STUDY ON CLIMATE CHANGE ADAPTATION STRATEGIES FOR IRRIGATION AFFAIRS IN TAIWAN

Ming-Hua Tsai[1], Wei-Taw Lin[2], Gwo-Hsing Yu[3]

Abstract

Climate change has caught more and more attention around the world. With the increase in the intensity and frequency of extreme climate events, more catastrophic damage may impact on various water consumers. Accordingly, agriculture, the major consumer of water resource, is predicted to be struck more severely than the other sectors, indicating the importance of agricultural water resource management. However, precipitation in Taiwan is characterized by uneven distribution both spatially and temporally. This feature is predicted to be more significant in the future according to the trend of climate change. Therefore, more comprehensive and provident plans for Irrigation Associations are desired to sustain agriculture from the impacts of climate change.

This study analyzed strategies adopted by other countries and considered in the cropping patterns and environment in Taiwan. Except present adaptation strategies, management should be effectively executed as precaution. Thus, four constructive suggestions were made in this study: 1) improving water use efficiency. 2) Establishing flexible agricultural water allocation mechanisms. 3) Utilizing multiple functions of paddy field. 4) Constructing an early-warning system. With adequate management, the impact of climate change could be diminished. Meanwhile, non-agriculture sectors could be assisted by Irrigation Associations to deal with the threat and opportunity of climate change, building a sustainable future together.

Keywords: Climate change, irrigation, strategy, small land holder

[1] Director, Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan, Taipei, Taiwan

[2] Section Chief, Irrigation Management Section, Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan, Taipei, Taiwan, E-mail: lwt@coa.gov.tw

[3] Direct, Water Resources Management and Policy Research Center and Professor, Dept. of Water Resources and Environmental Eng., Tamkang University, Tamsui, Taipei County, Taiwan 25137, E-mail: e133@mail.tku.edu.tw

Introduction

In its 4th Evaluation Report, the UN Intergovernmental Panel on Climate Change (IPCC) stated that climate change will increasingly worsen the water resources and food security around the world (IPCC, 2007). As the largest consumer of global water resources (around 70%), the world agriculture has been profoundly impacted in particular. With continuing growth of world water consumption on a larger scale (UNEP, 2002), food consumption in each country was predicted to an increment of 9% on average by 2030 (FAO, 2002), and to be compounded by the fact that reduction in food production in major food production countries due to various causes in recent years (IFPRI, 2009), therefore the world food supply would be critically influenced. Thus, many countries nowadays are attempting to ensure food supply self-sufficiency for reason of food security. In this regard, keeping of sufficient water supply rates becomes the most key policy for water resources. Since Taiwan is located in the Asian monsoon region suitable for paddy rice growing with an annual total rainfall highly exceeding irrigation water requirements for paddy, should flexible farming systems and efficient water uses be appropriately practiced and if there are no competitive water uses of other purposes, the water for paddy rice irrigation in this country will be free from insufficiency. Moreover, from the point of view of efficient uses of land and water resources, the paddy fields usually can sufficiently utilize rainfalls not only beneficial to bumper rice production but also helpful to ecological environment in paddy-growing regions including Taiwan in adaptation to climate change. The latter benefits have had substantial effects to related sectors of this country in taking actions for adaptation to the climate change.

Especially in Asia, due to the increasing frequency of occurrences of droughts and other extreme weather events caused by climate change, the availability of water resources will be more unstable. As a result, crop physiology will be impacted by temperature rise as to raise the growing demand of water for agriculture production. For instance, in mid-latitude China, irrigation water demand will be further increased by 6% to 10% for every degree Celsius of the temperature rise (Qin, 2002). Likewise, if Japan expects to maintain current food output, it will need to increase irrigation water by 5% to meet the increment of evaporation (+20%) due to warming temperature (WRD, MoLIT, 2008). Given the situation of limited water resources during dry season in Asia, the issues of assurance of food security while coping with the competitions from industrial and domestic water uses as well as the climate change become imperative and pressing matters of concern, especially for the countries including Taiwan using significant amounts of water for agriculture.

I. Impact of climate change on agricultural water resources in Taiwan

1. Water resources in Taiwan

The rainfall in Taiwan averages about 2,500mm per year, which is 2.5 times the world average. However, being a densely populated small island with vast steep hillsides, the water share per capita in Taiwan (4,074m^3/year) is just one fifth of the global average, ranked as the 18th among the most water-deficiency countries. Moreover, it is very difficult for Taiwan to store water for irrigation use, of which about 70 % is drawn from rivers and to allocate and distribute water resources which are attributable to the factors of (1) uneven temporal and spatial distribution of water and (2) distinctive dry and wet seasons (WRA, MOEA, 2005). From observation of the tendency of current climate change, although the total annual rainfalls have not changed drastically in Taiwan, its distribution patterns over the years shows a tendency of more frequent drought and flood events (Figure 1).

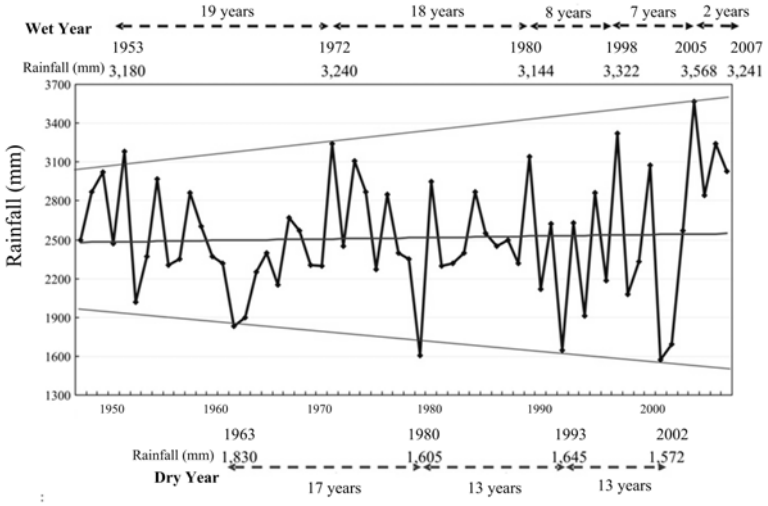

Figure 1. Trend of increasing droughts and floods in Taiwan based on observed average annual rainfalls.
(Source: Water Resources Management and Policy Research Center, Taiwan, 2009)

Consequently the rainfall patterns appear to be by and by difficult to meet the water requirements for the existing farming systems, particularly for the transplanting and growing stages of the first rice-crop periods usually in the dry season (Figure 2).

As a result, for the irrigation associations such as the Hsinchu Irrigation Association (IA), which have not any reservoir to store rainfalls in summer season, the adequacy of water supply in their service areas will decrease in dry season (Figure 3).

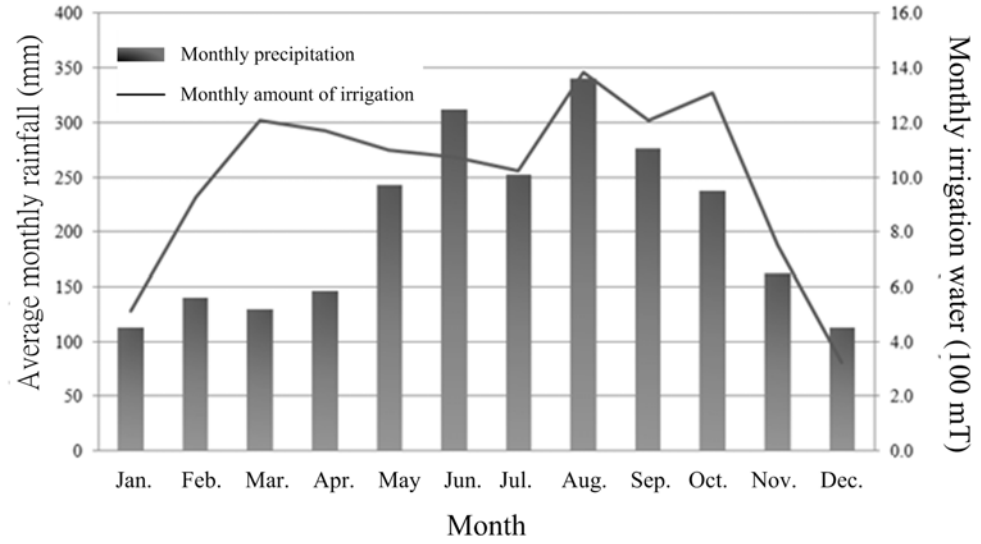

Figure 2. Average monthly rainfalls and irrigation water in Taiwan (from2002~2008)

Sources:

Rainfall data：Central Weather Bureau, Taiwan

Water consumption data：Council of Agriculture, Executive Yuan, ROC (Taiwan)

(Analyzed by Water Resources Management and Policy Research Center, Taiwan)

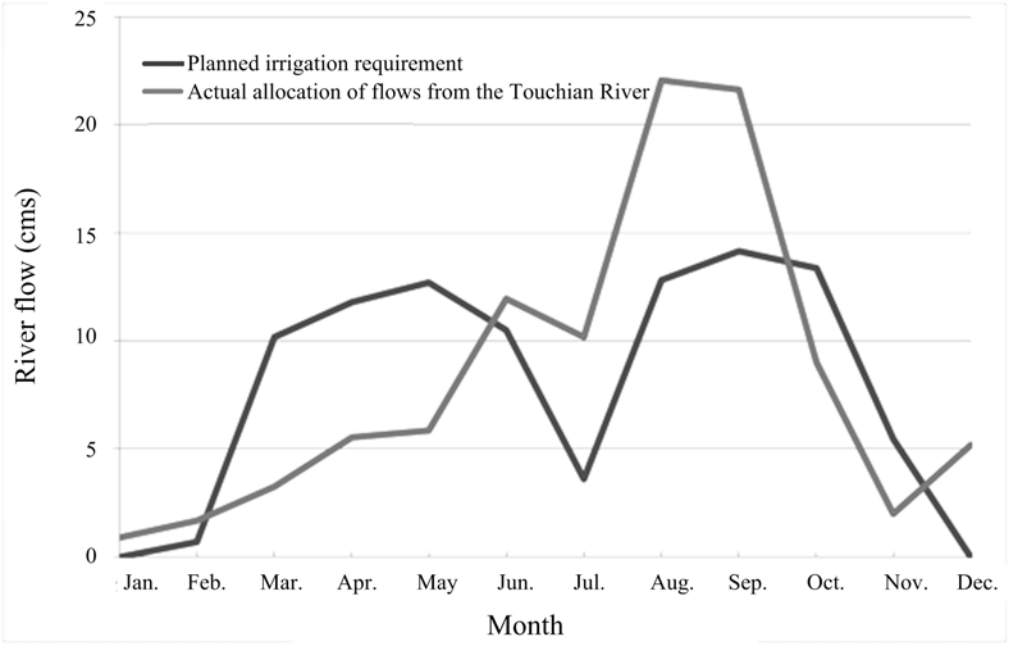

Figure 3. Agricultural water demands and available river flows.of Hsinchu Irrigation Association, Tawian

(Analyzed by Water Resources Management and Policy Research Center, Taiwan)

On the other hand, for the IAs like the Shihmen IA, which depend mainly on reservoir water supply, the inflow patterns to the reservoirs originally built for storing water in wet season have changed (Figure 4) and the storage capacities of the reservoirs are menaced by increasingly serious sedimentation due to the climate change. Furthermore, within the service areas of some IAs there have been developed industrial parks and hence have been inhabited with dense population, therefore huge volumes of water have been consumed and suspensions of irrigation thus often happened in recent years. These cases have evidenced that, with or without reservoirs, the water sources of IAs in Taiwan have been influenced by climate change. This notable fact indicates that positive planning of suitable strategies for adaptation as well as mitigation of climate change has to be conducted by Taiwan's agricultural water resources related agencies to ensure adequate water supply in the future.

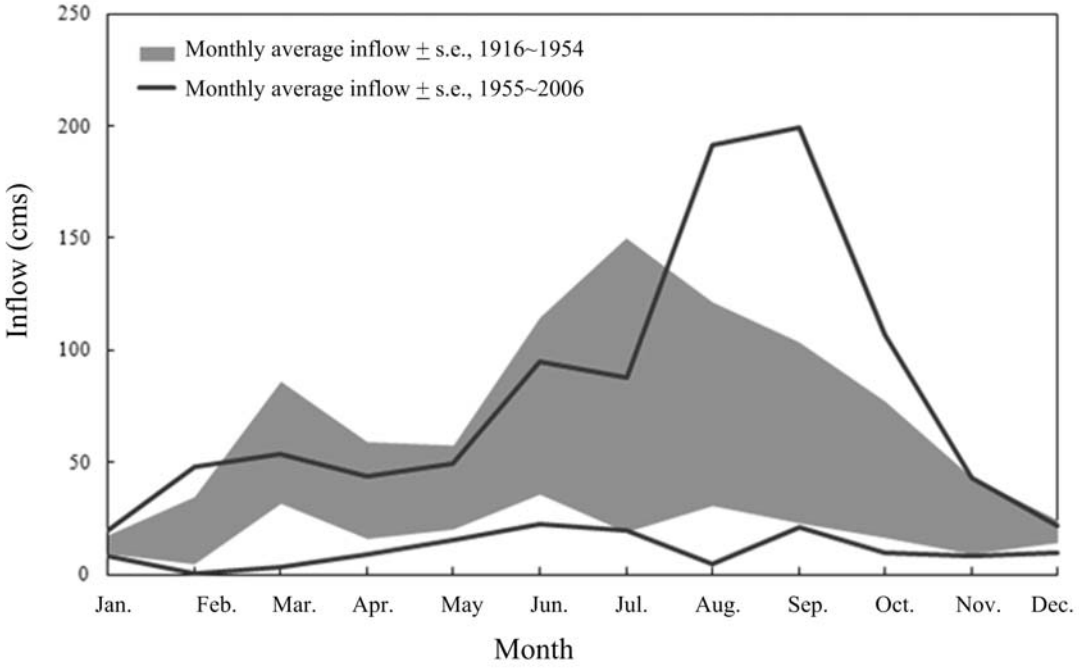

Figure 4. Comparison of the monthly inflow patterns of Shihmen Reservoir, Taoyuan, Taiwan during periods of 1916~1954 & 1955~2006. (s.e.=standard error)
(Analyzed by Water Resources Management and Policy Research Center, Taiwan)

2. The impact of climate change on agriculture in Taiwan

The scope of impacts of climate change on the agricultural water resources in Taiwan may cover three aspects: water quality, water quantity and hydropattern.

(1) Water quality

Stream flows during the dry season will become much lower, which will lead to reduction of self-cleaning and pollutants-carrying capacity. As the pollutant concentration increases, safety of irrigation water will be degraded severely as to cause decrease of available water for irrigation. It has been found that, from review of the monitored data, unqualified irrigation water has mainly existed in western Taiwan region where insufficient water sources often occur during dry seasons, especially from January to February (Figure 5). Moreover, man-made water pollutions have further exerted impacts on agricultural water quality. Consequently the water at many intakes and in canals cannot well meet the irrigation water quality standards in dry seasons. Although they may be diluted by using the clean water from other sources, the water pollution problems will be more critical once the severe drought comes.

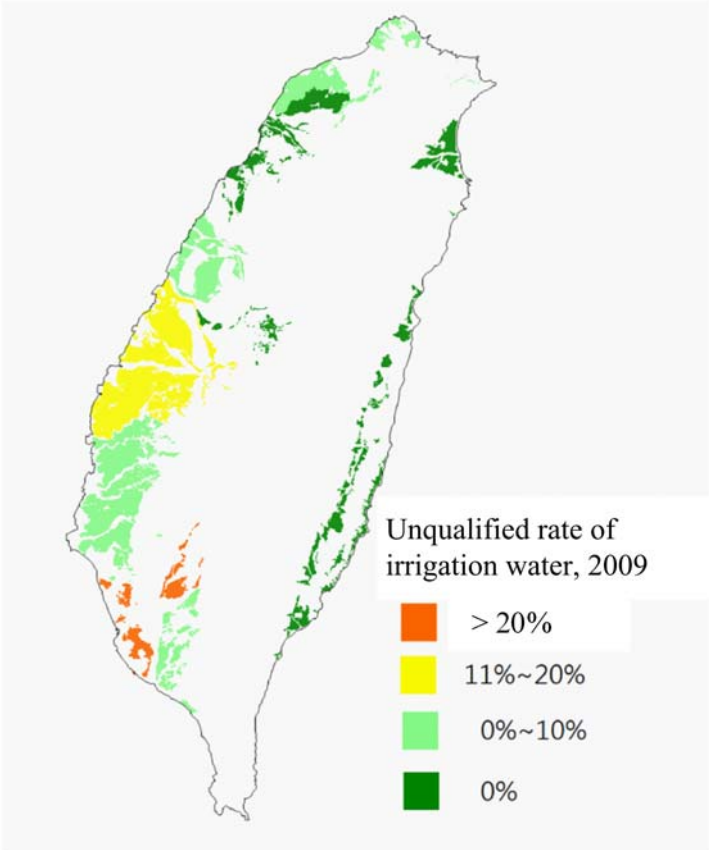

Figure 5. Unqualified rate of irrigation water in Taiwan, 2009
(Analyzed by Water Resources Management and Policy Research Center, Taiwan)

(2) Water quantity

Taiwan has experienced a temperature increment of 0.8℃ over the past century. It is noticeable that the annual average temperature has increased for the last 8 consecutive years, which was 0.1℃ higher than the global averaged increment of temperature (CWB, R.O.C, 2009). The paddy rice may thus grow faster and shorten its total growth period, but as the solar radiation increases the average total evapotranspiration (ET) for each rice-crop period is estimated to rise by 2.1% and 6.8% within the future 30 and 60 years, respectively (Chen *et. al*., 2007). According to the Central Weather Bureau, R.O.C (1994), over the past 100 years the rainfalls in the major rice production areas in Taiwan, notably in the southern region, has decreased by 10 to 34 mm every ten years. This phenomenon suggests that, if the current rice-growing area is to be sustained, the irrigation water supply will be further increased.

(3) Hydropattern

The increase of temperature due to climate change will lead to acceleration of hydrologic cycles, which will cause more uneven temporal and spatial distributions of rainfalls. In consequence, higher intensity rainfalls and more frequent severe droughts will occur. Over the past century, besides the rising temperature phenomenon, the humidity and rainfall have gradually decreased and extreme weather intensities have become more severe across Taiwan (CWB, R.O.C, 2009). These changes have induced alteration of inflow patterns to and reduction of capacities of the reservoirs in Taiwan, which has made the IAs depending on reservoir water supply more difficult to carry out existing irrigation requirement schemes (Figure 4). Meanwhile, in the last 100 years the typhoons striking Taiwan were also more frequent, increasing by 0.1 - 0.3 occurrence every ten years (CWB, R.O.C, 2009). Moreover, the rainfall intensities and amounts induced by these typhoons were also increasing. For instance, when Typhoon Morakot hit Taiwan in 2009, the cumulative rainfalls in the southern region reached 2,800 mm in only two days. The heavy rainfalls led to a loss of around NT$ 1.502 billion in total, in addition to the triggering of severe land sliding as well as erosion of hilly slopes that eventually caused heavy siltation in the southern Zengwen Reservoir, the largest reservoir in Taiwan. The total volume of siltation in the reservoir exceeded 90 million cu. m, which reduced the reservoir capacity by one sixth, and thus adversely influenced the supplements to agricultural water use (statistics from WRA, MOEA).

The extreme weather also causes higher frequencies of drought events which often lead to water shortages of domestic and industrial

water supply, and hence needs of shifts of agricultural water to supplement the deficits of those demands. For instance, the irrigation was ever stopped in order to shift its water to supplement the domestic and industrial water demands in five years between 2002 and 2010 (statistics from the COA). Statistics of drought events occurring from 1982 to 2009 provided by the IAs revealed that during the past 10 years, the numbers of years that rice crop suffered from droughts and water shortages were 4 as compared to 2.9 during 1992 ~ 2001. Consequently, those IAs that depend on run-of-river sources have been facing mounting difficulties in drawing water for irrigation due to worsening erratic river flows.

II. Adaptation strategies for agricultural water in various countries for coping with climate change

Climate change has influenced countries across the world. Regardless of their differences in geographic conditions and or industrial situations, they have formulated adaptation strategies to cope with their agricultural water resources problems. These strategies may be categorized in the following six directions: (1) investment in irrigation infrastructure, (2) upgrading of water resource utilization systems, (3) development of water-save technologies, (4) strengthening of early warning and countermeasure systems, (5) adjustment of farming patterns, and (6) improvement of crop varieties (Table 1).

Table 1. Categories of contemporary national adaptation strategies for agricultural water resources in the world

Strategy	Program
Investment in irrigation infrastructure	● Improvement of irrigation infrastructure through judicious development and optimized layout of water resources. (China) ● Effective utilization of existing irrigation facilities to ensure the essential water supply capacities. (Japan) ● Upgrading of the management and maintenance of existing water resources supply systems, and building of dams for irrigation. (NAPAs) ● Promotion of construction of farm ponds and other water storage facilities. (India)
Complement to the water resource	● Redistribution of water rights. (Japan) ● Strict management and adjustment of existing water uses in the event of abnormal water shortage.. (Japan) ● Saving of 10% to 15% irrigation water quantities by pricing the irrigation water. (Israel)

application system.	● Distribution of water resources in equitable amounts during droughts. (United Kingdom) ● Stipulation of the methods for levying the charges of agricultural water resources and discharge of waste water into irrigation canals. (Germany) ● Establishment of mechanism for allocation of and compensation to the agricultural water shifted to industrial use during droughts. (Germany) ● Stipulation of specifications and policies for management of water rights. (Germany) ● Scheduling of national water saving periods, and with authority's stipulations that all irrigation water use quantities should meet government' criteria; such as in certain areas are only permitted to be irrigated at night during the designated period. (France)
Strengthening of the early warning and response system	● Conduction of long-term research of and assistance to decision makers in identification & clarification of the impacts of climate change on agriculture and industries, and ratios of impacts & uncertainty. (United Kingdom) ● Assessment of the damage in agricultural sector in terms of monetary values. (United Kingdom) ● Identification of high-risk areas of water shortage by means of assessment of their vulnerability, and then execution/ improvement of adaptation strategies. (Japan) ● Assessment of the vulnerability of regions as well as agriculture and impact of extreme climate on agricultural production, thereby effectively integrating related factors including climate change impact, risk management, water resources and irrigation facilities for development of tools for decision-making. (Australia) ● Implementation of monitoring programs for water quality and quantity, and comprehensively planning of management system for agricultural water uses. (NAPAs) ● Defining the priorities of various adaptation programs and integrating the models for irrigation and agriculture, to accommodate the anticipated impacts of climate change on water resources and irrigation water. (UNPD)
Development of water-save technology	● Promotion of water-save measures in northern and northwestern regions of China. (China) ● Extension of the ration of water saving and automatic irrigation system facilities to a total of 90%. (Israel)
Improvement	● Selection and cultivation of drought-tolerant crop varieties.

of crop varieties	(China) ● Improvement of crop cultivation techniques. (Japan) ● In coping with poor harvests of cereal grains caused by high temperature and drought in summer, agricultural departments to formulate measures for adjustment of farming patterns to relieve agricultural damage and loss and hence to enhance food security. (Spain) ● Implementation of crop diversification, including introducing of drought-tolerant crops. (NAPAs)
Adjustment of farming system	● Adjustment of cropping system. (China) ● Saving agricultural water uses through changes of crop categories and farm management & operations. (United Kingdom) ● Shifting of the crop cultivation areas and control of the environment of husbandry sites. (Japan) ● Setup of long-term plans for the farmlands with elevations below sea levels. (the Netherlands) ● In the northern Europe (Scandinavia), promotion of the agricultural management improvement projects for adaptation to relatively longer crop growing seasons. (European Union) ● Extension of crop rotation area. (European Union) ● Adjustment of crop growing and harvest seasons. (UNPD)

III. Adaptation strategies for agricultural water resources in Taiwan

To cope with the previously mentioned problems due to climate change in Taiwan, the Council of Agriculture (COA) has issued the following agricultural administration policies in 2009: (1) strengthening of multi-functional irrigation infrastructure, (2) improvement of basic environment for agricultural production, (3) full development of productive, ecologic and living functions of agricultural water resources, (4) building up national Geographic Information System for irrigation, (5) upgrading of irrigation management efficiencies, and (6) full uses of the resources of IAs to develop water resources related industries. In Table 2 are displayed various measures and emphatic adaptation strategies formulated for agricultural water resources.

Table 2. Major irrigation works in Taiwan & other countries in relation to agricultural water resources adaptation strategies.

Council of Agriculture (COA), Taiwan	**Other Countries**
I. Renovation & improvement of old irrigation canals and facilities.	● Investment in irrigation infrastructure.
II. Conducting integrated planning of farmland consolidation projects by taking into account local industrial cultural, ecological and living environments.	● Investment in irrigation infrastructure.
III. Renovation & improvement of irrigation canals and farm drains in previous farmland consolidated areas..	● Investment in irrigation infrastructure.
IV. Promotion of ecology-based & safety-oriented irrigation infrastructure.	● Investment in irrigation infrastructure.
V. Promotion of upland crop irrigation and modernization of its management, and support & guidance to the farmers for constructing pipeline systems for upland crop irrigation.	● Develop agricultural water saving technology.
VI. Introducing of Geographic Information System, Internet and other electronic-related technologies for application to irrigation management system.	● Improvement of water resource application system.
VII. Protection of natural paddy environment and improvement of irrigation management system, to increase paddy field's functions of groundwater recharge, water retention, and flood mitigation.	● Strengthening of water resources utilization system. ● Augmentation of early warning and response system.

VIII. Monitoring of water quality in irrigation canals & drains to ensure water quality.	● Augmentation of early warning and response system.

IV. Recommended adaptation strategies, direction and implementation approach for Taiwan's agriculture

Strategy 1. Strengthening of water-saving measures for agriculture to increase water use efficiencies.

Direction:

(1) To maintain agricultural water quality, quantity and facilities.

(2) To formulate adequate water-saving measures for irrigation.

(3) To promote agricultural water use efficiencies.

Concrete implementation approach:

a. To set policies and guidelines for agricultural water resources in coping with climate change.

b. To strengthen water quantity observation and quality monitoring management, and actively research and develop effective early warning system.

c. To restrict discharging of drainage water into irrigation canals, and gradually implement separation of irrigation systems from drainage systems.

d. To enhance renewal and improvement of major water drawal and conveyance and distribution works.

e. To implement comprehensive farmland consolidation projects, and increase investment in irrigation water allocation as well as storage facilities.

f. To continually promote water-save irrigation measures.

g. To continually extend the water-save pipeline irrigation for upland crops.

h. To fortify research and development of the drought-tolerant and high-yield crop varieties.

i. To assess comprehensively the potential of agricultural water resources and set up flexible farming systems in various areas.

Strategy 2. Establishment of flexible agricultural water-use system.

Direction:

(1) To manage agricultural water uses to adapt to extreme weather conditions.

(2) To vitalize the proper use and economic utilization of agricultural water.

(3) To establish funds for shifting of agricultural water to other purposes.

Concrete implementation approach:

a. To set up water supply mechanism for vitalizing agricultural water resources.

b. To study the adjustment of farming systems in the areas with menace of high-risk water deficiency.

c. To develop irrigation management technologies for integrated uses of subsurface and surface water.

d. To recommend to the Executive Yuan (Cabinet) on establishment of the Fund for Implementation of Shift of Agricultural Water to Other Purposes".

Strategy 3. Storing water and recharging groundwater with the water retended in paddy fields.

Direction:

(1) To utilize wisely the paddy field's tri-functions of production, ecology and living to relieve the climate change impacts.

(2) To fully develop the paddy field's water storage and flood retention functions to minimize the damage caused by typhoons and floods.

(3) To recharge groundwater through paddy fields so as to store water in/beneath farms.

Detailed implementation approach:

a. To speed up establishment of mechanism for evaluation of the multi-functions of the rice agriculture.

b. To augment the productive, ecologic and living functions of paddy fields to mitigate the impacts of climate change.

c. To extend the education and propagation to the farmers on topics of the tri-functions of paddy fields (production,

ecology and living).

d. To promote the setup of demonstration plots for groundwater recharge through and flood retention in paddy fields, and then extend gradually the area of such practice.

Strategy 4. Review and strengthening of the operation and management of agricultural water resources to support the early warning system of droughts and floods

Direction:

(1) To reform and renovate the existing irrigation facilities.

(2) To review and augment the water resources management strategies.

(3) To take appropriate countermeasures for the damage of water intake works in the wake of floods.

Detailed implementation approach:

a. To comprehensively review the early warning and countermeasure systems for droughts and floods, by taking into consideration the impacts of climate change.

b. To comprehensively study the fragility of agriculture water resources and associated facilities under impacts of climate change, and on the effective arrangement of investments in irrigation-related industries.

c. To formulate measures for post-disaster reconstruction of irrigation facilities and related financial support mechanisms.

Summaries and Conclusions

The recommended adaptation strategies for Taiwan's agriculture are as blow: strengthening of water-saving measures, establishment of flexible agricultural water-use system, use paddy fields as retention pools, review and strengthening the operation and management of agricultural water resources.

References

FAO, 2002. World Agriculture: Towards 2015/2030 Summary Report, Food and Agriculture Organization of the United Nations.

Hua Xie and J. Wayland Eheart, 2004. Effects of Climate Change on Irrigation Decisions and Low Flow Frequency for a Typical Agricultural River Basin of

the Midwestern US, World Water and Environmental Resources Congress 2004.

IFPRI, 2009. Climate Change: Impact On Agriculture and Costs Of Adaptation, International Food Policy Research Institute.

IPCC, 2007. IPCC Fourth Assessment Report: Climate Change 2007 (AR4), Intergovernmental Panel on Climate Change.

UNEP, 2002. UNEP in 2002 : Environment for Development, United Nations Environmental Program.

Central Weather Bureau,1994. Analysis and Assessment of Climate Change in Taiwan. (in Chinese)

Central Weather Bureau, 2009. 1897-2008 Statistics of Climate Change in Taiwan. (in Chinese)

Qin, D. 2002. China's National Assessment Report on Climate Change, Science Press. (in Chinese)

Department of Bioenvironmental Systems Engineering, National Taiwan University. 2004. The Climate Change Impacts on Hydrology and Water Resources Management and Adaptation Strategies. (in Chinese)

Chen, S. H., Chen G. H., Huang J. T., Yao, M. H., Lee P. H. and Shen, Y, 2007. Effects of Global Warming to Rice Production in Taiwan, Agronomy Society of Taiwan. (in Chinese)

Water Resources Management and Policy Research Center, Tamkang University, Taiwan, 2008. Improving capability for water resource affairs management and policy-planning, Water Resources Agency, Ministry of Economic Affairs. (in Chinese)

Ministry of Land, Infrastructure, Transport and Tourism, 2008. Water Resources in Japan. (in Japaness)

Water Resources Agency, Ministry of Economic Affairs, 2005. Introduction to the Water Resources Agency, Ministry of Economic Affairs. (in Chinese)

Council for Economic Planning and Development, 2008. Assessment of Long-term Effects of Climate Change and Adaptation Strategies, General Report I. (in Chinese)