

## **Screening for Climate Change Adaptation in China:**

A process to assess and manage the potential impact of climate change on development projects and programmes in China

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## Executive Summary

“Climate change is a major global issue of common concern to the international community. It is an issue involving both environment and development, but it is ultimately an issue of development.” (NDRC 2007 China’s National Climate Change Programme)<sup>1</sup>.

In line with global change, China’s climate has witnessed significant change in the last 50 years. These changes include increased average temperatures, rising sea-levels, glacier retreat, reduced annual precipitation in North and Northeast China and significant increases in southern and northwestern China. Extreme weather and climatic events are projected to become more frequent in the future and water resource scarcity will continue across the country. Coastal and delta areas will face greater flood and storm risk from sea level rise and typhoon generation.

The impacts of climate change have the potential to slow-down economic and human development in China, and therefore present risks to the efficiency and effectiveness of development investments. At the same time, in some cases climate change may create more favourable circumstances which can provide opportunities for economic growth and human development.

This project developed a screening framework to assist with assessment of climate change impacts and integration of adaptation into development projects. To enable the application of the framework in a wide range of projects and sectors, it does not prescribe a single model, methodology or tool. It is a systematic step-by-step process for assessing climate change impacts and adaptation responses.

The screening framework has 3 phases, relating to framing, analysis and decision making:

1. A rapid qualitative analysis of the entire development investment to identify potentially significant problems posed to a development project by climate and/or socio-economic change;
2. A semi-quantitative and quantitative analysis of impacts that climate change may have on the development investment, and the adaptation options that might be required to enable the investment to achieve its intended beneficial outcomes. This includes a cost benefit analysis of the adaptation options to indicate their economic efficiency;
3. An analysis to assess the suitability of different adaptation options against a range of appropriate decision-making criteria to suggest the preferred option. This includes assessing the option of making no major additional changes to the project (“no changes currently needed”). Under this option, ongoing monitoring of climate impacts and maintenance of flexibility to cope with potential change is recommended.

As climate change impacts become more apparent, adaptation is an increasingly important area of work around the world. In China the publication of the National Climate Change Programme by NDRC in 2007 has given impetus to adaptation in the context of sustainable development. A crucial role for this research project has therefore been to strengthen capacity and raise awareness by sensitising experts to the systematic management of climate change impacts through adaptation.

The screening framework established and tested here is not intended as a finished tool. Instead, it provides the iterative base for a cycle of learning involving testing, discussion, refinement and re-testing. Importantly, it serves as a means to promote debate over how development investments in China can integrate the management of climate change impacts in the future. Although the framework has been applied *post-hoc* rather than as an integral part of the design process, it has been shown to provide a clear framework for prioritization, analysis of impacts, examination of adaptation effectiveness and decision making.

Climate change impacts will be overlaid onto existing variations in climate, including extreme events. While there has been limited consideration of future climate change in water sector developments to date, the research highlights that there is significant experience of managing climate impacts in China. Adaptation processes may therefore require enhancing existing measures in light of a changing climate, as well as developing new measures. Crucially, adaptation requires a process of ongoing monitoring and assessment as scientific understanding of climate change develops.

The examples of adaptation proposed in the case studies in the Huai (floodplain drainage improvements and improved flood forecasting and warning), Hai (land use change, water pricing policies and water conservation projects), and Shiyang river basins (water conservation and water transfers) demonstrate the need for tackling demand-side aspects of development investments in the water sector such as water pricing and water conservation measures, as well as supply-side factors such as canal lining or raising embankments. Across sectors, this shows how soft technologies and management measures will be equally as important as hard engineering solutions in tackling climate change.

The case studies also highlight the importance of considering the wider implications of adaptation measures including risk transmission and 'mal-adaptation', such as where vulnerability to floods may be inadvertently increased downstream by upstream flood prevention measures. The economic efficiency of measures tested using the cost benefit analysis exercises is just one means of assessing adaptation options. The multi criteria analysis provides a useful means of informing the decision-making process by providing a systematic basis to assist in evaluating the many aspects of adapting to future climate change.

Next steps for the research include receiving feedback from decision makers working in the water and other sectors. The case studies demonstrate the need to investigate how to link screening processes with formal planning, design and implementation processes in order to match the suggested framework to decision making needs. In particular, screening for climate change impacts needs a better understanding of how current planning and implementation currently tackle uncertainty in both climate and other parameters. Uncertainty over the future is inevitable, but the research also demonstrates the need for improved data on climate change scenarios and impact assessments across China to inform planning and decision making in the water and other sectors.

It is hoped that this will stimulate debate and foster further efforts tailored to specific planning, design and implementation procedures in the water sectors and other sectors in China and elsewhere.

## Section A: Adapting to Climate Change Impacts in China

### Adaptation: Addressing climate change impacts

In line with global change, China's climate has witnessed significant change in the last 50 years. These changes include increased average temperatures, rising sea-levels, glacier retreat, reduced annual precipitation in North and Northeast China and significant increases in southern and northwestern China.

Greater extremes have led to more frequent drought in North and Northeast China, and more severe floods in the Yangtze River and southeastern China. Extreme events are projected to become more frequent in the future and water resource scarcity will continue across the country. Coastal and delta areas will face greater flood and storm risk from sea level rise and typhoon generation<sup>ii</sup>.

The impacts of climate change have the potential to slow-down economic and human development in China, and therefore present risks to the efficiency and effectiveness of development investments. At the same time, in some cases climate change may create more favourable circumstances which can provide opportunities for economic growth and human development.

Potential negative impacts include:

- Direct threats (e.g. damages from extreme weather and climatic events to project infrastructure);
- Indirect threats (e.g. health impacts that reduce productivity of agriculture);
- Underperformance (e.g. agricultural projects that fail when rainfall decreases);
- 'Mal-adaptation' (inadvertently increasing vulnerability, e.g. policies that encourage population movement into high risk areas).

In order to minimise negative impacts and maximise opportunities, it is therefore crucial to **manage potential impacts** by anticipating changes and adapting development planning and programmes to account for a changing future climate. This is known as **adaptation**, which can be defined as *a process by which strategies to moderate, cope with and take advantage of the consequences of climate change are enhanced, developed, and implemented*<sup>iii</sup>.

In an extreme case, identified climate change impacts may lead to a decision not to go ahead with a particular plan or project. In most cases, however, it will simply require adjustments to a plan or project to account for potentially different future climatic conditions.

The approach taken to adaptation acknowledges that:

- Climate impacts may not be the most important constraint on development objectives; climate considerations therefore need to be embedded in a planning process that considers all risks.
- The basis for adapting to the future climate lies in improving the ability to cope with existing climate variations. Climate change projections inform this process to ensure that current coping strategies are consistent with future climate change.
- In tackling current hazards, adaptation processes can draw on approaches to disaster risk reduction, as well as tackling gradual changes and new hazards.
- Because of uncertainty over future climate variability and change, management responses should build in flexibility to cope with a range of different potential future climate regimes.
- Managing climate impacts enables an examination of how wider development processes can contribute to reducing vulnerability to climate change.

This study identifies a screening approach to assess and manage the potential impact of climate change on development projects and programmes in the water sector in China. **Climate change screening** refers to a systematic process of evaluating development projects to determine the extent to which their objectives and activities might be affected by future climate-related impacts, and to identify adaptation options to reduce resulting adverse impacts and exploit opportunities.

It is hoped that this will stimulate debate and foster further efforts tailored to specific planning, design and implementation procedures in the water sectors and other sectors in China and elsewhere.

### Testing a process to screen for climate change: Water sector case studies

This study developed and tested a generic screening framework for assessing the effects of climate change on development projects in China. The framework was tested in four case studies representing contrasting water sector development projects. The case studies projects, geographical location, objectives and partners are shown in Table 1. The case studies demonstrate the use of the screening framework rather than acting as the focus of the study.

*Table 1: Case studies for testing the screening framework*

Case study	Development project	Region and broad objectives	Related partners
1	Flood control and land drainage management project	Huai River Basin; Reduce flooding and waterlogging	World Bank, Ministry of Water Resources
2	Management of Miyun reservoir for water security for Beijing	Chaobai in Hai River Basin ; Sustainable water supply to Beijing	Chinese National Environmental Protection Agency (CEPA), Ministry of Water Resources, World Bank, Global Environment Facility, Municipality of Beijing
3	Water Conservation Project for China	Hai River Basin ; Improved agricultural water use efficiency	Ministry of Water Resources, World Bank
4	Integrated Restoration Plan for the Shi Yang River Basin	Shi Yang River Basin ; Sustainable water management	Shi Yang River Basin Administration Bureau

## Section B: Overview of the Adaptation Screening Framework

### Introduction

The study developed a screening framework to assist with assessment of climate change impacts and integration of adaptation into development projects. Given the wide range of development investments, even within a single sector, the framework does not prescribe a single model, methodology or tool. Instead it is a systematic step-by-step process for assessing climate change impacts and adaptation responses. It is intended as a means of promoting debate and discussion, rather than as a fixed method of addressing climate change impacts.

The screening framework has 3 phases (Figure 1), which operate at increasing levels of detail:

- A rapid qualitative analysis of the entire development investment to identify potentially significant problems posed to a development project by climate and/or socio-economic change;
- A semi-quantitative and quantitative analysis of impacts that climate change may have on the development investment, and the adaptation options that might be required to enable the investment to achieve its intended beneficial outcomes;
- An analysis to assess the suitability of different adaptation options against a range of appropriate decision-making criteria to find the preferred option. This includes assessing the option of making no additional major changes to the project (a "No changes currently needed" option). Under this option, ongoing monitoring of climate impacts and maintenance of flexibility in water sector systems to cope with potential change is recommended.

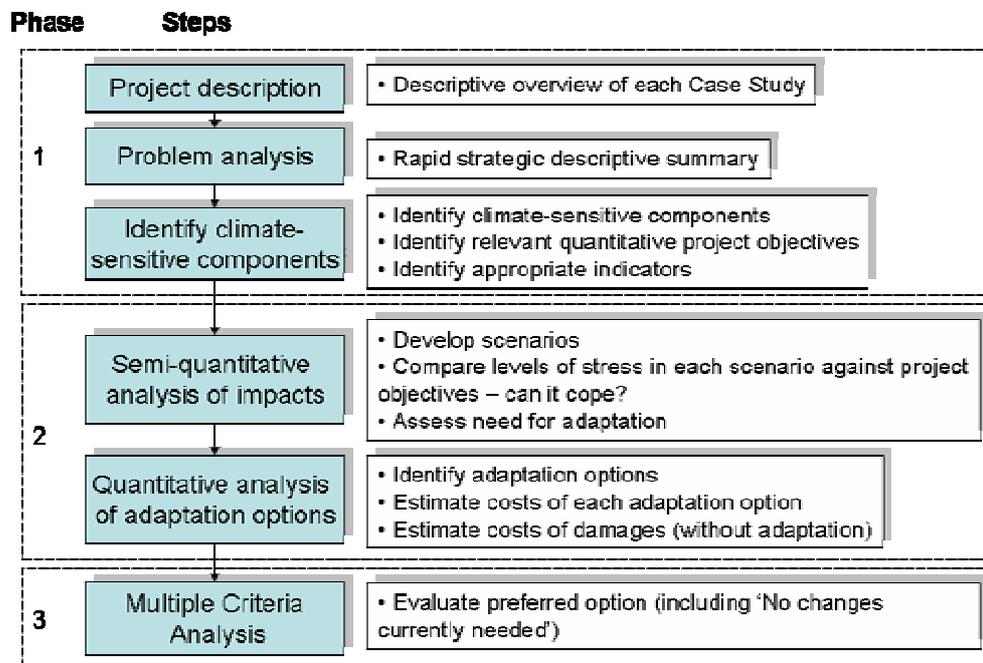


Figure 1 Overview of the phases and steps of the climate screening framework

The following sections provide an initial description of each of the phases of the screening framework. The worked examples from the case studies are presented for each phase. The results are brief summaries of the analysis provided in the full study.

## Section C: Phase 1- Rapid qualitative analysis

The first phase is a rapid qualitative analysis of the development project under consideration to identify potential climate change impacts and climate-sensitive components. This identifies the project components to be studied in greater detail in the quantitative analysis.

### Project description

This provides a descriptive overview of the geographical area of each case study, its aims and objectives and the associated activities of the project.

### Problem analysis

This carries out a rapid descriptive summary of the case study development project, including:

- Current climate hazards that might affect the development project (e.g. drought, flooding, low flows, water quality) and potential impacts (e.g. crop loss, ill health, damage to property).
- Current and planned infrastructure (e.g. flood defences, reservoirs, water treatment systems), management systems (e.g. flood forecasting, reservoir releases, irrigation scheduling) and supporting practices (e.g. water quotas, irrigation technologies, drought monitoring systems, flood warning systems) of the development project.
- Ecosystem sensitivity (e.g. areas of greatest climate sensitivity and/or historic change in vulnerability).
- Climate change variables (e.g. observed and projected climate trends, including changes of extreme events such as more intense rainfall and longer droughts) and the possible consequences of climate change for the development project (e.g. changed water availability, increased irrigation demand, changed sewage volumes).
- Socio-economic change (e.g. increased population, reduced agricultural area, increased development of flood plains).

### Identification of climate-sensitive components of the development project

This focuses on the key climate sensitive elements of the project by identifying:

1. Components of the development project which are sensitive to climate change (e.g. reservoirs, sewage treatment works, flood defence works, irrigation scheme, water abstraction management practice)
2. Quantified objectives of these components (e.g. flood defence standard, outflow quality from sewage treatment works);
3. Relevant secondary climate impact indicators (e.g. surface water availability for irrigation; inflow rates for sewage treatment works)
4. Relevant human activity issues and indicators (e.g. population served by sewage treatment works, increased competition for water)
5. The time period of analysis that is appropriate to the development project. This may represent the lifespan of proposed new infrastructure, or the time period of a development project or restoration plan.

Worked examples of case studies from Phase 1 are summarised for each of these stages in the following boxes:

## Project description

### Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin

The 270,000 km<sup>2</sup> Huai River basin is one of the seven major river systems in China and produces one sixth of the nation's food and a quarter of national cash crops. The World Bank-funded '*Huai River Basin Flood Management and Drainage Improvement*' project aims to increase agricultural productivity and farmers' incomes by better protecting properties and lives along the lesser tributaries of the Huai River Basin against floods and waterlogging. The project will provide improved flood control and drainage works and strengthened institutional capacity.

### Case Study 2 – Management of Miyun Reservoir

The Miyun Reservoir is fed by the 15,788km<sup>2</sup> catchments of the Chao and Bai rivers in the Haihe basin. The inflow to the Miyun Reservoir has been decreasing due to rainfall change and human activities in recent years, which has brought great pressure on the municipal water supply to Beijing City. The objective of the Beijing municipal government is to increase water inflow into the Miyun Reservoir supply in order to satisfy demand.

### Case Study 3 – Water Conservation Project in the Hai river basin

The 318,000 km<sup>2</sup> Hai River Basin in Northern China includes the national capital of Beijing. The '*Water Conservation Project for China*' covered 27 counties in the provinces of Beijing, Tianjin, Shandong and Liaoning. The project invested in physical improvements to irrigation and drainage systems, agronomy and management measures in order to: 1) increase agricultural production and farmer incomes; 2) realize water saving; 3) promote integrated water resources management and sustainable water utilization.

### Case Study 4 – Shiyang River Basin Integrated Restoration Plan

The 41,600 km<sup>2</sup> Shiyang River Basin is located in Gansu Province. The overall objective of the '*Shiyang River Basin Integrated Restoration Plan*' is to prevent environmental degradation and sustain a sound ecosystem for human wellbeing in Minqin. Water saving strategies and ecological restoration will reduce water abstraction and raise groundwater tables in the Minqin Basin.

## Problem analysis

### Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin

The Huai River basin has a history of flooding and droughts. The slow discharge rate and poor drainage leads to floods and associated waterlogging, especially in the lower reaches. Recent large floods occurred in 1991, 2003 and 2007, in 1991 preceded by a severe drought. These events result in widespread crop yield losses in an area where population is projected to rise to 210 million by 2050.

The Huai is a highly controlled river with more than 5,700 dams with a total storage capacity of 23 billion m<sup>3</sup>, over 50,000 km of levees, and 22 flood diversion and storage areas are designated along the middle main stream. As the basin is in a climate transition zone, high levels of uncertainty exist in prediction of future precipitation, but it is probable that the Huaihe will experience more frequent extreme floods and droughts in the future.

### Case Study 2 – Management of Miyun Reservoir

There is a long term decreasing precipitation trend in the basin and 5 successive drought years from 1999 to 2003, leading to serious water supply problems to Beijing. The active storage capacity of the reservoir has also been reduced through siltation. The overall runoff in the basin from 2000 to 2005 has declined by about 66 percent

since the 1950s. The Baihebao reservoir water transfer has been used on five occasions since its creation in 2003 and has delivered a total of  $2 \times 10^8 \text{m}^3$ .

In addition to supplying Beijing city, the Miyun reservoir catchment has a population of 2.18 million people, produces 1.38 million tons of foodstuffs and has 1.92 million head of livestock.

Climate change projections using the SRES A2 and B2 scenarios suggest that average annual temperature may increase by 2.4 - 2.8°C and precipitation may increase by around 4 - 5% by 2050, increasing average annual inflow into the reservoir.

#### Case Study 3 – Water Conservation Project in the Hai river basin

The Hai basin is the most water scarce region in China. Per capita water availability is roughly  $300 \text{m}^3$ , only about one seventh of national average level. Groundwater over-extraction has led to falling water tables (particularly under some cities), land subsidence in some rural areas and deteriorating water quality near the coast. Many rivers have lost their normal runoff functions and more than 90% of wetlands have shrunk in area.

The overall irrigation water use efficiency is only 35-50% for surface systems and 70% for well systems, due to weak incentives, low water pricing and poor infrastructure. The current water pricing policy in the agricultural sector in the basin does not provide water users with effective incentives to save water. The present gap between total water supply and demand in the Hai River Basin is about 4 percent of total water use.

The population of the basin has increased 20% since the 1950s and total water use has increased 4.4 times, with agricultural water use declining to 70 % by 2004, and industry and domestic use increasing to 15 % each. There is considerable future uncertainty, with the projected annual precipitation change under the B2 scenario ranging from -6% to +5% in 2025, and from -8% to +12% in 2050. However, projected warmer temperatures are likely to lead to increased irrigation demand, further aggravating the supply-demand imbalance.

#### Case Study 4 – Shiyang River Basin Integrated Restoration Plan

Frequent drought has significant impacts for socio-economic and ecological systems across the Shiyang River Basin. These result in reduced crop yields, shrinking rivers, dried-up lakes, and the degradation of habitable oases, which are highly reliant on the water resources flowing from the Qilian Mountains. The Minqin Oasis has shrunk by  $289 \text{km}^2$  since the 1950s to  $1313 \text{km}^2$ .

The basin hosts a system of 8 main reservoirs, almost 4000km of canals and 16,900 wells, and two inter-basin water transfers into the Shiyang River Basin. Water supply has mostly been for agricultural irrigation (86% of total use) with water use efficiency around 46-61%. Recently, increasing volumes have been supplied for industry and public water supply.

In the past 20 years, the population of the Shiyang River Basin has increased by 33%, the irrigation area has increased by 30%, crop yield has increased by 45%, and GDP has increased by a factor of six. However, water resources have decreased by 1%, resulting in the water supply and demand conflict.

Under the A2 and B2 future climate scenarios, by 2050 average annual temperature is projected to increase 2 – 3°C and precipitation to increase by 5-10%. Rising temperatures will accelerate glacier melt and increase precipitation and evaporation in the mountains, potentially leading to short term increases in runoff and middle term decreases. Moreover, the temperature rises will also lead to increased water demand from irrigation, and also industry and public water supply.

## **Identification of climate-sensitive components of the Development Project**

### **Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin**

1. The main climate sensitive components of the “Huai River Basin Flood Management and Drainage Improvement” project are the flood defences and drainage systems.
2. The quantifiable project objective is to upgrade the drainage capacity for the rivulets and depressions from once in less than 3-5 years to once in 5-20 years.
3. The relevant secondary climate impact indicators are the level of the groundwater table that can be controlled by the drainage works, and the surface water availability for irrigation.
4. The relevant human activity issues and indicators are the population served by the drainage works and the percentage of the income of residents from farming.
5. Given the economic importance of the river basin and the long lifespan of the engineering works, the time period of the analysis is up to 2050.

### **Case Study 2 – Management of Miyun Reservoir**

1. The main climate sensitive component is the Miyun reservoir, which is sensitive to climate -induced changes to its inflows.
2. The quantifiable project objective is to provide water security for Beijing.
3. The key secondary climate impact indicator is the surface water inflow to the reservoir.
4. The human activity issues and indicators are derived from the Haihe Water Resources Plan which extends to 2025
5. The time period for analysis is 2025 and 2050.

### **Case Study 3 – Water Conservation Project in the Hai river basin**

1. The main climate sensitive component is the water resource system, which is sensitive to both changes to the overall basin water balance and agricultural water demand.
2. The quantifiable project objective is to achieve an overall water balance for the river basin, allowing groundwater over-abstraction if there is “spare” surface water available.
3. The major secondary climate indicators are surface and groundwater resources available for capture by water conservation projects, and the water deficit.
4. Water demand is the main human activity indicator. The business-as-usual (BAU) scenario assumes a continuation of current trends and existing plans in water and food policy, management and investment.
5. The forecast time for the analysis is 2030, with 2004 used as the base year.

### **Case Study 4 – The Shiyang River Basin Integrated Restoration Plan**

1. The key climate change sensitivities within the Integrated Restoration Plan (IRP) are water resources, water demand and ecological water requirements.
2. The quantifiable project objectives are no overdraft of groundwater abstraction and to maintain a specified area of shallow groundwater depth (<3m) in the downstream area to maintain wetlands.
3. The above objectives can be turned into an integrated goal that is the water flowing into Hongyashan Reservoir, as given by the flow at the Caiqi gauging station. The incoming water to Hongyashan represents the balance of water allocation between the upstream and downstream areas, and also indirectly controls the groundwater and ecological environment protection.
4. Human activity indicators are taken from the planning scenarios from the IRP, including those covering economic restructuring, emigration, water transfers, water use development.
5. 2015 and 2025 have been selected as investment periods against which to assess compliance with the Integrated Restoration Plans objectives.

## Section D: Phase 2 - Semi quantitative and quantitative analysis

The second phase assesses the impact of projected climate change on the development project, the potential need for adaptation under identified future conditions, and the options for adaptation. Time restrictions did not permit modelling of climate change scenarios and their impacts. Instead, a range of potential scenarios was generated using expert judgement based on existing model outputs.

The phase is divided into a semi quantitative analysis of impacts and a quantitative analysis of adaptation options to determine their costs and benefits.

### Semi-quantitative analysis of impacts

This assesses the need for adaptation by determining the extent to which a project's objectives are threatened by future climate change impacts. This is shown graphically in Figure 2. The analysis works through the case study information:

1. Developing realistic scenarios of secondary climate impact indicators (e.g. surface water availability for irrigation changes by +10 to -20 %) for the chosen time period based on the range of climate change projections
2. Developing a range of scenarios of human activity indicators (e.g. population served by sewage treatment works changes by +20 to -5 %)
3. Evaluating the contribution of existing and proposed infrastructure/management systems to achieving the case study development project's stated objectives
4. Comparing levels of stress against infrastructure objectives to assess the ability to cope with changes from scenarios (and the need for adaptation)

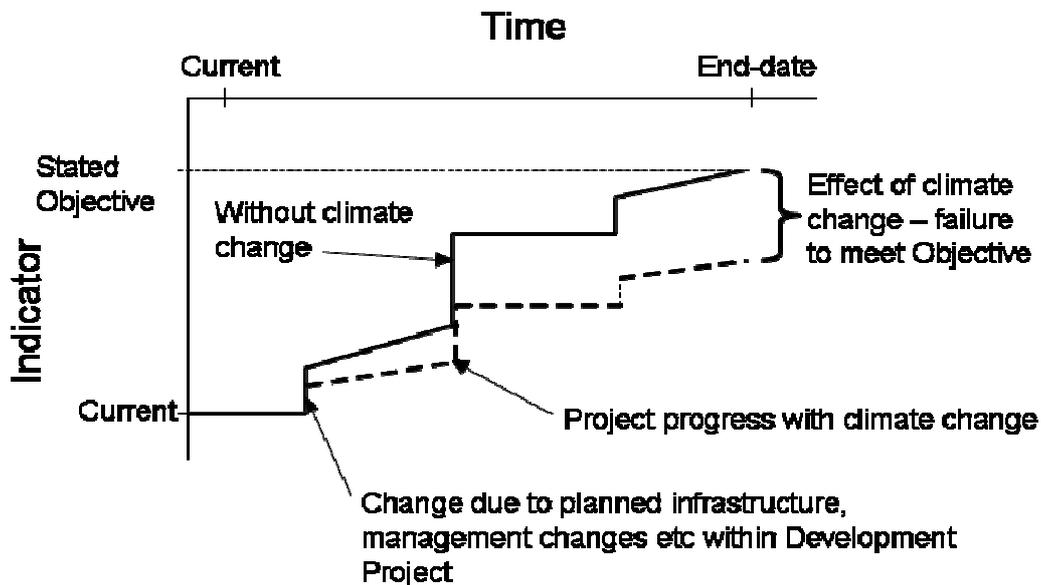


Figure 2 Schematic diagram showing how climate change may potentially cause a failure to achieve anticipated project objectives

### Quantitative analysis of adaptation options

The semi-quantitative analysis highlights areas where adaptation measures are necessary. The quantitative analysis of these adaptation options then estimates the economic efficiency of adaptation. This is then used in Phase 3 to inform the decision making process. This analysis undertakes the following steps for each case study:

1. For those scenarios in which the development project might fail to achieve its stated objectives, identify adaptation options to reduce potentially unacceptable impacts.
2. Estimate future costs of adaptation at net present value.
3. Estimate benefits of adaptation measures, if implemented: increased financial/economic output due to adaptation and/or avoided damages (e.g. due to irrigated crop losses, loss of energy generation), at net present value:

	Current climate		Future climate	
Current Project	Costs 1	Benefits 1	Costs 1	Benefits 2
Adapted Project			Costs 2	Benefits 3

Additional costs of adaptation = Costs 2 – Costs 1

Additional benefits of adaptation = Benefits 3 – Benefits 2

4. Calculate benefit-cost ratios (B/C) of adaptation, to determine whether the proposed adaptation is economically efficient, as a contribution to decision making. If individual adaptation options are being considered, their B/C ratios can be compared, but with due consideration of the magnitudes of their benefits.
5. Identify any costs for which estimates, on the basis of current knowledge, could not be produced.

Worked examples of case studies from Phase 2 are summarised for each of these stages in the following boxes:

### Semi-quantitative analysis of impacts

#### Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin

1. In the absence of detailed hydrological modelling of the waterlogged areas, it has been assumed that there is a proportional relationship between precipitation and the waterlogged area. The approximately 5% increase in average annual rainfall has been assumed to lead to a 5% ( $\pm 10\%$ ) reduction in the area in which the Huai River Basin Flood Management and Drainage Improvement Project has decreased waterlogging.
2. The range of scenarios of human activity indicators are those used in the World Bank's Cost-Benefit analysis
3. Without climate change, the average annual decrease in the waterlogging area is  $6.4 \times 10^4$  ha. Economic analysis by the World Bank shows that the net present value of annual costs and average annual benefits of the project are  $4.24 \times 10^9$  RMB (of which avoidance of capital assets losses are  $3.23 \times 10^9$  RMB) and  $7.57 \times 10^9$  RMB (of which the benefits of waterlogging mitigation are  $0.43 \times 10^9$  RMB, flood control of  $0.34 \times 10^9$  RMB, irrigation of  $0.68 \times 10^9$  RMB and navigation of  $0.18 \times 10^9$  RMB), respectively, at a discount rate of 12%. The economic NPV is  $3.32 \times 10^9$  RMB, with the ratio of benefits and costs being 1.78
4. The increase in precipitation associated with climate change will cause the area in which the project has decreased waterlogging to change by  $+0.34$  to  $-1 \times 10^4$  ha, and the waterlogging mitigation benefits will change by  $-23.56$  to  $+66.78 \times 10^6$  RMB thus the overall effect becomes ambiguous.

#### Case Study 2 – Miyun Reservoir (Hai river basin)

1. The changes in temperature and precipitation result in a 10-12 % increase in average annual inflow into the reservoir in 2050 (range -14.5 to 31.5%). However inflows in 2025 change by -1 to +8 % (range -9.5 to 13%), with the decrease under the A2 scenario.
2. With its water supply focus, no scenarios of human activity indicators were used.
3. The Miyun reservoir currently provides 60% of Beijing's water supply.
4. The Miyun reservoir will fail to provide current levels of water supply in 2025 under the A2 scenario, but will provide improved water supply due to increased inflows under the B2 scenario and also in 2050 under both scenarios. The consequence of these changes is that the water resource situation in the watershed of Beijing may become more severe in 2025 but will have eased by 2050.

#### Case Study 3 – Water Conservation Project China in the Hai river basin

1. Increases in average temperature of 1.3-1.5°C and precipitation changes of -1 to +3% will lead to increases in the water deficit of 0-3 km<sup>3</sup>. Extreme rainfall scenarios lead to the water deficit changing by -9 to + 9 km<sup>3</sup>.
2. Under the BAU scenario, the total water use in the Hai River Basin in 2030 will increase by 56 %, from 38.45 km<sup>3</sup> to 55.35 km<sup>3</sup>. The major driver of increased water use is industry whose use will increase by 301 % by 2030. Domestic water use will also increase by 39 %, but irrigation water use will decline by 2 %.
3. Without both water price increases and climate change, the water supply and demand gap in the Hai River Basin will reach 11.93 km<sup>3</sup> by 2030, an increase from 4 % (in 2004) to 22 % of total water use. To rebalance the water scarcity without climate change by water pricing (imposing 80% of price increases on industry and 20% on the irrigation sector), the irrigation water price under BAU needs to be increased by a factor of 0.4-1.8 and industry by 1.4-4.3.
4. The A2 scenario will see an increase in the water deficit from 12 km<sup>3</sup> to 15 km<sup>3</sup> (range 3 to 21 km<sup>3</sup>) by 2030 whilst the B2 scenario will see little change from 12 km<sup>3</sup> (range 3 to 20 km<sup>3</sup>), indicating that the BAU water price increases will not resolve the water deficit under the A2 scenario.

#### Case Study 4 – the Shiyang River Basin Integrated Restoration Plan

1. Scenarios of expected reductions in runoff in the catchment due to climate range from -6.5% in 2015 to -9.4% in 2025.
2. Human activity indicators are as used in the IRP model.
3. The reductions in abstraction and improved water management due to the IRP are expected to improve GDP in the basin by around 120 x10<sup>8</sup> Yuan (or ~40%).
4. With climate change but without adaptation, the IRP fails to achieve its anticipated improvements in inflows to the Hongyashan reservoir. Inflows to Hongyashan reservoir due to climate change reduce by 7.3 % by 2015 and 10.7% by 2050. To capture the climate uncertainty flow reductions of 5 - 15% are realistic.

## Quantitative analysis of adaptation options

### Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin

1. Three potential adaptation options have been identified to reduce the adverse impacts of climate change on the project objectives. These are to:
  - Dredge a network of drainage canals and ponds (to increase the storage capacity of floodwater) and to use the spoil to raise the average land level to reduce waterlogging;
  - Develop improved high level carriers in the floodplain to transfer runoff to the river;
  - Enhance the development of flood and drought monitoring, forecasting, warning and operating systems
2. The costs of adaptation, specifically of canal digging and land raising, are based on local prices of  $12 \times 10^3$  RMB (current value) per  $1 \times 10^3$  m<sup>3</sup> of earthwork. However, the costs per km<sup>2</sup> range from 825 -4629  $\times 10^3$  RMB depending on whether the canals are constructed for a water depth of 1 or 2 m, and the proportion of the land raised.
3. According to the data in the World Bank's economic analysis, the increased average waterlogging mitigation benefits are  $11.8 \times 10^6$  RMB per km<sup>2</sup> of decreased waterlogging.
4. The resultant estimated benefit/costs ratio for the climate change adaptation measures is about 1.64 (range 1.6 – 14.9, assuming  $\pm 50\%$  uncertainty on costs and benefits).
5. Operations and Maintenance costs have not been included in the calculations.

### Case Study 2 – Management of Miyun Reservoir

1. Three adaptation options have been identified to increase the inflows to the Miyun reservoir over the next 30 years, and thus increase water supply for an A2 future:
  - Hebei province will convert paddy fields to rain-fed agriculture in upper reaches of Miyun Reservoir. Beijing municipal government will pay economic compensation for the loss and provide the project funds for water resource conservation;
  - Construction of a 160km water diversion channel from the Lanhe river to the Chaohe river whose water flows into Miyun reservoir
  - Construct sewage treatment plants to increase effluent re-use
2. The costs of the adaptation measures range from  $18 \times 10^8$  Yuan (treatment plants),  $52 \times 10^8$  Yuan (paddy conversion) to  $151 \times 10^8$  Yuan (water diversion), which together will provide an additional inflow of  $3.3 \times 10^8$  m<sup>3</sup>/a.
3. The additional benefits of the three adaptation measures are  $853.39 \times 10^8$  Yuan
4. With a standard discount rate of 12%, the total NPV over the 30 years is  $136 \times 10^8$  Yuan and an overall benefit to cost ratio for the climate change adaptation of 1.8.
5. The benefits only relate to the GDP value of the increased inflows.

### Case Study 3 – Water Conservation Project of China in the Hai river basin

1. Two adaptation options have been identified to redress the water balance- further increased water price rises (with 80% of the price increases imposed on industry and 20% on the irrigation sector) and engineering projects which provide physical improvements to the irrigation and drainage systems.
2. To fully rebalance the water scarcity by increasing the water price in 2030 under the A2 scenario, irrigation water price will need to be raised by a factor of 0.4-2.1 (range 0.1 – 2.9) and industrial water by 1.8-4.2 (range 0.4 – 5.8). The costs in terms of lost crop revenue for a mixed (20:80) water pricing policy will range from 15-81 billion Yuan in a normal year to 4-112 billion Yuan in extreme (wet or dry years) as compared to 15-70 billion Yuan under BAU. Price rises (and associated crop revenue losses) under the B2 scenario will be lower than the BAU unless extreme decrease in precipitation occurs. The economic cost of implementing the engineering water saving projects in the irrigation sector (based on 5.3 Yuan per 1 m<sup>3</sup> of water saved) is near to the upper level of the cost of adopting the mix water pricing policy, but much lower than only adopting irrigation water pricing policies.

3. The benefits of balancing the water deficit are in terms of increased irrigation area and increased crop revenue or increased industry GDP. The benefits of increased crop revenue under the A2 scenario are 2.99 billion Yuan in a normal year to 0.65-4.13 billion Yuan in extreme (wet or dry years) as compared to 2.63 billion Yuan under BAU. If the benefits are obtained by industry, then the increase in industrial GDP is 4859 billion Yuan in a normal year to 1050 to 6708 billion Yuan in extreme (wet or dry years) as compared to 3896 billion Yuan under BAU. Price rises (and associated crop revenue losses) under the B2 scenario are generally lower than the BAU.

4. If the potential benefits are only gained by the irrigation sector, the cost-benefit ratio is less than 1 for all climate scenarios. Adopting a mixed water pricing policy increases the benefit-cost ratio, particularly if industry receives the benefits. The benefit-cost ratio of the water saving projects is at the lower level of the mixed water pricing policy.

#### Case Study 4 – the Shiyang River Basin Integrated Restoration Plan

1. Three adaptation options were identified: (1) increased investment in planned water saving projects, (2) increased investment in water transfers from the Yellow River and (3) direct financial subsidy for lost GDP.

2. The costs of adaptation are  $8.5 - 33.9 \times 10^8$  Yuan (for further water saving projects),  $9.8-39.2 \times 10^8$  Yuan (for water transfers) and  $7.2-24.3 \times 10^8$  Yuan (for financial subsidies) depending on the flow decrease.

3. The benefits of adaptation are given by the resulting increased GDP in the basin, which range from  $17.7 - 58.7 \times 10^8$  Yuan depending on the change in reservoir inflows.

4. The cost-benefit ratio ranges (depending on the climate change scenario) from 1.73-2.08 for water saving, 1.5 – 1.8 for increase water transfers and 1.0 for the subsidies. This indicates that the water saving and water transfers make economic sense, but the ratio decreases with decreasing flow.

5. The benefits only relate to GDP change.

## **Section E: Phase 3 - Adaptation options assessment**

### **Multi criteria analysis**

This phase provides a simple framework to inform decision making on adaptation options. This used a multi criteria analysis framework to think through and discuss adaptation options in the context of a range of potential decision making criteria. The process of undertaking the multi criteria analysis may be considered more important than the results as it opens decision making to a wide range of criteria. The results of the economic analysis outlined in the earlier section are just one of these criteria for choosing between options. Decision making criteria are weighted for their importance as part of the discussion.

Ideally a wide stakeholder group should be involved in the multi criteria analysis as part of the consultative process. Due to time constraints, the group for each case study was limited, but included technical experts and policy makers working in the field related to the case study topic and region. Criteria developed varied between the case studies and results of the assessments are shown in the box below, followed by an example table of the multi criteria analysis for one of the case studies.

The assessment process undertook the following steps for each case study:

1. Identify a range of decision-making criteria for evaluating the different options such as cost-effectiveness, unintended consequences (e.g. increased groundwater abstraction to compensate for reduced surface water irrigation water), likelihood of occurrence, and practicality of the option. The selected criteria will vary between Development Investments as a consequence of differing priorities of decision makers.
2. Evaluate adaptation options against the criteria to identify preferred option(s) for implementation into the design process for the case study development project. These include an option of "No changes currently needed" in addition to the existing project.
3. Where a "No changes currently needed" option is the final outcome, the rationale should be recorded and guidance given as to whether flexibility in design to allow for future adaptation is recommended.

### **Adaptation options assessment results**

#### **Case Study 1 – Flood Control and Land Drainage Management in the Huai River Basin**

A 'do nothing additional' was evaluated against two potential adaptation options (the combined floodplain drainage improvements and improved forecasting and warning) using eight criteria. Both adaptation options scored significantly better than the "No changes currently needed" option.

#### **Case Study 2 – Management of Miyun Reservoir**

As future reservoir inflows generally increase, except under the A2 scenario for 2025, adaptation to climate change is unlikely, and therefore the "No changes currently needed" option is the probable response. Nevertheless the analysis highlights the future water resources challenges faced by Beijing owing to its continued economic growth and increasing water demand, and the probable need for water demand management.

#### **Case Study 3 – Water Conservation Project of China in the Hai river basin**

"No changes currently needed" was evaluated against three potential adaptation options (2 water pricing policies and the engineered water saving) using six criteria. Mixed water pricing scored significantly better than "No changes currently needed". However, engineered water saving scored only marginally better than "No changes currently needed", whilst irrigation pricing scored the lowest.

#### **Case Study 4 – the Shiyang River Basin Integrated Restoration Plan**

"No changes currently needed" was evaluated against two potential adaptation options (investment in water saving and water transfers) using nine criteria. Investment in water saving scored best, whilst investment in water transfers scored the same as "No changes currently needed".

An example of the multi criteria analysis undertaken for adaptation options is shown in Table 2.

Table 2: Example of a multi criteria analysis for adaptation options in Case Study 4: Shiyang river basin Integrated Restoration Plan.

Criteria		Water Saving Investment		Water Transfer Investment		No changes currently needed	
Weight		Score	Comments and Details	Score	Comments and Details	Score	Comments and Details
Low	Current and future focus	4	The restoration plan will consider future impacts in context of current impact.	4	The restoration plan will consider future impacts in context of current impact.	2	Lack of consideration of climate change.
High	Fit with existing practices	4	Fit with the water saving objective and policy in SY River Basin.	3	Higher administrative costs. Poor fit with current practice.	4	Current practices in basin do not consider climate change.
Med	Cost effectiveness	4	Measurable environmental and social benefit Positive benefit for water saving society.	2	Negative benefit for Yellow River management.	3	No investment for dealing with climate change impact, so there is risk.
High	Adaptive flexibility	4	Generally small scale, easy to adjust.	2	Once built, difficult to change.	4	Option may retain flexibility given climate change uncertainty.
Med	Practical considerations	4	Easily accepted by locals.	2	Refer to Yellow River water management and benefit of other province.	4	Minimum investment and effort
High	Scaling up	4	Easy for scaling up.	4	Easy for scaling up.	4	N/A
Low	Knowledge level	3	Current warming trend but future uncertainty.	3	Current warming trend but future uncertainty.	1	Uncertainty over future impacts
High	Policy Coherence	4	Water saving is long term measure. High policy coherence with the state.	3	The project will create benefit for local population.	2	Limited climate change policy in China currently.

## Section F: Key lessons and conclusions

As climate change impacts become more apparent, adaptation is an increasingly important area of work around the world. In China the publication of the National Climate Change Programme by NDRC in 2007 has given impetus to adaptation in the context of sustainable development. A crucial role for this research project has therefore been to strengthen capacity and raise awareness by sensitising experts to the systematic management of climate change impacts through adaptation.

The screening framework established and tested here is not intended as finished tool. Instead, it provides the iterative base for a cycle of learning involving testing, discussion, refinement and re-testing. Importantly, it serves as a means to promote debate over how development investments in China can integrate the management of climate change impacts in the future. Although the framework has been applied *post-hoc* rather than as an integral part of the design process, it has been shown to provide a clear framework for prioritization, analysis of impacts, examination of adaptation effectiveness and decision making.

Climate change impacts will be overlaid onto natural variability in climate, including extreme events. While there has been limited consideration of future climate change in water sector developments to date, the research highlights that there is significant experience of managing climate impacts in China. Adaptation processes may therefore require enhancing existing measures in light of a changing climate, as well as developing new measures. Crucially, adaptation requires a process of ongoing monitoring and assessment as scientific understanding of climate change develops.

The examples of adaptation proposed in the case studies demonstrate the need for tackling demand-side aspects of development investments in the water sector such as water pricing and water conservation measures, as well as supply-side factors such as canal lining or water diversion projects. Across sectors, this shows how soft technologies and management measures will be equally as important as hard engineering solutions in tackling climate change.

The case studies also highlight the importance of considering the wider implications of adaptation measures including risk transmission and 'mal-adaptation', such as where vulnerability to floods may be inadvertently increased downstream by upstream flood prevention measures. The economic efficiency of measures tested using the cost benefit analysis exercises is just one means of assessing adaptation options. The multi criteria analysis provides a useful means of informing the decision-making process by providing a systematic basis to assist in evaluating the many aspects of adapting to future climate change.

Next steps for the research include receiving feedback from decision makers working in the water and other sectors. The case studies demonstrate the need to investigate how to link screening processes with formal planning, design and implementation processes in order to match the suggested framework to decision making needs. In particular, screening for climate change impacts needs a better understanding of how current planning and implementation currently tackle uncertainty in both climate and other parameters. Uncertainty over the future is inevitable, but the research also demonstrates the need for improved data on climate change scenarios and impact assessments across China to inform planning and decision making in the water and other sectors.

## Footnotes and Bibliography

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