# 12. Impact and Adaptation Assessment on a National Scale: Case Studies on Water in China

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**Summary.** In order to assess vulnerability to climate change, not only the degree of climate change impact but also the adaptive capacity of the region with regard to the impact needs to be considered. To achieve such an assessment, a national-scale impact assessment model is being developed. This paper introduces two case studies related to water problems in China. One of them is a scenario for an assessment of future water withdrawal and consumption in China taking into consideration alternative future socio-economic development patterns. This indicates that the adoption of appropriate policies and efficient technologies can ensure that future water consumption is maintained at the current level, even though water withdrawal will increase under all socio-economic scenarios, which reflects the expected increase in industrial withdrawal. In the other case study, an evaluation is made of the adaptation policies in China for mitigating current flood damage due to climate variability as well as the future increase in flood damage due to climate change is evaluated. Investment in infrastructure for flood prevention in accordance with the expected future climate change can also reduce current flood damage and is found to be robust and low-regret adaptation strategy.

## 12.1 Introduction and Framework of AIM/Impact [Country]

As shown in Chap. 3 (see the chapter by Harasawa *et al.*), an AIM/Impact model has been developed mainly for the purpose of assessing climate change impacts on several sectors (water, agriculture, ecosystems, and human health) on a global scale and it has been used to elucidate the regions that would be significantly affected by anticipated climate change. However, in order to assess the vulnerability of a region to climate change, not only the degree of the impacts of climate change, but also the adaptive capacity of the region to cope with these impacts needs to be considered. To analyze concrete adaptation measures for mitigating climate change impacts, more detailed analysis is required on an appropriate spatial scale corresponding to that of the stakeholders (e.g. governments, local communities, individuals) with regard to the adaptation measures. Moreover, the role of each country in reporting the results of impact

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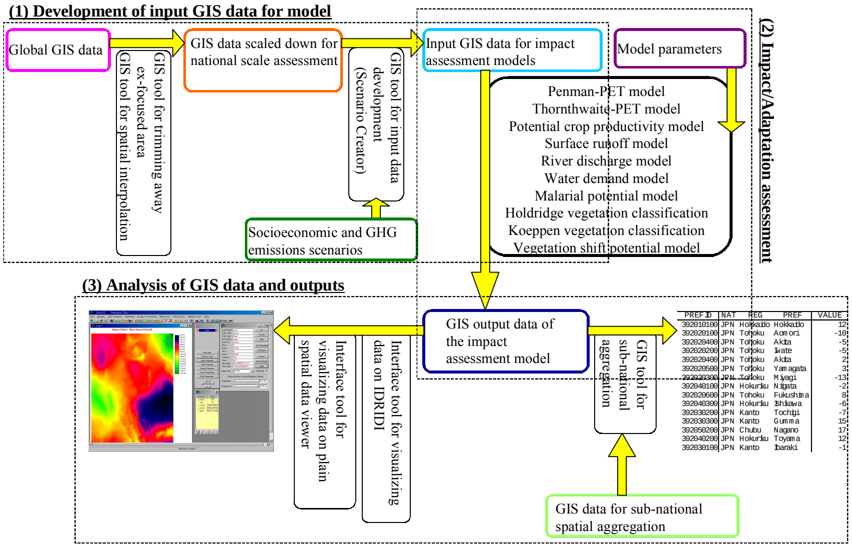
assessment to international processes, such as the National Communication for the UNFCCC, increases the importance of national scale assessments carried out by each country itself. Within the AIM/Impact project, there are increasing requests from collaborative research teams in the Asian countries to pay more attention to assessments on the national scale. Taking into account this situation, the development of a national-scale assessment model of impact and adaptation has started, mainly based on the models that have been developed for AIM/Impacts on the global scale. This has been named AIM/Impact [Country].

AIM/Impact [Country] is a package of impact models, tools, databases, and visualization modules with a user interface to enable these elements to be operated in an integrated way. AIM/Impacts [Country] is used to assess climate change impacts on various sectors on a national scale. Fig. 1 shows the framework of AIM/Impact [Country], which illustrates the elements of the package (data, models, tools, parameters, etc.) and their relationships and dependencies. Impact assessment models for several sectors form the central part of the package (the upper right rectangle bounded by a dotted line in Fig. 1). Tools and databases included in the package support the development of national-scale input data for the impact assessment models (the upper left rectangle bounded by a dotted line in Fig. 1) and the spatial and numerical analysis of the output results of an assessment (the bottom rectangle bounded by a dotted line in Fig. 1). Although ready-made standardized data and model parameters are provided with the models and tools for countries with data limitations, these can be replaced by the users according to the specific conditions of each country. A visualization tool with simple functions to graphically display the spatial data and results is also included



| PREF ID | NAT | REG | PREF | VALUE |
|---|---|---|---|---|
| 392010100 | JPN | Hokkaido | Hokkaido | 12 |
| 392020100 | JPN | Tohoku | Aomori | -10 |
| 392020400 | JPN | Tohoku | Akita | -5 |
| 392020200 | JPN | Tohoku | Iwate | -5 |
| 392020400 | JPN | Tohoku | Akita | 2 |
| 392020500 | JPN | Tohoku | Yamagata | 3 |
| 392020300 | JPN | Tohoku | Miyagi | -13 |
| 392040100 | JPN | Hokuriku | Niigata | -2 |
| 392020600 | JPN | Tohoku | Fukushima | 8 |
| 392040300 | JPN | Hokuriku | Ishikawa | -6 |
| 392030200 | JPN | Kanto | Tochigi | -7 |
| 392030300 | JPN | Kanto | Gumma | 15 |
| 392050200 | JPN | Chubu | Nagano | 17 |
| 392040200 | JPN | Hokuriku | Toyama | 12 |
| 392030100 | JPN | Kanto | Ibaraki | -1 |

**Fig. 1.** Framework of AIM/Impact [Country] (see color plates)

in the package, and users can quickly view the spatial information without purchasing expensive GIS software.

While the main focus of AIM/Impact has been the assessment of the direct physical impact of climate change, AIM/Impact [Country] is designed to more explicitly consider socioeconomic aspects of the problem and adaptation, besides the physical impacts. Therefore, in this chapter, two recent case studies related to water problems in China are introduced, whose models are planned to be included into AIM/Impacts [Country] in a more generalized form. Section 2 describes an assessment of future water withdrawal and consumption in China taking into consideration alternative future socio-economic development patterns. Section 3 introduces an assessment of adaptation policies in China for mitigating current flood damage due to climatic variability as well as future increased flood damage due to climate change.

## 12.2 Projection of Water Demand through 2032

### 12.2.1 Water withdrawal and consumption under alternative socioeconomic development scenarios

According to the dynamic changes related to human activities, such as the increase in the population, industrialization, irrigation development, shortages of water resources and consequent environmental problems are becoming more obvious in many regions of the world. If the rapid development scenario is taken, which assumes a significantly higher rate of population increase and industrialization in developing countries, more severe and more frequent water shortages are expected to occur. More extensive water shortages can be a factor limiting future socioeconomic development. There is even speculation that regional conflicts or wars may occur as a result of competition for limited water resources in the 21st century.

While such a pessimistic view of the prospects for water resource problems is being emphasized, future water demand depends substantially on future socio-economic conditions, such as population changes and levels of economic development. Since future socioeconomic conditions are still uncertain, diverse sets of future development scenarios that could be potentially be chosen need to be analyzed. In order to assess the impact of climate change on water resources, the estimation of water demand taking into consideration socioeconomic conditions is as important as the estimation of future water supply under altered climatic conditions.

In this study, an assessment model of water withdrawal and water consumption on a national scale was developed and then used to estimate water withdrawal and consumption in China under four alternative future development scenarios for the period from 1995 to 2032. In the model, historical trends in the irrigated area and the population supplied with water as well as assumed future trends in relation to various socioeconomic factors, such as an increase in the population and economic development, are taken into account to estimate future withdrawal and consumption. In many studies for the projection of water demand made so far, the amount of water withdrawal has been taken as the index of water demand. However, for the purpose of evaluating the quantitative balance between water supply and demand in order to investigate any shortfall in water supply, water consumption is a better index than water withdrawal. Here, water withdrawal means the gross amount of water taken from water resources for human activities, on the other hand, water consumption means the net amount of water consumed mainly through evaporation before the water is recycled to form part of the available water resources. The ratio of water consumption to water withdrawal is called the water consumption ratio, while the ratio of water returned to water resources to water withdrawal is called the return flow rate. In the industrial and domestic sectors, most of the withdrawal is discharged back to replenish water resources (the water consumption ratio is low), thus the amount of water consumed is relatively small even if water withdrawal increases rapidly in future. On the other hand, in the agricultural sector, most withdrawal is consumed through evaporation and transpiration (the water consumption ratio is high).

### 12.2.2 Water demand model

Figure 2 shows the estimated flow of water withdrawal and water consumption. Water withdrawal and consumption in three sectors (industry, agriculture, domestic) are estimated separately. For the base year (1995), sectoral water withdrawal data compiled by the World Resource Institute (2001) is used. Firstly, based on the scenario for socioeconomic factors (urban/rural population and economic growth) and technological factors (water use efficiency improvements in each sector), future water withdrawal in each sector is estimated. Then, considering the scenario for the water consumption ratio, future water

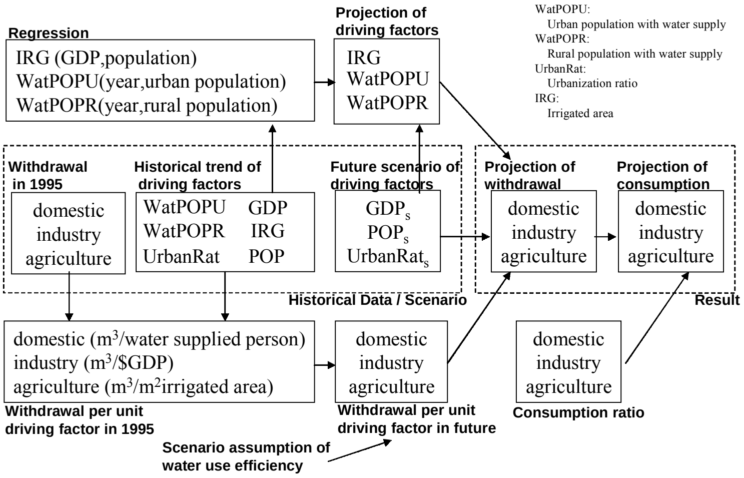


**Fig. 2.** Overview of water demand model

consumption is calculated. The basic driving force for changes in industrial water withdrawal is economic growth in the model. It is assumed that industrial water withdrawal will change in proportion to changes in the GDP. The amount of irrigated area is taken as the driving force for any change in agricultural water withdrawal. Agricultural water withdrawal is assumed to change in proportion to any change in the irrigated area. The future irrigated area is estimated from a multi regression with the logarithm of population and the logarithm of per capita GDP as the explanatory variables. The population supplied with water is taken as the driving force for domestic water withdrawal. The future population supplied with water is estimated taking into consideration the historical trend of the ratio of the population supplied with water and the future population scenario. In order to take into account technology improvements, sectoral withdrawals based on the basic driving forces are then multiplied by a factor for water use efficiency improvements, which is assumed taking into consideration the form of socioeconomic development. The sectoral water withdrawals calculated in this way are summed up to provide the total water withdrawal for the country. Some portion of the withdrawal is consumed mainly through evaporation, while the other portion is recycled to replenish the water resource. In our model, the ratio of the consumed volume to the withdrawal (consumption ratio) is assumed to be 0.16, 0.8, and 0.3 for the industrial, agricultural and domestic sectors, respectively, according to information from Shiklomanov (1998).

### 12.2.3 Scenarios

Water withdrawal and consumption in the three sectors under the alternative four sets of assumptions regarding socioeconomic changes are estimated (Table 1). These four scenarios of socioeconomic changes are identical to the scenarios adopted in the global environment outlook 3 (GEO3) formulated by UNEP (2001). The comparative level of population change, economic development, and water-use efficiency improvements for the four scenarios are shown in Table 1. Among these, the scenarios for population change and economic development are deduced from the scenario of GEO3.

The scenario for water use efficiency improvements was set by the authors by maintaining consistency with the background sequence of the GEO3 scenarios. In the PR scenario, it is assumed that currently available efficient water use technologies will be introduced from the first half of the projected period (1995 – 2015) with the support of environmental policies, and that innovative efficient water use technologies will become available in the second half of the period of the projection (2015 – 2032). In the GT scenario, water use efficiency improvements in the first half will be at the same level as in the MF scenario. However, efficient technologies will be available in the second half of the period. In the MF scenario, technology improvements are slower to emerge than in the PR scenario in the first half, and are slower to emerge than in the PR and the GT scenarios in the second half of the period. In the FW scenario, water use technology improvements are much slower to emerge than in the other scenarios for the whole period of the projections.

**Table 1.** Socioeconomic development scenarios analyzed in the study

| | Market Forces (MF) | Fortress World (FW) | Policy Reforms (PR) | Great Transition (GT) |
|---|---|---|---|---|
| Population growth rate | Medium | High | Medium | Medium |
| Economic growth rate | High | Low | High | Medium |
| Water use efficiency improvements | Medium | Slow | Rapid | Medium – Rapid |

### 12.2.4 Analysis

Figure 3a - 3c shows the water consumption for the three sectors. A common trend for all the scenarios is that industrial consumption will increase even taking into consideration water use efficiency improvements. Reflecting the expected rapid economic growth and industrialization, the growth of industrial consumption will be the greatest in the MF scenario. In the PR scenario and the GT scenario, the growth of industrial consumption will be slightly lower than that in the MF scenario, while it is rather low in the FW scenario due to slow economic growth. As for agricultural consumption, this will not increase significantly even in the FW scenario with a high increase in the population. It will decrease in the other scenarios with a lower increase in the population and higher water use efficiency improvements. These trends reflect the recent historical situation, which indicates that irrigation in China has reached saturation point. Domestic consumption will increase only in the FW scenario due to its high increase in population and low rate of efficiency improvements.

Figure 4a and 4b show the total water consumption and total withdrawal in China, respectively. By comparing these two figures, it can be found that they have a different order with regard to the scenarios. In viewing the results of withdrawal, the MF scenario involves the largest increase. This is because industrial withdrawal will increase much more rapidly in the MF scenario than in the other scenarios. On the other hand, the reason of the second highest total withdrawal in the FW scenario is not an increase in industrial withdrawals, but an increase in agricultural and domestic withdrawals reflecting rapid population growth and slow efficiency improvements. However, when viewing the results of consumption, the FW scenario will show the greatest increase, and the MF scenario does not show a significant increase. Moreover, water consumption will decrease slightly in the PR scenario and the GT scenario. This difference of order between consumption and withdrawal is caused by the high water consumption ratio in the agricultural sector. This result indicates that it is very important to differentiate water consumption and withdrawal when assessing water demand.

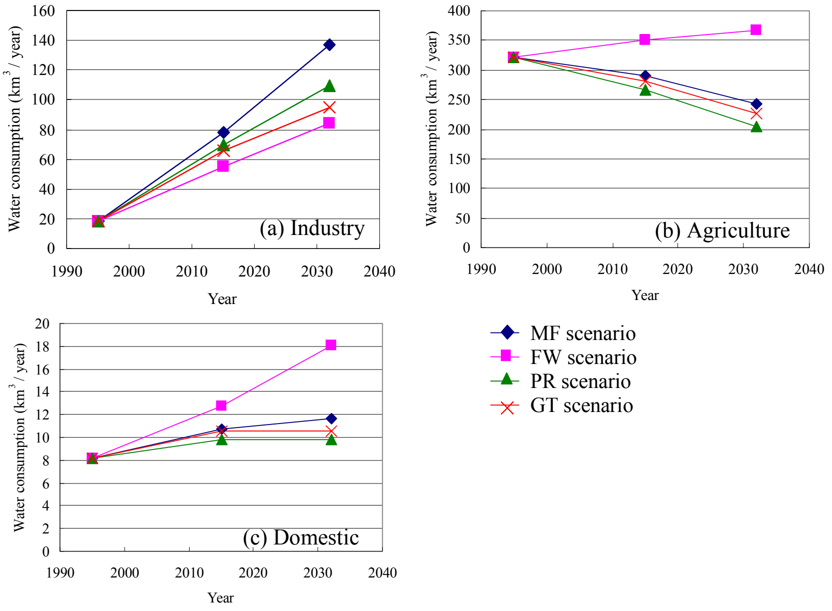


**Fig. 3a-3c.** Water consumption in the three sectors ($km^3$/year)

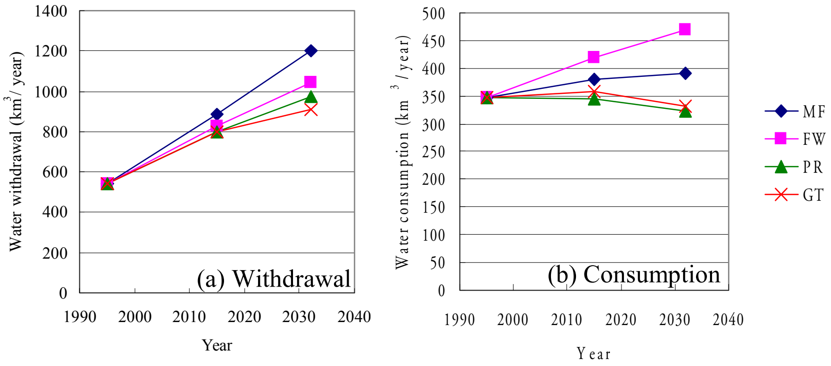


**Fig. 4a and 4b.** Total water withdrawal and consumption

### 12.2.5 Findings and future improvements

In this case study, water withdrawal and consumption in China under four alternative future development scenarios were estimated for the period from 1995 to 2032. Although withdrawal will increase in all the scenarios, reflecting the significant increase in industrial withdrawal, water consumption can be kept at the current level if appropriate policies are adopted to accelerate the introduction of efficient technologies. Increasing industrial water consumption, which is unavoidable under rapid industrialization, can be accommodated through efficiency improvements in the agricultural sector.

This study requires improvement with regard to some points. Firstly, in this study, only the quantity of water withdrawn from water resources and consumed through human activities has been analyzed. However, water quality has not been considered in any form. Even if a sufficient quantity of water is available for future human activities, the actual quality of the water may not be appropriate for some uses. The aspect of water quality should be included in the assessment. Secondly, the results of the assessment depend substantially on the assumptions with regard to water use efficiency improvements as well as on the socioeconomic scenarios for the driving forces. In this study, the assumptions regarding efficiency improvements are set exogenously considering the historical trend. However, these assumptions need to be related to the availability of concrete technology options for more efficient water use. Detailed databases on technology options with information on costs and level of efficiency need to be developed to add greater reality to the assessment.

## 12.3 Adaptation Policies in China for Mitigating Flood Damage

### 12.3.1 Importance of long-term adaptation policy

Adaptation to climate change impacts is considered to be an important and efficient strategy. Nevertheless, the efficiency of each adaptation strategy has not been sufficiently analyzed to make it possible to propose a detailed action plan, though adaptation options have been compiled for each sector. The limitations are mainly derived from the following features of climate change impact and adaptation studies: (a) the climate change impacts are still uncertain; (b) the mechanisms of adaptation are too complex to be evaluated. In spite of these difficulties, each country should actively seek to elucidate what can and should be done in the early 21st century to mitigate the negative impacts of climate change, as there are long time lags in relation to the introduction of capital stock and new technologies in human activities in response to changing economic conditions.

China is expected to experience significant impacts on the hydrological cycle from climate change. However, it is very difficult for the Chinese government to introduce a long term adaptation policy since China places the priority on short- to medium-term policies. In order for China to introduce long term policies, the benefits of the integration of long term adaptation policies with short term policies need to be evaluated. A macroeconomic model is introduced to evaluate the effects of investment in flood mitigation infrastructure in China considering climatic variability and climate change.

### 12.3.2 Model structure

There are some references to the multi-sector models such as by Duraiappah (1993) and Masui *et al.* (2000). In this study, the focus is a dynamic optimization model with two economic sectors: the agricultural sector and the non-agricultural sector. Two climate discount factors are considered in the model: damage from climatic variability and damage from climate change. The solution of this model is highly normative, since the production and distribution of goods are determined so as to maximize the temporary sum of the discounted utility derived from final consumption. The set of model equations is presented below.

#### Objective function

The fundamental assumption is that policies should be designed to maximize the generalized level of consumption now and in the future. This approach rests on the view that more consumption is preferred over less, and in addition that increments of consumption become less valuable as consumption levels increase (Nordhaus 1994). In technical terms, these assumptions are embodied by maximizing a social welfare function that is the discounted sum of the utility of per capita consumption. The objective function to be maximized is:

$$\text{Max } U = \sum_t \left[ \left(\prod_i C_i(t)^{v_i}\right) \times (1+\rho)^{-t} \right] \tag{1}$$

Where $U$ is the flow of utility, $C_i$ is the flow of consumption from sector $i$ per capita at year $t$, and ρ is the pure rate of social time preference that allows for distinguishing the relative emphasis on different generations, a value of 0.03 per year is applied by Nordhaus (1994). Also set to 0.03. ν is the consumption share of each sector product, the sum of $v_i$ ($i$=1,2) is equal to 1. The planning horizon spans 105 years, from 1995 to 2100, with each time period in the model specification representing a one-year interval.

#### Production function

Total intermediate input and the production factor are aggregated to obtain total output using the Leontief production function. The total outputs of the agricultural and non-agricultural sectors are expressed as follows:

$$Ya(t) = \min\left( \frac{Maa(t)}{a2a}, \frac{Mna(t)}{n2a}, \frac{YGDPa(t)}{a2ao} \right) \tag{2}$$

$$Yn(t) = \min\left(\frac{Mnn(t)}{n2n}, \frac{Man(t)}{a2n}, \frac{YGDPn(t)}{n2no}\right) \tag{3}$$

Where, *Ya(t)* and *Yn(t)* are the total outputs of the agricultural and non-agricultural sectors, respectively; *Maa(t)* and *Man(t)* are intermediate inputs from the agricultural sector to both the agricultural and non-agricultural sectors, respectively; *Mnn(t)* and *Mna(t)* are intermediate inputs from the non-agricultural sector to both the non-agricultural and agricultural sectors, respectively. *YGDPa(t)* and *YGDPn(t)* represent the productions of the agricultural and non-agricultural sectors; *a2a*, *n2a*, *n2n*, and *a2n* are input coefficients and are equal to 0.16064, 0.24199, 0.59804, 0.05394 respectively; a2ao and n2no are production factors and are equal to 0.59737 and 0.34803, respectively. They are aggregated from six sectors (SSB 1999).

Agricultural production is expressed as follows:

$$YGDPa(t) = Aa(t) \times Ka(t)^{\beta} \times La(t)^{\gamma} \times F(t)^{\lambda} \tag{4}$$

Where *Aa(t)* is the total factor of productivity; *Ka(t)* is the capital stock, *La(t)* is the labor input, *F(t)* is the land input, β is the elasticity of the capital input, γ is the elasticity of labor, λ is the elasticity of land. Based on the historical data from 1972 to 1995, β, λ and γ are determined to be 0.55, 0.20 and 0.25 in agriculture, respectively, during the period 1991-1995 (Zhu and Liu 1998).

The non-agricultural sector production is expressed as a function of technology, capital and labor.

$$YGDPn(t) = An(t) \times Kn(t)^{1-\alpha} \times Ln(t)^{\alpha} \tag{5}$$

Where α is the elasticity of output with respect to capital, *An(t)* is the total factor of productivity, *Kn(t)* is the capital stock, *Ln(t)* is the labor input. The non-agricultural capital elasticity (α) is set to 0.3 in this study according to the latest study by Jiang *et al.* (1998).

It is assumed that land is primarily used for agricultural activities, and that the total area remains unchanged throughout the simulated period, which is the goal of the government in guaranteeing the supply of food for its huge population. Since the rapid development of the non-agricultural sector accounts for some land, keeping the total area unchanged involves reclaiming some abandoned areas that in general have contributed to a decline in land quality. According to a study (Gao *et al.* 1998), land quality decreased 2.53% from 1985 to 1995 at mean annual rate of 0.25%. It could be expected that the occupation of cultivated land will approach zero when the population growth reaches zero and the urbanization process basically stops. So it is assumed that land quality will decrease 0.25% annually until 2030 and 0.15% per year from 2031 to 2050 and 0% after 2050.

### National accounts and capital constraints

The distribution relation of goods is of the standard input-output style. It states that the total sectoral output must be equal to the sum of consumption demand, investment, intermediate requirements, and adaptation investments, taking into consideration negative climate change impacts. It is assumed that the non-agricultural sector is the primary sector that contributes to capital formation for itself as well as for the agricultural sector. Imports and exports are not considered independently in goods distribution.

$$Ya(t) = Ca(t) + Ia(t) + Iav(t) + Iac(t) + Maa(t) + Man(t) \tag{6}$$

$$\begin{aligned} Yn(t) = {} & Cn(t) + In(t) + Inv(t) + Inc(t) \\ & + Mnn(t) + Mna(t) + Ina(t) \end{aligned} \tag{7}$$

Where, *Ia(t)*, *Iav(t)* and *Iac(t)* are contributions of the agricultural sector to agricultural capital stock, investment for flood control, and extra investment for projected flood damage from climate change. *In(t)*, *Inv(t)* and *Inc(t)* are contributions of the non-agricultural sector to non-agricultural capital stock, investment for flood control, and extra investment for projected flood damage from climate change. *Ca(t)* and *Cn(t)* represent the consumption of agricultural and non-agricultural goods, respectively; *Ina* is the contribution of the non-agricultural sector to the formation of agricultural capital stock.

$$Ka(t) = (1-\delta)Ka(t-1) + Ia(t-1) + Ina(t-1) - Dak(t-1) \tag{8}$$

$$Kn(t) = (1-\delta)Kn(t-1) + In(t-1) - Dnk(t-1) \tag{9}$$

$$INF(t) = (1-\delta)INF(t-1) + Iav(t-1) + Inv(t-1) \tag{10}$$

$$INFc(t) = (1-\delta)INFc(t-1) + Iac(t-1) + Inc(t-1) \tag{11}$$

Where: δ is the depreciation rate of the capital stock and flood mitigation infrastructure; *Ka* and *Kn* are capital stocks of the agricultural and non-agricultural sectors, respectively; *INF*, *INFc* are the infrastructure stock that is designed to mitigate flooding from climatic variability and projected climate change, respectively, *Dak* and *Dnk* are the flooding damage to capital stocks of the agricultural and non-agricultural sectors.

The respective capital stocks for the agricultural sector and for all sectors in 1995 were 395.91 billion Yuan (Zhu and Liu 1998) and 5663.3 billion Yuan (Jiang *et al.* 1998) at 1980 prices. Both of them are converted, based on the overall retail price index (SSB 1996), to 1300.21 billion Yuan and 17298.74 billion Yuan at 1995 prices. The stock of the infrastructure for flood mitigation was 26.045 billion Yuan in 1995 at 1995 prices, too, calculated cumulatively from 1956. The depreciation rate of the capital stock and infrastructure in China varies from year to year, with a tendency towards a gradual increase. The depreciation rate for the fixed assets of stated-owned enterprises increased from 4.1% in 1980 to 5.5% in

1992 (SSB 1995). It is set at 5% in this study.

### Damage function

It is quite difficult to establish the damage function between flood mitigation infrastructure stock per capita and flood damage to the agricultural and non-agricultural sectors, respectively, since there exists only very limited reported flood damage, and even that is in an aggregated form. There are two types of direct flood damage: damage to land/crops in the agricultural sector, and damage to capital stock in both sectors. The first type damages crop yields by inundation, often leading to a loss of the harvest, or damages land as a result of erosion or fluvial and alluvial sedimentation. In the latter case, floods not only destroy the sown crops, but also make future cultivation impossible. In this study, it is assumed that flood damage to land has no impact on future use.

Based on the total direct flood damage and the statistical data for the sown crops covered and affected by flood (SSB 1981), the following damage functions are established.

$$Dnkv(t) = 10^{nk0} \times \left[ INF(t-t') / P(t-t') \right]^{nk1} \tag{12}$$

$$Dakv(t) = 10^{ak0} \times \left[ INF(t-t') / P(t-t') \right]^{ak1} \tag{13}$$

$$Dalv(t) = 10^{al0} \times \left[ INF(t-t') / P(t-t') \right]^{al1} \tag{14}$$

Where, *Dnkv*, *Dakv*, *Dalv* represent damage to capital stocks of the non-agricultural and agricultural sectors, and land, respectively. *P* is population. *t'* is the time lag during which investment takes effect and equals 5; *nk0*, *nk1*, *ak0*, *ak1*, *al0*, *al1* equal to 1.513, -0.918, 0.794, -0.771, 0.984, -0.355, respectively.

By assuming that equations (12)~(14) are still applicable in the future if climate change occurs and that the marginal cost of reducing unit flood damage from climate change is the same as that from climatic variability, the damage functions of climate change can be derived from equations (12)~(14).

$$Dnkc(t) = 10^{nk0} \times \left[ \frac{INFc(t-t')}{P(t-t')} + \left( \frac{Dc(t)}{10^{nk0}} \right)^{1/nk1} \right]^{nk1} \tag{15}$$

$$Dakc(t) = 10^{ak0} \times \left[ \frac{INFc(t-t')}{P(t-t')} + \left( \frac{Dc(t)}{10^{ak0}} \right)^{1/ak1} \right]^{ak1} \tag{16}$$

$$Dalc(t) = 10^{al0} \times \left[ \frac{INFc(t-t')}{P(t-t')} + \left( \frac{Dc(t)}{10^{al0}} \right)^{1/al1} \right]^{al1} \tag{17}$$

$$Dnk(t) = (Dnkv(t-1) + Dnkc(t-1)) \times YGDPn(t-1) \tag{18}$$

$$Dak(t) = (Dakv(t-1) + Dakc(t-1)) \times YGDPa(t-1) \tag{19}$$

$$F(t) = F0 \times [1 - Q(t)] \times [1 - Dalv(t) - Dalc(t)] \tag{20}$$

$F$ is the effective land input considering flood damage and the reduction of land quality. The equation for climate change damage, $Dc(t)$, is expressed as

$$Dc(t) = D_{ref} T(t)^2 / 6.25 \tag{21}$$

Where $T(t)$ is the temperature increase in year $t$. Damage caused by flooding under climate change with a 2.5°C increase in temperature is assumed to be $D_{ref}$, the quadratic term of the temperature reflects the assumption that the damage is quadratic, along with the temperature increase (Nordhaus 1994). Based on a study of physical impacts on surface runoff, and the intensity and frequency of floods under projected climate change (paper in preparation), it is assumed that the flood damage under a future climate in the year 2100 will double, and the damage from climate change is the same as the current maximum damage of 3.9% in 1994.

### Growth rate of technology and the total productivity factor

The growth rate of technology during the period 1991-1995 was 2.5% for the agricultural sector (Zhu and Liu 1998) and 3.1% for all sectors, estimated based on a study (Jiang *et al*. 1998). The figure 3.1% is taken as the approximate growth rate of technology in the non-agricultural sector due to the approximately 20% share of the total GDP held by the agricultural sector. So the initial values for the technology growth rate for the agricultural and the non-agricultural sectors are 2.5% and 3.1%, respectively. Due to a lower technological level and a lower contribution of technology growth to economic growth (about 30%) (Ministry of Agriculture 1996; Jiang *et al*. 1998), it is expected that technology growth will continue to speed up within the next several decades, and then level off and afterwards decline annually. So it is assumed that the rate of change in the technology growth rate is to be 1%, 0% and -1%, annually for the periods 1996-2030, 2031-2050 and 2051-2100, respectively. The growth rates of technology for the agricultural and the non-agricultural sectors at year t are estimated as follows (Nordhaus 1994):

$$GTa(t) = GTa(t-1) \times [1 + \varphi a(t)] \tag{22}$$

$$GTn(t) = GTn(t-1) \times [1 + \varphi n(t)] \tag{23}$$

where $\varphi a(t)$ and $\varphi n(t)$ are the rates of change in technology growth for the agricultural and the non-agricultural sectors. $GTa$ and $GTn$ are the growth rates of technology for both sectors. Then the total productivity factors are calculated as,

$$Aa(t) = Aa0 \times \exp[GTa(t)] \tag{24}$$

$$An(t) = An0 \times \exp[GTn(t)] \tag{25}$$

The values of the total productivity factors in the initial year, *Aa0* and *An0*, can be calculated, based on equations (4) and (5).

### Population and labor

Labor is assumed to be proportional to population. According to a report (Li *et al.* 2000), demographers at the China Renmin University put forward three population scenarios for the next 100 years (High, Medium and Low). The projected population in 2100 is 1.5 billion, 1.0 billion, and 0.8 billion under High, Medium and Low scenarios, respectively. The common assumption for the three scenarios is that population increases from 1.21 billion in 1995 to near 1.4 billion by 2010, 1.6 billion by 2030 and then levels off after 2030 until 2035. The population growth rate in 1995 is 1.0605%, and the decrease in the rate of population growth from 1996 to 2030 is estimated to be 1.6%.

In 1995, 52.2% of the labor force was employed in the agricultural sector and 47.8 % in the non-agricultural sector (SSB 1996). As the share of the agricultural sector declines along with economic development, labor migrates to the cities and enters the formal or informal labor market. In this research, a simplified migration scenario is assumed in which 70% and 80% of labor will be employed in the non-agricultural sector by 2050 and 2100 respectively.

## 12.3.3 Scenarios of adaptation and climate change

Four scenarios combining climate change and investment in the flood mitigation infrastructure were assumed for simulation, based on the assumption that policy makers will optimize investment in flood prevention infrastructure to reduce the cost of damage caused by floods from the current climatic variability, whether climate change occurs or not (Table 2).

1. CnAn: policymakers do not arrange adaptation investment for the projected climate change and climate change does not occur.
2. CyAn: policymakers believe climate change will not occur and thus no adaptation investment is implemented to mitigate flood damage from climate change, but unfortunately, climate change occurs.
3. CyAy: policymakers believe climate change will occur and thus adaptation investment is arranged to mitigate flood damage from climate change and climate change occurs.
4. CnAy: policymakers believe that climate change will occur and adaptation investment is arranged to mitigate flood damage from climate change, the amount of investment is assumed to be the same as that in CyAy, but climate change does not occur.

**Table 2.** Scenarios considering policy options and the probability of climate change occurring

| | Invest | Climate change | |
|---|---|---|---|
| | | Yes | No |
| Policy options | Yes | CyAy | CnAy |
| | No | CyAn | CnAn |

### 12.3.4 Analysis

The model first is run on the following assumptions: population growth follows the medium scenario (1.0 billion in 2100); the non-agricultural sector employs 70% of the labor force by 2050 and 80% by 2100; the marginal adaptation costs of adapting to climate change are assumed to be the same as those for current climatic variability. Taking CnAn as a base scenario, flood damage to cultivated land (Fig. 5) from climatic variability and climate change is expected to increase to 1.13% in 2100 even if investment takes climate change into consideration and climate changes do occur (scenario CyAy); the highest level of damage is about 1.58% around 2050. The damage gradually increases to 3.11% by the end of the century when there is no investment in flood prevention infrastructure to combat projected climate change (scenario CyAn). When climate change does not occur while adaptive investment is being implemented (scenario CnAy), flood damage is lower than the base scenario (scenario CnAn) as adaptation investment adds extra adaptive capacity, thus mitigating the damage from climatic variability. Damage to the agricultural capital stock and non-agricultural capital stock (Figs. 6 and 7) under these four scenarios shows a similar pattern to that of agricultural land.

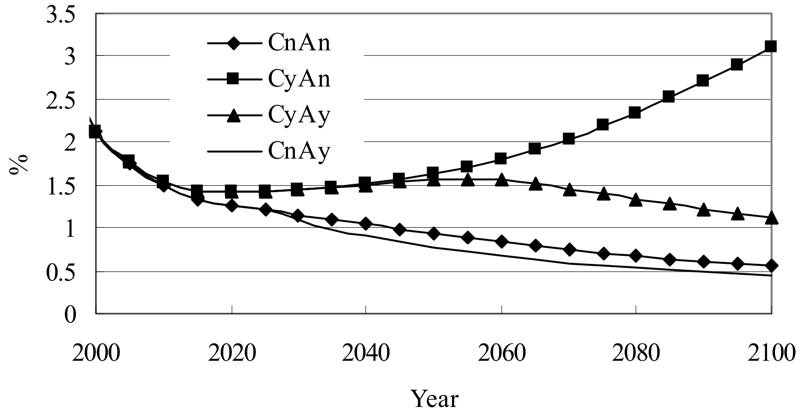


**Fig. 5.** Flood damage to cultivated land

Investments ignoring climate change will cause damage starting around 2020 when climate change occurs.

Utility per capita decreased by 0.83% when no adaptation investment is implemented while climate change occurs, but the reduction can be reduced to 0.1% if adaptation investment is implemented (Fig. 8).

Changes in utility per capita were accumulated to analyse the effects of long term adaptation policy and short term policy. Two criteria (“maximax” and “maximin”) for decision making under uncertainty were applied in the study to select the best option in response to uncertain climate change. The maximax criterion is based on the assumption of an optimistic decision maker. The best outcomes expected under each decision alternative considering uncertainty are compared, and the alternative that represents the best of the best outcomes is selected. The maximin criterion is based on the assumption of a conservative (pessimistic) decision maker. Worst outcomes expected under each decision alternative are compared, and the alternative that represents the best of the worst outcomes is selected.

**Table 3.** Decision making based on changes in utility

| | Invest | Climate change | | Best option | |
|---|---|---|---|---|---|
| | | Yes | No | Maximax | Maximin |
| 1995-2100 | Yes | -563.2 | -17.6 | | ✓ |
| | No | -4158.7 | 0.0 | ✓ | |
| 1995-2020 | Yes | -22.8 | -1.8 | | |
| | No | -21.4 | 0.0 | ✓ | ✓ |

The result (Table 3) shows the best option in the short term is not to adapt to climate change. In the long term, the best option is to adapt to climate change, if policy makers prefer risk aversion decisions (maximin criterion).

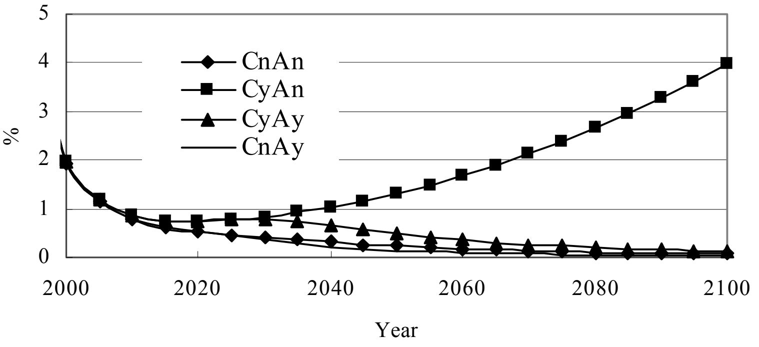


**Fig. 7.** Damage to capital stock in the non-agricultural sector

**Fi**

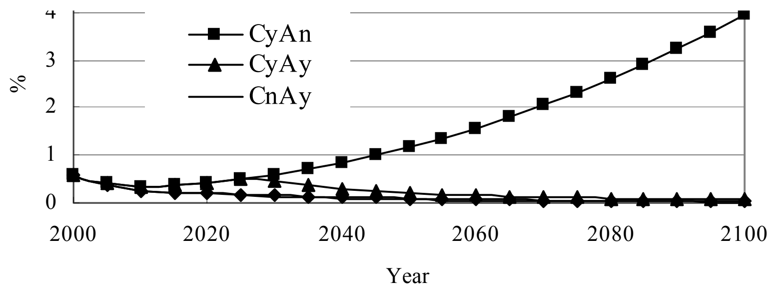


**Fig. 6.** Damage to capital stock in the agricultural sector

### 12.3.5 Findings from the simulation

In this case study, a dynamic macroeconomic model dealing with investment optimization considering climate variability and climate change is created and a simulation extended for 105 years from 1995 to 2100 in China. A feature of this model is that it considers two sectors, two discount factors from climatic variability and climate change, as well as labor migration and capital flows existing between the two sectors. The following results have been obtained by using this model:

1. Investments that are optimized ignoring climate change will cause severe damage starting about 2020 and reaching its peak by 2100 when climate change occurs. Optimizing investment considering both climatic variability and climate change can effectively mitigate flood damage from climate change.
2. Investment against projected climate change is the best option from a century-long perspective in a situation of uncertainty in relation to climate change. In the short term, the best option is not to invest.

## 12.4 Conclusion

The importance of impact assessment on a regional or national scale has been increasing. In order to evaluate regional impacts and adaptation measures, in addition to spatially detailed data, new assessment tools that consider diverse alternative socioeconomic development paths and effective adaptation strategies are expected to be developed. Moreover, there is also a need for tools to build more facilities for local actors, who are better able to comprehend the significant problems and the feasible solutions, to evaluate impact and adaptation strategies by themselves. AIM/Impacts [Country] is expected to meet these needs.

In this report, the results of case studies on China were presented, where collaborative research with local organizations has continued for a long time. In the next stage, while the AIM/Impact [Country] model continues to be developed and refined, the area that is subject to national scale assessment will expand from China to the South and Southeast Asian countries, where the most drastic socioeconomic developmental transformation and serious climate change impacts are expected.

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