas, while the overall water levels are also to low and much required nutrients for the spawning carps, such as plankton, are blocked behind the barrages. In addition, a UNDP scoping study[25] has identified a total of thirteen threats to the Halda breeding habitat:

1. Industrial discharges to either the main river or its tributaries from paper mills, dyeing factories and tanneries
2. Furnace oil pollution from the Peaking Power plant
3. Runoff and transport activities at brickfields
4. Reduced flow due to the Haraldua Rubber Dam, near Bhujpur, and associated abstractions
5. Reduced flow due to 11, mostly right-bank, tributaries, including the Halda irrigation Project
6. Salinity intrusion via the Karnafuli River, and its regulation by releases from Kaptai Lake
7. Channel straightening but cutting off meanders, destroying the breeding habitats
8. Deforestation of the upper catchment causing siltation
9. Legal and illegal dredging disturbing the food supply of the benthic feeding Ruhi and Kali Baush
10. Regional/local climate change, resulting from the moisture balance in the dry season, reducing the frequency of thunderstorms that trigger spawning
11. Illegal (often night time) fishing brood fish
12. Agrochemicals washed into the river
13. Global climate change is expected to increase the intensity of droughts and reduce flow in rivers in the dry season[26] and therefore worsen the effects of: (i) saline intrusion; (ii) industrial pollution; and (iii) the demand for irrigation abstraction.

Valuing water for ecosystem purposes, such as the production of fish, can help address conflicts between consumptive and ecosystem uses by identifying the all material benefits and costs of different policies. Valuation can be applied to policies that increase the quantity or quality of water available for environmental uses, as well as other policies such as removing barriers that impede the movement of fish. If the value of water in the production of fish exceeds the value of water in agricultural production, this indicates that it would be more efficient to reallocate water to fish, and vice versa. Without explicit or implicit valuation, this this comparison is not possible.

8.3.1. Approach in ideal world

The removal of water retention structures which store water for agricultural production, and consequently reduce downstream flow and impede the movement of fish would have a number of effects. It would reduce the volume of water available for agriculture in the dry season, particularly for the production of boro rice. On the other hand, it would increase the volume of water available for fish and allow them to move throughout the system. Water valuation needs to capture both effects.

For the effect of reducing water for agricultural use, the approach outlined in the agricultural case study would be largely applicable. This would involve modelling the total net benefit from agriculture with and without the barriers. This requires assumptions around the mechanisms by which land, water and other inputs are allocated to different land uses, the resulting allocation of land, water and other inputs (recognizing that this might not be optimal), and the associated benefits and costs. The effect of removing the barriers is to reduce the volume of water available for agriculture at different times. This adds complexity to the approach outlined in the agricultural case study, which was based on a groundwater resource and assumed that available water could be used at any time throughout the year.

When modelling an unregulated surface water system, it is generally necessary to model water use and apply the water availability constraints at a shorter time step, such as monthly. It also requires assumptions around how use at different time steps affects annual production.

[25] UNDP Report on Scoping Study on Environmental Health and Water Quality in Rivers and Ecologically Critical Areas in Bangladesh.

[26] Whitehead et al. 2015. *Environ. Sci.: Processes Impacts;* 17, 1057-69.

For the effect on fish, it is necessary to model the total net benefit from the resource with and without the barriers. This requires a model of the physical process, including the relationship between effort (such as labor and nets) and catch (output of fish and eggs). The effect of removing the barriers could be to increase the catch associated with a given effort. Ideally, the analysis also needs to account for other factors that affect the resource, such as pollution and urban water use. For example, if water pollution from industry is sufficiently bad, removing the barriers might not be enough to allow the resource to recover. There would be benefits from modelling this as a dynamic process, partly because it could take an extended period of time for the resource to return to equilibrium. In addition to the model of the physical process, it is also necessary to model the decisions that determining the effort in a given context, as well as the costs of effort and the benefits of catch. Relevant examples include Stanfel et al. (1988), Suri et al. (2008) and Li et al. (2011) (Box 4).

During the assessment, the social and environmental impacts, including for example the nutritional impact of less protein availability, need to be identified and included in the analysis.

Box 4: Numerical Simulation for Optimal Harvesting Strategies of Fish Stock in Fluctuating Environment (Li et al. 2011)

This paper develops a numerical simulation for the optimal harvesting strategies of fish stock. Stochastic behaviour of environmental factors was included in the optimisation of harvesting strategies. This determines a relation in which the maximum sustainable yield and biomass varies with environmental factors, such as variation in the intrinsic growth rate and environmental carrying capacity. The obtained relation can be applied for the management of fisheries and will allow determination of the economically optimal long-term strategy for commercial fisheries.

8.3.2. Approach for now

Given time and data restrictions, a simplified modelling approach which compares the value of water for agriculture and for fisheries was chosen.

Please note that the calculations were not executed for this pilot study, as the aforementioned PFS for the Study on Developing Operational Shadow Prices for Water to Support Informed Policy and Investment Decision Making Processes was approved. This study will further assess these pilots.

8.3.3. Methodology

The removal of the barriers will reduce the water available for agricultural use in the boro season. On the other hand, it will increase the water available for environmental use and enable fish to move throughout the system. The overall benefits to the community of removing the barriers can be decomposed as:

$$\Delta\Pi = \Delta\Pi_A + \Delta\Pi_E \qquad (12)$$

where $\Delta\Pi_A$ is the change in total net benefit to agricultural uses and $\Delta\Pi_E$ is the change in total net benefit to environmental uses.

Agriculture

Similarly, as in pilot study #1, the change in total net benefit to agricultural uses is given by:

$$\Delta\Pi = \sum_i N_i \Delta X_i \qquad (13)$$

with N_i being the net benefit per hectare, excluding water costs for land use i and X_i being the area of land use i.

The net benefit will depend on the potential land use change that takes place as a result of removing the barriers, and the relative net benefit per hectare of different land uses. This requires the same economic data as the agricultural case study, including non-water costs and revenue per hectare.

Given the timeframes, it is recommended that ΔX_i is based on expert opinion of what is feasible given water availability in the scenarios and realistic in terms of irrigator behaviour. For example, an expert might conclude that 70% of land currently devoted to production system X would shift to production system Y if the barriers were removed.

Fish

Similarly, the change in total net benefit to environmental uses is given by:

$$\Delta\Pi_E = \sum P_j \Delta Q_j - \sum P_k \Delta Q_k \qquad (14)$$

where the subscript j denotes outputs from the fishing industry (primarily fish and eggs) and the subscript k denotes inputs to the fishing industry (such as nets and people). The parameters P reflect either benefits or costs, while the variables Q reflects either physical outputs or physical inputs, depending on the context and subscripts.

The change in the productive capacity of the fish resource associated with removing the barriers will affect the relationship between outputs and inputs. If there are more outputs for a given vector of inputs, there will be a corresponding increase in total net benefit. The extent of this increase depends on the benefits to the community from fish and eggs.

It needs to be noted that there could also be a behavioral response, with the change in productive capacity potentially affecting decisions around inputs. For example, if the fish stock improves, people who had shifted to other activities may return to the fishing industry, increasing the use of labor and other inputs. The effect of this change depends on the costs to the community from input use.

8.3.4. The way ahead

To allow for the application of the simplified approach, following data are required:

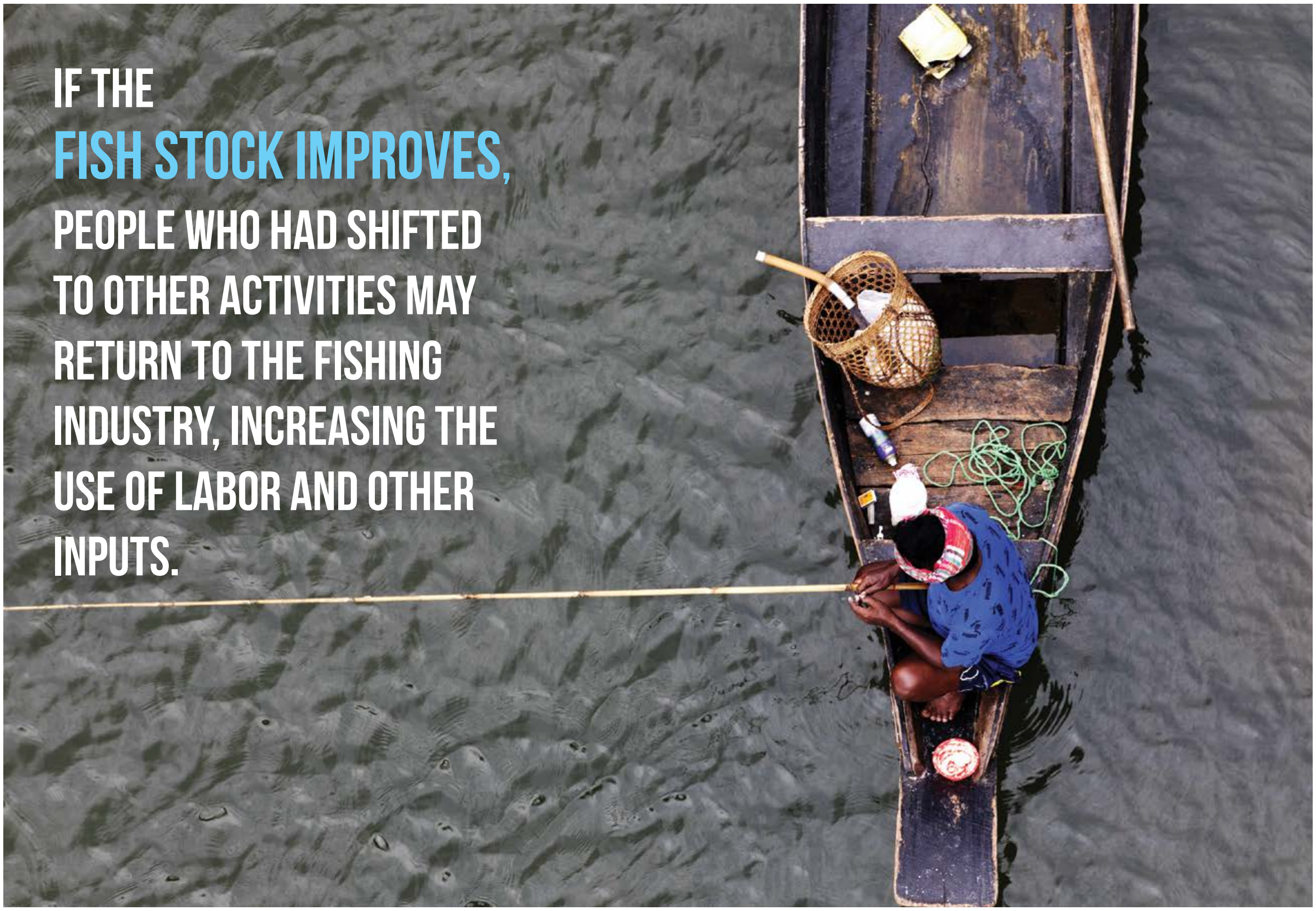
Agriculture

- The net benefit per hectare excluding water costs for each land use
- Change in area of each land use due to removing barriers

Fish

- Social benefit of outputs of fishing industry (such as fish and eggs)
- Social cost of inputs to fishing industry
- Change in output of fishing industry due to removing barriers
- Change in input to the of fishing industry due to removing barriers

As in Pilot Study #1 and #2, it is required to move towards the advanced methodology to relax some of the stated assumptions and gain a better overall picture of the value of water for all users. For this, discussions with the respective units of the Government of Bangladesh, such as the Ministry of Agriculture, Ministry of Environment, Ministry of Water, BWDB etc. are required to understand which data can be potentially collected as part of the overall data collection to ensure a sustainable application of this method.



9. Roadmap and Recommendations

This paper provides a brief overview of state-of-the art valuing water methodologies and their applicability to the Bangladeshi context. To provide a better understanding of how valuing water can support informed decision-making, three pilot studies were illustrated. For each pilot study, two methodological approaches were presented: the ideal methodology (assuming sufficient data availability) and a simplified methodology (using data which are available now). To date, the simplified methodology was applied to two pilot studies, namely 1) Optimizing cropping patterns in Barind Tract and 2) Addressing falling groundwater tables in Dhaka.

To further move the initiative of Valuing Water in Bangladesh forward, the National Steering Board (NSB) of the Bangladesh Water Multi-Stakeholder Partnership (BWMSP) set up a High-Level Valuing Water Committee to lead this initiative. The Principal Coordinator, SDG Affairs, PMO chairs this Committee. Other members of the Committee include representatives from the Ministry of Water Resources, Ministry of Planning, Ministry of Agriculture, Ministry of Environment and Forests, Ministry of Industry, Ministry of LGRD&C, Dhaka Water Supply and Sewerage Authority (DWASA) and any other relevant government agencies, as well as key private sector representatives, academia and non-governmental agencies as per the discretion of the chair of the proposed committee. The High-Level Valuing Water Committee is supported by the Technical Valuing Water Committee.

The objectives of the High-Level Valuing Water Committee are to:

1) Further understand the applicability of Valuing Water in Bangladesh;
2) Further corroborate the three pilot studies initiated in the Position Paper on Valuing Water conducted by 2030 Water Resources Group;
3) Find practical and consensual ways of streamlining valuing water into the existing policy and regulatory framework; and
4) Drive the implementation and enforcement of streamlining valuing water into the existing policy and regulatory framework.

Building on this Position Paper, the High Level Valuing Water Committee, with support of the Technical Valuing Water Committee, and in cooperation with the Ministry of Water Resources, developed a Proforma for Study Proposal (PFS) on a Study to Develop Operational Shadow Prices for Water to Support Informed Policy and Investment Decision Making Processes. It was approved by the Ministry of Water Resources and is now being implemented by WARPO.

The study has three major parts to develop operational shadow prices for water in order to support informed policy and investment decision making, namely:

- **Part 1** – Developing Shadow Prices for Water in Bangladesh: Development of the conceptual framework around valuing water for Bangladesh and development of a harmonized set of shadow prices for water - differentiated by region, season, sector and source. It also provides for capacity building around applying the shadow prices for water in decision making processes for the public and private sectors, as well as for civil society.

- **Part 2** – Streamlining Valuing Water into Public Investment Decision Making: Currently, public investment decisions in Bangladesh are made based on Development Project Proforma/ Proposals (DPP), following the guidelines provided by the Planning Commission of the Ministry of Planning of the Government of Bangladesh. A financial analysis is required to assess the profitability of the investment, i.e. the revenues, capital, operation and maintenance expenditures. Further, an economic analysis is required to assess the investment's impact on the wider economy, society and environment. However, to date the approach to this analysis, using specified shadow prices, does not include the impact on water resources. Part 2 aims at including the shadow prices for water into the Development Project Proforma/Proposals (DPP) Manual and revise the DPP format accordingly.

[27]Prepared by General Economics Division (GED) of the Planning Commission, Ministry of Planning (2014).

- **Part 3** – Identifying and Demonstrating Options to Operationalize the Shadow Price for Water in Private Sector Decision Making: As with public investment decision making, it is crucial that also the private sector understands and considers the impact of its investment decisions on water resources and the resultant implications on its business model. This allows for improvements in water use efficiency, damage and compensation assessments, conservation actions and offsetting, risk assessments of policy changes, as well as reporting on performance to its stakeholders. Selected multi-national companies have already started considering the value of water in their investment decisions and have reported the beneficial outcomes. Given the importance of the private sector in addressing Bangladesh's water resources management challenges, it is crucial to identify and promote options for making shadow prices operational for private sector decision making processes. Part 3 – in cooperation with selected companies – will trial the shadow prices developed in Part 1 in their operations and optimize these to offer a benefit to private sector decision making.

Further, WARPO is considering to the use the shadow price for water – once developed - in its industrial water use policy..

Given the novelty of developing shadow prices on a national level and incorporating these into public and private decision making, a collaborative approach across all stakeholder groups is of key importance. The collaborative development of shadow prices not only improves their overall quality, it also allows stakeholders to gain trust in the numbers which will then pave the way for a wider adoption across the public and private sectors, as well as civil society.

Realizing the trade-off between academic rigor and implementability, given data constraints, it is suggested to follow a step-by-step approach, in which the assessment and incorporation of the value of water is improved over time, while allowing the important conversations around the value of water to mature simultaneously.

The overall objective is to increase awareness around the value of water and to use valuing water as a solid foundation to aid future informed decision making – for the public and private sectors – to support sustainable water resource management and thus sustainable socio-economic development.

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Annex 2
Overview of Water Valuation Methodologies

Methodology	Overview	Considerations
Revealed preference Market Prices	Data on the water price and water use can be used to estimate a point on the demand curve. Where there is sufficient variation in water prices, it is possible to statistically estimate the demand curve.	This approach may be unreliable where: • Users cannot freely adjust their water use (shortages) • Users are not optimizing (behavioral economics) • There are substantial market failures (externalities) The success of this approach depends on: • Data are available or can be collected • There is sufficient variation in prices • There are no prohibitive statistical challenges • There is sufficient statistical expertise
Revealed preference Surrogate Market – Hedonic Pricing	The value of water can sometimes be estimated through related markets. For example, the value of water is frequently capitalized into land prices.	The success of this approach depends on: • The value of water is captured in related markets • Data are available or can be collected • There is sufficient variation in access to water • There are no prohibitive statistical challenges • There is sufficient statistical expertise
Revealed preference Production Function	The value of water can also be estimated through modelling the production process and associated benefits and costs. The residual value of water is given by the net benefits production with water (excluding water costs) less the net benefits of production without water.	The success of this approach depends on the ability to model water demand, i.e. one requires that production processes and associated benefits and costs are represented with sufficient accuracy This will only be feasible if: • Data are available or can be collected • There is sufficient modelling expertise
Cost-based Replacement Cost	The replacement cost or value refers to the amount that an entity would be willing to pay to replace an asset at the present time, according to its current worth.	The success of this approach depends on: • The benefits associated with the ecosystem good or service can be assessed • There is an alternative source of product, infrastructure or technology providing similar benefits to society • The costs of this alternative can be assessed • Data are available or can be assessed
Cost-based Mitigative or Avertive Expenditures	The value of water can be estimated by costing expenditures, which would be required to avoid or mitigate the loss of ecosystem services.	The success of this approach depends on: • The negative effects or hazards that would arise from loss of ecosystem can be assessed • The affected population can be clearly identified • Mitigative or avertive measures exist and can be assessed • Data are available or can be collected • There is sufficient modelling expertise

Methodology	Overview	Considerations
Cost-based Damage Cost Avoided	The value refers to the maximum willingness to pay in monetary terms to avoid a certain damage.	The success of this approach depends on: • The protective ecosystem services, as well as the on- and off-site damages that would occur as a result of the loss of these services can be assessed • The affected population can be clearly identified • The likelihood and frequency of the damaging events can be determined
Stated preference Contingent Valuation (CV)	The value of water can be estimated based on the responses of users to hypothetical scenarios. For example, a user could be asked what volume of water they would demand at different prices	The success of this approach depends on: • Users are able to understand the scenarios • Users are able to formulate sensible responses • Users are honest in their responses • The surveys can be undertaken • There is sufficient expertise in study design • There is sufficient statistical expertise
Stated preference Contingent Analysis	Similarly, to CV, the value of water can be estimated based on responses from users on different hypothetical situations which described using their characteristics or attributes. Respondents are asked to either rank them or choose between them.	See above
Stated preference Choice Experiments	Similarly to CV, the value of water can be estimated based on the responses of users to choose between alternative proposed scenarios, such as policies. For example, a user could be asked whether he prefers large quantities of low quality water or small quantities of high quality water.	See above

Annex 3 – Workshop Discussions

Valuing Water—Industry

Case Study: The textile industry in Dhaka
Questions: How can the water used be valued?
How can the impact from untreated wastewater be valued?

Methodology	Potential Approach	Key question
Revealed Preference Market prices	The water and wastewater charges from the textile industry and other industries will be used for the assessment	• Do they pay any charges? • Do these charges reflect the true costs? • Is there variation in prices across users or over time?
Revealed Preference Surrogate Market Price	The price difference of industrial land value with and without good (clean) water access is used as basis for the assessment.	• Is the value of water captured in land markets, i.e. is land more expensive with shallow GW or (clean) SW?
Revealed Preference Production function	Assessment whether a change in quantity or quality in water affects the output and profits of the textile company.	• Can reasonable data be obtained on the production process and associated benefits and costs?
Cost-based	The costs to replace GW with SW for textile companies is used as basis for the assessment.	• Can data be obtained on the supply and treatment costs for SW?
Stated preference	The Willingness to Pay for different volumes of water at different prices and qualities will be assessed.	• Can questions be posed that will elicit realistic responses?

Worker dyeing fabric with pot of orange dye.

Valuing Water—Urban

Case Study: Residential Apartment Complexes in Dhaka
Questions: How can the water used be valued?
How can the impact from untreated wastewater be valued?

Methodology	Potential Approach	Key question
Revealed Preference Market prices	The water and wastewater charges for residents and and other urban users will be used for the assessment	• Do they pay any charges? • Do these charges reflect the true costs? • Is there variation in prices across users or over time?
Revealed Preference Surrogate Market Price	The price difference of residences with and without good (clean) water access is used as basis for the assessment.	• Is the value of water captured in land markets, i.e. is land more expensive with shallow GW or (clean) SW?
Revealed Preference Production function	NA	NA
Cost-based	The costs to replace GW with SW for residential usage is used as basis for the assessment.	• Can data be obtained on the supply and treatment costs for SW?
Stated preference	The Willingness to Pay for different volumes of water at different prices and qualities will be assessed.	• Can questions be posed that will elicit realistic responses?

Area of Dhaka the Capital of Bangladesh.

Annex 3 – Workshop Discussions *(continued)*

Valuing Water—Agriculture

Case Study: Rice Production in the Barind Tract (NW)
Questions: How can the water used be valued?
How can the impact from untreated wastewater be valued?

Methodology	Potential Approach	Key question
Revealed Preference Market prices	The water and wastewater charges from the textile industry and other industries will be used for the assessment	• Do they pay any charges? • Do these charges reflect the true costs? • Is there variation in prices across users or over time?
Revealed Preference Surrogate Market Price	The price difference of industrial land value with and without good (clean) water access is used as basis for the assessment.	• Is the value of water captured in land markets, i.e. is land more expensive with shallow GW or (clean) SW?
Revealed Preference Production function	Assessment whether a change in quantity or quality in water affects the output and profits of the textile company.	• Can reasonable data be obtained on the production process and associated benefits and costs?
Cost-based	The costs to replace GW with SW for textile companies is used as basis for the assessment.	• Can data be obtained on the supply and treatment costs for SW?
Stated preference	The Willingness to Pay for different volumes of water at different prices and qualities will be assessed.	• Can questions be posed that will elicit realistic responses?

Annex 4 – Overview of complete methodologies for valuing water *(pilot studies)*

Pilot Study #1: Optimization of cropping patterns in High Barind Tract

Approach in ideal world

To estimate the value of water to agriculture in the Barind Tract it is necessary to quantify the value of water in different uses, how water is allocated across uses, and hydrological constraints. Understanding the mechanisms for allocating water is important because it determines how an increase in water availability would be distributed across users (or how a decrease would be rationed). This is relevant even when the allocation mechanism is not in question. Understanding the hydrological constraints is relevant since the starting point for water availability matters. All else equal, the greater the availability of water, the higher the total value of water and the lower the marginal value of water.

The economic component of the ideal approach captures the behavior of irrigators, such as whether to irrigate and what quantity of water to use. It is also captures the benefits and costs of water use to irrigators. The hydrological component captures groundwater levels based on factors including recharge and abstraction. This is typically implemented through water balance equations and can be challenging in complex systems where the resource may be poorly understood. The hydrological component helps to ensure that the economic component is realistic, for example, that water use cannot exceed water availability.

The economic component needs to include the demand function for water by irrigators (either explicitly or implicitly) to capture the behavior of irrigators or the benefits and costs of water use. The demand function shows the quantity of water used at different prices, including the quantity demanded at a zero price. The demand function can also be used to estimate the value of increasing or decreasing water use. The demand function can be modelled at different levels of aggregation from the individual level to the system level, with the appropriate level depending on the application.

There are a number of options for estimating demand functions, including:

- Revealed preference (prices): Collect data on actual water use and water prices (and other factors that affect water use) and estimate the demand function statistically. Participants at the stakeholder workshop indicated that there are private groundwater markets in many areas, with payment being made through crop sharing arrangements. There are no direct volumetric data on water use, but there are ways of calculating it indirectly.

- Production function: Collect data on outputs such as rice and inputs such as water and estimate the production function statistically. To reduce estimation bias, it is sometimes possible to estimate the production function indirectly by exploiting the duality between the production and cost functions. The demand function can be derived from the production function (or cost function) and data on prices. Participants at the stakeholder workshop suggested that farm management surveys had been conducted and provide a potentially rich source of information on physical inputs and outputs as well as financial data.

- Stated preference (contingent valuation): Ask irrigators what quantity of water they would use at different hypothetical water prices and estimate the demand function statistically. Participants at the stakeholder workshop could not point to any existing stated preference studies, suggesting that new surveys would be required to implement stated preference options.

Which option is most appropriate depends on the circumstances. If sufficient data were available, the revealed preference approach based on observed behavioral responses to water prices would likely be most appropriate. The ideal data set for this analysis would cover multiple irrigators over multiple time periods and have substantial variation in prices.

Irrespective of how user demand is estimated, the broader system model could be implemented using mathematical programming approaches. These approaches can be used to determine how water is allocated. In convex problems where non-linearities are particularly important non-linear programming and mixed integer programming (with piecewise linear approximations) can be used. Where dynamics are especially important dynamic programming can be used. Relevant examples of mathematical programming approaches include Ruhul et al. (1997), Alaya et al. (2003) and Tilahun (2002) (Box 1).

During the assessment, social or environmental values need to be discerned and should be used in conjunction with other approaches.

Approach for now

In the timeframes available for this pilot it has only been possible to undertake a simple version of this approach. In particular, there was not sufficient time for data collection or modeling. The production function approach was used, but with a highly simplified type of production function (known as fixed proportions). It was also assumed that the prices of outputs and inputs other than water are fixed. This is an important limitation because the policies considered could affect prices, especially land prices.

The main simplification in the hydrological component is that annual water availability is assumed to be equal to average annual recharge available for irrigation. This abstracts from dynamic complexities such as short-term variation and the transition towards the long-term equilibrium.

Methodology

The following sets out the key equations for implementing the pilot approach. All variables and parameters are defined on an annual basis.

Economic component

The key economic equation is:

$$\Pi = \sum_i N_i X_i \qquad (1)$$

where Π is total net benefit excluding water costs, N_i is the net benefit per hectare excluding water costs for land use i and X_i is the area of land use i. In this case, the land use refers to a possible production system which can be comprised of a number of crop rotations.

The net benefit per hectare excluding water costs can be disaggregated into:

$$N_i = R_i - M_i - L_i - K_i - D_i \qquad (2)$$

where R_i is the benefit of output per hectare for land use i, M_i is the materials and equipment cost per hectare for land use i, L_i is the labour cost per hectare for land use i, K_i is the capital cost per hectare for land use i, and D_i is the land cost per hectare for land use i.

All relevant benefits and costs should be included. If relevant costs are excluded, the value of water will be overstated (see Young 2005).

This can be further disaggregated. For example, labor costs per hectare can be expressed as:

$$L_i = \sum_j P_{ji}^L Q_{ji}^L \qquad (3)$$

where P_{ji}^L is the hourly cost of labor type j for land use i and Q_{ji}^L is the number of hours of labour type j required for land use i. The shadow prices used in these cost calculations (such has the hourly cost of labour) should reflect the opportunity cost rather than the financial cost. For example, the financial cost associated with the labor of the owner of the farm is generally zero. However, there is an opportunity cost as the farmer has less time for other worthwhile activities. The same principles apply when estimating the benefit of output consumed by the household – just because the output is not sold, does not mean that it has zero value.

The calculations above can be performed from the perspective of the farmer or all members of the community (which would also include the farmer). For example, from the private perspective of the farmer, the hourly cost of hired labor is their wage. From the social perspective of the community, the hourly cost could be substantially lower if the hired labor would otherwise be involuntarily unemployed. It is appropriate to take a private perspective in understanding irregular behavior, but in evaluating the benefits and costs of different allocation mechanisms it is better to take a social perspective.

Hydrological component

The area of land that can be allocated to different land uses is constrained by the following equation:

$$\sum_i W_i X_i \leq \overline{W} \qquad (4)$$

where W_i is the water requirement per hectare for land use i and $\overline{W}$ is aquifer recharge available for irrigation. If there are other users of the aquifer, their use should be subtracted from recharge to calculate the relevant value for irrigation.

Land component

In addition, the area of land that can be allocated to different land uses is constrained by various factors, including flood risk and soil suitability:

$$X_i \leq \overline{X}_i \textit{ for all } i \qquad (5)$$

where $\overline{X}_i$ is the maximum area available for land use i.
Finally, land use cannot be negative:

$$X_i \geq 0 \textit{ for all } i \qquad (6)$$

Applying the model

There are a number of ways of using these equations to inform the policy questions raised above. In terms of user values, these equations give an estimate of the net benefit of an additional unit of water for different land uses:

$$\frac{\partial \Pi}{\partial V_i} = \frac{N_i}{W_i} \text{ for all } i \qquad (7)$$

where V_i is the volume of water used in land use i. They also provide an estimate of the total net benefit associated with incremental changes in water use across all land uses:

$$\Delta\Pi = \sum_i \frac{N_i}{W_i} \Delta V_i \qquad (8)$$

In terms of system values, the equations can be used to estimate the value of water to agriculture under the simplifying assumption that the allocation of water to different land uses is efficient (which may or may not approximately hold). This can be implemented through a linear programming approach where Π is maximized subject to the constraints above.

Data needs

The data requirements are summarized in Table 5. See the previous subsection for context.

Table 5: Data requirements for agriculture

Parameter	Definition	Source
R_i	benefit of output per hectare for land use i	
M_i	materials and equipment cost per hectare for land use i	
L_i	labour cost per hectare for land use i	
K_i	capital cost per hectare for land use i	
D_i	land cost per hectare for land use i	
W_i	water requirement per hectare for land use i	
$\overline{W}_i$	aquifer recharge available for irrigation	
$\overline{X}_i$	maximum area available for land use i	

Pilot Study #2: Addressing falling groundwater tables in Dhaka

Approach in ideal world

In order to estimate the value of groundwater, it is necessary to understand how a reduction in groundwater availability would affect water use and water supplied from alternative sources. This depends in part on the responses of water managers and water users to a reduction in groundwater availability. It is also necessary to calculate the costs and benefits associated with these changes. For example, what are the costs of rationing water to households or substituting towards surface water? As in the agricultural example, the approach requires a model of the key economic and hydrological factors relevant to the system.

The economic component should consider all users of water, such as households and industry, and their respective demands. It should also include the costs of all water sources, including alternatives to groundwater. This includes any constraints on the availability of water from alternative sources. For example, there could be relevant limits on the availability of surface water, especially in the dry season. Comprehensiveness is important because it is not possible to evaluate the value of a particular source of water without reference to demand and alternative sources. The hydrological component should encompass both management rules and physical processes such as stochastic groundwater recharge and surface water inflows.

Estimating the demand functions for different users could be more challenging than in the agricultural example because of the heterogeneity of users. In particular, there are fundamental differences between households (who can be modeled as being utility maximizing) and industry (who can be modeled as being profit maximizing). These differences may necessitate different approaches to estimating demand.

Not all approaches to estimating demand are likely to be feasible. The approaches are discussed below:

- Revealed preference (prices): Collect data on actual water use and water prices (and other factors that affect water use) and estimate the demand function statistically. Participants at the stakeholder workshop suggested that there would not be sufficient variation in urban water prices to use them as a basis for estimating demand for households or industry.

- Revealed preference (hedonic pricing): Collect data on land prices and the determinants of land prices, including access to water and estimate the relationship statistically. A hedonic pricing study of the value of proximity to the lake in Dhaka has been undertaken. While this study is not directly applicable to the value of groundwater in consumption, it does indicate that the relevant property data could be available. The concern amongst participants is that there would not be sufficient variation in access to water to lead to variation in land values, in which case hedonic pricing would not be applicable.

- Production function: Collect data on outputs and inputs such as water and estimate the production function statistically. The production function approach appears to be the most promising option for estimating demand by industry. Some participants from industry indicated that they have data available on their production processes and would be willing to share this data. However, there are questions as to whether these data would be sufficiently representative of industry in general in Dhaka. The approach used in the simplified example below is a simple example of production function approach. Unfortunately, the production function approach does not apply to households since they do not have a production function.

- Stated preference (contingent valuation): Ask households what quantity of water they would use at different hypothetical water prices and estimate the demand function statistically. Stated preference approaches could be the best option for estimating the values for households in Dhaka. Participants indicated that a government survey is regularly conducted which includes questions on willingness to pay, although whether this would be sufficient is unclear. Participants also noted the importance of including women in the surveys as they are typically responsible for obtaining water for the household.

Irrespective of how user demand is estimated, the broader system model should be dynamic, so that changes over time in the economics and hydrology are explicitly represented. It would also be desirable to be spatially explicit to reflect the fact that there are constraints on the movement of water. For example, it might not be feasible to supply certain users from a particular water source. This can be implemented through a nodal structure, which represents different aspects of the model (such as a water treatment plant or group of factories) as points in a directed graph. Each node has a water balance equation showing inflow and outflow at different time steps.

Monte Carlo simulation approaches are often applied to urban water problems. Simulation approaches to implementing the economic and hydrological components (see above) allow for substantial complexity in terms of dimensionality, non-linearity, and randomness. The latter means that the impact of reduced groundwater availability can be simulated over a large number of future states of the world. The results can be expressed as a confidence interval rather than simply a point estimate, and the point estimates that derive from a Monte Carlo simulation are likely to be more accurate than the point estimates from a non-linear deterministic model. From a practical perspective, simulation approaches are also relatively easy to develop and communicate to policy makers.

Monte Carlo simulations can be combined with optimization techniques such as evolutionary algorithms to estimate how water managers and water users would respond to changes in groundwater availability. As discussed above, this is pertinent to estimating the system value. Relevant examples include Cui et al. (2003), Mortazavi et al. (2012) and Johns et al. (2014) (Box 2).

During the assessment, social or environmental values need to be discerned and should be used in conjunction with other approaches.

While the approach concentrates on water quantity, valuation techniques can be applied to inform decisions around water quality, which is a critical water management issue in Dhaka.

Box 2: Optimizing water supply headworks operating rules under stochastic inputs: Assessment of genetic algorithm performance (Cui et al. 2003)

This study combines genetic algorithms with Monte Carlo simulations in order to determine the least cost operation management plan of an urban water system, which consists of a number of interconnected reservoir systems. This process optimises the key operating rules for the complex system, with features including managing demand growth, stochastic reservoir inflow volumes, highly variable climatic conditions and various water management rules. Similar approaches are widely applied for supply augmentation planning and other aspects of urban water management and could be applied in Bangladesh.

Approach for now

In the timeframes available for this pilot it has only been possible to undertake a simplified modelling approach based on the replacement cost method. This is because of the time involved in collecting data and building models to implement the more advanced approaches.

The key assumptions are:

- groundwater is a scarce resource for the textiles industry, so a reduction in groundwater availability would reduce production (without an increase in supply from an alternative water source)

- groundwater depletion has no effect on water users other than the textiles industry

- alternatives to groundwater that are included in the model (for a particular time of year) are available in unlimited quantities at constant average costs although the costs of alternatives could so high as to be prohibitive

- the value of water to the textiles industry can be accurately estimated using the residual approach.

Methodology

Suppose that there is less groundwater available for use in the textiles industry. There are two possible responses, either use less water or increase supply from an alternative source. Both responses have a cost which can be used to estimate the value of groundwater to the textiles industry. For the textiles industry, there are costs associated with using less water, such as reduced revenue in production is impacted or capex and opex associated with more water efficient technologies, and costs associated with alternative sources of supply. If the textiles industry selects the least costly option, the net cost of reduced groundwater availability can be expressed as:

$$N = min\ (V, A_i,..., A_i) - G \quad (9a)$$

where N is the net cost of reduced groundwater availability (BDT/m³), V is the value of water to the textiles industry (BDT/m³), A_i is the cost of the i^{th} alternative source of water (BDT/m³), and G is the cost of groundwater (BDT/m³).

If there are no alternatives to replace groundwater (see Box 3) or the cost of this replacement exceeds the value of water to the textiles industry), production will not be profitable, and the net cost of reduced groundwater availability is:

$$N = V - G \quad (10)$$

The value of water to the textiles industry can be estimated using the residual value approach as set out in equations 1, 2, 3 and 7. This involves estimating the net benefit excluding water costs and dividing by the volume of water used.[28] Each factory will have a specific value of water.

Aside from the value of water to the textiles industry, the cost of groundwater and water from alternative sources needs to be determined. Taking the example of surface water as a possible alternative water source, the cost of surface water could be expressed as:

$$A=R+T+D \quad (11)$$

where R is the cost of the surface water itself (in that the water is no longer available for other uses), T is the cost of treating surface water, and D is the cost of distributing surface water. A similar equation can be formulated for each of the other alternative water sources under consideration.

The cost of groundwater generally just depends on the cost of extraction and on the license fee to abstract water.

As in the previous case study, it is important to distinguish between private and social costs and benefits. For example, if the use of surface water by the textiles industry imposed costs on downstream users due to reduced water availability, but these costs were not reflected in the price of surface water to the textiles industry, the social costs would tend to exceed the private costs. To understand the behavior of the textiles industry, the focus should be on private costs and benefits. To inform public policy, the focus should be on social costs and benefits. Hence, data should ideally be collected to inform both perspectives.

Box 3: Imperfect alternatives

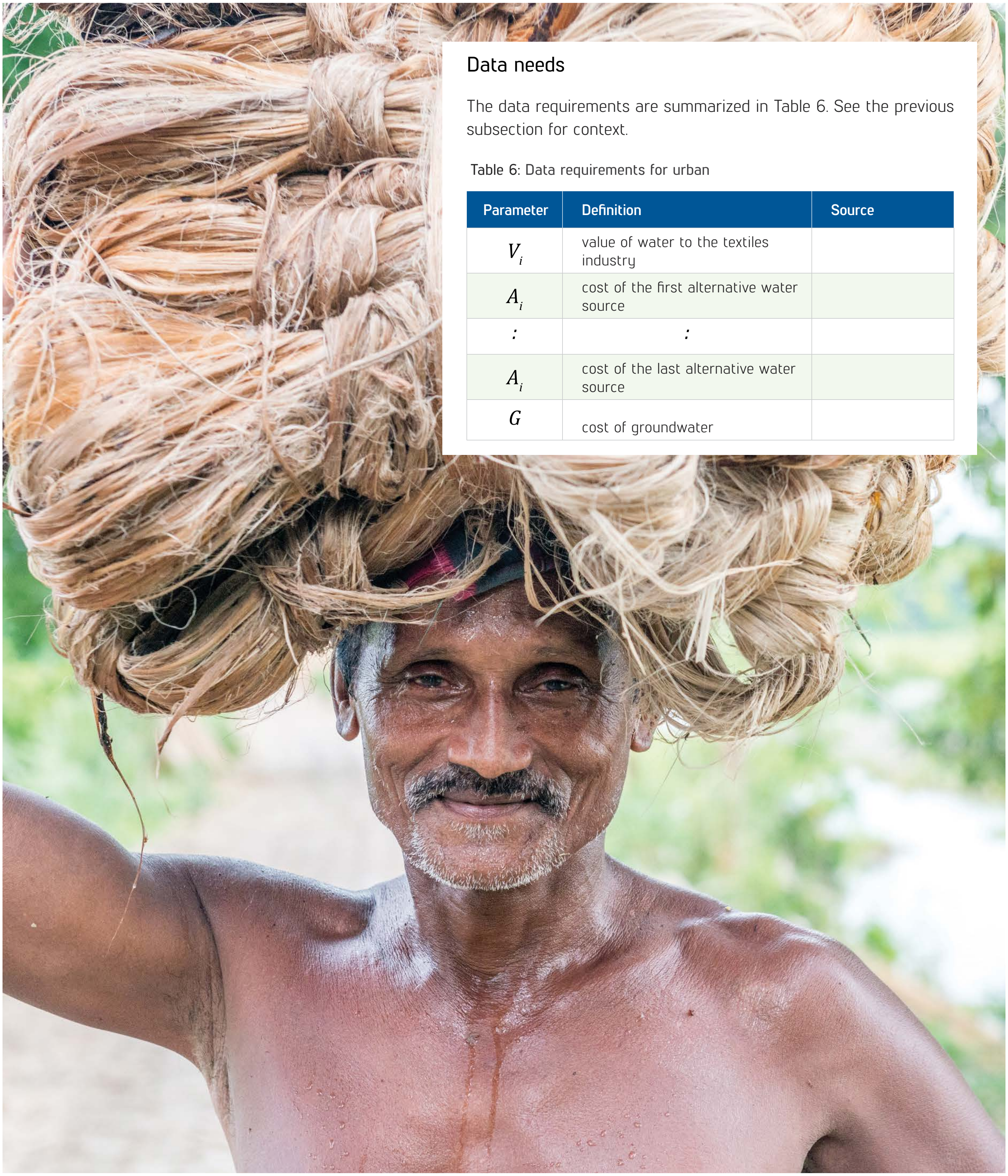
In some cases, the alternatives to groundwater might be highly imperfect. For example, in the dry season the availability and quality of surface water might not be sufficient to substitute for groundwater in the textiles industry. Hence, in these parts of Bangladesh surface water would only be a substitute for part of the year.

There are no simple approaches for accounting for imperfect alternatives. In the case of surface water, Equation 9 could be evaluated for the dry season and wet season:

$$N= s_D\ (min(V, A_{1D},..., A_{1D})-G) + s_W\ (min\ (V, A_{1W},..., A_{1W})-G) \quad (9b)$$

where s_D is the share of dry season months in a year and s_W is the share of wet season months in a year. However, this formulation assumes that there are no annual fixed costs associated with textiles production or alternative water sources and is not recommended partly because it will overstate the viability of alternative water sources that are only available for part of the year. As a result, the estimated value of groundwater would tend to be understated.

[28] Note that unlike agriculture the parameters should not be expressed on a per hectare basis.



Data needs

The data requirements are summarized in Table 6. See the previous subsection for context.

Table 6: Data requirements for urban

Parameter	Definition	Source
V_i	value of water to the textiles industry	
A_i	cost of the first alternative water source	
:	:	
A_i	cost of the last alternative water source	
G	cost of groundwater	

Pilot Study #2: Addressing falling groundwater tables in Dhaka

Approach in ideal world

The removal of barriers would have a number of effects. It would reduce the volume of water available for agriculture in the dry season, particularly for the production of boro rice. On the other hand, it would increase the volume of water available for fish and allow them to move throughout the system. Water valuation needs to capture both effects.

For the effect of reducing water for agricultural use, the approach outlined in the agricultural case study would be largely applicable. This would involve modelling the total net benefit from agriculture with and without the barriers. This requires assumptions around the mechanisms by which land, water and other inputs are allocated to different land uses, the resulting allocation of land, water and other inputs (recognizing that this might not be optimal), and the associated benefits and costs. The effect of removing the barriers is to reduce the volume of water available for agriculture at different times. This adds complexity to the approach outlined in the agricultural case study, which was based on a groundwater resource and assumed that available water could be used at any time throughout the year. When modelling an unregulated surface water system, it is generally necessary to model water use and apply the water availability constraints at a shorter time step, such as monthly. It also requires assumptions around how use at different time steps affects annual production.

For the effect on fish, it is necessary to model the total net benefit from the resource with and without the barriers. This requires a model of the physical process, including the relationship between effort (such as labor and nets) and catch (output of fish and eggs). The effect of removing the barriers could be to increase the catch associated with a given effort. Ideally, the analysis also needs to account for other factors that affect the resource, such as pollution and urban water use. For example, if water pollution from industry is sufficiently bad, removing the barriers might not be enough to allow the resource to recover. There would be benefits from modelling this as a dynamic process, partly because it could take an extended period of time for the resource to return to equilibrium. In addition to the model of the physical process, it is also necessary to model the decisions that determining the effort in a given context, as well as the costs of effort and the benefits of catch. Relevant examples include Stanfel et al. (1988), Suri et al. (2008) and Li et al. (2011) (Box 4).

The approach as set out above focuses on the value of water to agriculture and fish and does not account for the social value of water (or other environmental values). Where social values are important this approach should be used in conjunction with other approaches.

Box 4: Numerical Simulation for Optimal Harvesting Strategies of Fish Stock in Fluctuating Environment (Li et al. 2011)

This paper develops a numerical simulation for the optimal harvesting strategies of fish stock. Stochastic behaviour of environmental factors was included in the optimisation of harvesting strategies. This determines a relation in which the maximum sustainable yield and biomass varies with environmental factors, such as variation in the intrinsic growth rate and environmental carrying capacity. The obtained relation can be applied for the management of fisheries and will allow determination of the economically optimal long-term strategy for commercial fisheries.

Approach for now

Fully implementing the approach outlined above would not be feasible in the time available. The simple alternative is to conduct a rapid assessment of the key effects, drawing on expert opinion where possible in lieu of more advanced approaches. The key assumptions are:

- expert opinion is a sufficiently accurate basis for estimating changes in agricultural land use in response to removing the barriers
- the barriers are the only driver of effort and catch (external factors, such as water pollution from municipal and industrial sources, have not had a material influence)
- the prices of outputs and inputs other than water are fixed for both agriculture and fish
- the only environmental benefits from increased environmental flows relate to fish
- the fish resource is currently in long term equilibrium.

Methodology

The removal of the barriers will reduce the water available for agricultural use in the boro season. On the other hand, it will increase the water available for environmental use and enable fish to move throughout the system. The overall benefits to the community of removing the barriers can be decomposed as:

$$\Delta\Pi = \Delta\Pi_A + \Delta\Pi_E \qquad (12)$$

where $\Delta\Pi_A$ is the change in total net benefit to agricultural uses and is the change in total net benefit to environmental uses.

Agriculture

Based on the agricultural case study, the change in total net benefit to agricultural uses is given by:

$$\Delta\Pi = \sum_i N_i \Delta X_i \quad (13)$$

The interpretation of the parameters, variables and subscripts is unchanged from the agricultural case study, with N_i being the net benefit per hectare excluding water costs for land use i and X_i being the area of land use i.

This depends on the land use change that takes place as a result of removing the barriers, and the relative net benefit per hectare of different land uses. This requires the same economic data as the agricultural case study, including non-water costs and revenue per hectare.

Given the timeframes, it is recommended that ΔX_i is based on expert opinion of what is feasible given water availability in the scenarios and realistic in terms of irrigator behaviour. For example, an expert might conclude that 70 per cent of land currently devoted to production system X would shift to production system Y if the barriers were removed.

ΔXi is based on expert opinion of what is feasible given water availability in the scenarios and realistic in terms of irrigator behaviour. For example, an expert might conclude that 70 per cent of land currently devoted to production system X would shift to production system Y if the barriers were removed.

Fish

Similarly, the change in total net benefit to environmental uses is given by:

$$\Delta\Pi_E = \sum_j P_j \Delta Q_j - \sum_k P_k \Delta Q_k \quad (14)$$

where the subscript j denotes outputs from the fishing industry (primarily fish and eggs) and the subscript k denotes inputs to the fishing industry (such as nets and people). The parameters P reflect either benefits or costs, while the variables Q reflects either physical outputs or physical inputs, depending on the context.

The change in the productive capacity of the fish resource associated with removing the barriers will affect the relationship between outputs and inputs. If there are more outputs for a given vector of inputs, there will be a corresponding increase in total net benefit. The extent of this increase depends on the benefits to the community from fish and eggs.

Complicating matters, there could also be a behavioral response, with the change in productive capacity potentially affecting decisions around inputs. For example, if the fish stock improves, people who had shifted to other activities may return to the fishing industry, increasing the use of labor and other inputs. The effect of this change depends on the costs to the community from input use.

A simple approach to estimating ΔQj and ΔQk would be to estimate the changes in outputs and inputs since the barriers were introduced, either based on survey data or expert opinion. These values could then be plugged into equation (14) to estimate the environmental value of water.

Data needs

The data requirements are summarized in Table 7. See the previous subsection for context.

Table 7: Data requirements for fish

Parameter	Definition	Source
Agriculture		
N_i	the net benefit per hectare excluding water costs for land use i	
ΔX_i	change in area of land use i due to removing barriers	
Fish		
P_j	social benefit of output j	
P_k	social cost of input k	
ΔQ_j	change in output j due to removing barriers	
ΔQ_k	change in input k due to removing barriers	

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