GLOBAL CHANGE AND THE MANAGEMENT OF WATER RESOURCES:
AN ECONOMIC APPROACH

Socioeconomic and policy aspects of adaptive water management in the global context in the perspective of climate change

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Policy Summary

Overview
The objective of this deliverable is provide an overview on some important issues of the economic approach relevant to water management. Particularly, we provide a theoretical framework which is able to deal with water quantity and quality explicitly and then discuss the possible economic approaches to water management in the context of climate change.

Background
Different approaches towards solving water problems have been proposed. Integrated Water Resources Management (IWRM) has become one of the most important options, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Economic models can support water policies aiming at sustainable allocation and quality conservation of water. In the literature of economic analysis of water issues, there exists a class of models which deal with the integrated analysis, the so-called hydro-economic modelling aiming to capture the complexity of interactions between water and the economy. The lack of sound theoretical framework(s) hampers the progress of IWRM.

Methodology
In this report, we start with the discussion on the background of the socio-economic and institutional aspects related to water management and the special features of water. The hydrological cycle and the properties regarding the rivalry/non-rivalry and excludability/non-excludability of the water resources are also discussed. This helps us to address the economic mechanisms of dealing with water use efficiency and water quality in different situations. Section 3 explores the economic mechanisms of managing the water quantity for water as a rival good (i.e. a private good or a common-pool resource) and a non-rival good (a public good or a club good) in welfare programs. We elaborate on the economic instruments of dealing with water quality issues, including how pollution compensation (or tax) should be determined in section 4. In Section 5 we further discuss the adaptation to climate change and uncertainty. In section 6 we illustrate how to manage water using the theoretical framework in two examples and the discussion of policy implications. Finally, some research and policy agenda are discussed.

Policy relevance
Based on the proposed theoretical framework, we may apply it to the practical water management issues in different circumstances. If water is a non-private good (i.e. a common-pool resource, or a public good) due to the missing market of water, the first requirement for reducing the water demand is to define the water rights. By clearly defining and distributing the water use rights, water markets can be created that can lead to efficient solutions. The policy agenda is thus to establish proper water rights and water markets and to price the water use by shadow pricing if water is a common-pool or a public good. This involves proper institutional arrangements.

As far as water quality issue is concerned, it is in general important to improve the water quality because of its impact on economic activities and environmental services. The causes of water pollution are mainly the emissions from economic activities. From the perspective of policy making, it is thus important to implement proper measures particularly the economic instruments to reduce the emissions, such as the polluters pay principle. Institutional arrangement may be needed for implementing such policies.
Conclusions and future research

The theoretical framework proposed in this document can be used for dealing with complex water problems including the climate change in different settings. The optimal solution to a specified welfare program for a specific setting provides the optimal response strategies, i.e. the most efficient allocation of the economy including water use and the efficient level of water quality for the society. As such, we contribute to the literature by providing a theoretical model framework which can deal with the challenges in water management analysis, including water pricing and dealing with externalities and compensation.

As far as the climate change is concerned, adaptation to climate change requires sound understanding of the climate change impact on the water system and the economic system. This remains the future research direction. Incorporation of this impact and the uncertainty in the framework may bring more insights into the adaptation measures. This also requires further study.
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1 Introduction

The world is facing serious water shortages and large risks of flooding or droughts in many regions. Millions in the world are suffering from water pollution with tremendous risk for health, particularly for the poor and for children. These problems will be aggravated in the future by many driving forces such as population growth, increase in economic activity and increasing demand for water. The problems will become even more serious due to the global change, including deterioration of ecosystems and climatic change, which will lead to changes in precipitation and evaporation. In addition, sea level rise may cause serious problems in the densely populated estuaries and coastal areas.

There are many potential solutions identified to these problems. Opportunities exist to improve the situation through: i) managing driving forces, ii) improving water supply if possible, iii) reducing water demand if necessary and possible, iv) improving water quality, v) changing institutions where required, vi) capacity building, vii) generating and allocating funds efficiently, viii) integrating economic and ecological systems, and ix) reducing impacts of natural hazards.

The detailed measures of managing the driving forces could include promoting stabilising world population through education and health programs. For economic developments we could focus on selective economic growth, searching for sustainable industries and activities with low water intensity at locations with water scarcity. Another important measure is to reduce impacts of climate change both through mitigation of climate change and adaptation to climate change, because climate change will tend to have a strong negative impact on global water problems.

On the water supply side, we can improve water supply and storage capacity using reservoirs and dams - provided that it is ecologically acceptable - or we can promote desalination. In addition, rural water provision can be fostered by increasing the number of bore holes, and by improving water allocation by means of economic incentives.

On the demand side of water, we can decrease the water demand by improving water use efficiency. Other measures include changing agricultural production patterns, for instance selecting water efficient crops and vegetation, and using drip irrigation method as well as reuse of water.

Water pollution can be harmful to organisms and plants which live in the water bodies. Water pollution also reduces the availability of clean drinking water for humans and animals. Therefore, reducing pollution such as “point” and “non-point” sources is very fundamental. Examples are investing in waste water treatment plants and integrated sanitation/biogas systems, reducing the use of pesticides and herbicides and using the integrated pest management (IPM) programmes. Also it is relevant to use the natural absorption capacity of the environment.

Institutional arrangements provide other options to improve water use efficiency, as water has been “free” (i.e. unpriced) for many users. There is much to be done through institutional arrangement to achieve water use and allocation efficiency, such as improving existing institutions, introducing river basin authorities for transboundary rivers, using economic instruments, for instance by establishing water markets and introducing tradable water use rights. As far as equity issues are considered, block pricing of water could be introduced.

Although there are alternative ways to solving the water problems, optimal water management requires efficient and effective solutions, both from a private and social economic perspective. Efficient allocation requires clear insight in water use rights and proper pricing of water depending on the local circumstances. Water pricing can generate funds for investments in the water sector. Proper water pricing is a way to achieve efficient water use and allocation efficiency. International financial transfers can be used for equity concerns.

The amount of water allocated to meet basic human and environmental needs depends on biological, ecological but also socio-political considerations. Theses interactions between the water systems at the watershed level and human activities should be well understood and fully integrated in water
management. Hence, a watershed and ecosystems approach is essential for optimizing the water system. For example, concerning the environmental absorption and regeneration capacity we need to understand the functioning of the water system. This would enable us to keep rivers flowing, and to prevent deterioration of flora and fauna, i.e. to assure the functioning and productivity of the ecosystem. Therefore, using watershed and ecosystems approach in water management and considering the natural absorption capacity and assimilative capacity are essential elements.

For water related natural disasters we need carefully-designed disaster programmes and early warning systems for Tsunami’s and other natural hazards, like hurricanes and typhoons. This is also a relevant topic for water management that is based on solid cost benefit analysis of alternative policy options.

Integrated water management cannot be applied without adequate capacity building and training of water managers and water users. Education and training for integrated water management, particularly in developing countries may be one of the most-effective measures of the management package.

Economic models can support water policies aiming at sustainable allocation and quality conservation of water (see e.g. Braden and van Ierland, 1999). In the literature of economic analysis of water issues, there are at least four strands of economic models or methods: i) game theoretical models (see Ansink and Ruijs, 2008); ii) valuation methods (Viscusi et al., 2008; ); iii) integrated hydro-economic models (Cai et al. 2003; Heinz et al. 2007; Varela-Ortega et al. 2007); and iv) optimization models (e.g. Fisher, 2008). These models or approaches deal with water issues from different perspectives. For example, game theoretical approaches are mainly used for establishing inter-regional or -national water allocation agreements. Valuation methods are usually used for the non-market goods in the cost-benefit analysis of water projects. Integrated hydro-economic models integrate the economic processes with the hydrological processes to examine and evaluate specific “what-if” scenarios and provide results and insights more directly relevant for water management decisions and policies. Optimization models allocate the available water so as to maximize total benefits from water. Although specific economic models incorporated with the concept of watershed and ecosystems approaches have been found, feedback effects of water changes on the economy and changes in the economy on the water system are often missing in practice (Brouwer and Hofkes, 2008), with the exception in Keyzer (2002). The lack of sound theoretical framework(s) hampers the progress of analyzing the impact of climate change. Batten (2007) identified the following challenges for economists. First, environmental costs and other externalities must be incorporated into water pricing regimes. Second, we must develop ecological sustainable water trading regimes that facilitate efficient allocation of water for all uses (including ecosystem services). Third, we must address the issue of qualitative changes in the long run. New tools and approaches are needed (Batten, 2007).

Considering the complexity of water management issues as addressed above, in this document we aim to provide an overview on some important issues of the economic approach relevant to water management. Particularly, we provide a theoretical framework which is able to deal with water quantity and water quality management. The organization of this document is as follows. Section 2 will discuss the background of the socio-economic and institutional aspects related to water management and the special features of water. This will help us to address the economic mechanisms of dealing with water pricing, allocation and water use efficiency in different situations. Section 3 explores the economic mechanisms of managing the water quantity for water as a private good, or a common-pool resource or a public good. In section 4, we elaborate on the economic instruments of dealing with water quality issues, including how pollution compensation (or tax) should be determined. Section 5 discusses the possible economic approaches to water management in the context of climate change. Section 6 discusses the policy implications of implementing water management in two examples: one about the groundwater management and the other about the waste water quality management for households. Section 7 summarizes the policy agenda based on the current situations, and discuss the future research directions in the field of water management.
2 Socio-economic and institutional aspects and special features of water

2.1 Socio-economic aspects

Uses of water can be categorised into three groups: to meet the basic human needs, the environmental needs and the other water uses by industry, agriculture as well as by households exceeding basic needs (Kemper, 1996). The first two categories are based on the basic needs, i.e. they are essential for life and thus non-negotiable, while the third category is related to uses exceeding basic needs, i.e. economically and politically articulated demand, which can be managed by means of various instruments.

Access to sufficient and safe water is essential for human welfare and good health. In many developing countries access to safe water is not available and a lot of time is spent on collecting and transporting water over long distances, particularly by women. From an economic point of view it is interesting to observe that in many societies free access to water is considered as a basic right. Once the needs for water are met, the demands exceeding these needs can be dealt with. With increasing scarcity it seems logic to use a pricing mechanism to allocate resources in a more efficient way. This pricing of water, which is easily accepted in the richer countries, leads to many complications in developing countries because of the inability to pay for water of poor families. However, if water is not properly priced excessive use and waste of water will occur. As the value of water very much depends on its scarcity or abundance in local circumstances, the water price needs to be set according to the local circumstances, based on the demand for and supply of the resource. But income transfers or compensation is needed if the poor cannot pay for water.

A resource is allocated efficiently when it is put to its highest valued use. In the case of water, competing uses in, for example, industry, agriculture and tourism calls for efficient allocation. Achieving the efficient or optimal water allocation would require that the marginal cost of providing the water are equal to the marginal benefits obtained and that the marginal benefits will be identical in all uses. This means shifting the use of water within or between sectors, e.g. between different crops in agriculture, or from agricultural to industrial use.

An efficient allocation of water by means of the market mechanism requires that the use rights are clearly defined. In practice the use rights of water in rivers or in groundwater are not clearly defined and this complicates the efficient allocation of resources. This often leads to controversies on who is entitled to use the water and in what quantities. This can also lead to upstream-downstream controversies, because excessive use of water by upstream users reduces the opportunities for downstream users.

A similar setting holds for water quality issues, where upstream riparians may pollute the water as such that downstream users are suffering. This requires coordination between upstream and downstream actors to regulate pollutions and to share the costs of abatement for instance according to the polluter pays principle. These upstream-downstream issues can arise within a country, leading to discussion amongst provinces or communities, but also at the international level, sometimes leading to international disputes and negotiations.

From a socioeconomic point of view the challenge is to develop a sustainable water system that can cover the needs of the population for the drinking water, the need of industry and agriculture and the need of nature for water in an efficient manner. This requires a careful balancing of the various demands and an optimal use of the opportunities provided by the hydrological cycle, the geographical circumstances and the accumulated water available in
aquifers or reservoirs as well as other resources. In an interesting paper Hellegers et al. (2008) clearly show that water issues in the world can no longer be separated from energy, food and environmental issues. The high energy prices drive up the price of water pumping and water transportation, and the increasing demand for food, biofuels and nature intensify the demand for water and the competing claims on scarce water resources.

A sustainable water management system should be capable of dealing with the variability of precipitation over the seasons and the years, and the risks of both flooding and droughts should be managed in an optimal manner. Given the changing climate it becomes essential to make societies more climate-proof and resilient to periods of prolonged drought or excessive precipitation. This requires in some regions the development of better storage capacity and similar adjustments. In other regions we may particularly require better facilities to allow for a safe runoff, or protection against flooding. In all cases it is essential to balance the costs and the benefits on the basis of cost-benefit analysis (CBA) and adapt efficient risk-control strategies in order to avoid wasting public and private funds in protective measures or to avoid excessive damages as a result of a lack of adaptation to changed circumstances.

2.2 Institutional arrangements

In some industrialized countries water management has led to institutional arrangements where water pricing according to scarcity is a common practice. In other regions of the world the water use rights are based on traditional use rights and the institutional settings have difficulties in facing the increased demand for fresh water in the various sectors or regions, which leads to very inefficient and harmful solutions. This calls for a revision of the institutions by dealing with the scarcity issues in an efficient manner. Water pricing and clear allocation of water use rights can provide solutions in these circumstances, but issues like income redistribution and impacts on the income of the poor need to be considered as well.

For transboundary rivers, we need to establish international agreements amongst the riparian countries for water quantity and quality issues. For these purposes international river basin authorities are often established to settle on transboundary water issues. We can expect that as a result of global change the pressure on these river systems will increase and that potential conflicts will aggravate.

In developing countries still millions of individuals have no access to clean and safe drinking water. This requires huge programmes for providing drinking water facilities in rural areas e.g. by means of boreholes or rural piped water systems. These need to be provided in combination with proper sanitation systems in order to improve the hygienic situations in rural areas. Also in many megacities in the third world these basic sanitation and water facilities are still lacking and thus it is needed to provide the institutional setting and the investment funds required to improve the living conditions in these circumstances.

In industrialised countries institutions in charge of water management issues should be capable of managing the risk and raising the funds for required investments. In developing countries the institutions and the funds are often lacking to adjust. This calls for intensified international cooperation for enhancing institutions, for capacity building, and for investment in water and sanitation programmes. In addition, safety programs, investment in dikes and flood protection are required, for instance, in vulnerable coastal zones, or mountainous areas prone to extreme weather events.
2.3 Special features of water

2.3.1 As an economic good of a natural resource

In order to understand how water can be managed through an economic approach, we first need to understand the economic functions and the embodied values as well as the characteristics of water. In the literature, the functions of water are classified in different ways. For example, Briscoe (2005) classified five types of values of water: irrigation of agriculture, hydropower, household purposes, industrial purposes, and environmental purposes. Obviously, the first four values are directly related to the economic activities and therefore can be treated as direct input function of water, while the last (environmental purposes) is related to the maintenance of wetlands, wildlife support and river flows and therefore can be treated as the environmental services function of water. Young (2005) identified five classes of values of water from the perspectives of water uses: 1) commodity benefits, 2) waste assimilation benefits, 3) public and private aesthetic, recreational, and fish and wildlife habitat values, 4) biodiversity and ecosystem preservation, and 5) social and cultural values. In the classification of Young, waste assimilation benefits are directly related to the competing use of water, so the first two can be treated as the input function of water to economic activities. The third and fourth values include those linked to the amenity services and the environmental services of water, and are therefore classified as the environmental service function. Environmental services of water can also be viewed as an economic function because it is related to the regeneration of the natural resources and the amenity function of the resource (Zhu, 2004). In the context of economic approach to water problems, we often focus on the input function (such as production and consumption) and the environmental services (e.g., providing regeneration of the natural resources and amenity to human beings) in the economic system. This is consistent with the Dublin statement “water has an economic value in all its competing use and should be recognized as an economic good.”

Although water can be treated as an economic good, we have to understand the characteristics of water because water is different from the goods in standard economics. Firstly, water is part of the environmental resource systems. There are two primary types of water in the natural state: surface water consisting of the rivers, lakes, and oceans and underground water beneath the earth’s surface in soils or rocks. Water can also be classified into fresh water, brackish water, and saline water according to the concentration of dissolved salts. Normally, moderately or highly saline water is of little use to humans. Humans cannot drink saline water directly, nor is it suitable for irrigating crops. Fresh water is the most important resource for the survival of most terrestrial organisms. According to its re-generation property, water can be considered a renewable or a non-renewable resource. On the one hand, water as a non-renewable resource (such as fossil water) follows bio-physical laws. On the other hand, water as a renewable resource (such as river water) follows the hydrological laws and an annual flow of water is provided.

Secondly, water, like any natural resource, follows the first thermodynamic law: water cannot be created nor destroyed. This does not mean that we do not have the problem of water scarcity, because water resources also follow the second thermodynamic law: the use of water in the economic system will transform water from low entropy to high entropy. Therefore, water after use will be in the state of high entropy, or “waste” water, as clean water may become scarce.

Thirdly, unlike most economic goods, water is physically not subject to any technological change and to a large extent homogenous. The associated hydrological process

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1 Strictly speaking, it is the water constituents (H and O) that cannot be created or destroyed in the natural system.
is a reproduction process of renewable water resource. Although water may be scarce, the basic constituents are never ‘destroyed’ and permanently being renewed through the hydrological processes. In this context Keyzer (2000) defines sustainable use in relatively straightforward terms as an association of demand and stock levels that can replicate indefinitely (Keyzer, 2000).

2.3.2 Rivalry/non-rivalry and excludability/non-excludability

Due to the physical attributes, natural water often has the property of non-rivalry and non-excludability. Non-rivalry refers to a situation in which the use of water by one individual does not reduce the availability of water by another. Non-excludability refers to the property that it is impossible to exclude people from using in a physical and legal sense. According to the different levels of involvement of non-rivalry and non-excludability, we may classify water as different types of good (or bad) in economic terms as follows:

- Water is a private good if its use is both rival and excludable.
- Water is a public good if its use is both non-rival and non-excludable.
- Water is a common-pool resource (or open access resource) if its use is rival but non-excludable.
- Water is a club good if its use is non-rival but excludable (Grafton et al. 2004).

According to these properties, we may find many examples for different types of water: a private good, a public good, a common-pool resource, or a club good. Firstly, water is often a private good if use of water is both rival and excludable. The typical water uses such as drinking water, agricultural and industrial water are the private goods. This kind of water use is competing; the water use for one purpose makes the water unavailable for the other purposes. It is exclusive because one can exclude the others using water e.g. by piping the water to his/her own location. For this type of water, we can achieve the efficiency of water use through the existing market. For example, households pay the water bill for its use of drinking water to the water deliver company and the water price is the market price. There are also examples of “underpriced” water, for instance, in agriculture. That’s why we need proper pricing of water or establish the water markets in case there is no market. When water is a private good, we can achieve the efficient allocation of competing use of water among different sectors through water markets.

Secondly, flood-control projects are public goods because the benefits of projects can be enjoyed by anybody without extra costs (they are non-rival and non-excludable). Flooding water is a public bad because nobody in the flooding area can be excluded and that one person suffers from the troubles of flooding does not reduce the suffering of other people. A beautiful stream can be a public good because your enjoyment of the beauty of the stream does not reduce the possibility of other people enjoying it (non-rivalry) and the exclusion cost (such as building a wall or a fence around the stream) is too high. When water has the property of “public good”, it is difficult for us to manage it through the market mechanisms directly because there is simply no market and there will be “free-riders”. It, therefore, often involves the government involvement or institutions.

Thirdly, groundwater has been a common-pool resource in many regions of the world, because its use is rival and the exclusion costs can be very high. On the one hand, groundwater is rival, because your extraction will reduce the groundwater table (there is a limited volume of water under ground) and the extraction possibility of other people will thus
be reduced. On the other hand, the exclusion costs of using groundwater are very high. You have to stop people extracting water either by physical means such as setting monitoring equipment in many locations or by setting institutions such as laws, which incur high transaction costs or monitoring costs. Both physical and institutional means for excluding people are costly. That’s why that groundwater has been a common-pool or open access resource for many years in many regions. So far, some countries or international organizations have set up a number of institutions such as water rights, and groundwater extraction laws against the over-extraction of the groundwater, aiming to prevent the groundwater overuse.

Finally, fishing water can be a club good if fishing men have to pay for fishing and it is to some extent non-rival. In this case, the exclusion costs are low; simply introducing the fishing license or asking fishing men to pay the membership fee can exclude fishing for free. But fishing water itself is non-rival because many people can go fishing at the same time and location as long as no congestion occurs, although the number of fish in the lake will go down if fish are continuously caught. Another example for club goods can be a national park (e.g. with nice landscape or nice waterfall), which can be protected by a nature conservation organization and for which people have to pay contributions to visit.

Furthermore, we have to deal with both water quantity and water quality issues in water management. Water quantity is closely related to water scarcity. Water scarcity can be caused by the natural environment or by the human activities. The global water system can be explained as the hydrologic cycle - the cycling of water in the oceans, atmosphere and biosphere. Precipitation, evaporation and runoff determine the water availability in the different seasons at various locations of the globe. In some areas water is abundant; while in other regions absolute water scarcity occurs. The patterns of precipitation and evaporation show huge variations over the seasons and over the years, which always has led to periods of drought and incidental floods in many areas. For example, there are problems of water scarcity in arid and semi-arid areas. But in some other regions water in the natural environment is not scarce but people can also face the problem of water shortage, which can be caused by the high demand (e.g. water demand is larger than water supply), for example, in the summer season people use a lot of water for bathing and watering their gardens. Scarcity can be linked to the rivalry property of water, because rivalry causes the competing use of water. For water without rivalry (e.g. the recreational water), the scarcity is not relevant. Therefore, management of water quantity requires us to understand the causes of the scarcity and the involved property such as rivalry or non-rivalry. For example, in arid area, we may consider storing water. In the case of high seasonal demand, we may introduce peak-low prices.

Water quality is closely related to water pollution. Water pollution can be caused by human activities directly, but the environmental processes can also contribute to water pollution following the bio-physical laws. For example, global change, particularly climate change, can worsen the water quality due to a higher temperature. To manage water quality is therefore to understand the impacts on water quality from both the economic system and the environmental system. If water pollution is caused by economic activities, the 'polluters pay principle' may play a role in the management of water quality. In the case of environmental change, we may pay more attention to the interaction between the economic and the environmental system and the options for adaptation. Besides, a decrease in water quality also contributes to the reduction of water quantity because less clean water is available in the case of lower water quality. In this case, we may consider the treatment and or reuse of “waste” water.

It has been shown that water has a lot of special features in different circumstances. These different features call for different management methods and different economic approaches.
Economic models can support water policies aiming at sustainable allocation and quality conservation of water (Braden and van Ierland, 1999; Turner et al., 2004, Fisher, 2008). In the literature of economic analysis of water issues, there exists a class of models which deal with the integrated analysis, the so-called hydro-economic modelling aiming to capture the complexity of interactions between water and the economy (Cai et al. 2003; Heinz et al. 2007). However, the lack of sound theoretical frameworks hampers the progress of dealing with water use efficiency and analysing the impacts of climate change in relation to the water problem. The complexity has brought a lot of challenges for economists such as the incorporation of the environmental costs and other externalities into water pricing regimes, the development of ecological sustainable water trading regimes that facilitate efficient allocation of water for all uses (including ecosystem services), and the discussion of the issue of qualitative changes in the long run as well as the feedback effects of water changes on the economy and changes in the economy on the water system (Brouwer and Hofkes, 2008; Batten, 2007; Keyzer, 2002). To tackle these challenges, we need new tools and approaches. In this context, we develop a theoretical model framework which deals with the interactions between the economic system and the water system considering the feedback effects in both directions. The framework illustrates how to cope with the economic functions of water, and how to consider both the water quantity and the water quality problems. This will be further elaborated in the following sections.
3 Economics of water quantity management

3.1 Water valuation in welfare programs

3.1.1 Valuation of rival water as an input to economic activities

Water quantity management is closely related to water scarcity. This can be managed through increasing water supply or reducing water demand in the first place. Water is a basic need for human life. For dealing with the competing use of water, the social objective is to achieve efficiency and equity of water allocation. An economic approach to the efficient allocation of water can also help decision-makers to achieve the distributional goal if equity is considered in the social objective.

From the supply side, we may achieve an increased supply by several manners, e.g. through water transportation, water storage, use of fossil water and desalination. Many water projects (e.g. technical measures such as capturing, storing, delivering and treating water) exist, aiming to increase water supply in many regions of the world.

From the demand side, water demand can be reduced through technical measures for users. In households, we can introduce water saving equipment, taps, water saving shower heads, and reducing waste of water in gardens etc. In industry, water saving technologies can be applied and reuse and recycling of water is often a very good solution. In agricultural irrigation, efficient technologies can be applied and water saving is also possible by choosing the right crops.

Except for the technical measures on the supply and the demand side of water, public policies such as reallocation of water between competing water-using sectors can also be proposed. Nevertheless, all these measures or policies incur costs. Therefore, they require an assessment about whether such a measure or a policy is economically reasonable and socially desirable. Cost-benefit analysis (CBA) is commonly used for evaluating water projects and water policies. CBA is built on welfare theory and considers whether a measure or a policy is acceptable for society on the grounds of allocative efficiency (Hanley and Spash, 1998). Rather than seeking a full optimum solution in welfare optimization theory, CBA in practice typically examines whether a change from given conditions would represent a desirable shift, balancing the predicted beneficial and adverse effects generated by the proposal (Young, 2005b).

In applied CBA, benefits and costs must be expressed in monetary terms by applying the appropriate prices to each physical unit of input and output. It is essential that correct prices are used that cover the full costs of water provision, including external costs related to pollution or damage to nature. If payments for environmental services are accounted, the price of water will increase and more efficient water use will occur. The prices used in applied CBA are interpreted as expressions of willingness to pay (WTP) for a particular good or service (Young, 2005).

When water is a normal private good, the standard economic approach is to use the equilibrium market price of water for CBA. In reality, however, water is often lowly-valued (underpriced). This creates a lot of waste of water use (e.g. an artificial demand for water). To achieve the efficiency of water use, we can use the so-called full-cost pricing and provide the water users incentives to save water. If water is a non-private good (i.e. a common-pool resource, or a public good) due to the missing market of water, the first requirement is to establish the water markets. By clearly defining and distributing the water use rights, water
markets can be created that can lead to efficient solutions. In this case the so-called shadow prices can be identified, which reflect the WTP of the water users.

Economically, the efficiency of water allocation can be achieved through the first welfare theorem. The objective of society according to the first welfare theorem is to maximise the social welfare subject to the economic and technical constraints. It shows that for given ownership of endowments, the resulting equilibrium allocation of the welfare program reflecting the social objective is Pareto-efficient. However, the resulting allocation may be considered to be unacceptable from an equity perspective. A very careful design of the institutions is required to arrive at socially desirable outcomes that consider both allocative efficiency and distributional aspects. The potential compensation criterion is useful in separating efficiency and equity. This is addressed in the second welfare theorem. For the equity concern, the distributional goal can be achieved through the allocation with transfer which is also Pareto-efficient (Ginsburgh and Keyzer, 2002). If the gains outweigh the losses, it would be possible for the gainers to compensate fully the losers with money payments and still be better off with the policy.

The welfare theorems indicate that Pareto-efficiency is achieved when the marginal benefits of using a good or service (e.g. water) are equal to the marginal costs of supplying the good. In welfare economics, (shadow) prices are determined by the marginal value of the resources (e.g. water). When markets are absent or ineffective, resource (water) value is measured in the context of specific objectives as if the markets existed. As such, the value of water in a welfare program, which reflects its contribution to the objectives, is called the shadow price of water. The way of determining the water value in a welfare program is called shadow pricing. Because of the economic value of water to water users, shadow pricing of water can determine the willingness to pay of users. Shadow price or accounting price of water can therefore reflect the value of water.

If water is a rival and excludable private good, the efficient allocation can be realized by a welfare program with a real water market. If water is a common-pool resource, its use is rival but non-excludable. The non-excludability of water is caused by the fact that there are no clearly defined property rights. To achieve the optimal allocation of a common-pool resource, we can define a property right and establish a (pseudo-)market for it. Particularly, in a welfare program we can determine the optimal allocation of a common-pool water resource and the shadow price of water, with the institutions of water rights and pseudo-market.

The welfare economic theory provides a basis for economic valuations of water use because water is an input (to production and consumption) to economic activities (Keyzer, 2000). The input function of water is valued by shadow prices in a market or pseudo-market in a welfare context. Let us consider an economy with r commodities indexed by \( k = 1, 2, \ldots, r \). The commodity space is an r-dimensional space, denoted by \( R^r \). There are two types of agents who make decisions: producers (firms) and consumers. There are n producers, indexed by \( j = 1, 2, \ldots, n \). Each producer \( j \) is endowed with a technology, represented by a set \( Y_j \), which belongs to \( R^r \). Let \( y_j \) be the production plan with a vector of outputs and inputs of producer \( j \), and the outputs of production carry a positive sign and inputs a negative sign. The feasible production plan is expressed as: \( y_j \in Y_j \). The producer chooses from the set of feasible production plans such that it maximises his profit, defined as \( py_j \), where \( p \) is the price vector. The problem of

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2 A resource allocation is Pareto-efficient when it is impossible to reallocate resources to make an economic agent better off without making at least one economic agent worse off.
the producers can be described as: \( \Pi_j(p) = \max_{y_j} \{py_j \mid y_j \in Y_j \} \), where \( \Pi_j(p) \) is the resulting maximal profit.

There are \( m \) consumers, indexed by \( i = 1, 2, \ldots, m \). Every consumer is endowed with commodity endowments \( \omega_i \) for sale and sets his or her consumption plan. The consumption of any commodity cannot be negative: \( x \in R^+_n \). Each consumer is also faced with a budget constraint: \( px_i \leq h_i \), where \( h_i \) is the income of consumer \( i \). The income consists of two parts: the proceeds \( p\omega_i \) of selling the endowment \( \omega_i \) and the distributed profits \( \sum_j \theta_{\omega_j} \Pi_j(p) \), expressed as: \( h_i = p\omega_i + \sum_j \theta_{\omega_j} \Pi_j(p) \), where \( \theta_{\omega_j} \) is consumer \( i \)'s non-negative share in firm \( j \).

All profits are distributed so that \( \sum_i \theta_{\omega_j} = 1 \) for producer \( j \). The welfare program where water is a rival good or common-pool resource reads:

\[
W(\alpha) = \max \sum_i \alpha_i u_i(x_i) \\
x_i \geq 0, \text{all } i, y_j, \text{all } j,
\]

subject to

\[
\sum_i x_i \leq \sum_j y_j + \sum_i \omega_i, \quad (p)
\]

\( y_j \in Y_j \),

where \( x_i \) is the vector of consumption goods (including water), \( y_j \) is the vector of net output including water, \( \omega \) is the vector of initial endowments. Parameter in bracket \( (p) \) gives the vector of shadow prices of the rival goods (including water), \( \alpha_i \) is the welfare weight of consumer \( i \) and is chosen such that his/her budget constraint holds,

\[
p x_i = p \omega_i + \sum_j \theta_{\omega_j} \Pi_j(p).
\]

By solving such a welfare program, the resulting solution shows the optimal allocation of goods including water with rivalry and their optimal shadow prices \( (p) \).

This welfare program sets up the mechanism of water quantity management based on economic efficiency. For the concern of equity, direct transfers can be made e.g. from the rich to the poor, which can be incorporated in the budget constraints. Therefore, it can be used to deal with many policy options raised in the introduction section quantitatively.

### 3.1.2 Valuation of non-rival water amenity

Theoretically, the amenity function of water is possibly analysed in welfare economics because amenity function and willingness to pay for the amenity value can enter the utility functions of the consumers. This can be incorporated in a welfare program, where water as an input is a rival good for consumption and production but its amenity value as a non-rival good has impacts on the utility.

In the model, we consider water as a private good (i.e. an input for economic activities as consumption good and intermediate good with given initial endowment) and as a public good (i.e. water has amenity service, which is non-rival and non-excludable). The welfare program in which water has input function (as a rival good) and amenity value (as a public good) reads:
\[
\max \sum_i \alpha_i u_i(x_i, g_i) \\
\]
\[
x_i \geq 0, g_i \geq 0 \text{ all } i, y_j \text{ all } j, y^+ \geq 0,
\]
subject to
\[
\sum_i x_i - \sum_j y_j \leq \sum_i \omega_i \quad (p),
\]
\[
g_i = y^w_i \quad (\phi),
\]
\[
F_j(y_j) \leq 0,
\]
\[
F_g(y^+, y_j) \leq 0
\]

where \(x_i\) is the vector of consumption goods including water, \(g_i\) is the vector of non-rival consumption of water amenity for consumer \(i\). \(y^+_w\) is environmental amenity indicator for water which is “produced” according to a transformation function \(F_g(\cdot)\), which relates the water amenity indicator to the “production” process probably following a bio-physical law, \(y_j\) is the vector of net output including water produced according to a transformation function \(F_j(\cdot)\) following a certain production technology, positive one indicating outputs and negative one indicating inputs. \(\omega\) is the vector of initial endowments. Parameters in brackets give the shadow prices of the rival goods including water (\(p\)) and the amenity services of water (\(\phi_i\)). \(\alpha_i\) is the welfare weight of consumer \(i\) and is chosen such that the budget constraint holds,

\[
p x_i = p \omega_i + \sum_j \theta_j \Pi_j(p).
\]

The equilibrium solution to this welfare program can show the shadow price of water as a rival good (within the vector \(p\)) and the shadow price of water amenity as a public good (\(\phi_i\)). These shadow prices are actually the willingness to pay of the water users for water as a rival good and as a public good.

In this program for non-rivalry and non-excludability of amenity value, consumers will not pay for the consumption of the amenity value. Thus, no expenditure on the non-excludable good enters the consumer budget because the consumers will not pay for it when they are not excluded. But if a certain institution exists so that the consumers agree to pay, or have to pay for it, then the expenditure on this consumption should enter to the budget. This is actually similar to the case of club goods where exclusion is achieved by paying membership fee.

If water has the property of a club good, i.e. non-rivalry but excludability, the same welfare program (2) can be used because the non-rivalry is modelled through the amenity value \(g\) in the utility function, while the excludability is simply modelled through the consumer budgets. When the consumption of the non-rival good is excludable (by physical or institutional means), the consumers pay for it. Therefore the budget constraint in the program (2) changes into:

\[
p x_i + \phi_i g_i = p \omega_i + \sum_j \theta_j \Pi_j(p),
\]

where \(\phi_i g_i\) is the expenditure of consumer \(i\) on non-rival good \(g\).

We have shown how the amenity value of water can be measured in a welfare program. This is only one of the primary approaches. This approach employs constructed
models comprising a set of behavioural postulates (i.e. profit or utility maximization) and involves the logical processes to reason from general premises to particular conclusion, which is actually the so-called ‘deductive technique’ (Young, 2005b). In literature, the amenity value of water or environmental and recreational values are often measured by the so-called non-market valuation methods. These methods employ inductive logic, usually as formal statistical or econometric procedures, to infer generalizations from individual observations, so they are also called ‘inductive techniques’ by Young (2005b). Next section will give a more detailed discussion on the methods.

3.2 Non-market valuation methods

Water amenity is a non-rival and non-excludable public good. Water-related environmental public goods include outdoor recreation, aesthetic enjoyment of water in its natural surroundings, water quality improvement and other environmental benefits. Valuation of these water-based functions is based on the WTP. There are three primary valuation methods that can be applied to valuing water services or measuring benefits of environmentally-related water uses. They are: 1) the contingent valuation method (CVM); 2) the hedonic property valuation method (HPM), and 3) the travel cost or recreational demand method (TCM).

The CVM directly asks an individual to state his or her value for a resource change and is called a ‘stated preference’ approach (Shaw, 2005). The CVM relies on a survey of agents’ preferences, conducted either personally (face-to-face) or remotely (by mail or telephone). This technique is classified as a direct, hypothetical method of nonmarket valuation. It is direct in that valuation is not inferred from “demand-associated” evidence; instead agents are asked to provide specific details about their values. For example, agents could be asked if they would pay a certain amount of money to go boating on specific lake if the water level was at a certain level. By proposing different fees to different respondents and by varying the water level, demand-revealing data are generated. As such, the boating demand for lake water is estimated and the water price can be induced because of the relationship between the water level and water quantity (Griffin, 2006).

The HPM uses observed differences over time or spatially, across properties, in the value of property (lake shorefront house versus house from lake shoreline) to reveal value for the resource (Shaw, 2005). If one of house’s (or land’s) characters involves linked water rights to access to water, then it maybe possible to see how water affects house (or land) value, thereby explicitly valuing water. That is, “water access value” or “water use value” might be inferred from house (or land) value. Hedonic pricing method is classified as an indirect, observed method of non-market valuation. It is indirect because the valuation of water being sought is inferred from the values witnessed for another commodity (e.g. house, or land). It is observed because the data are created by actual market transactions. In application, the price is regressed against the characteristics to see if price is well related to these characteristics. It is necessary to presume a specific functional form, generally expressed as: \[ p = f(w, \text{char}_1, \text{char}_2, \ldots) \], where the water variable, \( w \) can be in a variety of ways depending on the circumstances. Once the estimation is complete, the most immediately interesting finding \( \frac{\partial f}{\partial w} \), or the rent differential, is theoretically the contribution of water to the value of land or house (Griffin, 2006).

The TCM uses individual’s cost to and from a recreation destination to proxy the price of a unit of the non-market good, a ‘trip’ to a destination. By tracing out the demand for the good, which in water-based recreation is a lake, a river, or ocean, one can then recover estimates of consumer’s surplus for resource changes. The intuition is that a rational individual would not
take a trip to a destination unless the total value of doing so exceeded the cost. The TCM approach is known as a 'revealed preference' approach, because we get a revelation of the value of the resources by observing trip-taking behaviour rather than directly asking a person his or her value for a lake (Shaw, 2005). Studies using the TCM for valuing the environmental and recreational services of water can be found in literature (see e.g. Ward, 1987).
4 Economics of water quality management

4.1 Incentives for clean water

Water provides environmental services including support of, and habitat for aquatic life, and riparian area animals and plants, and birds that feed on aquatic life. Humans use water for drinking, growing food, cooking, bathing, for other domestic uses and for recreational activities such as boating, swimming, fishing and water-skiing. Humans sometimes just enjoy simply looking at, or being near, a water body. These activities are referred to as water’s service flows to humans. Many ecological and human service flows of water can be disrupted by pollution of the groundwater or the surface water. Water pollution is the contamination of water bodies such as lakes, rivers, oceans, and groundwater caused by human activities. Pollutants can be toxic or non-toxic and toxic ones may impair the ecological and human services that water provides.

Water pollution hits all continents. Despite improvements in water quality in some industrialised countries, problems are aggravating in emerging economies and developing countries. Industrial pollution, non-point sources and waste water discharges of households lead to lack of oxygen in river systems and increase the concentrations of toxic and harmful pollutants. In coastal water severe algae blooms occur as a result of excessive nutrient concentration and oxygen concentration are far too low in many areas, for instance, in several areas in the Mediterranean Sea.

Human access to safe drinking water and sanitation (sewage systems and waste water treatment plants) in the world is still not ensured. The WHO (2008) estimated that one billion people are without access to safe drinking water. Ingesting toxic substances can lead to health problems, even death from cancers, mutations, blindness, and a host of illness, although it is complicated to know the exact linkages between ingestion of particular concentrations of pollutants and health consequences, and the latency period. Besides, infant mortality in developing countries is still largely caused by poor water quality, or even by no access to the safe drinking water supply (Shaw, 2005). Solving this kind of health problems is basically to solve the access problem of the poor to clean drinking water. Therefore, we need legislations, finances and waste water treatment as well as sanitation systems for the poor. We may also need water standards as proposed by the authorities e.g. Europe’s Water Framework Directive (WFD), World Health Organization (WHO), United Nations Environmental Programs (UNEP), and United Nations Development Programs (UNDP).

Poor water quality also has negative impacts on the economic activities of human beings because of the decreased capacity for life support and reduced water quantity caused by the regeneration process following hydrological processes. For example, lower quality water can have negative effects on crop growth or fish production.

Summarizing, the two important impacts of low water quality are the health and the economic impact. Therefore, we need to manage water quality to reduce its negative impacts on health and economic activities. This can be realized through different technical measures, financial measures, policy measures and economic instruments. But which measures are feasible for solving the water quality problem? We need balancing their costs and benefits because of our limited budgets. The EU WFD promotes the economic principles such as the polluter pays principle. It recommends applying economic methods such as cost-effectiveness analysis to support the identification of measures to achieve the environmental objectives. It calls for a
wider consideration of economic instruments (e.g. water pricing, charges and taxes) to provide adequate incentives for reducing pressures exerted on water resources.

4.2 Economic approach to water quality management

4.2.1 Cost-effectiveness analysis and cost-benefit analysis

Since different measures or policies can deal with water quality issues, we may need to select one or a combination of a few measures in terms of their costs, benefits and effects for the consideration of effectiveness and efficiency. Cost-effectiveness analysis (CEA) and CBA are the important methods for economic evaluation of alternative options.

When we want to meet a certain standard, or effect of water quality, we may use the so-called CEA approach to compare the different measures or combinations of measures in terms of their costs and identify the least-cost way to achieve the goal. One good example of using the CEA method to find the least costly way to reduce nitrate pollution to groundwater can be found in Rinado and Strosser (2008). The EU WFD set the drinking water threshold value of 50 mg/l for nitrate concentration. The main nitrate pollution in the ground water in EU is mainly from the agricultural and municipal waste water collection and treatment. Therefore, the potential measures for reducing groundwater pollution (aiming at stabilising average nitrate concentration in groundwater at 50 mg/l) include sector-specific measures. For agricultural sector, measures considered include adopting agri-environmental measures with lower fertiliser use, the replacement of cropped area by meadows, in particular in water resources protection zones, better management of farm yard manure on farm or the shift to organic farming. For the municipal sector, measures identified included the installation of new sewage and waste-water treatment facilities, the renewal of leaking sewage, the connection of disconnected households to public sewage networks or the installation and efficient management of sceptic tanks. CEA is then calculate the costs for each measure and find the one with the highest cost-effectiveness ratio.

However, the problem can be complicated when the different options envisaged do not lead to the same environmental outcome. This can be the case, for instance, when different levels of contaminated site remediation are envisaged, or when the targeted pollution concentration is not fixed by law. In such situations, water planners may be interested in assessing not only the costs of alternative options but also their benefits. Cost-benefit analysis thus provides a rational and systematic framework for identifying and assessing in monetary terms all positive and negative effects of alternative options. One of the examples of using CBA for water quality management studies is found in Rinado and Strosser (2008), where two different objectives are compared in terms of their annual costs and benefits. Similarly to the water quantity management by CBA, it may also involve the non-marketed valuations such as TCM, HPM and CVM for the non-market function of the water quality (e.g. the recreational and aesthetic values of water quality).

4.2.2 Water quality management in a welfare program

Economically how can we solve or improve water quality efficiently? Water quality has impacts on utility because of the health effects. Water quality has impacts on production because of the input function and the environmental or ecological services. Therefore, it is possible to include a water quality indicator, which has impact on utility and production function, in the economic model. We can use the similar welfare program (2) to represent the water quality. Since water pollution is caused by emissions, we also consider the
compensation by polluters pay principle in the welfare program. The welfare program which includes the water quality impacts on utility and production and compensation for pollution reads:

$$\max \sum_i \alpha_i u_i(x_i, g_i)$$

subject to

$$x_i \geq 0, g_i \geq 0 \text{ all } i, y_j \text{ all } j, y^+_w \geq 0,$$

$$\sum_i x_i - \sum_j y_j \leq \sum_i \omega_i \quad (p),$$

$$e \leq \sum_j e_j \quad (\psi),$$

$$g_i = y^+_w \quad (\phi_i),$$

$$F_j(y_j, g_j, e_j) \leq 0,$$

$$F_g(y^+_w, e) \leq 0$$

where $g_i$ is water quality indicator for consumer $I$, $y^+_w$ is water quality indicator which is “produced” according to a transformation function $F_g(.)$, where total emissions ($e$) from the production processes have impacts on the water quality. This transformation function can be the hydrological process. $y_j$ is the vector of inputs and outputs following a certain production technology according to a transformation function $F_j(\cdot)$, where water quality $g$ plays a role in the production process and there are also emissions $e_j$. Since the total emissions are the sum of emissions from individual producers, the compensation that the polluter has to pay can be based on the shadow price of emission $\psi$. This $\psi$ can also be used as the tax rate for emissions (or emission tax). Parameter $(\phi_i)$ indicates the shadow price of water quality, implying the costs of increasing the water quality by one unit. $\alpha_i$ is the welfare weight of consumer $i$ and is chosen such that the budget constraint holds,

$$px_i = p\omega_i + \sum_j \theta_j \Pi_j(p).$$

This welfare program can be applied for dealing with the industrial pollution problem, transboundary water management, upstream and downstream interaction and pollution compensation and charges. Depending on the excludability/non-excludability nature of the water quality, the above budget constraint can either contain the payment for enjoying the water quality or not as in the case of water amenity value in Section 3.

The framework proposed here is consistent with the hydro-economic modelling framework, because the process of water quality transformation is a hydrological process model. Besides, ecological restoration can also be considered in the transformation functions. As such, this model framework can be easily extended to include the integration of the economic system and the hydrological processes.
5 Adaptation to climate change

5.1 The climate change impacts and modelling

As we have discussed that water is an economic good with special functions such as input function and amenity function and with the special features such as (non-)rivalry and (non-)excludability. The water system also follows the hydrological and bio-physical processes in the natural environment.

Climate change can affect the quantitative and qualitative status of water resources by altering hydrological cycles and systems, which in turn, affect variables including intensity and frequency of floods and droughts, water availability and demand and water quality, including temperature and nutrient content. Glaciers provide a nice buffering effect: in the summer, the glacier melts and keeps the flows high, providing a seasonal fluctuation of water supply. However, an increase in surface temperatures due to climate change has important consequences for the hydrological cycle, particularly in regions where water supply is currently dominated by melting snow or ice. In a warmer world, less winter precipitation falls as snow and the melting of winter snow occurs earlier in spring. Even without any changes in precipitation intensity, both of these effects lead to a shift in peak river runoff to winter and early spring, away from summer and autumn when demand is highest. Where storage capacities are not sufficient, much of the winter runoff will immediately be lost to the oceans. With more than one-sixth of the Earth’s population relying on glaciers and seasonal snow packs for their water supply, the consequences of these hydrological changes for future water availability are likely to be severe (Barnett et al., 2005). Problems with water may occur through extreme weather events, like typhoons, hurricanes and thunderstorms, and some areas of the globe are particularly vulnerable for these events, e.g. the Gulf of Mexico, the delta of Bangladesh. In mountainous and hilly areas landslides occur as a result of prolonged precipitation and saturation of the soil, leading to many victims almost every year. There is a wide range of vulnerabilities across Europe. These reflect the diverse hydrological situation, such as long and dry summers in the south, and high river-flow periods in the north due to snow-melt (EEA, 2007).

To deal with the water problems arising from the climate change, the economic models should be capable to incorporate the impacts of climate change on water resources in the economic system. For example, a Dutch study was conducted to determine the damages due to flooding and salination by combining the climate change scenarios with economic development (Jonkhoff et al., 2008). The model framework for flooding includes a damage and victims module and a land use scanner in a spatial general equilibrium model, being used to estimate the damage that might occur due to a flood with a variable rate of water flow and water depth, future land use and economic development and indirect effects on labour, product and housing markets on the spatial levels of 40 Dutch regions based on flooding scenarios. For estimating the damages of salination especially to agriculture (e.g. damages to crop if salt or brackish water is used for irrigation) and drinking water supply, a three-dimensional groundwater flow model is used to consider the impact of climate change on groundwater levels and salt level, combining the geographical data on land use and yields. This is a good exercise for modelling the impacts of climate change on water system and economic aspect. Nevertheless, much should still be done considering the complexity of the issue including the difficulty of establishing the specific relationship between different elements and calibrating the model parameters due to lack of data. Moreover, the lack of sound theoretical framework(s) also hampers the progress of analysing the impacts of climate change in relation to the water
5.2 Towards an integrated modelling framework

To adapt to the climate change impact in water management, the modelling approaches should be able to consider the nature of climate change and its impact on the water system and its interaction with the economic system. At least this is theoretically feasible. This could include the following concepts. Firstly, we need to distinguish water stocks and flows, and allow for reproduction over an infinite horizon so as to account for the hydrological cycles including the climate impacts on the water hydrological cycles. Secondly, process-based models which describe the hydrological cycles should be incorporated in the economic models (see e.g. Keyzer, 2000). The economic framework for this purpose is the general equilibrium theory and the incorporated capital theory, which was gradually accepted as the core economic framework. The water valuation in this framework is based on the concept of marginal valuation. Water is treated as a stock, which is influenced by the demand for water. The stock depends on the inflows and outflows. The objective function is to maximize the value function, which is the multiplication of water demand and the return to water use or the shadow price, subject to the water stock reproduction process (stock depends on the previous stock and inflows minus the outflows, or demand and water inflow balances). The multiplier of the water inflow balance in each time period gives the marginal value of the annual inflow. The sum of these marginal values over periods is equal to the derivative of the value function with respect to the water inflow, which is the shadow price of water stock.

The integration of the economic valuation and the hydrological process fits in the literature of integrated hydro-economic modelling (see e.g. Cai et al., 2003; Elmahdi et al., 2007; Heinz et al., 2007; Brouwer and Hofkes, 2008). By hydro-economic modelling, feedbacks and interactions between the economic system and the water system in the perspective of climate change can be represented. Hydro-economic simulation models can be used to examine and evaluate specific “what if” scenarios, while the hydro-economic optimization models help identify the ‘best’ policy options. The potential contributions of hydro-economic modelling to an integrated water management include:

- Integration of water supply and demand,
- Development of better solutions to water scarcity,
- Optimize reservoir operations with competing water demands,
- Modelling storm water management and economic flood control options
- Development of cost-effective solutions for water quality objectives
- Incorporation of climate change impacts
- Economic assessment of various water policies, such as standards, pricing, markets and entitlement reallocation (Heinz et al., 2007).

Besides, we may also consider the measures which aim to reduce the impacts of climate change both through mitigation of climate change and adaptation to climate change. The major mitigation measures include the switch to the alternative energy technologies, agricultural practices, forest management and waste management etc. (IPCC_WGIII, 2007), while the important adaptation measures include the crop diversification, irrigation, water management, disaster risk management and insurance (IPCC_WGII, 2007). All these measures should be incorporated in the integrated hydro-economic model with specific
technological possibilities. They can also be analysed by the traditional cost-benefit analysis or cost-effective analysis depending on the circumstances.

5.3 Dealing with uncertainty

Uncertainty refers to situations in which the appropriate data may be fragmentary or unavailable. Causes of uncertainty include insufficient or contradictory evidence as well as human behaviour. The human dimensions of uncertainty, especially coordination and strategic behaviour issues, constitute a major part of the uncertainties. Climate change is an uncertain process. Uncertainty prevails with regard to the pace of change as well as the economic impact in the long term. The economic effects of climate change are characterised by a long chain of causes and effects, resulting in multiple sources of uncertainty. In the economic analysis of climate change, Peterson (2006) classifies three categories of uncertainty: parametric uncertainty due to imperfect knowledge, stochasticity due to natural variability in certain processes, and the uncertainty about values of the discount rate. Uncertainties in the hydrological system arise from internal variability of the climate system, uncertainty in future greenhouse gas and aerosol emissions, the translation of these emissions into climate change by global climate models, and hydrological model uncertainty such as changes in evaporation, soil moisture and runoff (IPCC, 2008). Walker et al. (2003) describe five uncertainty sources in the model-based water management process: context and framing, input uncertainty, model structure uncertainty, parameter uncertainty and model technical uncertainty.

Therefore, in order to consider the policy options for sustainable water management in the presence of climate change, uncertainty concepts should be incorporated in the economic analysis. Accounting for different uncertainties concerning climate change and water management, different approaches to the relevant economic analysis can be used. Sensitivity and scenario analysis are the most common approaches to deal with uncertainty in policy and project appraisal (Brouwer and De Blois, 2008). Sensitivity analysis is a way to deal with parametric uncertainty. Sensitivity analysis can be used as a tool to answer the question of how sensitive model outputs are to changes in model inputs, varying input parameters that are not known with certainty (see e.g. Pastres and Ciavatta, 2005). Scenario analysis is a way to deal with both parametric uncertainty and stochasticity in providing prospects for the future. For example, Jonkhost et al. (2008) used the scenario analysis approach to estimate the damages under the four combined economic and climate change scenarios. Pallottino et al. (2005) use scenario analysis for water system planning and management under conditions of climatic and hydrological uncertainty. As for the uncertainty related to the value of discount rate, sensitivity analysis is used in the climate change models such as in Kann and Wayant, (2000) and Nordhaus (1993). Furthermore, Weikard and Zhu (2005) propose using the concept of dual discount rates in the CBA of environmental policies to capture the impacts of long-run climate change, i.e. a consumption discount rate to evaluate the marketed goods and a (lower) environmental discount rate to evaluate the stock of environmental resources or environmental quality change in order to maximize the social well-being.
6 Policy implications of water management in two examples

The economic principles discussed in sections 3 and 4 can be applied in many real world cases. The specification of the water issues in economic models is the first step for integrated water management. Policy options may be obtained from the results of well-designed integrated models. In this section we discuss the policy implications of water management practices in the Netherlands in two examples: one about quantity management and the other about quality management.

6.1 Groundwater quantity management

Groundwater management in the Netherlands is an important issue. First, the groundwater tables in the Netherlands are rather shallow, because of the country’s low lying soil surface. Second, the intensification of agricultural activities has contributed to the lowering of groundwater levels in several ways, i.e. through the intensified drainage of agricultural areas in order to raise production, increased agricultural groundwater extraction for sprinkling purposes, and the enhanced evapotranspiration of crops as a result of increased crop yields (Hellegers, 2001). Therefore, groundwater needs management through both institutions and economic instruments.

In absence of institutional arrangement, groundwater is a common-pool resource. Therefore, users will continue to use the water and finally over-exploit it. The reason is that the groundwater is rival but non-excludable. The only way to prevent the over-exploitation is to provide the user rights. By doing so, we exclude the users who do not have the rights to use water. The water right system is an institution for water management; it includes provisions which determine access to water.

Economically, groundwater management involves the proper pricing of groundwater use under the water right institutions. Since water is used for economic activities it can be priced through the welfare program according to its marginal value. Such a pricing can lead to the most efficient use of the groundwater. Therefore, the policy implication of the groundwater management in the Netherlands includes the provision of water rights and pricing the water use properly.

6.2 Water quality management

We take the example of water quality management in the Netherlands for discussion. In the Netherlands, the surface water quality is affected mainly by nutrients (N,P,K) originating from human beings and animals. This pollution enters surface water bodies. The pollution sources can be distinguished into point-sources (e.g. waste water treatment, municipal sewage system) and other sources (e.g. manure discharges, external pollution from abroad entering the Dutch bathing water through rivers Rhine, Meuse and Scheldt). According to the inventory of potential sources of pollution, we may waste water accordingly. The measures include management targeted at the point sources, and aimed at the elimination or dislocation of discharges etc. (Brouwer and Bronda, 2005). For evaluating the feasibility of different measures, CBA could be conducted. This involves the calculation of the costs and the benefits. For calculating the benefits, the CVM could be used for valuing the water quality. This is well-documented in Brouwer and Bronda (2005).
As far as water quality management is concerned, we may also use the polluters pay principle, as water is polluted by some agents. The policy implication is to make the polluters pay for their discharge. The payment can be determined in the welfare program where polluters have influences on the water quality, and thus production level of producers, consumer utility and eventually the social welfare. The payment for pollution can be determined by the shadow value of the emissions, because emissions have negative impacts on the water quality and negative impacts on the social welfare. To maximize the social welfare under the economic and emission constraints, compensation can be made from polluter to the water users. For achieving this, proper institutions and monitoring systems are needed.
7 Policy and research agenda

This document discusses the fundamental issues related to water: the classification of water use (input function and amenity function), the special features of water use (rivalry/non-rivalry and excludability/non-excludability). Based on this discussion, we further discuss the economic mechanisms of water pricing and water allocation. We develop a theoretical model framework which deals with the interactions between economic system and water system considering the feedback effects in both directions, cope with the economic functions of water, and consider both the water quantity and the water quality problems.

When water is a private good, the standard economic approach is to use the full-cost pricing to achieve the efficient use of water and provide the water users incentives to save water because underpriced water creates a lot of waste of water use. For alternative policy options (such as competing use of water among sectors) in the case of water scarcity, we may use the market price of water for CBA. If water is a non-private good (i.e. a common-pool resource, or a public good) due to the missing market of water, the first requirement for reducing the water demand is to define the water rights. By clearly defining and distributing the water use rights, water markets can be created that can lead to efficient solutions. The policy agenda is thus to establish proper water rights and water markets and to price the water use if water is a common-pool or a public good. This requires new institutional arrangements.

As far as water quality is concerned, it is important to provide safe drinking water to the poor for reducing the negative health impacts of low quality water. It is also important to improve the water quality in general because of its impact on economic activities and environmental services. The causes of water pollution are mainly the emissions from economic activities. There are technical measures, economic instruments and policy measures to reduce water pollution. From the perspective of policy making, it is thus important to implement proper measures to reduce the emissions, such as the polluters pay principle. Institutional arrangement may be needed for implementing such policies.

Water valuation is the basic step for an applied CBA for assessing alternative options in water management context. The complexity of water resource management requires that we take the integrated approaches which can consider both the economic and hydrological aspects. The important tasks for dealing with the water resource problems are to improve the valuation methods, and the representation of the hydrological cycle in the economic models. As such we can better cope with the increasing challenges in water resource management.

Adaptation to climate change in water management is another important future task for both scientific research and policy making. Climate change can affect the quantitative and qualitative status of water resources by altering hydrological cycles and systems, which in turn, affect variables including intensity and frequency of floods and droughts, water availability and water quality, including temperature and nutrient content (EEA, 2007). To deal with the water problems arising from the climate change, the economic models should be capable of incorporating the impacts of climate change on water resources in the economic system and vice versa. The integration of the economic valuation and the hydrological process fits into the literature on the so-called integrated hydro-economic modelling. By hydro-economic modelling, feedbacks and interactions between the economic system and the water system in the perspective of climate change are needed. Hydro-economic simulation models are used to examine and evaluate specific ‘what if’ scenarios, while the hydro-economic optimization models help identify the ‘best’ policy options.

We may also consider the measures which aim to reduce the impacts of climate change both through mitigation of climate change and adaptation to climate change. These measures can
be analysed by the traditional cost-benefit analysis or cost-effective analysis depending on the circumstances. The incorporation of these measures in economic modelling for dealing with water management remains an important task for economists. Besides, uncertainty issues related to the climate change impacts in water management remain an important research topic.

Cost-benefit analysis for alternative policy options will be further used in the domain of water resource management. More emphasis will be put on the benefits of environmental services of water resource, where proper discounting rates should be used. Particularly, the concept of dual discount rates, which incorporates the inseparable utility function of the consumer, should be playing a role in the future CBA (Weikard and Zhu, 2006). Providing more accurate evaluation of water policies or water projects should be one of the future research areas.
8 References


