Vulnerability Reduction and Portfolio Approach:

Key Aspects for Assessing Effective Water Adaptation Options in the Face of Uncertainties

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About the Water Governance Facility (WGF)

The WGF is a collaboration between the United Nations Development Programme (UNDP) and the Stockholm International Water Institute (SIWI). The WGF implements parts of the UNDP Water and Ocean Governance Programme (WOGP) by providing strategic water governance support to low- and middle-income countries to advance socially equitable, environmentally sustainable and economically efficient management of water resources and water and sanitation services. The ultimate aim of the Facility's work is to improve lives and livelihoods and reduce poverty, inequalities and exclusion.

The WGF works with multiple thematic areas such as water supply and sanitation, integrated water resources management, transboundary water, climate change adaptation, gender, human rights and water integrity. It works in several countries in regions such as sub-Saharan Africa, the Middle East and North Africa, Central and South Asia, and Latin America. The WGF Report series aims to provide in-depth, high-quality and accessible contents on water governance-related issues for water and development professionals and practitioners.

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Acronyms and abbreviations

AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
HDI	Human Development Index
IPCC	Intergovernmental Panel on Climate Change
ODA	Official Development Assistance
RCM	Regional Climate Model
SIWI	Stockholm International Water Institute

Content

Executive summary

The latest IPCC Assessment Report (AR5) provides evidence that the impacts of climate change are strongest and most comprehensive for hydrological systems. At the same time, there is a huge gap between adaptation needs and the uptake of adaptation actions or programmes. One of the identified issues for the slow uptake of funds for adaptation measures is the difficulty in assessing adaptation effectiveness. Another challenge in developing water adaptation options is tackling the issue of uncertainties, which arise from both climatic factors (the extent of temperature increase and its impacts on fresh water resources across regions) and non-climatic factors (e.g. scenarios on population growth, economic growth, changing lifestyle and their effects on water demand). Effective adaptation options should perform well under plausible uncertainty scenarios. This paper discusses the use of two key aspects in assessing effective water adaptation options: vulnerability reduction as an alternative effectiveness criterion and a portfolio approach to ensure the robustness of water adaptation options against uncertainties.

The most common criterion currently used to evaluate adaptation effectiveness is the additionality principle. This principle asserts that the financial sources for financing water adaptation and/or the proposed intervention, in this case the water adaptation action or programme itself, should be additional to the business-as-usual scenario. Despite solid reasoning for the use of this criterion, there are currently conceptual and implementation challenges to applying the principle in practice.

This paper explores the use of vulnerability reduction as a key effectiveness criterion to assess water adaptation investments. This means that effective water adaptation options are measured against how much they reduce the vulnerability level of the affected community. The Water Vulnerability Index (WVI) provides an alternative for measuring the community's vulnerability to water resources and services. The index, which captures multidimensional aspects of biophysical, social and economic vulnerability, is based on the same approach as the IPCC Fourth Assessment Report (2007). This approach bears similar logic to the impact/risk concept in AR5. Vulnerability mapping provides insight into the distribution of impacts across different water users and ecosystems. Climate change impacts often hit the most vulnerable groups in the community (the poor, women, indigenous people, and the elderly) the hardest; thus the impacts can exacerbate existing equity issues. This vulnerability mapping facilitates the identification of hotspot areas, in which water vulnerability level is high and priority adaptation investments are urgently required. Hence, the assessment of adaptation effectiveness can create synergy in addressing equity issues since adaptation priority is tilted toward those hotspot areas with the highest vulnerability. To facilitate a cross-country or sector comparison, the discussion also looks at a simpler and practical alternative to measure vulnerability reduction.

An adaptation portfolio is characterized by many policy choices rather than a single, most optimal adaptation option. The portfolio can perform better under a plausible range of uncertainty scenarios, thus it provides greater flexibility against uncertainties and precludes decision-makers from maladaptation or being locked in unnecessarily costly adaptations. This adaptation portfolio often comprises low- or no-regret adaptation options, and can take the form of water demand management strategy, economic instruments (water-trading, risk-sharing instruments), infrastructure modifications, technical solutions, institutional redesign, implementation of new standards, regulations, and integration of better information into decision-making. This integrated information may include: a climate-water knowledge platform on transboundary basins, improving access to updated climate information, and capacity building to enhance water managers' adaptive capacities.

Both vulnerability reduction and an adaptation portfolio constitute key aspects for assessing effective adaptive water investments under uncertainties.

1. Introduction

1.1. Climate change impacts on water

Climate change and variability are taking place at a faster rate than previously predicted. A World Bank study by the Potsdam Institute for Climate Impact Research and Climate Analytics (2012) points out that the level of warming is likely to exceed 3°C and is on course toward 4°C. The evidence of the impacts of climate change is strongest and most comprehensive for hydrological systems (IPCC, 2014).

The impacts on human well-being might differ by non-climatic stressors and adaptive capacities. These impacts will be felt by the water sector directly in water delivery services and management, and indirectly through water-sensitive sectors, such as agriculture, energy, forestry, fisheries, and mining. The impacts of a temperature increase will be distributed unequally and slant toward the world's poorest regions, which have the least economic, institutional, scientific and technical capacity to cope and adapt. The Potsdam Institute's report (2012) also suggests that the risks to human support systems in terms of food, water, ecosystems and human health, can be extremely severe particularly in northern and eastern Africa, the Middle East and South Asia. At worst, the risks include regime shift in ecological and socio-economic systems (Crépin et al. 2012, Polasky et al. 2011). Adaptive water management is crucial to mitigate and reduce the extent of these risks.

1.2. Water adaptation financing gap

Within the negotiation processes of the United Nations Framework Convention on Climate Change (UNFCCC) the adaptation agenda has gained increasing importance, from the Nairobi Work Programme in 2005 to the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts in 2013. COP20 in 2014 adopted a two-year plan of the executive committee of this Warsaw International Mechanism.

Despite this increasing recognition of the importance of adaptation and the pressing needs for unlocking investments toward adaptive water management, the IPCC report (2014) also highlights the gap between global adaptation need and the available funds. The required annual investment for water is estimated at USD 1.32 trillion under the business-as-usual scenario (Green Growth Alliance, 2013). The additional costs of adapting to an approximately 2°C warmer world by 2050 for water supply and flood protection are estimated to be in the range of USD 14.4-19.7 billion annually (World Bank, 2010).

Even without taking into account the impacts of climate change, the current investment gap is still very large. The World Bank's Global Water Practice project has a planned annual lending of only USD 4-5 billion. The pledge of global funds dedicated especially for adaptation amount to USD 2.6 billion, of which 88 per cent are already deposited, while the disbursed funds by 2014 were merely USD 496.7 million (21 per cent of deposited funds).[1] Beyond those global funds, the private sector is estimated to have spent at least USD 84 billion in the past three years to manage water scarcity risk (Clark, 2014).

1.3. Challenges in measuring adaptation effectiveness using the additionality principle

The slow uptake of adaptation investment can be partly attributed to the issue of measuring the effectiveness of adaptation finance. The additionality principle is commonly employed as an effectiveness criterion for allocating international adaptation funds. Additionality refers to the determination of whether or not an activity or project is different from a baseline or "what would have happened otherwise". In essence, the additionality principle is related to two aspects: 1) financial additionality; and (2) programme additionality.

The implementation of the additionality principle is not very straightforward and countries have varying views on the interpretation of the principle (Fallasch and De Marez, 2010, Ballesteros and Moncel, 2010). This problematic implementation is shown by the experience in allocating adaptation finance, in which the effectiveness of funded adaptation projects is often questionable. Therefore, a number of studies have proposed the use of alternative criteria and approaches that can better assess adaptation effectiveness: for example, Barr, Fankhauser, and Hamilton (2010), Fankhauser and Burton (2011), Gillenwater (2011), and Stadelmann et al. (2012).

1.4. Effective water adaptation against uncertainties through the portfolio approach

Another important dimension for assessing the effectiveness of adaptation options is its robustness against uncertainties that stem from climatic factors (the extent of temperature increase and its impacts on the availability and variability of fresh water resources) and non-climatic factors (e.g. scenarios on population growth, economic growth, changing lifestyle and their effects on water demand). Uncertainty has always been an integral part of water resources planning and management. Climate change and variability, however, has augmented the level and range of uncertainties that water resource planners and managers should take into account in their work. The extent of climate change uncertainty increases the further into the future and the more local the impact predictions are. Addressing uncertainty is especially relevant for planning water infrastructure investments that involve a medium- to long-term lifetime of even longer than 100 years.

[1] Data from www.climatefundsupdate.org/data by September 2014.

A portfolio of adaptation options, which is characterized by many policy choices rather than a single, most optimal adaptation option, takes into account a plausible range of uncertainties and the long-term impact of the changes in water resource availability, variability and use. Thus, a portfolio approach provides greater flexibility and a higher resilience against uncertainties because it does not lock adaptation strategy to a single-shot solution that might prove to be too expensive or insufficient for a different future scenario of water availability and variability. These adaptation options might include, for instance, water demand management strategy, economic instruments, infrastructure modifications, or improved decision-making processes that integrate climate information. The adaptation portfolio often comprises low- or no-regret adaptation options, which are options that are little affected or unaffected by the uncertainties of climate change scenarios.

1.5. The focus and structure of the paper

In view of the discussion above, this paper focuses on two key aspects in assessing effective water adaptation options: first, the use of vulnerability reduction as an alternative effectiveness criterion; and, second, using a portfolio approach to ensure the robustness of water adaptation options against uncertainties. The examination of the first focus is presented in Chapter 2. The chapter begins with a review of the challenges surrounding the use of the additionality principle, before looking at an alternative effectiveness criterion, which is the vulnerability reduction of the communities most affected by climate change impacts on water resources and services. The analysis is based on the identification of hotspot areas or areas where climate change impacts are most significant. These hotspot areas indicate where critical actions are required and where planned adaptation actions will have the most effect. This alternative effectiveness criterion offers a potential solution to the problematic implementation of the additionality principle for assessing water adaptation options. The paper proceeds with a discussion on approaches to define, measure and map water vulnerability in Chapter 3. Vulnerability mapping provides an insight into the most vulnerable water users and ecosystems. It enables equity issues to be tackled through an analysis of how the chosen adaptation options can improve or better equalize the distribution of climate risks across community groups.

Subsequently, Chapter 4 elaborates the rationale for using the portfolio approach, the characteristics of an adaptation portfolio, and how this portfolio can be developed. With a clearly formulated vulnerability reduction target as a goal of an adaptation portfolio, the proposed water investments can be straightforwardly assessed in terms of effectiveness and robustness. A failure to satisfy these two aspects will run the risk that water investments might not have significant effects in reducing climate risks or, even worse, they might result in maladaptation.[2] With the flexibility it brings, an adaptation portfolio ensures that the minimum intended net benefits of adaptation options will still occur in spite of the uncertainties.

The use of both vulnerability reduction as an effectiveness criterion and an adaptation portfolio approach is expected to enhance the resilience of water resource management and to encourage further uptake of the required investment funds.

[2] Maladaptation is an action or process that increases the vulnerability to climate change-related hazards.

2. Adaptation effectiveness criterion

2.1. Additionality: concept and practice

As previously mentioned, the concept of additionality can be defined in terms of: 1) financial additionality; and 2) adaptation measure additionality. The most relevant aspect for assessing the effectiveness of adaptation investment is the second one; thus more discussion will be focused on this aspect.

Financial additionality

The first aspect of the additionality principle stems historically from the view that financial resources for adaptation should be "new and additional" to those already committed for existing official development assistance (ODA). This principle is firmly supported in international climate law through several instruments, i.e. the UNFCCC (1992, Article 4.3), the Kyoto Protocol (1997, Article 11.2), the Bali Action Plan (2007, paragraph 1e), and the Copenhagen Accord (2009, paragraph 8).

In the broader context of climate finance, J. Brown, Bird, and Schalatek (2010) offer four definitions on additionality in relation to ODA and the technical as well as political implications of using each alternative definition (Table 1).

The implementation of any of the definitions crucially requires the tracking of overall ODA funds as well as specific climate-related ODA flows. In practice, current tracking of climate-related ODA flows is still rather limited. This tracking is even more challenging for the adaptation-related funds, with the exception of targeted funds, such as the Adaptation Fund.

Table 1. Four definitions of climate finance additionality

	Definition	Technical considerations	Political considerations
1	Aid that is additional to (over and above) the 0.7% ODA target	Easy to track given that it is measuring an increase at disbursement level and technically feasible but raises same questions around the validity of the ODA tracking system and what gets counted as climate finance.	Most countries have difficulty reaching the 0.7% target in the first place, so politically challenging to raise the target. Supported by international development community.
2	Increase in climate finance on 2009 ODA levels directed at climate change activities	Easy to track given that it is measuring an increase at disbursement level and technically feasible but current issues with ODA tracking. There will be no diversion from development objectives for donors who have already met their 0.7%, but may not be the case for those who have not.	Some issues with setting 2009 as financial baseline – implies different things depending on if donor has met the 0.7% target or not. Those donors who have not given to ODA-related climate finance before 2009 will have a lower baseline compared to those who have, implying equity issues.
3	Rising Official Development Assistance (ODA) which includes climate change finance but limited (e.g. to X%)	Aid diverted to climate finance causes changing the composition of finance if overall levels of ODA are not raised sufficiently. Issues around how to know what percentage is the right level – and should ideally only apply to governments who have already met their 0.7% so that the percentage of ODA spending going to climate change is above the 0.7% for development related efforts. Still need to secure additional channels of funding over and above a percentage of ODA, especially if limited to only 10% as is the case with UK proposal.	Countries which have already met their 0.7% target will not want those who have not to sacrifice this original goal for climate change objectives. It signifies a diversion in priorities. Setting the percentage in relation to ODA spending means funding is based on a country's current contributions, even if they are insufficient. Contributions are therefore not based on ability to pay, unlike one set on percentage of GNI.
4	Complete separation between ODA and CC financing	Emphasis on separation of funds at source. Need to ensure that new sources of finance are mainstreamed with existing ODA flows - technically challenging.	Would allow concerns regarding diversion of ODA funds away from development goals to be allayed. Politically challenging to agree what a new financial mechanism would look like, who should be in charge of the tracking, and how it will be tracked.

ODA, official development assistance; GNI, gross national income; CC
Source: J. Brown, Bird, and Schalatek (2010)

Separation of adaptation funds from development funds may also create barriers to efforts to integrate adaptation policies into the development agenda. An adaptation option that improves capacities of decision-makers for better planning of water risk reduction, for example, is likely to improve the resilience of development capacities and safeguard development progress against water-related hazards. Good governance and institutional capacities of public institutions are normally associated with greater adaptive capacity. A better synergy perspective should look at adaptation as development under a changing climate (Stern, 2009).

Although it is important to ensure that the flow of adaptation funds from donor countries to recipient countries will not ultimately reduce the dedicated ODA, these definitions do not address the more important issue of how to secure the necessary funds for adaptation investment through new and/or innovative ways and how to assure that the funds are allocated effectively.

Programme additionality

Regardless of which funding sources are used for adaptation actions, it is imperative that the available funds are allocated in the most cost-effective way. Considering our focus on effectiveness, the additionality principle is currently the commonly used criterion to evaluate the effectiveness of climate policies in general, including adaptation.

The second aspect of the additionality principle comes from the climate mitigation domain that requires mitigation measures to generate additional greenhouse gases emission reductions. In the context of adaptation, the additionality principle brings the implication that adaptation funds should be used to support adaptation responses that would not otherwise take place under a counterfactual baseline. This second aspect is the focus of assessing the effectiveness of adaptation programmes. There is, however, a lack of clarity in defining and measuring the counterfactual baseline, thus creating challenges on how to clearly define this principle.

This criterion has long been discussed in the context of environmental policy and its application is advocated in the context of environmental markets, such as water quality trading and payments for ecosystem services schemes for better watershed management. Unfortunately there has not been a commonly held understanding of the definition and how to best implement it. In theory, the additionality principle is used to determine whether a proposed activity will generate some "extra good" in the future relative to a reference scenario, which is designated as a baseline. The underlying idea is that the activity or proposed intervention should perform better than the baseline (Gillenwater, 2012).

To illustrate the application of the additionality principle for water management, take as an example the New York City Watershed Protection Program. As the regulator, the New York City Department of Environmental Protection aims to maintain and protect the high-quality source of drinking water at the upstream by, among other things, providing co-funding for farm infrastructure improvements that will result in lower nutrient pollution discharge to the river. If a farmer's decision to improve farm infrastructure will happen only if the farmer receives co-funding, then the policy intervention meets the additionality criterion. If the farmer would have invested in the infrastructure improvement anyway, then the intervention fails the additionality criterion.

The use of the additionality principle for environmental policy is considered important for three main reasons (Bennett 2010). First, it ensures that the proposed policy can achieve its targeted environmental outcome. Second, additionality avoids redundancy of policy intervention and thus wasting of financial resources. Third, the principle boosts investors' confidence as it guarantees that their investments will alter business-as-usual. Nevertheless, the experience from the implementation of the additionality principle as an evaluation criterion for Clean Development Mechanism (CDM) projects[3] has shown that the corroboration of the principle entails a very complicated and lengthy validation process, which compromises the efficiency of the project as a policy intervention (Lövbrand, Rindefjäll, and Nordqvist, 2009, Olsen, 2007).

The implementation of the additionality criterion for adaptation policy is clearly stated for the Adaptation Fund. The Fund was established to expedite climate-proof measures in the most vulnerable countries and it is one of the very few funding instruments specifically earmarked for adaptation. The Fund was deemed innovative in terms of: 1) providing direct access for developing countries to the resources of the Fund, through the nomination of National Implementing Entities or Multilateral Implementing Entities; 2) its innovative source of funding, including that from the Certified Emission Reduction (CER) Monetization Program[4] ; and 3) its governance structure, particularly its board composition with mostly developing country members.[5]

Considering the huge gap between the need for adaptation funding and the available funds, there is fairly intense competition for eligible countries in acquiring those funds. Nevertheless, the effectiveness of the funds to achieve their intended purpose is still questionable (see Box 1).

The data on fund allocation across countries and the study by Barr, Fankhauser, and Hamilton (2010) show that not all the projects took place in countries considered to be the most vulnerable by various measures. This fact highlights the urgent need for a clearer and standardized definition and methodology to assess vulnerability and project effectiveness.

Gillenwater (2012) reviews a number of reasons why the implementation of additionality is challenging. First, it requires

[3] CDM is one of the three market-based mechanisms of climate change mitigation measures within the Kyoto Protocol under the UNFCCC. It is a project-based carbon market in which emission reductions generated by CDM projects in non-Annex I Party (developing countries) can be used to offset emissions of Annex I Party (developed countries) of the Kyoto Protocol.

[4] CER is a carbon credit generated by a CDM project. Through the CER Monetization Program, carbon credits can be transferred into cash to be used as a funding source for Adaptation Fund.

[5] Adaptation Fund, "Accessing Resources from the Adaptation Fund: The Handbook", www.preventionweb.net/files/13786_Handbook.English1.pdf

Box 1. The additionality of projects under the Adaptation Fund

The Adaptation Fund is a financial instrument that was created by the UNFCCC through a series of decisions of the Conference of Parties. Although the operational mechanism was decided in 2007, funded projects were first approved in 2009.

To be eligible for the Fund, countries must be "developing country Parties to the Kyoto Protocol that are particularly vulnerable to the adverse effect of climate change". The term "particularly vulnerable" is not clearly defined by the UNFCCC and this ambiguity poses challenges in distributing the scarce resources in a reasonable, fair and transparent manner (Remling, Persson, and Davis, 2012).

Project approval and allocation of resources to the proposed adaptation projects must satisfy strategic priorities, policies and guidelines. These include: consistency with sustainable development strategies, cost-effectiveness, vulnerability level, urgency level and risk from delay; ensuring access to the fund in a balanced and equitable manner; capturing lessons learned in project design and implementation; securing regional co-benefits; maximizing multi-sectoral or cross-sectoral benefits; and adaptive capacity.

The effectiveness of funded projects is evaluated on the basis of the additional resilience resulting from the project. The lack of uniformity in defining additionality compared with project baseline gives rise to difficulties in assessing the effectiveness of the projects (Fukuda, Wakiyama, and Shimizu, 2011).

If vulnerability is defined to be proportional to the country's income level, the data (by September 2014) shows that 35 country projects have been approved with a total funding of USD 232 million and USD 96 million (45 per cent) disbursement.[6]. Out of 35 projects: 13 projects are located in countries categorized by the World Bank in 2014 as upper-medium income, or even high income; 17 projects are in lower-middle income countries; and only five projects are in low income countries. Considering countries' overall vulnerability to climate change according to a study by Barr, Fankhauser, and Hamilton (2010), 16 projects (46 per cent) are located in countries that face high climate change impacts (category I and II), while the rest are located in countries with low climate change impacts (category III and IV).

a comparison to an unobserved baseline, i.e. a scenario under identical circumstances except for the absence of the policy intervention. Second, it involves a situation of asymmetric information and misaligned incentives. Since the regulator or funding institution does not have the full information regarding the true baseline, there is an incentive for the parties that seek funding to provide biased information in order to receive more funds. For example, if the government does not know the exact current nutrient pollution level from each farm at the upstream and that baseline is the basis for paying compensation to farmers, there is a perverse incentive for the farmers to exaggerate their pollution level in order to get more compensation from the government to reduce their pollution level. Third, there are multiple factors that influence behaviour so that the baseline might have changed anyway in the future from the current assumptions underlying the business-as-usual scenario. All these result in a high degree of subjectivity in defining the baseline and render it very challenging in validating additionality. These challenges in the implementation of additionality have brought about discussion on alternative ways for assessing adaptation effectiveness.

2.2. Vulnerability reduction as an effectiveness criterion

The importance of the effectiveness criterion to assess investments in water adaptation is based on two underlying concerns: 1) assuring that the proposed programme or projects constitute successful or "good" adaptation; and 2) the challenge of allocating limited funds for adaptation to priority programmes or projects. This section discusses how vulnerability reduction can potentially address both concerns.

As in other policy interventions, the issue of governance is crucial for a successful adaptation. Effectiveness is one of the basic evaluation criteria for successful adaptation, similar to those for policy evaluation, i.e. efficiency, effectiveness, equity and legitimacy. The difference between policy evaluation in general and water adaptation in particular is that water adaptation is very much local and context specific. In cases where it is more challenging to conduct efficiency assessments because there is little information from which to obtain estimations on the net benefit of adaptation, cost-effectiveness analysis can be performed to derive efficiency. Neil Adger, Arnell, and Tompkins (2005) underscore that equity of adaptation outcome and the legitimacy of the decision-making process regarding adaptation are central to the concept of resilience. Water adaptation that implies inequitable development will undermine the potential welfare gain in the future. If it lacks legitimacy, then it will have less chance of full implementation.

The basic concept of effectiveness asserts how an activity meets its predetermined objective. Effective water adaptation can be evaluated on how the proposed investment can achieve its objectives: for example by looking at how it reduces impacts

[6] Data from www.adaptation-fund.org/funded_projects/interactive

and exposure, or reduces risk of water-related disasters, or promotes water security. Adaptation effectiveness can sometimes be evaluated in a more straightforward manner: for example, to what extents the investments in rainwater-harvesting infrastructure can reduce the vulnerability of water users to projected scenarios of water scarcity. Often, the effectiveness is more elusive to assess as it depends on the sequence and interaction of many factors affecting adaptation; thus the causal relationship on vulnerability reduction is also more complex (Neil Adger, Arnell, and Tompkins, 2005).

A greater emphasis on one or two evaluation criteria might influence other criteria positively or negatively. For example, Stadelmann et al. (2012) review a trade-off or synergy between equity and cost-effectiveness criteria of approved projects under the Adaptation Fund, depending on the chosen indicators for those criteria. A greater emphasis on effectiveness might also come at the expense of efficiency. This is very much the case for flood protection infrastructure. A flood defence structure to anticipate a 100-year return period flood provides protection against future climate change and variability, but the level of protection will vary over time when there is substantial change in future flood risk. However, with very limited resources, constructing this flood defence structure at present might neither be very efficient nor constitute the most optimal adaptation option.

Making vulnerability reduction an effectiveness criterion actually ensures the synergy between effectiveness and equity, when vulnerability reduction puts the priority on improving the conditions of those community groups and ecosystems at highest risk, or the hotspots. This means that identification of hotspots also becomes the basis for allocating funds for adaptation investments. For local or national level decision-makers, this identification requires measuring and mapping of vulnerability before and after the proposed water adaptation options.

It is important to be aware that climate change adaptation is a more complex issue than a typical resource allocation problem for several reasons (Fankhauser and Burton, 2011, Ranger et al. 2010). First, there are intricate links between adaptation and other socio-economic trends, such as economic growth and development. For instance, it is often difficult to differentiate between water adaptation to climate change and to non-climatic stressors. Second, the complexity of adaptation decisions due to the need to harmonize adaptation across spatial and temporal scales. Third, there is high uncertainty regarding local climate outcomes; thus the final impact on affected ecosystems and water users is also highly uncertain.

The implication of the above reasons for vulnerability measurement is the complexity of formulating a vulnerability index. Contrary to additionality, vulnerability measurement and mapping is much less subjective. Nevertheless, the selection of indicators and the aggregation techniques may substantially affect the magnitude of the index. Therefore, there should be both solid reasoning and practical considerations, especially regarding data availability, in measuring the vulnerability index. There is also, interestingly, a close relationship between adaptation and development. Adaptation to climate conditions is in fact one of the oldest challenges of mankind (Fankhauser and Burton, 2011). Cases of maladaptation can be found in many instances, but it is the lack of adaptation or "adaptation deficit", which is often linked to under-development (Burton, 2009). Together, development and adaptation measures would produce vulnerability reduction against climate change.

For the purpose of allocating adaptation funds across countries, there needs to be a simpler and more generic approach to vulnerability measurement in order to facilitate a more practical comparison of vulnerability across countries. This can be done, for example, by using relevant existing indices that contribute to water vulnerability, or creating a more standardized, sector-specific water vulnerability index (WVI). A more elaborate discussion on the measurement and mapping of water vulnerability reduction is presented in the following chapter.

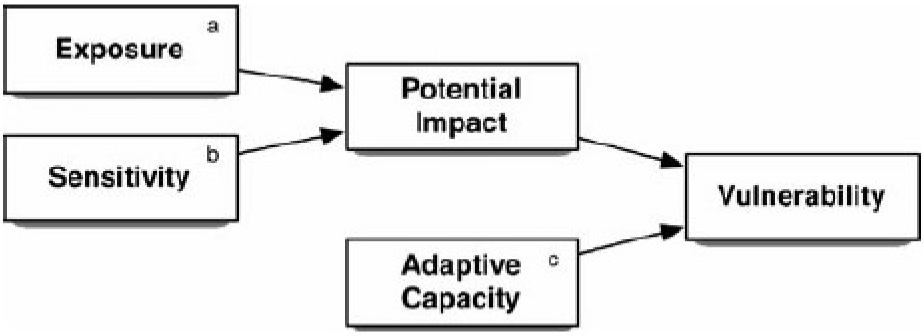
3. Measuring water vulnerability reduction

3.1 Vulnerability concept

The measurement of water vulnerability follows the more general concept of vulnerability to climate change formulated by the IPCC. The Fourth Assessment Report (AR4) of IPCC (2007) defines vulnerability as:

"the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity"

Vulnerability is determined by three components: a system's exposure to current and future climate impacts; its sensitivity to climate hazards in terms of both natural and socio-economic aspects; and its adaptive capacities. Box 2 and Figure 1 explore the definition of the vulnerability concept and its relation to the risk management concept in AR5. This definition is also employed in measuring the vulnerability of a basin or region.



Source: Barr, Fankhauser, and Hamilton (2010)
Figure 1. Vulnerability to climate change and its components

Box 2. Vulnerability and risk

Exposure: climatic stimuli impacting a system that represent the character, magnitude and rate of change and variation in the climate, the background climate conditions within a system and any changes in those conditions. Examples of typical exposures: temperature, precipitation, evapotranspiration, water balance, extreme events such as heavy rain and drought (Fritzsche et al. 2014).

Sensitivity: the responsiveness of a system to climate influences or the degree to which outputs change in response to changes in climatic inputs. For instance: reliance on climate-sensitive economic sectors such as agricultural or fisheries, a highly sensitive mangrove ecosystem with high biodiversity, or high population density.

Together, exposure and sensitivity result in potential impact. As an example: heavy rain on the upper part of a watershed with soil susceptible to erosion will result in high potential impact of erosion.

Adaptive capacity: the ability of a system to transform itself, in order to be better equipped to deal with the new external stimuli. For instance: knowledge, data, institutions, finance, governance. The latest IPCC report (2014) has added a further focus on risk as climate change poses significant risks for human and natural systems (see Figure 2). The new focus on risk stems from aligning the climate vulnerability concept to disaster risk reduction. Nevertheless the underlying logic is still the same, in which climatic stressors affect a particular system of interest, e.g. a farm within a basin, and produce potential harms, i.e. the "vulnerability" term in AR4, or impacts/risk in AR5 (see Figure 3). The concept of vulnerability or climate risk is also multidimensional as it entails physical and socio-economic processes.

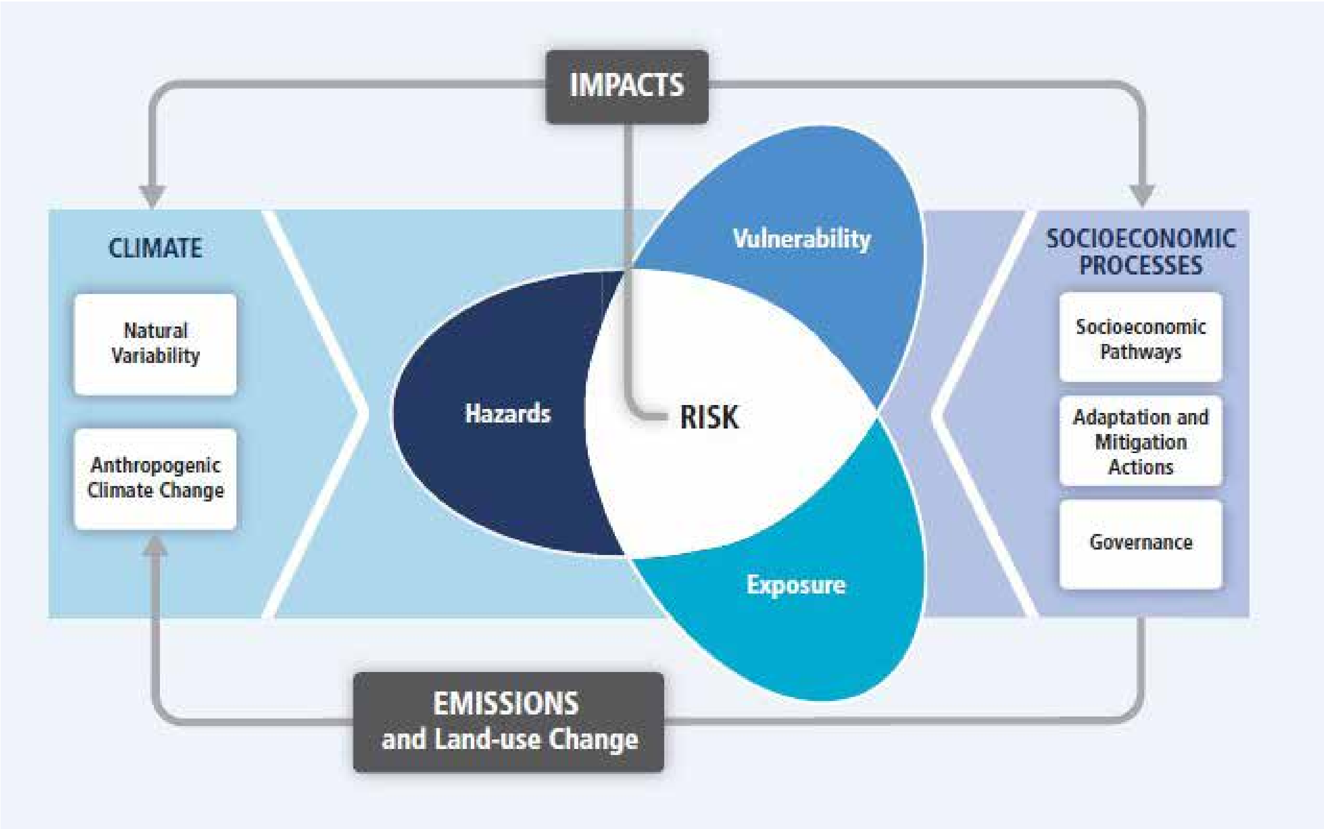


Figure 2. Risk of climate change impacts
Source: IPCC (2014)

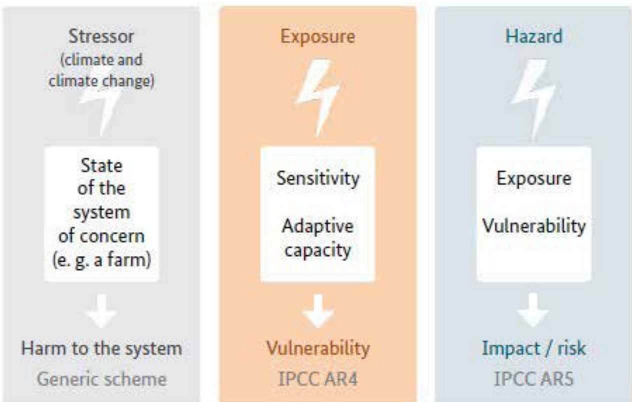


Figure 3. General logic of vulnerability and risk assessment
Source: Fritzsche et al. (2014)

In the context of water resource management, the assessment of vulnerability can be viewed through a biophysical and socio-economic lens because each basin supports economic, social and ecological systems that may be vulnerable to various water-related risks and damages, such as waterborne diseases, droughts and flooding. Biophysical vulnerability has its root in the field of natural hazards and focuses on the concept of risk (Ragab 2002, Guldmann 2004), which defines vulnerability as the potential damage caused to a system by a climate event or hazard (Freeman 2001). Considering the interface between the socio-economic and the biophysical, vulnerability assessments are increasingly conducted with the focus on social vulnerability (Bagis 1997, Gleick 1993, Lupu 2002).

3.2 Water vulnerability mapping

The impacts of climate change on water availability and variability are distributed differently across time and geographical scope as well as water users. Vulnerability mapping translates this distribution of impacts into identification of hotspot areas where priority adaptation investments are urgently required. For instance, insights into significant local adverse impacts on specific sectors (e.g. sanitation and public health), economic structures (small- or large-scale agriculture) or community groups (the rural poor, women) can be better understood once vulnerability mapping is conducted.

By conducting vulnerability mapping, the baseline of how different groups of communities and economic sectors are affected by existing water variability is measured and potential future impacts of proposed adaptation investments can be assessed. An understanding of the socio-economic interdependencies among networks of water use, users and services will help foresee and limit future water crises.

The mapping is facilitated through the use of a composite index, the WVI, which represents water vulnerability across the relevant scale, for example in terms of spatial unit, water use sectors or community groups. The main challenge of constructing this index lies in obtaining the necessary information at the required scale. Selection and collation of information for this purpose should be directed toward readily available data that is most relevant to assess the specific circumstances of water adaptation.

3.3 Water vulnerability index

The concept of vulnerability raises important equity and distributional questions because the final impacts of climate change will vary across community groups and some groups will experience more severe damages. Climate change impacts often hit the most vulnerable groups in the community (the poor, women, indigenous people and the elderly) the hardest, and thus the impacts can exacerbate existing equity issues. The equity dimensions can be accounted for, inter alia, through appropriate weighting in a composite index. The development of an index aims to bridge and incorporate both biophysical and socio-economic vulnerability that responds to the location-specific vulnerability.

To construct a WVI, we combine the IPCC AR4 definition and hazard risk reduction approach to derive the theoretical components constituting the WVI. The WVI consists of three main components: 1) the predicted climate impacts or exposure, Ec; 2) sensitivity of the system (water users, sectors, ecosystems), Sc; and 3) adaptive capacities, Ac. Each of the components will be determined by selected indicators and the value will be normalized.

The chosen method to aggregate index components is crucial as it has significant implications for the magnitude of the composite index and the sensitivity of the composite index to changes in indicator values. We follow the same method as the UNDP approach in aggregating the Human Development Index (HDI) dimensions: health, education and income. At the beginning, HDI aggregated its dimensions using an arithmetic method. Despite its simplicity, arithmetic aggregation of index components has several shortcomings. Therefore, the recent HDI uses the geometric average as the aggregation method.

The use of a geometric average as an aggregation method for WVI has three implications. First, it treats each component as equally important and there is no perfect substitutability among vulnerability components. The latter means that a low biophysical vulnerability, for example, cannot perfectly compensate for a high vulnerability in other aspects (social, economic and institutional). Second, the resulting index is less sensitive to the choice of normalization method. Third, the weight of each vulnerability component needs not be determined as this can be difficult to decide. For further discussion on aggregation methods and their implications for the substitutability of index components, some studies exemplify the approach taken for the HDI (Nathan, Mishra, and Reddy, 2008, Klugman, Rodríguez, and Choi 2011, Palazzi and Lauri, 1998).

As presented in the following equation, WVI is a normalized composite index of its water vulnerability components, Vc. Vulnerability components should include most relevant indicators representing biophysical, socio-economic and institutional aspects. Since each of these variables is a normalized variable, the variability component is also a normalized variable.

$$WVI = \sqrt{(Vc=1 * Vc=2 * \ldots * Vc=n)} \quad \text{where } Vc = Ec * Sc - Ac$$

The degree of biophysical exposure (Ec) and the system's sensitivity (Sc) to water variability can be measured using the results from regional climate model (RCM) and hydrological data. The relevant social, economic and social aspects of WVI can be constructed by selecting a number of existing and most relevant indicators or proxy variables. It might be the case that there are already existing indices that estimate potential impacts as results of exposure and sensitivity. Then it will be better to use and integrate these existing indices into WVI rather than self-estimating the relevant vulnerability component.

As an example, a manager of a water utility needs to assess a portfolio of adaptation options to ensure water delivery services for an urban coastal municipality in the next 30 years. In this case, the manager should take into account all relevant water vulnerability components that might include the impacts of drought risk on water supply security, the effect of temperature rise on future water demand, and the resilience of water treatment facilities and distribution systems against sea level rise. The selection of relevant indicators to construct WVI is very context specific with an emphasis on practical consideration. The following section provides an illustration of the range of indicators that decision-makers can use to measure water vulnerability. These indicators and proxy variables will be suitable to assess water adaptation options at a local scale.

For global or cross-country comparison, an example of a simpler approach though not specific for water adaptation is given by Barr, Fankhauser, and Hamilton (2010). They propose that adaptation funds should be allocated using three criteria at country level: climate change impacts for sectors (agriculture, disaster, health, and coastal zones), adaptive capacities (five indicators including governance indicator and Gini coefficient), and implementation capacity using "Country Performance and Institutional Assessments". Füssel (2010) takes a slightly different approach by suggesting generic indices of vulnerability assessment that are sector specific or hazard specific. In this case, he looks at water, food, health and coastal ecosystems.

3.4 Vulnerability indicators

Choosing indicators for vulnerability constitutes an important step towards assessing candidate adaptation investment options. This information will give an input into how alternative adaptation measures could be designed to address the vulnerability hotspots. The biophysical indicators may be obtained from the RCM and hydrological models. On the other hand, the social, economic and institutional measurements of adaptive capacities might cover a much wider range of indicators, which tend to vary more at the local level.

Table 2. Illustrative indicators for water vulnerability

Vulnerability element	Indicators	Proxy variables
Exposure	Drought risk	Surface water supply index (SWSI), Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), expected range of annual precipitation rate below a minimum threshold
	Flood risk	Flood speed and volume
	Typhoon	Incidence and degree of typhoons
	Sea level rise	Mean wave height, mean tide range, shoreline change
Sensitivity	Ecological sensitivity	Geographical type, population density, number of the poor living in hazard-prone areas, current land productivity, current watershed quality
	Current water shortage and scarcity level	Per capita water availability, groundwater replenishment rate, current supply-demand gap across groups of water users
	Current water variability	Difference in minimum and maximum precipitation rate across time and spatial scale
	Economic sensitivity to water variability	Economic sectors that are highly sensitive to climate exposure (primary sectors), contribution of those sectors to GDP, level of subsidies to water-related goods and services
	Current demographic vulnerability	Numbers and characteristics of the demography, numbers of stakeholders in the poverty level, percentage of households with seasonal jobs, number of households working in primary sectors, social and cultural values of water
	Predicted health impacts	Increase in vector-borne areas
	Predicted increased water demand due to warmer climate	Population growth, economic growth, consumptive lifestyle
	Predicted impacts on watershed quality deterioration	Deforestation rate, water pollution rate, land use change
Adaptive capacities	Technological level	Range of climate smart technological options, potential for technological advances (R&D capacity)
	Climate smart investments	Planned and proposed investments to address water variability by water use, users and services
	Decision-making process	Capability to manage differences in views and interpretation of information, credibility of decision-makers, transparency, stakeholder engagement in decision-making, institutional accountability
	Stock of human capital	Education level, numbers of professionals in relevant water and vulnerable sectors, educational expenditure
	Stock of social capital	Property rights, social cohesion, level of freedom of expression, number and power of community service organizations and pressure groups
	Financial resources	Available resources for water resource management and the distribution across user groups, access to international bond markets, the extend of trade barriers that restrict access to international funds
	Risk-sharing instruments	The availability of risk-pooling and risk-sharing instruments, effectiveness of the instruments
	Legal framework	The existence of legal instruments to support changes to more adaptive development process

Source: Own analysis, developed from Snover et al. (2007), Bagis (1997), (Kibaroglu (2007), Zubair et al. (2005), Bjarnadottir, Li, and Stewart (2011), Sullivan and Meigh (2005), Berkhoff (2008), Hahn, Riederer, and Foster (2009), Pandey and Jha (2011), Sowers, Vengosh, and Weinthal (2011)) and inputs on some variables from John Joyce.

Snover et al. (2007) provides a checklist of how to assess information regarding adaptive capacity. There are a number of approaches to derive indicators for adaptive capacities,; these includeamong others are the social vulnerability index to environmental hazards such as flood, drought and hurricane (Bagis 1997, Kibaroglu, 2007, Zubair et al. 2005, Bjarnadottir, Li, and Stewart 2011), assessing local climate vulnerability through the water poverty index (Sullivan and Meigh, 2005), groundwater vulnerability (Berkhoff, 2008), a pragmatic vulnerability for rural areas regarding water scarcity (Hahn, Riederer, and Foster 2009, Pandey and Jha, 2011). Institutional and political adaptive capacities also constitute an important part, especially in transboundary water basin management (Sowers, Vengosh, and Weinthal, 2011). These indicators usually include variables that denote water resource availability, access to water, effectiveness of water management capacities, ecological integrity, and other relevant social and economic indicators.

The objective is to design a composite index of water vulnerability that builds on an integrated adaptation assessment at the appropriate scale. Presently there is still limited work on developing a composite index that reflects the vulnerability of water use, users and services with in an integrated perspective at the micro and macro socio-economic scales.

Table 2 presents illustrative indicators and proxies to assess water vulnerability that span from the micro to macro levels of socio-economic data. Each local or basin context might takes on various approaches in determining which indicators will suit best the local needs, contexts, and data. The approraches might take advantage of statistical techniques, factor analysis and expert judgement to result in a list of indicators that best suit a particular basin. The results of the vulnerability index can then be mapped to gain visual information about the locus of vulnerability. Stakeholder engagement will also create learning for relevant decision- makers which can enhance their future adaptive capacities (Malone and Engle, 2011). The engagement of those stakeholders can boost legitimacy to of the whole adaptation process that in turn will affect the effectiveness of adaptation investments.

4. Portfolio approach to address uncertainty in adaptation investment

4.1. Why the portfolio approach?

A central issue in adaptation investment planning is the treatment of multiple layers of uncertainties that shape the choice of adaptation strategies. Uncertainty is a multidimensional concept. There are many types of uncertainty: ontological, epistemic, ambiguity, unpredictability, insufficient knowledge and multiple knowledge frames (i.e. different ways of understanding the system), natural, social or technical (Brugnach et al. 2008). Some uncertainties are reducible while others are not. They are relevant to formulating strategies as they can distort decision-making in numerous ways.

Distortions in investment planning from uncertainties can lead to under- or over-estimation of the required investment. They can cause too costly and unnecessary measures or insufficient levels of investments, which can threaten past investments and future progress. In the presence of uncertainty regarding climate change impacts and the baseline (business as usual) information, investment decisions need to be sufficiently flexible to cope with gradually occurring as well as extreme climate-related hazards, while being cost-effective in view of resource scarcity (Dang, Michaelowa, and Tuan, 2003, Keskitalo 2009, Klein, Schipper, and Dessai, 2003, Callaway, 2003). Making unnecessary investments that might impose irreversible consequences, which render it difficult to cope with future climate, can result in maladaptation (Ranger and Garbett-Shiels, 2011, Hallegatte, Lecocq, and de Perthuis, 2011).

Water investments involve long-term horizons in which uncertainty will have more pronounced impacts than shorter-term investments. Flexibility in the water investment planning process avoids locking investments with large redundancies to cope with extreme events, while assuring that there are available measures to meet safety margins in case of extreme events (Lempert and Groves, 2010, Hallegatte, 2009). Planning for adaptive water management dynamically should not be framed as a one-off assessment of adaptation options (Catenacci and Giupponi, 2010). Instead, it should be viewed as a continuous adaptive process that takes into account the arrival of new and updated information as well as learning from previous decisions. Therefore, flexibility and adaptive processes should play a significant role in long-term adaptation investment decisions. The portfolio approach can provide a high degree of flexibility by developing an adaptation investment strategy that can cope with a wide range of climate change and variability scenarios (Cromwell III, Smith, and Raucher, 2007). A portfolio approach is characterized by many adaptation options (measures and instruments) across different sectors and vulnerable water user groups.

The portfolio approach underscores the importance of building a number of adaptation measures that will work within a broader range of risks rather than relying upon a single adaptation measure as a bulletproof solution. Therefore, a portfolio approach should constitute the basis of water adaptation planning (Brown et al. 2010, Groves, Yates, and Tebaldi, 2008, Waage and Kaatz, 2011).

This approach helps decision-makers to avoid maladaptation in the presence of irreversible investment decisions and irreversible impacts of the chosen adaptation portfolio. At the same time, it allows them to take advantage of the arrival of new information that can encourage them to make water investments at the right time. When decision-makers identify the need to upgrade the current water resource management system to respond to climate change, this might imply two different kinds of investments (Kibaroğlu, 2006). First, investments in highly capitalized projects with irreversible implications, such as multipurpose hydraulic infrastructure, interbasin water transfer schemes or construction of water delivery systems for agricultural purposes. Second, investments in system improvement that is relatively resilient against hydrologic variability and climate change impacts. Assessment of the need for system upgrade should differentiate those two investments and formulate which investment would make for more robust water resource management.

4.2. Characteristics of the portfolio approach

The adaptation portfolio can encompass both supply-side and demand-side management options as the impacts of climate change will significantly affect both elements of water resource management. These options include the use of economic instruments, such as water-trading, risk-pooling and risk-sharing instruments; infrastructure modifications; technical solutions and institutional redesign; implementation of new standards; regulations; and integration of better information into decision-making. This integrated information may include: a climate-water knowledge platform on transboundary basins, improving access to updated climate information, and capacity building to enhance water managers' adaptive capacities. Exploration of possible adaptation portfolios can be performed using various analytical techniques, literature review and expert judgement, as well as stakeholder consultation.

The portfolio can involve adaptation options that are most relevant at different spatial scales and across different timeframes. It is built by looking at a number of the plausible variety of tipping points, which could easily exist (Yohe, 2009) and are "intolerable" (Tol and Yohe, 2007). In many cases, the portfolio also includes no-regret or low-regret adaptation options. No-regret adaptation options are those that are not affected by climate uncertainties, while low-regret options are those that are little affected by climate uncertainties.

All no-regret measures are the low-hanging fruits that will increase the resilience of the water resource system regardless of climate change. Likewise, measures that reduce the level of uncertainty or vulnerability should also be encouraged

(Figure 4). Spatially appropriate and managed demand-side measures that improve water-use efficiency and productivity are considered as no-regret measures, which are likely to give more control and flexibility to water management. Measures that reduce the level of uncertainty or vulnerability should also be encouraged, such as improved access to updated climate information; market-based instruments to enhance water-use efficiency; and capacity building for adaptive water management.

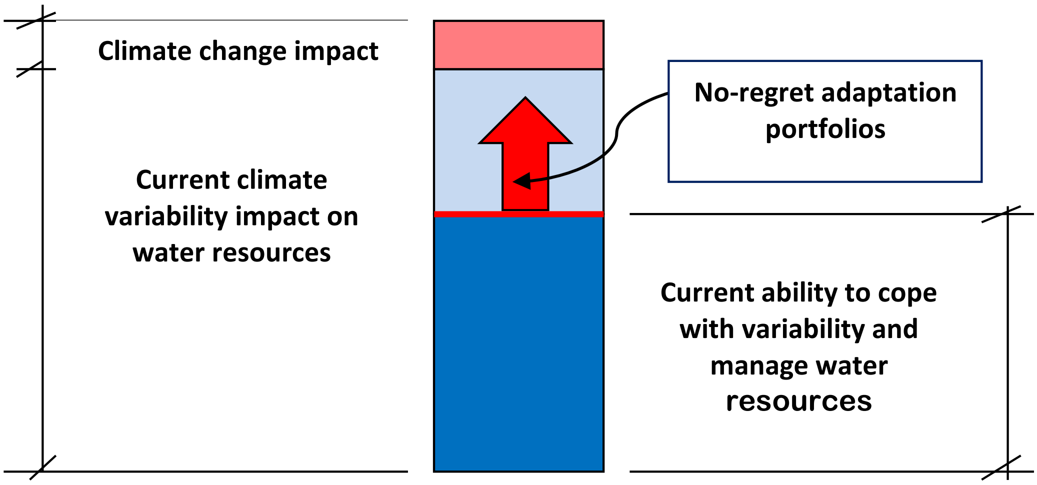


Figure 4. Effectiveness of no-regret adaptation portfolios
Source: Harlin (2010)

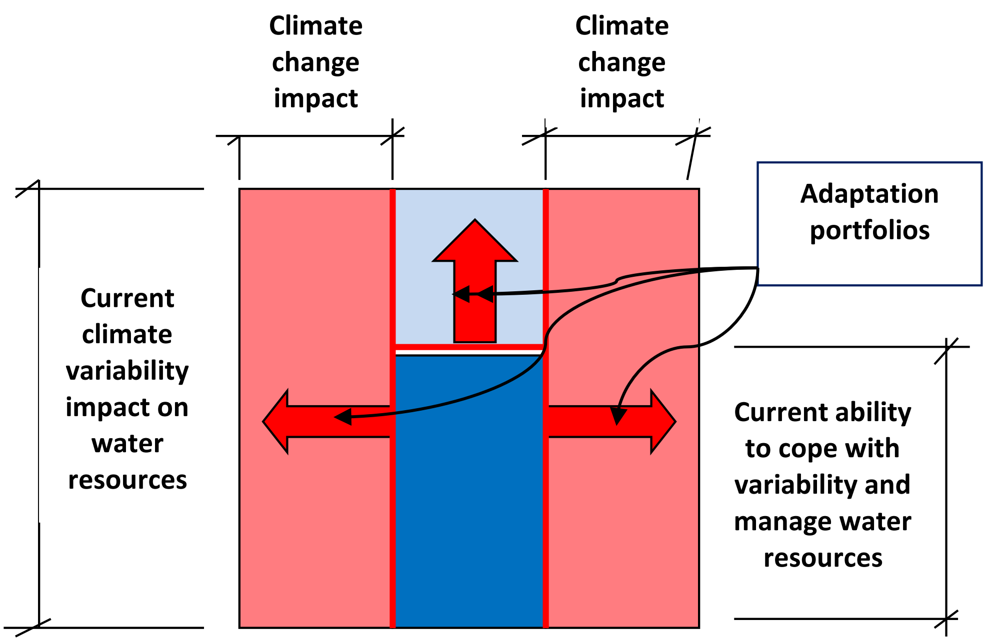


Figure 5. Effectiveness of adaptation portfolios with paradigm shift
Source: Harlin (2010)

No-regret adaptation portfolios might not be sufficient in cases where the risks pertaining to the extreme end of plausible climate change impacts have the potential to bring about significant systemic step changes, such as forced migration and death resulting from threatened food security. This requires a paradigm shift and step change in the approach to water management and development pathways (Figure 5). In these cases, the critical adaptation investment is very likely to be different from the existing support and financial resources provided to the current system.

Ranger et al. (2010) summarize four types of no-regret adaptation measures:

a. options to manage current climate variability, e.g. risk information and monitoring, research, and insurance system;
b. options to manage non-climatic drivers of risks, e.g. reducing leakage in distribution system, water quality management, enhanced planning and building regulation controls;
c. relatively short-lived options compared to the time horizon of climate change, e.g. changing crop varieties in agriculture;
d. broader measures aimed at reducing vulnerability and building resilience to shocks and general stresses, such as early warning systems and emergency response for flooding, building water transfer networks between regions, capacity building (skills, knowledge and information).

Implementation of some options will differ based on the level of climate risk and the relative costs and benefits of each adaptation option. This portfolio approach allows for sequential decision-making processes in which several measures or instruments can be implemented following one another as new information becomes available or the level of uncertainties is reduced.

4.3. Developing an adaptation portfolio

Considering that adaptation is a long-term process and the timing to undertake appropriate adaptation options affects the stream of adaptation benefits, the following approaches are suggested as a basis on which to develop adaptation portfolios (Hallegatte, 2009, Kibaroğlu, 2006, Fankhauser and Burton, 2011):

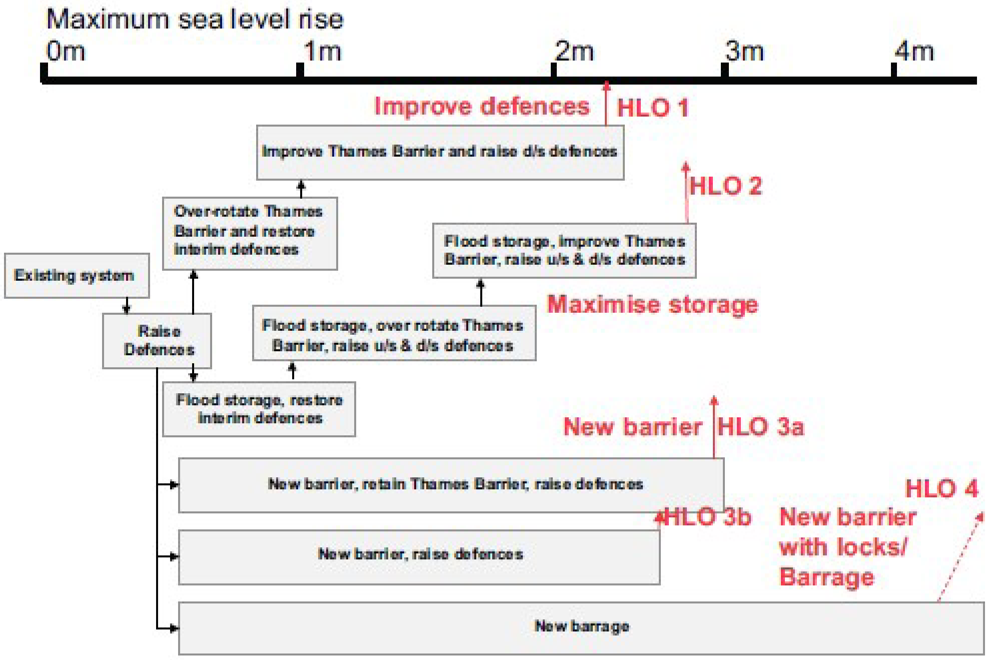
a. choosing no-regret portfolios that yield benefits even in the absence of climate change over "climate justified" portfolios that are only justifiable provided the predicted climate variability takes place;
b. prioritize measures that help prevent costly retrofits in the future;
c. give precedence to measures with long lead time thus requiring an early start, such as research into resilient crops;
d. favour reversible and flexible options;
e. buying "safety margins" in new investments;
f. promoting soft adaptation strategies, such as including long-term perspective;
g. prevent irreversible loss, for instance through protection of fragile ecosystems;
h. reducing decision time horizons.

To synergize adaptation and development measures for vulnerability reduction, McGray et al. (2007) identify the need to develop four categories of measures:

a. measures that address the broader scope of stress (whether climate-related or not), such as health, sanitation and poverty eradication;
b. creation of "response capacity", such as resource management practices, planning systems and effective public institutions;
c. the management of current climate risks, including flood and drought prevention, and disaster risk reduction and management;
d. policies specifically addressing anthropogenic climate change, such as accelerated sea level rise and an increased incidence of extreme weather events.

The most robust adaptation portfolio can be obtained by putting together a mix of individually robust adaptation options or by selecting the most robust portfolio among a number of adaptation portfolios. The use of rigorous decision methods to select robust adaptation options within a portfolio can be crucial, especially when the stakes are high and no-regret options are limited (Ranger et al. 2010, Fankhauser et al. 2013). Since climate change adaptation is often characterized by deep uncertainty, robust decision-making has been recommended as the appropriate method to select adaptation options (Lempert et al. 2006, Dessai and Hulme, 2007, AMCOW, 2012).

Robust decision-making evaluates the performance of each adaptation option or adaptation portfolio under a wide range of scenarios. Thus, it ensures that adaptation portfolios are effective to meet management objectives and to reduce vulnerability against a large ensemble of scenarios (no-regret and paradigm shifts). The robustness of adaptation portfolios can be judged against a number of performance indicators that reflect management objectives, critical indicators that represent reduced vulnerability, as well as other relevant criteria that indicate how well the water management functions against the ensemble of scenarios. Sensitivity analysis can further be conducted to investigate the effects of uncertainties in some variables on the performance of adaptation portfolios. Robust policies are those whose favourable performance is relatively insensitive to the key uncertainties and different preferences held by decision-makers. An example of the application of the portfolio approach is the UK Thames Estuary 2100 project (Ranger et al. 2010). The objective of the project was to provide a plan to manage flood risk in London and the Thames Estuary over the next 100 years to cope with a wide range of possible future sea level rise. The existing flood defence system was designed to last until 2030. The project aimed to examine whether and when the current flood defence system might need to be modified and provide a forward plan to 2100. The required adaptation portfolio needed to anticipate both climatic and development stressors. The project used a real options approach as a decision method to examine the benefits of incorporating flexibility into a long-lived and irreversible infrastructure project.



HLO, high-level option
Figure 6. High level adaptation options and pathways for the Thames Estuary 2100 project
Source: Haigh and Fisher (2010)

The analyses demonstrated that no-regret measures, such as extending the lifetime of existing flood management infrastructure, can effectively buy some time before investing in irreversible decisions, such as a new and expensive barrier. The adaptation portfolio identifies possible "high-level options" (indicated in Figure 6 by red lines) to illustrate the adaptation pathway to follow in response to different thresholds of sea level rise. The example shows the benefits of systematically taking into account several adaptation options to respond to a range of possibilities of climatic and non-climatic risks. The approach provides flexibility to avoid locking in costly adaptation measures, especially in the case of long-lived infrastructure.

5. Conclusions

The use of the additionality principle as the most commonly employed criterion for adaptation effectiveness is based on solid reasoning. Nevertheless, the difficulty in reaching a common understanding on additionality, the baseline and validation methods to assess the additionality of an adaptation programme/project poses a serious implementation problem. Continued use of the principle requires a much clearer definition and more systematic framework and methods in implementation.

Departing from that implementation problem, the paper discusses water vulnerability reduction as an alternative criterion for assessing water adaptation effectiveness. Even though conceptually vulnerability reduction has always been the objective of adaptation and theoretically there exists an extensive literature on approaches for measuring and mapping vulnerability, the assessment of water adaptation investment in practice rarely uses this criterion. The use of vulnerability reduction does not necessarily refute the value of the additionality principle. On the other hand, the vulnerability reduction criterion can better clarify how the

The challenge is to encourage the use of vulnerability reduction and its measurement approach as the basis to assess water adaptation investment options. Vulnerability measurement is important not only for the purpose of resource allocation and prioritizing optimal water adaptation options but also as a means to monitor the resilience of water users and systems against climatic and non-climatic stressors over time.

The WVI can capture the multidimensional issues of vulnerability and integrate biophysical, social, economic and institutional factors. The result of this index measurement informs decision-makers on the interrelationships among the vulnerability components and pinpoints which components require further improvement. Vulnerability mapping further indicates the location of hotspot areas and highlights where critical adaptation investments are required to reduce the vulnerability of those areas. In this light, vulnerability reduction can also create synergies between effectiveness and equity criteria as it facilitates better distribution of climate risks across water users and geographical areas.

An effective adaptation action is also characterized by resilience against climatic and non-climatic uncertainties, which are more of an issue for adaptation than for mitigation, especially for water adaptation that involves long-lived investments. Adaptive water management should adopt a portfolio approach, which encompasses several adaptation options that perform well under a wide range of plausible scenarios. This adaptation portfolio provides higher flexibility and robustness that preclude decision-makers from undertaking maladaptation or unnecessarily costly adaptation investment.

The portfolio often comprises no-regret or low-regret adaptation options, which are not or very little affected by climate uncertainties. The development of the adaptation portfolio should also pay more attention to soft adaptation options that are more likely to produce synergy with the development agenda in improving the capacities for development and reducing the vulnerability to climate change.

Both vulnerability reduction and an adaptation portfolio constitute key aspects for assessing effective adaptive water investments under uncertainties.

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Vulnerability Reduction and Portfolio Approach:

Key Aspects for Assessing Effective Water Adaptation Options in the Face of Uncertainties

The impacts of climate change have been reported to be strongest and most comprehensive for hydrological systems; however, there is a wide gap between adaptation needs and the uptake of adaptation actions or programmes. One limiting factor in funding adaptation measures is the difficulty in assessing adaptation effectiveness. Another challenge is tackling the issue of uncertainties, which arise from both climatic and non-climatic factors. Effective adaptation options should perform well under plausible uncertainty scenarios.

This paper discusses two key aspects for assessing effective water adaptation options: first, vulnerability reduction as an alternative effectiveness criterion; and second, a portfolio approach to ensure the robustness of water adaptation options against uncertainties. Departing from the problematic implementation of the additionality principle as the most common effectiveness criterion, the paper maintains that effective water adaptation options are measured against the resulting reduction in the level of water vulnerability of the affected community. The concept, measurement and mapping of the water vulnerability index are further explored with respect to its potential implementation. Considering the high level of uncertainties surrounding water adaptation contexts and the long-term nature of water infrastructure, the use of a portfolio approach provides higher flexibility that precludes decision-makers from undertaking maladaptation or unnecessarily costly water investments. The characteristics of adaptation portfolios and the basic steps to develop them are subsequently presented.

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