THAILAND

TECHNOLOGY NEEDS ASSESSMENTS REPORT FOR CLIMATE CHANGE

ADAPTATION

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FOREWORD

The importance of science and technology has been highlighted as tools for mitigation and adaptation for both developed and developing countries. The latter, in particular, has become more pressing to develop and acquire key technologies to cope with climate change, including disaster in various forms and severity. The globalization of environmental protection, in some sense, has increased enormous pressure on developing countries while trying to continue their economic development, making it necessary to identify their own technological priorities.

Thailand is no exception, even though there is a certain level of technological research and development, capabilities and achievement. It is thus an opportune time to assess and prioritize technological needs for climate change. Various technologies in vulnerable sectors –energy, agriculture, water resource and modeling – were identified through extensive analyses of data on current and projected science and technology capabilities, drivers, and barriers in Thailand.

The Ministry of Science and Technology, Thailand, through the National Science Technology and Innovation Policy Office, has analyzed and prioritized the technologies required for nation-wide mitigation and adaptation regimes. The "Technology Needs Assessments and Technology Action Plans Report for Climate Change Mitigation/Adaptation in Thailand" is the first comprehensive report providing the technology requirements and their subsequent action plans in terms of climate change mitigation and adaptation. This report is significant for investors, technology developers, scientists, intelligence communities, analysts and policy makers in facilitating the growth of national prosperity under the impact of climate change leading to the green growth that are sustainable.

(Dr. Plodprasop Suraswadi)
Minister of Science and Technology

PREFACE

Thailand today faces a number of challenges affected by climate change. These include ever-increasing natural and human-made disaster – such as, extreme weather events, land-slide, flood, draught, rising sea level, biodiversity loss, and health damage – ,which if not addressed may lead to catastrophic consequences. Climate change is no longer a mere scientific concept owned by scientists but moved into our daily lives as more and more people become concerned with the complexity of this issue. The latest available data on greenhouse gas emissions from Thailand show that emissions continue to increase, underscoring the need for action while sustaining the economic reinforcement. To cope with the climate situation, it would be reasonable for Thailand to prioritize its technology strategies and identify problem areas in terms of policy objectives on mitigation and adaptation.

As a first step, it is necessary for Thailand to assess whether their current efforts in improving technological capability have been successful in supporting mitigation and adaptation. The review and analysis of Thai technologies could reflect whether the current technology-related policies and national research system support mitigation and adaptation and whether they are in harmony with other related impacts such as social acceptance and economic cost. Appropriate approaches to the technologies that would best-suit the stage of national development would be desirable. These investigations could provide a wide range of strategic options for policy-making both in the short and longer terms.

The National Science Technology and Innovation Policy Office (STI) continues to broaden and deepen its involvements in climate change mitigation and adaptation, particularly, in technology development and technology transfer policy. However, any technological change does not occur in isolation. It can have considerable impact on the people, culture, economy, and society in the overall context. Scientists, investors, economists and policy makers should work together towards developing technology with full awareness of the complex interactions and relationships within the system. STI's aim is, therefore, to bridge the cooperation among government agencies, private sectors, academia and industry in strengthening the policy implementation in a sustainable manner. In responding to the global and local climate concerns, STI conducts the research project entitled "Technology Needs Assessments and Technology Action Plans Report for Climate Change Mitigation/Adaptation in Thailand" among one of the first fifteen countries from Africa, Asia, Latin America, Caribbean, and Europe to conduct the projects funded by the UNEP Division of Technology, Industry and Economics (DTIE) in collaboration with the UNEP Risoe Centre.

I believe the results of the well thought out findings in this report could provide Thailand not only the mitigation and adaptation strategic plan and policy recommendations to the Thai government but also identifying opportunities for capacity building, research collaborations, private and industrial participations, and technologies transfer to enhance socio-economic sustainability in the long-term. It is also our belief that the outcome would benefit not only our own country but the global community as a whole.

P. Durongkaveroj

(Dr. Pichet Durongkaveroj)
Secretary General
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Abbreviations:

List of Abbreviations could follow the format below.

AIT	Asian Institute of Technology
AOGCM	Atmosphere-Ocean Coupled General Circulation Model
AR4	IPCC Fourth Assessment Report: Climate Change 2007
ASEAN	Association of South East Asian Nations
BB	Bureau of the Budget
BIOTEC	National Center for Genetic Engineering and Biotechnology
BOAC	Budget for Overseas Academic Conferences
CBD	Convention on Biological Diversity
CCAM	Conformal-cubic atmospheric model
CCKM	Center of Excellence for Climate Change Knowledge Management
CDM	Clean Development Mechanism
CICERO	Center for International Climate and Environmental
CIST	Climate Impact Science and Technology Center
CMU	Chiang Mai University
CWRM	Community water resource management
DEM	Digital elevation model
DDPM	Department of Disaster Prevention and Mitigation
DOA	Department of Agriculture
DOAE	Department of Agriculture Extension
DNA-CDM	Designated National Authority for the Clean Development Mechanism
DSS	Decision support system
DTIE	Division of Technology, Industry and Economics
EGAT	Electricity Generating Authority of Thailand
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GCM	General Circulation Model
GEF	Global Environment Facility
GHG	Greenhouse gas
GIS	Geographic information system
GISTDA	Geo-Informatics and Space Technology Development Agency
GM	Genetically modified
GMO	Genetically modified organism
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
HAII	Hydro and Agro Informatics Institute
IDO	Indian Ocean Dipole
IEA	International Energy Agency
IMNV	Infectious myonecrosis virus
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual property rights
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IUWRM	Integrated urban water resource management
JMA	Japan Meteorological Agency
LDD	Land Development Department
KMUTT	King Mongkut's University of Technology Thonburi
KU	Kasetsart University
MAS	Marker Assisted Selection
MCDA	Multi-criteria decision analysis
MICT	Ministry of Information and Communication Technology
MONRE	Ministry of Natural Resources and Environment
MOAC	Ministry of Agriculture and Cooperatives
MOE	Ministry of Education
MOI	Ministry of Interior

MOST	Ministry of Science and Technology
MU	Mahidol University
NCCC	National Committee on Climate Change
NCAR	National Center for Atmospheric Research
NDWC	National Disaster Warning Center
NESDB	National Economic and Social Development Board
NESDIS	National Environmental Satellite, Data, and Information Service
NGOs	Non-governmental organizations
NOAA	National Oceanic and Atmospheric Administration
NSO	National Statistical Office
NSTDA	National Science Technology Development Agency
PCD	Pollution Control Department
PDO	Pacific Decadal Oscillation
OAE	Office of Agricultural Economics
ONEP	Office of National Resources and Environmental Policy and Planning
R&D	Research and Development
RID	Royal Irrigation Department
SCADA	Supervisory Control and Data Acquisition
SMEs	Small and medium enterprises
STI	National Science Technology and Innovation Policy Office
TAP	Technology Action Plan
TDRI	Thailand Development Research Institute
THAIST	Thailand Advanced Institute of Science and Technology
TGO	Thailand Greenhouse Gas Management Organization
TMD	Thai Meteorological Department
TNA	Technology Needs Assessment
TRF	Thailand Research Fund
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
URC	UNEP Risoe Centre
WRF(ARW)	Weather Research and Forecasting (Advanced Research WRF)

TNA and TAP Report for Climate Change Adaptation in Thailand

1. Background

Many countries are concerned about global warming and have committed to taking action against the threat. By 2010, one hundred and ninety three parties have ratified the Kyoto Protocol; however, only 37 countries (Annex I countries) have committed themselves to reducing their greenhouse gas (GHG) emissions to the levels required in the treaty (UNFCCC). Thailand ratified the Kyoto Protocol in August 2002 but has no legal binding target to reduce or to limit its GHG during the first commitment period. Thailand, however, can become involved in the carbon trading market through the Clean Development Mechanism (CDM).

In order to cope with climate change, both mitigation and adaptation measures and technologies are needed. The UN defines mitigation, in the context of climate change, as human intervention to reduce the sources or to enhance the sinks of greenhouse gases. Adaptation technology, on the other hand, is defined as finding and implementing promising approaches for adjusting to adverse effects from climate change. A technology needs assessment (TNA) is an effective process that provides a country the opportunity to track its need for new equipment, techniques, services, capacities and skills for both climate change mitigation and adaptation.

The United Nations Environment Programme (UNEP), on behalf of the Global Environment Facility (GEF), is implementing a new round of TNAs with objectives that go beyond identifying technology needs narrowly. These TNAs will lead to the development of a national technology action plan (TAP) that prioritizes technologies, recommends an enabling framework for the diffusion of these technologies, and facilitates the identification of good technology transfer projects and their links to relevant financing sources. The TAP will systematically identify the practical actions necessary to reduce or remove political, financial and technological barriers.

The UNEP Division of Technology, Industry and Economics (DTIE) in collaboration with the UNEP Risoe Centre provide targeted financial, technical, and methodological support to assist 36 countries to conduct TNA projects. Thailand is one of the first fifteen countries from Africa, Asia, Latin America and the Caribbean, and Europe being supported in the first round, which began in 2010.

The overall objectives of the Thai TNA and TAP project discussed in this report are as follows:

- To identify, assess, and prioritize technological needs for GHG mitigation and adaptation.
- To access information on technology transfers and increase public awareness on climate change issues.
- To evaluate the various social issues relevant to the proposed policy, conduct an analysis on the pros and cons of different control strategy alternatives, and provide estimates of the costs and impacts of legislative mandates.

2. The uses of TNAs and TAPs

This report provides an assessment of the technology needed for nationwide mitigation and adaptation actions. The results of the analysis are useful for policy makers to build a roadmap for internal mitigation and adaptation technologies and to align with the global community. This report helps Thailand to identify technological needs and reinforce its capacity in the area of climate change.

3. Structure of the report

This report is a policy analysis summary and is organized as follows:

- Section I is the TNA report, which focuses on technology prioritization for the agricultural, water resource, and modeling sectors.
- Section II lays out the TAPs for the specific sectors selected in Section I through a prioritization process.
- Section III elaborates cross-cutting issues for the TNAs and TAPs of the nation's different sectors.

Section I

Technology Needs Assessment

Technology needs assessment (TNA)

Executive summary

As one of the six countries in Asia supported by the Global Environmental Facility (GEF) through the UNEP to prepare climate change technology needs assessments (TNA), the Royal Thai Government assigned the National Science Technology and Innovation Policy Office (STI) as the Thai TNA coordinator. The Asian Institute of Technology (AIT) is the regional center under the TNA project for Asia. This section elaborates the process and result of the TNA intended to identify, to assess the status of, and to prioritize various adaptation technologies that play a role in defining how Thailand can adapt to the effects of climate change on the prioritized sectors. The information and assessment in this section is a fundamental for the section II, Technology Action Plan (TAP).

As climate change affects various sectors and stakeholders in the country, the first step of the TNA is to identify the highly impacted sectors in urgent need of adaptation technology. Thus, on July 12, 2010, the Office of National Resources and Environmental Policy and Planning (ONEP), under the Ministry of Natural Resources and Environment, and the STI, under the Ministry of Science and Technology, launched the first meeting for the Thailand Technology Needs Assessment project to identify the highly impacted sectors. Experts and stakeholders in climate change technology participated in this first meeting to discuss their viewpoints and concluded that adaptation technology is needed for the agricultural sector, water resources management sector, and modeling sector. Subsequently, to develop a TNA for targeted sectors, the Steering Committee appointed three technology workgroups for the three sectors including 1) the National Center for Genetic Engineering and Biotechnology (BIOTEC), the National Science and Technology Development Agency (NSTDA), for the agriculture sector, 2) the Hydro and Agro Informatics Institute (HAII) for the water resource management sector, and 3) the Center of Excellence for Climate Change Knowledge Management for the modeling sector. The members of these workgroups also serve as national consultants. Here we summarize the assessment processes and findings of each sector as follows:

1. Agricultural Sector

Thailand's agricultural sector is a large sector consisting of various subsectors. This TNA, however, will focus only on selected subsectors rather than the entire agricultural sector to ensure that adaptation technologies of interest can be translated and implemented in the most effective manner. Thus, first of all, the target subsectors were identified by considering their vulnerability to climate change and contributions to the country's economic development and food and energy security. A meeting with expert consultants and stakeholders held on May 11, 2011, concluded that field crops and aquaculture are the two subsectors most vulnerable to climate change and need immediate attention in terms of technology development and transfer. It should also be noted here that while this TNA is being developed to meet the needs of target sub-sectors, many of these technologies are cross-cutting and can be applied across many other agricultural sub-sectors as well.

In the development of the TNA, adaptation technology in five areas were initially proposed and discussed. They are climate forecast and early warning systems, crop improvement, precision farming practices, post-harvest technology, and animal nutrition and feed technology. The criteria used in the prioritization of adaptation technologies within the target sub-sectors were 1) impact of technology, 2) technology capability, 3) policy and regulation, and 4) public perception and farmer acceptance. Based on the two stakeholder meetings using these four criteria, the experts voted for these following three types of adaptation technologies: forecasting and early warning systems (37%), crop improvement technology

(31%), and precision farming technology (17%). Forecasting and early warning systems is to reduce the risk of damage from extreme climate events and pest/ disease outbreaks as well as to increase the ability to select the right crops based on specific planting time and crop cycle, while crop improvement for climate resilience (Marker Assisted Selection (MAS) and genetic engineering) is to reduce the risk of yield loss while increasing resource efficiency. Finally, precision farming technologies is to enable farmers to make informed decisions concerning their farming operations as well as to reduce inputs while maintaining maximum productivity and minimizing the effects on the environment.

MAS has been developed in the country for quite some time and is ready to use as well as transfer to other countries in a south-south cooperation manner. However MAS is currently limited to jasmine rice KDML105 and glutinous rice RD6; meanwhile, the other crops have undergone much less research. Furthermore, crop improvement for climate resilience needs more molecular breeders, physiologists, plant pathologists and entomologists. In addition to genetic engineering technology, successful plant transformation has been limited to few plant species due to a lack of government support and strong opposition from several local NGOs. Today, genetic engineering is heavily covered by patents, perceived intellectual property issues creating the impression of a barrier to technology transfer.

Precision farming in Thailand is at a nascent stage of development. Even though some technologies such as drip irrigation system, customized fertilizer and closed system for aquaculture have already been transferred to pioneer farmers, the number of technology recipients is quite limited. Most projects and initiatives are still at a pilot/ prototype-building stage.

Forecasting and early warning systems are being used to monitor and predict weather patterns as well as soil conditions. The software supporting these systems is typically imported. Furthermore, the use of simulation models to predict pest/disease patterns is still rare, with several research institutes only beginning the preliminary development work, therefore requiring technology and knowledge transfer from more technologically advanced countries.

2. Water Resource Management Sector

Thailand has encountered a variety of water resource management problems ranging from floods to droughts. Thailand’s water resource management is facing both natural and management challenges. The natural challenges are from natural variability. For example, there is great spatial and temporal rainfall variability. Some areas suffer from both drought and floods repeatedly, sometimes, in the same year. In addition, disasters such as storms are recently more severe and more unpredictable. On the other hand, the management challenges include the lack of flexibility and buffering capacity of the current infrastructure. Also, infrastructure and stream channels are not properly maintained. Drought and flood are handled separately. So, in places where both problems arise, redundant investments are inevitable. Land use change, particularly deforestation and mono-crop plantation in the headwater streams, alters watershed runoff characteristics. Communication breakdown and lack of awareness of governmental agencies and the public are also critical.

Consequently, the changing water situation in Thailand and the current situation of water infrastructure management were the two primary facts used to analyze the country’s top challenges and goals in water resource management. These help define objectives of technology transfer and diffusion. Water security and agriculture security is pinpointed as Thailand’s goals for water resource management and six objectives for technology transfer and diffusion are as follows: 1) Increasing security in terms of capital water supply, 2) building flexibility for management in all types of supply and demand scenarios, 3) minimizing damage from disasters, 4) maximizing water usage efficiency, 5) including all sectors in the management, and 6) building knowledge/know-how and data for management. In short, the prioritized technologies must be able to alleviate problems or increase efficiency of the infrastructure management system, as well as develop the competency of the domestic human resources.

Technology prioritization comprised three major steps, which were taken with stakeholder engagement during three focus group sessions and one national public hearing on the technology needs assessment for water resource management. The first step involved reviewing the possible technology groups and listing the technology options. A preliminary list of technologies as well as their contributions to the water resource management objectives of Thailand previously mentioned were prepared, discussed, and summarized after the focus group sessions with experts from the academic, governmental, and private sectors. The preliminary list was then publically reviewed in the national public hearing workshop to obtain feedback from all stakeholders and to ensure that all of the relevant adaptation technologies were included. The final list of possible adaptation technologies include (1) environmental observation, (2) weather and hydrological modeling, (3) flood and drought risk management, (4) operation of water infrastructures, (5) community water resource management: CWRM, (6) integrated urban water resource management (IUWRM), and (7) early warning systems.

Two categories of criteria including impact and capacity assessments were used to prioritize adaptation technologies based on the multi-criteria decision analysis. Impact assessment judges the importance of technologies from the outputs and outcomes of technology implementation, while capacity assessment evaluates Thailand's current state of technology and readiness for technology implementation through SWOT analysis. Stakeholders participated in the criteria review and in the scoring of all technology groups and technologies. The high-impact technologies that Thailand is not ready to develop and to implement were then selected and prioritized as "technology needs." The rankings are: 1) networking (via pipes or canals) and management of infrastructures (including zoning) under the technology group#4 (the operation of water infrastructure), 2) seasonal climate prediction under the technology group# 2 (weather and hydrological modeling), and 3) sensor web using observation and/or modeling data under the technology Group # 7 (the early warning).

All of the selected technologies are vital adaptation technologies for increasing the capacity and efficiency of water resource management and disaster management in Thailand. In addition, they are appropriate tools for driving the country toward its national policies and strategies. Furthermore, while individual technology needs and technology development are important, the development of a system that integrates all of the technologies to support decision making is the most crucial part of the success of Thailand's water resource management. The hard or structural technologies need to consider systematic engineering and a multi-objective approach in order to ensure a long-life cycle and to maximize flexibility to cope with all scenarios of water supply and demands in the face of climate change.

3. Modeling Sector

The modeling sector is working at the interfaces between climate change and other affected sectors, including the agricultural sector and water resource management sector. It provides adaptive tools for coping with undesired consequences of climate change. Modeling tools are recognized as needed technology for both the agricultural and water resource management sectors. The goal of the Thailand modeling sector is to provide effective tools and integrated systems that enable other affected sectors to develop reliable assessments and strategic plans for mitigation and adaptation purposes. The affected sectors include the climate sector, water resource management sector, natural disaster sector, transportation sector, industrial sector, energy sector, agriculture sector, social sector, economic sector, and health sector. Special attention is placed on the water resource management and agricultural sectors because of their national relevance discussed previously.

The process for technology prioritization comprises of five major steps that involve stakeholder engagement through focus group sessions and a national public hearing on technology needs assessments. The first step involved reviewing possible technology categories and brainstorming technology options. Three categories of modeling sector needs resulted from the brainstorming including hardware, software, and database management. Then, in the 2nd step, we identified the modeling tools used in various sectors and looked at them as candidates for use in an integrated, cross-sectoral modeling tool for Thailand. Then, the modeling candidates and technology options of each category were evaluated during the focus group sessions by experts of the affected sectors from academic, governmental, and private parties. Next, the preliminary list of selected technology options resulting from the focus group meetings was then publically reviewed at the national public hearing workshop to obtain feedback from all the stakeholders and to ensure that all relevant adaptation technologies were included. The criteria, weights, and scores were proposed by the national consultants and commented by the stakeholders during the stakeholder consultation. Performance efficiency, cost worthiness, and acceptability were the three categories of criteria considered in the MCDA. The performance efficiency was judged by the ease of use and the forecastability, while cost worthiness was evaluated by considering the further development and the transferability of the technologies. The acceptability evaluates the level of international and national acceptability of the technologies. Each criterion had equal weight for scoring, and three levels of scores, *good*, *fair*, and *poor* available for evaluation. Finally, a final focus group was held to listen to the experts' comments about the technology options revised after the public hearing. The top-priority technology need in each category was then selected for technology action plan (section II).

According to the technology prioritization process, the national data center ranked the highest among the technologies in the hardware category, while the national data transfer/management process ranked the highest among the technologies in the database management category. Finally, the WRF (ARW) model ranked the highest among the candidate models in the integrated model category.

A data center contains the essential hardware, a large collection of data from various relevant and creditable sources. In addition, it also serves as a data distributor to users and organizations that can benefit from using the network. Without a reliable data center, it is difficult to obtain a meaningful modeling result. Because modeling climate change impacts can be useful for the adaptation of various sectors, ranging from the climate sector to the health and economic sectors, an integrated data center is highly desirable. Such a data center would make it easy for users to access all of the data required for cross-sectoral modeling efforts. Although Thailand has a few data centers, these data centers only store data dedicated to specific purposes to comply with the authority and responsibilities of their corresponding governmental agencies, making it more difficult to obtain data for cross-sectoral modeling efforts. In other words, unlike several other countries, Thailand does not have an integrated national data center. The benefits of having a national data center include enhancing the efficiency of domestic and international data collection and exchange, providing a data network for all the stakeholders and responsible parties, and serving as an official information distributor to all the stakeholders and responsible agencies. A national data center can promote both data collection, data application, and research in the short term and long term.

Several governmental agencies in Thailand, for example, the Department of Meteorology, Royal Irrigation Department (RID), and Pollution Control Department (PCD), daily monitor and record observed data regarding the weather, water, and air quality, respectively. Typically, these data are used to develop the domestic weather forecast. However, climate change is a global phenomenon; thus, its impact cannot be modeled by using only the observed data of our country. As a minimum requirement, data from other countries in Southeast Asia must be considered as inputs of climate change modeling. Yet, Thailand has no official and effective means of data collection, data transfer, and database management on a regional level. Only a few research institutes in Thailand have attempted to collect and manage data from other sources, domestically and regionally, for such a modeling effort. Thus, national data transfer/management is required to equip the national data center with creditable and intensive data. The data needed include GCM data, climate data, weather data, and observation data of Southeast Asia.

Last but not least, although various governmental and public stakeholders in Thailand utilize several modeling tools, each sector uses a specific model favorable for the application of interest, and we do not see the use of an integrated model, which allows for climate change impact estimations across the sectors. To be more effective, Thailand should utilize an integrated model, which allows for the analysis of climate change impacts across the sectors. An integrated model can also help to assess how a climate change impact from one sector consequently affects another sector. From the expert opinion in a group meeting, the WRF (ARW) model ranked the highest among the candidate models in the integrated model category addressed the need of agricultural sector and water resource management sector.

1. Introduction

1.1 Overall Objectives of the TNA

The purpose of a TNA is to assist in identifying and analyzing high-priority technology needs to facilitate the transfer of environmentally sustainable technologies and programs to a country (UNFCC 2011). A TNA provides a country the opportunity to track its need for new equipment, techniques, services, capacities and skills for mitigating GHG emissions and reducing the vulnerability of sectors and citizens' livelihoods to climate change. In addition, a TNA is one of the key elements used to enhance technology transfer. Technology transfer refers to a set of processes covering the flow of know-how, experience and equipment for mitigating and adapting to climate change across different stakeholders such as governments, private sector entities, financial institutions, NGOs, and research and education institutions (IPCC 2002). It is designed to promote the transfer of clean technology from developed countries to developing countries.

When mentioning the term *technology*, most people often think of the application of science and scientific methods and machines to achieve a goal. The term *techno*, however, also means "art, skill, and craft." Thus, the term *technology*, in this report, includes not only scientific knowledge and applications such as machines, infrastructure and equipment but also the art and management such as domestic wisdom and practices. We reviewed various technologies from simple, local management practices to sophisticated, advanced technology. Here, we begin section II with the nation's climate change circumstances and rationally journey to the conclusion of this TNA.

1.2 National circumstances on climate change

GHG emissions in Thailand have increased by approximately 4.7% per year from 2000 to 2008. The largest source of emissions is the electricity generation sector (78 million tons, MT), followed by the industrial sector (67 MT) and the transportation sector (51 MT) (Figure 1) (International Energy Agency 2010).

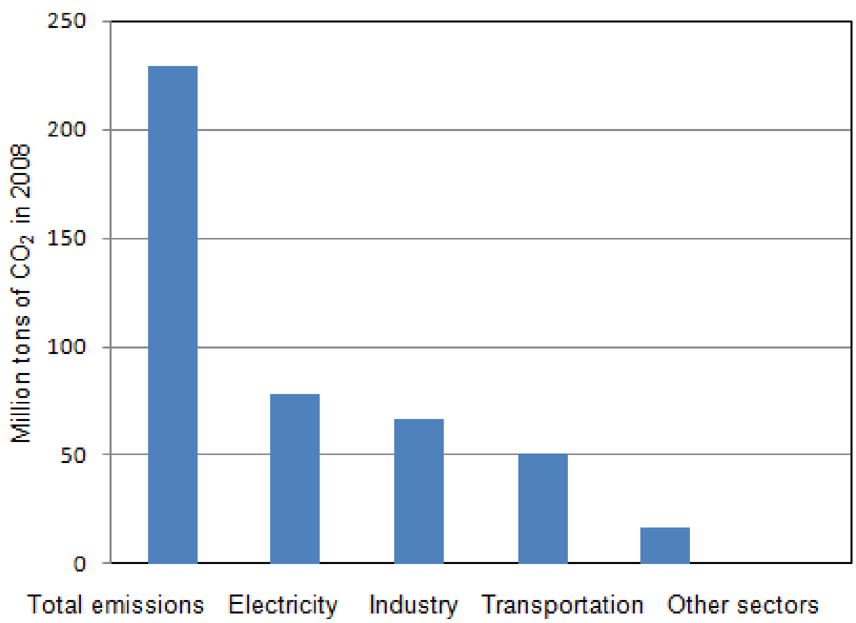


Fig 1 GHG emissions by sector in 2008 (million tons)
Source: IEA (International Energy Agency 2010)

An analysis from the Intergovernmental Panel on Climate Change (IPCC) projected that Thailand will experience an increase in temperature of 1.4 to 5.8 ºC over the period from 1990-2100(IPCC 2001). The projected climate condition of Thailand under this global warming threat is being studied by various researchers. A few general circulation models (GCMs) have predicted that the current average temperatures in Thailand of 21.5-27.5 °C may increase to 25-32 °C. Fig 2 illustrates an example of such a simulation, suggesting temperature increases in all regions, especially in the eastern and southern parts of Thailand(Thongtanakul 2009). Similarly, two studies by Chinvanno (Chinvanno 2009; Chinvanno 2009) concluded that the hot season, defined as days with a maximum over 33 °C, would be longer by 2-3 weeks.

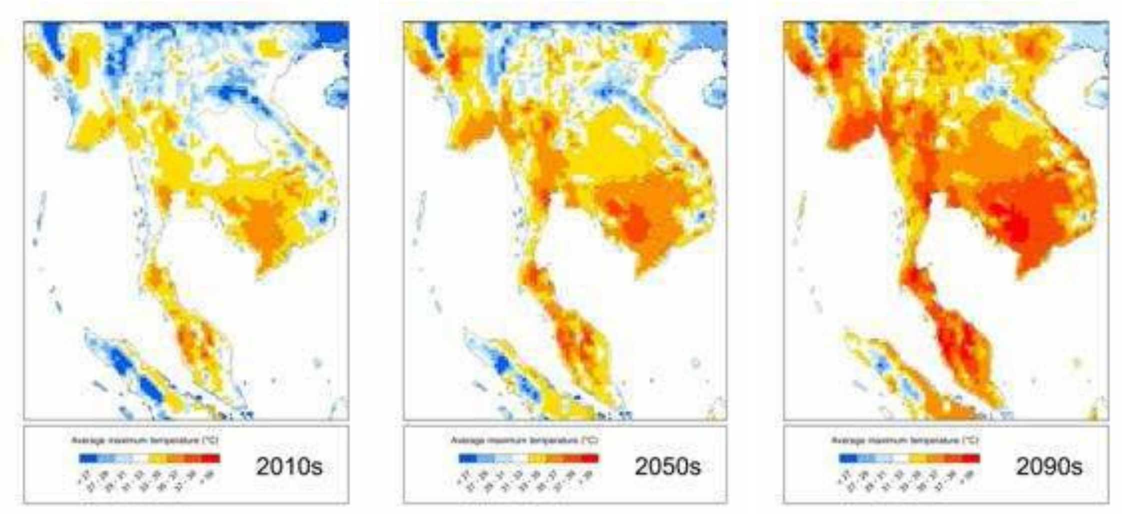


Fig 2 Trend of future changes in average maximum temperature in Southeast Asia

The impacts from climate change are not proportionally distributed among the GHG producers. In other words, the impacts are unavoidable and unpredictable for Thailand even though Thailand is not a major GHG producer. Global warming causes changes to the seasons, such as in the pattern and intensity of rainfall. Moreover, it can increase the intensity of El Nino and La Nina, which typically occur in Thailand every 4-10 years. Temperature changes and rising sea levels threaten to decrease fishery, agriculture, and aquaculture yields. Corals might suffer more severe bleaching due to the continual rising of the ocean temperature. Several sectors—including agriculture, water and coastal resources, and land use—are vulnerable to climate change and require adaptation technologies. The two national priority sectors facing direct impacts are the agricultural and water resource sectors.

Agriculture is still a fundamental part of the Thai economy and social structure. Global climate change could affect agriculture in various ways. The effects of climate change introduce 1) more frequent extreme events likes floods, droughts, and storms, 2) abnormally severe weather, and 3) a rise in temperature (Rerkasem 2011). The adaptive capacity of farms and farmers in the country is an important element of the country's food and economic security and should be regarded as a national priority. The Office of Agricultural Economics (OAE) regards rice, sugar cane, cassava, and palm oil as major national economic crops and has called for governmental support to acquire sufficient climate change adaptation technology (ONEP and UNDP 2010).

Thailand has 25 river basins in total and many sub water systems throughout the country. Over the past several decades, Thailand has encountered a variety of water resource management problems, ranging from flooding to droughts; some parts of Thailand experience both flooding and drought in the same year. These water resource management issues severely interrupt the social and economic growth of the country. Due to the nature of Thailand's agricultural-based economy, proper management of its water resources is imperative.

1.3 National sustainable development strategies for climate change

The Office of Natural Resources and Environmental Policy and Planning (ONEP), under the Ministry of Natural Resources and Environment (MONRE), is the core agency responsible for the national climate change plan, strategy, activity, and the nation's cooperation internationally in climate change negotiations. ONEP works under the National Committee on Climate Change Policy and serves as the national agency to the UNFCC(ONEP and UNDP 2010). ONEP developed National Strategies for Climate Change (2008-2012) aimed at mitigation and adaptation activity promotion. The strategies contained in this first national plan can be divided into six approaches.

1. Building capacity to adapt and reduce Thailand's vulnerability to climate change impacts: This strategy aims to protect and conserve natural resources as well as to improve adaptability in the natural resource, agricultural, and industrial sectors.
2. Promoting greenhouse gas mitigation activities based on sustainable development: Its goal is to promote clean technology in the various sectors. Mitigation activities could include, for instance, increasing energy efficiency, promoting the use of renewable energy, minimizing solid waste and chemical use in farms, recycling material, as well as increasing carbon sinks.
3. Supporting R&D to better understand climate change and its impacts as well as adaptation and mitigation options: This approach aims to provide useful information to policy makers via technical and academic support from climate change researchers.
4. Raising awareness and promoting public participation: The objective of this approach is to motivate public awareness and to promote common understanding on the roles of the local community on climate change issues.
5. Building the capacity of relevant personnel and organizations to establish a framework for knowledge and technology coordination and integration: This strategy aims to promote collaboration between personnel and organizations involved in climate change to transfer and share knowledge, technology, and experience.
6. Supporting international cooperation to accomplish the common goal of climate change mitigation and sustainable development: This approach promotes international cooperation to transfer and share knowledge, technology, and experience.

To enable the implementation of the National Strategy for Climate Change, ONEP transformed these strategies into the "National Master Plan on Climate Change 2010-2019." The ten-year master plan consists of three approaches:

Strategy 1: Creating adaptability to respond and reduce the impacts of climate change.

Strategy 2: Supporting GHG reduction and increasing carbon sinks under sustainable development schemes.

Strategy 3: Integrating knowledge, databases, and tools on climate change management.

The government has also established new institutes to cooperatively work within the national frameworks. A description of these new institutions follows.

The National Committee on Climate Change (NCCC)

The National Climate Change Sub-committee was first established under the National Environmental Board after the country ratified the UNFCCC in 1992. In 2007, the government upgraded the National Climate Change Sub-committee to the National Committee on Climate Change (NCCC), chaired by the prime minister. The committee comprises of experts and high-level officers from related ministries. The committee formulates climate change policy and provides guidance/framework for negotiations in international forums.

The Thailand Greenhouse Gas Management Organization (TGO)

The TGO was established in 2007 as a public organization. While the NCCC sets policy, the TGO serves as the Thai Designated National Authority for the Clean Development Mechanism (DNA-CDM). The main role of the TGO is to screen, approve, and monitor CDM projects as well as to promote CDM projects and the Certified Emission Reduction Market. The organizational structure of Thailand's climate change institutes is shown in Fig3.

The ministries mentioned above also work cooperatively with government agencies (see Table 1). For example, the NCCC's committee members are from the Ministry of Energy, Ministry of Industry, Ministry of Science and Technology, Ministry of Finance, Ministry of Agriculture and Cooperation, Ministry of Transport, Ministry of Public Health, Ministry of Foreign Affairs, and Ministry of Information Communication and Technology. In addition to governmental efforts, there are several climate change initiatives and activities performed by active private agencies, academic institutes, civic societies, and NGOs.

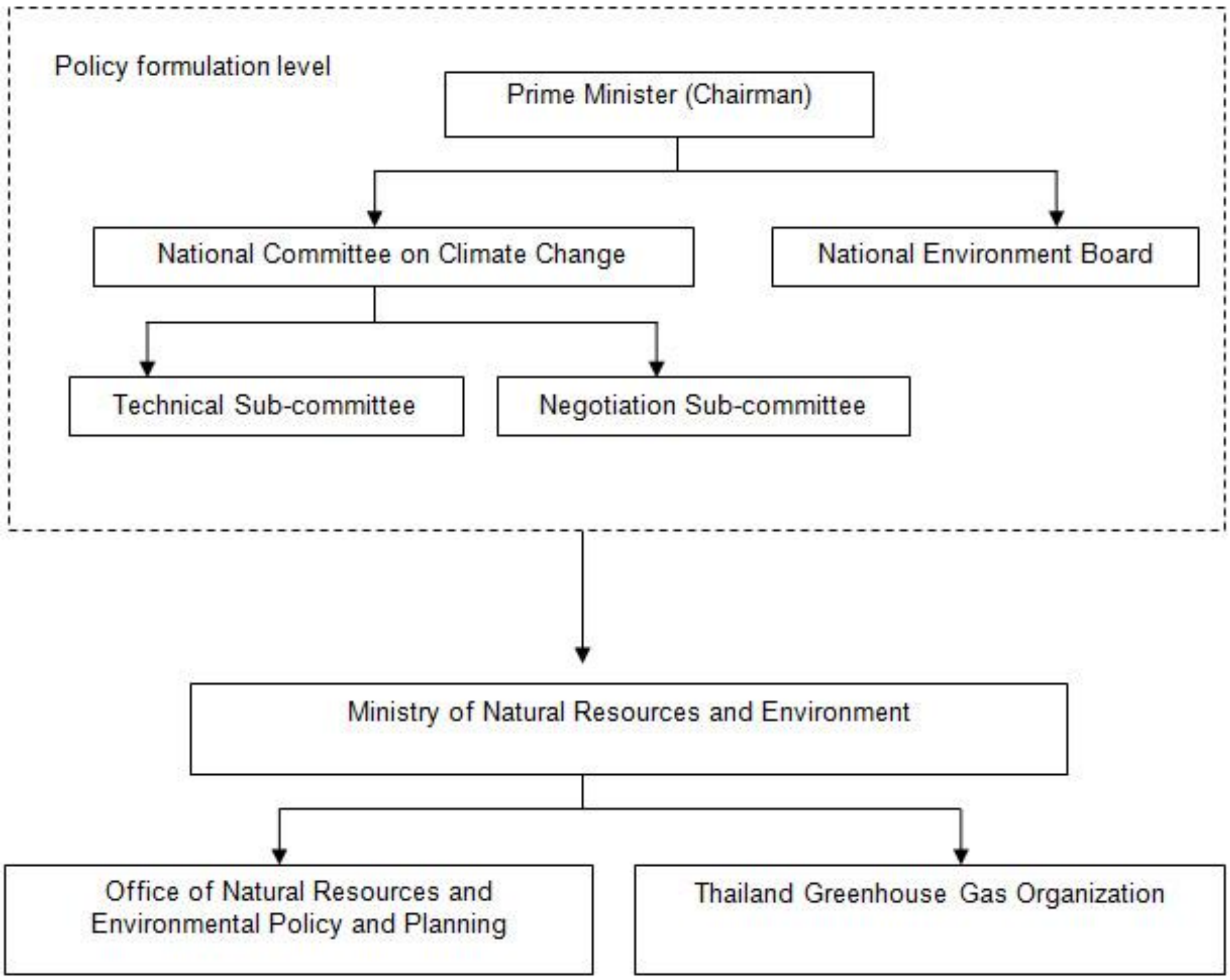


Fig3 The organizational structure of the climate change institutes of Thailand
Source: adapted from ONEP and the UNDP (2010) (ONEP and UNDP 2010)

Table 1 List of government agencies participating in the climate change issue

Government agency	Missions
Ministry of Natural Resources and Environment	
Department of Water Resources	Integrated water resource management
Ministry of Energy	
Office of Energy Policy and Planning	National energy policy
Department of Alternative Energy Development and Efficiency	Development and promotion of clean energy such as renewable energy, biofuel, and energy efficiency
Ministry of Agriculture and Cooperatives	
Land Development Department	Land preservation through the prevention of soil erosion and land degradation
Department of Agriculture	Agricultural productivity
Department of Agricultural Economics	Economic information source for crop adaptation, planning, and assessment of the implications
Department of Fisheries	Promotion and control of fishery practices
Royal Irrigation Department	Water supply for agricultural
Ministry of Industry	
Department of Industrial Works	Pollution control, promotion of GHG reduction through energy saving and clean technology
Thai Industrial Standards Institute	Industrial standards and manufacturing standards
Ministry of Public Health	
Department of Health	Information source on the health impacts from climate change, the spreading of insects, pests and infectious diseases
Ministry of Education	
Ministry of Education	Climate change education in schools and universities
Ministry of Science and Technology	
National Research Council of Thailand	R&D on climate change
Thai Meteorological Department	Weather forecast and climate observation
Geo-informatics and Space Technology Development Agency (GISTDA)	Monitoring of geographical changes, satellite imaging, GIS maps, remote sensing
Climate Impact Science and Technology (CIST)	Research organization on the impacts of climate change
Office of the Council of State	Involvement with natural resources and environmental legislation
Ministry of Interior	
Department of Public Works, Town and Country Planning	Land use planning and urban management
Local government authorities	Management and protection of local natural resources and the environment
Department of Disaster Prevention and Mitigation	Natural disaster prevention and climate change mitigation and adaptation

1.4 National climate change adaptation policies and actions

This section reviews the national climate change adaptation policies and attempts related to the nationally relevant sectors (i.e., water resource management and agricultural sections) to be discussed next. This information will be used as the basis for the TNA process and technology prioritization process discussed in Section 3.

The national policies and actions related to climate change adaptation on water resource management can be summarized as follows:

1. Study of the National Water Policy Framework (Ad Hoc Committee considering the study for solving water problems 2008) (in the subsection on risk-type and area-based policies for risk reduction)

Target 1: Reduce both flood and drought risks.

• Strategy 1: Develop a water network system connecting water resources, flood areas, and drought areas.

• Strategy 2: Increase the capital water supply and storage capacity.

Target 2: Reduce drought risks.

• Strategy 1: Develop a water network system connecting water resources, flood areas, and drought areas.

• Strategy 2: Increase the capital water supply and storage capacity.

• Strategy 3: Promote community involvement and participation in water resource management.

Target 3: Reduce flood risks.

• Strategy 1: Develop a water network system connecting water resources, flood areas, and drought areas.

• Strategy 2: Increase the capital water supply and storage capacity.

2. All-area policies for risk reduction

Target 1: Build the capacity of water resource management.

• Strategy 1: Build the capacity for water resource management by supporting IT uses in data collection and the maintenance of infrastructures.

Target 2: Conserve and rehabilitate water resources and the environment.

• Strategy 1: Increase the capital water supply and storage capacity using nonstructural measures.

Target 3: Promote community involvement in water resource management.

• Strategy 1: Promote community involvement and participation in water resource management.

• Strategy 2: Build the capacity for water resource management.

3. Study of the crisis of decreasing the water level of the Mekong River(Committee on the Crisis of Low Water Level in Mekong River 2010)

<u>Strategies for international cooperation</u>

• Strategy 4: Increase the country's ability to manage water resource by

- Measure 1: Cooperative management of water infrastructures.
- Measure 3: Installing rainfall, water-level, and runoff sensors on tributaries at the merging point on the mainstream Mekong River for monitoring and warning.

<u>Strategies for domestic management of water and energy</u>

• Strategy 2: Manage the water infrastructures on the tributaries of the Mekong River.

• Strategy 3: Increase the water supply inventory and storage capacity.
• Strategy 4: Increase the ability to distribute water.
• Strategy 5: Promote community involvement and participation in water resource management.

2. Institutional arrangement for the TNA and stakeholder involvement

As one of the six countries in Asia supported by the Global Environmental Facility (GEF) through the UNEP to prepare climate change technology needs assessments, the Royal Thai Government assigned the National Science Technology and Innovation Policy Office (STI) as the Thai TNA coordinator. With the Asian Institute of Technology (AIT) as the regional centre for Asia, the present institutional arrangement for the Thai TNA project followed the UNEP RISØ centre-recommended structure is illustrated in Fig 4 with the details discussed below.

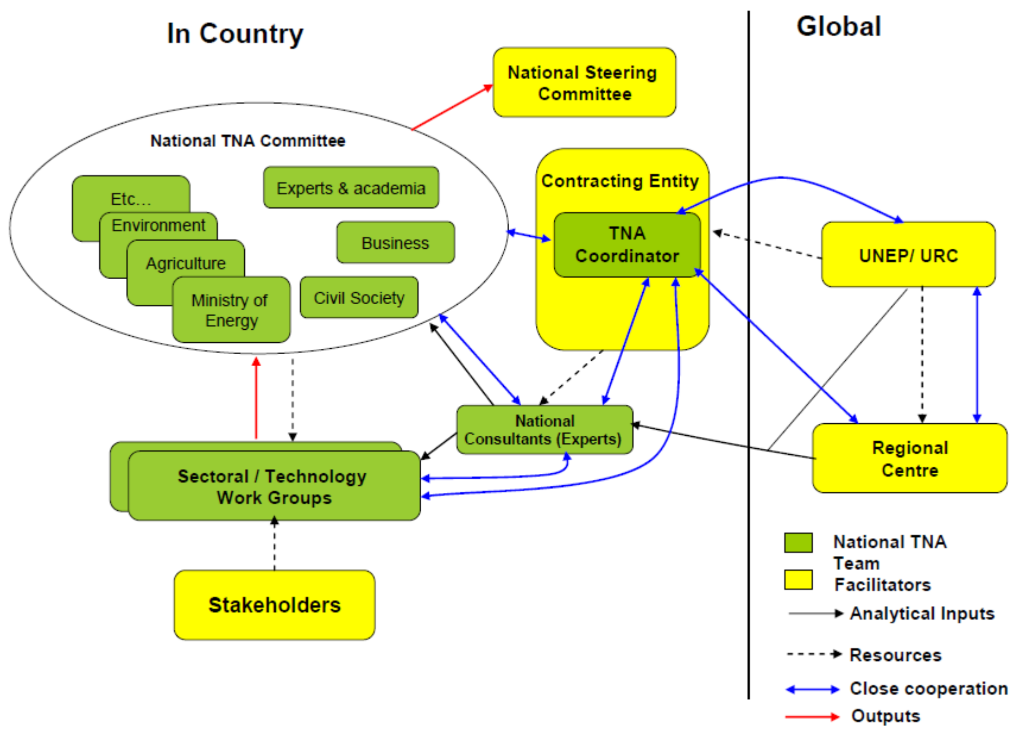


Fig 4 Institutional arrangement for the TNA project as suggested the UNEP RISØ centre.

Various stakeholders from government agencies, academic institutes, and private sectors are engaged in the national structure at various levels. The national TNA committee has Naksitte Coovattanachai (Senior Advisor to Secretary-General, STI) as its chairman, and its committee members are representatives from (1) the Department of Industrial Work, the Ministry of Industry; (2) the Health Systems Research Institute, the Ministry of Public Health; (3) the Energy and Environment Cluster, the National Science Technology Development Agency; (4) the Thailand and Environment Institute (an NGO); (5) the Energy Policy and Planning Office, the Ministry of Energy; (6) the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi; (7) the Joint Standing Committee on Commerce, Industry, and Banking; (8) the Thailand Greenhouse Gas Management Organization (a public organization); (9) the Department of Alternative Energy Development and Efficiency, the Ministry of Energy; (10) the Thailand Research Fund; (11) the Office of Natural Resources and Environmental Policy and Planning; and (12) the National Science Technology and Innovation Policy Office. The National Steering Committee has the permanent secretary of the Ministry of Natural

Resources and Environment as its chairman, and the Steering Committee contains representatives from (1) the Ministry of Foreign Affairs, (2) the Ministry of Agriculture and Cooperatives, (3) the Ministry of Transport, (4) the Ministry of Energy, (5) the Ministry of Science and Technology, (6) the Ministry of Public Health, (7) the Ministry of Industry, (8) the National Economic and Social Development Board, (9) the Thai Meteorological Department, (10) the Pollution Control Department, (11) the Royal Forest Department, (12) the Department of Water Resources, (13) the Department of Marine and Coastal Resources, (14) the Thailand Greenhouse Gas Management Organization (a public organization), (15) the Thailand Research Fund, (16) the Federation of Thai Industries, (17) academia, and (18) the Office of Natural Resources and Environmental Policy and Planning (as the secretariat). The working groups (which also serve as national consultants) for selected sectors (as described next) were appointed by the National Steering Committee as discussed in detail in Section 3.1 (see "Process and criteria of sector selection"). Various stakeholders of each selected sector were engaged during focus group meetings and national public hearings as discussed in detail in Section 4.

3. Sector prioritization

3.1 Process and criteria of sector selection

On July 12, 2010, the Office of National Resources and Environmental Policy and Planning (ONEP), under the Ministry of Natural Resources and Environment, and the National Science Technology and Innovation Policy Office (STI), under the Ministry of Science and Technology, launched the first meeting for the Thailand Technology Needs Assessment project. Fifty-four experts and stakeholders in climate change technology participated to discuss their viewpoints and to identify the highly impacted sectors. The meeting concluded that mitigation technology is needed for energy efficiency and the renewable energy sector while adaptation technology is needed for the agricultural sector, water resources management, and modeling sector. The four selected sectors are also in line with the National Strategy on Climate Change Management (A.D. 2008 – A.D. 2012(Natural Resources and Environmental Policy and Planning 2008)) and the 1st National Policy and Plan on Science, Technology, and Innovation (A.D. 2012 – A.D. 2022(National Science Technology and Innovation Policy Office 2012)) . The energy sector and the agricultural sector are the main focus of Pillar 1: building capacity for climate change adaptation, Pillar 2: promoting GHG mitigation, and Pillar 3: promoting research and development on adaptation and mitigation of the national strategy on climate change management. Similarly, the climate change adaptation using the modeling sector and the adaptation of the agricultural sector are incorporated in Strategy 3.1 of the 1st National Policy and Plan on Science, Technology, and Innovation while the GHG mitigation for the energy sector and the adaptation for the water resource management sector are planned in Strategy 3.2 and 3.4 of the same plan. In addition, the results of UNFCC research concurs: according to one study of the UNFCC (United Nations Framework Convention on Climate Change 2006), agriculture and water resource are the top two sectors vulnerable to climate change. The study showed that among various sectors, experts chose agriculture the most vulnerable sector (83 countries), followed by the water resources (76 countries), and coasts and marine sectors (59 countries) (Fig 5).

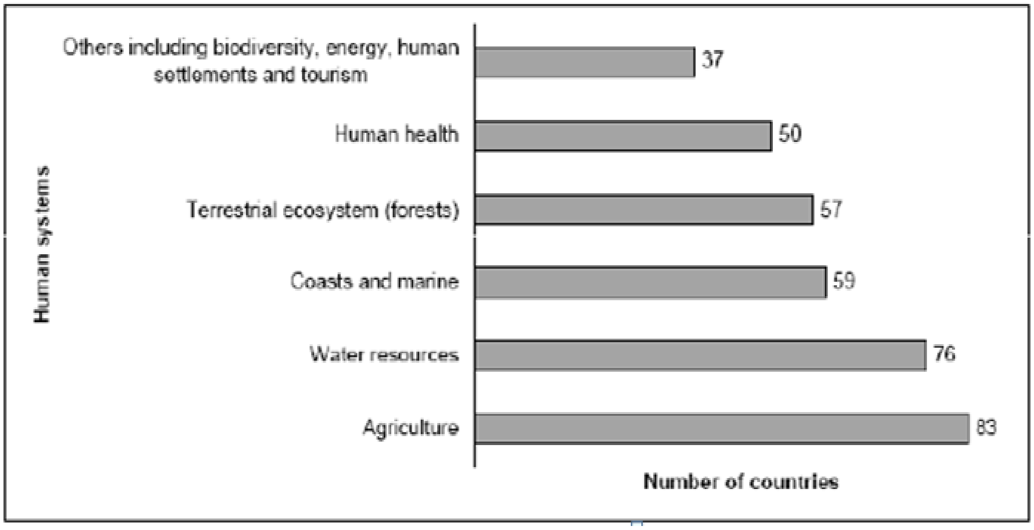


Fig 5 Percentage of countries reporting key vulnerability of these sectors
Source: UNFCC, 2006 (United Nations Framework Convention on Climate Change 2006)

To develop a TNA for targeted mitigation technology and adaptation technology, the Steering Committee appointed four technology workgroups composed of members from the following institutions: (1) Science and Technology Research Institute, Chiang Mai University for the energy efficiency and renewable energy sector, (2) the National Center for Genetic Engineering and Biotechnology (BIOTEC), the National Science and Technology Development Agency (NSTDA), for the agriculture sector, (3) the Hydro and Agro Informatics Institute (HAII) for the water resource management sector, and (4) the Center of Excellence for Climate Change Knowledge Management for the modeling sector. The members of these workgroups also serve as national consultants.

3.2 An overview of the selected sectors

This section provides an overview of the current and projected circumstances of the selected sectors. The information in this section will be used in technology selection and prioritization, which are discussed in Sections 4 and 5.

3.2.1 Agricultural sector

Agriculture is a very important sector of Thailand because the country relies on its agricultural-based economy. There are approximately 13-14 million farmers in Thailand (NSO 2011), over 40% of the current Thai workforce. Large amounts of various agricultural products including rice, cassava, sugarcane, and shrimp are exported annually, producing a lot of revenue to the country, approximately 31,000 million USD annually, as averaged from 2009-2010 (Ministry of Commerce). Thailand plays a crucial role in global food security according to the fact that Thailand has a one-third share of the global rice market, and rice is a staple food for over half of the world's population (FAO 2004), accounting for over 20% of the global caloric intake. In addition to rice, shrimp production, an aquacultural activity, is one of the country’s major economic activities and a main source of export revenue. It involves a great number of shrimp farmers as well as those working in related industries. Besides food, Thailand’s agricultural products such as cassava and sugarcane have the potential for also serving as sources for alternative energy, although currently the amount of cassava and sugarcane produced is just enough for consumption and not quite sufficient for producing biofuel.

Agriculture greatly depends on nature and is undeniably affected by global climate change. The impacts of climate change on agriculture include temperature rises, increasing carbon dioxide concentrations, and climatic variability, which causes more frequent extreme events such as floods, droughts, storms and abnormally cold years as discussed in the *Water Resource Section*. Similarly, latitudinal and altitudinal shifts in ecological and agro-economic zones, land degradation, rises in the sea level, and soil salinity are also greatly affecting agricultural activities and yields (FAO 2004). In addition, indirect consequences of climatic variability are the outbreaks of new pests and diseases as well as the spreading and shifting of the ranges of existing ones.

The Intergovernmental Panel on Climate Change AR4 (2007) estimated that just a 1-3 ºC rise in temperature would bring about a higher agricultural yield in temperate zones but have a reverse effect in the tropic ones, making developing countries in the tropical region, particularly Asia, vulnerable (AR4 2007). This could mean that subsistence agriculture, coffee and banana crops, and tropical biodiversity could wither in places such as Ecuador, Colombia, northern Indonesia and Thailand(Sachs 2011). To be precise, a 2.5-10% drop in agricultural yields in Asia is expected by the year 2020 due to climate change. Similarly, a climate change simulation model has predicted that by 2080, without any interfering measures, the average cereal crop yield in Thailand will have decreased by 2.5-5% (Easterling 2011). As mentioned above, the agriculture section of Thailand has important roles, both as a global food supplier and a local economic driver. Unless measures are undertaken to deal with the effects of climate change, Thailand's agricultural-based economy, its food security, and the food security of the world (as supplied by Thailand) will be under threat. Below, we elaborate on the current and the projected national circumstances of the agricultural sector, with a specific focus on rice crops, cassava, sugarcane, and aquaculture as well as Thailand's national climate change adaptation policies for the agricultural sector.

Rice crops

It is estimated that in the year 2010 roughly 3 billion people in the world consumed rice. In the same year, the world produced a total of 441.03 million tons of rice. China is the world's largest rice producer, followed by India and Indonesia (Table 2). However, Thailand is the world's largest rice exporter, holding about 29% of the global market share. Surprisingly, the rice productivity in Thailand is still relatively low (only ~ 5% of the world's total rice) mostly due to biotic and abiotic stresses. Climate change can both directly and indirectly cause biotic and abiotic stresses. As discussed in the *Water Resource Management Section*, various climate simulation models indicate that the northeastern part of Thailand has a great tendency for drought and changes in rainfall patterns, temperature, and sunshine exposure. All of these will directly affect agricultural practices in the region (OAE 2011). Rice, while with relatively tolerant at the vegetative stage, is very sensitive to high temperatures during the reproductive stage, particularly during flowering. In addition, a study by Endo et al. (2009) showed that temperatures greater than 35 ºC can damage rice crops in the pollination and reproduction stage, causing them to stop flowering, resulting in poor pollination and slow growth rates (Endo 2009). Yamakawa et al. (2007) also showed in their experiment that high temperatures can affect the grain-filling metabolism of developing rice, *Nipponbare*, during the milky stage (Yamakawa 2007). Therefore, ripening under high temperature can result in the occurrence of grains with various degrees of chalky appearance and decreased weight. Furthermore, climate change has an effect on soil salinity (LDD 2007). Currently, Thailand has about 3.36 million hectares with a saline soil problem, making former rice croplands unfarmable. This problem is aggravated in the northeast of Thailand by salt content in groundwater being pulled to the soil surface. Although this process has been happening slowly, overtime it will become a major problem in agriculture (LDD 2007). Several attempts to remediate saline areas in Thailand have been made, but a lot remains for further amendment. Biotically, high temperature is one of the factors leading to the outbreak of brown plant hoppers in 2009, affecting approximately 0.3 million hectares of paddy fields and destroying approximately 1.1 million tons of rice paddy, worth about 1.1 billion baht (Meerod, Tipphong et al. 2011).

In brief, climate change causes productivity losses both in quantity and quality, affecting the long-term competitiveness of the country's rice export as well as global food security.

Table 2 The world's major rice producers and exporters

Country	Production		Export (million tons)	
	(million tons)	Production (%)	(million tons)	Market share (%)
China	136.6	31	0.6	2
India	89.1	20	2.2	7
Indonesia	37.1	8	0.0	0
Bangladesh	31.0	7	0.0	0
Vietnam	24.6	6	6.2	21
Thailand	21.2	5	8.5	29
Other	101.4	23	12.0	41
Total	441.0	100	29.5	100

Source: Office of Agricultural Economics, 2010 (Office of Agricultural Economics 2010).

Cassava

Over the last five years (from 2004-2009), Thailand produced about 25 to 30 million tons of cassava roots annually. However, in 2010, productivity decreased to 22 million tons (OAE 2010) due to a drought that catalyzed an outbreak of pink aphids/mealy bugs. This caused a shortage of cassava in the market as the demand that year was as high as 29 million tons. As a short-term solution, the amount of cassava exported was decreased to avoid an impact on domestic consumption. Consequently, in 2010, only 3% of cassava roots were used for ethanol production (Fig 6). As a matter of fact, in Thailand, cassava is mostly cultivated in dry areas, resulting in substantially lower yields per area than in India, where cassava crops receive the benefits of proper irrigation systems (Table 3). Currently, the area for cassava cultivation in Thailand is limited to approximately 1.2 million hectares. Therefore, to increase productivity without increasing the farming area, resource management technology is an attractive solution. For example, cassava farms using drip irrigation systems produces twice to three times as much crops as those without. If Thailand can increase cassava productivity, several industries, including starch, animal feed, and ethanol production, will benefit.

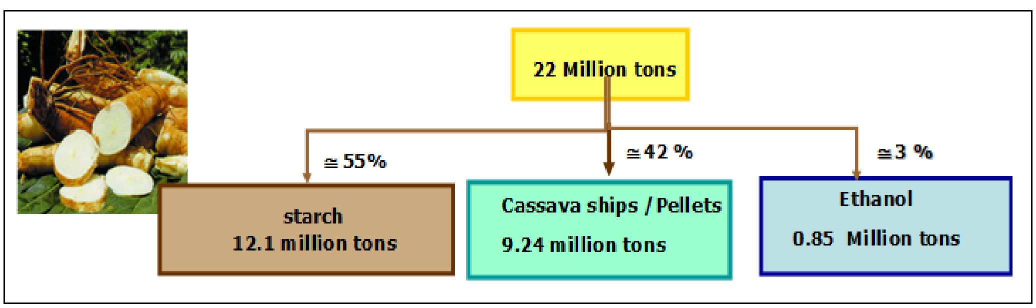


Fig 6 Supply of cassava root in 2010
Source: Office of Agriculture Economics, 2010(Office of Agricultural Economics 2010) and Denworalak, 2010(Denworalak 2010)

Table 3 Average yields of cassava per hectare by country in 2008

Country	Average yield (tons/hectare)
India	33.6
Thailand	21.3
Indonesia	18.1
Vietnam	16.9
Brazil	14.1
Global average	12.5

Source: Office of Agricultural Economics, 2009 (Office of Agricultural Economics 2009)

Major issues in cassava production throughout the world are pests and diseases (Jarvis, Upadhyaya et al.). Climate change can stimulate such biotic stress. Mealybugs, a well-known cassava pest in Latin America and Africa but rarely problematic in Southeast Asia, have spread over about 200,000 hectares in the eastern and northeastern parts of Thailand this year (2011), damaging as much as 50% of total productivity. Apart from pests and diseases, just like in the case of rice, climate change can also bring about abiotic stress such as flooding, leading to a shortage of cassava both for domestic consumption and export. One simulation predicted that the cassava productivity in 2090-99 will have decreased by 43% in comparison to the amount produced in 1980-89 (base year) due to climate change and decreased soil properties (OAE 2011). Another model, built to simulate cassava farming under different climatic conditions, showed that in the future, up to 37% of the country's total cassava farm coverage (i.e., the critical areas) may give a yield below 70% of the average yield in the base year (Pannangpech, Buddhaboon et al. 2009).

Sugarcane

Annually, Thai farmers typically cultivate approximately 1.12 million hectares of sugarcane, producing ~70 million tons of sugarcane and exporting ~1.4 billion USD. As in the case of rice and cassava, climate change can both directly and indirectly cause biotic and abiotic stresses. For example, from 2005 to 2006, the annual sugarcane yield of Thailand declined to only ~47 million tons mainly due to drought. During the harvest season from February and March 2010, Thailand experienced a sharp temperature rise, especially during the daytime, in many areas including sugarcane fields. This reduced both sugarcane productivity and quality, leading to a 4.3% decrease in the amount of raw materials available for sugar mills. Droughts were expected to continue to trouble the sugarcane harvest season this year (2011) (OAE 2011). A study on the potential impacts of climate change on sugarcane production, using the DSSAT-CANEGRO model along with the climate scenarios from the regional climate model CCAM, reveals that climate scenarios may have positive influences on the fresh sugarcane yield, but not as much on the sugar yield per ton of fresh sugarcane (Jintrawet and Pramanee 2005). However, the model does not take into account other factors such as weeds, insects, diseases, and flooding. As a matter of fact, sugarcane farmers do face the risks of disease outbreaks, catalyzed by climate variability.

Aquaculture

Aquaculture is a major agricultural subsector in Thailand. In 2009, Thailand yielded approximately 765,000 tons of aquacultural production for domestic consumption and export, of which shrimp represented the country's main aquaculture export and generated an income of over 2,660 million USD. In the same year, the shrimp industry also hired over 0.7 million workers (Research 2009). As of 2010, Thailand had approximately 32,000 shrimp farms (Fisheries 2010), covering a total area of 30,000 hectares (Office of Agricultural Economics 2009) and producing approximately 540,000 tons of shrimp. This represents a 16% increase from the previous year in response to the relatively high global price of shrimp in the second half of 2009 (due to epidemics of shrimp diseases and unfavorable climate conditions for shrimp farming in many competing countries).

As in the other cases, climate change can bring about direct and indirect biotic and abiotic stresses. In 2011, for example, around 500 kg of shrimp in farms located in Surat Thani, a coastal province in the South, were seriously damaged by flooding. In addition, changes in water temperature can greatly affect the overall health and growth of farm-raised shrimp by stimulating conditions for shrimp diseases such as bacterial infections and viral attacks. Some of the viral diseases including IMNV disease and white spot syndrome are uncommon in Thailand because they usually spread in low-temperature conditions. However, a sharp temperature drop in 2011 caused an outbreak of white spot disease. Both flooding and white spot disease in 2011 are expected to decrease shrimp productivity for the year by 170,000 tons or 30% from that of the previous year (Yodpinij 2011).

3.2.2. Water resource management sector

Thailand is located at the center of Southeast Asia. The climate is tropical and is characterized by seasonal monsoons. The average annual precipitation of Thailand is 1,374 millimeters, which is higher than the global average of 1,050 millimeters according to Global Precipitation Climatology Project (GPCP) data. Over the past several decades, Thailand has encountered a variety of water resource management problems ranging from floods to droughts. At different periods of the year, some regions face water scarcity while others suffer from flooding and water pollution. Unfortunately, several parts of Thailand experience both flooding and drought in the same year. For example, in 2010, floods damaged more than 1.76 million hectares. During the same period, from November 2010 to June 2011, over 39 provinces experienced droughts, causing the government to allocate a budget of more than 550 million USD and 13 million USD to relieve the problems and help flood and drought victims, respectively (DDPM 2011).

These water resource management issues severely interrupt the social and economic growth of the country. Due to the nature of the agricultural-based economy of Thailand, proper management of water resources is imperative. Climate change alters the weather patterns and accentuates the weather extremes. Undoubtedly, these stresses affect the types of water resource management practices and strategies that are required; adaptive technologies are needed to allow us to live harmoniously and sustainably in the changing environment. In sum, climate change might be responsible for 1) greater spatial and temporal rainfall variability and 2) more severe and unpredictable meteorological disasters, both of which lead to flooding, drought, and coastal erosion problems, requiring improvements to current water management practices. Below, we elaborate the current and the projected national circumstances regarding rainfall variability, meteorological disasters, floods, droughts, and coastal erosion as well as national climate change adaptation policies for water resource management.

Rainfall variability

Statistical records on both rainfall and climate projection analysis agree upon a trend toward greater spatial and temporal rainfall variability in Thailand. A statistical analysis of the annual precipitation rate of Thailand using a 56-year record (1951–2006) reveals an obvious contrasting between the low precipitation rates (lower than normal value) of the latest 30 years with the high precipitation rates (higher than normal value) of the first 20 years. This suggests that, overall, the precipitation rate over the past 56 years in Thailand has been decreasing (Kornrawee 2007). While the precipitation rate has been decreasing annually, the intensity of the rainfall, calculated by dividing the total annual precipitation with the number of rainy days, has been increasing in every region of the country. Fig 7 illustrates the increasing trend of the annual rainfall intensity over the last 10 years. On average, the intensity of the total rainfall of the country has increased by around 0.6 mm per day over the past 10 years.

Annual regional precipitation trends vary substantially. On average, annual rainfall totals for the central and eastern regions of Thailand are decreasing, while in the northern and the northeastern regions, they are increasing (Limchilakarn 2010). Total rainfall generally increases from November to April and decreases from May to October. The number of rainy days in the central, the eastern, and the northern regions is decreasing (by about 67% at all stations) at a rate of 0.05–1.3 days per year. From

November to April, the number of rainy days is decreasing in the central region (by 0.3 days per year) and the eastern region (by 0.4 days per year), while during the same period, the number of rainy days is increasing in the lower northern and the northeastern regions (by 0.8 days per year).

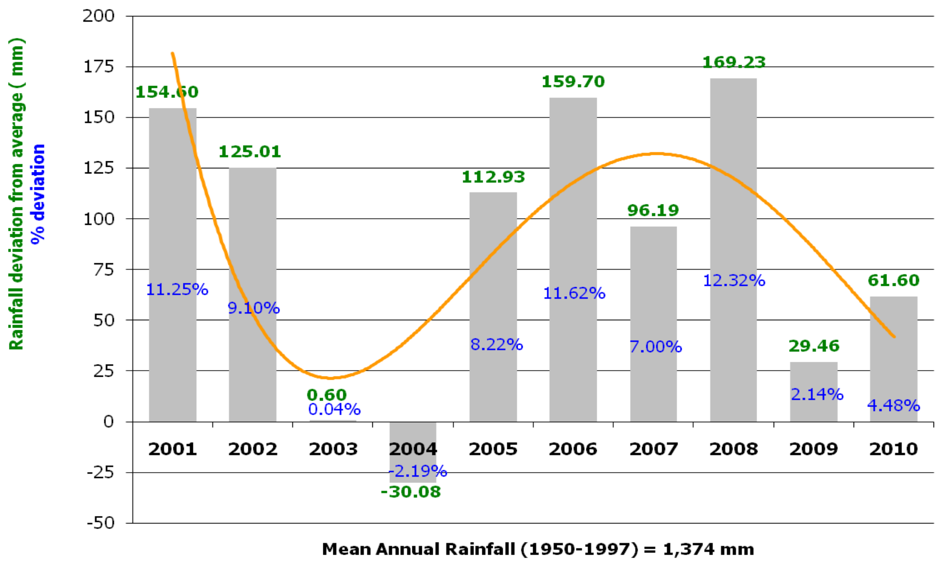


Fig 7 Rainfall deviation from 2001-2010 in comparison to the base line, the average from 1950-1997 (Thanapakpawin 2011)

In addition to the observed data discussed above, several climate projection analyses support the trend of the greater spatial and temporal rainfall variability in Thailand. Koontanakulvong and Chaowiwat (2011) utilized downscaled GCM data in CCCMA3.0, PRECIS ECHAM4, and MRI to produce water situations of the present (1979-2006), the near future (2015-2039), and the far future (2075-2099) (Koontanakulvong and Chaowiwat 2011). Their analyses predicted decreased rainfall in the northern, central, northeastern, and southwestern regions and increased rainfall in the western and southeastern parts of Thailand in the near future. For the far future, all of the models showed increased rainfall for all regions except for CCCMA3.0, which projected decreased rainfall in the South. These overall results are in good agreement with the climate projection analysis by Chiwanno et al. (2010) cited in (Koontanakulvong and Chaowiwat 2011), which suggests that the annual precipitation in every part of Thailand will probably increase, especially in the central region (by 15-25%) and the upper northeast (by 25-50%), by the end of the century. The results of Thongtanakul (2009) (Thongtanakul 2009), as depicted in Fig 8, concur.

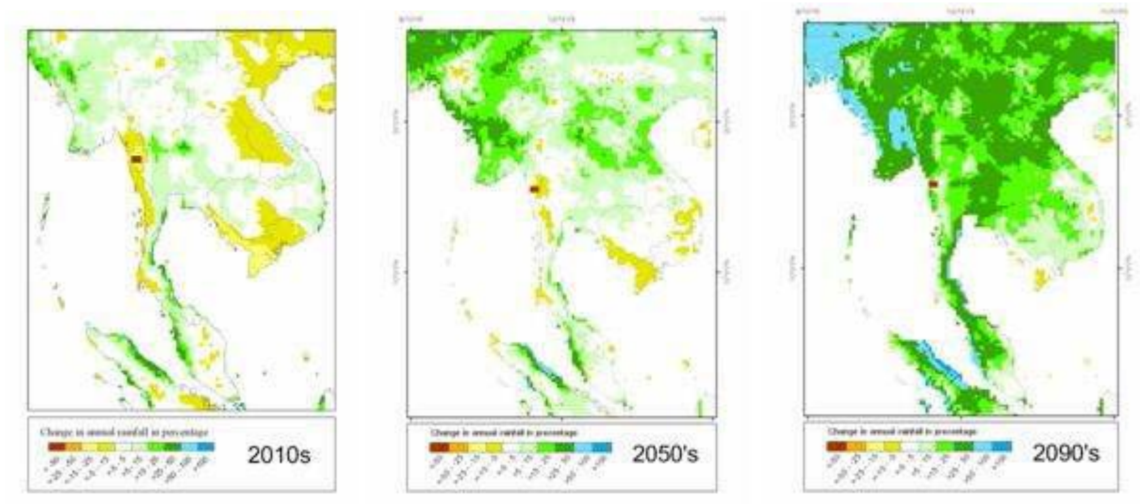


Fig 8 Trend of future changes in annual precipitation in Southeast Asia

In the future, the number of rainy days is not expected to change from the present very much, except the in the northeastern and the eastern regions, which may experience 1-2 weeks and 2-4 weeks of additional rainy days per year, respectively. Several projection analyses also suggest the potential for greater intensity and the higher frequency rainfall in the future (Kundzewicz 2004; Kundzewicz 2007), which might lead to greater risks of flash floods and inundation floods, which are discussed next.

Meteorological Disaster

A precipitation anomaly in this region is generally caused by oscillations in both the Pacific and Indian Oceans, examples of which include the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Pacific Decadal Oscillation (PDO). Recent data show that these oscillations are becoming more frequent (Fig 9), which is hypothesized to be the cause of several disasters including the severe drought in the early 2010 due to a strong El Nino, the severe flooding in the late 2010 due to the abrupt change to a strong La Nina, increased tropical cyclone intensities, and the increased Asian summer monsoon precipitation variability (Zhao 2005; IPCC 2007). However, this hypothesis is still under debate and is the subject of intensive research (Singhrattna, Rajagopalan et al. 2005; IPCC 2007; Ray, Garfin et al. 2007; Lebel, Snidvongs et al. 2009).

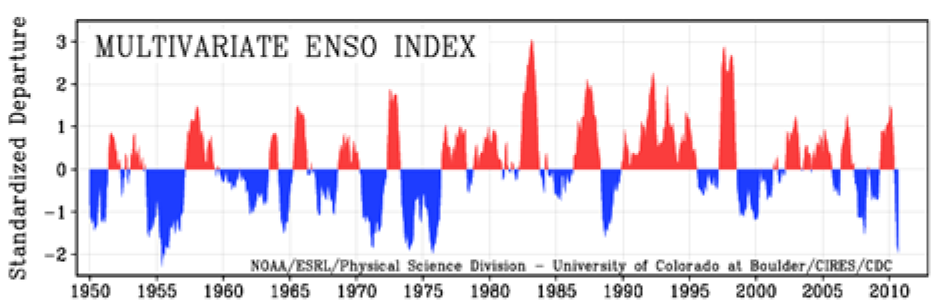


Fig 9 Multivariate ENSO index for 1955-2010
Source: Climatic Data Center/NESDIS/NOAA (National Center for Atmospheric Research (NCAR) 2011; The National Environmental Satellite Data and Information Service (NESDIS) 2011)

Flood

The Land Development Department (LDD 2005) conducted a statistical analysis based on the frequency of floods in Thailand and characterized flood prone area into three groups based on the risk of flood occurrence. The first group is the high risk area, as specified by the flood occurrence of 8-10 times in 10 years. The high risk areas cover 20 provinces with 3,100 sq.km. or 0.6% of the entire area of Thailand. Most are located in the northern region (~2,137 sq.km) and the northeastern region (~960 sq.km), while only a small fraction is in the central region (~2 sq.km.). The second group is the medium risk area, as specified by the flood occurrence of 4-7 times in 10 years. The medium risk areas cover 23 provinces with 4,759 sq.km. or 0.93% of the entire area of Thailand. Most are located in the northern region (~2,836 sq.km.) and the northeastern region (~1,889 sq.km.), while some are in the central region (~34 sq.km.). The last is the low risk area, as specified by the flood occurrence of less than 3 times in 10 years. The low risk areas cover 70 provinces with 33,007 sq.km. or 6.43% of the entire area of Thailand. They are distributed throughout the country, comprising of 10,684 sq.km in the northern region, 8,347 sq. km. in the northeastern region, 6,608 sq.km in the central region, 4,466 sq. km. in the southern region, and 2,902 sq.km. in the eastern region. The losses from flooding statistics of Thailand are summarized in Table 4.

Table 4 Losses from floods in Thailand

Year	Number of events	Number of provinces	Losses		
			Injury (person)	Dead (person)	Value (million THB)
2002	5	72	0	216	13,385.31
2003	17	66	10	44	2,050.26
2004	12	59	3	28	850.65
2005	12	63	0	75	5,982.28
2006	6	58	1,462	446	9,627.41
2007	13	54	17	36	1,687.86
2008	6	65	0	113	7,601.79
2009	5	64	22	53	5,252.61

Source: DDPM, 2011 (DDPM 2011)

Koontanakulvong and Chaowiwat (2011)(Koontanakulvong and Chaowiwat 2011) utilized downscaled Global Climate Model data (GCM) in CCCMA3.0, PRECIS ECHAM4, and MRI models to project the areas prone to flooding in the near future (2015-2039) and the far future (2075-2099) due to climate change (Koontanakulvong and Chaowiwat 2011). Their analysis shows that, in the near future, the flood prone areas in the Chao Phraya Tachin basin group, Mae Khong basin group, and East Southern basin group will be affected by climate change. Around 18.76% of the current flood prone areas might decrease, in size, significantly, 8.49% of these areas may only decrease slightly, and around 26.68% is predicted to remain unchanged. On the other hand, around 18.74% of the current flood prone areas might increase in size slightly, while 27.33% of flood prone areas will increase substantially. As for the far future, the analysis shows that the flood prone areas in the Chao Phraya Tachin basin group, Mae Khong basin group, and West Southern basin group will be affected. Around 19.41% of the current flood prone areas might decrease in size significantly and 6.34% of flood prone areas may decrease only slightly, while around 25.16% is predicted to remain unchanged. On the other hand, around 11.91% of the flood prone areas might increase slightly, while 37.19% of areas prone to flooding may increase substantially.

For the flood-prone areas in Bangkok and its surrounding suburban areas, Babel et al. (2009)(Babel 2009) projected the effects of climate change. They revealed that, by 2050, the flood-prone areas of Bangkok and Samut Prakan will have expanded by approximately 180 km^2 due to climate change. This change represents about a 30% increase in the flood-prone area from its size in 2008. Furthermore, 7% of the area of these provinces may remain inundated for over a month. Much of the areas prone to increased flooding will be located in the western part of Bangkok where existing and planned flood protection infrastructures (dykes and pumps) may be inadequate for dealing with the higher flood levels predicted for the future. The flood volume will increase by the same percentage as the precipitation, but the peak flood discharge will increase even more. This observation corresponds to unequal travel times of floods from upstream catchments. Storm surge is important, but will have less of an effect on flooding. It is estimated that the flood-prone areas in Bangkok and Samut Prakan will increase by about 2% due to the effects of storm surges striking the western coast of the Gulf of Thailand.

Drought

Droughts typically occur during the dry season, from January to March, but sporadically occur during the rainy season, from June to July (Fig 10). Droughts have a great impact on the agricultural sector and the livelihood of rural communities, especially on the 204,800-sq.km rain-fed agricultural areas (~ 40% of the country), most of which are in the Northeast. In the past decade, severe droughts have occurred, such as in 2004, 2005, 2009 and 2010. The 2005 drought caused a water shortage that affected the industrial sector in the Eastern Seaboard. This raised the water supply price for industry to as high as4.8 USD per 1 m^3 (usually 0.4 USD per 1 m^3).

The Land Development Department (LDD 2005) also conducted a statistical analysis based on the occurrence of droughts in Thailand and characterized repetitious drought areas into three groups. The first group contains the high risk areas as specified by having a drought every 13 years. The high risk areas cover 61 provinces and 69,452.34 sq.km. Most are located in the northeastern region (42,516.28 sq.km), the northern region (16,831.35 sq.km), the central region (7,608.48 sq.km), and the eastern region (2,336.23 sq.km). The second group contains the moderate risk areas, as specified by having a drought every 45 years. The moderate risk areas cover 22 provinces and 14,871.64 sq.km. Most are located in the northeastern region (13,416.77 sq.km), the eastern region (1,217.49 sq.km), the northern region (124.79 sq.km.), the central region (111.44 sq.km), and the southern region (1.15 sq.km). The last is the low risk area group, as specified by having a drought every 6-10 years. The low risk areas are spread across 21 provinces and 11,718.28 sq.km. Most are located in the northeastern region (9,133.21 sq.km), the eastern region (2,293.38 sq.km), the central region (135.30 sq.km), and the northern region (49.90 sq.km). The losses from drought statistics of Thailand are summarized in Table 5 (DDPM 2011).

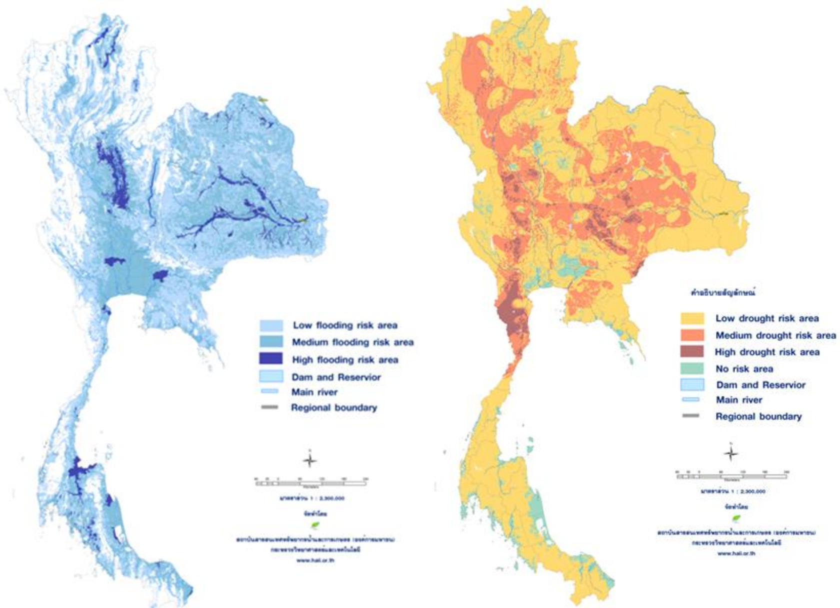


Fig 10 (Right) Drought risk map and (Left) flood risk map
Source: DDPM, 2011 (DDPM 2011)

Koontanakulvong and Chaowiwat (2011)(Koontanakulvong and Chaowiwat 2011) utilized downscaled GCM data in CCCMA3.0, PRECIS ECHAM4, and MRI models to project the areas prone to drought in the near future (2015-2039) and far future (2075-2099) due to climate change. Their analysis shows that, in the near future, the drought areas in the Chao Phraya Tachin basin group, Mae Khong basin group, and Western coast basin group will be affected by climate change. Around 6.72% of the current drought areas might decrease in size significantly, while 16.01% may slightly decrease, and around 64.15% will remain unchanged. On the other hand, around 10.31% of the current drought-prone areas might increase in size slightly, while 3.80% of the areas will increase substantially. As for the far future, the analysis shows that the drought areas in the Chao Phraya Tachin basin group, Western coast basin group and Salawin basin group will be affected by climate change. Around 7.19% of the current drought-prone areas might decrease in size significantly, while 39.50% have a slight chance of decreasing, and around 41.99% will probably remain unchanged. On the other hand, around 8.06% of the drought areas might increase slightly, while 3.26% might increase substantially. Similarly, Chiwanno et al. (2010) cited in (Koontanakulvong and Chaowiwat 2011)) projected the impact of the climate conditions and revealed that the dry season in a year will be 2-3 month longer for the entire drought area by the end of the century.

Table 5 Losses from droughts in Thailand

Year	Number of province	Losses		
		Victim (person)	Damaged agriculture area (rai)	Value (million THB)
2002	66	12,841,110	2,071,560	508.78
2003	63	5,939,282	484,189	174.32
2004	64	8,388,728	1,480,209	190.66
2005	71	11,147,627	13,736,660	7,565.86
2006	61	11,862,358	578,753	495.27
2007	66	16,754,980	1,350,118	198.30
2008	61	3,531,570	524,999	103.90
2009	62	17,353,358	594,434	108.34

Source: DDPM, 2011 (DDPM 2011)

Coastal Erosion

Sea level rises promoted by climate change place coastal areas under threat of severe coastal erosion and seawater encroachment. The rate of sea level change due to climate change varies according to the latitude. It is generally accepted that glacial melting substantially causes sea level rises in high- and middle-latitude areas but not in low-latitude areas, which means the sea level of Thailand should not rise much. However, the Gulf of Thailand appears to be an exception. It is reported that the sea level at Sattahip Bay in the eastern part of the Gulf of Thailand increases, on average, around 2.5 mm per year, while the sea level at Koh Lak decreases, on average, around 0.4 mm per year. This is in good agreement with a study by Trisirisatayawong et al. (2011)(Trisirisatayawong, Naeije et al. 2011), which reports that the sea level in the Gulf of Thailand and South China Sea rises around 0.40-2.38 mm per year, except at Koh Lak where the sea level reduces by 1.41 mm per year (Trisirisatayawong, Naeije et al. 2011). In addition to the sea level rise, another important cause of coastal erosion in Thailand, especially for muddy and sandy coastlines, are land use problems, including the changing of mangrove forests to shrimp farms in muddy coastal areas and inappropriate uses of some sandy coastal areas.

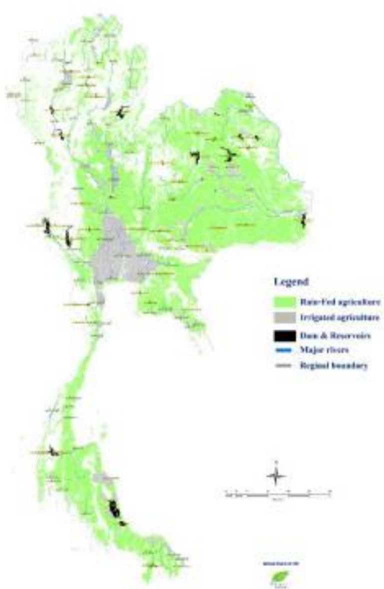
Infrastructure

The current infrastructure for water resource management in Thailand is facing serious flexibility, capacity, and maintenance problems. The primary means for water collection are large and medium sized reservoirs, which are mostly located in the upper parts of watersheds, and only a few are chained or cascaded. Therefore, when it rains in the lower part of a watershed, that rainwater cannot be collected and stored for a future use in the dry season. As shown in

, while the water budget of Thailand is amply supplied by a large amount of rainfall, only 6% of it is collected by the current infrastructure. Presently, only 17% of the all agricultural areas (approximately 246,400 sq. km.) are irrigated (Figure 11). Most of the irrigated areas are in the central part of the country. However, it is unpractical to develop new large or medium reservoirs to irrigate all agricultural areas because of the uncertainty of collectable water, topographical feasibility, and social restrictions. Thus, a secondary system of numerous small reservoirs, community ponds, and distribution networks is an alternative to alleviate the flexibility and capacity problems in those areas. Furthermore, the current infrastructure and stream channels are not adequately maintained. Stream bank erosion and sediment deposits greatly reduce the storage capacity of reservoirs and streams. Pipe leakage greatly compromises the efficiency of the distribution system. Drought and flood matters are handled separately; therefore, in places where both problems arise, redundant investments are inevitable. On top of these infrastructure issues, land use changes, particularly deforestation and mono-crop plantation near the headwater streams alters watershed runoff characteristics, which affect the performance of the existing water reservoirs.

Table 6 Recent (2005-2010) rainfall variability and inflow variability of large reservoirs

Region	Rainfall Mm3	Rainfall variability	Inflow Mm3	Inflow (% of Rainfall)	Inflow Variability (%)
Central & West	122,239	3%	13,988	11.4	29%
North	167,783	15%	14,708	8.8	20%
Northeast	243,605	10%	8,783	3.6	26%
South	139,352	6%	5,847	4.2	26%
East	64,356	10%	978	1.5	32%
Nation-average	745,338	6%	44,303	5.9	19%



Region	Agricultural area (km2)			% Irrigated agricultural area
	Total	Irrigated area	Rain-fed area	
North	45,936	6,080	39,856	13.2%
Northeast	106,704	6,384	100,320	6.0%
East	8,832	656	8,176	7.5%
Central	46,864	24,432	22,432	52.1%
South	38,896	4,784	34,112	12.3%
Total	**247,232**	**42,336**	**204,896**	**17.1%**

Fig 11 Irrigated and rain-fed agricultural areas in Thailand

3.2.3 Modeling Sector

The modeling sector is working at the interfaces between climate change and other affected sectors, including the agricultural and water resource management sectors. It provides adaptive tools for coping with undesired consequences of climate change; as will be seen later in this report, modeling tools are recognized as needed technology for both the agricultural and water resource management sectors. Three main technological components of the modeling sector include hardware, database management, and software. Here, we provide an overview of the data centers (hardware), database management, and software available in Thailand.

Data Center

A data center contains the essential hardware, a large collection of data from various relevant and creditable sources. In addition, it also serves as a data distributor to users and organizations that can benefit from using the network. Without a reliable data center, it is difficult to obtain a meaningful modeling result. As data are crucial in modeling, a data center must keep a high standard for assuring the integrity and functionality of its hosted computer environment. Because modeling climate change impacts can be useful for the adaptation of various sectors, ranging from the climate sector to the health and economic sectors, an integrated data center is highly desirable. Such a data center would make it easy for users to access all of the data required for cross-sectoral modeling effort. Table 7 gives examples of national and international data centers from several countries throughout the world. These data centers are integrated data centers, which provide data for multidisciplinary and cross-sectoral modeling. On the other hand, Table 8 summarizes the data centers in Thailand. These data centers only store data dedicated to specific purposes to comply with the authority and responsibilities of their corresponding governmental agencies, making it more difficult to obtain data for cross-sectoral modeling efforts. In other words, Thailand does not have an integrated national data center.

Table 7 International data centers for climate change modeling

Institution	Country	Feature	Contact
1.National Climatic Data Center (NCDC)	USA	• The world's largest active archive of weather information. • NCDC partners include regional climate centers, and state climatologists. • NCDC is part of the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), and the National Environmental Satellite, Data and Information Service (NESDIS).	Address: National Climatic Data Center Federal Building 151 Patton Avenue Asheville NC 28801-5001 USA 828-271-4800 FAX: 828-271-4876 Webpage: http://www.ncdc.noaa.gov/oa/ncdc.html
2. The National Center for Atmospheric Research (NCAR)	USA	• NCAR is a federally funded research and development center devoted to service research and education in the atmospheric and related sciences. • A primary NCAR activity is creating models that enhance human understanding of the atmosphere, the Earth system, and the Sun. • Its efforts help scientists worldwide to better understand and continually refine the knowledge of how the Earth's systems work. Other parties, such as national and regional leaders, also use this information to make decisions ranging in scale from local to international.	Address: The National Center for Atmospheric Research P.O. Box 3000, Boulder, CO 80307-3000 USA Email: http://ncar.ucar.edu/
3. The National Water and Climate Center (NWCC)	USA	• The functions of the NWCC are natural resource planning support, data acquisition and management, technology innovation, partnerships and joint ventures, and technology transfer.	Address: Natural Resources Conservation Service National Water and Climate Center 1201 NE Lloyd Blvd., Suite 802 Portland, Oregon 97232-1274 USA Webpage: http://www.wcc.nrcs.usda.gov/

Institution	Country	Feature	Contact
4. World Data Center for Climate (WDCC)	Germany	• Data for climate research are collected, stored and disseminated. • No raw data storage for example from satellites or climate models is housed in the WDCC itself because raw data storage on a global scale is beyond the scope of the available facilities. • Close cooperation with thematically corresponding data centers like Earth observation, meteorology, oceanography, pale climate and environment is planned in order to establish a complete network for climate data. • The WDCC is maintained by Model and Data (M&D), which is hosted at the Max-Planck-Institute for Meteorology, in cooperation with the German Climate Computing Center (DKRZ).	Address: World Data Center for Climate Deutsches Klimarechenzentrum - DKRZ World Data Centre for Climate Bundesstraße 45a 20146 Hamburg Germany Tel: +49 (40) 46 00 94 - 105 Fax: +49 (40) 46 00 94 - 119 Webpage: http://mud.dkrz.de/wdc-for-climate/
5. World Meteorological Organization (WMO)	Switzerland (UN)	• It is the UN system's authoritative voice on the state and behavior of the earth's atmosphere, its interaction with the oceans, the climate it produces, and the resulting distribution of water resources. • WMO promotes cooperation in the establishment of networks for making meteorological, climatological, hydrological and geophysical observations, as well as the exchange, processing and standardization of related data, and assists technology transfer, training and research. • It also fosters collaboration between the national meteorological and hydrological services of its members and furthers the application of meteorology to public weather services, agriculture, aviation, shipping, the environment, water issues and the mitigation of the impacts of natural disasters.	Address: World Meteorological Organization, 7bis, avenue de la Paix, Case postale No. 2300, CH-1211 Geneva 2, Switzerland Tel.: + 41(0)22 7308111 Fax: 7308181 Webpage: http://www.wmo.int/pages/index_en.html

Institution	Country	Feature	Contact
6. Japan Meteorological Agency (JMA)	Japan	• JMA is a core member in the implementation of a number of scientific and technical WMO programs, with many experts contributing to technical commissions and associated working bodies of the organization. • JMA is also actively involved in international programs organized by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Civil Aviation Organization (ICAO) and others.	Address: Japan Meteorological Agency, 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan Webpage: http://www.jma.go.jp/jma/indexe.html
7. Center for International Climate and Environmental (CICERO)	Norway	• CICERO's mission is to conduct research and provide reports, information and expert advice about issues related to global climate change and international climate policy with the aim of acquiring knowledge that can help mitigate the climate problem and enhance international climate cooperation.	Address: CICERO P.O. Box. 1129 Blindern, N-0318 Oslo, Norway Telephone: +47 22 85 87 50 Fax: +47 22 85 87 51 E-mail: admin@cicero.uio.no Webpage: http://www.cicero.uio.no/home/index_e.aspx
8. The International Pacific Research Center (IPRC)	USA	• IPRC is an international climate research center, with a focus on the Asia-Pacific region. • The mission of IPRC is to provide an international research environment dedicated to improving mankind's understanding of the nature and predictability of climate variations and changes in the Asia-Pacific region, and to developing innovative ways to utilize knowledge gained for the benefit of society. • The Asia-Pacific Data-Research Center (APDRC) is building towards a vision of one-stop shopping for climate data and products for the users.	Address: Pacific Ocean Science and Technology Bldg., Room 401 1680 East-West Road, University of Hawaiʻi Honolulu, Hawaiʻi 96822 USA Telephone: +1 808.956.5019 Fax: +1 808 956.9425 Webpage: http://iprc.soest.hawaii.edu/

Institution	Country	Feature	Contact
9. Center for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM – SEAP)	Indonesia	• CCROM – SEAP is a research center at Bagor Agriculture University. Its mission is to enhance the capability of society in Southeast Asia and the Pacific to better understand the impacts of climate variability and climate change and to manage the risks and opportunities of those events to improve human welfare and the environment. • It specializes in research and activity regarding 1) the formulation of tools, methods, and approaches for managing climate risks across spatial and temporal scales, 2) the generation of demand driven bio-physical, socioeconomic and impact data, 3) information and knowledge for managing climate risks at various spatial scales, and 4) education and training to support increased climate risk manage efforts.	Address: Gedung Fisik dan Botani Lantai 2 Kampus IPB Baranangsiang Jalan Pajajaran Bogor 16143 Jawa Barat, Indonesia Telephone: +62 251 8313709 Fax: +62 251 8310779 E-mail: ccromseap.ipb@gmail.com Webpage: http://ccromseap.ipb.ac.id/
10. Malaysian Meteorological Department (MMD)	Malaysia	• It aims to be a world-class meteorological center providing excellent services nationally and internationally. • It provides effective meteorological and seismological services to improve the protection of life property and the environment; increase safety on land; sea and in the air; and enhance quality of life and sustainable economic growth. • It participates in international programs on research, data collection and exchange, and other related activities in meteorology. • It provides training in meteorology.	Address: Malaysian Meteorological Department, Jalan Sultan, 46667 Petaling Jaya, Selangor Darul Ehsan. Malaysia Telephone: 6(03) 7967 8000 Fax: 6(03) 7955 0964 E-mail: pengurusan@met.gov.my Webpage: http://www.met.gov.my/index.php

Table 8 Climate change modeling data centers in Thailand

Institution	Province	Feature	Contact
1. Thai Meteorological Department; Climatological Center	BKK	• Monitors and analyzes regional weather situations in Thailand and evaluates and reports the impacts of the weather. • Forecasts the weather and the weather fluctuation; promotes research and the development of appropriate technologies for Thailand. • Cooperates with domestic and foreign organizations to follow up with the progress and development of long term weather forecast. • Serves as the official source of data and news regarding the weather in Thailand.	Address: Thai Meteorological Department 4353, Sukhumvit Rd., Bangna, BKK 10260 Telephone: (662) 399-4566 , (662) 399-4568-74 E-mail: webmaster@tmd.go.th Webpage: http://www.tmd.go.th/en/
2. Thailand's National Disaster Warning Center Thailand (NDWC)	Nontaburi	• Serves as the data center for natural disaster. • Has the authority to command in a critical situation and warn about the natural disaster in an accurate and precise manner. • Provides updates about natural disasters and public warnings.	Address: NDWC Rattanathibet Road, Bang Kra Sor, Muang, Nontaburi 11000 Telephone: +662 279 0430 Webpage: http://www.ndwc.or.th/
3. The Southeast Asia Start Regional Center (SEA START RC)	BKK	• Serves as the regional research node of the Southeast Asia Regional Committee for START (SARCS). • Established under a memorandum of understanding between Chulalongkorn University, the National Research Council of Thailand, and International START.	Address: Southeast Asia START Regional Center, 5th Floor Chulawich Building, Chulalongkorn University, Bangkok 10330 Telephone: +66 2 2189464-7 Fax: +66 2 2519416 E-mail: webmaster@start.or.th Webpage: http://www.start.or.th/

Data Collection and Database Management

Several governmental agencies in Thailand, for example, the Department of Meteorology, Royal Irrigation Department (RID), and Pollution Control Department (PCD), daily monitor and record observed data regarding the weather, water, and air quality, respectively. Typically, these data are used to develop the domestic weather forecast. However, climate change is a global phenomenon; thus, its impact cannot be modeled by using only the observed data of our country. As a minimum requirement, data from other countries in Southeast Asia must be considered as inputs of climate change modeling. Yet, Thailand has no official and effective means of data collection, data transfer, and database management on a regional level. Only a few research institutes in Thailand have attempted to collect and manage data from other sources, domestically and regionally, for such a modeling effort (as shown in Table 9).

Table 9 Status of data collection in Thailand

Thai research institute/organization	Data sources	Weather data
Department of Mathematics, Faculty of Science, King Mongkut's University of Technology Thonburi (KMUTT)	Thai Meteorological Department and National Centers for Environmental Prediction	Weather data as model inputs
Atmospheric Physics Research Unit, Faculty of Science, Chiang Mai University	National Center for Atmospheric Research (NCAR)	Wind components, vertical motion, temperature, relative humidity, tropospause temperature, surface pressure, surface pressure, surface temperature, sea surface temperature, precipitable water, tropopause pressure
National Disaster Warning Center (NDWC)	Asia Disaster Preparedness Center (ADPC)	Disaster forecasting such as earthquakes, typhoons, landslides and floods.
The Southeast Asia Start Regional Center (SEA START RC)	Asia-Pacific Network for Global Change Research (APN)	Weather forecasting data

Modeling Software

As mentioned earlier, the modeling sector is working at the interfaces between climate change and other affected sectors. As a result, there are various choices of modeling software capable of estimating climate change impacts for a particular sector. In addition, some kinds of software are capable of estimating the impact for various sectors. Table 10 summarizes modeling tools used by different sectors in Thailand. It should be noted that each sector uses a specific model favorable for the application of interest, and we do not see the use of an integrated model, which allows for climate change impact estimations across the sectors.

Table 10 Modeling tools used by various sectors in Thailand

Sector	Model/Technology	Producer/Developer	Name of Organizations
Disaster	WRF WRW	NCAR	Thai Metrological Department, CCKM
	Mike model	DHI, Sutus Weesakul, Pro. Supat (AIT), Mr. Sin Sinsakul	Royal Irrigation Department, Water Department, Land Development Department, Bangkok University, GISTDA, Hydrographic Department
	Coastal erosion /remote sensing model	Hydrographic Department and GISTDA, Mr. Adul Bennui	Prince of Songkla University and GISTDA
	Flood /landslide / arid areas (Weighting Rating)/Potential Surface Analysis	Reference theory from geographic information	Land Development, Royal Irrigation Department, Department of Disaster Prevention and Mitigation, GISTDA Department of Mineral Resources, Office of the National Economic and Social Development Board
	Drought of E-san	Dr. Charat Mongkolsawat (Director of the Geographic Information Center, Khon Kaen University)	Khon Kaen Univeristy
	Tsunami: modeled by mathematical equations	Used the theory from the numerical method subject	Department of Disaster Prevention and Mitigation
	Collapsed hole and landslide	N/A	Department of Mineral Resources
	WAM	Department of Meteorology, Department of Hydrology	Department of Meteorology, Department of Hydrology

Sector	Model/Technology	Producer/Developer	Name of Organizations
Decadence of natural resource	Soil erosion: the universal soil loss equation (USLE), and revised universal soil loss equation (RUSLE)	USDA	Land Development and Educational Institution, Pro. Nipon Tungtam
	RMA2	M. Pramote, Marine Science, Chulalongkorn University	N/A
Agriculture	Crop simulation: Decision support system for agro-technology transfer (DSSAT)	ICASA.net , Dr. Auttachai Jintawate, Dr. Methi Eksing, Chiang Mai University	Department of Ground Water Resources Department of Land Development Kasetsart University Chiang Mai University
	Land Evaluation Model (FAO)	Mr. Kamron Saifak FAO 1975,1983	Land Development Department Office of Agricultural and Economics
	FARMMIN	Plant Research International B.V. (Wageningen, The Netherlands)	-
Water	Cropwat	Dr. Boontiam, Ubonratchathani University, FAO	-
	Aqua crop	FAO	-
	SWAT	USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA	Dr. Kampanat Pakdeekul, Faculty of Envronment, Mahidol University ,START, Royal Irrigation Department
	USDR 1975	USDA	Royal Irrigation Department, Office of Agricultural and Economics

Sector	Model/Technology	Producer/Developer	Name of Organizations
Economics	GTAP	Purdue University, USA	Faculty of Economics, Chulalongkorn University and Thammasat University, Fiscal Policy Research Institute Foundation, Office of Agricultural Economics, Center for International Trade Studies. University of the Thai Chamber of Commerce /TDRI
	TDRI-CGE	Thailand Development Research Institute	Thailand Development Research Institute
	QTEM	International Trade Center/University of the Thai Chamber of Commerce	University of the Thai Chamber of Commerce
Health	(Weighting Rating)/Potential Surface Analysis Information system Geography	It is a geographic information theory	Department of Health
	Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MIASMA)	Dr. Pim Martens International Centre for Integrated Assessment and Sustainable Development (ICIS), Maastricht University, Netherlands	-
Urban Planning	The city plan	Dr. Jariya	START
	The California Urban and Biodiversity Analysis (CURBA)	University of California, Berkeley	-

Sector	Model/Technology	Producer/Developer	Name of Organizations
Climate change	PRECIS	SEA START RC	SEA START RC
	RegCM3	JGSEE KMUTT	JGSEE KMUTT
	MM5	Chiang-Mai University	Chiang-Mai University
	WRF	SEA START RC, Department of Hydrology, HAII.	SEA START RC, Department of Marine Hydrology
	WAM	Department of Hydrology and Marine	Department of Marine Hydrology
Energy	LEAP	Stockholm Environment Institute	JGSEE KMUTT
Industrial	DRCSC's	The Development Research Centre (DRC) of China's State Council	-
Communication	Program CUBE: Program uses for NAM, e-BUM model analysis	CITILABS, USA	Ministry of Communications

4. Technology Prioritization for the Agricultural Sector

The impact of climate change on the agricultural sector is unavoidable. Efforts must be made to ensure that Thailand can adapt to the changing climate. Thailand's agricultural sector is a large sector consisting of various subsectors. This project, however, will focus only on selected subsectors rather than the entire agricultural sector to ensure that adaptation technologies of interest can be translated and implemented in the most effective manner. Thus, first of all, the target subsectors were identified by considering their vulnerability to climate change and contributions to the country's economic development and food and energy security as shown in Fig 12.

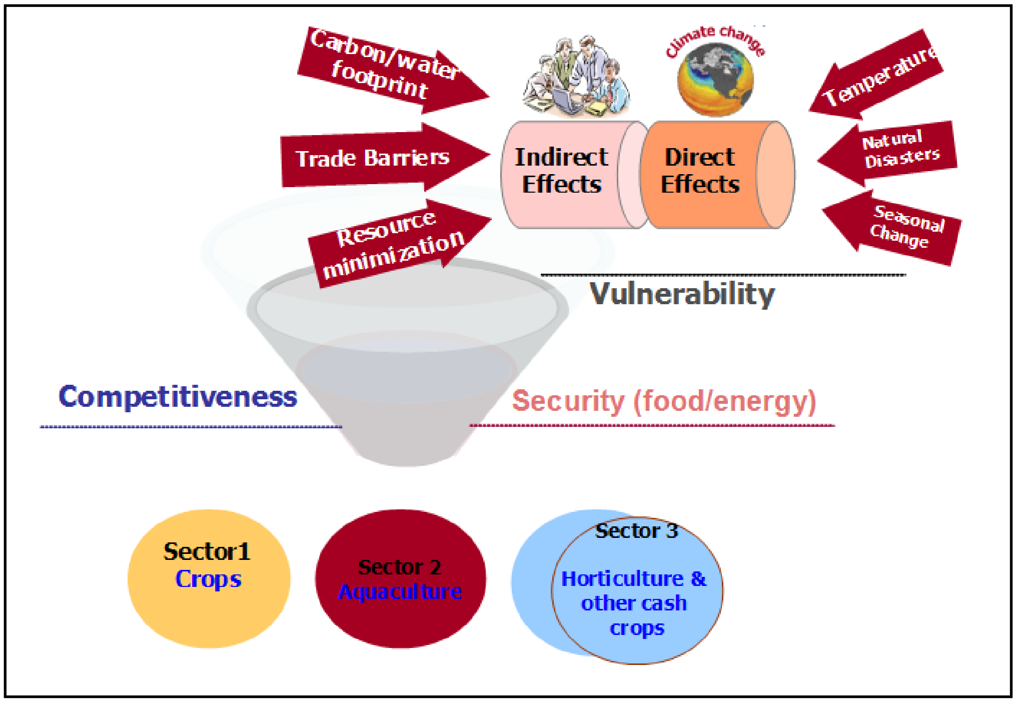


Fig 12 Schematic diagram conceptually representing subsector identification

The identification process consists of two steps. First, a climate change vulnerability analysis for each subsector was conducted. Both the direct and indirect impacts of climate change were considered. Direct impacts include factors like temperature rises, seasonal changes, and natural disasters that can damage productivity, while indirect impacts involve the specification of resource optimization in terms of water and carbon footprints, as a non-tariff barrier. A meeting with expert consultants and stakeholders was held on May 11, 2011, and it was concluded that field crops and aquaculture are the two subsectors most vulnerable to climate change (Table 11). Then, as the second step, the selected subsectors were further prioritized according to their impact on the economy as well as food and energy security (Table 12).

Table 11Summary of the rationale behind subsector selection

Sub-sectors	Level of impacts	Rationale
Field crops (rice crop, cassava, sugarcane)	High	Field crop production is sensitive to climate change as it is difficult to control temperature as well as diseases and pests in open spaces. Climate change consequences (such as high temperature, photo periods, droughts, floods, storms, and pests) are most likely to have wide and deep impacts on crop farming.
Aquaculture (shrimp)	High	Water temperature, water conditions and flooding have dramatic effects on aquaculture production.
Vegetables	Low	Vegetables are sensitive to climate extremes. However, in Thailand vegetables are grown in irrigated areas with sufficient water supply. Some are also grown in a closed system.
Fruit trees	Low	Yield loss will only occur in the case of long-term flooding, high temperature fluctuation, and extreme weather conditions. Irrigation and water management are the key means for reducing such risks.

Source: Brainstorming Session (11th May, 2011)

Table 12 Summary of the impact analysis of the selected agricultural subsectors

	Contribution to Thailand		Contribution to the World
	Income	**Energy security**	**Food security**
Rice	✓	-	✓
Cassava	✓	✓	-
Sugarcane	✓	✓	-
Shrimp	✓	-	-

Table 12 summarizes the results of the impact analysis. In conclusion, based on the two criteria, field crops including rice, cassava, and sugarcane_and aquaculture including shrimp are the top priority subsectors for further TNA. Thus, an assessment of adaptation technologies that match the needs of these sub-sectors is essential. Technology options have been derived from literature reviews and experts' opinions. The five identified options have to do with the following: weather forecast and early warning systems, crop technology improvement, precision farming practices, postharvest technology, and animal nutrition and feed technology. These technology options were then prioritized by brainstorming, discussing, re-identifying, and re-ranking them by the experts until they reached an agreement. Below, we discuss the details of the technology overview, technology prioritization process, and results for the agricultural sector.

4.1 Overview of possible adaptation technology options and their adaptation benefits

Adaptation technology in five areas were initially proposed and discussed. They are climate forecast and early warning systems (including sensor technology, decision support system, simulation modeling, and early warning system), crop improvement (including marker assisted selection and genetic engineering), precision farming practices (including Remote sensing, drip irrigation, soil sensor, bioplastic soil cover, bioplastic tunnel/pests), post-harvest technology (including packaging, logistics, food safety), and animal nutrition and feed technology (including alternative protein source, high protein source). The details of each technology are described in Annex 1.

4.2 Criteria and process of technology prioritization

4.2.1 Process

Next, a stakeholder meeting was held on June 17, 2011. Thirty-seven experts (see in Annex 3) and stakeholders from the governmental, private, and academic sectors were gathered to prioritize technologies best matching the adaptive needs of the targeted subsectors using the four criteria discussed in the next section. Technology options identified included the five groups of technologies mentioned above: (1) forecasting and early warning technology, (2) crop improvement technology, (3) precision farming/resource management technology, (4) post-harvest technology, and (5) animal nutrition and feed technology. The prioritization process consisted of two steps. First, technologies were identified and ranked, using a card technique (as shown in Fig 13 on the right hand side). With this card technique, each expert obtained three cards and he/she could propose one preferable technology option per one card. Thus, each could propose the maximum of three technologies. The proposed technologies would be categorized into the five groups of technology above. The percentage of which the proposed technologies fell into each group of technology was calculated, and the five groups of technologies were ranked accordingly. Then, the top-ranked technologies were discussed through a brainstorming process. At the end of the meeting, the preliminary results were concluded, while the details were left to be filled in later. Consequently, a public hearing was held on June 24, 2011 to further elaborate on the prioritized technologies.

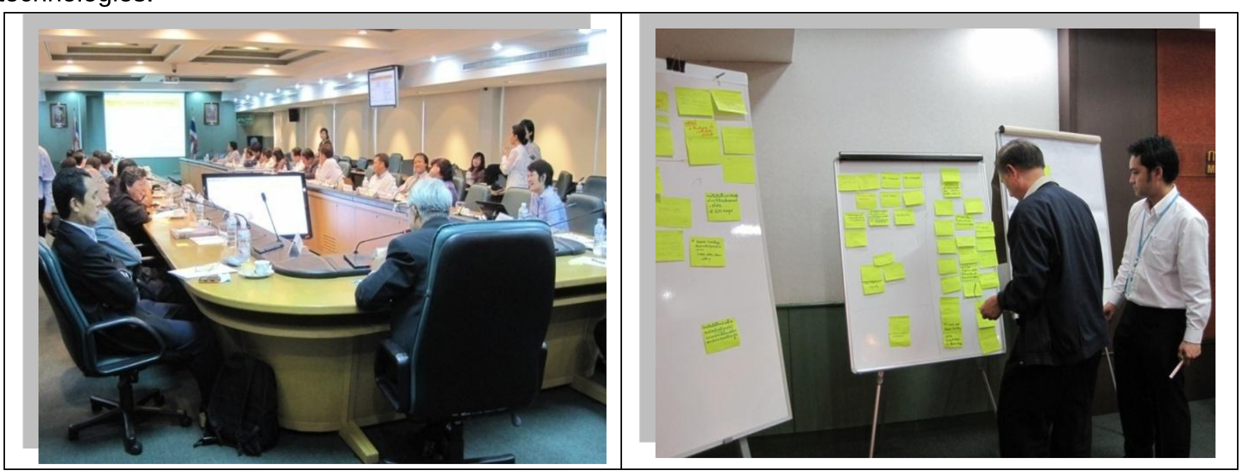


Fig 13 Stakeholder meeting for technology prioritization on June 17, 2011

4.2.2 Criteria

Figure 14 shows the four criteria used for ranking the adaptation technologies of each targeted subsector. The four criteria included the impact of the technology, technology capability, policy and regulation, and public perception, which included farmer acceptance. The rational and definition of these criteria can be described as follows. The impact of the technology refers to the potential benefits of each adaptation technology, measured by the net reduction of loss (incurred by climate change), as well as the cost effectiveness of technology development and utilization. Technology capability refers to the country's ability to develop, adopt, and use each adaptation technology within a 10-year timeframe. This will include both technologies that require the transfer of knowledge and know-how from abroad and those that can be researched and developed domestically. There are three sub-criteria for technology capability: R&D and technology capability, technology absorption, and technology diffusion. R&D and technology capability refers to the country's R&D readiness in terms of the existing research at varying stages, number of researchers, quality of researchers, and R&D infrastructure in both the public and private sectors. This includes the readiness to transfer possessed technology to less developed countries as well. Technology absorption represents the capability of human resources in the public and private sectors to acquiesce new technologies. This also includes research network, technology development and technology transfer. Technology diffusion refers to the readiness of supporting systems to facilitate the transfer of technology and knowledge to farmers. Policy and regulation criteria here refers to the alignment of each technology with existing policy and regulations that can facilitate the success of such technology in terms of the research and development, production, application, and consumption of products related to that adaptation technology. If a high potential technology is currently not supported by any government policy, policy research should be conducted to explore the possibility of such technology and to recommend the introduction or modification of policy to reflect the country's level of technological development. Last but not least, a good technology option must be accepted by the pubic and farmers for effective implementation.

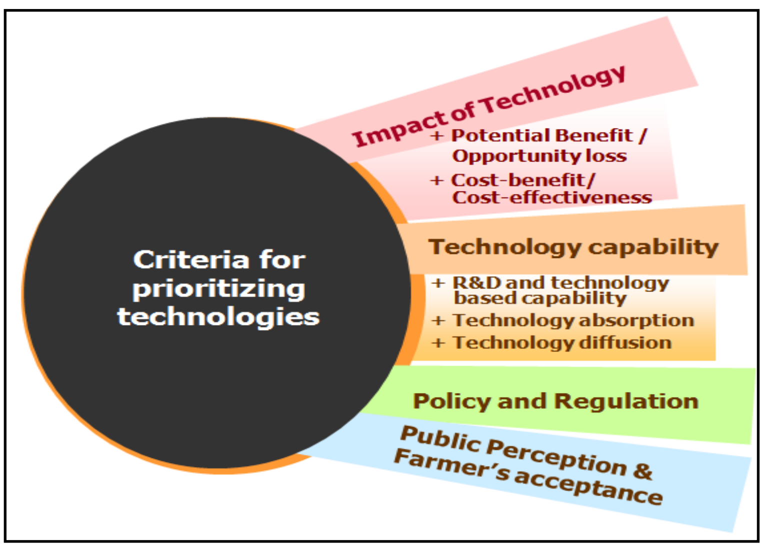


Fig 14 Prioritization criteria for the agricultural sector

4.3 Results of technology prioritization

Using the four criteria described in Section 4.2 as a guideline, experts and stakeholders identified, ranked, and discussed adaptation technologies for the agricultural sector. The experts voted for these following three types of adaptation technologies: forecasting and early warning systems (37%), crop improvement technology (31%), and precision farming technology (17%). The results are shown in Table 13.

Table 13 Results of technology prioritization

Adaptation Technology	1st meeting %	Adaptation Technology	2nd meeting %
Forecasting and early warning			
Crop modeling, forecasting, warning, tele-metering, data management	37	Early warning system, long-term weather forecasting system	41
Crop improvement technology			
Drought tolerance, flood tolerance , water optimization, disease and pest resistance	31	Marker assisted selection and genetic engineering for drought and flood tolerance, disease and pest resistance	33
Precision farming/resource management			
Water management, soil management, simulation, green house, bio-security	17	Remote sensing, drip irrigation, soil sensor, bioplastic soil cover, bioplastic tunnel/pests	17
Post-harvest Packaging, logistics, food safety	10	*Other* CO_2 capture in plants	9
Animal nutrition and feed Alternative protein source, high protein source	5		

* A = Ready/easy B = Medium C= Difficult

An important issue rose during the prioritizing and brainstorming sessions about the difference of readiness among the selected technologies. Some technologies such as molecular breeding or MAS have been developed in the country and are ready to be implemented as well as transferred to other partner countries, especially those in the Mekong region. Similarly, precision farming technologies, such as the management of soil, water, and pests/diseases are effortless to implement due to the availability of resources such as R&D and human resources. On the other hand, forecasting/early warning systems and genetic engineering are still at the nascent stage of development. For these, it is crucial to effectively couple national innovation efforts with knowledge transfer from developed countries.

5. Technology prioritization for Water resource management sector

Adaptation technologies for the water resource management sector was prepared by the national consultants and finalized after several rounds of public hearings. Seven groups of adaptation technologies were identified: (1) environmental observation, (2) weather and hydrological modeling, (3) flood and drought risk management, (4) operation of water infrastructures, (5) community water resource management: CWRM, (6) integrated urban water resource management (IUWRM), and (7) early warning systems. The details of each option are provided next.

5.1 Overview of possible adaptation technology options and their adaptation benefits

The list of adaptation technologies arranged according to the seven groups, status of technology, and prioritization criteria are summarized in Table 14. The statuses of technology and prioritization criteria were determined by the experts. The detailed description of each technology options in each technology group is available in Annex 1.

Table 14 Summary of adaptation technologies, the status of the technologies, and their descriptions for water resource management

Technology for Climate Change Adaptation	* Status of Technology Availability & Accessibility A= Easy B= Medium C= Difficult	Objectives: Increase security in terms of capital water supply	Build flexibility for management in all types of supply and demand scenarios	Minimize damage from disasters	Maximize water usage efficiency	Include all sector in the management	Build knowledge/know-how and data for management	Explanation
1. Environmental Observation			●	●			●	Basic data on water resources such as rainfall and weather parameters, water resources and stream network map, and satellite images and geographic information system (GIS) for water resource management
1.1 Automatic telemetry (e.g. rainfall, stream flow/water level, and water quality)	A							
1.2 Water resource surveying	A							
1.3 Remote sensing	B							
1.4 Mapping and geographic information system (GIS) and other supporting data	A							
2. Weather & Hydrological Modeling			●	●			●	Numerical models for analysis or forecast of weather, surface and groundwater runoffs and levels, and water quality used as a tool for operational water management such as estimating stream flow rate, locating inundation areas, and planning for flood routing
2.1 Seasonal climate prediction	C							
2.2 Short-range forecasting	B							
2.3 Hydrological modeling	A							
2.4 Hydraulic modeling	A							
2.5 Groundwater modeling	B							
2.6 Water quality modeling	B							
3. Flood and Drought Risk Management		●	●	●	●	●	●	Flood and drought risk analysis to prioritize areas based on flood and drought risk levels in terms of volume of water. Result from the analysis is put forth for strategic planning of area-based policy and measures, to assign priority to risk areas, and for allocating appropriate budget size for project implementation.
3.1 Risk assessment	B							
3.2 Risk treatment								
3.2.1 Structural technologies/practices for risk reduction (irrigation structure/rubber dam)	A							
3.2.2 Nonstructural technologies/practices for risk reduction	A							
3.3 Drought risk treatment								
3.3.1 Strategies for developing and managing secondary and emergency water resources (including conjunctive use)	B							

Technology for Climate Change Adaptation	* Status of Technology Availability & Accessibility A= Easy B= Medium C= Difficult	Objectives						Explanation
		Increase security in terms of capital water supply	Build flexibility for management in all types of supply and demand scenarios	Minimize damage from disasters	Maximize water usage efficiency	Include all sector in the management	Build knowledge/know-how and data for management	
3.3.2 Technology for increasing water-use efficiency (water demand management by 3R technologies)	B							
4. Operation of Water Infrastructures		●	●	●			●	Water infrastructures such as dams, reservoirs, and distribution network are tools for managing surface water resources. The use of technology for management of such infrastructures, both on individual basis and for networking structures, helps in planning, operation, and maintenance to ensure optimum infrastructure conditions to serve their purposes in all scenarios.
4.1 Scenario setting for both supply and demand	C							
4.2 Networking (via pipes or canals) and management of infrastructures (including zoning)	B							
4.3 Optimization (e.g. dynamic dam/networking rule curve) and decision support system (DSS)	C							
4.4 Monitoring and maintenance	B							
4.5 Automization and SCADA	B							
4.6 Salt water intrusion management	B							
5 Community Water Resource Management: CWRM		●	●	●	●	●	●	CWRM integrates both supply and demand management of natural or man-made water resources as well as land reform at a community level. The goals are to solve water shortage for drinking, household use, and agriculture, and to reduce flooding risks based on the community's desire to analyze, identify, and manage its own problems. Community participation and partnership with local government and alliances and the integration of indigenous knowledge and new skills are keys to success.
5.1 Data management	A							
5.2 Survey and mapping, including developing a community stream water flow concept diagram	A							
5.3 Water balance for risk analysis and production planning	B							
5.4 Engineering enhancement to increase efficiency in local water management (including rain harvest and wind break)	A							
5.5 Knowledge management	A							
5.6 Nonpoint source water pollution management	B							

Technology for Climate Change Adaptation	* Status of Technology Availability & Accessibility A= Easy B= Medium C= Difficult	Objectives: Increase security in terms of capital water supply	Build flexibility for management in all types of supply and demand scenarios	Minimize damage from disasters	Maximize water usage efficiency	Include all sector in the management	Build knowledge/know-how and data for management	Explanation
6. Integrated Urban Water Resource Management (IUWRM)		●	●	●	●	●	●	IUWRM is the practice of managing water supply, wastewater, and storm water as components of a basin-wide management plan. The goal is to have synergies between water, the environment, and the economy and society for sustainable development and to increase resilience to cope with weather extremity.
6.1 Water supply management	B							
6.2 Develop an urban water supply and drainage concept diagram	C							
6.3 Technology for increasing water-use efficiency (Water demand management with 3R technologies)	B							
6.4 Waste & sanitation management	A							
6.5 Urban flood management	B							
7. Early Warning			●	●		●	●	Warning technology, including database system for integrating data from various agencies, analytical processing (forecasting, monitoring, mapping, reporting), and dissemination of warning notification. Early warning is necessary to prepare appropriate response to mitigate disaster impacts.
7.1 Sensor web using observation and/or modeling data	B							
7.2 Warning criteria based on season, area, and risk type	B							
7.3 Disaster communication	A							

5.2 Criteria and process of technology prioritization

5.2.1 Objective and Framework

The goal of Thailand's water resource management is to establish water security, both at the macro and micro levels using a flood and drought risk management framework. Macro-level water management relies on water-supply and water-distribution infrastructures. Macro-level management serves Thailand's irrigated agricultural areas (approximately 42,336 km^2), industrial sectors, and urban or municipal areas. On the other hand, micro-level water management utilizes micro-scale infrastructures to serve ~204,896 km^2 of Thailand's rain-fed, non-irrigated agricultural areas. Thus, the focus is on water supply management that equips the country with the ability to handle all rainfall scenarios, whether it rains above or below dam catchments or in water-abundant areas or water-stressed areas. In other words, Thailand needs engineering and management technology options that are flexible enough to reduce its exposure and sensitivity, while maximizing its adaptive capacity for dealing with climate change risks and impacts. To achieve water security, adaptation technology options must comply with the following objectives and strategies (Table 15).

Table 15 Objectives and strategies for Thailand water resource management

Objectives	Strategies
1. To increase security in terms of the capital water supply	- Increasing the water supply inventory, storage capacity, and distribution network - Developing water network systems connecting water resources, flood areas, and drought areas
2. To build flexibility for managing all types of supply and demand scenarios	- Developing water network systems connecting water resources, flood areas, and drought areas - Building secondary and emergency water resources for risk management
3. To minimize damages from disasters	- Building capacity for water resource management - Protecting and rehabilitating the ecosystem
4. To maximize water usage efficiency	- 3-R techniques (**R**educe-**R**euse-**R**ecycle)
5. To involve all sectors in the management of water resources	- Sharing and exchanging data and experience across the sectors - Collaborative participation in planning and operations - Networking
6. To build knowledge/know-how and data for management	- Collecting and managing data systematically

5.2.2 Process

Technology prioritization comprised three major steps (Fig 15), which were taken with stakeholder engagement during three focus group sessions and one national public hearing (Table 16).

The first step involved reviewing the possible technology groups and listing the technology options. A preliminary list of technologies as well as their contributions to the water resource management objectives of Thailand previously mentioned were prepared, discussed, and summarized after the focus group sessions with experts from the academic, governmental, and private sectors. The second step included specifying the criteria, weights, and scores for the technology assessment. The criteria, weights, and scores were proposed by the national consultants and commented upon by the stakeholders during a focus group session. The last step involved prioritizing the technologies from the 1st step using the process obtained from the 2nd step. The last step was done in the national public hearing. Each participant was asked to provide scores for each possible adaptation technology group according to the two criteria. Then, the technology prioritization process was performed by ranking the total score of each technology. High impact technologies that scored the least in the capacity assessment were identified as the weaknesses of the country and, therefore, were classified as "technology needs" in this report. The top three technologies in this category were then selected for the technology factsheet preparation and for the technology action plan.

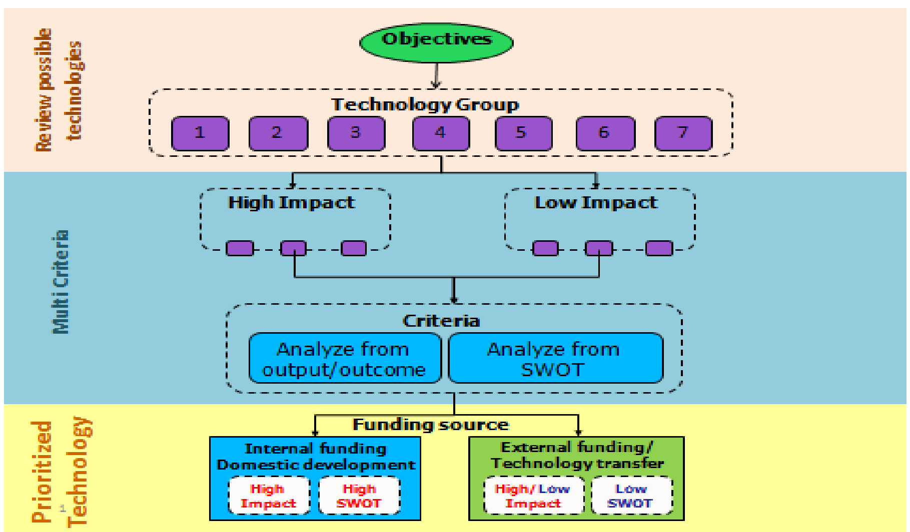


Fig 15 Framework for technology prioritization for the water resources management sector

Table 16 Meeting dates, locations and participants of the focus group sessions and the national public hearing for stakeholder engagement in the water resources management sector

Type	Date	Place	Stakeholder
Focus group session	10 June, 2011	Meeting Room 2, Floor 8, Hydro and Agro Informatics Institute.	Asian Institute of Technology, Kasetsart University
	14 June, 2011	Meeting Room 1, Floor 14, Hydro and Agro Informatics Institute.	Project Manager in Water Engineering, ASDECON Corporation.
	20 June, 2011	Office of Project Management, Royal Irrigation Department of Thailand	Royal Irrigation Department of Thailand.
National public hearing	24 June, 2011	Boardroom 1 , Queen Sirikit National Convention Center Bangkok, Thailand	Royal Irrigation Department of Thailand, Marine Department of Thailand, The National Water Resources Board, Agriculture, Natural Resource and Environment Planning Office (ANEO), Department of Environment, Bangkok Metropolitan Administration, Thailand International Development Cooperation Agency, Ministry of Foreign Affairs, Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand, The Industrial Environment Institute, The Federation of Thai Industries, National Science Technology and Innovation Policy Office, ASDECON Corporation Co., Ltd, Eastern Water Resources Development and Management Public Company Limited, Charoen Pokphand Group, DHI Thailand.

5.2.3 Criteria

Assessments of a technology's impact and capacity formed the two criteria in the MCDA. The impact assessment judges the importance of a technology from the outputs and outcomes of the technology's implementation, while the capacity assessment evaluates Thailand's current state of technology and readiness for its implementation through a SWOT analysis. Each criterion in each category had equal weight for scoring, and three levels of scores were available for judging as specified in Table 17. For scoring and ranking, technology groups and technology options with high impact (high scores in the impact assessment) but low current capability to be domestically implemented (low scores in the capacity assessment) were identified as the technology needs requiring external funding support and/or technology transfer.

Table 17 Criteria and scores for technology prioritization in the water resources management sector

Impact assessment (Outputs/Outcomes)		Capacity assessment (SWOT Analysis)	
Agricultural communities gain direct benefits	3: Easy 2: Medium 1: Difficult	**S: Readiness in knowledge, human resources, and required infrastructure**	3: Very ready 2: Medium 1: Not ready
Urban areas and industries gain direct benefits	3: Easy 2: Medium 1: Difficult	**W: Scale of investment**	3: Cheap 2: Medium 1: Expensive
Build security for government to cope with climate change	3: High 2: Medium 1: Low	**O: Time horizon to see tangible success**	3: Fast 2: Medium 1: Slow
Beneficial to other sectors such as agriculture and energy	3: High 2: Medium 1: Low	**T: Resistance from other sectors or conflicts between agencies**	3: Low 2: Medium 1: High

5.3 Results of technology prioritization

Technologies were prioritized based on their impact and capacity. Both criteria had equal weight, and each had three grades: high, medium, and low. Experts and stakeholders participated in reviewing the criteria and scoring the impact and capacity of each of the technologies. The results of this technology prioritization process are summarized in Table 18. The high-impact but low-capacity technologies were then noted as technologies requiring external funds or technology transfer (left column). The high-impact and high-capacity technologies were classified as technologies requiring domestic development (right column). The top three technology groups with high impact but low capacity are 1) operation of water infrastructures, 2) weather & hydrological modeling, and 3) Early Warning. To form the technology action plan (TAP), the top-ranked technology option for each of the top three groups mentioned above were selected. They include the following:

Rank 1. The networking (via pipes or canals) and management of infrastructures (including zoning) under the technology group "Operation of Water Infrastructures."

Rank 2. Seasonal climate prediction under the technology group "Weather & Hydrological Modeling."

Rank 3. Sensor webs using observation and/or modeling data under the technology group "Early Warning."

It should be noted that although the technology option “structural technologies/practices for risk reduction (irrigation structures/rubber dams” under the technology group “Flood & Drought Risk Management” has the higher rank than the technology option “sensor webs using observation and/or modeling data” under the technology group “Early Warning”, the latter is selected for TAP because Thailand can domestically research and develop the former without the TAP for technology diffusion and transfer. The technology diffusion and transfer is more useful for the sensor webs. The prioritized technologies should also be aligned with the direction of national development. In fact, the selected prioritized technologies in Table 18 very well support Thailand’s national policies, strategies, and measures, as summarized in Table 19.

The relevant policies are laid out in the “National Strategy on Climate Change Management 2008-2012,” the “Study of the National Water Policy Framework: Risk-type Area-based Policies and All-area Policies,” and the “Study of the Crisis of the Decreasing Water Level of the Mekong River.” An observation made regarding the “National Strategy on Climate Change Management 2008-2012” is that this national strategy does not have an explicit strategy or measures regarding the operation of existing water infrastructures.

It should also be noted here that while this TNA is being developed to meet the needs of each sectors. Many of these technologies are cross-cutting and can be applied across many other agricultural sub-sectors as well. In the next steps, prioritized technologies in this report will be re-confirmed and re-analyzed in order to identify barriers/challenges hindering the development, transfer/acquisition, deployment, and application of such technologies. A Technology Action Plan includes developed technologies reprioritized within the country.

Table 18 Prioritized technologies: impact and capacity

Ranking based on the impact assessment (for external funding/technology transfer)	Ranking based on the capacity assessment (for domestic development)
Operation of Water Infrastructures	**Environmental Observation**
1. Networking (via pipes or canals) and management of infrastructures (including zoning) 2. Salt water intrusion management	1. Telemetry
Weather & Hydrological Modeling	**Community Water Resource Management (CWRM)**
3. Seasonal climate prediction	2. Surveying and mapping, including conceptual diagrams of community stream water flow
	3. Engineering enhancement to increase local water management efficiency (including rain water harvesting and wind breaks)
Flood & Drought Risk Management	**Flood & Drought Risk Management**
4. Structural technologies/practices for risk reduction (irrigation structures/rubber dams)	4. Nonstructural technologies/practices for risk reduction 5. Strategies for developing and managing secondary and emergency water resources (including conjunctive use)
Early Warning	**Operation of Water Infrastructures**
5. Sensor web using observation and/or modeling data	6. Scenario setting for both supply and demand
Integrated Urban Water Management (IUWRM)	**Integrated Urban Water Management (IUWRM)**
6. Urban flood management	7. Developing an urban water supply and drainage conceptual diagram

Table 19 Prioritized technologies in the context of Thailand's national policies and strategies

National policy/strategy/policy study	Strategies and measures	Selected technologies
1. National Strategy on Climate Change Management 2008-2012	Strategy 1: Building capacity to adapt and reduce vulnerabilities to climate change impacts • Path 1.1: Building capacity in assessing impacts from climate change - Measure 1: Developing a weather database and weather forecast system to accurately forecast weather in all regions - Measure 4: Developing a geographic database to display natural resources, ecosystems, biodiversity, important agricultural areas, industries, cultural and art sites, and settlements • Path 1.2.1: Preventing and mitigating losses from impacts on natural resources, ecosystems, and biodiversity - Measure 2: Rehabilitating forests, water resources, mangroves, shorelines, and soil to retain balanced ecosystems and biodiversity - Measure 6: Planting vetiver grass to reduce soil erosion and retain soil moisture • Path 1.2.2: Preventing and mitigating loss from impacts of disasters and settlements - Measure 5: Developing tools for a warning system • Path 1.2.3: Preventing and mitigating loss from impacts on agriculture areas, industries, and important heritage, cultural and art sites - Measure 1: Improving and developing a forecast and warning system for agriculture - Measure 2: Creating mechanisms to help and mitigate impacts from disasters on farmers, such as providing pumps and necessary infrastructures	- Weather & hydrological modeling: **Seasonal climate prediction** - CWRM: Surveying and mapping, including concept diagrams of community stream water flow -Flood and drought risk management: Nonstructural technologies/practices for risk reduction -Early Warning: **Sensor web** using observation and/or modeling data -Weather & hydrological modeling: **Seasonal climate prediction** -Flood and drought risk management: Structural technologies/practices for risk reduction (irrigation structure/rubber dam), nonstructural technologies/ practices for risk reduction, strategies for developing and managing secondary and emergency water resources (including conjunctive use) - CWRM: Surveying and mapping, including concept diagrams of community stream water flow, engineering enhancement to increase the efficiency of local water management (including rain harvesting and wind breaks)

National policy/strategy/policy study	Strategies and measures	Selected technologies
	Strategy 3: Support R&D to better understand climate change, its impacts, and the country's adaptation and mitigation options • Path 3.2.1: Building knowledge on natural resources, ecosystems, and biodiversity - Measure 12: Improving the sensor system and collection of rainfall and runoff data	Environmental observation: Automatic telemetry
2. Study of the National Water Policy Framework 2.1 Risk-type area-based policies for risk reduction	Target 1: Reducing both flood and drought risks • Strategy 1: Networking reservoirs in the areas affected by both flooding and drought. • Strategy 2: Increasing the capital water supply and storage capacity Target 2: Reducing drought risks • Strategy 1: Networking reservoirs in the areas affected by both flooding and drought. • Strategy 2: Increasing the capital water supply and storage capacity • Strategy 3: Promoting community water resource management and community participation Target 3: Reducing flood risks • Strategy 1: Networking reservoirs in the areas affected by both flooding and drought • Strategy 2: Increasing the capital water supply and storage capacity	-Flood and drought risk management: Structural technologies/practices for risk reduction (irrigation structure/ rubber dam), nonstructural technologies/practices for risk reduction
2.2 All-area policies for risk reduction	Target 1: Capacity building for water resource management • Strategy 1: Building the capacity for water resource management by supporting IT use for data collection and the maintenance of infrastructures Target 2: Conserving and rehabilitating water resources and the environment • Strategy 1: Increasing the capital water supply and storage capacity by non-structural measures	Environmental observation: Automatic telemetry - Operation of Water Infrastructures: **Networking** (via pipes or canals) **and management of infrastructures** (including zoning) -Flood and drought risk management: Nonstructural technologies/practices for risk

National policy/strategy/policy study	Strategies and measures	Selected technologies
	Target 3: Promoting community water resource management • Strategy 1: Promoting community water resource management and community participation • Strategy 2: Building the capacity for water resource management	reduction - CWRM: Surveying and mapping, including concept diagrams of community stream water flow, engineering enhancement to increase the efficiency of local water management (including rain harvesting and wind breaks)
3. Study of the Crisis of the Decreasing Water Level of the Mekong River	Strategies for international cooperation • Strategy 4: Increasing the ability to manage water resources by - Measure 1: Cooperative management of water infrastructures - Measure 3: Installing rainfall, water-level, and runoff sensors on tributaries at the merging point with the mainstream Mekong River for monitoring and warning	- Operation of Water Infrastructures: **Networking** (via pipes or canals) **and management of infrastructures** (including zoning) - Environmental Observation: Automatic telemetry
	Strategies for domestic management of water and energy • Strategy 2: Management of water infrastructures on the tributaries of the Mekong River • Strategy 3: Increasing the water supply inventory and storage capacity • Strategy 4: Increasing the ability to distribute water • Strategy 5: Promoting community water resource management and participation	- Operation of Water Infrastructures: **Networking** (via pipes or canals) **and management of infrastructures** (including zoning) -Flood and drought risk management: Structural technologies/practices for risk reduction (irrigation structures/rubber dams) - Community Water Resource Management

6. Technology Prioritization for the Modeling Sector

Adaptation technologies were prepared by the national consultants for the modeling sector and finalized after several rounds of focus group meetings and a public hearing. The following three adaptation technologies were chosen: (1) a national data center, (2) national data transfer/management, and (3) integrated modeling using the Weather Forecasting Technology (WRF (ARW) Model). The details of each option are described below.

6.1 Overview of the possible adaptation technology options and their adaptation benefits

As mentioned in the overview of the modelling sector, Thailand needs adaptation technologies in the area of data center, data transfer, and integrated modelling. All three are discussed in details in Annex I.

6.2 Criteria and process of technology prioritization

6.2.1 Objectives and Framework

The goal of the Thailand modeling sector is to provide effective tools and integrated systems that enable other affected sectors to develop reliable assessments and strategic plans for mitigation and adaptation purposes. The affected sectors include the climate sector, water resource management sector, natural disaster sector, transportation sector, industrial sector, energy sector, agriculture sector, social sector, economic sector, and health sector (see **Fig 16**). Special attention is placed on the water resource management and agricultural sectors because of their national relevance discussed in the previous sections.

The modeling sector has three major components which are hardware, data, and software. The only logical choices for the hardware and the data in the national scale are the national data center and the national data transfer system, respectively. Thus, these two components need no prioritization. The technology prioritization process is mainly necessary for choosing the most appropriate integrated software to serve the needs of various sectors in the country. Thus, the prioritization process and criteria discussed here are mainly for prioritizing the software candidates.

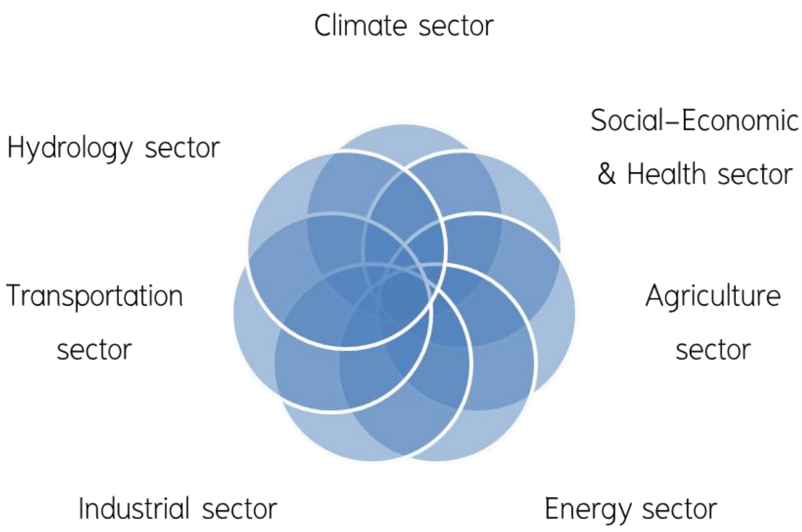


Fig 16 Sectors affected by the modeling sector

6.2.2 Process

The process for technology prioritization comprises of five major steps (Fig 17) that involve stakeholder engagement through focus group sessions and a national public hearing on technology needs assessments (Table 20).

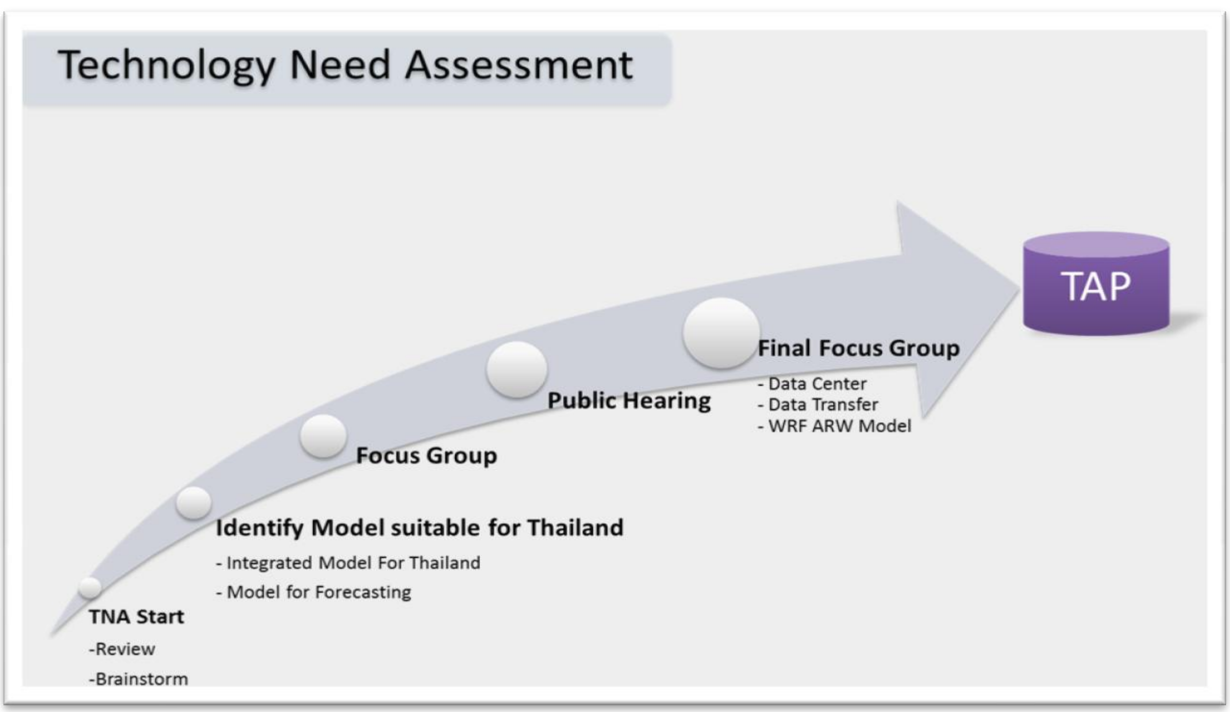


Fig 17 Technology prioritization process

The first step involved reviewing possible technology categories and brainstorming technology options. Three categories of modeling sector needs resulted from the brainstorming; Table 20 summarizes these three broad technology categories. Then, in the 2nd step, we identified the modeling tools used in various sectors and looked at them as candidates for use in an integrated, cross-sectoral modeling tool for Thailand.

Table 21 summarizes the selected models used in different sectors and the reasons of their selection. Then, the modeling candidates and technology options of each category were evaluated during the focus group sessions by experts of the affected sectors from academic, governmental, and private parties. Next, the preliminary list of selected technology options resulting from the focus group meetings was then publically reviewed at the national public hearing workshop (Fig 18) to obtain feedback from all the stakeholders and to ensure that all relevant adaptation technologies were included. The criteria, weights, and scores (to be discussed next) were proposed by the national consultants and commented by the stakeholders during the stakeholder consultation. Finally, a final focus group was held to listen to the experts' comments about the technology options revised after the public hearing. The top-priority technology need in each category was then selected for technology action plan.

Table 20 Three broad categories of technology needs for climate change in the modeling sector

Technology	Function
Data Base Management	Data structure • Data input-output formats Input data management • Database management system • Standard data format • Data mining Inter-model data transfers • Data formats converters • Data distribution
Hardware	Computer • Cluster computer • Distribution computing • Cloud computing Storage • Data center Network • Distribution center • Connection center
Model software	Model structure • Interconnection • Models connection • Models transfer • Data transfer • Data formats

Table 21 Selected models used in different sectors and the reasons for their selection

Sector	Model/Technology	Reason of selection
Disaster	WRF (ARW)	Model for short-term, mid-term, long-term forecasting
	Mike model	Model for instant flood and coastal erosion
	Coastal erosion /remote sensing model	Utilizing data satellite and data of coastal hydrology
	Flood /landslide / Arid areas (Weighting Rating)/Potential Surface Analysis	Analysis by mathematics
	Drought of E-san	Use of geographic information and data satellite
	Tsunami: Modeled by mathematical equations	Physical analysis using a physical model
	Collapsed hole and landslide	Physical analysis using a physical model
	WAM	Modeling from wave prediction
Decadence of natural resource	Soil erosion: Universal soil loss equation (USLE) and the revised universal soil loss equation (RUSLE)	Having complete data and a standard converter which can be used with the experimental data: ground cover index(C) and soil stability (K)
	RMA2	Hydrodynamic model for coastal erosion
Agriculture	Crop simulation: Decision support system for agro-technology transfer (DSSAT)	Mechanistic model, capable of modeling growth and crop yields, to tailor the design of optimal fertilizers needed under a climate change scenario
	Land Evaluation Model (FAO)	Suitable area selection for irrigation planning
	FARMMIN	Simulation of nutrient flow (including nutrient losses such as the leaching of nitrate and volatilization of ammonia) and profitability.

Sector	Model/Technology	Reason of selection
Water	Cropwat	Water and crop management
	Aqua crop	Water and crop management
	SWAT	Integrated models of physical landscape for water management
	USDR 1975	Suitable area selection for irrigation planning
Economics	GTAP	Simulation of the effects of international economic policy changes, especially those of international trade policies Evaluation of the effects of international trade on pollution
	TDRI-CGE	Examination of the economic relation system and analysis of the effect of economic policy
	QTEM	Prediction of an economic crisis and its effect, especially on international trade, import and export, and the trade balance
Health	(Weighting Rating)/Potential Surface Analysis Information system Geography	Searching for the area which has latency in epidemics
	Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MIASMA)	Modeling several health impacts of global atmospheric change including the following features: 1) Vector-borne diseases, including malaria, dengue fever, and schistosomiasis. 2) Thermal heat mortality and UV-related skin cancer due to stratospheric ozone depletion. 3) The models are driven by population and climate/atmospheric scenarios, applied across baseline data on disease incidence and prevalence, climate conditions, and the state of the stratospheric ozone layer.

Sector	Model/Technology	Reason of selection
The city plan	The city plan	Modeling Heat Island effect
	The California Urban and Biodiversity Analysis (CURBA)	Assessing the impact of land-use changes on the environment
Climate change	PRECIS	Dynamic downscaling of climate prediction
	RegCM3	Dynamic downscaling of climate prediction
	MM5	Dynamic downscaling of climate prediction
	WRF	Dynamic downscaling of climate prediction
	WAM	Wave forecasting
Energy	LEAP	-Energy outlooks (forecasting) -Greenhouse gas mitigation analysis -Strategic analyses of sustainable energy futures
Industrial	DRCSC's	Analyses of the impacts of globalization and trends in liberalization on environmental pollution
Communication	Program CUBE: use for NAM, e-BUM model analysis	The program for running the model NAM and e-BUM (NAM). Model for international transportation planning: Developed from the database system of the Department of Policy and Transportation Planning. This model can be use for the analysis of the domestic transportation plan.

Fig 18 The national public hearing workshop

6.2.3 Criteria

Performance efficiency, cost worthiness, and acceptability were the three categories of criteria considered in the MCDA (Figure 19). The performance efficiency was judged by the ease of use and the forecastability, while cost worthiness was evaluated by considering the further development and the transferability of the technologies. The acceptability evaluates the level of international and national acceptability of the technologies. Each criterion had equal weight for scoring, and three levels of scores, *good*, *fair*, and *poor* (Figure 19), available for evaluation. After scoring and ranking, the technology option with the highest score in each group was regarded as the technology need and moved forward in our process for developing a technology action plan.

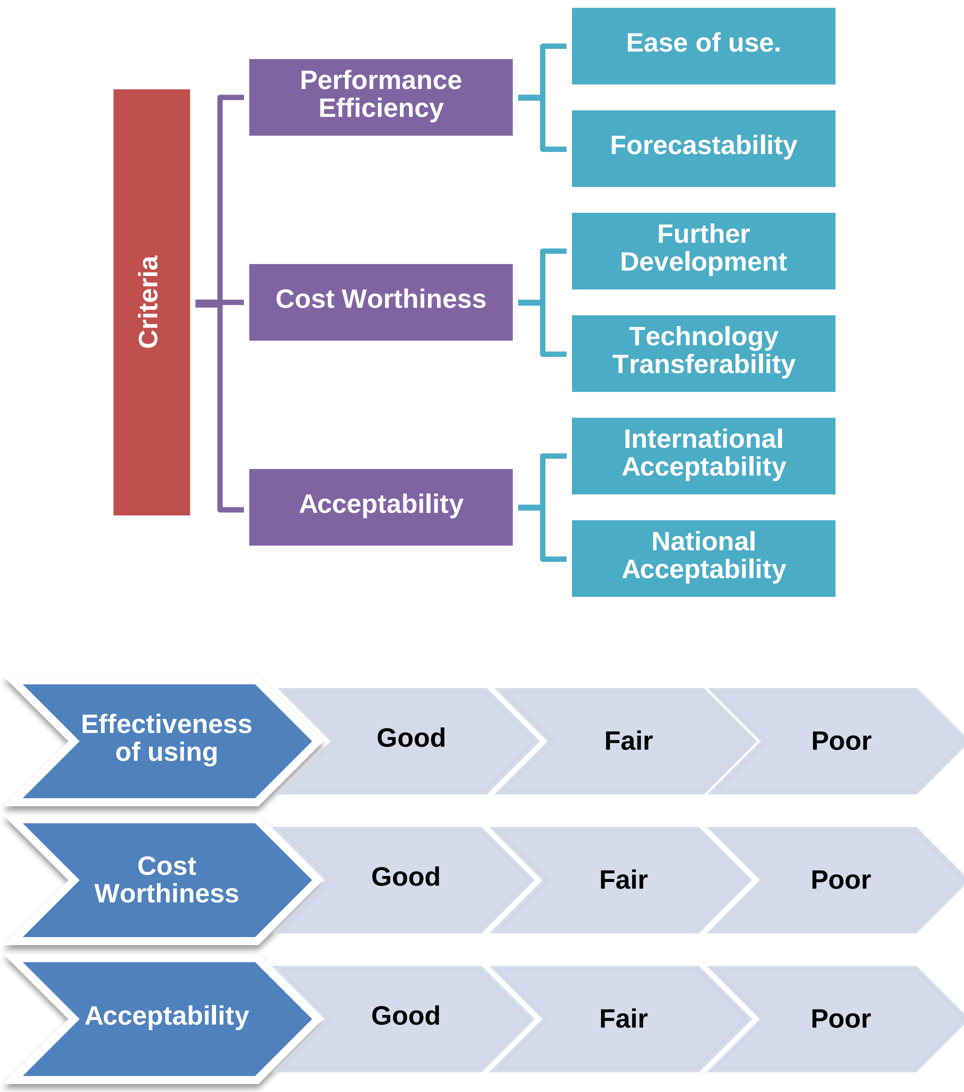


Fig 19 Three criteria for technology prioritization

6. 3 Results of technology prioritization

According to the technology prioritization process of software candidates, the WRF (ARW) model ranked the highest among the candidate models in the integrated model category. Table 22- Table 24 illustrate the detailed results of the technology prioritization by stakeholders from various sectors when considering 1) the three main evaluation criteria (i.e. performance efficiency, cost worthiness, and acceptability), 2) ability to address the need of the two top-priority sectors (i.e. agricultural and water resource management sectors) , and 3) status of technology availability, respectively. As shown in Table 22, the WRF(ARW) model is scored as “Good” for both disaster and climate change and can be used to address almost all specific applications in these sectors. Nevertheless, The WRF (ARW) is not a model for serving specific needs of the two top-priority sectors, i.e. agricultural and water resource sectors. For example, the WRF(ARW) could neither do land evaluation for the agricultural sector nor do water drainage planning for the water resource sector. However, the WRF(ARW) model can address both weather forecasting and future climate prediction which are the major inputs for other specific models for both agricultural and water resource management sectors. Thus, as shown in Table 23, the WRF(ARW) model can address both requirements for agricultural and water resource management sectors and selected the capable integrate model choice for Thailand.

Table 22 Result of technology prioritization for integrated modeling tools based on the three main criteria (G=Good, F=Fair, P=Poor)

Sector	Model/Technology	Performance efficiency			Cost worthiness			Acceptability			Total
		G	F	P	G	F	P	G	F	P	
Disaster	WRF (ARW)	✓			✓			✓			**G**
	MIKE Model	✓					✓	✓			**F**
	Coastal erosion /remote sensing model		✓			✓			✓		**F**
	Flood /landslip /Arid areas/Weighting Rating/Potential Surface Analysis			✓	✓				✓		**F**
	Drought of E-san			✓	✓					✓	**P**
	Tsunami/ Modeled by mathematical equations.		✓		✓				✓		**F**
	Collapsed hole and landslide		✓			✓			✓		**F**
	WAM	✓				✓		✓			**G**
Decadence of Natural resource	Soil erosion Universal soil loss equation (USLE) and RUSLE (Revise Universal soil loss equation)		✓		✓				✓		**F**
	RMA2		✓			✓			✓		**F**
Agriculture	DSSAT (Decision support system for agro_ technology transfer)Crop simulation	✓			✓				✓		**G**
	Land Evaluation Model (FAO)	✓			✓				✓		**G**
	FARMMIN		✓			✓			✓		**F**

Sector	**Model/Technology**	**Performance efficiency**			**Cost worthiness**			**Acceptability**			**Total**
		G	F	P	G	F	P	G	F	P	
Water	CROPWAT		✓			✓			✓		**F**
	Aqua crop		✓			✓			✓		**F**
	SWAT		✓			✓			✓		**F**
	USDR 1975		✓		✓					✓	**F**
Economics	GTAP	✓				✓			✓		**F**
	TDRI-CGE	✓				✓		✓			**G**
	QTEM	✓				✓			✓		**F**
Health	Potential Surface Analysis Information system Geography (Weighting Rating)		✓			✓			✓		**F**
	MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)	✓					✓		✓		**F**
	The California Urban and Biodiversity Analysis (CURBA)	✓					✓		✓		**F**
Climate change	PRECIS	✓			✓				✓		**G**
	RegCM3		✓		✓				✓		**F**
	MM5		✓		✓				✓		**F**
	WRF	✓			✓			✓			**G**
	WAM		✓			✓			✓		**F**
Energy	LEAP		✓			✓			✓		**F**
Industrial	DRCSC's		✓			✓			✓		**F**
Communication	Program CUBE (Program uses for NAM, e-BUM model analysis	✓					✓	✓			**F**

Table 23 Integrated model selection according to the requirement of the two top-priority sectors (agricultural and water resource management sectors)

Model Feature Required by Other Sectors		Model Prioritized	Comment
Weather forecasting	- Short-term: daily weather forecasting for the period of 1-7 days to forecast the near future for better accuracy.	WRF	The model must be equipment and technology support (Hardware, Software, Data and etc.)
	- Mid-term: weekly and monthly weather forecasting to help agricultural planning and other researches.		
	- Long-term: seasonal weather forecasting for long-term planning such as agricultural and water management.		
Future climate prediction	- Projection in the future ranging from decades to centuries	PRECIS, RegCM3, MM5, WRF,WAM	The models get by transfer Climate and Weather Data from International Climate Center
	- Creating climate scenario in Thailand: To help future projection according to the conditions of such scenarios.		
	- Developing the high-resolution climate data is use dynamic downscaling		

Table 24 Status of technology availability ranked during the stakeholder meetings and public hearing

Type	Adaptation Technologies	* Status of Technology Availability	Objectives
Model Technology	Integrated modeling	**C**	To decision making support for planning.
	Weather Forecasting Technology (WRF (ARW) Model).	**A**	To forecasting weather in three periods (short-term, mid-term, and long-term)
Model equipment and Technology support	National Climate Data Center	**B**	To the central storage weather and climate data for collecting and distribution data to public
	Transferring Climate and Weather Data	**A**	To support data to using in weather forecasting models and climate prediction models
* A = Ready/easy B = Medium C= Difficult			

7. Conclusions

The present TNA report for climate change adaptation in Thailand is supported by the Global Environmental Facility (GEF) through the UNEP. The National Science Technology and Innovation Policy Office (STI) is assigned as the Thai TNA coordinator. The first step of the TNA is to identify highly impacted sectors in urgent need of adaptation technology. Thus, the first meeting for the Thailand Technology Needs Assessment project was launched on July 12, 2010 and could identify three highly impacted sectors including the agricultural sector, water resources management sector, and modeling sector. Subsequently, to develop a TNA for targeted sectors, the Steering Committee appointed three technology workgroups for the three sectors including 1) the National Center for Genetic Engineering and Biotechnology (BIOTEC), the National Science and Technology Development Agency (NSTDA), for the agriculture sector, 2) the Hydro and Agro Informatics Institute (HAII) for the water resource management sector, and 3) the Center of Excellence for Climate Change Knowledge Management (CCKM) for the modeling sector. The assessment processes and findings of each sector are as follows:

1. Agricultural Sector

Thailand's agricultural sector is a large sector consisting of various subsectors. This TNA, however, will focus only on selected subsectors rather than the entire agricultural sector to ensure that adaptation technologies of interest can be translated and implemented in the most effective manner. Thus, first of all, the target subsectors were identified by considering their vulnerability to climate change and contributions to the country's economic development and food and energy security. A meeting with expert consultants and stakeholders held on May 11, 2011, concluded that field crops and aquaculture are the two subsectors most vulnerable to climate change and need immediate attention in terms of technology development and transfer. It should also be noted here that while this TNA is being developed to meet the needs of target sub-sectors, many of these technologies are cross-cutting and can be applied across many other agricultural sub-sectors as well.

In the development of the TNA, adaptation technology in five areas were initially proposed and discussed. They are climate forecast and early warning systems, crop improvement, precision farming practices, post-harvest technology, and animal nutrition and feed technology. The criteria used in the prioritization of adaptation technologies within the target sub-sectors were 1) impact of technology, 2) technology capability, 3) policy and regulation, and 4) public perception and farmer acceptance. Based on the two stakeholder meetings using these four criteria, the experts voted for these following three types of adaptation technologies: forecasting and early warning systems (37%), crop improvement technology (31%), and precision farming technology (17%).

2. Water Resource Management Sector

Thailand has encountered a variety of water resource management problems ranging from floods to droughts. Thailand's water resource management is facing both natural and management challenges. The natural challenges are from natural variability while the management challenges include the lack of flexibility and buffering capacity of the current infrastructure. Consequently, the changing water situation in Thailand and the current situation of water infrastructure management were the two primary facts used to analyze the country's top challenges and goals in water resource management. These help define objectives of technology transfer and diffusion which are: 1) Increasing security in terms of capital water supply, 2) building flexibility for management in all types of supply and demand scenarios, 3) minimizing damage from disasters, 4) maximizing water usage efficiency, 5) including all sectors in the management, and 6) building knowledge/know-how and data for management. In short, the prioritized technologies must be able to alleviate problems or increase efficiency of the infrastructure management system, as well as develop the competency of the domestic human resources.

In the development of TNA, the following seven possible adaptation technologies were initially proposed: (1) environmental observation, (2) weather and hydrological modeling, (3) flood and drought risk management, (4) operation of water infrastructures, (5) community water resource management: CWRM, (6) integrated urban water resource management (IUWRM), and (7) early warning systems. Then, two categories of criteria including impact and capacity assessments were used to prioritize these adaptation technologies based on the multi-criteria decision analysis. Impact assessment judges the importance of technologies from the outputs and outcomes of technology implementation, while capacity assessment evaluates Thailand's current state of technology and readiness for technology implementation through SWOT analysis. The high-impact technologies that Thailand is not ready to develop and to implement were then selected and prioritized as "technology needs." The rankings are: 1) networking (via pipes or canals) and management of infrastructures (including zoning) under the technology group#4 (the operation of water infrastructure), 2) seasonal climate prediction under the technology group# 2 (weather and hydrological modeling), and 3) sensor web using observation and/or modeling data under the technology Group # 7 (the early warning).

3. Modeling Sector

The modeling sector is working at the interfaces between climate change and other affected sectors, including the agricultural sector and water resource management sector. It provides adaptive tools for coping with undesired consequences of climate change. Modeling tools are recognized as needed technology for both the agricultural and water resource management sectors. The goal of the Thailand modeling sector is to provide effective tools and integrated systems that enable other affected sectors to develop reliable assessments and strategic plans for mitigation and adaptation purposes. The affected sectors include the climate sector, water resource management sector, natural disaster sector, transportation sector, industrial sector, energy sector, agriculture sector, social sector, economic sector, and health sector. Special attention is placed on the water resource management and agricultural sectors because of their national relevance discussed previously.

The process for technology prioritization comprises of five major steps that involve stakeholder engagement through focus group sessions and a national public hearing on technology needs assessments. The first step involved reviewing possible technology categories and brainstorming technology options. Three categories of modeling sector needs resulted from the brainstorming including hardware, software, and database management. Then, in the 2nd step, we identified the modeling tools used in various sectors and looked at them as candidates for use in an integrated, cross-sectoral modeling tool for Thailand. Then, the modeling candidates and technology options of each category were evaluated during the focus group sessions by experts of the affected sectors from academic, governmental, and private parties. Next, the preliminary list of selected technology options resulting from the focus group meetings was then publically reviewed at the national public hearing workshop to obtain feedback from all the stakeholders and to ensure that all relevant adaptation technologies were included. The criteria, weights, and scores were proposed by the national consultants and commented by the stakeholders during the stakeholder consultation. Performance efficiency, cost worthiness, and acceptability were the three categories of criteria considered in the MCDA. The performance efficiency was judged by the ease of use and the forecastability, while cost worthiness was evaluated by considering the further development and the transferability of the technologies. The acceptability evaluates the level of international and national acceptability of the technologies. Each criterion had equal weight for scoring, and three levels of scores, *good*, *fair*, and *poor* available for evaluation. Finally, a final focus group was held to listen to the experts' comments about the technology options revised after the public hearing. The top-priority technology need in each category was then selected for technology action plan (section II).

According to the technology prioritization process, the national data center ranked the highest among the technologies in the hardware category, while the national data transfer/management process ranked the highest among the technologies in the database management category. Finally, the WRF (ARW) model ranked the highest among the candidate models in the integrated model category.

Section II:

Technology Action Plans

Executive summary

Followed up with the Technology Needs Assessments (Section I), Section II develops the Technology Action Plans (TAPs) for selected technologies of the three sectors. In general, the development process consists of 1) setting up preliminary targets for technology transfer and diffusion of each technology option, 2) identifying barriers, 3) investigating possible solutions to address the barriers for the transfer and diffusion of technology, 4) and eventually developing a technology action plan for each technology option by considering legislation and regulation, financial incentives, institutional arrangement, infrastructure, R&D support, and human resource development. The specific development processes and findings of each sector can be summarized as follows:

1. Agricultural Sector

According to the TNA for the agricultural sector, the three groups of selected technologies include 1) forecasting and early warning systems in order to reduce the risk of damage from extreme climate events and pest/ disease outbreaks as well as to increase the ability to select the right crops based on specific planting time and crop cycle, 2) crop improvement for climate–resilient [Marker Assisted Selection (MAS) and genetic engineering] to reduce the risk of yield loss while increasing resource efficiency, and 3) precision farming technologies in order to enable farmers to make informed decisions concerning their farming operations as well as to reduce inputs while maintaining maximum productivity and minimizing the effects on the environment.

Subsequently, the Technology Action Plans (TAPs) for each technology were developed. In this process, barriers to the transfer and diffusion of the three prioritized technologies were identified as follows (Table 25).

Table 25 Barriers to the transfer and diffusion of the three prioritized technologies

Forecasting and early warning systems	Crop improvement technologies	Precision farming technologies
(1) Lack of technologies that can predict pest and diseases outbreaks within the country (2) Lack of forecasting tools for biological and physical data (fossil or sediment to investigate the past weather condition (3) Lack of skilled personnel to develop climate change simulation models (4) Lack of linkage between skilled personnel and relevant organizations (5) Limitation on data accessibility and data redundancy (6) Lack of high-quality and efficient forecasting tools (7) Lack of pest/ disease databases (8) Lack of implementation/ action plan to deal with pest/ disease outbreaks	(1) Limited research (in scope) for Marker Assisted Selection (2) Lack of government support and strong opposition from local NGOs for genetic engineering technology (3) Lack of genetic bank for wild relative and non native plant of economic crops. (4) Access to genetic resources is limited due to a unclear environmental policy (5) Intellectual properties issues, especially patents in the field of genetic engineering (6) Lack of supportive policy/ legislative frameworks for research, risk assessment and commercialization.	(1) Lack of suitability of imported technologies in Thailand's context (2) Limited application of remote sensing and GIS technologies (3) Ineffectiveness of technology programs for the farmers (4) Limited accessibility of high-quality analytical tools (5) Lack of necessary skills for agricultural technologies (6) Limited and fragmented research networks (7) Lack of biological database that can be used in a decision support system (8) Lack of "economies of scale" in the agritronics industry (major cost of precision farming)

Having identified and analyzed the barriers to technology transfer and diffusion, the TAPs could be divided into 3 phases, namely short-term (3 years), medium term (5 years) and long term (5 years) as shown in Table 26 - Table 28.

In conclusion, Thailand needs an international support on two major areas. One is a capacity building starting with the joint Master's level course through a consortium of leading international universities, local universities, research centers and private companies. A fund of 10 million USD is estimated to support the travel expenses of leading experts to conduct courses in Thailand as well as to provide learning materials and a learning facility to support approximately 150 students. This could be achieved with the framework of the Thailand Advanced Institute of Science and Technology (THAIST), an institute dedicated to develop Thai human resources for example, Thailand Advanced Institute of Science and Technology and Tokyo Institute of Technology (TAIST) under THAIST framework is a collaboration involving the National Science and Technology Development Agency (NSTDA) and partner universities both domestic and international to develop Thai human resources. TAIST serves as a virtual institution and focal point. NSTDA provides researchers to act as adjunct professors, supplying research projects and scholarships for graduate students. The participating institutions or universities from overseas provide world class background, expertise and experience, academic instruction and research advice. The Thai universities include King Mongkut's University of Technology Thonburi (KMUTT) and Mahidol University (MU).

Another is to support Thailand as an ASEAN training hub for adaptation technologies in agriculture in the context of south-south collaboration. Linking with international organizations and experts is also desirable to ensure the portable application with the cross cutting technologies. Implementation of this project needs sufficient funding in the key areas, along with high efficiency equipments. A total subsidy of 35,000 US dollars is estimated to operate comprehensive, hands-on training course on selected technologies for approximately 20 persons/ year. Three different types of training courses include 3-5 days workshop, 3 months training course, and 6 months for advanced research course. Areas of emphasis include simulation models for forecasting and early warning, marker assisted selection, risk assessment on GM product and precision farming skills. The center would also host the International Workshop on adaptation technologies to be applied in the agricultural sector, attracting academics and industry representatives from many countries to share their expertise and experience, with a strong emphasis on real world applications. This project idea could follow the successful model of the Molecular Rice Breeding Program for the Mekong Region Project which aimed at promoting the implementation of Marker Assisted Selection (MAS) for rice breeds in the Mekong region, particularly in Laos, Cambodia and Myanmar, through a comprehensive hands-on training program and through the sharing of genomic information and research facilities. The first phase of the project took place in 2004-2006 with financial support from the Rockefeller Foundation, Kasetsart University and BIOTEC/ NSTDA. During 2007-2008, the project obtained funding from the Generation Challenge Program (GCP) under the project title "Community of Practices" concept applied to Rice Production in the Mekong Region: Quick conversion of popular rice varieties with emphasis on drought, salinity and grain quality improvement (CoP Project), to continue the development of backcross introgression lines.

Table 26 TAPs for forecasting and warning systems

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
Technology capability	• Lack of technologies that can predict pest and diseases outbreaks within the country	• Encouraging public and private collaboration to develop such software • Developing a simulation model with a scale suited for Thailand's geographic areas	• Developing a simulation model/software to predict pest and disease outbreaks (e.g., Aquaculture Information System)	• Establishing an early warning system center of pest and disease outbreaks.	• Establishing an early warning system center of agricultural disasters that links to those of neighboring countries and covers economic crops (both domestic and international)	MOAC, NSTDA, TMD, GISTDA
	• Lack of forecasting tools for biological and physical data, weather conditions (pests)	• Promoting research and development on climate forecasts using biological and physical data	• Encouraging cooperation between simulation modelers and biologists to develop a model/system using biological data.	• Developing, together with international experts, a simulation model that can forecast using biological and physical data		NSTDA, CCKM, TMD, GISTDA
	• Lack of skilled personnel to develop climate change simulation models	• Collaborating with research institutes from overseas to provide training on the development of pest/disease simulation models	• Establishing international research collaboration on modeling • Building capacity through simulation model/software training workshops and seminars	• Enhancing the skills of climate change researchers and providing research grants in the area of pest/disease simulation model development	• Establishing a collaborative center for the development of personnel in the field of forecasting and early warning systems (Training Hub)	NSTDA, TMD, GISTDA, CCKM, TRF and universities around the country

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
		• Building a network of simulation modelers and establish domestic research collaboration				
	• Lack of linkages between skilled personnel and relevant organizations	• Providing training to develop a simulation model in such subjects as GIS, radar, and computerized data analysis • Building a research network (visiting professors) for technology transfer from overseas	• Providing training to enhance personnel's skills • Creating a public-private partnership domestically to link skilled personnel to relevant organizations	• Establishing collaboration with overseas research institutes/ governments for technology transfer		NSTDA, TMD, GISTDA, CCKM, TRF and universities around the country
Infrastructure	• Limitation on data accessibility and data redundancy	• Developing National Spatial Data Infrastructure (NSDI)	• Developing NSDI Portal (clearinghouse FGDS) to access systems of other organizations • Developing standards and integrate FGDS with NSDI manual • Developing a database for space-based images, satellite maps.	• Getting the FGDS ready for data integration and service system • Using FGDS by all governmental agencies, with the public being able to access information	• Establishing National Spatial Data Infrastructure (NSDI) of which its databases are complete and of high quality and with a unified set of standards.	GISTDA and Involved parties

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
	• Lack of high-quality and efficient forecasting tools	• Developing or acquiring powerful forecasting tools such as radar and super computers.	• Financing the development or acquisition of such tools as radar and supercomputers to be used for forecasting and early warnings of pest/disease outbreaks.	• Developing/using a satellite communication system to give early warnings to farmers. Farmers must be able to connect to the system via computer, radio communication, SMS and mobile phone.		TMD, NSTDA
	• Lack of pest/disease databases	• Developing unified databases that use the same standards both nationally and regionally.	• Assigning a central agency to act as a hub for pest and disease information exchange • Encouraging and building a data network for forecasting and early warnings of pest and diseases. • Building an early warning system for aquaculture diseases (Aquaculture Information System)	• Installing sensors and related equipment to collect both geographic and pest/disease data • Updating and integrate existing databases that provide complete (nation-wide, regionally and provincially) and high-quality data • Collaborating with neighboring countries in the Greater Mekong Subregion on developing and using a unified set of standards for data.	• Establishing a central agency to act as a hub for exchanging climate change information and pest/disease data • Developing a data network to support the distribution and exchange of data among relevant organizations	MOAC, OAE, GISTDA

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	**Medium-term (5 yr)**	**Long-term (10 yr)**	
Policy and Regulation	• No action plan to deal beforehand with pest and disease outbreaks	• Using the bird flu warning system as a model to develop emergency plans for pest and disease outbreak of brown plant hoppers in rice or an outbreak of pink aphids in young cassava. • Implementing policy measures specified in the National Strategy on Climate Change Management B.E. 2551-2555, where possible, while encouraging relevant players to put forward policy mechanisms that will facilitate the adoption of related strategic measures by research organizations.	• Assigning responsibility to relevant organizations to promote collaboration on the issues • Raising public awareness and encourage technology transfer on pest/disease outbreaks • Promoting collaboration between organizations, especially at the regional and international levels	• Expanding the National Spatial Data Infrastructure (NSDI) and ensuring public accessibility	• Ensuring that the National Strategy on Climate Change Management B.E. 2551-2555 is put in to practice effectively	MOAC, CMU, BOAC, TRF, MICT, GISTDA, MICT MONRE

Table 27 TAPs for crop improvement technologies

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Technology capability	• Marker Assisted Selection (MAS) is limited to certain crops (e.g. rice) while other crops have undergone less research • Plant transformation success has been limited to few plant species due to lack of government support and strong opposition from local NGOs.	• Providing funding for R&D crop improvement on technologiesfor adaptation to climachange, which include molecular breeding, physiology, high throughput screening, plant pathology and entomology. • Promoting research and development of molecular breeding through international collaboration with leading academic institutes as well as private companies. • Promoting the use of MAS for commercial breeding by transferring technology to local public and private institutes.		• Putting a strategic plan for crop improvement in the national agenda. • Promoting research collaboration with the international research institutes and private companies • Providing training programs or scholarships to increase the number of skilled researchers by collaboration with international institutes as well as academic institutes and private companies using the THAIST program • Transferring MAS to plant breeders by collaborations between government-to-government and public-private partnerships for wider utilization. • Setting up the hub of human resource development of crop improvement in ASEAN (South-South Collaboration) by collaboration with international organizations		-Public and private sectors, MOAC, Universities

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Infrastructure	• Lack of genetic banks for wild relatives and non native plants of economic crops.	• Establishing a national germplasm bank for long term plant conservation and efficient access to genetic diversity for crop improvement.		• Requesting international organizations (e.g., FAO, CGIAR) to allow and provide access to more genetic resource materials especially on crop wild relatives and non native plant to Thailand.	• Establishing a national and regional network of seed germplasm bank for long term preservation	Public and private sectors
Policy/Regulation	• Limited accessibility to genetic resources	• Coordinating with the international organization to ease access to more genetic resource materials that can contribute to adaptation in the face of climate change through increased interdependency caused by the global shifts of climate zones.				
Infrastructure	• Lack of high throughput screening facilities includes those for genotypic and phenotypic screening.	• Placing a substantial investment in a high throughput phenotypic and genotypic screening facility (to provide national facility services) to increase the efficiency of crop improvement for adaptation to climate change. Furthermore, this facility may serve as a regional service center for the Greater Mekong Sub-region			• Investing in a high throughput phenotypic and genotypic screening facility to serve as a national service to increase the efficiency of crop improvement for adaptation to climate change	

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Policy and Regulation	• Most GMOs are covered by patents.	• Calling for an assistant to negotiate the use of license and technologies as well as promote research and development of genetic engineering technology with leading international academic institutes, private companies and ASEAN network e.g. the Papaya Biotechnology Network.		• Working with international organizations such as ISAAA to encourage private patent holders to share their GM technology techniques and tools		Public and private sector
	• The absence of supportive policy and legislative frameworks for genetic engineering research, risk assessment and commercialization	• Setting clarified rules or standards for a GM field experiment • Seeking a policy approval for GM commercial cultivation with risk assessment and controlling mechanism • Arranging various activities to promote public awareness in science and regulation of genetically modified organisms.	• Setting clarified rules or standards for a GM field experiment and a commercial level			Policy makers

Table 28 TAPs for precision farming technologies

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Technology Capability	• The unsuitability of imported technologies or software to the Thai context	• Self-developing precision farming technologies that best suit the needs for Thai agricultural sector • Promoting a collaboration mechanism between public and private sectors	• Promoting technology transfer and collaboration between local, regional, and international institutes			NSTDA /KU /Public and private research institutes
	• Limited application of remote sensing and GIS technologies	• Developing or using open source GIS software	• Developing or using open source GIS software	• Developing and applying remote sensing and GIS technologies to small and medium sized farms		GISTDA /NSTDA /Public/Private research institutes
	• The use of technology only in large companies. • Unequally distribution of the technology to local farmers	• Promoting applications of precision farming technologies to increase productivity and reduce production input	• Arranging seminars, focus group to stimulate learning process , sharing ideas and experiences	• Building a network of model farmers through trainings across the country		OAE /KU /DOA /DOAE /Royal Initiative Discovery Institute /Universities around the country

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
	• Inaccessibility of high-quality analytical tools	• Promoting R&D of soil nutrient sensors that are easy to use and affordable to Thai farmers • Disseminating soil-sampling knowledge and innovation through the "soil doctor" network	• Promoting the use of soil test kit and smart fertilizer through the "soil doctor" network	• Developing a soil test kit that can measure soil nutrients accurately and precisely, with a focus on ease-of-use and affordability		KU/LDD /GISTDA /OAE /Public and private research institutes
	• Lack of necessary skills to use agricultural technologies	• Providing training courses for farmer, focusing on how to collect and analyze data	• Providing training courses for farmer, focusing on how to collect and analyze data	• Providing small and medium sized farmers throughout the country with training courses/workshops on precision farming	• Ensuring that small and medium sized farmers throughout the country have a farm-based database and can apply it to its fullest potential	OAE /KU /DOE /DOAE /Universities and research institutes around the country
	• Lack of research networks and collaborations	• Helping researchers/ practitioners to enhance their skills necessary for precision farming • Building a network of relevant researchers, stakeholders, and organizations	• Enhancing the skills of researchers/practitioners through training workshops and seminars • Building a research network through public and private partnership	• Providing research grants and scholarships in the area of precision farming		

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	**Medium-term (5 yr)**	**Long-Term (10 yr)**	
		• Developing curriculum on precision farming				
Infrastructure and database development	• Limited data and the lack of a biological database that can be used in a decision support system	• Developing the hub for compiling biological/agricultural database • Developing DSS software that links biological/agricultural databases	• Building a network of biological/agricultural data which include scientific knowledge, technology and innovation • Building a portal/clearinghouse/gateway that provides biological data in a digital format • Setting a data standard and write a manual of data exchange for relevant organizations	• Regularly collecting and compiling biological/agricultural data in a digital format and ensuring that such data are complete, nation-wide, and in the same standard format. • Developing DSS software that links biological/agricultural databases and ensuring that they are easy access to farmers.	• Updating the biological/agricultural database that contains data from the whole country and provides full data services • Ensuring that small and medium sized farmers can access high-quality DSS • Ensuring participation from governmental agencies, private organizations, and general public (farmers)	DOA /DOAE /MU /KU /Royal Initiative Discovery Institute

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Market mechanisms	• Lack of competitiveness in the agritronic market which leads to the high cost of precision farming technology	• Promoting the country's agritronic industry for technological advancement and reduction in the costs of acquiring technology	• Conducting a cost-benefit analysis/project feasibility study for precision farming in various types of farms	• Promoting the country's agritronic industry both technologically and commercially	• Developing model farmers who have successfully tried and tested precision farming technologies, throughout the country	MICT /OAE /NSTDA

2. Water resource management sector

According to the TNA for the water resource management sector, three selected technologies are 1) networking and management of infrastructures, 2) seasonal climate prediction, and 3) sensor web. These three technologies are crucial in every part of water resource management roadmap, from forecasting, planning, operation to disaster management. Components of each prioritized technology are analyzed in terms of technical requirement, transfer and diffusion requirement, and current status of accessibility and readiness for implementation (Table 29- Table 31). Then, the technology action plans are prepared (Table 32). Recommendations for overall management are as follows:

The institutional framework:

In order to facilitate collaboration across the ministries and to follow up on performance, the roles and responsibilities of the departments within each ministry should be allocated based on their missions. These missions can be divided into 8 groups: 1) policy, assessment and evaluation, 2) capital water, headwater or upstream area, and the environment, 3) primary irrigation system, 4) secondary irrigation system, 5) community water management system, 6) water supply system, 7) disaster prevention and alleviation system, and 8) supportive system.

Regulations and policy:

1) To ensure the consistency of the operation, every policy related to water resource management needs to be revised and the primary laws or parent laws for water resource management need to be determined via public hearing and participation from various sectors.

2) Knowledge related to water should be included in the school curriculum at the primary school, secondary school, and all levels to enable learners to understand the geographical attributes of Thailand and the necessity of water management in their own area.

3) The prioritisation of areas should be driven onward and the specific measures for each area should be identified in order to solve and alleviate problems of flood, drought, as well as areas with both floods and drought.

In addition, Thailand would benefit from an international support for water resource management capacity development and international knowledge networking project. The main objectives of this project idea are 1) to vigorously and systematically develop the capability of Thailand's human resources in water resource management, from government agencies to educational institutes, and from private sectors and to local communities, 2) to create an international knowledge network which enables the exchange of knowledge and research work as well as the transfer of technologies among water resource management agencies around the world, and 3) to create skilful human resources in water resource management through international collaborative research scholarships at the master and Ph.D. levels. The benefits from the project include 1) promoting knowledge and technology exchange that benefits the climate change adaptation of the water resource management, 2) increasing an awareness of the benefits of the systematic application or utilization of water resource management technology among personnel in the government sectors, academic institutes, and private sectors, and 3) increasing water resource management manpower within the government sectors and academic institutes that would help create a strong foundation for the country.

Table 29 Technology statue, accessibility, and solutions of Networking and management of structure

Technology	Components	Status/ Accessibility	Solution
Networking and management of infrastructures	1.1 Reservoir chainage design	Developing / Limited	**Economic** • Providing a focus and budget for the maintenance and operation of community water infrastructure, both large and small • Applying GIS technology when planning additional investment • Allocating a budget for the development of the control system **Capacity** • Creating knowledge, research work, as well as personnel relating to the advanced analysis of data and water situation model • Developing and deploying open source technologies which can be easily maintained • Receiving the transfer of knowledge in the design of water structure which supports various operation models, linkage methods, and the automatic water traffic control system • Creating a network for research among educational institutes • Analyzing the water situation in various cases and the effects of climate change • Developing detailed geo-informatics data • Deploying GIS technology in mapping the water traffic and link data from water measurement stations • Constructing water storage facilities and the management system • Scheduling a structure maintenance plan into the calendar • Transferring knowledge and creating awareness of the maintenance of water structure
	1.2 Dynamic rule curve	None /Limited	
	1.3 Optimization	Developing / Limited	
	1.4 Monitoring and Maintenance	Mature /Limited	

Table 30 Technology statue, accessibility, and solutions of Seasonal climate prediction

<table>
<tr><th>Technology</th><th>Components</th><th>Status& Accessibility</th><th>Solution</th></tr>
<tr><td rowspan="5">Seasonal climate prediction</td><td>2.1 Earth observation data</td><td>Mature /Limited</td><td rowspan="5"><u>Economic</u>
• Waiving the costs of the technologies and devices used in long-range weather forecasts, i.e. satellite image data, imported data from the world climate model, as well as high performance computers and calculating network systems, or providing discounts to enable the maximum effectiveness of the long-range weather forecast operation
• Planning a budget for the maintenance of the survey satellite to ensure continuous and accurate data
<u>Capacity</u>
• Creating a collaboration network for both national and international levels to exchange knowledge, research work, as well as improve experts in the relevant fields, as follows:
o Satellite image survey and data processing: Accurate and thorough survey and data processing will surely result in the high accuracy of the forecast outcomes.
o The development and calibration of water or salinity measuring heads
o Atmospheric science, physics, oceanography, mathematics, and other subjects related to data modification and completion, the application of a global climate model and models that would increase the definition of the outcomes, as well as the analysis and interpretation of the outcomes received from the models
o Global climate model and models that would increase the definition of the outcomes: High definition will maximize the accuracy of the outcomes.
o Cluster and Grid computing: Not only can this be used in estimating the appropriate sizes of the calculating devices, but it will also help to maximize the efficiency of the operation.</td></tr>
<tr><td>2.2 Data assimilation</td><td>Developing / Limited</td></tr>
<tr><td>2.3 AOGCM</td><td>Developing / Limited</td></tr>
<tr><td>2.4 Downscaling</td><td>Developing / Limited</td></tr>
<tr><td>2.5 Computing and Networking Systems</td><td>Mature /Limited</td></tr>
</table>

Table 31 Technology statue, accessibility, and solutions of Seasonal climate prediction

Technology	Components	Status& Accessibility	Solution
Sensor web	3.1 Real-time Observation	Mature/ limited	**Economic** • Planning a budget for the maintenance of the devices and support of devices/research work which have been developed domestically • Waive the copyright fees **Capacity** • Improving the utilization and exchange of the data and the research outcomes. Making it easier for the users to access at no cost. • Developing a data verification/screening system. • Determining common data standards. Creating appropriate data collection procedures. • Providing a training for data administrators so that they have consistent knowledge and understanding, which will enable accurate data collection. • Vigorously develop government sector personnel in the fields of mathematic programme development/GIS and research. • Promoting collaboration with foreign agencies/private sectors in conducting research in order to transfer technology. • Determining clear policy and agreement from the state's management in order to create understanding in the co-ownership of data and data sharing. • Gathering needs and developing a model system consistent with the needs of both management and operators. • Providing knowledge and understanding of how the system operates for management and operators in order to establish an effective line of command. • Clearly identifying duties regarding disaster warning in order to show linkages between agencies.
	3.2 Models for short-term run off and weather estimation	Mature/ accessible	
	3.3 Event Detection and Projection	An early stage/ None	
	3.4 Real-time Satellite Monitoring	An early stage/ None	
	3.5 Data linkage system and data warehouse centre	Developing / Limited	
	3.6 DSS	Mature / Limited	
	3.7Work flow management system	None/ None	

Table 32 Technology action plans for water resource management

Technology	Strategies	Activities	Timeline	
			Short-term (1-3 Yrs)	Long-term (3-5 Yrs)
1.Networking and management of infrastructures	**Capability Development**	1. Arranging educational activities/exhibitions in the local areas	✓	
		2. Encouraging schools to teach subjects on water resource management beginning at the high school level	✓	
		3. Learning from local wisdom, and water storage and distribution technologies	✓	
		4. Developing experts specializing in analyzing data and an advanced water situation prediction model	✓	
	Investment	5. Continuously allocating a budget for the production of high resolution geographical information to monitor changes	✓	
		6. Investing in system/measuring devices and database system for decision making	✓	
		7. Increasing the amount of the budget allocated to the local administration for the development and maintenance of local water sources		✓
	Organisational structure development	8. Working with communities to listen to opinions and problems which differ in each area	✓	
		9. The Royal Irrigation Department acts as the core agency in its operation and coordination with local administration to connect local water sources to irrigation waterways.		✓
		10. The ggovernment agencies and the educational institutes work together to develop research and technology which support the management of water structure, water traffic maps, and data system.		✓

Technology	Strategies	Activities	Timeline	
			Short-term (1-3 Yrs)	Long-term (3-5 Yrs)
	Policy and law	11. Reducing duplication of effort by reviewing the missions and responsibilities of each agency involved		✓
		12. Determining rights and responsibilities of the local administration regarding community water management		✓
		13. Working together in scheduling maintenance plans and duties into the calendar		✓
2.Seasonal climate prediction	**Capability Development**	1. Providing educational scholarships to students in the fields of survey, data calibration, data completion, climate model development, computing mathematics, and mainframe computing resource management	✓	
		2. Increasing manpower in the fields of modeling and data analysis within research agencies	✓	
		3. Exchanging research scholarships/seminars/trainings on seasonal climate prediction among agencies	✓	
		4. Brainstorming on the requirements, application, and communication of prediction and warning data	✓	
		5. Arranging trainings on the application of the prediction and warning data for different groups of users and distribute user manuals to the communities	✓	
		6. Increasing the definition of the outcomes derived from the models in order to maximize accuracy		✓
		7. Providing consultancy services to high school students in order to encourage them to study mathematics and physics		✓

Technology	Strategies	Activities	Timeline	
			Short-term (1-3 Yrs)	Long-term (3-5 Yrs)
		8. Providing trainings in the field of meteorology to university personnel		✓
	Investment	9. Obtaining and developing devices/methods in calibrating water or salinity measuring head	✓	
		10. Obtaining and developing devices, instruments, and software to be used in data modification and completion	✓	
		11. Assessing the needs for high-performance computers required in calculating/processing the models		✓
		12. Obtaining high-performance computing system and create an infrastructure system network with relevant agencies		✓
	Organizational structure development	13. Coordinating among agencies to create research collaboration which enables exchange of knowledge	✓	
	Policy and law	14. Waiving/reducing costs of data, devices, and instruments used in conducting research	✓	
		15. Conducting further research on imported devices, instruments, and models so that they are suitable and applicable to Thailand		✓
		16. Waive/reduce tax on devices and research instruments developed domestically		✓
3.Sensor web	**Capability Development**	1. Developing the capabilities of data administrators to enable them to collect/prepare data accurately and according to the standard before distributing it to other agencies	✓	
		2. Providing knowledge and understanding regarding how the system operates with both management and operators in order to set an efficient line of command	✓	

Technology	Strategies	Activities	Timeline	
			Short-term (1-3 Yrs)	Long-term (3-5 Yrs)
		3. Conducting test operation to ensure readiness prior to operation under real circumstances	✓	
		4. Developing government personnel involved in the R&D in mathematic programmes/GIS		✓
	Investment	5. Investing in the procurement of high-quality devices for the survey of water sources	✓	
		6. Determining long-term budget plan to assure that it covers maintenance	✓	
		7. Dividing the operation phase to reduce costs and provide time for the R&D of the success case	✓	
		8. Allocating budget to support relevant agencies to participate in the establishment of a data sharing centre and research work which can be easily accessed at no cost		✓
	Organisational structure	9. Assigning missions/duties in data collection, research and development, data distribution, and field work in the disaster area to each relevant agency	✓	
	development	10. Clearly determining the disaster warning workflow to show linkages among agencies, line of command, and disaster alleviation based on the severity of the area	✓	
	Policy and law	11. Promoting devices/research work which have been developed and manufactured domestically	✓	
		12. Promoting research collaboration with foreign agencies/private companies in order to receive and transfer technologies	✓	

Technology	Strategies	Activities	Timeline	
			Short-term (1-3 Yrs)	Long-term (3-5 Yrs)
		13. Determining clear policy/agreement from state management in order to create understanding among the relevant agencies in the collection and co-ownership of data and data sharing	✓	
		14. Setting common data standards and appropriate procedures for data collection	✓	
		15. Vigorously developing the government personnel in R&D in mathematic programmes/geo-informatics technology, and support research study		✓

3. Modeling Sector

According to the TNA for the modeling sector, the three groups of selected technologies include 1) national data center to serve as an essential infrastructure needed for domestic and international data collection and exchange, 2) national data transfer and management to establish official and effective means of data collection, data transfer, and database management, especially for the regional-level data needed for modeling climate change impacts, and 3) integrated modeling to provide and promote the use of an integrated tool for modeling climate change impacts across different sectors.

Subsequently, the Technology Action Plan (TAPs) to address all the three components was developed. In this process, barriers to the transfer and diffusion of the three prioritized technologies were identified. Eventually, the TAPs were developed and could be divided into 3 phases, namely short-term (3 years), medium term (5 years) and long term (5 years) as shown in Table 33.

In conclusion, Thailand needs an international support on integrated national data center equipped with an effective integrated national data transfer/management process. Implied by the title, the main objectives are to (1) establish a national data center for data collection, integration, and distribution to all impacted sectors and (2) implement effective mechanisms to collect, transfer, and manage domestic, regional, and international data relevant for climate change impact modeling. This project is beneficial for both governmental agencies and private institutes of all sectors utilizing climate change modeling for planning and decision making. The national data center maximizes the efficiency of data utilization, promotes cross-sectoral coordination and data exchange, and minimizes the total cost of the country's data transfer/management by reducing data transfer/management repetition and redundancy. Last but not least, this initiation will strengthen Thailand's potential to become a hub of climate change knowledge in the region. This project is essential for the success of Thailand's sustainable development priorities, especially for the water resource management and agricultural sectors. The estimated budget for this project is around 0.5 million USD.

Table 33 Technology action plan and activity timeline

Item	Barrier	Timeline Activity		
		Short-term	Mid-term	Long-term
Capacity	• Lack of skilled human resources	• Training and workshop	• Continuous human resource development (a series of training courses)	
	• Lack of the high performance hardware and central apparatus room	• Purchasing hardware	• Hardware maintenance and upgrade	
	• Lack of data for climate change modeling	• Collecting/purchasing relevant data including (but not limited to) GCMS, weather observation, climate, observation data from foreign institutions/data centers	• Improving the quality and quantity of the data to increase the capability for regional-scale modeling	
	• Lack of experience in using climate change models	• Support for Thai technical staff to train at foreign institutes which have technical assistantship agreements • Supporting a joint research effort between a Thai institute and a foreign technical partner	• Offering scholarships to support Thai staff to continue their higher education abroad, especially at foreign institutes which have technical assistantship agreements, in fields relevant to climate change modeling	
	• Highly sophisticated nature of the model for weather forecasting • Inadequacy of region-specific parameters needed for accurate and precise modeling, especially for tropical climate forecasting	• Promoting more study and calibration efforts to improve the precision and accuracy of the model	• Keeping up with the model's developments and advancements • Calibrating and configuring the model to suit Thailand's tropical climate	

Item	Barrier	Timeline Activity		
		Short-term	**Mid-term**	**Long-term**
Regulatory	• Unavailability of detailed operational policy • Lack of adequate governmental policy to support the center's establishment	• Issuing policy to facilitate the data center's operation. • Establishing more governmental assistance	• Developing and implementing the detailed operational policies	• Evolved policy that fully supports the effective operation of the data center
	• Legal and administrative limitation on data disclosure and access	• Proposing policy or legislation promoting data disclosure and cross-agency coordination • Preparing data transfer agreements with foreign agencies/institutes	• Developing agreements and partnerships with foreign agencies/institutes	
Institutional	• Lack of cooperation and communication between the involved institutions • Lack of data exchange among governmental agencies, private companies, academic institutions, and the nonprofit organizations	• Improving integrated national data exchange and management protocols	• Continuous development and refinement of integrated national data exchange and management protocols	• Increasing institutional capacity, management and organizational experience through cooperation with international data centers
	• Lack of data storage	• Establishing a national data center to collect information, both domestically and internationally	• Developing the national data center by giving it the potential to support database expansion	• Database expansion • Improving the quality and performance of the data center
	• Lack of effective data collection in Thailand	• Coordinating with all the related governmental agencies to collect data domestically	• Increasing the capacity of the coordination center by collecting data from both the public and private sectors	• Integrating data collected from all sectors

Item	Barrier	Timeline Activity		
		Short-term	Mid-term	Long-term
Economic	• Lack of the required budget for the establishment and operation of the national data center	• Coordinating with the government to support the data center infrastructure • Recruiting support from the organizations holding primary responsibility such as the Thai Meteorological Department, National Disaster Warning Center and NSTDA • Collaborating with international climate data centers such as NCDC, NCAR, and NCDC	• Recruiting support from secondarily responsible parties interested in climate and weather data collection such as Chiang Mai University and KMUTT • Collaborating with both national and international organizations for data center development	
	• Lack of funding	• Applying for financial support from both domestic and foreign funding agencies		• Welfare for support. Climate change Adaptation in Thailand
	• Lack of a budget for human resource development	• Each organization provides a budget for training of its staff		

TAPs for the prioritized technologies in the Agricultural sector

1. Preliminary targets for technology transfer and diffusion based on Section I

Three groups of adaptation technologies that best suit Thailand's specific needs have been selected as discussed in the TNA. This section goes on identifying and analyzing technology targets, barriers, and solutions for the transfer and diffusion of the three selected technologies including forecasting and early warning systems, crop improvement technologies, and precision farming technologies.

Increasing the forcastability of the weather and pest or disease outbreaks is the first target for technology transfer and diffusion of the forecasting and early warning systems. This group of technology could reduce the risk of farm damage and increase crop yields by allowing farmers to select more appropriate planting times and crop cycles. To implement the forecasting and early warning systems, the following data are needed: data on climate patterns, pest and disease outbreaks and past yields, impacts of climate change on agricultural ecosystem, and simulation models. An overview of the required data for the forecasting model is showed in Fig 20.

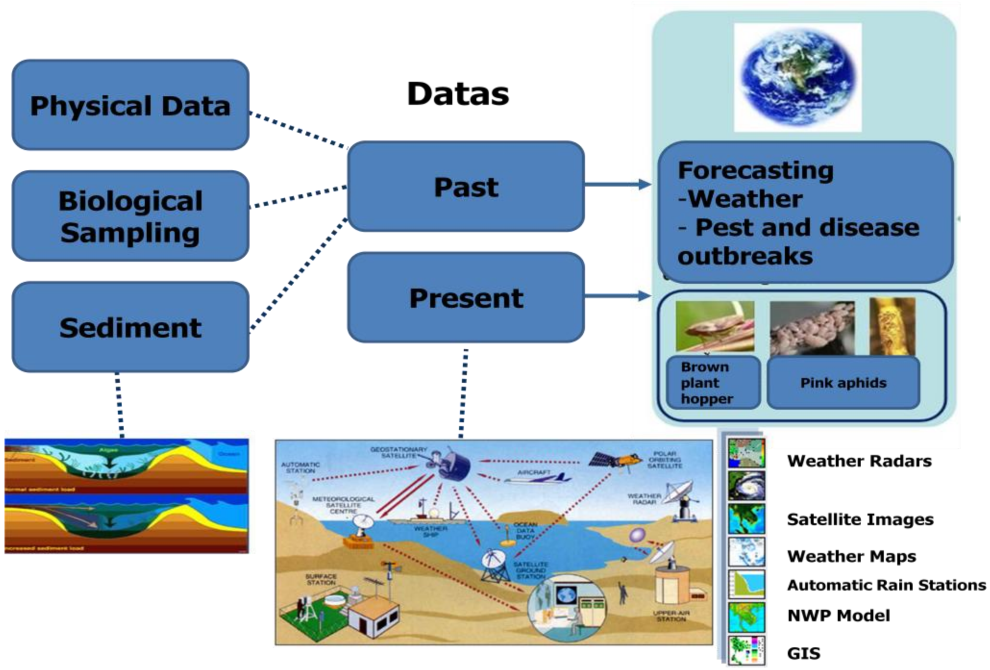


Fig 20 Overview of the forecasting and early warning system
Source: Sachs and Myhrvold (2011)(Sachs 2011) and Thai Meteorological Department (2011) (Thai Meteorological Depart 2011)

The second target group for technology transfer and diffusion is the technology that reduces the risk of yield loss while improving the efficiency of resource consumption for sustainable agriculture development. Crop improvement strategies under climatic variability may include (1) increasing the resilience of agricultural ecology to changing climates, (2) improving tolerance to abiotic stress such as drought, flash flooding, stagnant flooding, salinity, and temperature variation, (3) increasing photosynthetic efficiency, (4) increasing water-use and nitrogen-use efficiency, (5) decreasing non-photoperiod sensitivity, and (6) improving pest and disease resistance.

The third target of technology transfer is to encourage the use of precision farming technologies so that farmers can make informed decisions. To apply this technology, the following data are required: regional data on soil conditions, available water, wind, temperature and sunshine levels, local pests and diseases, and biological data of animals, plants, pest and diseases. The data will be incorporated in the Decision Support System (DSS) for resource management. An overview of the required data for precision farming technology can be seen in Figure 2.

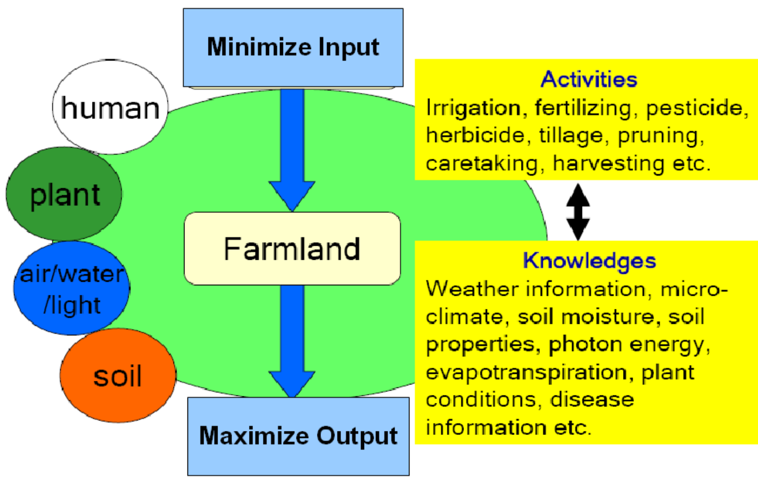


Fig 21 Precision farming technologies
Source: (Kerdcharoen 2009)

2. Barrier analysis

2.1 Barrier identification and analysis for the transfer and diffusion of forecasting and early warning systems

The barriers to the transfer and diffusion of forecasting and warning systems can be summarized into four aspects: technology capability, infrastructure and database development, human resource development, and policy and regulation. The details of these barriers are discussed in this section. The overall technology barrier involves the limitations of the decision making model. Similarly, research essential for the technology application are still in a nascent stage of development. Besides, the lack of data integration and collaboration among research institutes is one of the key challenges for technology development.

2.1.1 Technology capability

- **Lack of biological and physical data for simulation**

In Thailand, there is no laboratory to conduct isotopic and sediment analyses, essential physical and biological input data of simulation technologies. If needed, the analyses must be done through laboratories abroad, such as the laboratory at the University of Washington, specialized in developing and applying molecular and isotopic techniques to decipher climate, geochemical and biochemical processes over the past 2,000 years (Sachs and Myhrvold, 2011).

This lack of analytical techniques leads to the lack of an essential database. Due to the lack of an updated database, the existing models can only forecast and trace back 10-20 years. Meanwhile, with the use biological data/indicators (isotopic or sediment analysis), scientists can conduct a simulation as far back as the ice age (Sachs and Myhrvold, 2011). For example, biological indicators (e.g., fish, insects, algae, plants and birds) have been used in many studies to determine the role they might play in the early detection of El Nino Southern Oscillation (ENSO) events (Guralnick, 2002). Alternatively, local bio-indicators might be integrated in the model to give more accurate predictions and to compensate for the lack of a biological and physical database, as discussed above. Local farmers have long observed local bio-indicators to help them make strategic decisions. For instance, an observation of certain bio-indicators months before the start of a production cycle can help them predict the weather or pest/disease outbreaks and subsequently adjust their planting and cultivation activities accordingly. By integrating this with the use of forecasting models, their forecasts would be more accurate.

- **Software for forecasting and early warning of pest and diseases**

Most of the software for forecasting and early warning used in Thailand is imported; the following are a few examples, Numerical Weather Prediction (NWP), Decision support system for agro-technology transfer (DSSAT), the Erosion-Productivity Impact Calculator Model (EPIC), the Land Evaluation Model and FARMMIN, and the White Leaf Estimator version 1.0. Most of the software, however, does not completely fit the unique attributes of the country such as its pest and disease outbreaks.

The key barrier is the lack of skilled human resources in the field of forecasting/early warning simulation to develop programs that match Thailand's environmental conditions. Moreover, the lack of a research network, expert collaboration, and unified management has resulted in insufficient and unclear data for an integrated model and integrated policy.

2.1.2 Infrastructure and database development

- **Weather forecasting tools**

Similar to the software, most of the advanced tools or devices for the weather forecast are imported. Due to the lack of funding and devices, current forecasts are not as effective as they should be. For example, the Thai Meteorological Department has insufficient data storage power and lack analytical tools such as supercomputers, an automatic weather station, and weather radars.

- **Database standardization**

Even though a data center for forecasting and providing early warnings of pest and diseases is essential for supplying complete and reliable modeling inputs, one such data center does not exist. The existing databases are underused and not exploited to their full potential. The basic infrastructure and databases needed for forecasting and early warning are scattered among governmental agencies (GISTDA, TMD, MOAC, MONRE, etc), government-owned enterprises (EGAT), and private companies (Charoen Pokphand Foods: CPF Group). Each agency or institute has compiled their own database, resulting most prominently in database redundancy and in data in different format standards and units of analysis. The key barrier to implementing a forecasting and warning model is the lack of data standardization, which has produced data of inconsistent formats, quality and reliability.

2.1.3 Policy and Regulation

The National Strategy on Climate Change Management 2008-2012 was set as a comprehensive guideline for the national and local levels in preparation for the measurement, research and development of forecasting/early warning systems, technology transfer, public awareness strategy, and collaboration among researchers. However, the goal of this strategic plan has not yet been able to deal beforehand with pest and disease outbreaks (e.g., brown plant hoppers and pink aphids). Even though a pandemic of brown plant hoppers is being currently monitored by biologists/scientists, it is being done using a traditional method, without the aid of a forecasting and early warning model.

2.1.4 Others (Lack of data, management and coordination)

A lack of data and model validation could result in the inaccuracy of the simulated outcome. Also, there is very little active coordination between organizations to efficiently collaborate on forecasting and early warning model development, maintenance, and data sharing. Lastly, there has been neither policy-related work nor the transfer of knowledge to public.

2.2 Barrier identification and analysis for the transfer and diffusion of crop improvement technology

Crop improvement is becoming a crucial technology in dealing with the issues of climate change impacts. Therefore, one of the main objectives of crop improvement as an adaptation technology is to reduce the risk of yield loss while increasing resource efficiency in order to support sustainable development in the agricultural sector. Examples of crop improvement technologies that have been currently active in Thailand are Marker Assisted Selection (MAS) and genetic engineering. In this section, the barriers to the transfer and diffusion of these two technologies will be discussed and can be categorized into four aspects: technology capability, infrastructure and database development, human resource development, and policy and regulations.

2.2.1 Technology capability

- **Marker Assisted Selection (MAS)**

MAS applications in rice breeding, an advanced technology, has mainly focused on KDML105 jasmine rice and RD6 glutinous rice. Meanwhile, other crops have undergone only limited or no R&D. For example, cassava, one of the more important economic crops in Thailand, could benefit from the application of MAS to resist the mosaic virus, the most deadly disease to cassavas. Moreover, to promote MAS R&D, technical development and training programs for plant breeders should be offered, especially those in crop improvement programs for adapting to climate change, molecular breeders, physiologists, plant pathologists and entomologists. Furthermore, linkages between molecular and conventional breeders are needed. A combination of molecular and phenotypic selection should become routine in breeding programs. Enhanced capacity in the field of physiology is urgently needed, as it is a key process of genetic control (Campos et al., 2004).

- **Genetic engineer**

Thailand was one of the first countries in the region to invest in research on genetic engineering and adopted a national biosafety guideline in 1992. However, progress has been relatively slow in comparison to that of other ASEAN countries, which have further developed genetic engineering for use on a commercial scale. In Thailand, successful plant transformations have been limited to only a few plant species due to insufficient government support and NGO protests.

2.2.2 Infrastructure

Marker Assisted Selection (MAS)

The lack of funding for seed conservation in the country is a serious issue. Seed banks are needed to prolong *ex-situ* seed viability under a cold and dry condition to reserve plants for future use (Prada, D., 2009). However, conserving seed germplasm is a long-term endeavor (Kundu et al., 2008). In Thailand, many different seed collections are mainly used for the specific purposes of their collectors, and the conservation facilities are usually unsuitable for medium- and long-term storage. The maintenance of a seed bank is unaffordable for plant breeders and for Thai SMEs. Although the Ministry of Agriculture and Cooperatives has established a long-term seed storage facility, its insufficient operating budget for conserving plant genetic resources is also a vexing problem.

Advanced technologies needed for research in this field are pretty costly and require the help of the government. Success of crop improvement largely depends on the ability to identify and access genetic diversity, including new or improved variability for target traits. Research has indicated that crop wild relatives can aid crops in adapting to climate change. Wild crop relatives provide more genetic diversity than their cultivated cousins. Rice and wheat retain about 30-40% of the genetic diversity of their wild relatives, soybeans retain 50%, and maize retains approximately 75% (Fig 22). For developing high yielding varieties under abiotic stress conditions, plant breeders normally use a direct selection approach for yield stability over multiple locations, for which results might take about 10 years. Today, high-throughput screening technology in a controlled facility has the advantage of quantifying the morpho-physiological traits that influence abiotic stress adaptation, which in turn will complement yield selection criteria. However phenotype and genotype screening facilities appear to be too expensive for the breeders and for SMEs in Thailand.

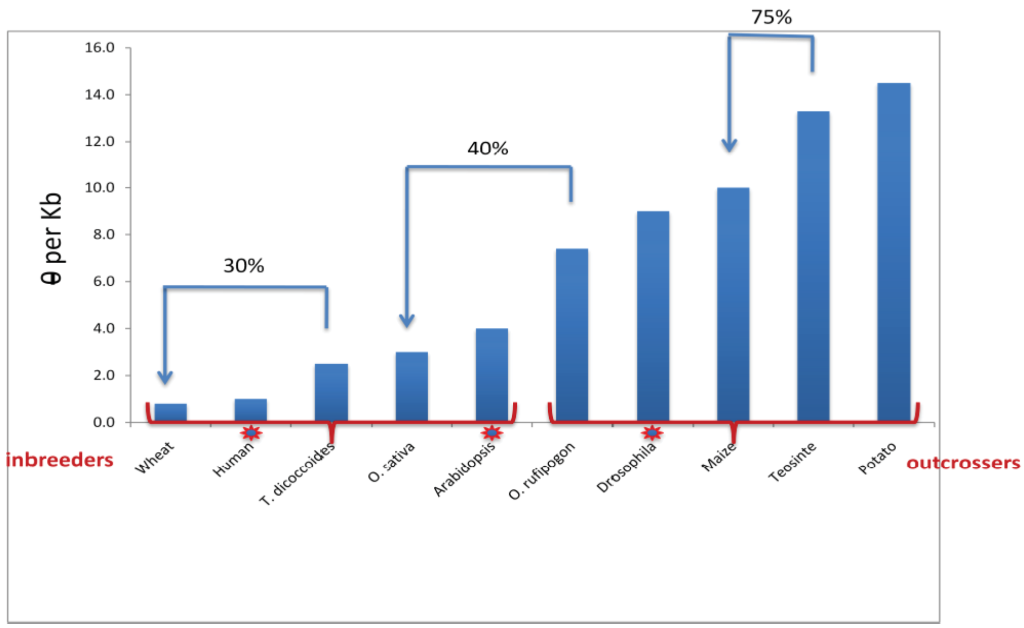


Fig 22 Genetic diversity in various cultivated crops and wild relatives. Arrows indicate the proportion of wild diversity retained in the maize, wheat, and rice cultivated genepool

2.2.3 Policy and Regulation

MAS

The Convention on Biological Diversity (CBD) produced Nagoya Protocol is an international agreement aimed at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way. However, real access to genetic resources is still limited in many countries due to a complex policy environment. At present, there are approximately 150 different crops being traded in the world market, only 35 of which are covered by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) – a treaty that sets a multilateral legal framework that facilitates the exchange of genetic resources. There is an increased demand by countries to facilitate access to more genetic resource materials through increased interdependency caused by global shifts in climate zones (Jarvis).

Genetic engineering

Thailand's Biosafety Guideline was initiated in 1992 by the National Center for Genetic Engineering and Biotechnology (BIOTEC). The missions cover R&D of field testing and commercialization.

However, environmental regulations and stringent standards of product safety testing initiated in the late 1990s led to many cancelations of GMOs R&D projects, which caused a huge drop in scientific output.

In 2007, the Ministry of Agriculture and Cooperatives set experimental stations for GM crops. The experiment not only focused on GM crop testing but also the effects on human health and the environment as well as public opinions. The experimental plan clearly described the planting area, type of crop, and control methods. Then, the plan was submitted to the cabinet for approval before the experiment's launch.

Intellectual property rights (IPR) have also become a major concern. In the field of climate-tolerance crops, serious concerns have been expressed over the monopoly that a few companies hold on genes patents. Examples of such companies are Monsanto (US), DuPont (US), BASF (Germany), Bayer (Germany), and Syngenta (Switzerland). They have filed 532 patent documents (a total 55 patent families) on "climate-ready" genes at patent offices around the world. Intellectual property issues have created many prospective barriers, especially on technology transfer. Policy debate about the subject of intellectual property rights in the transfer of biotechnology is an urgent need. Examples of patent transgenic plant traits related to climate change are showed in Table 34.

Table 34 Examples of patent transgenic plant traits related to climate change

Utility	Name of gene	Assignees
Drought and salt tolerant	*AVP*1 (a vacuolar H^+-pyrophosphatase)	University of Connecticut (Farmington, CT, US) Whitehead Institute for Biomedical Research (Cambridge, MA, US) Beth Israel Deaconess Medical Center, Inc. (Boston, MA, US)
	*AtPRG*5 (a proton gradient regulation 5 polypeptide)	University of Georgia Research Foundation, Inc. (Athens, GA, US)
	Csp (cold shock protein)	Monsanto Technology LLC (St. Louis, MO, US)
	*DRO*5 (lateral organ boundaries domain protein)	Dow AgroSciences LLC (Indianapolis, IN, US)
	*PRDT*1 (Pathogen Resistant Drought Tolerant)	Agrinomics LLC (Portland, OR, US)
	*KAT*1 (K^+in channel protein)	Regents of the University of California (Oakland, CA, US)
	OsNACx (plant-specific transcription factor NAC family)	Huazhong Agricultural University (Wuhan, CN)
	*gb*1 (glycine- betaine aldehyde dehydrogenase)	Monsanto Technology LLC
Low nutrient requirement or improvement the nutrient quality	- *ASN*-A (asparagine synthetase) - GS (glutamine synthetase)	New York University (New York, NY, US)
	- GS (glutamine synthetase) - AS (Asparagine synthetase) - GOGAT (alfalfa aspartate aminotransferase)	AJINOMOTO CO., INC. (15-1, Kyobashi 1-chome, Tokyo, JP)
	P-PII (plant nitrogen regulatory PII)	New York University (New York, NY, US)
	- glycolate oxidase or glycolate - ehydrogenase gene - glyoxylate carboligase gene - tartronic semialdehyde reductase gene	Bayer CropScience AG (Monheim, DE)
	AlaAT (barley alanine aminotransferase)	The Governors of the University of Alberta (Edmonton, Alberta, CA)
	FDA(Fructose-1,6-bisphosphate aldolase)	Monsanto Technology LLC (St. Louis, MO, US)
Disease resistant	receptor on the plant side that recognizes the pathogen - *RPS*4 - *RCH*2	RIKEN (Saitama, JP)
	*RAR*1	Syngenta Participations AG (Basel, CH)
	RNAi of *MLO* (integral plasma membrane-localized protein)	BASF Plant Science GmbH (Ludwigshafen, DE)
	*PRDT*1 Pathogen Resistant Drought Tolerant	Agrinomics LLC (Portland, OR, US)

Public perception is another important issue that should be taken into account. Due to the lack of knowledge and communication, some groups do not agree with introducing GMOs. In addition, a lack of clear policy direction from the government and negative press should be addressed.

THAI TOPIC, a nonprofit organization, conducted a survey in December 2003 in order to gauge the public perception and understanding on the adoption on genetically modified plants and animals. Data obtained from 2,454 samples, representing stakeholders from all five regions of the country (North, Northeast, Central, East and South), reveal that the public agrees that research and development of GMOs is important to the country's economic well-being. Goals of GMO research and development include the enhancement of nutritional values, to obtainment of various flower colors, and the enhancement of vaccine and drug production. The public insists that all genetically modified foods should be labeled.

2.3 Barrier identification and analysis for the transfer and diffusion of precision farming

Precision farming in Thailand is still at a nascent stage of development. Barriers to the transfer and diffusion of precision farming technologies can be divided into four areas: technology capability, infrastructure/database, human resource development, and market mechanisms.

2.3.1 Technology capability

Precision farming technologies play important roles in maximizing yields and minimizing costs. The technology compiles related data and controls resources for more precise and efficient farming. Technological barriers are listed as follows: the feasibility of imported technology, limited applications of remote sensing and GIS technologies, accessibility of high-quality analytical tools, lack of necessary skills for agricultural technology, and limited and fragmented research networks.

Feasibility of imported technologies

Precision farming hardware and software in Thailand are mostly imported especially those related to sensor networks, such as weather station sensors, soil sensors, plant disease sensors, yield monitoring sensors, and chemical sensors. Since precision farming requires a specific set of data (on particular climate, geographic, and agricultural characteristics), imported technologies cannot be used to their full capacity in a local context, resulting in reduced accuracy and durability.

Limited application of remote sensing and GIS technologies

In the past, remote sensing and GIS technologies were used mostly within governmental agencies because they were too expensive and too complicated for various groups of users. Recently, however, GPS technologies become more affordable and accessible, creating a good opportunity for the use of these technologies in agriculture. Applications of remote sensing and GIS technologies can be diverse. Examples include the use of these tools to analyze the suitability of plant production and arrange proper zoning, to create farm maps, to collect and analyze pest and diseases for future forecasting or monitoring/warning purposes, to evaluate risks of natural disasters, to build an irrigation system, and to manage plant nutrients. However, even with the availability of these technologies at cheaper prices, the use of remote sensing and GIS technologies in Thailand's agricultural sector is still limited to a few large private farming operations such as the CP Corporation or the Mitpon Sugar Corporation. Precision farming has not been established in small and medium sized farms in the country (Sikhio model, Nakhon Ratchasima).

Accessibility of high-quality analytical tools

Data collection and analysis of soil nutrients are required for precision farming both at micro and macro levels. For example, soil data should be collected at least every 20 square meters (20x20 meters), or every 0.4 – 1 hectare (Robert, 2002). Therefore, soil sampling and testing is considered to be a crucial part of precision farming. For farmers, this could lead to a major problem because they may have neither the necessary sampling and testing tools nor knowledge to conduct the test themselves. If soil data cannot be collected and complied at a micro level, it is difficult to extend or link these databases to the macro-level, e.g. the soil information database developed by the Land Development Department.

In addition to increasing the accessibility of soil analytical tools to general farmers, public awareness is key to success applications of precision farming. IT channels could create public awareness of these new technologies. In Denmark, agricultural consultants and wholesale fertilizer companies are the center of agricultural information. In the USA, the Eastern Corn Belt, fertilizer companies, agricultural consultants, university experts, and successful farmers are also found to be important sources of information (Fountas et al., 2005).

Ineffectiveness of technology transfer to farmers

GIS data/information related to soil property and plant demand for nutrients have been available to the public for quite some time but most farmers are not utilizing such data/information in their agricultural practice. This is due to the fact that technology transfer in Thailand has been top-down; policies and information on desired agricultural practices (e.g., the selection and use of crop breeds, fertilizers, and pesticides) are pushed down from the central government to the provinces, and then from districts to sub-districts, and finally down to the farmers, with the expectation that farmers will do as recommended. This technology pushing approach, as opposed to listening to the needs of farmers, is hampering effective technology transfer to the farming sector.

Lack of necessary skills for agricultural technology

A majority of Thai farmers are still lacking the necessary skills for practical precision farming applications. Even though small and medium sized farmers in Thailand have utilized local wisdom in their farming, they do not possess the skills required to systematically and scientifically measure, collect, and analyze agricultural data to improve efficiency and productivity. In addition, it has been found that the age, attitude, and education of farmers can prove to be significant barriers to the adoption of precision farming (Akridge and Whipker, 1999; NRC, 2011).

Limited and fragmented research networks

Similar to other fields of research, skillful researchers in the area of precision farming are most in need. In addition, lack of collaboration among research institutes has resulted in fragmented results or an incomplete database for precision farming. Thus, research outcomes do not contribute much to the country's agricultural practice. Collaboration among researchers, especially in multidisciplinary fields, is thus required to help deliver precision farming to its full potential.

Lack of Market mechanisms

The Agritronic industry in precision farming is very small and has relatively low competition on the supply side. This lack of competitiveness leads to high technology costs which prohibits farmers who may be interested in adopting and applying precision farming tools. This problem may exacerbate chronic low-priced yields as well. For example, an application of precision farming to low-priced crops such as rice crops or cassava may not be economically feasible, whereas the use of precision farming for high-priced crops such as orchids and grapes may increase their value even more. Moreover, the study of Akridge and Whipker (1999) reported that the key barriers of precision practices to farmers are cost (61%), slow adopters (34%), inadaptability of cropping programs (24%), and lack of skills (19%).

2.3.2 Infrastructure and database development

Currently, biological databases to support decision making in the field of agriculture are still limited. The knowledge and database related to science, technology, innovation, local wisdom, and the Royal's projects are redundant and scattered over various governmental units. In addition, data inconsistency such as in the units of analysis and data formats could cause inconvenience and confusion for users.

2.4 Linkages of the barriers identified

The overall problems and barriers in the agricultural sector are discussed in this section. By integrating the results of the barrier analysis in previous section, the barriers have been classified to three main aspects: technology capability, infrastructure and database development.

2.4.1 Technology capability

The fundamental problem of technology capability is the lack of skillful programmers or scientists to developed modeling tools. For this reason, most of the advanced tools are imported and cannot be suitably used for the local condition and environment. Moreover, the lack of collaboration among researchers/institutes also leads to incomplete analyses. For example, MAS research has mostly been conducted on rice while other important economic crops have been neglected. Similar to genetic engineering, successful plant transformation has been limited to a few crops.

Besides the lack of skilled human resources and research collaborations, inefficiency in distributing and delivering technology to farmers is also a barrier. Old fashion top-down command measures have proven to be ineffective. The farmers or real practitioners should be able to use technology (e.g., precision farming) by integrating it with local wisdom or bio-indicators to make their own farming plans.

2.4.2 Infrastructure and database development

Lack of infrastructure development funding is a major barrier since both the hardware and software of the technology are imported. For example, the Thai Meteorological Department is still short in terms of its data storage capacity and analytical tools. Similarly, MAS requires a seed bank with an operating budget.

The lack of a central database is identified as the top rated barrier. No center or organization manages or compiles databases in a clear, accurate, and accessible format for future use in research. The inputs for the model still lack a clear standard format, a quality and reliable verification system, and a model validation system. In addition, discontinuous data collection can make the situation worse.

Moreover, there is no real researcher network since each institute works on its own database or project, resulting in incomplete databases. For example, the Ministry of Agriculture and Cooperatives has long collected such data/information for forecasting and early warning of pest and diseases. The data, however, have been scattered across various departmental units.

2.4.3 Policy and regulation

The lacks of an implementation plan, intellectual property rights, and a guideline on conducting a field experiment are the major barriers for this technology.

An implementation plan is a key element to ensure the successful delivery of government policies. For example, the National Strategy on Climate Change Management 2008-2012 has not yet accomplished its goal of dealing with pest and disease outbreak. Intellectual property rights (IPR) seem to be a major concern for GM. Few companies hold patents on genes; this creates a barrier to technology transfer. Similar to MAS, the ability to access genetic resources in many countries is very limited. In addition, the lack of a clear guideline and regulation for conducting GM field tests are main obstacles that need to be resolved.

3. Enabling framework for overcoming the barriers

3.1 Possible solutions to addressing the barriers to the transfer and diffusion of forecasting and warning system technology

Possible solutions to overcoming the barriers blocking the transfer and diffusion of forecasting and warning system technology are discussed as follows:

(a) Technology Capability

- Promoting research and development on climate forecasting using biological and physical data: Cooperation between modelers and biologists is required to develop a model/system that can handle biological and physical data. The system must be able to link back (and compare) its forecasts to data collected with traditional data collection methods.
- Promoting research and development on local simulation modeling software: It has been suggested that this be done through a public and private partnership in which relevant organizations co-develop technologies. An example is a combination of simulation models and GIS of biodiversity data that can forecast and give proper warnings on climate extremes and pest/disease outbreaks.
- Encouraging research collaboration between local researchers (in the fields of modeling, biology and agriculture) and overseas experts for capacity building and training.
- Developing local open source GIS software and data modules suitable for each region in the country so that farmers can make use of GIS information to manage their farms more effectively.
- Increasing the number of experts in the areas of simulation and forecasting: This can be done through programs that promote knowledge transfer and exchange among organizations, training on simulation modeling, and collaborating with overseas research institutes.
- Encouraging relevant governmental agencies to raise public awareness about climate change, especially among those farmers who may be affected: Recommendations must be easy to understand and match the needs of farmers/farming communities.

(b) Infrastructure and database development

Weather forecasting tools

- Financing the development of high-quality and high-end tools needed for collecting/analyzing climate-related data as well as forecasting/warning of pest and disease outbreaks.
- Making use of a satellite communication system to give warnings of natural disasters: Farmers must be able to link to the system via a computer, a radio communication, or a mobile phone.

Database standards

- Upgrading and integrating existing databases into a National Spatial Data Infrastructure (NSDI) that provides complete and high-quality data on a single standard: It should accomplish this by putting emphasis on the following (1) setting unified standards for data structure, collection, storing, control, and quality testing; (2) selecting a responsible organization to spearhead the initial integration of the data and maintain the system in the long run; (3) identifying important components of geographic information system and the organizations that handle them; and (4) building a data network, with a data clearinghouse that will pull metadata from different data owners into a system that is accessible through the Internet.
- Collaborating with neighboring countries in the Greater Mekong Subregion (GMS) on developing and using a unified set of data standards, and domestically developing standards for an Aquaculture Information and Warning System.

Pest and disease databases

- Encouraging the establishment of a central agency to collect and exchange climate-related information and create a pest and disease database.
- Encouraging the development of a data network for forecasting and early warning of pest/disease outbreaks and collaborating with neighboring countries to use a unified set of data standards.

(c) Policy/Regulation

- Using the bird flu warning system as a model to draft an emergency plan for agricultural disasters such as an outbreak of brown plant hoppers in the rice paddy fields or an outbreak of pink aphids in young cassava.
- Implementing policy measures specified in the National Strategy on Climate Change Management 2008-2012, where possible, while encouraging relevant players to put forward policy mechanisms that will facilitate research and development organizations to adopt related strategic measures.

3.2 Possible solutions to addressing the barriers to the transfer and diffusion of crop improvement technology

Possible solutions to addressing the barriers to the transfer and diffusion of crop improvement technologies are listed as follows:

Marker Assisted Selection (MAS)

(a) Technology capability (R&D capacity)

- Providing financial support for crop improvement technology R&D to adapt to climate change, which would support developments in Marker Assisted Selection (MAS), physiology, high throughput screening technology, plant pathology and entomology.
- Collaborating with international research institutes to strengthen the technology capability of domestic academic institutes and private companies.
- Promoting the use of marker-assisted selection for commercial breeding by way of technology transfer to local public and private institutes.
- Formulating a course on MAS through consultation with prestigious research universities such as Cornell University, University of California Davis, Wageningen University and Research Centre, local universities and private companies.
- Providing in-bound and out-bound visiting scientist fellowships to facilitate technology transfer and the exchange of experiences between leading international experts and Thai researchers/practitioners in the key areas such as phenotyping-genotyping association and high throughput screening.
- Positioning Thailand as an ASEAN training hub in the framework of South-South Cooperation, and linking with international organizations and experts with the ultimate goal of ensuring global food security.

(b) Infrastructure

- Establishing a national germplasm bank for long-term plant conservation and providing access to genetic diversity for crop improvement.
- Placing a substantial investment in a high throughput phenotyping and genotyping screening facility (to provide national facility services) to increase the efficiency of crop improvement for adaptation to climate change: Furthermore, this facility may serve as a regional service center for the Greater Mekong Subregion.

(c) Policy/Regulation

- Coordinating with the FAO for case access to more genetic resource materials that can contribute to adaptation in the face of climate change through increased interdependency caused by the global shifts of climate zones.

Genetic Modification in Thailand

(a) Technology Capability (R&D Capacity)

- Promoting research and development of genetic engineering technologies through international collaboration with leading academic institutes as well as private companies and networks such as the Papaya Biotechnology Network (research collaboration with the international research institutes to strengthen GM technology).
- Asking an international organization to assist in negotiation of using the licensed genes and technologies that help crops adapt to extreme environments, especially drought–tolerant genes or technologies to improve resource use efficiency in plants.
- Formulating a course on genetic engineering through consultation with a consortium of leading universities and private companies.

(b) Policy/Regulation

- Supporting the policy to confine field trials of locally developed genetically modified products in order to enable research progress so that informed science-based decisions can be made on the safety of the GM crops.
- Seeking policy approval for the commercial cultivation of GM plants under strict risk assessment and controlling mechanisms.

(c) Intellectual Property Rights

- Working with international organizations such as the ISAAA to encourage private patent holders to share the GM technology techniques and tools so that developing countries can benefit from the third wave of agricultural revolution with the ultimate goal of ensuring global food security.

(d) Public Perception

- Arranging various activities to promote public awareness in science and regulation of genetically modified organisms. This can be done through various channels such as public seminars and mass media communication (newspaper, newsletters, radio, television and public survey).

3.3 Possible solutions to addressing the barriers to the transfer and diffusion of precision farming technology

Solutions to addressing the barriers to the transfer and diffusion of precision farming technologies can be categorized into the following areas: technology capability, infrastructure and database development, human resource development, and market mechanisms. The solutions are listed as follows:

(a) Technology capability

Suitability of imported technologies

- Supporting the development of precision farming technologies that best suit the particular needs of the country's agricultural sector, especially through public and private partnerships in research and development: This is to take advantage of technologies being tailored to local users.
- Creating a collaborative mechanism between the public and private sectors, both domestically and internationally, to develop precision farming tools (especially sensor technologies) that are most suitable for Thailand's climate and geography.

Limited application of remote sensing and GIS technologies

- Developing and/or making use of open source GIS software with an interface designed to maximize farmers' accessibility. Efforts must be spent on ensuring that farmers can access high-quality, reliable, and free-of-charge GIS software, leading to successful technology diffusion and adoption.
- Developing and applying remote sensing and GIS technologies to small and medium sized farms.

Ineffectiveness of technology transfer programs to farmers

- Encouraging the application of precision farming technologies, in order to increase productivity and reduce production input, through user participatory programs: For example, to help farmers analyze soil nutrients and give the right amount of fertilizer, knowledge transfer must be done in such a way that farmers are helping each other by sharing ideas, exchanging experiences, and then collectively solving problems and making decisions. In trainings, users must participate from the beginning to the end of the process. Farm communities must also play an important part in the learning process, passing down knowledge to the next generation of farmers in a sustainable manner.

Accessibility of high-quality analytical tools

- Researching and developing the soil nutrient sensors that are easy-to-use and affordable for the Thai farmers. This may be an extension of the N-P-K Soil Test Kit under the Smart Fertilizer Project, to make soil sampling easier for small and medium sized farmers. Also, the "Soil Doctor" Network, whose members are scattered all over the country, can be used as a public awareness channel for this program Fig 23 .

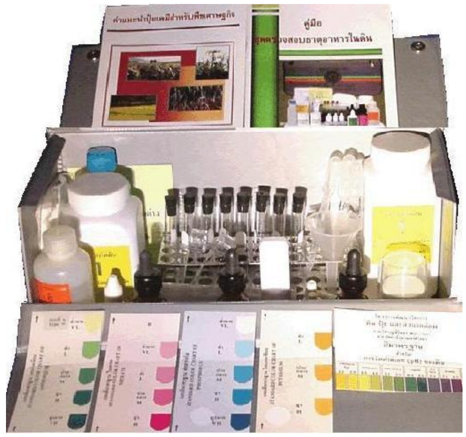


Fig 23 N-P-K Soil Test Kit under the Smart Fertilizer Project
Source: (Attanandana 2007)

Lack of necessary human skills

- Providing farmers with precision farming courses, focusing on how to collect and analyze relevant data to improve productivity while reducing resource consumption.

Limited and fragmented research networks

- Building a network of relevant researchers, stakeholders, and organizations: Public relations activities to attract more interested parties for further collaboration is also recommended.
- Encouraging researchers/practitioners in the area of precision farming to improve their necessary skills by aligning with the country's agricultural needs. This can be done through various modes of capacity building such as research grants, scholarships, training workshops, seminars, and networking.
- Learning from the experiences of international experts and applying them to Thailand's context: This can be done by having Thai researchers/practitioners visit model sites overseas and exchange knowledge with personnel from countries/places that excel at precision farming, especially those small countries with thriving farms/food production despite their unfertile lands and unfavorable climatic conditions (such as Israel and the Netherlands).

(b) Infrastructure and database development

- Building a central database that stores or links all biological/agricultural data in a digital format: This database should cover bodies of scientific knowledge, technology, innovation, local wisdom, and information about the Royal's projects.
- Using the database as a key component of a decision support system (DSS) designed for small and medium sized farmers: For example, the farmers must be able to use a combination of such a database and the DSS to answer temporal questions (e.g., "When to start planting which plant?" "When to give fertilizer?") as well as spatial questions (e.g., "Where to put in which plant/crops?" "How much fertilizer should be given for which part of the farm?") In addition, both the database and the whole DSS must be constantly upgraded to guarantee accuracy and reliability so as to build trust in farm users.

- Ensuring that the database and DSS are easily accessible. The system should allow access from the Internet and mobile phones.

(c) Market mechanisms

- Promoting the country's agritronics industry, both technologically and commercially, with the goal of achieving economies of scale by helping drive the prices of relevant technologies down: This is not only to encourage the adoption of precision farming technologies within the country, but also to decrease the country's dependency on imported technologies and build self-made technologies better suited the country's context.
- Expediting the development of model farmers, who have successfully tried and tested precision farming technologies throughout the country.
- Conducting a cost-benefit analysis/project feasibility study for the application of precision farming to actual plant and animal sites. A heavy focus should be placed on the agricultural products that are the country's main economic strengths.

4. Technology action plans

Having identified/analyzed the barriers to technology transfer and diffusion, the TAPs are summarized in 3 phases: short term (3 years), medium term (5 years) and long term (5 years), see Table 35-Table 37.

Table 35 Summary of the TAPs for agricultural forecasting and early warning systems

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
Technology capability	• Lack of technologies that can predict pest and diseases outbreaks within the country	• Encouraging public and private collaboration to develop such software • Developing a simulation model with a scale suited for Thailand's geographic areas	• Developing a simulation model/software to predict pest and disease outbreaks (e.g., Aquaculture Information System)	• Establishing an early warning system center of pest and disease outbreaks.	• Establishing an early warning system center of agricultural disasters that links to those of neighboring countries and covers economic crops (both domestic and international)	MOAC, NSTDA, TMD, GISTDA
	• Lack of forecasting tools for biological and physical data, weather conditions (pests)	• Promoting research and development on climate forecasts using biological and physical data	• Encouraging cooperation between simulation modelers and biologists to develop a model/system using biological data.	• Developing, together with international experts, a simulation model that can forecast using biological and physical data		NSTDA, CCKM, TMD, GISTDA
	• Lack of skilled personnel to develop climate change simulation models	• Collaborating with research institutes from overseas to provide training on the development of pest/disease simulation models	• Establishing international research collaboration on modeling • Building capacity through simulation	• Enhancing the skills of climate change researchers and providing research grants in the area of pest/disease simulation model development	• Establishing a collaborative center for the development of personnel in the field of forecasting and early warning systems (Training Hub)	NSTDA, TMD, GISTDA, CCKM, TRF and universities around the country

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
		• Building a network of simulation modelers and establish domestic research collaboration	model/software training workshops and seminars			
	• Lack of linkages between skilled personnel and relevant organizations	• Providing training to develop a simulation model in such subjects as GIS, radar, and computerized data analysis • Building a research network (visiting professors) for technology transfer from overseas	• Providing training to enhance personnel's skills • Creating a public-private partnership domestically to link skilled personnel to relevant organizations	• Establishing collaboration with overseas research institutes/ governments for technology transfer		NSTDA, TMD, GISTDA, CCKM, TRF and universities around the country
Infrastructure	• Limitation on data accessibility and data redundancy	• Developing National Spatial Data Infrastructure (NSDI)	• Developing NSDI Portal (clearinghouse FGDS) to access systems of other organizations • Developing standards and integrate FGDS with NSDI manual • Developing a database for	• Getting the FGDS ready for data integration and service system • Using FGDS by all governmental agencies, with the public being able to access information	• Establishing National Spatial Data Infrastructure (NSDI) of which its databases are complete and of high quality and with a unified set of standards.	GISTDA and Involved parties

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
			space-based images, satellite maps.			
	• Lack of high-quality and efficient forecasting tools	• Developing or acquiring powerful forecasting tools such as radar and super computers.	• Financing the development or acquisition of such tools as radar and supercomputers to be used for forecasting and early warnings of pest/disease outbreaks.	• Developing/using a satellite communication system to give early warnings to farmers. Farmers must be able to connect to the system via computer, radio communication, SMS and mobile phone.		TMD, NSTDA
	• Lack of pest/disease databases	• Developing unified databases that use the same standards both nationally and regionally.	• Assigning a central agency to act as a hub for pest and disease information exchange • Encouraging and building a data network for forecasting and early warnings of pest and diseases. • Building an early warning system for	• Installing sensors and related equipment to collect both geographic and pest/disease data • Updating and integrate existing databases that provide complete (nation-wide, regionally and provincially) and high-quality data • Collaborating with neighboring countries	• Establishing a central agency to act as a hub for exchanging climate change information and pest/disease data • Developing a data network to support the distribution and exchange of data among relevant organizations	MOAC, OAE, GISTDA

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-term (10 yr)	
			aquaculture diseases (Aquaculture Information System)	in the Greater Mekong Subregion on developing and using a unified set of standards for data		
Policy and Regulation	• No action plan to deal beforehand with pest and disease outbreaks	• Using the bird flu warning system as a model to develop emergency plans for pest and disease outbreak of brown plant hoppers in rice or an outbreak of pink aphids in young cassava. • Implementing policy measures specified in the National Strategy on Climate Change Management B.E. 2551-2555, where possible, while encouraging relevant players to put forward policy mechanisms that will facilitate the adoption of related strategic measures by research organizations.	• Assigning responsibility to relevant organizations to promote collaboration on the issues • Raising public awareness and encourage technology transfer on pest/disease outbreaks • Promoting collaboration between organizations, especially at the regional and international levels	• Expanding the National Spatial Data Infrastructure (NSDI) and ensuring public accessibility	• Ensuring that the National Strategy on Climate Change Management B.E. 2551-2555 is put in to practice effectively	MOAC, CMU, BOAC, TRF, MICT, GISTDA, MICT MONRE

Table 36 Summary of the TAPs for crop improvement technologies

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Technology capability (R&D capacity)	• Marker Assisted Selection (MAS) is limited to certain crops (e.g. rice) while other crops have undergone less research • Plant transformation success has been limited to few plant species due to lack of government support and strong opposition from local NGOs.	• Providing funding for R&D on crop improvement technologiesfor adaptation to climachange, which include molecular breeding, physiology, high throughput screening, plant pathology and entomology. • Promoting research and development of molecular breeding through international collaboration with leading academic institutes as well as private companies. • Promoting the use of MAS for commercial breeding by transferring technology to local public and private institutes.		• Putting a strategic plan for crop improvement in the national agenda. • Promoting research collaboration with the international research institutes and private companies • Providing training programs or scholarships to increase the number of skilled researchers by collaboration with international institutes as well as academic institutes and private companies using the THAIST program • Transferring MAS to plant breeders by collaborations between government-to-government and public-private		-Public and private sectors, MOAC, Universities

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
				partnerships for wider utilization. • Setting up the hub of human resource development of crop improvement in ASEAN (South-South Collaboration) by collaboration with international organizations		
Infrastructure	• Lack of genetic banks for wild relatives and non native plants of economic crops.	• Establishing a national germplasm bank for long term plant conservation and efficient access to genetic diversity for crop improvement.		• Requesting international organizations (e.g., FAO, CGIAR) to allow and provide access to more genetic resource materials especially on crop wild relatives and non native plant to Thailand.	• Establishing a national and regional network of seed germplasm bank for long term preservation	Public and private sectors
Policy/ Regulation	• Limited accessibility to genetic resources	• Coordinating with the international organization to ease access to more genetic resource materials that can contribute to adaptation in the face of climate				

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
		change through increased interdependency caused by the global shifts of climate zones.				
Infrastructure	• Lack of high throughput screening facilities includes those for genotypic and phenotypic screening.	• Placing a substantial investment in a high throughput phenotypic and genotypic screening facility (to provide national facility services) to increase the efficiency of crop improvement for adaptation to climate change. Furthermore, this facility may serve as a regional service center for the Greater Mekong Subregion			• Investing in a high throughput phenotypic and genotypic screening facility to serve as a national service to increase the efficiency of crop improvement for adaptation to climate change	
Policy/ Regulation	• Most GMOs are covered by patents.	• Calling for an assistant to negotiate the use of license and technologies as well as promote research and development of genetic engineering technology with leading international		• Working with international organizations such as ISAAA to encourage private patent holders to share their GM technology techniques and tools		Public and private sector

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
		academic institutes, private companies and ASEAN network e.g. the Papaya Biotechnology Network.				
	• The absence of supportive policy and legislative frameworks for genetic engineering research, risk assessment and commercialization	• Setting clarified rules or standards for a GM field experiment • Seeking a policy approval for GM commercial cultivation with risk assessment and controlling mechanism • Arranging various activities to promote public awareness in science and regulation of genetically modified organisms.	• Setting clarified rules or standards for a GM field experiment and a commercial level			Policy makers

Table 37 Summary of TAPs for precision farming technologies

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
Technology Capability	• The unsuitability of imported technologies or software to the Thai context	• Self-developing precision farming technologies that best suit the needs for Thai agricultural sector • Promoting a collaboration mechanism between public and private sectors	• Promoting technology transfer and collaboration between local, regional, and international institutes			NSTDA /KU /Public and private research institutes
	• Limited application of remote sensing and GIS technologies	• Developing or using open source GIS software	• Developing or using open source GIS software	• Developing and applying remote sensing and GIS technologies to small and medium sized farms		GISTDA /NSTDA /Public/Private research institutes
	• The use of technology only in large companies. • Unequally distribution of the technology to local farmers	• Promoting applications of precision farming technologies to increase productivity and reduce production input	• Arranging seminars, focus group to stimulate learning process , sharing ideas and experiences	• Building a network of model farmers through trainings across the country		OAE /KU /DOA /DOAE /Royal Initiative Discovery Institute /Universities around the country

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	Medium-term (5 yr)	Long-Term (10 yr)	
	• Inaccessibility of high-quality analytical tools	• Promoting R&D of soil nutrient sensors that are easy to use and affordable to Thai farmers • Disseminating soil-sampling knowledge and innovation through the “soil doctor” network	• Promoting the use of soil test kit and smart fertilizer through the “soil doctor” network	• Developing a soil test kit that can measure soil nutrients accurately and precisely, with a focus on ease-of-use and affordability		KU/LDD /GISTDA /OAE /Public and private research institutes
	• Lack of necessary skills to use agricultural technologies	• Providing training courses for farmer, focusing on how to collect and analyze data	• Providing training courses for farmer, focusing on how to collect and analyze data	• Providing small and medium sized farmers throughout the country with training courses/workshops on precision farming	• Ensuring that small and medium sized farmers throughout the country have a farm-based database and can apply it to its fullest potential	OAE /KU /DOE /DOAE /Universities and research institutes around the country
	• Lack of research networks and collaborations	• Helping researchers/practitioners to enhance their skills necessary for precision farming • Building a network of relevant researchers, stakeholders, and organizations • Developing curriculum on precision farming	• Enhancing the skills of researchers/practitioners through training workshops and seminars • Building a research network through public and private partnership	• Providing research grants and scholarships in the area of precision farming		

Item	Barriers	Solutions	Technology Action Plan			Involved Parties
			Short-term (3 yr)	**Medium-term (5 yr)**	**Long-Term (10 yr)**	
Infrastructure and database development	• Limited data and the lack of a biological database that can be used in a decision support system	• Developing the hub for compiling biological/agricultural database • Developing DSS software that links biological/agricultural databases	• Building a network of biological/agricultural data which include scientific knowledge, technology and innovation • Building a portal/clearinghouse/ gateway that provides biological data in a digital format • Setting a data standard and write a manual of data exchange for relevant organizations	• Regularly collecting and compiling biological/agricultural data in a digital format and ensuring that such data are complete, nation-wide, and in the same standard format. • Developing DSS software that links biological/agricultural databases and ensuring that they are easy access to farmers.	• Updating the biological/agricultural database that contains data from the whole country and provides full data services • Ensuring that small and medium sized farmers can access high-quality DSS • Ensuring participation from governmental agencies, private organizations, and general public (farmers)	DOA /DOAE /MU /KU /Royal Initiative Discovery Institute
Market mechanisms	• Lack of competitiveness in the agritronic market which leads to the high cost of precision farming technology	• Promoting the country's agritronis industry for technological advancement and reduction in the costs of acquiring technology	• Conducting a cost-benefit analysis/project feasibility study for precision farming in various types of farms	• Promoting the country's agritronic industry both technologically and commercially	• Developing model farmers who have successfully tried and tested precision farming technologies, throughout the country	MICT /OAE /NSTDA

5. Project ideas for international support

Project 1: Formulation of graduate courses to promote capacity building for technology diffusion and transfer in agricultural sector through international collaboration and networking (5 years plan)

This is to formulate graduate courses related to the technology diffusion and transfer in agricultural sector through a consortium of leading international universities, local universities, research centers, and private companies for the purpose of human resource capacity building. This could be achieved using the framework of the Thailand Advanced Institute of Science and Technology (THAIST), an institute dedicated to develop Thai human resources. Please read about a successful story of such a consortium for capacity building in Annex 2.

Requirements for international support

A financial support of 10 million USD is estimated to support the travel expenses of leading experts to teach courses in Thailand and to equip learning materials as well as learning facilities to support approximately 150 students.

Project 2: Establishment of an ASEAN training hub for adaptation technologies in Agriculture. (5 years plan)

This aims to establish a national training center in Thailand as an ASEAN training hub in the context of south-south collaboration, linking with international organizations and experts with the ultimate goal of ensuring the world's food security. The activities of the knowledge and training hub for adaptation technologies may include providing various short training courses for practitioners such as a 3-5 days workshop, a short term research training (3 months), and an advanced research training (6 months). The center will emphasize on multi-disciplinary lessons in related fields. Research projects and internships with farmers and agribusiness parties will provide practical experience and collaboration they need for future success. Areas of emphasis include simulation models for forecasting and early warning, marker assisted selection, risk assessment on GM product, and precision farming skills. Agricultural practitioners should be able to use and develop innovative techniques and gain an access to the top of the line equipments and facilities including both hardware and software. The center would also host an international workshop on adaptation technologies to be applied in the agricultural sector, attracting academics and industry representatives from many countries to share their expertise and experience, with a strong emphasis on the real world applications. This program could also follow the successful model of the Molecular Rice Breeding Program for the Mekong Region (in the box below)**.**

Requirements for international support

Thailand would need a sufficient funding/ grant/ scholarship in the key areas, along with high efficiency training equipments. A subsidy of 35,000 US dollars is estimated for operating a comprehensive hands-on training course on selected technologies for approximately 20 persons/ year. In addition, collaboration with prestigious overseas academic/ research institutes from overseas to design the training courses is imperative. Similarly, collaboration on research and development of adaptation technologies, especially customization of the techniques to meet the country's specific needs, is essential. This can also build a network of researchers/ practitioners/ experts in related fields (such as simulation, phenotyping-genotyping association, high throughput screening, and precision farming) both domestically and internationally. Consequently, this network will provide training skills and forums to exchange ideas in a self-sustained manner.

TAPs for the prioritized technologies in the Water resource management sector

1. Preliminary targets for technology transfer and diffusion based on Section I

The water resource sector has adapted the framework shown in Fig 24 to develop a technology action plan. Five steps were taken:

Step 1: Selecting the three most promising technology options for the TAP by referring to the prioritized technologies in the TNA described in Part I (shown also in Fig 25)

Step 2: Developing a technology map and identifying the technology requirements, status, and accessibility of the three selected technologies.

Step 3: Analyzing the problems and barriers related to technology transfer and diffusion with respect to four aspects: economic, regulatory, institutional, and capacity.

Step 4: Studying the application of each technology on both macro and micro levels.

Step 5: Developing technology action plans in response to the targets for technology transfer and diffusion in Thailand.

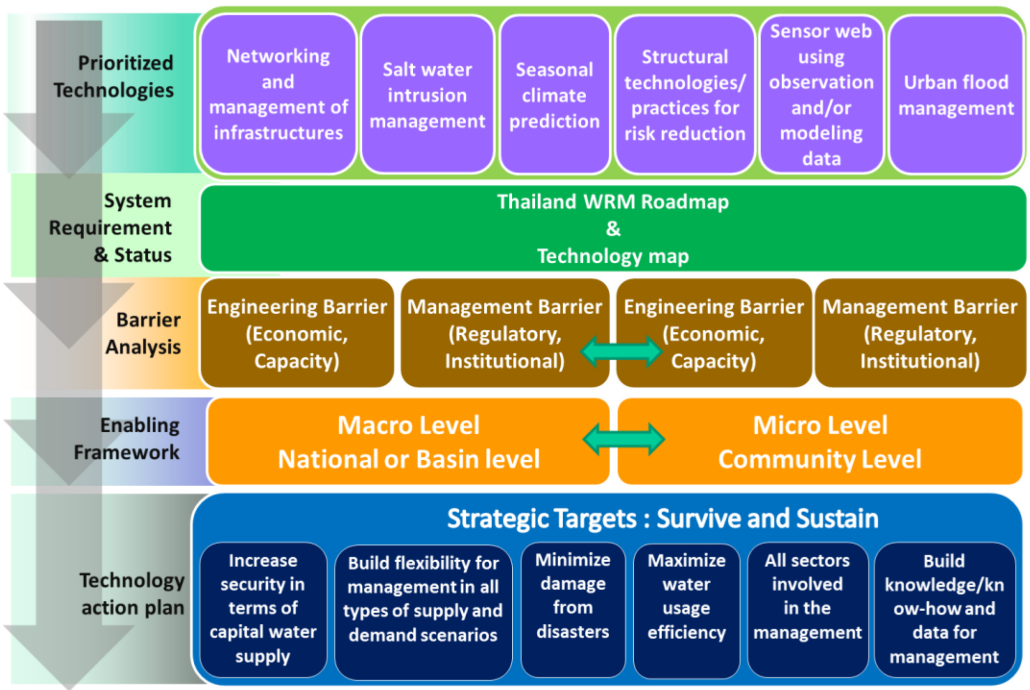


Fig 24 TAP Framework

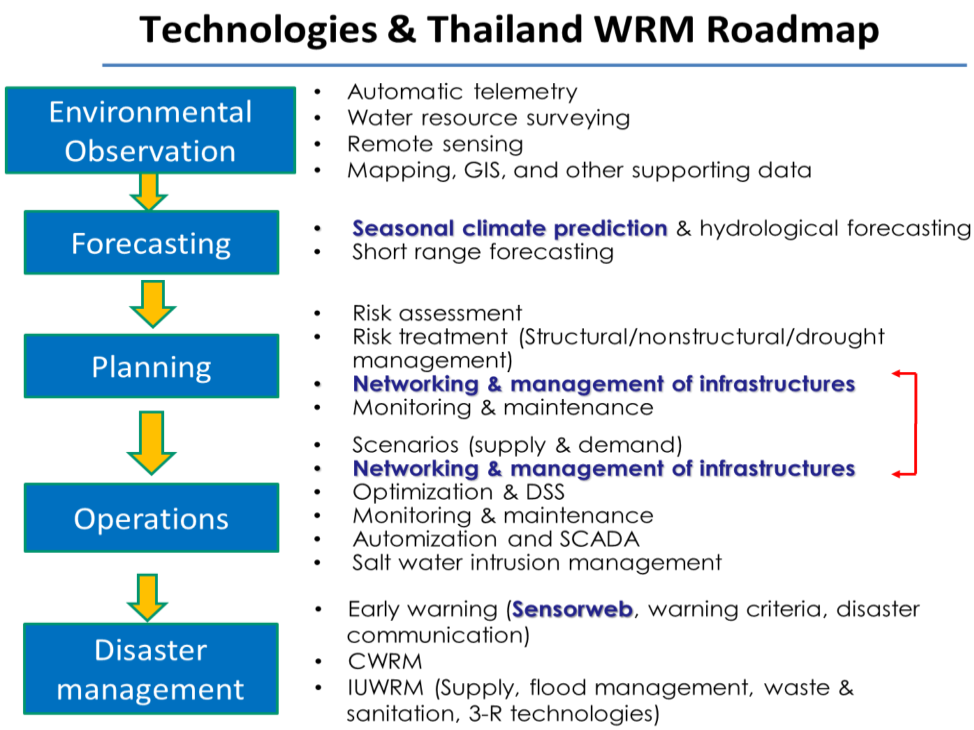


Fig 25 Thailand Water Resource Management (WRM) Roadmap

The products of the five steps are presented in the four sections of this report. Steps 1 and 2 produced the “Preliminary Targets for Technology Transfer and Diffusion,” while Step 3 resulted in the “Barrier Analysis.” Step 4 is discussed in “Enabling Framework,” and Step 5 has led to the TAP.

The preliminary targets of technology transfer and diffusion have been set in accordance with the national policy and strategy to create water resource stability and sustainability. The prioritized technologies must be able to alleviate problems, upgrade infrastructure management systems, and improve human resource competency. The specific preliminary targets are as follows:

- To increase water supply security.
- To build flexibility for managing all types of water supply and demand scenarios.
- To minimize damage from disasters.
- To maximize the efficiency of water usage.
- To include all stakeholders in water management.
- To build knowledge/know-how and data for water management.

Arranging the prioritized technologies from the TNA in accordance with the Thailand WRM Roadmap (Fig 25) produced three selected technologies: (A) the networking and management of water infrastructures, (B) seasonal climate prediction, and (C) sensor webs. These three technologies capture the important aspects listed in the roadmap, which are forecasting, planning, operation, and disaster management. It should be noted that most of the participants in the National Public Hearing Workshop agreed that environmental observation is well developed in terms of both technology/devices and human resources. Thus, it was not chosen for technology transfer and diffusion.

Prior to analyzing the barriers, we analyzed the requirements for development, requirements for transfer and diffusion, and the status and accessibility of each selected technology. The networking and management of water infrastructures consists of the following tools: reservoir network design, the dynamic rule curve, water management optimization, and water monitoring and maintenance systems. The technology description, requirements for development, requirements for transfer and diffusion, and status and accessibility of each technology are summarized in Table 38. Database system and data management are the most common requirements for this group of technologies. Requirements for transfer and diffusion are experts, budget, and participation from all stakeholders. Reservoir network design and optimization for water management are in developing states while water monitoring and maintenance is the only well developed technology. On the contrary, reservoir management guided by the dynamic rule curve has not been developed yet. The technologic accessibility of this group of technology is rather limited.

Seasonal climate prediction consists of these following tools: earth observation data, data assimilation, the atmosphere-ocean coupled general circulation model (ACGC), the downscaling method, and computing and networking systems. The technology descriptions, requirements for development, requirements for transfer and diffusion, and status/accessibility of each type of technology are summarized in Table 39. Database system and technology suitable for domestic use are the most in need of development. Data accessibility, budget, and experts are required for transfer and diffusion. Earth observation data and a computing and networking system are at a mature state, while data assimilation, ACGC, and downscaling are in a developing state. Similarly to the previous group of technology, the accessibility of this group of technology is limited.

A sensor web consists of the following tools: real-time observation models for short-term run off and weather estimation, event detection and projection, real-time satellite monitoring, a data linkage system and data warehouse center, data display system (DSS), and work flow management system. The technology description, requirements for development, requirements for transfer and diffusion, and status/accessibility of each technology are summarized in Table 40. Technology and database are the most in need of development. Experts and collaboration among research centers are required for transfer and diffusion. Real time observations, models for run-off forecasting, and data display systems are fully developed technologies and ready to be implemented, unlike workflow management technology, which has yet to be developed. Event detection and precision technology are at an early stage of development. Models for run-off forecasting can be accessed, while other technologies are limited or inaccessible.

Table 38 Technology maps of networking and management of water infrastructures

Technology maps -A- networking and management of water infrastructures				
Components	**Description**	**Requirement for Development**	**Requirement for Transfer and Diffusion**	**Status/ Accessibility**
Reservoir network design	The design that helps understanding reservoir connections	• High resolution data on geographical and physical features (Light Detection and Ranging – LIDAR) • The real-time water data linked to seasonal climate prediction and hydrological forecasting models • Data linkage within river basins • Data linkage across river basins • Risk assessment • The design of reservoir networks and crossed canals	• Negotiation for mutual benefits for water users both within and across the river basins • Participation of all stakeholders • Construction technology	Developing/ Limited
Reservoir management guided by the dynamic rule curve	The rule curve is derived from historical data of river flows and water demands. The curve shows the minimum water level requirement in the reservoir at a specific time to meet the particular purposes for which the reservoir is designed. During normal flow, the reservoir may be kept at the rule curve level. During	• Inflow data • Real-time discharge rate data of internal water and downstream water • The reservoir and canal connection design	• Risk assessment • Scenario analysis of drainage and sewerage • A mutually understandable and acceptable terms and conditions from stakeholders • Reservoir management expert	None/ Limited

Technology maps -A- networking and management of water infrastructures				
Components	**Description**	**Requirement for Development**	**Requirement for Transfer and Diffusion**	**Status/ Accessibility**
	heavy flow, the water level may be allowed to rise above the rule curve. If floods are expected, the reservoir is drawn down below the rule curve before the water arrives. Under a low flow condition or drought period, the reservoir may be drawn below the rule curve or emptied.			
Optimization for water management	This project aims at building water infrastructure networks, maximizing the efficiency of water resource management, while minimizing floods and drought risks and conflicting demands	• Real-time data of the water situation • Automatic control and instruction according to the targets	• The control targets, e.g. to reduce the risk of floods and droughts • Water management experts	Developing/ Limited
Water monitoring and maintenance system	A system that monitors and maintains water infrastructure and its supporting systems	• Database system • Ability to display the status of devices • Prioritizing maintenance work	• Costs of water per unit, both fixed and variable costs that change in proportionally to production	Mature/ Limited

Table 39 Technology maps of Seasonal climate prediction

Technology maps - B - Seasonal climate prediction				
Components	**Description**	**Requirements for Development**	**Requirement for Transfer and Diffusion**	**Status/ Accessibility**
Earth observation data	Remote sensing and *in-situ* data collection for model initialization and calibration	• High coverage (spatial and temporal), improved quality, and reliability of sensors • Modified technology to suit current conditions	• Data accessibility for both domestic and foreign data • Collaboration between organisations that possess or collect data • Understanding data application	Mature/ Limited
Data assimilation	Method to combine observation and model results to produce best estimations of the current and the past of a system	• Understand strength and limitation of data from the model	• Experts in atmospheric science/physics, oceanography, and mathematics	Developing/ Limited
Atmosphere-Ocean Coupled General Circulation Model (AOGCM)		• Outcome of the assemble expectation • Understand the factors that affect climate and seasonal variation	• Experts in atmospheric science/physics, oceanography, and mathematics	Developing/ Limited

Technology maps - B - Seasonal climate prediction				
Components	**Description**	**Requirements for Development**	**Requirement for Transfer and Diffusion**	**Status/ Accessibility**
Downscaling method	In general, global climate models (GCMs) are run at coarse spatial resolution which is unable to resolve important sub-grid scale features such as clouds and topography. The downscaling method can be used to overcome this problem. It is a technique that takes outputs from the model and adds information at a size smaller (or local-scale surface weather) than the grid.	• Understanding of the local-scaled surface weather/climate • Understanding of the application of the forecast outcomes (e.g., estimate of the harvesting period, design cultivation calendar)	• Experts in atmospheric science/physics, oceanography, and mathematics • Ability to interpret the results of the forecast and to communicate to all stakeholders	Developing/ Limited
Computing and Networking Systems	Computing hardware, configuration, and communication technology	• Cluster and grid computing, parallel computing • Hardware sizing, hardware configuration	• Moderate price	Mature/ Limited

Table 40 Technology maps of sensor web

Technology maps - C - Sensor web				
Components	**Description**	**Requirements for Development**	**Requirement for Transfer and Diffusion**	**Status & Accessibility**
Real-time Observation	• Sensor that measures water levels, the amounts of rainfall, and soil humidity • Exploration robots e.g. robotic plane, an exploration ship • Automatic data transmission system that can transfer information when a high risk situation occurs	• Model monitoring system • Data analysis • Data transmission system • The interoperable communication incorporating to satellite communication system • Develop maintaining program for the monitoring station	• The suitability of the geographical condition of the area where devices will be used • Maintenance and station monitoring officer	Mature/Limited
Models for run off forecast	• Models to forecast and estimate rainfall and run off	• Detailed information of each area • Ability to locate the position • Automatically compute and interpret the receiving data • Up-to-date model	• Geological and meteorology data • Experts	Mature/ Accessible

Technology maps - C - Sensor web				
Components	**Description**	**Requirements for Development**	**Requirement for Transfer and Diffusion**	**Status & Accessibility**
Event Detection and Prediction Technology	• The technology that observes and monitors images or data before, during, or after unusual events	• Database system • The accuracy and completeness of the data	• Experts in developing programs for automatic analysis, processing, and interpreting images	An early stage/None
Real-time Satellite Monitoring	• Real-time aerial photographs/satellite images	• Satellite and image transmission system	• Geo-informatics technology • Experts in developing programs, processing, and interpreting images	An early stage/None
Data linkage system and data warehouse	• A networking system linking the relevant agencies	• Network system • Standard for data entry • Database system	• Inter-agency collaboration • Accurate and reliable data • Updated data	Developing/ Limited
Data display system (DSS)	• Showing analytical data, i.e. spatial data reports, tables, statistics	• Appropriate data for users e.g. executives and the operators		Mature/ Limited

Technology maps - C - Sensor web				
Components	**Description**	**Requirements for Development**	**Requirement for Transfer and Diffusion**	**Status & Accessibility**
	• Tool that is used for easy access, manipulation, and visualization			
Workflow management system	• A computer system that manages and defines a series of tasks, automate redundant tasks, and ensure that uncompleted tasks are followed up on	• Supporting system	• Preliminary test • Experts and system operators	None/None

2. Barrier analysis

In the previous section, requirements for the technology transfer, technology status, and accessibility of the selected technologies (i.e., networking and management of water infrastructures, climate prediction, and sensor web) have been discussed. In this section, the barriers of the selected technologies are analyzed and described. The barriers are mainly economic and capacity issues.

2.1 Barrier identification and analysis for the transfer and diffusion of the networking and management of water infrastructures

Barriers to the networking and management of water infrastructures are summarized in Table 41. Mostly, the main economic barriers are lack of funding for the initial project investment and program maintenance. On the other hand, since reservoir management guided by the dynamic rule curve has not been developed in Thailand (see the previous section), the economic barrier is not the main obstacle of this technology. The main barriers are lack of know-how in the design of a reservoir network and the lack of an essential database such as geographic data.

Table 41 Barriers to the networking and management of water infrastructure

Components	Barriers
Reservoir network design	**Economic:** • Lack of a maintenance budget
	Capacity: • Lack of know-how in the design of a reservoir network • Lack of geographic data (e.g. *digital elevation model,* DEM) • Lack of analyzing and tracking correlations between previous water situations and the climate change data
Reservoir management guided by the dynamic rule curve	**Economic:** • None
	Capacity: • Lack of a database, research works, and experts • Lack of a network system to operate the reservoirs systematically
Optimization for water management	**Economic:** • High investment for system and device development
	Capacity: • Lack of knowledge in the developing an automatic water traffic control system • Lack of a water storage system for agriculture and industry in order to create stability
Water monitoring and maintenance system	**Economic:** • Lack of maintenance budget
	Capacity: • Lack of monitoring and maintenance technologies

2.2 Barrier identification and analysis for the transfer and diffusion of climate prediction technology

Table 42 shows the summary of seasonal climate prediction barriers. There is no economic barrier for implementing data assimilation and the downscaling method. On the contrary, earth observation data, ACGS, and computing and networking system require high investment costs. With regard to Thailand's technological capacity, the lack of experts is a common barrier.

Table 42 Barriers to seasonal climate prediction

Components	Barriers
Earth observation data	**Economic:** • High investment cost for example, satellite imagery
	Capacity: • Lack of experts • Lack of a regional collaboration network for sharing and exchanging data • Lack of a maintenance program • Lack of technology in the development of measuring water heads or salinity
Data assimilation	**Economic:** • None
	Capacity: • Lack of research works and experts in atmospheric sciences/physics, oceanography, and mathematics • Lack of expert collaboration
AOGCM Atmosphere-Ocean Coupled General Circulation Model have the advantage of removing the need to specify fluxes across the interface of the ocean surface. These models are the basis for sophisticated model predictions of future climate.	**Economic:** • High investment cost
	Capacity: • Lack of experts and devices
Downscaling	**Economic:** • None
	Capacity: • Lack of experts and devices • Lack of skills in interpreting the outcomes and communicating them to the recipients
Computing and Networking System	**Economic:** • High investment cost on high performance computing system
	Capacity: • Lack of experts

2.3 Barrier identification and analysis for the transfer and diffusion of sensor web technology

Table 43 showed a summary of sensor web barriers. Most of the technologies in this group face no economic barriers, except real-time observation and real-time satellite monitoring, which require high investment costs. With regard to the technological capacity of Thailand, lack of experts and collaboration are major barriers.

Table 43 Summary of sensor web barriers

Components	Barriers
Real-time Observation	**Economic:** • High investment cost for surveying devices • Lack of a maintenance budget
	Capacity: • Lack of data sharing • Lack of data validation
Models for runoff forecast	**Economic:** • None
	Capacity: • Lack of research works including short-range run off models and the short-range weather forecast models • Lack of data linkage among the models • Data is not updated regularly
Event Detection and Projection Technologies	**Economic:** • None
	Capacity: • Lack of a standard data format • Lack of experts to develop programs for automatic analysis, processing, and interpreting images
Real-time Satellite Monitoring	**Economic:** • High operating cost • Lack of funding
	Capacity: • Lack of experts
Data linkage system and data warehouse	**Economic:** • None
	Capacity: • Lack of a data sharing network that allows users to easily access databases
Data display system (DSS)	**Economic:** • None
	Capacity: • Lack of a system to automatically analyze a situation to support a command
Workflow management system	**Economic:** • None
	Capacity: • Lack of experts

2. 4 Linkages of the barriers identified for the water resource sector

The overall problems and barriers in the water resource sector are discussed in this section. In the previous section, the economic and capacity barriers of each technology are discussed. The most common economic barrier is the lack of a budget, while the most common capacity barrier is lack of experts and collaboration. By integrating the results of the barrier analysis in the previous section, the overall barriers can be classified into three main aspects: institutional framework and data integration, human resources, and water resource management.

2.4.1 Institutional Framework and Data Integration

- **Collaboration among governmental agencies and institutes**

In Thailand, there are more than ten governmental agencies and institutes responsible for or involved in issues related to water resources. Some of them are under ministries (eight ministries) while the others are independent governmental institutes. While each has key responsibilities as officially identified in acts and ministerial regulations, in practice their missions and authorities overlap and appear to have no unity, both in terms of the management system and in terms of geography. This is due to the lack of collaboration among governmental bodies and political instability. To be more specific, frequent changes of managerial officers, transfers of operational officers, and issues of national policies and strategies without solid action plans at the local level are the major causes of the inefficiency and discontinuity of governmental water resource management implementation.

By non-collaborative working, water resource data are scattered among several governmental agencies and institutes. Advanced infrastructure for collecting data for water resource management is operated by the key governmental bodies, whereas the local authorities still work with outdated tools. Thus, unsurprisingly, the data from these different agencies are inconsistent. In addition, the accessible data related to the structure of bodies of water in Thailand are mostly those at the macro level (collected by the key governmental agencies), but the data at the micro level are not integrated with the key institutes and cannot be accessed easily. Most of them must be obtained from the local governments.

- **Information technology for data management**

In terms of information technology for data collection and management, we can see that data collection using large automatic instruments would provide more accurate data and be easier to implement in terms of investment than those requiring domain knowledge. Investment in instrumental maintenance for continuous data collection and the capacity development of the local staff in technology application have also been overlooked. So far there has been no standard in systematic data collection or management to link the data from the regions to a central database, which would make the data easily available for use.

2.4.2 Human resource development

- **Formulation of national policy and regulations**

Thailand's national strategies and policies related to science and technology are facing a serious implementation problem due to the lack of participation from other parties. The lack of staff capacity development in climate change is also another important issue. This is due to inefficient knowledge transfer and distribution. Knowledge has clustered within the educational and governmental institutes without fair accessibility from the general public and the private sectors. This leads to low efficiency and low practical achievement in human resource development. Surprisingly, the general public is not aware of the key factors affecting climate change, including the impacts in terms of occupation, commodity production, and agriculture as a result of water resource variations.

Technology applicators should fully understand the process of water and local attributes before developing or applying any technology. Executives or high-level officers should share their knowledge with operators at all levels.

- **Capacity and ability of local officers**

According to the First Decentralization to Local Government Organization Plan in 2000, the central government bodies responsible for issues related to natural resources have transferred 245 missions related to consumptive water to local authorities. Moreover, 45 other missions and 114 projects have additionally been transferred according to the second plan, 2008. The aim is to provide local authorities with independence in policy setting and management, as well as budget management, according to their assigned missions. However, due to the rush in transferring these missions regardless of the readiness of the local authorities, these local authorities cannot manage the development of water bodies appropriately or allocate budgets efficiently.

At present, the local authorities are eligible to request a budget for the maintenance and development of water bodies in their local areas. However, they still lack understanding and knowledge of the issues related to water resources, as well as awareness of the importance of the application of simple technology to plan for construction and to manage data and data collection systems related to water bodies (e.g., GPS, satellite images). Therefore several local water bodies lack maintenance and a spatial or graphic database ready to be utilized for project development planning.

2.4.3 Water resource management

- **Analysis of flood and drought problems**

The problem of flood and drought disaster in Thailand has been getting worse. Due to various geographical attributes, some areas face flooding while the others face drought. Unfortunately, some face both flooding and drought. This is a big problem for farmers, as it worsens the problems that they already have.

The government has attempted to solve this problem. However, due to insufficient budget and outdated data, their solutions have not been effectively implemented for the specific attributes of each area. Flood and drought problems have been managed separately. Risks to the areas of flooding, drought, or both should be assessed and prioritized according to their severity. So far there no concrete measure has been taken to solve this problem. Nowadays water resource-related research and development agencies have realized the importance of integrated data analysis of both floods and droughts, and have proposed some specific measures applicable for each minor river basin.

- **Risk assessment**

A risk assessment, which takes into account rainfall analyses, flood and risk map creation, and the water balance (the balance of the water supply and demand), for instance, is often conducted and averaged for an area on an annual basis. This practice may conceal the drought and flooding problems because spatial variability and temporal variability are not considered. This is because the total annual water supply may exceed the annual demand; however, during a particular month, the demand may overshoot the supply, especially during a month of sporadic rain such as July or August. Moreover, the increasing weather extremes from climate change may make the statistical approach outdated in terms of managing water resources.

3. Enabling a framework for overcoming the barriers

Various dimensions of the barriers of each technology have been identified in the previous section. In this section, to overcome those barriers, an overview of an enabling framework is discussed. The aim is to illustrate the barriers and possible frameworks, as well as the related stakeholders.

3.1 Possible solutions to addressing the barriers for the transfer and diffusion of the networking and management of water infrastructures

Overall, the possible solutions to overcoming the barriers to effective water infrastructure networking and management can be divided into two aspects: economic and capacity. The possible solution to overcoming the economic barriers is to allocate budgets for the maintenance and operation programs for community/local water infrastructures. To address the capability barriers, possible solutions include the following: (1) promoting research, especially on advanced analysis of data and water situation modelling, (2) promoting knowledge transfer in the design of water structures that supports various operational models and automatic water traffic control systems, (3) creating research networks among educational institutes, (4) performing a scenario analysis on climate change and its effects on water resources, (5) developing geo-informatics data, (6) using GIS technology for mapping water traffic and measuring data from each station, and (7) building water storage facilities and supporting systems. In addition, stakeholders that could be involved in technology development and implementation are listed in Table 44.

Table 44 Barrier identification and analysis for the transfer and diffusion of technology for the networking and management of water infrastructures

Barriers and Solutions –A. Networking and management of water infrastructures			
Components	**Barriers**	**Solutions**	**Stakeholders**
Reservoir network design	**Economic:** • Lack of a maintenance budget **Capacity:** • Lack of know-how in the design of a reservoir network • Lack of geographic data (e.g., *digital elevation model,* DEM) • Lack of analyzing and tracking correlations between previous water situations and the climate change data	**Economic:** • Allocating a maintenance and operational budget **Capacity:** • Receiving knowledge transfer in the design of a reservoir network • Creating a research network among the educational institutes • Developing geo-informatic data • Performing a scenario analysis on climate change and its effects on water resources	• MOAC • MNRE • EGAT • BB • MOI • MOST • MOE
Reservoir management guided by the dynamic rule curve	**Economic:** • None **Capacity:** • Lack of a database, research works, and experts	**Economic:** • None **Capacity:** • Promoting related research	• MOAC • EGAT

Barriers and Solutions –A. Networking and management of water infrastructures			
Components	**Barriers**	**Solutions**	**Stakeholders**
Optimization for water management	**Economic:** • High investment costs for developing systems and devices **Capacity:** • Lack of knowledge on the development of an automatic water traffic controlling system • Lack of water storage systems for agriculture and industry in order to create stability	**Economic:** • Allocating a budget for developing systems and devices **Capacity:** • Receiving knowledge transfer on an automatic water traffic control system • Developing water storage and management systems	• MOAC • MNRE • MICT • EGAT
Water monitoring and maintenance system	**Economic:** • Lack of a budget **Capacity:** • Lack of monitoring and maintenance technologies	**Economic:** • Allocating a budget for monitoring and maintenance programs **Capacity:** • Promoting open source technology • Creating an awareness program on the monitoring and maintenance of water infrastructures	• MOAC • EGAT • MOI

3.2 Possible solutions to address the barriers to the transfer and diffusion of seasonal climate prediction technology

The barriers typically found when conducting a long-range weather forecast include the high costs of essential devices and technologies (e.g., satellite image data, input data for the global climate modelling, and high performance computers) and a networking system for calculations. Moreover, capacity barriers such as the lack of knowledge, research, and human resources for analyzing and processing the satellite image data and for developing and calibrating the water or salinity measuring heads are very critical. Similarly, such capacity barriers in other branches of science (atmospheric science, mathematics, and oceanography) related to data modification and completion are imperative. Also, the unavailability of knowledge and experience in interpreting and communicating the outcomes to the recipients is also a threatening barrier.

Solving the root causes of these barriers would enable the highest efficiency of long-range weather forecasting and the further development of research on long-range weather forecasts. These technologies can also be used as tools for climate change monitoring, water saturation prediction, and decision making on Thailand water resource management policy. Therefore, we propose the following practical solutions. The enabling framework and the related stakeholders to overcoming the barriers to each technology are summarized in Table 45. Possible solutions to addressing economic barriers include (1) waiving the costs related to the technologies and devices used in long-range weather forecasts or providing discounts to enable the maximum effectiveness of the long-range weather forecast operation and (2) planning a budget for the maintenance of the survey satellite to ensure continuous and accurate data. To overcome capacity barriers, the solution involves the creation of a collaborative network both domestically and internationally to exchange knowledge, research, and human resources in the relevant fields, which are listed as follows:

- Satellite imaging survey and data processing: Accurate and thorough surveying and data processing will result in highly accurate forecast outcomes.
- The development and calibration of water or salinity measuring heads.
- Atmospheric science, physics, oceanography, mathematics, and other subjects related to data modification and completion, the application of a global climate model and models that would increase the definition of the outcomes, as well as the analysis and interpretation of the outcomes received from the models.
- Global climate modelling that would increase the definition of the outcomes: High definition will maximize the accuracy of the outcomes.
- Cluster and grid computing: Not only can this be used in estimating the appropriate sizes of the calculating devices, but it also helps maximize the efficiency of the operation.

Table 45 Barrier Identification and analysis for the transfer and diffusion of seasonal climate prediction technology

Barriers and Solutions – B. Seasonal climate prediction			
Components	**Barriers**	**Solutions**	**Stakeholders**
Earth observation data	**Economic:** • High investment costs **Capacity:** • Lack of experts • Lack of a regional collaboration network for sharing and exchanging data • Lack of a maintenance program • Lack of technology in the development of water measuring heads or salinity	**Economic:** • Waiving data fees for the recipient countries **Capacity:** • Creating a regional collaboration network for data exchange and knowledge transfer on satellite image data processing, especially for an automatic data processing system • Designing a maintenance program • Developing technology in water measuring heads or salinity	• MOAC • MICT • MNRE • MOST • MOE
Data assimilation	**Economic:** • None **Capacity:** • Lack of research and experts in atmospheric sciences/physics, oceanography, and mathematics • Lack of expert collaboration	**Economic:** • None **Capacity:** • Creating a regional collaboration network for the data exchange and knowledge transfer of satellite image data processing, especially for an automatic data processing system • Connecting the research network with those in other fields	• MICT • MOST • MOE • MOAC • MNRE

Barriers and Solutions – B. Seasonal climate prediction			
Components	**Barriers**	**Solutions**	**Stakeholders**
AOGCM	**Economic:** • High investment costs **Capacity:** • Lack of experts and devices	**Economic:** • Waiving expenses or fees **Capacity:** • Collaborating with AOGCM consulting agencies • Supporting/building personnel and research work on AOGCM • Connecting with research networks overseas	• MICT • MOST • MOE • MOAC • MNRE
Downscaling	**Economic:** • None **Capacity:** • Lack of experts and devices • Lack of skills in interpreting the outcomes and communicating them to the recipients	**Economic:** • None **Capacity:** • Receiving knowledge transfer • Creating a collaboration network	• MICT • MOST • MOE
Computing and Networking System	**Economic:** • High investment costs **Capacity:** • Lack of experts	**Economic:** • Receiving discounts **Capacity:** • Developing knowledge of the cluster and grid computer's scalability and creating a research network for further research and development	• MICT • MOE

3.3 Possible solutions to addressing the barriers for the transfer and diffusion of sensor web technology

The summary of an enabling framework and related stakeholders to overcome the barriers of each technology is summarized in Table 46. Overall, the possible solutions for addressing the economic barriers include allocating funds for maintenance programs and research works and waiving the copyright fees. For the capacity barriers, the possible solutions are listed as follows: (1) promoting the utilization and exchange of the data and the research outcomes among stakeholders, (2) providing an accessible database free of charge, (3) developing data verification and screening systems with low uncertainty, (4) developing data standardization and data collection procedures, (5) providing training programs for data administrators to enable accurate data collection, (6) providing governmental scholarships or training programs to increase the number of skillful human resources in the fields of mathematic program development and GIS, and (7) promoting international collaboration in conducting research for technology transfer.

Table 46 Barrier identification and analysis for the transfer and diffusion of sensor web technology

Barriers and Solutions – C. Sensor web			
Components	**Barriers**	**Solutions**	**Stakeholders**
Real-time Observation	**Economic:** • High investment costs of surveying devices • Lack of a maintenance budget **Capacity:** • Lack of data exchange • Lack of data validation	**Economic:** • Allocating budget for the maintenance of the devices and supporting locally-developed devices/research works **Capacity:** • Promoting data exchange as well as utilizing research outcomes • Developing systems for data auditing/screening	• MOAC • MNRE • MICT • MOST
Models for runoff forecasts	**Economic:** • None **Capacity:** • Lack of research works • Lack of data linkage among the models • Data are not updated regularly	**Economic:** • None **Capacity:** • Promoting data sharing as well as utilizing research outcomes	• MOAC • MNRE • MOST • MOE • MICT • MOI

Barriers and Solutions – C. Sensor web			
Components	**Barriers**	**Solutions**	**Stakeholders**
Event Detection and Projection technologies	**Economic:** • None **Capacity:** • Lack of data format standardization • Lake of experts in developing programs for automatic analysis, processing, and interpreting images	**Economic:** • None **Capacity:** • Setting data format standardization and appropriate data collection procedures • Providing training for administrators so that they have updated knowledge and understanding, which enhances the quality of data collection • Developing governmental sector personnel in the field of mathematic program research and development. • Promoting collaboration with foreign agencies/private sectors in conducting research	• MOAC • MOST • MOE
Real-time Satellite Monitoring	**Economic:** • High operating cost • Lack of a budget **Capacity:** • Lack of experts	**Economic:** • None **Capacity:** • Promoting collaboration with foreign agencies/private sectors in conducting research for technology transfer • Developing governmental sector personnel in the fields of mathematic programming and GIS research and development	• MICT • MOST • MOE

Barriers and Solutions – C. Sensor web			
Components	**Barriers**	**Solutions**	**Stakeholders**
Data linkage system and data warehouse	**Economic:** • None **Capacity:** • Lack of a data sharing network that allows users to easily access the database	**Economic:** • None **Capacity:** • Developing national policy and agreement to create common understanding of the co-ownership of data and data sharing • Setting data format standardization and appropriate data collection procedures • Providing training for administrators so that they have updated knowledge and understanding, which enhances the quality of data collection	• MICT
Data display system (DSS)	**Economic:** • None **Capacity:** • Lack of system to automatically analyze the situation to support a command	**Economic:** • None **Capacity:** • Promoting collaboration with foreign agencies/private sectors in conducting research for technology transfer • Increasing coordination and information sharing among researchers and practitioners	• MOI • MOAC • MNRE • MICT

Barriers and Solutions – C. Sensor web			
Components	**Barriers**	**Solutions**	**Stakeholders**
Workflow management system	**Economic:** • None **Capacity:** • Lack of experts	**Economic:** • Waiving copyright fees **Capacity:** • Providing knowledge on the operation of the system to executives and operators in order to efficiently prioritize command procedures	• MOI • MOAC • MICT

3.4 Overall recommended solutions for the water resource management sector

It is important to start with regulation and policy formulation for water resource management to ensure the consistency of the operation. Related policies and regulations should be revised by integrating public or stakeholder opinions. Moreover, water resource management knowledge should be included in a school curriculum to develop the understanding and ability of the locals to protect and manage their water resources.

In addition, to facilitate collaboration across the ministries and to follow up on performance, the roles and responsibilities of the departments within each ministry should be allocated based on their missions. These missions can be divided into eight groups: (1) policy formulation, assessment and evaluation; (2) managing main community water systems, headwater or upstream areas; (3) managing core irrigation systems; (4) managing subsidiary irrigation systems; (5) managing community water management systems; (6) managing water supply systems; (7) managing disaster prevention and alleviation systems; and (8) managing supporting systems.

4. Technology action plan, project ideas, and IPR issues in the water resource management sector

4.1 Technology action plan

The overall solutions to overcoming the capability and economic barriers can be grouped into four strategic plans: capability development, investment, organization structure development, and policy and regulation revision/formation. In this section, the technology action plan of each strategy is analyzed. The plan includes the activities, timelines, stakeholders, and indicators (both qualitative and quantitative) to facilitate the technology's implementation.

4.1.1 Technology action plan for the networking and management of water infrastructures

The capability development of water infrastructure management emphasizes on developing educational programs for both local people and researchers. In terms of investment, a budget for developing and maintaining local water infrastructure should be provided and allocated to local administrative organizations. The organizational structure should be rearranged to avoid redundant work; importantly, the central and local organizations should work cooperatively. Most of the activities cover 1-3 years, except for organization structure management and policy and regulation, which requires 3-5 years. Technology action plans for the networking and management of water infrastructures is summarized in Table 47.

Table 47 Technology action plans for the networking and management of water infrastructures

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
Capability Development	**A1.** Arranging educational activities/exhibitions in the local areas/learning from local wisdom	1-3	- Communities - Local authorities - Educational institutes	- Participants' responses to survey questions
	A2. Encouraging schools to include water resource management subjects at the high school level	1-3	- Educational institutes - Local authorities	- Number of subjects on water resource management - Number of educational institutes teaching subjects related to water resource management
	A3. Increasing the local water storage capacity	1-3	- Communities - Local authorities	- Number of water storage facilities
	A4. Developing experts in analyzing data and advanced water situation predictive models	1-3	- Educational institutes	-Number of specialists/experts
Investment	**A5**. Allocating funding for the development of high-resolution geo-informatics series	1-3	- Government agencies - Educational institutes	- Number of high resolution geo-informatics series
	A6. Investing in system/measuring devices and a database system for decision making	1-3	- Government agencies -Local authorities	- Budget for measuring devices and a database system
	A7. Allocating budget from local administration for developing and maintaining local water infrastructure	3-5	- Thailand Local Administration	- Number of water resource projects and maintenance programs
Organisational structure development	**A8**. Listening to the problems and working with local communities on water resource management	1-3	- Communities - Local authorities	- Number of water management collaborations
	A9. Assigning the Royal Irrigation Department as the core agency for operation and collaboration with the	3-5	- the Royal Irrigation Department - Local Administration	- Number of communities that can connect their water sources to the irrigation waterways

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
	local administrative organizations to connect the community water sources to the irrigation waterways		- Communities	
	A10. Encouraging collaboration between government agencies and educational institutes to develop research works and technology to support water structure management, water traffic maps, and databases	3-5	- Government agencies - Educational institutes	- Number of research and technologies that support water structure management
Policy and law	**A11**. Reducing duplicate work between governmental agencies by reviewing missions and duties and clearly describing responsibilities	3-5	- Central agencies - Local authorities	- Performance evaluation
	A12. Clearly describing the legal rights and duties of the local administration on community water management	3-5	- Thailand Local Administration - Communities	- Duty description
	A13. Preparing a water structure maintenance calendar	3-5	- Central agencies - Local authorities	- Maintenance calendar

4.1.2 Technology action plan for seasonal climate prediction

The capability development of seasonal climate prediction highlights increasing the number of programmers, model developers, and mathematicians. The major investment in this technology group is on training programs (which includes the user manuals), not on advancing the technology. Policywise, an adjustment is required on the tax waiver criteria for modeling instruments and databases. The technology action plans for seasonal climate prediction is summarized in Table 48.

Table 48 Technology action plans for seasonal climate prediction

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
Capability Development	**B1.** Providing scholarships for students in the fields of surveying, data calibration, data completion, climate model development, computing mathematics, and mainframe computing resource management	1-3	- educational institutes - central agency	- Number of scholarship recipients
	B2. Increasing human resources in the field of model development and data analysis	1-3	- educational institutes - central agencies	-Number of experts in model development and data analysis
	B3. providing cross-agencies agency with seasonal weather forecasting scholarships/seminars/training programs on seasonal weather forecasting both domestically and internationally	1-3	- educational institutes - central agencies	- the number of researches scholarships/seminars - the number of seminars/trainings participants
	B4. Organizing focus groups or brainstorm meetings to discuss or bring up new ideas on improving forecast and warning models	1-3	- the media - civil society - warning agency - central agency - research agency - educational institutes	-Number of participants/agencies
	B5. Arranging training programs and preparing a manual for forecast and warning data users	1-3	- the media - civil society - warning agency - central agency - research agency	- user manual - user evaluation questionnaire -number of trainings and participants
	B6. Preparing data interpretation standards or manuals to increase the accuracy of the outcomes	3-5	- educational institutes - relevant agencies/ organisations	- Accuracy of the outcomes from the model
	B7. Increasing the number of mathematicians and physicists	3-5	- educational institutes - relevant agencies/ organisations	- Number of students in mathematics and physics program
	B8. Providing training programs in the field of meteorology	3-5	- educational institutes - the Meteorological	- Number of experts in meteorology

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
			Department - research agency	
	B9. Encouraging research collaboration and data exchange	1-3	- educational institutes - relevant agencies	- Number of research collaborations
Investment	**B10.** Obtaining and developing devices, instruments, and software for data modification and completion	1-3	- relevant agencies/ organizations - educational institutes	- progress in data system
	B11. Assessing the needs of high-performance computers required in calculating/processing the models	3-5	- central agencies - educational institutes	- the number of needs assessment reports for high-performance computers
	B12. Obtaining high-performance computing systems and creating an infrastructure network to facilitate collaboration among the relevant agencies	3-5	-central agencies	- the number of high-performance computing systems
Organizational structure development	**B13.** Encouraging collaboration among relevant agencies to develop collaborative research and exchange knowledge	1-3	- central agencies - educational institutes - foreign agencies	- the amount of research work - the number of agencies
	B14. Waiving/reducing expenses on data, devices, and instruments used in research work	1-3	- relevant agencies - educational institutes	- percentage of expenses spent on data, devices, and instruments used for research
Policy and regulation	**B15.** Driving further research on imported devices, instruments, and models so that they are suitable for and applicable in Thailand	3-5	- educational institutes - central agencies	- the amount of research work being utilized and referred to
	B16. Waiving/reducing taxes on research devices and instruments developed domestically	3-5	- relevant agencies/ organizations	- percentage of tax reduction on domestically-developed devices, instruments, and research

4.1.3 Technology action plan for the sensor webs

The capability development of sensor webs emphasizes increasing number of experts and practitioners, especially for governmental sectors. Device purchasing and maintenance are the major areas requiring technology investments. Technology action plans for the sensor web is summarized in Table 49.

Table 49 Technology action plans for the sensor web

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
Capability Development	**C1.** Enhancing the performance of data administrative officers to ensure that they can collect and prepare data according to the standard before distributing the data to other agencies (urgent)	1-3	- relevant agencies	- the number of personnel capable of transferring knowledge on data collection and preparation
	C2. Providing knowledge and understanding on how the system operates to both managers and operators in order to set an efficient line of command	1-3	- the management and the operators	- the number of trainings/meetings
	C3. Conducting pre-operation tests to ensure readiness prior to the operation under real circumstances (urgent)	1-3	- relevant agencies	- the number of meeting participants - the number of pre-operation tests
	C4. Developing governmental personnel involved in R&D in mathematic programs/geo-informatics	3-5	- government agencies - educational institutes	- the number of personnel in the fields of mathematic programs/geo-informatics
Investment	**C5.** Investing in the procurement of high-quality devices used in conducting water source surveys	1-3	- the Bureau of the Budget	- the budget ratio spent on the procurement of survey devices
	C6. Determining a long-term budget plan to cover maintenance	1-3	- government agencies	- the number of maintenance budget plans
	C7. Dividing operational phases to reduce costs and provide time for R&D of the model (success case)	1-3	- government agencies	- the budget ratio of operational costs - the amount of research work related to model development

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
	C8. Allocating budget to support relevant agencies to participate in the establishment of a data-sharing center and research work which can be easily accessed at no cost	3-5	- the Bureau of the Budget - relevant agencies	- the budget ratio spent on the creation of a data-sharing center
Organisational structure development	**C9.** Determining the missions/duties of each relevant agency in data collection, R&D, data distribution, and field work in disaster affected areas (urgent)	1-3	- relevant government agencies - local authorities and communities in disaster-affected areas	- the number of missions and duties of each agency - a plan for operations in disaster-affected areas
	C10. Clearly assigning disaster warning workflow in order to show linkages among relevant agencies, line of command, and disaster alleviation according to the severity of each area (urgent)	1-3	- central agencies - local authorities	- the number of disaster warning workflows - the number of agencies determining the disaster warning workflow
Policy and regulation	**C11.** Promoting devices and supporting locally-developed devices/research work	1-3	- central agencies - educational institutes	- the number of devices/research works developed domestically
	C12. Promoting research works in collaboration with foreign agencies/private companies in order to receive and transfer the technologies	1-3	- educational institutes - foreign agencies - government agencies - private companies	- the amount of research works
	C13. Clearly determining policy/agreement from state management in order to create understanding among agencies involved in data collection, co-ownership, and data sharing (urgent)	1-3	- management from the relevant agencies	- the number of data agreements

Strategies	Activities	Timeline (year)	Stakeholders	Indicators
	C14. Setting data standardization and data collection procedures	1-3	- relevant government agencies	- the number of regulations on the standards for data collection - the number of agencies determining data standards
Policy and regulation	**C15.** Developing the R&D capability of governmental personnel in mathematic programs/geo-informatics technologies	3-5	- government agencies - educational institutes	- the number of policies on the development of personnel in the fields of mathematics/geo-informatics technology - the amount of research work

The activities under the technology action plan for 1) networking and management of water infrastructures, 2) seasonal climate prediction, and 3) sensor web are codified as A, B, and C, respectively. The technology action plan of each technology is presented as follows:

Table 50 Technology action plans for water resource management

Strategies	Activities		Timeline				
			2012	2013	2014	2015	2016
Capability Development	1)	A1. Arranging educational activities/exhibitions in the local areas/learning from local wisdom	✓	✓	✓		
	2)	A2. Encouraging schools to include water resource management subjects at the high school level	✓	✓	✓		
	3)	A3. Increasing local water storage capacity	✓	✓	✓		
	4)	A4. Developing experts in analyzing data and advanced water situation predictive models	✓	✓	✓		
	5)	B1. Providing scholarships for students in the fields of surveying, data calibration, data completion, climate model development, computing mathematics, and mainframe computing resource management	✓	✓	✓		
	6)	B2. Increasing human resources in the field of model development and data analysis	✓	✓	✓		
	7)	B3. Providing scholarships/seminars/training programs in seasonal weather forecasting to agencies domestically and internationally	✓	✓	✓		
	8)	B4. Organizing focus groups or brainstorm meetings to discuss or bring up new idea on improving forecast and warning models	✓				
	9)	B5. Arranging training programs and preparing a manual for forecast and warning data users	✓				
	10)	B6. Preparing data interpretation standards or manuals to increase the accuracy of the outcomes			✓	✓	✓
	11)	B7. Increasing the number of mathematicians and physicists			✓	✓	✓
	12)	B8. Providing training programs in the field of meteorology			✓	✓	✓

Strategies		Activities	Timeline 2012	2013	2014	2015	2016
	13)	C1. Enhancing the performance of data administrative officers to ensure that they can collect and prepare data according to the standard before distributing the data to other agencies	✓				
	14)	C2. Providing knowledge and understanding on how the system operates to both managers and operators in order to set an efficient line of command	✓	✓	✓		
	15)	C3. Conducting pre-operation tests to ensure readiness prior to operation under real circumstances	✓				
	16)	C4. Developing governmental personnel involved in R&D in mathematic programs/geo-informatics			✓	✓	✓
Investment	1)	A5. Allocating budget for the development of high-resolution geo-informatics series	✓	✓	✓		
	2)	A6. Investing in system/measuring devices and a database system for decision making	✓	✓	✓		
	3)	A7. Allocating budget from the local administration for developing and maintaining local water infrastructures			✓	✓	✓
	4)	B9. Encouraging research collaboration and data exchange	✓	✓	✓		
	5)	B10. Obtaining and developing devices, instruments, and software for data modification and completion	✓	✓	✓		
	6)	B11. Assessing the needs of high-performance computers required in calculating/processing the models			✓	✓	✓
	7)	B12. Obtaining a high-performance computing system and creating infrastructure network to aid collaboration among the relevant agencies			✓	✓	✓
	8)	C5. Investing in the procurement of high-quality devices used in conducting water source surveys	✓	✓	✓		
	9)	C6. Determining a long-term budget plan to cover maintenance	✓				

Strategies	Activities		Timeline				
			2012	2013	2014	2015	2016
	10)	C7. Dividing operational phases to reduce costs and provide time for R&D of the model	✓				
	11)	C8. Allocating budget to support the participation of relevant agencies in research work and establishing a data-sharing center, where data can be easily accessed at no cost			✓	✓	✓
Organisational structure development	1)	A8. Listening to the problems and working with local communities on water resource management	✓	✓	✓		
	2)	A9. Assigning the Royal Irrigation Department as the core agency for operation and collaboration with the local administrative organizations to connect the community water sources to the irrigation waterways			✓	✓	✓
	3)	A10. Encouraging collaboration between government agencies and educational institutes to develop research works and technology to support water structure management, water traffic maps, and databases			✓	✓	✓
	4)	B13. Encouraging collaboration among relevant agencies to develop collaborative research and exchange knowledge	✓	✓	✓		
	5)	C9. Determining missions/duties of each relevant agency in data collection, R&D, data distribution, and field work in disaster affected areas	✓				
	6)	C10. Clearly assigning disaster a warning workflow in order to show linkages among relevant agencies, line of command, and disaster alleviation according to the severity of each area	✓				

Strategies		Activities	Timeline				
			2012	2013	2014	2015	2016
Policy and law	1)	A11. Reducing duplicate work between governmental agencies by reviewing their missions and duties and clearly describing responsibilities	✓	✓	✓		
	2)	A12. Clearly describing the legal rights and duties of the local administration in community water management	✓	✓			
	3)	A13. Preparing a water structure maintenance calendar	✓	✓			
	4)	B14. Waiving/reducing expenses on data, devices, and instruments used in research work	✓	✓	✓		
	5)	B15. Driving further research on imported devices, instruments, and models so that they are suitable and applicable for use in Thailand			✓	✓	✓
	6)	B16. Waiving/reducing taxes on research devices and instruments developed domestically			✓	✓	✓
	7)	C11. Promoting devices and supporting locally-developed devices/research work	✓	✓	✓		
	8)	C12. Promoting research works in collaboration with foreign agencies/private companies in order to receive and transfer the technologies	✓	✓	✓		
	9)	C13. Clearly determining policies/agreements from state management in order to create understanding among agencies involved in data collection, co-ownership, and data sharing	✓				
	10)	C14. Setting data standardization and data collection procedures	✓	✓			
	11)	C15. Developing the R&D capability of governmental personnel in mathematic programs/geo-informatics technologies			✓	✓	✓

5. Project ideas for international support

Project Title: the Water Resource Management Capacity Development and International Knowledge Networking Project

Motivation

The main objectives of Thailand water development and management are to increase security in terms of capital water supply, to build flexibility for management in all types of supply, to minimize damage from disasters, to maximize water usage efficiency, to involve all sectors in the management, and to build knowledge/know-how and data for management. Overall, the main obstacles of technology transfer and diffusion in Thailand to achieve these goals are institutional framework and lack of knowledge and vigorous capability development of personnel involved in water resource management. To be able to build a strong technological foundation for Thailand, these issues need to be concretely approached.

These proposed project ideas are suggested as short-term action plans, offering immediate actions and rapid outcomes, for the three prioritized technologies. The focus is on human resource capability development, i.e. to create learning opportunities and to get ready to receive new knowledge and new technologies. The project consists of four consecutive sub-project ideas: 1) organizing a seminar on climate change and water resource management, 2) organizing technical training/workshops on climate change and water management in the form of a network of knowledge and international training scholarships, 3) presentation of papers/research proposals, and 4) granting research scholarships and international collaborative research scholarships. The main tools of the project ideas are activities related to the first national conference on climate change and national water resource management in Thailand. The target participants include water resource personnel and climate change experts from all sectors. The conference also enables knowledge exchange among overseas experts and local personnel. This project requires approximately 10.5 million baht (0.34 million USD; given 1 USD = 31 baht) for the first year and 31.3 million baht (1 million USD) for the second year.

The main objectives of this project idea are 1) to vigorously and systematically develop the capability of Thailand's human resources in water resource management, from government agencies to educational institutes, and from private sectors and to local communities, 2) to create an international knowledge network which enables the exchange of knowledge and research work as well as the transfer of technologies among water resource management agencies around the world, and 3) to create skilful human resources in water resource management through international collaborative research scholarships at the master and Ph.D. levels.

The benefits from the project include 1) promoting knowledge and technology exchange that benefits the climate change adaptation of the water resource management, 2) increasing an awareness of the benefits of the systematic application or utilization of water resource management technology among personnel in the government sectors, academic institutes, and private sectors, and 3) increasing water resource management manpower within the government sectors and academic institutes that would help create a strong foundation for the country.

TAPs for the prioritized technologies in the modeling sector

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1. Preliminary targets for technology transfer and diffusion based on Section I

1.1 Preliminary Target of a National Data Center

The development of an integrated national data center for Thailand has been set as a preliminary target (See Fig 26). Initiating this national data center will create the essential infrastructure needed for domestic and international data collection and exchange, provide a data network for all the stakeholders and responsible parties, and serve as an official information distributor to all the stakeholders and responsible agencies. An integrated data center of this scale is imperative for achieving complicated missions including collecting, managing, and distributing massive amounts of data to the various sectors that would benefit from climate change impact modeling tools.

1.2 Preliminary Target of National Data Transfer and Management

The preliminary target of national data transfer and management technology is to establish official and effective means of data collection, data transfer, and database management, especially for the regional-level data needed for modeling climate change impacts. This technology is an essential supporting element for the first technology option, the national data center. Without establishing sound national data transfer management, the efficacy of the proposed national data center would decline. Fig 26 illustrates how data from domestic and international data sources could be transferred to the national data center.

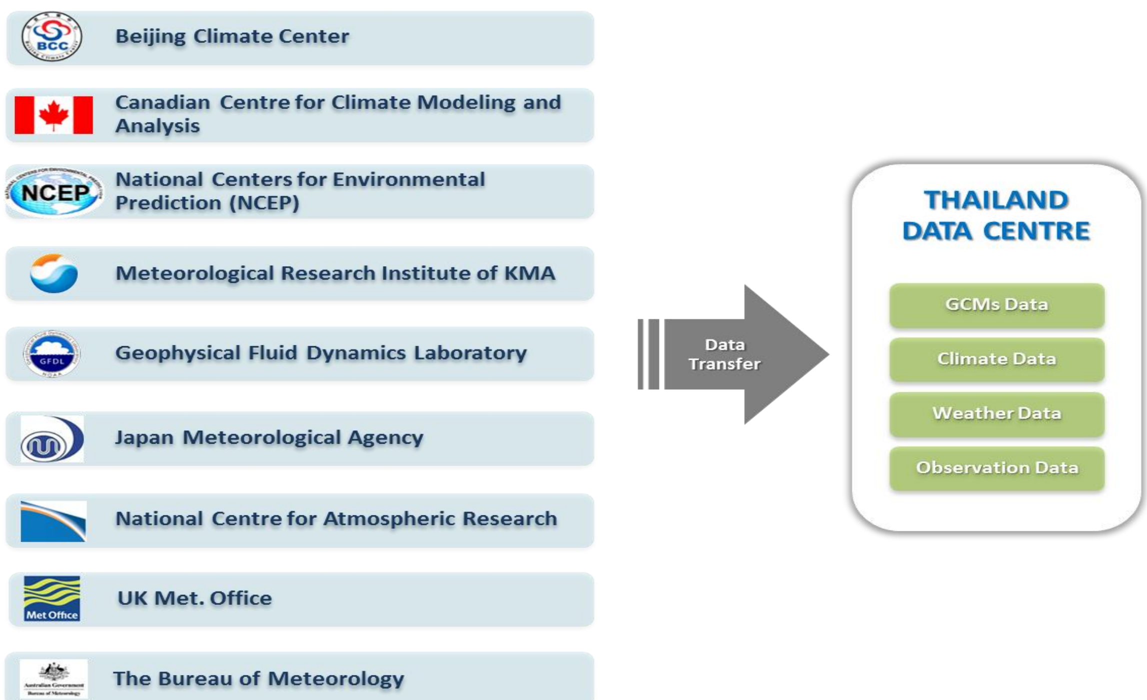

Fig 26 A proposal for using the Thailand data center for national data transfer/management

1.3 Preliminary Target of Integrated Modeling

The preliminary target for this integrated modeling technology is to provide and promote the use of an integrated tool for modeling climate change impacts across different sectors. This will help assess how a climate change impact of one sector consequently affects another sector, thus unifying the climate change modeling efforts of Thailand (see Fig 27). The WRF (ARW) model was selected as the best candidate according to the TNA. The barrier analysis and technology action plan (TAP) further discussed in this report will focus on this WRF model.

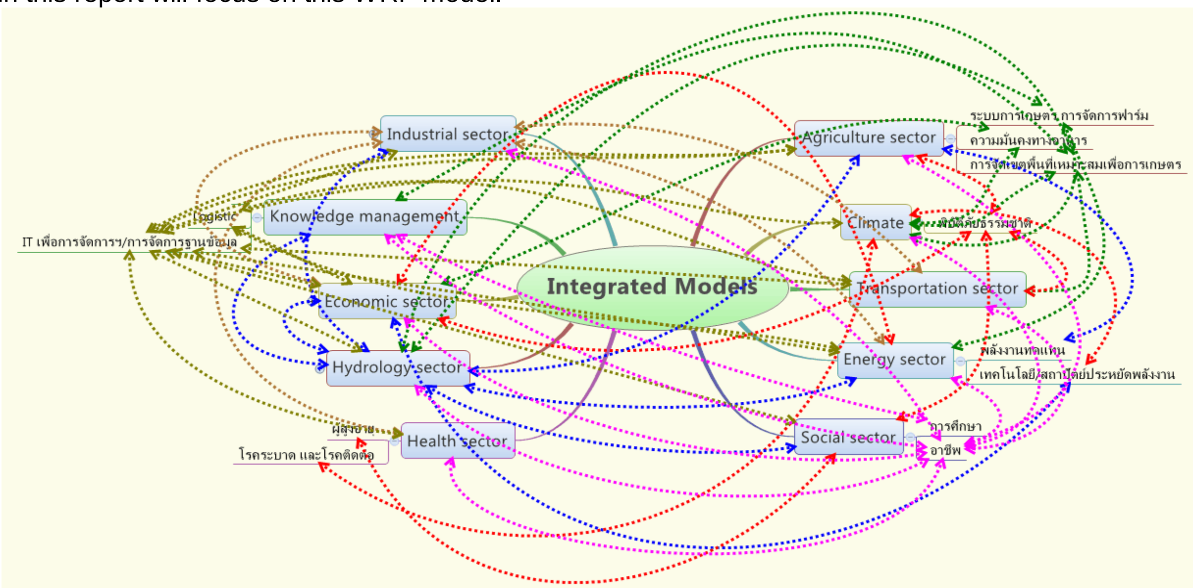

Fig 27 Framework for integrated modeling

2. Barrier Analysis

2.1 Barrier identification and analysis for the transfer and diffusion of data from the national data center

According to the brainstorming session with various stakeholders, the following types of barriers to technology transfer and diffusion in the establishment of the national data center were identified: capacity, regulatory, institutional, and economic barriers. The details are briefly summarized below.

The first basic barrier type encompasses the capacity issue: the technological, human resource, and human resource development aspects of capacity. Technically, Thailand has limited technical capacity for managing and maintaining an integrated national data center because Thailand has only three climate change data centers, each of which handles data from different sources and is not integrated with the others. For this reason, technology transfer and diffusion, which would enable Thai researchers and research organizations to improve Thailand's relevant technological capacities, are very critical. Consequently, Thailand lacks skillful human resources for operating and optimizing the national data center. We have no expert with hand-on experience because this is relatively new technology for the country. Last but not least, Thailand lacks also an adequate training program and education curriculum to prepare our human resources for operating and utilizing the national data center.

The second barrier is a regulatory barrier. Thailand has no operational policy in place to facilitate the operation of the national data center. Furthermore, the Royal Thai Government has no available policy to provide the adequate support needed for the establishment and the management of an integrated national data center. This leads to the third barrier, the institutional barrier. Although, several governmental agencies are authorized to collect particular types of data relevant to climate change modeling, they do not communicate and corporate to integrate the data. In addition, there is not enough collaboration and information exchange among the governmental agencies, private sectors, and academic sectors. Also, neither governmental agencies nor those of the private sector have sufficient management capacity and operational experience for such a national data center. The last kind of barrier is an economic barrier one. The establishment, management, and operation of the center require a large investment. Also human resource training requires a budget. Thailand has neither of them in place.

2.2 Barrier identification and analysis for the transfer and diffusion of national data transfer/ management

According to the brainstorming session with various stakeholders, the barriers to technology transfer and diffusion for the establishment of national data transfer and management share the same features as those of the national data center: capacity, regulatory, institutional, and economic barriers. The details are briefly described below.

The first capacity barrier is that Thailand does not have enough data for climate change impact modeling. We have only limited amounts of data monitored and collected by some governmental agencies, which can provide just a small fraction of what is needed for effective climate change modeling. Thus, we need to transfer data from other sources outside of the country. Secondly, because Thailand has never had a national data center, we lack the technological capacity and experience of transferring and managing the relevant data (such as GCMs, climate, weather, observation data) across governmental agencies in the country and from other data centers around the world. In addition, we lack the human resource capacity and human resource development capacity for such an operation. Policywise, several current legal and administrative rules and protocols prohibit effective data transfer and data access domestically. Currently, a lot of the data collected by governmental agencies are restricted, and there is no regulatory mechanism to facilitate data exchange and public access. This can be a critical obstacle for the success of national data transfer/management. As for institutional barriers, its roots are the same as those of the institutional barriers for the national data center: communication and data integration across institutions (either governmental agencies or private and academic institutes) are nonexistent. Thus, to be successful in domestic data transfer, an effective system for cross-institutional data transfer is imperative. In addition, Thailand does not have in place any protocol for obtaining data from and transferring data to a foreign data center. This is an important institutional barrier at the international level. The most critical institutional barrier is that we do not have a national data center to transfer and manage this large amount of data. None of current Thai governmental agencies handling climate change related data are capable of transferring and managing the integrated data on a national and international scale. Last but not least, the economic barrier is a critical one, just like in the case of the national data center. Currently, Thailand has no funds for data subscription. Also, human resource training regarding data transfer and management requires a budget.

2.3 Barrier identification and analysis for the transfer and diffusion of the WRF (AWR) model

The brainstorming session with various stakeholders identified capacity, technology, and economic barriers to the technology transfer and diffusion of the WRF (AWR) model as an integrated model for Thailand. The details are briefly summarized below.

Just like the previous two technology types, lack of knowledge, experience, and human resources remains major capacity barriers to Thailand’s use of the WRF model. Although a few governmental agencies and research institutes in Thailand have experience in using WRF, the majority of institutes in the various sectors do not. As a result, most of the sectors may not have enough skills and experience to use WRF confidently and effectively. In addition, the amount of trained experts capable of using WRF is very limited. This will seriously obstruct the technology transfer and diffusion of WRF. The second barrier is the technology barrier. As mentioned earlier, most of the sectors do not have hand-on experience using WRF for climate change impact modeling. Consequently, they might not fully know the requirements, the limitations, the accuracy, the precision, and the developments (including the new features) of the model. In addition, to utilize WRF, we need a high-performance computer. This leads to the economic barriers since the use of WRF requires investments in infrastructure, computers, technology distribution, and human resource training.

2.4 Linkages of the barriers identified

Noticeably, the barriers of technology transfer and diffusion for the three selected technology options share several common features, and several of them have arisen from the same roots. The first barrier is the technology barrier. This appears to be the origin of the various capacity barriers. For example, Thailand does not have adequate technological know-how and experience in using the WRF model, managing a national data center, and handling massive data transfer and management. Consequently, Thailand may not have enough human resources and the human resource development capacity to effective transfer and diffuse the three technologies to the various sectors. This is perhaps because Thailand has never had a policy to promote the use of an integrated modeling tool, a national data center, and integrated data transfer/management. In addition, several legal and administrative conditions and protocols prohibit data transfer and data exchange across different governmental agencies. This regulatory barrier leads to institutional barriers for both the national data center and national data transfer/management because the regulatory barrier creates a non-collaborative atmosphere among the different institutions. This demolishes communication and data integration across institutions (whether they be governmental agencies or private and academic institutes). Last but not least, the transfer and diffusion of every technology option will face an economic barrier. Because these technology options are designed to operate on a national scale, large investments are required for the initiation and management of technological transfer, database purchasing, infrastructure development, and human resource development.

3. Enabling framework for overcoming the barriers

3.1 Possible solutions to addressing the barriers to technology transfer and diffusion for a national data center

To overcome the technology transfer and diffusion barriers for the creation of the type of national data center described in the previous section, the following framework incorporating possible solutions for capacity, regulatory, institutional, and economic barriers is proposed. First, to overcome technology capacity issues, it is advisable to hire a foreign expert, knowledgeable on the design and management of integrated data centers, to help initiate Thailand's data center. Second, Thailand needs a human resource development system to distribute the knowledge and to cultivate skillful human resources for the data center's management and utilization. This human resource development system can be a series of training courses or a formal undergraduate or graduate curriculum, or a combination of them. Third, to resolve the regulatory barrier, the Royal Thai Government should issue and implement an operational policy to facilitate the operation of the national data center. Furthermore, the Royal Thai Government should develop a policy providing the adequate support needed for the establishment and the management of an integrated national data center. Fourth, to resolve institutional barriers, all the parties including governmental agencies, academic institutes, and those of the private sector should establish a collaborative agreement and system to allow for integrated data exchange and management through the national data center. In addition, through this collaborative effort, the institutes in Thailand should establish a database and verify the completeness of the data collected to ensure that the national data center will be supplied with all the relevant and creditable data needed for climate change impact modeling. Also, cooperation with international data centers is recommended because the Thai national data center would be able to directly gain valuable management and operational experience and supervision, which will increase the institutional capacity of the country. Last, to drive all of these possible solutions, financial support from governmental and/or non-governmental sources is essential.

3.2 Possible solutions to addressing the barriers to technology transfer and diffusion for national data transfer/management

To overcome the identified barriers to technology transfer and diffusion for national data transfer/management, the following framework incorporating possible solutions for capacity, regulatory, institutional, and economic barriers is proposed. To resolve the capacity barrier due the lack of data, the purchasing of essential data from various data centers around the world might be the most practical measure. In addition, just like in the case of the national data center, Thailand needs a human resource development system to distribute the knowledge and to cultivate skillful human resources for data transfer and management. To address the regulatory barrier, the Royal Thai Government should issue and implement a legal agreement allowing data exchange and transfer among all responsible parties such as governmental agencies, academic institutes, and private institutions. This will create an atmosphere of partnership and stimulate data transfer for the good of the climate change modeling sector. As for the institutional barrier, the impotence of the current Thai institutes to manage massive amount of transferred data, the suggested measure is to establish a national data center, which is essentially the same as the first selected technology option discussed above. Thus, this institutional barrier of data transfer would be taken care of when Thailand implements the first technology option, the establishment of the national data center. Also the institutional barrier of no collaborative action among different institutes will also be relieved when Thailand takes the corrective measure for addressing the regulatory barrier discussed above. Lastly, financial support from governmental and/or non-governmental sources is essential, especially for purchasing data and developing human resource training programs.

3.3 Possible solutions to addressing the barriers to the technology transfer and diffusion of the WRF (ARW) model

To overcome the barriers to the technology transfer and diffusion for the WRF (ARW) model identified in the previous section, the following framework incorporating possible solutions for technology, capacity, and economic barriers is proposed. To address the technological barrier of using the WRF model, a sector or an institute unfamiliar with the WRF model should be encouraged to visit the WRF website to benefit from the WRF tutorial, user guideline, and information regarding the model’s limitations and requirements, all of which are provided by the WRF developer. In addition, technical assistance through directly inquiries to the technical support team of the WRF developer should be encouraged to help resolve any specific technical issues. As for the technological barrier regarding hardware and infrastructure, a high-performance computer in compliance with the WRF requirements should be provided for the modeling application. An effort to calibrate the WRF model to ensure its proper application in Thailand should be initiated. To alleviate the capacity barrier due to the lack of human resources, a training session or workshop by the WRF developer to introduce advanced WRF features essential for specific applications relevant to the different sectors is recommended. This training session or workshop should be at an advanced level since the basic application and usage of WRF is available for self-learning on the WRF developer’s website. Thailand should survey the advanced WRF training topics required by all the sectors prior to designing the training session. Lastly, financial support from governmental and/or non-governmental sources is essential, especially for purchasing a high-performance computer, conducting a technical workshop, and calibrating the model.

4. Technology action plan

According to the barriers and the possible solutions discussed above, the technology action plan for each selected technology option has been divided into three phases, namely short term (3 years), medium term (5 years) and long term (5 years). In addition, an estimation of the funding needed for each phase is also proposed as follows (Table 51-53):

Table 51Technology action plan and activity timeline

Item	Barrier	Timeline Activity		
		Short-term	Mid-term	Long-term
Capacity	• Lack of skilled human resources	• Training and workshop	• Continuous human resource development (a series of training courses)	
	• Lack of the high performance hardware and central apparatus room	• Purchasing hardware	• Hardware maintenance and upgrade	
	• Lack of data for climate change modeling	• Collecting/purchasing relevant data including (but not limited to) GCMS, weather observation, climate, observation data from foreign institutions/data centers	• Improving the quality and quantity of the data to increase the capability for regional-scale modeling	
	• Lack of experience in using climate change models	• Support for Thai technical staff to train at foreign institutes which have technical assistantship agreements • Supporting a joint research effort between a Thai institute and a foreign technical partner	• Offering scholarships to support Thai staff to continue their higher education abroad, especially at foreign institutes which have technical assistantship agreements, in fields relevant to climate change modeling	
	• Highly sophisticated nature of the model for weather forecasting • Inadequacy of region-specific parameters needed for accurate and precise modeling, especially for tropical climate forecasting	• Promoting more study and calibration efforts to improve the precision and accuracy of the model	• Keeping up with the model's developments and advancements • Calibrating and configuring the model to suit Thailand's tropical climate	

Item	Barrier	Timeline Activity		
		Short-term	Mid-term	Long-term
Regulatory	• Unavailability of detailed operational policy • Lack of adequate governmental policy to support the center's establishment	• Issuing policy to facilitate the data center's operation. • Establishing more governmental assistance	• Developing and implementing the detailed operational policies	• Evolved policy that fully supports the effective operation of the data center
	• Legal and administrative limitation on data disclosure and access	• Proposing policy or legislation promoting data disclosure and cross-agency coordination • Preparing data transfer agreements with foreign agencies/institutes	• Developing agreements and partnerships with foreign agencies/institutes	
Institutional	• Lack of cooperation and communication between the involved institutions • Lack of data exchange among governmental agencies, private companies, academic institutions, and the nonprofit organizations	• Improving integrated national data exchange and management protocols	• Continuous development and refinement of integrated national data exchange and management protocols	• Increasing institutional capacity, management and organizational experience through cooperation with international data centers
	• Lack of data storage	• Establishing a national data center to collect information, both domestically and internationally	• Developing the national data center by giving it the potential to support database expansion	• Database expansion • Improving the quality and performance of the data center
	• Lack of effective data collection in Thailand	• Coordinating with all the related governmental agencies to collect data domestically	• Increasing the capacity of the coordination center by collecting data from both the public and private sectors	• Integrating data collected from all sectors

<table>
<tr><th rowspan="2">Item</th><th rowspan="2">Barrier</th><th colspan="3">Timeline Activity</th></tr>
<tr><th>Short-term</th><th>Mid-term</th><th>Long-term</th></tr>
<tr><td rowspan="3">Economic</td><td>• Lack of the required budget for the establishment and operation of the national data center</td><td>• Coordinating with the government to support the data center infrastructure
• Recruiting support from the organizations holding primary responsibility such as the Thai Meteorological Department, National Disaster Warning Center and NSTDA
• Collaborating with international climate data centers such as NCDC, NCAR, and NCDC</td><td colspan="2">• Recruiting support from secondarily responsible parties interested in climate and weather data collection such as Chiang Mai University and KMUTT
• Collaborating with both national and international organizations for data center development</td></tr>
<tr><td>• Lack of funding</td><td colspan="2">• Applying for financial support from both domestic and foreign funding agencies</td><td>• Welfare for support. Climate change Adaptation in Thailand</td></tr>
<tr><td>• Lack of a budget for human resource development</td><td colspan="3">• Each organization provides a budget for training of its staff</td></tr>
</table>

Table 52 Estimation of the funding needed for the technology action plan

Item	Barrier	Short-term Funding Plan (THB)		Mid-term and Long-term Funding Plan (THB)	
Capacity	• Lack of skilled human resources	• Training data center management • Training data management • Data center maintenance	1,000,000	• Continuous human resource development (a series of training courses)	2,000,000
		• Training and workshop with the WRF developer or domestic and international WRF experts: 1. Basic WRF 2. WRF-Var 3. MET	1,000,000	Continuous human resource development by keeping up with WRF upgrades and advancements	2,000,000
	• Lack of a central apparatus room	• Building server room	5,000,000	• Hardware maintenance and upgrade	5,000,000
	• Lack of data for climate change modeling	• Collecting/purchasing the relevant data including (but not limited to) GCMS, weather observation, climate, observation data from foreign institutions/data centers	10,000,000	• Improving the quality and quantity of the data to increase the center's regional-scale and global-scale modeling potential	5,000,000
	• Lack of experience in using climate change models	• Supporting Thai technical staff to train at foreign institutes which have technical assistantship agreements • Supporting a joint research effort between a Thai institute and a foreign technical partner	5,000,000	• Offering scholarships to Thai staff to pursue higher education abroad, especially at foreign institutes which have technical assistantship agreements, in fields relevant to climate change modeling	5,000,000
Institutional	• Lack of data storage	• Establishing a national data center to collect information, both domestically and internationally	10,000,000	• Developing agreements and partnerships with foreign agencies/institutes.	5,000,000

Table 53 Estimation of funding needed for purchasing/transferring data from various data centers around the world

Institution	Country	Data Collection	Conditions for Collecting Data	Required Funding (THB)
1. Beijing Climate Center	China	GCM data Climate data Weather data Observation	Partnership Data exchange	10,000,000
2. Canadian Center for Climate Modeling and Analysis	Canada			
3. National Centers for Environmental Prediction (NCEP)	USA			
4. National Center for Atmospheric Research (NCAR)	USA			
5. Korea Meteorological Administration	Korea			
6. Geophysical Fluid Dynamics Laboratory	USA			
7. Japan Meteorological Agency	Japan			
8. UK Met Office	UK			
9. The Bureau of Meteorology	Australia			

5. Project ideas for international support

<u>Project Title:</u> Improving the climate change modeling capability of Thailand by establishing an integrated national data center equipped with integrated national data transfer/management

Climate change is known to cause hydro-meteorological hazards (e.g., floods, droughts, heat waves, and storm surges) of increasing frequency and intensity, which potentially put quality of life, social systems, and economic systems in jeopardy. Climate change also affects the onset, duration, and variability of seasonal rainfall, which introduces uncertainty in natural ecosystems (including fishery spawning and bird migration) and tradition cropping calendars. The social and economic impacts of these increasing vulnerabilities often vary among communities, stakeholders, and vulnerable groups. Climate change impact modeling is an essential tool for climate change adaptation and mitigation for various sectors, including the water resource management, agricultural, energy, health, transportation sectors. As thoroughly discussed in the sections on barrier identification and the possible solutions to addressing the barriers to climate change modeling for Thailand, an integrated national data center equipped with an effective integrated national data transfer/management process is imperative and is proposed here as a project idea for international support. Implied by the project title, the main objectives of the project idea are to (1) establish a national data center for data collection, integration, and distribution to all impacted sectors and (2) implement effective mechanisms to collect, transfer, and manage domestic, regional, and international data relevant for climate change impact modeling. This project is beneficial for both governmental agencies and private institutes of all sectors utilizing climate change modeling for planning and decision making. The national data center maximizes the efficiency of data utilization, promotes cross-sectoral coordination and data exchange, and minimizes the total cost of the country's data transfer/management by reducing data transfer/management repetition and redundancy. Last but not least, this initiation will strengthen Thailand's potential to become a hub of climate change knowledge in the region. This project is essential for the success of Thailand's sustainable development priorities, especially for the water resource management and agricultural sectors. This project is proposed to address the barrier identification and the TAPs discussed above. The project scope, possible implementation, timeline activity, and estimated budget can be seen in Table 51 -53 and Fig 28 - Fig 29 respectively depict the TAPs for the establishment of the national data center and the national data transfer/management process. The estimated budgets for the national data center and the data transfer/management process are five and ten million Thai baht, respectively. Evaluations of the success of the project can be made by (1) surveying the user ratings of the data center's performance, (2) accounting for the number of the center's domestic and international partners, (3) verifying the improvements in climate change forecast accuracy, and (4) measuring the number of members or subscribers of the data center. The potential responsible institutes and coordinators of the project include, but are not limited to, the Center of Excellence for Climate Change Knowledge Management (CCKM) at Chulalongkorn University, Thailand, and the Thai Meteorological Department.

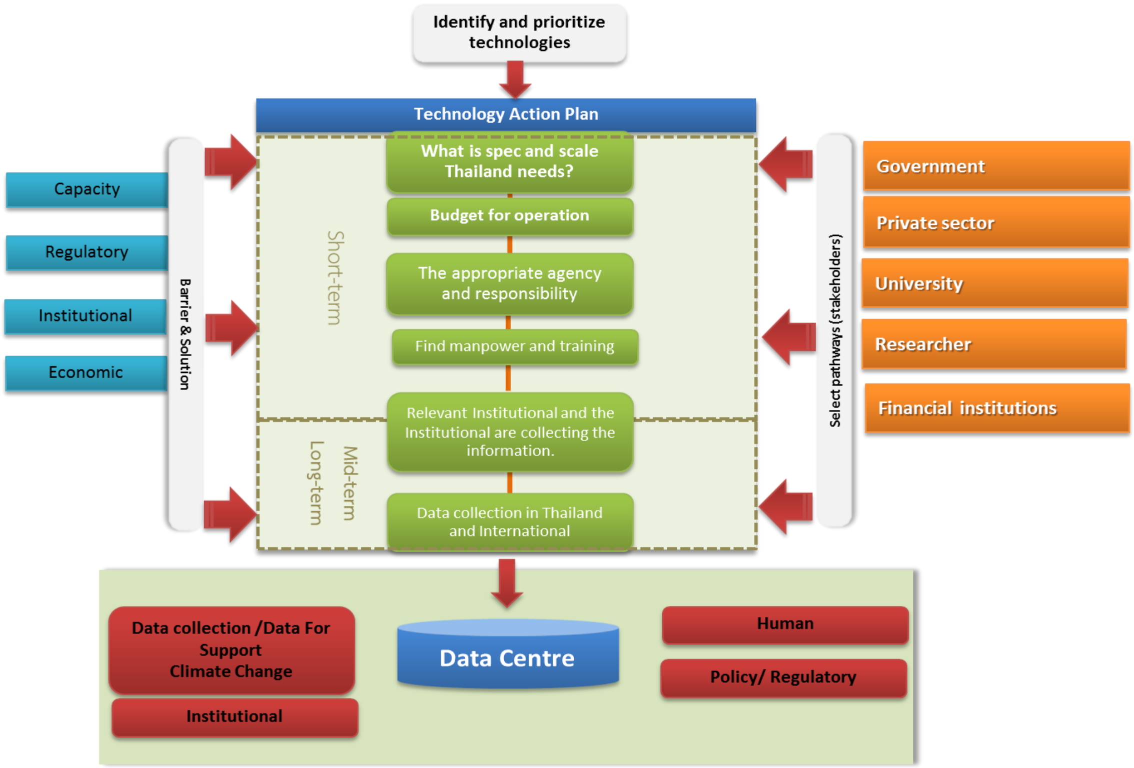

Fig 28 Technology action plan for the national data center

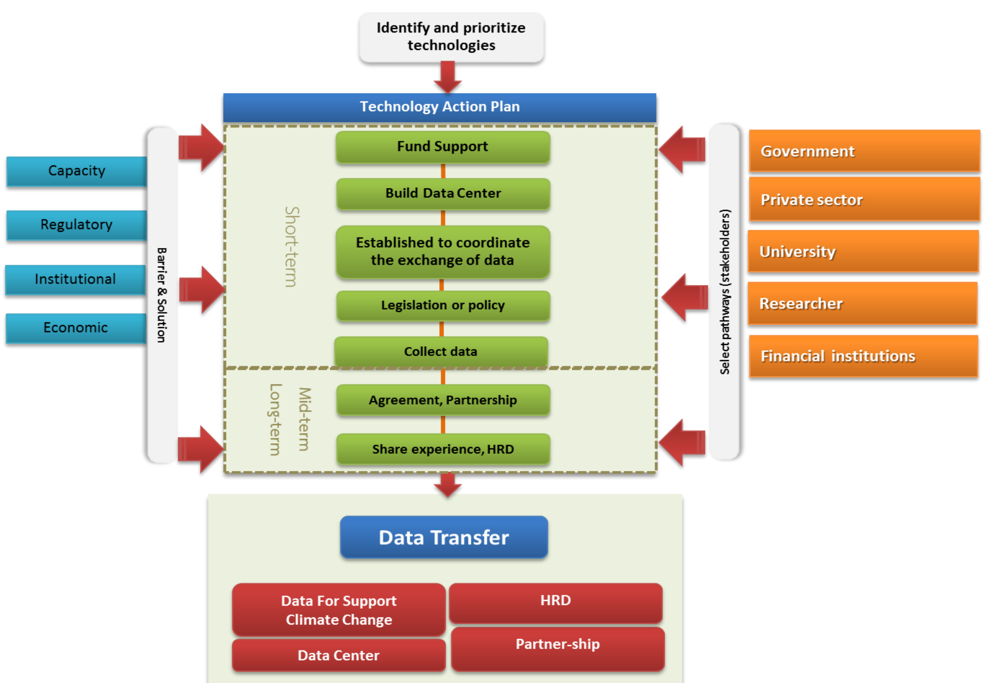

Fig 29 Technology action plan for the national data transfer and management process

Conclusion

Section II develops the Technology Action Plans (TAPs) for selected technologies of the three sectors. In general, the development process consists of 1) setting up preliminary targets for technology transfer and diffusion of each technology option, 2) identifying barriers, 3) investigating possible solutions to address the barriers for the transfer and diffusion of technology, 4) and eventually developing a technology action plan for each technology option by considering legislation and regulation, financial incentives, institutional arrangement, infrastructure, R&D support, and human resource development. The specific development processes and findings of each sector can be summarized as follows:

1. Agricultural Sector

According to the TNA for the agricultural sector, the three groups of selected technologies include 1) forecasting and early warning systems in order to reduce the risk of damage from extreme climate events and pest/ disease outbreaks as well as to increase the ability to select the right crops based on specific planting time and crop cycle, 2) crop improvement for climate–resilient [Marker Assisted Selection (MAS) and genetic engineering] to reduce the risk of yield loss while increasing resource efficiency, and 3) precision farming technologies in order to enable farmers to make informed decisions concerning their farming operations as well as to reduce inputs while maintaining maximum productivity and minimizing the effects on the environment.

Subsequently, the Technology Action Plans (TAPs) for each technology were developed. In this process, barriers to the transfer and diffusion of the three prioritized technologies were identified. The TAPs were established and divided into 3 phases, namely short-term (3 years), medium term (5 years) and long term (5 years) as shown in Table 35 - 37.

In conclusion, Thailand needs an international support on two major areas. One is a capacity building starting with the joint Master's level course through a consortium of leading international universities, local universities, research centers and private companies. A fund of 10 million USD is estimated to support the travel expenses of leading experts to conduct courses in Thailand as well as to provide learning materials and a learning facility to support approximately 150 students. Another is to support Thailand as an ASEAN training hub for adaptation technologies in agriculture in the context of south-south collaboration. Linking with international organizations and experts is also desirable to ensure the portable application with the cross cutting technologies. Implementation of this project needs sufficient funding in the key areas, along with high efficiency equipments. A subsidy of 35,000 US dollars is estimated to operate comprehensive, hands-on training course on selected technologies for approximately 20 persons/ year. Three different types of training courses include 3-5 days workshop, 3 months training course, and 6 months for advanced research course. Areas of emphasis include simulation models for forecasting and early warning, marker assisted selection, risk assessment on GM product and precision farming skills. The center would also host the International Workshop on adaptation technologies to be applied in the agricultural sector, attracting academics and industry representatives from many countries to share their expertise and experience, with a strong emphasis on real world applications.

2. Water resource management sector

According to the TNA for the water resource management sector, three selected technologies are 1 (networking and management of infrastructures, 2 (seasonal climate prediction, and 3 (sensor web. These three technologies are crucial in every part of water resource management roadmap, from forecasting, planning, operation to disaster management. Components of each prioritized technology are analyzed in terms of technical requirement, transfer and diffusion requirement, and current status of accessibility and readiness for implementation (Table 29 Table 31). Then, the technology action plans are prepared (Table 32). Recommendations for overall management are as follows:

<u>The institutional framework:</u>

In order to facilitate collaboration across the ministries and to follow up on performance, the roles and responsibilities of the departments within each ministry should be allocated based on their missions. These missions can be divided into 8 groups: 1) policy, assessment and evaluation, 2) capital water, headwater or upstream area, and the environment, 3) primary irrigation system, 4) secondary irrigation system, 5) community water management system, 6) water supply system, 7) disaster prevention and alleviation system, and 8) supportive system.

<u>Regulations and policy:</u>

1) To ensure the consistency of the operation, every policy related to water resource management needs to be revised and the primary laws or parent laws for water resource management need to be determined via public hearing and participation from various sectors.

2) Knowledge related to water should be included in the school curriculum at the primary school, secondary school, and all levels to enable learners to understand the geographical attributes of Thailand and the necessity of water management in their own area.

3) The prioritisation of areas should be driven onward and the specific measures for each area should be identified in order to solve and alleviate problems of flood, drought, as well as areas with both floods and drought.

In addition, Thailand would benefit from an international support for water resource management capacity development and international knowledge networking project. The main objectives of this project idea are 1) to vigorously and systematically develop the capability of Thailand's human resources in water resource management, from government agencies to educational institutes, and from private sectors and to local communities, 2) to create an international knowledge network which enables the exchange of knowledge and research work as well as the transfer of technologies among water resource management agencies around the world, and 3) to create skilful human resources in water resource management through international collaborative research scholarships at the master and Ph.D. levels. The benefits from the project include 1) promoting knowledge and technology exchange that benefits the climate change adaptation of the water resource management, 2) increasing an awareness of the benefits of the systematic application or utilization of water resource management technology among personnel in the government sectors, academic institutes, and private sectors, and 3) increasing water resource management manpower within the government sectors and academic institutes that would help create a strong foundation for the country.

3. Modeling Sector

According to the TNA for the modeling sector, the three groups of selected technologies include 1) national data center to serve as an essential infrastructure needed for domestic and international data collection and exchange, 2) national data transfer and management to establish official and effective means of data collection, data transfer, and database management, especially for the regional-level data needed for modeling climate change impacts, and 3) integrated modeling to provide and promote the use of an integrated tool for modeling climate change impacts across different sectors.

Subsequently, the Technology Action Plans (TAPs) for each technology were developed. In this process, barriers to the transfer and diffusion of the three prioritized technologies were identified. Eventually, the TAPs were developed and could be divided into 3 phases, namely short-term (3 years), medium term (5 years) and long term (5 years) as shown in Table 51.

In conclusion, Thailand needs an international support on integrated national data center equipped with an effective integrated national data transfer/management process. Implied by the title, the main objectives are to (1) establish a national data center for data collection, integration, and distribution to all impacted sectors and (2) implement effective mechanisms to collect, transfer, and manage domestic, regional, and international data relevant for climate change impact modeling. This project is beneficial for both governmental agencies and private institutes of all sectors utilizing climate change modeling for planning and decision making. The national data center maximizes the efficiency of data utilization, promotes cross-sectoral coordination and data exchange, and minimizes the total cost of the country’s data transfer/management by reducing data transfer/management repetition and redundancy. Last but not least, this initiation will strengthen Thailand’s potential to become a hub of climate change knowledge in the region. This project is essential for the success of Thailand’s sustainable development priorities, especially for the water resource management and agricultural sectors. The estimated budget for this project is around 0.5 million USD.

Section III

Cross-cutting issues for the National TNA and TAPs

Executive summary

The aims of this section are to identify common barriers of technology implementation that cut across the three highly-impacted sectors, agricultural sector, water management sector, and modeling sector and to analyze possible cross-sectoral capability development actions. This starts with identifying common needs and possible synergies that could be achieved across the sectors by addressing some key elements influencing multiple technologies of the three sectors. As a result, the following four major common barriers across sectors are identified: 1) technology capability, 2) infrastructure, 3) policy and regulation, and 4) economy. Knowing these barriers and their relationships will better enable decision makers to implement technologies in a manner that strategically copes with unseparatable technical, financial, ethical, and regulatory obstacles. The cross-cutting analysis also investigates possible cross-sectoral capacity development actions that could refine the proposed technology action plan (TAP). These further refinements are to overcome or lessen the cross-sectoral barriers and are summarized in Table 54 grouped into two parts: domestic actions and international actions (technology transfer from outside of the country). In brief, the lack of financial support and knowledge/expert seems to be fundamental barrier for technology development and implementation of the country. Both issues entail robust international supports, especially during the initial phase. On the other hand, for the domestic actions, most of the common barriers require policy enforcement or supporting mechanism. Such policies in principle can be listed as follow: policy on enhancing 1) research collaboration, 2) R&D budget, 3) GM field experiment, and 4) MOU with developed countries on technology transfer or research collaboration.

Last but not least, by evaluating all the technologies altogether based on their capability (maturity), accessibility, and cross-sectoral impact, the only highly accessible and mature technology is the model for run-off forecast. On the other hand, forecasting and early warning system and precision farming are in early stage of development but have a great potential to impact various groups of stakeholders across the sectors. Thus, these two technologies might be ranked as the first priority for future development.

Table 54 The further proposed actions to overcome or lessen cross-sectoral barriers

	Barrier	Short term
Require international action	Technology capacity	- Providing guidance/sharing knowledge on standardizing data format, data collection procedure, and data interpretation -Providing cross-sectoral training courses or multidisciplinary exchanged researchers
	Infrastructure	- Providing guidance/sharing knowledge on water resource management planning, seed banks, biosafety house, and networking system
	Policy and regulation	-Addressing IPR issues
	Economy	- Providing financial aids for an initial start up of cross-sectoral influencing projects such as national data center establishment, researcher exchange program, and training course
Domestic action	Technology capacity	- Providing guidance/sharing knowledge on standardizing data format, data collection procedure, and data interpretation -Regional collaboration on sharing data and research works
	Infrastructure	- Allocating budget for development and maintenance water infrastructure
	Policy and regulation	- Promoting policy on enhancing research collaboration, R&D budget, GM field experiment, MOU with developed country on technology transfer or research collaboration
	Economy	- Increasing R&D budget

1. Identified common barriers across the sectors

According to the barriers described in TAPs (Section II) for the three highly impacted sectors, the four major common barriers across sectors can be identified as follows; 1) technology capability, 2) infrastructure, 3) policy and regulation, and 4) economy. Although previously discussed in Section, II, the barriers of each technology for the three sectors are re-arranged in Table 54 to illustrate the four cross-sectoral barriers they share in common.

In sum, as shown in Table 54, we can conclude that lack of experts and researchers appears to be the most critical hurdle for all sectors. Similarly, lack of budget for technology development is also a serious barrier for most of the technology development. These two barriers, as a matter of fact, are interrelated and tied to the barriers of political and regulatory origins. For example, due to the lack of R&D budget, the number of research work as well as human resource development in sciences and technology for climate change adaptation cannot be sustained. Consequently, we could not develop necessary technologies ourselves, and most of the advanced technologies must be imported. Unsurprisingly, the imported technologies are, most of the time, costly and not suitable for local contexts making Thailand unable to exploit their full potential. This issue might be solved by the right political initiation. R&D supporting policy and policy enhancement on research collaboration are key catalysts to stimulate collaboration among agencies and would promote more advanced research while avoid duplication of effort.

The barriers on infrastructure are also under the umbrella of the budget and know-how barriers. For example, know-how in the design of reservoir network is still missing. Similarly, local water infrastructure requires budget for development and maintenance. The Thai Meteorological department is still in short of sufficient data storage and analytical tools. Furthermore, MAS requires seed banks and operating budget.

Below we separately elaborate the four major common barriers in details**.**

Table 55 Summary of common barriers of each sector

Sector	Type of technology	Technology capability				Infrastructure	Policy and regulation	Economic
		Database system and data management	Expert/Know-how to self-develop technology	Data standardization	Institutional collaboration			Budget
Water resource management	**Networking and management of water infrastructure**							
	Reservoir network design	✓	✓					✓
	Reservoir management guided by dynamic rule curve	✓				✓		
	Optimization for water management		✓			✓		✓
	Water monitoring and maintenance system		✓					✓
	Seasonal Climate Change							
	Earth observation data		✓		✓			✓
	Data assimilation		✓		✓			
	AOGCM		✓					✓
	Downscaling		✓					
	Computing and networking system		✓					✓

Sector	**Type of technology**	**Technology capability**				**Infrastructure**	**Policy and regulation**	**Economic**
		Database system and data management	Expert/Know-how to self-develop technology	Data standardization	Institutional collaboration			Budget
	Sensor web							
	Real time observation		✓					✓
	Models for runoff forecast	✓	✓					
	Event detection and projection technologies		✓	✓				
	Real-time satellite monitoring		✓					✓
	Data linkage system	✓						
	DSS					✓		
	Workflow management		✓					
Agriculture	Forecasting and early warning	✓	✓	✓			✓	
	Crop improvement		✓				✓	✓
	Precision farming	✓	✓					
Model	National data center		✓		✓		✓	✓
	National data transfer and management		✓		✓	✓		✓
	WRF (AWR) model		✓					✓

1. 1 Technology capability

1.1.1 Database system and data standardization

Lack of clear standards on format, quality, reliability, and continuity of input data is one of the key barriers for all sectors. Without data format, data collection protocol, and guideline for data interpretation, stakeholders could experience serious inconvenience and confusion in data acquisition and management. More importantly, this could diminish the accuracy of the outcome of technology implementation. So far there is no standard for systematic data collection and management. For this reason, setting unified standards for data structure, collection, storing, control, and quality testing is a first stepping stone for more advanced research development. In addition, database system should be compiled not only for the domestic level, but also for the regional level. A minimum data requirement from other countries in the Southeast Asia must be considered as inputs of a climate change modeling. As of now, each sector uses a specific data or model favorable for its application of interest. A more integrated model which allows the climate change impact estimation across the sectors should be promoted.

1.1.2. Expert and know-how

Limited skillful human resources are major constraint in developing and implementing technology. To ensure effective implementation, human resource development programs and continuous technical trainings to maintain the quality of staff members must be implemented. Due to the lack of experts and budget for research and development, most of the advanced technology is imported. Those imported technologies are not only expensive but also cannot capture local contexts, resulting in substandard outcomes. Thus, apparently, if neither Thailand can develop technology by itself, , nor could it manage to keep purchasing a full-option (costly) technology from other developed countries, it could not reach the full potential of climate change adaptation technology.

The root of these obstacles is evident when considering several important figures of the country. For example, the number of researchers per capita in Thailand is lower than the world average. On top of that, the budget allocation for R&D from both public and private sectors is also lower than the world average. According to statistic in 2008, there were 6.8 researchers per 10,000 while the world average researcher was 24.9 per 10,000. The R&D budget was accounting for 0.22 % of GDP while the world average was 1.01 % of GDP. The private sector allocated R&D budget 0.08 % of GDP while the world average was 0.63% of GDP. This reveals an important evidence of the major barrier for science and technology development in Thailand.

Another supporting fact that shows the lack of experts as well as R&D budgets in Thailand is number of registered patents. The overall registered patents in 2008 were 1,685,037 with an average of 29,052 patents for each country. Thailand has registered 6,741 patents worldwide, increasing 1.13 percent from 2007.

To overcome this barrier, the government should put a serious concern and be sincerely aware of this issue. The help from the outside of country is very important and could drive a major push to success as well.

1.1.3. Research/Institutional collaboration

Promoting a collaboration atmosphere between public and private sectors is an urgent need for the country. Collaborative effort between institutes could help avoid over expenses and duplication of the effort among governmental agencies and research institutes. It could also reduce fragmented analysis and incomplete results. The level of collaboration could extensively be done domestically, regionally, and internationally. Importantly, the collaboration should not cluster in government agencies or large private companies. It should expand to capture local context, geological context, and cultural context, e.g. local wisdom on water management or agriculture.

For Thailand, the collaboration is still limited even among governmental agencies itself. If there is a clear policy or high level coordination mechanism for cross-sectoral cooperation, it could open up to more channels for conducting advanced research or cutting-edge technology. To enable in implementation, it is necessary for the national focal points to cooperate and exchange information. The objective of information exchange and stakeholder collaboration is to formulate appropriate actions which would ensure greater mobilization of resources/data and further enhance the efforts from implementation agencies and stakeholders in fulfilling their support from the government and attracting international support.

1.2 Infrastructure

Many technology implementations in water management, agriculture and model sectors require massive infrastructure development, for example, data center for database management, water infrastructure network, GM or MAS seed banks, field trials for GM crops, and bio-safety greenhouse.

While building infrastructure is often the first target for many developing countries to spend their budget for technology development, the more important task is to utilize the full potential of the infrastructure, which requires maintenance and continuous upgrade. In many developing countries, absence of funding and expertise to maintain infrastructure has jeopardized the sustainability of infrastructure utilization. Furthermore, infrastructure for example massive infrastructure for water resource management sometimes comes with a complex web of social and regulatory issues (e.g., the "not-in-my-backyard" syndrome), which is often an enduring subject for public debate. All this can add to the time and cost required to put infrastructure in place to support technology adaptation.

1.3 Policy and Regulation

The solutions of some cross-cutting barriers are only at policy level, for example, policy frameworks on enhancing research collaboration, GM research frameworks, IPRs issue, and public perception and education on new technologies. Absence of appropriate national legal and policy frameworks on enhancing research collaboration prohibits technology development as well as its implementation. Effective implementation of the research collaboration requires a solid national plan, ensuring collaboration among government agencies, educational institutes, and private sectors. For example, research work on GM crops will continue to be at a nascent state, if the government does not set up rules or standard protocols for GM experiment compliable by all the stakeholders and acceptable by public. Thus, policy approval for GM commercial cultivation with subject to risk assessment and control mechanism should be established. In addition, various activities to promote public awareness in science and regulation of GM should be organized.

An issue that has provoked a debate between developed and developing countries is with respect to the intellectual property rights (IPRs). If a developing country desires to assimilate new technologies and increase its technological capacity, private IPR holders in a developed country might use IPRs as a tool to prohibit technology access. It would be globally beneficial to establish a WTO-style international treaty that attempts to remove barriers to the access of scientific and technological knowledge. IPR seems to be a major concern for GM crops. Only a few major companies hold patents on GM. Similar to MAS, accessibility of genetic resources in many countries (including Thailand) is very limited. To solve this problem, it is important to work with international organizations such as the ISAAA, as individual country or ASEAN community, to encourage private patent holders to share the techniques and tools of GM technology.

Public perception and education on climate change technology is another issue that requires national policy support. Tradition and public perspective can affect how technology is perceived, and compatibility of a new technology with the values and beliefs of a society can affect technology adoption. Such perspective can shape public opinion and the politics behind debates to define problems and acceptable technological solutions. For example, critics opposed GM experiments due to the lack of a robust regulatory framework to regulate GM crops and to monitor food safety. They are worried about unknown human health and environmental effects of GM crops and foods. For this reason, an emphasis should be placed on education curriculum to create public awareness and understanding on climate change and its technology implementation.

1.4 Low investment on R&D Budget

An obvious barrier to the application of any technology is lack of budget sufficient for capital investment, technology operation and maintenance, and human resource capacity development to implement the technology at its full potential. Technology implementation requires know-how and capacity of technological adaptation and dissemination. Building science and technology capacity requires investment in R&D. Funding for 1) the education and training of scientists and engineers, 2) scientific research and technology development activities, 3) promotion of technology transfer to commercial applications, and 4) dissemination of technology into the marketplace should come from both public or private sources. For Thailand, the level of R&D capacity is extremely low and not an attractive place for private investors. R&D is a cumulative process that requires not only financial investment but also the support from government and private sectors. Private investors look for opportunities with high return on investment while the government agencies can collaborate with private sectors to push forward technology options suitable for the needs of the country.

2. Technical capability and distribution scope of each technology

Besides evaluating technology implementation by considering the cross-cutting barriers, it is also important to examine technical capability and distribution scope of each technology. Due to the limitation of the resources including time, budget, and know-how, technologies should be prioritized based on their capability and distribution potential. Technical capability of the country for a technology is defined as the ability of Thailand to implement the technology of interest with its current resources (e.g. technical expertise, human resources, and infrastructure). Technical capability can be rated from high feasible to unlikely. Highly feasible (++) means this technology is mature and ready for implementation. Unlikely (--) means this technology has never been researched in Thailand. On the other hand, the distribution scope represents two important features: 1) stakeholders or technology user and 2) public policy involvement. Certain technologies are useful for a certain group of stakeholders (e.g. researchers in the lab vs. researchers in the field); thus, this technology can satisfy a need of only a certain group and may not involve any public policy issues. For example, Atmosphere-Ocean Coupled General Circulation Model (AOGCM) is utilized by experts in water resource management sector and modeling sector; it is only distributed in the limited group of specialized uses. Public does not get involved to this technology, and the distribution scope is defined to be low as it only satisfies the needs of a certain group. On the other hand, GM is defined as having a moderate distribution scope because it will be distributed to large numbers of farmers in the country, but it affects consumers and raises political issues. More examples of the evaluation of technical capability and distribution scope of each technology for the three highly impacted sectors are summarized in Table 56.

The only mature and highly accessible technology is model for run off-forecast. Water monitoring and maintenance system, DSS, Earth observation data, Real-time observation, computing and networking system are also at maturity stage of development, but the use of these technologies is limited in the research or lab boundary.

Forecasting and early warning system and precision farming are in early stage of development. However, various groups of user, particularly farmers, are able to access the implication these technologies. For this reason, these two technologies might be ranked as the first priority for future development.

GMO and MAS are also in an early stage of development. On the contrary, these two technologies may raise public concern; even though, medium to large group possibly will satisfy the technology implication.

Table 56 Implementation and distribution scope and technical feasibility

		Distribution Scope			
		satisfy a need only certain group (- -)	**May satisfy a need for medium or large group, but raises significant public policy issues (-)**	**Satisfies a need for medium or large group and raises no significant public policy issues (+)**	**Satisfies a strong need for large group and raises no significant public policy issues (++)**
Technical feasibility	**Highly feasible (++)**	-Water monitoring and maintenance system -DSS -Earth observation data -Real-time observation -Computing and networking system			- Model for run off-forecast
	Feasible (+)	- Reservoir network design - Optimization for water management - Data assimilation - AOGCM - Downscaling - Data linkage system and data water house		- National data center - National database management - WRF model	
	Uncertain (-)	-Event detection and prediction technology - Real-time satellite monitoring	- MAS - GMO		- Forecasting and early warning system - Precision farming
	Unlikely (--)	- Workflow management - Reservoir management guided by Dynamic rule curve			

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Annex 1: Technology Factsheets

Agricultural Sector

1. Overview of possible adaptation technology options and their adaptation benefits

Adaptation technology in five areas were initially proposed and discussed. They are climate forecast and early warning systems, crop improvement, precision farming practices, post-harvest technology, and animal nutrition and feed technology. The details of each technology are described below.

1.1 Forecasting and early warning technology

Forecasting and early warning technology refers to a group of technologies that generate information for farmers, thus enabling them to make an informed decision on the best types of crop varieties to plant. This also helps them to decide on the timing of specific farming activities in line with seasonal forecasts. Specific technologies in this group include, but are not limited to, Geographic Information System (GIS), simulation modeling, and early warning systems. Examples of some forecasting and early warning technologies are discussed as follows.

Sensor technology (remote sensing and proximal sensing) is the use of sensors to measure and collect relevant data at locations of interest. Examples of sensors used for precision farming include diagnostic, weather station sensor, soil sensor, and chemical sensor. These sensors can be put together to create a wireless sensor network. Installed in farms or areas of interest, these sensors can collect such data as soil moisture, temperature, sunshine reception, and chemical characteristics. These sensors may also be linked to a drip irrigation system so that plants can be given exact amounts of water and fertilizer automatically. If connected to local weather forecasting data, the irrigation system may stop giving out water when it is likely to rain, for example. A sensor network may also be used to monitor the emergence of plant diseases as well.

Geographic Information System (GIS) is a computer technology that seamlessly blends together cartography (use of maps), database, and statistical analysis. With a GIS, geographically referenced data can be collected, stored, manipulated, managed, analyzed, visualized, and linked to time periods. GIS is used in all kinds of fields including agriculture in which a GIS can report the breakouts of epidemics over time, human encroachment into forests, change in land use, etc.

Decision Support System (DSS) refers to a support system for agriculture that utilizes process-based computer models to predict growth, development, and yields from such data as local weather and soil conditions, crop management scenarios (rice, cassava, sugarcane, vegetables, and various other species) and genetic information. The model may predict resource dynamics (water, nitrogen, carbon), environmental impact (nitrogen leaching), and economic component. DSS can be used at a farm level to determine the impact of climate change on production, to predict a potential outbreak of pests/insects (brown plant hoppers, pink mealy bugs) and to suggest potential adaptation practices for farmers. It can also be used at a regional level to determine the impact of climate change at different spatial scales.

Simulation modeling is a technology that combines the power of mathematical models with that of computer technology. It is used to simulate real events or behaviors and to comprehend the impact of certain inputs on potential outcomes of interest (e.g., profits, losses, investment returns, and crop yields)

An early warning system is another technology that provides advance notice of extreme climate events or the threat of invasive pest species. It is an effective tool not only for farmers but also for government policy and planning officials who are directly responsible for preventive, responsive or contingency planning. The use of early warning systems means that a response to a possible disaster can be undertaken immediately, thus minimizing losses (OAE, 2011(Office of Agricultural Economics 2011)).

Table A 1-Summary of weather forecasting and early warning technologies developed in Thailand

Developers	Simulation model
Khon Kaen University	Spatial modeling of land suitability for rubber plantations in the Northeast.
Kasetsart University,Thammasat University, and the Asian Institute of Technology	Estimation of rain-fed rice yields using soil hydraulics as parameters
Suan Sunandha Rajabhat	Real time rainfall estimation using APT and metrological data
Chulalongkorn Prince of Songkla University	Modeling, simulation and visualization of water flooding
Early warning system	
The Office of Disease Prevention and Control 9th, Phitsanulok	Warning system for avian flu to prevent the spread of the disease and a disease/threat warning system using GIS technology in Phitsanulok
The Office of Disease Prevention and Control 9th, Phitsanulok	A brown plant hopper prediction and warning system is currently being developed by using information technology to compute and analyze such data such as the pest population, rainfall, temperature, relative humidity and stage of plant growth to automatically alert and provide information on the areas under threat of brown plant hopper attacks. With this system in place, anticipatory actions can be designed earlier so that harvest failures can be minimized.

1.2 Crop improvement technology

Crop improvement technology refers to an effort to develop crop varieties that can survive or even thrive in the changing environment. Crop improvement technologies now play a crucial role in dealing with issues related to climate change such as food and energy security. Plant traits needed for climate change adaptation may include flood tolerance, drought tolerance, effective water usage, effective nitrogen usage, and pest and disease resistance. However, conventional breeding, which is focused on crossing plant breeds that contain the most desirable traits, is of limited use since it is difficult, time-consuming, and sensitive to various environmental conditions. It may, for instance, take about 10 years to develop a new variety of rice using traditional crop breeding methods. To expedite the process, plant breeders can use a molecular breeding tool such as marker assisted selection (MAS) to help them achieve greater accuracy and speed in screening large populations of plants for desirable traits. This also allows them better control over the genes retained during plant breeding. By using this technique, plant breeders can also put together a number of desirable traits in a single breeding cycle, without having to go through thousands of plant screenings for physical and chemical characteristics under favorable environmental conditions (Glover 2008).To develop a new rice variety, this approach may consume only half of the time used by conventional crop breeding.

Genetic engineering/genetic modification is another crop improvement technology in the field of molecular breeding. It involves the direct incorporation, deletion, or modification of specific genes, including those from other species. Plants that have been through this process are called "genetically modified plants." While conventional breeding and MAS technology are constrained to traits or characteristics already existing in the species, genetic engineering can go beyond this limitation, widening the size of the available gene pool for specific traits, making possible the transfer of genes between unrelated species, and even removing undesirable traits through this process (Glover 2008). The genes of interest can also be transferred into a target crop in a single event, and it takes 5-6 years to develop cultivars with stable gene expression. The manipulated line can then be released for cultivation by the farmers or used as donor parents in conventional breeding and MAS (Sharma 2002). Table A 2 summarizes the uses of crop improvement technology in Thailand.

Table A 2: Summary of crop improvement technology in Thailand

Projects	Activity
Molecular Breeding	
Rice Gene Discovery Unit National Center for Genetic Engineering and Biotechnology, Kasetsart University Bureau of Rice Research and Development	- Developed Jasmine rice or KDML105 and RD6 glutinous rice that can thrive in adverse conditions
Molecular Rice Breeding Program for the Mekong Region	-Workshops on the second and third generations of backcrosses (BC2 and BC3) - Community of Practices
Genetic Modification	
	Developed papaya ring spot virus resistant (PRSV) papayas, tomato yellow leaf curl virus resistant tomatoes, delayed ripening papayas, chili vein banding mottle virus resistant chilies, and color changing orchids

1.3 Precision farming and resource management technology

Precision farming and resource management technology is the use of technologies to plant "the right seed in the right place depending on the field conditions or having the precise application of pesticides, nitrogen fertilizer or other inputs"(Scientific American 2009). Additional issues to be considered in order for system optimization using precision farming include economic benefits, environmental benefits, management practices and technological needed (Fig A 1). It must be noted that precision farming is suitable when land holdings are medium to large in size with enough variability across the fields. Other resource management technologies, including greenhouse technology and bio-secure technology, can be used together with precision farming applications. Greenhouse technology is a technology that provides a controlled environment for crops and other plants to grown in a favorable condition, thus giving high yields regardless of weather or season. A greenhouse is advantageous in that resources such as soil, water, fertilizer and light are strictly monitored and controlled to optimize plant growth. In addition, plants are also protected against wind, storms, pests, and diseases. Another benefit of greenhouse cultivation is that plants can be grown out of season as well.

On the other hand, the bio-security approach employs a set of preventive procedures designed to protect resident animals from the transmission of disease, invasion of alien species, and spread of diseases across the boundary. The application of bio-secure technology can help farmers identify the risks and formulate a strategy to deal with the risks ahead of time. Bio-security is becoming an important issue since global warming could cause the increase of pests and pathogens as well as the enhanced vulnerability of farm animals to diseases.

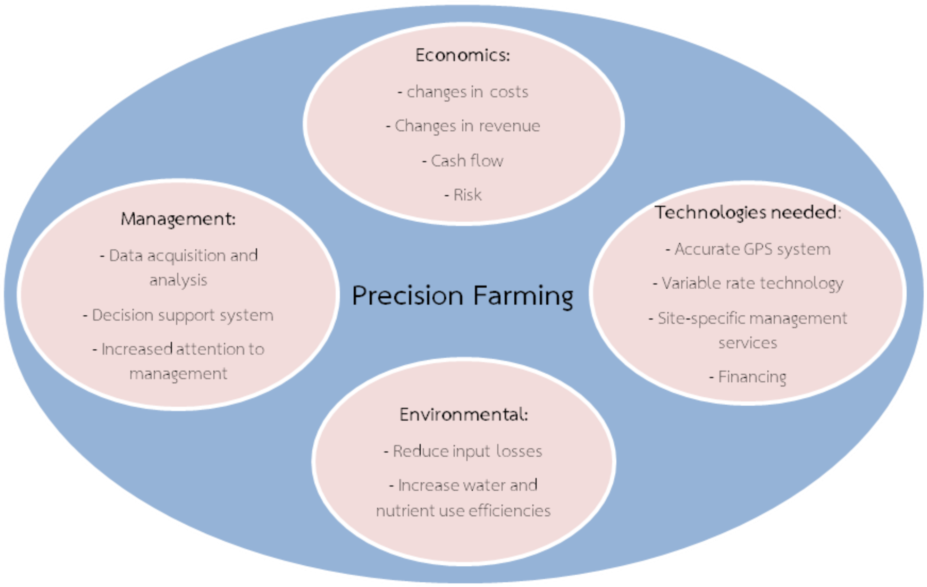


Fig A 1-Important issues related to precision farming
Source: Adapted from "Precision Farming" (Singh)

1.4 Postharvest technology helps to preserve and enhance the quality of agricultural products before consumption. The main factors that limit the storage life of food and other agricultural products are high temperatures and moisture. Examples of specific technologies include packaging, logistics, and food safety technology.

1.5 Animal nutrition and feed technology help produce animal feeds and supplements with the most appropriate level of nutrition and proportions for specific animals. The quality of the raw materials used in the manufacture of animal feed greatly depends on post-harvest practices. Examples of technologies in this category include alternative sources of protein, novel sources of high protein, and post harvest technology.

Water Resource Management Sector

2 Overview of possible adaptation technology options and their adaptation benefits

2.1 Environmental Observation

Automatic telemetry is a further development of field server instruments, resulting in an automatic system that allows for weather parameter measurement, connection, and communication. The system can measure and send the measured values to an identified recipient. The measured values include temperature, humidity, air pressure, light intensity, amount of rainfall, and water level, as well as the operational status of the instruments. The data will be sent to the server via a GPRS mobile telephone network. The received data will then be validated before being stored in the database system for future use. The data display system can provide numerical data of various forms (statistics, graphs, tables) and the operational status of the instruments via an Internet GIS-MIS or via a mobile telephone with the WAP page. Users can select the specific data, location, and time duration that they want to look at. They can also send messages via SMS.

The operation of the automatic telemeter instrument is not complicated. It uses a connection standard that is widely used and easy to understand. Its operation can be divided into the following three parts, based on how the instrument operates: (1) the measurement instrument, (2) the operation control and data transmission instrument, and (3) the electricity generating instrument and instrument protection set.

Water Resource Survey Technology is an important part of water management, including both flood and drought management. Appropriate water management in a particular area requires a water body database that includes for example the surface water bodies/ponds, as well as the waterways and direction of the water flow. Therefore, the data from satellite images and GIS not only help to facilitate the survey but also improve the survey's accuracy. The attributes of the water resources in each area changes all the time, both naturally and anthropogenically; therefore, water resource surveying is necessary and should be conducted continuously.

The data from satellite images and GIS help reduce complications and the amount of time required for the survey. They also facilitate the preparation of the site survey. Satellite imagery data make it possible to identify the location and size of the surface water bodies/ponds and to examine waterways in their current condition. In terms of flood and drought management, both satellite imaging and GIS technology can be applied to identify the extent of the flood area and its water movement, as well as to monitor the amount of water in the reservoirs and in the main waterways. This not only enables appropriate water management and the identification of at-risk areas, but also helps in conducting surveys on the changes in land use that affect the amount of water in the future so that future water management can be planned.

Remote sensing is an aerial sensor technology that detects and classifies objects on the Earth by propagated signals (i.e., electromagnetic radiation) emitted from satellites. Remote sensing techniques include aerial photos and satellite images. These remote sensing data can also be used to verify the accuracy of the data collected from the aforementioned telemetry or sensor technology.

Mapping and Geographic Information Systems (MIS and GIS) and other supporting data are information technologies that describe geography. They are designed to capture, store, manipulate, analyze, manage, and visualize all types of geographically referenced data. At present, GIS is not only limited to cartography but is also capable of various activities such as scientific investigation, natural resource management, and environmental impact assessments. GIS is an effective tool for water resource management as it gives a better understanding of the overall picture and pattern of the study area. The GIS/MIS, where non-geographical information regarding the particular area is overlaid with the

GIS, is useful for water resource management as it gives us a better understanding of the overall picture, relationship, pattern, and trends of the study area.

2.2. Forecasting and Hydrological Models

Weather models are one of the main tools for weather or rainfall prediction, while hydrological models are tools for surface runoff estimation. These models are comprised of a set of mathematical equations that represent the behavior of a physical system. Computers are utilized to make weather forecasts or runoff simulations by numerical methods. The information from these models is crucial to climate change adaptation and mitigation strategies for effective water resource management, which includes disaster warning and infrastructure management.

A number of models for weather and hydrological modeling are available with both free and commercial licensing. Based on different physics and mathematical backgrounds, these models were developed to solve particular types of problems; therefore, selecting a suitable model for analyzing problems can be very difficult. In Thailand, several attempts have been made to picture future climates with projected scenarios of GHG emissions (Chidthaisong 2010). However, there is still uncertainty regarding the simulated results. The information gained is insufficient for a decision maker to be able to confidently put forward long-term actions or investments. For Thailand, the technology for weather and hydrological modeling should address the following requirements: seasonal climate prediction, short-range forecasting, hydrological modeling, hydraulic modeling, groundwater modeling, and water quality modeling.

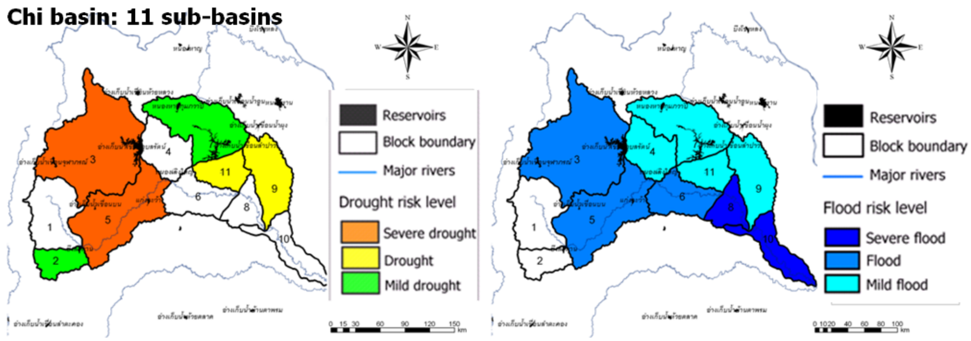
2.3. Flood and drought risk management

Flood and drought risk management is a management framework aimed at identifying, assessing, and treating flood and drought risks as well as minimizing the impacts of those risks. The framework involves collecting information, establishing the context, analyzing risks (sources, likelihood, and severity magnitude), planning and implementing risk treatment, and iteratively reviewing the process with the stakeholders. Flood and drought risk management reduces vulnerability to climate change and increases resilience. Risk assessment and risk treatment are two major components of risk management and are discussed below.

Table A 3-Major components and activities of risk management

Component	Activity
Risk assessment	Climate scenario analysis, monthly water balance to analyze risk type, timeframe, and magnitude, risk-area prioritization techniques
Risk treatment	Structural technologies/practices for risk reduction (irrigation structure/rubber dam), nonstructural technologies/practices for risk reduction.
Drought risk treatment	Strategies for developing and managing secondary and emergency water resources (including conjunctive use), technology for increasing water-use efficiency (water demand management by 3R technologies).

Examples of information used to prevent adverse affects from climate change via risk management can be seen in Fig A2- Fig A 3.



Sub-basins	Maximum water shortage (Mm^3)		Maximum excess water (Mm^3)
	Irrigated area	Rain-fed area	All areas
2.Lum Kan Chu	15	170	349
5.Lum Chi section 2 & 3	94	615	1,810

Fig A2-Drought risk (left) and flood risk (right) maps

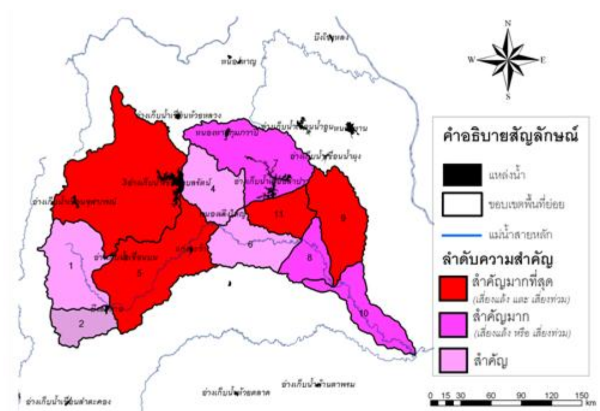


Fig A 3-Risk area prioritization

2.4 Operation of Water Infrastructure

Water resource infrastructures are the technical structures that regulate water resources to support a society. These structures are put in place, for instance, to support economic growth and to protect and mitigate the adverse effects on people and the environment from natural disasters. The design and construction of water resource infrastructures or facilities usually consider the environmental, social, institutional, and economic components of countries and communities for sustaining the long-term benefits of the infrastructure investment. These infrastructures need to be well operated in order to maximize the benefits and to minimize the damage from natural extremes.

In general, the capacity of a water resource infrastructure is based on the return period analysis of extreme events, while its operation is based on weather scenarios. As for Thailand, like other countries, recent data show that global warming has placed existing infrastructures at risk. The spatial and temporal changes of rainfall patterns, in particular, make infrastructure operations difficult. Cycles of weather extremes are becoming more frequent. Seasons in Thailand are obviously different from what they were like in the past, making them difficult to predict. The current operation of water resource infrastructures in Thailand are not optimal for handling what may come our way in the future and must thus become more robust and capable of handling a wider range of possible futures. The technology for water resource infrastructures and operations should be able to address the following requirements:

- Scenarios regarding both water supply and demand.
- The networking (via pipes or canals) and management of infrastructures (including zoning).
- An optimization (e.g., dynamic dam/networking rule curve) and decision support system (DDS).
- Monitoring and maintenance.
- Automation and SCADA.
- Salt water intrusion management.

2.5. Community Water Resource Management (CWRM)

Community water resource management is a risk-based adaptation approach that integrates both supply and demand management of natural or man-made water resources at the community level. The purpose is to sustain the community by providing enough water for household and agriculture use, solving water shortages and floods, and reducing the community's vulnerability. The core idea of CWRM is called "lean management," an approach to building a self-learning community that integrates the use of science and technology with local knowledge into its practices. In addition, community members can share their knowledge and experience to expand the CWRM network. Thus, sustainable development can be established because of the community's "endogenous growth." Ultimately, CWRM reduces the community's vulnerability to weather extremes, especially in rain-fed agricultural areas. The technology list for community water resource management is summarized in Table 4A.

Table A 4-Technology list for community water resource management

Technology Group	List of Technology	Application
(1.1) Data management	- Local Content Management System - Databases - Community websites	- Data gathering and systematic management - Data analysis for proper production/cultivation plans - Data sharing for market decision-making analysis Data examples: - Household data - Village data - Cropping calendars - Crop price trend - Geo-informatics
(1.2) Remote sensing and GIS technique for survey and planning	- Global Positioning System (GPS) devices - Geographic Information System (GIS) - Management Information System (MIS) - Satellite imaging - Echo-sounder	Surveying technology uses: - Locate stream networks and water resources - Defining head watershed areas - Selecting proper locations for developing reservoirs or check dams - Making ground surveys in specific areas
(1.3) Mathematical modeling for infrastructure design and monitoring water conditions	- Rainfall-runoff modeling - Water balance calculation	- Quantifying the amount of water reserved by check dams - Managing water demand to match the water supply situation of specific local areas - Monitoring the water supply level to ensure enough water for a targeted period
(1.4) Engineering enhancement	- Treatment system for the local drinking water supply - Air trap system for water pumps - Construction of additional irrigation systems and weirs	- Building the optimum infrastructure for a community's needs and also improving the quality of life of its people

2.6. Integrated Urban Water Resource Management (IUWRM)

IUWRM is the practice of managing the water supply, wastewater, and storm water as components of a basin-wide management plan. The goal is to have synergy between water, the environment, the economy, and the society for sustainable development. IUWRM contributes to climate adaptation by increasing the area's resilience to weather extremities and ensuring sustainable urban development. The key to IUWRM is the integration of traditionally separate functions, enabling them to work together harmoniously. These functions include water supply production and distribution, wastewater disposal, and urban stormwater runoff collection, as schematically illustrated in Fig A 4. The technologies and practices in IUWRM is summarized in Table A 5.

Fig A 4-Urban water cycle
Source: Join the Evolution (Join the Evolution 2009)

Table A 5-List of IUWRM technology and practices

	Topic	Area	Technology/Practice
1	Water supply management	Watershed protection	Land acquisition and stewardship program
			Stream corridor protection and buffer zone
			Environmental education and outreach programs
		Diversification of water supply	Rainwater harvesting from roofs
			Rainwater collection from ground surfaces
			Storm water and stream water collection in retention ponds
			Water reclamation and reuse
			Post-construction support for community-managed water systems
		Improving efficiency of water supply infrastructure	Monitoring and reporting technologies
			Leak management, detection and repair for storage and distribution networks
		Drinking water safety	Water quality monitoring and reporting technology
			Drinking water purification technology

	Topic	Area	Technology/Practice
2	Water demand management	Water conservation	Water-efficient fixtures and appliances
			Water reclamation and reuse technologies
3	Waste and sanitation management	Source-area control	Household water treatment and safe storage technology
		Conveyance control	Wastewater collection and conveyance infrastructure and technology
		End-of-pipe control and treatment	Constructed wetlands
			Combined sewage overflow (CSO) treatment technology
			Monitoring and reporting technologies
4	Flood management	Source-area control	Rainwater harvesting from roofs
			Green roofs
			Rainwater collection from ground surfaces
			Runoff collection in a retention pond (wet pond)
			Proper lot grading
			Cap off of storm laterals and install sump pumps
			Bio-filtration practices
		Conveyance control	Inlet controls on storm sewer system
			Infiltration/exfiltration systems (from Toronto water)
			Roadside swales (green street) and ditch networks
			Natural channel improvement for better channel hydraulics
			Conveyance infrastructure with sump pumps
		End-of-pipe control and treatment	Storm water ponds, constructed wetlands
			Underground infiltration basins Underground storage tanks
			Combined sewer overflow treatment technology

2.7. Early Warning System

The capability of preparing for and responding in a timely manner to any kind of hazard ensures minimum damage in terms of human lives and property. A proper and effective early warning system--integrating local expertise, research, and proven technology--is a key instrument. Data must be continuously and effectively collected, analyzed, assimilated, and disseminated to the stakeholders at all levels, from community residents to local operational personnel and central emergency command centers. An early warning system involves the use of a sensor web using observation and/or modeling data, warning criteria based on the season, area, and risk type, and disaster communication as described next.

A sensor web utilizes an Internet network and an automated response system to collect data in order to monitor and detect flooding events. The technologies integrated in the sensor web system include weather forecast modeling, rainfall and water level telemetry, satellite image processing, and a warning system. The process of a sensor web is displayed in Fig A 5, followed by a description of each component.

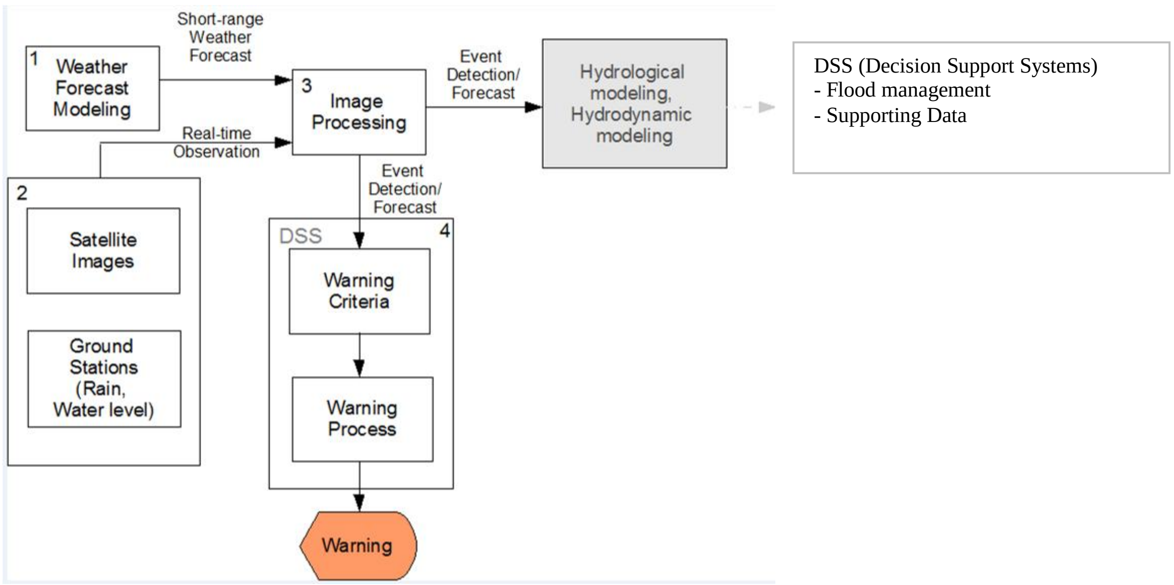


Fig A 5-the process of a sensor web used in an early warning system

Weather Forecast Model. A weather forecast model is designed to provide short-term weather forecasting such as a 3-day forecast. Typically, the model provides rainfall and wind maps using a 3-km grid.

Satellite Imaging and Ground Stations (Rainfall and Water Level). The observed data in the sensor web system are derived from satellite images, using MODIS (terra/aqua) and the Tropical Rainfall Measuring Mission (TRMM). MODIS sensing provides data twice a day (day and night). The TRMM is designed to monitor and collect tropical rainfall data. In addition, telemeters, the so-called *in-situ* sensors, are utilized to collect real-time rainfall and water level data throughout the whole country. The data is automatically sent from stations to the central server via GPRS every 10 to 30 minutes.

Image Processing. The summarized rainfall values from satellite and WRF images are generated using image processing techniques. The results of the processed images are compared with the estimated values in each grid with the flood threshold. This type of image processing can calibrate satellite rainfall estimation using ground station products.

Warning process. The processed information from weather forecasting models, satellite images, and ground stations provides the key inputs to a warning system. The rainfall estimates are compared to flood threshold criteria. When the rainfall exceeds the threshold criteria, the warning system is triggered. The warning messages are alerted on a website and sent out as text messages, indicating the critical areas or providing maps illustrating emergency regions.

Warning criteria based on season, area, and risk type The flood threshold criteria mentioned above are the statistical values derived from the historical records of the rainfall and flood events of the past five years. The physical characteristics of Thailand's watersheds (e.g., the area and slope) are also considered when analyzing and defining the flood threshold criteria.

Disaster Communication Disaster response requires effective and coordinated communication in order to avoid confusion and delay. Disaster communication consists of various levels of communication policies, systems, and guidelines, covering local to national scales. Various governmental agencies under a larger umbrella of authority have their roles in the early warning of disasters at different scales. A cooperative framework is required for channeling information across reliable communication systems and efficient interfaces for better response during disaster situations. In the event of an emergency, warning text and graphic representations of the data from the flood sensor web system are disseminated to the responsible disaster management authorities to enable timely decision making and management.

Modeling Sector

3. Overview of the possible adaptation technology options and their adaptation benefits

3.1 National Data Center

As mentioned in the overview of the modeling section, Thailand has several data centers, each of which is dedicated to a specific purpose. Thailand, however, does not have a national integrated data center like other countries. The benefits of having a national data center include enhancing the efficiency of domestic and international data collection and exchange, providing a data network for all the stakeholders and responsible parties, and serving as an official information distributor to all the stakeholders and responsible agencies. A national data center can promote both data collection, data application, and research in the short term and long term (see Fig A6). In order for Thailand to develop a national data center, several considerations must be taken into account. First of all, the national data center should be designed to be multi-tiered. A data center can be designed to have several tiers (Table 4A). The multi-tier model is the most common design for an enterprise, thus making it more suitable for a national data center than a server cluster model, which is better suited for a university or a scientific community. The multi-tier design is based on the web, application, and database layered design. This type of design supports many web service architectures, such as those based on Microsoft.NET or the Java 2 Enterprise Edition. These web service application environments are used by ERP and CRM solutions from Siebel and Oracle, to name a few. The multi-tier model relies on the network to provide security and application optimization services.

Fig A 6- Conceptual frameworks of Thailand's Data Center

Table A 6-Data Center Classification

Tier Level	Requirement	Performance
1	• Single non-redundant distribution path serving the IT equipment • Non-redundant capacity components • Basic site infrastructure guaranteeing 99.671% availability	Simplest, basic
2	• Fulfills all Tier 1 requirements • Redundant site infrastructure capacity components 99.741% availability	
3	• Fulfills all Tier 1 and Tier 2 requirements • Multiple independent distribution paths serving the IT equipment • All IT equipment must be dual-powered and fully compatible with the topology of the site's architecture • Concurrently maintainable sit infrastructure guaranteeing 99.982% availability • Concurrently maintainable site infrastructure guaranteeing 99.982% availability	
4	• Fulfills all Tier 1, Tier 2 and Tier 3 requirements • All cooling equipment is independently dual-powered, including chillers and heating, ventilating and air-conditioning (HVAC) systems • Fault-tolerant site infrastructure with electrical power storage and distribution facilities guaranteeing 99.995% availability	Most stringent, fully redundant subsystems

The multi-tier model uses software that runs as separate processes on the same machine via interprocess communication (IPC), or on different machines with communication over the network. Typically, the following three tiers are used: web-server, application, and database. Multi-tier server farms built with processes running on separate machines can provide improved resiliency and security. Resiliency is improved because a server can be taken out of service while the same function is still provided by another server belonging to the same application tier. Security is improved because an attacker can compromise a web server without gaining access to the application or database servers. Web and application servers can coexist on a common physical server; the database typically remains separate. Resiliency is achieved by load balancing the network traffic between the tiers, and security is achieved by placing firewalls between the tiers. One can achieve segregation between the tiers by deploying a separate infrastructure composed of aggregation and access switches, or by using VLANs (see Fig A 7).

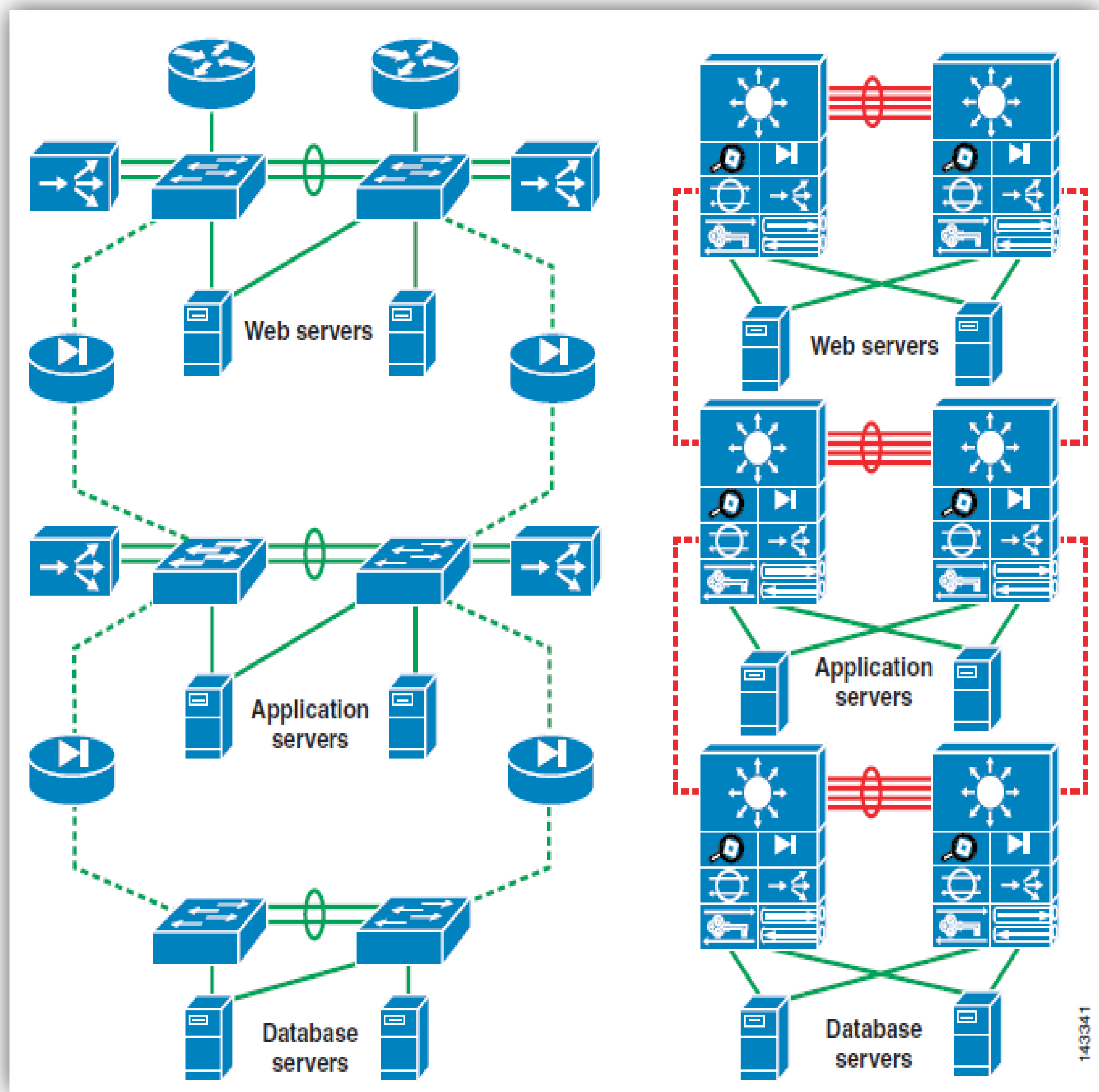


Fig A 7-Physical Segregation in a Server Farm with Appliances (A) and Service Modules (B) Source: Cisco Data Center Infrastructure 2.5 Design Guide (2007), Cisco Validated Design I(Americas Headquarters 2007)

In addition, the design of the national data center should comply with the TIA-942 Telecommunications Infrastructure Standards for Data Centers, which is the first standard that specifically addresses data center infrastructure. The TIA-942 covers site space and layout, cabling infrastructure, tiered reliability, and environmental considerations.

This proposed national data center on climate change has to achieve complicate missions such as collecting, managing, and distributing massive amounts of data for various sectors. Thus, it will consist of tens or hundreds of servers to support various systems, applications and services for different sectors. The optimization of the infrastructure for data management and services for this wide a range of applications is imperative. A key for infrastructure optimization is for the design to meet the nature of the data consumption of all the relevant sectors. For example, most of the users may be accessing an application based on servers in one location, while only a few may be accessing an application held on a different physical server. Based on this information, the data center designer can model the operations to see whether the data center should consolidate down to a single data center, or if it should host multiple sites, instead.

A data center consists of a physical structure and IT equipment. The physical infrastructure of a data center includes all of the facility equipment needed to provide power, cooling, and physical protection for the IT equipment. A typical data center consists of, at least, the following requirements: power of 100 KW, power density of 50 W/sq ft, life cycle of 10 years, average rack power of 1500 W, and redundancy of 2N. The total cost of ownership (TCO) of a rack in a data center is approximately 120,000 USD over the data center lifetime. In many cases, this cost is comparable to the cost of IT equipment that a rack is likely to contain over the data center's lifetime. Approximately, half of the lifetime per rack TCO of 120,000 USD is capital expense, and half is operating expense. These costs break down into categories as shown below.

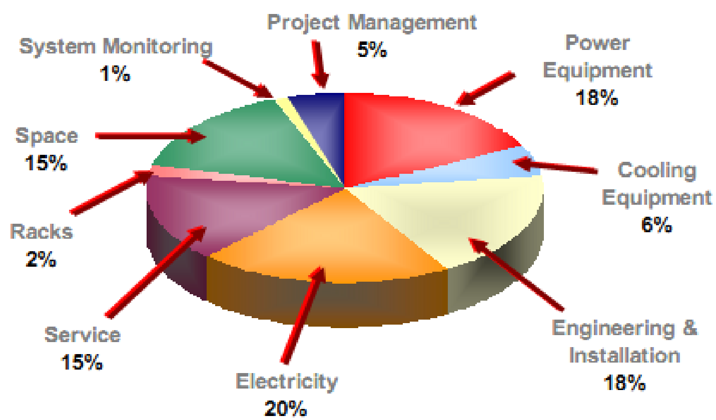


Fig A 8-Breakdown of TCO cost components for a typical rack in a high availability 2N data center

3.2 National data transfer/management

As mentioned earlier, Thailand has no official and effective means of data collection, data transfer, and database management, especially for regional-level data management for modeling climate change impacts. Thus, national data transfer/management is required to equip the national data center with creditable and intensive data. The data needed include GCM data, climate data, weather data, and observation data of Southeast Asia. Fig A **9** illustrates the idea of using the Thailand data center for national data transfer/management.

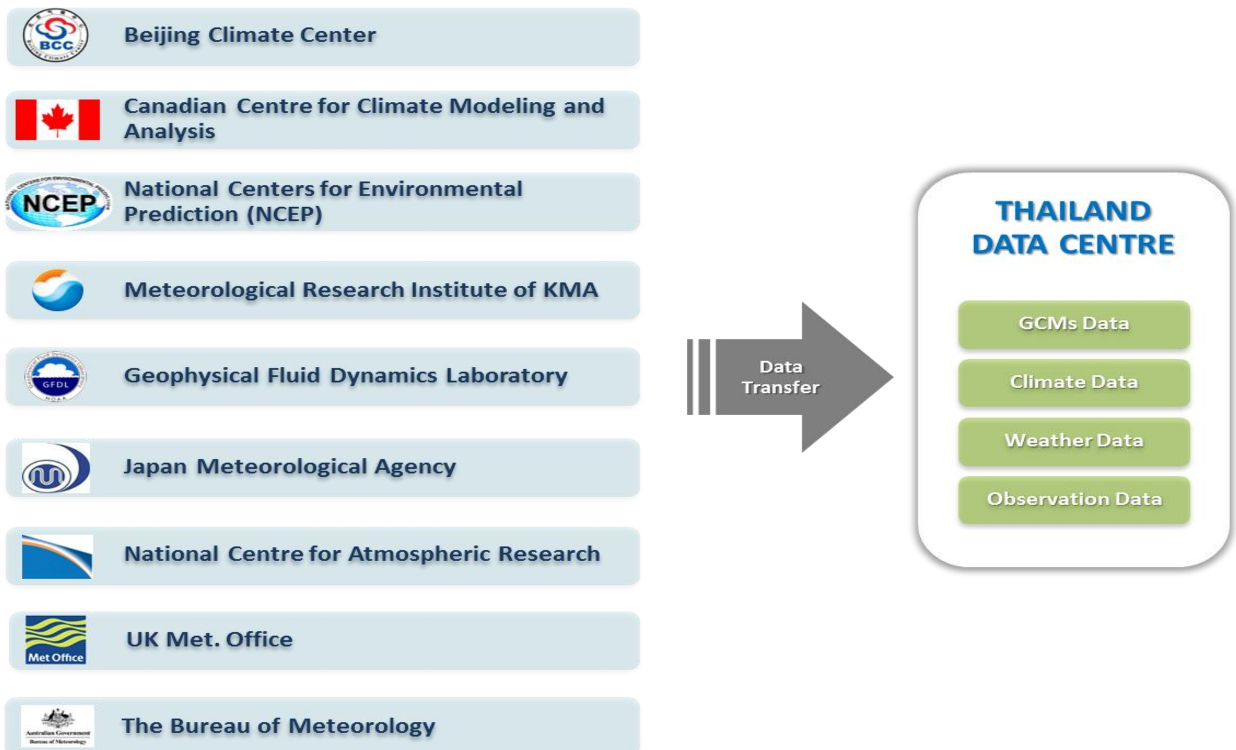


Fig A 9-An idea for using the Thailand data center for national data transfer/management

3.3 Integrated Modeling

As reviewed in the overview, each sector in Thailand uses a specific model favorable for the application of interest. To be more effective, Thailand should utilize an integrated model, which allows for the analysis of climate change impacts across the sectors. An integrated model can also help to assess how a climate change impact from one sector consequently affects another sector, as conceptually shown in Fig A 10. An integrated model can also identify threats from climate change impacts at a specific location. Appropriate adaptation strategies can then be developed for each specific region. Using existing agriculture, water resource, and ecosystem information, it is possible to examine which crops, cropping calendars, domestic animals, ecosystems, endangered species habitats and livelihoods will be most sensitive to any anticipated impacts. It also helps in identifying the critical issues and developing adaptation strategies for vulnerable systems, locations and communities.

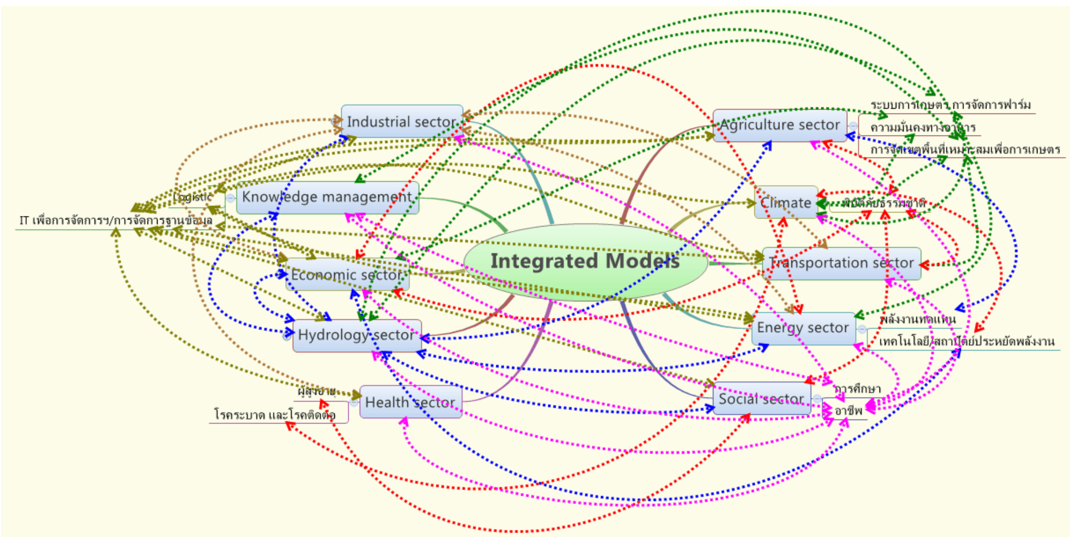


Fig A 10-An integrated modeling framework

<u>3.3.1 WRF Model</u>

The WRF model is an integrated modeling tool in the public domain and available free of charge. The present WRF (ARW) model was released as Version 3.3. The WRF model was developed at the National Center for Atmospheric Research (NCAR) which is operated by the University Corporation for Atmospheric Research (UCAR). It is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. The WRF model is suitable for a broad range of applications across scales ranging from meters to thousands of kilometers, including

- Idealized simulations (e.g., LES, convection, baroclinic waves).
- Regional and global applications.
- Parameterization research.
- Data assimilation research.
- Forecast research.
- Real-time NWP.
- Hurricane research.
- Coupled-model applications.
- Teaching.

The Mesoscale and Microscale Meteorology Division of NCAR is currently maintaining and supporting a subset of the overall WRF code (Version 3) that includes the following:

- WRF Software Framework (WSF).
- Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nests, grid, and observation nudging.
- WRF Pre-Processing System (WPS).
- WRF-DA data assimilation system.
- Numerous physics packages contributed by WRF partners and the research community.

WRF has a rapidly growing community of users, and workshops and tutorials are held each year at NCAR. The WRF model is currently operational at NCEP, AFWA, and other centers. The site illustrated in Fig A 11 provides information on WRF efforts and its organization, references to projects and forecasting involving WRF, links to the WRF users' page, real-time applications, and WRF-relate events. Several research organizations and governmental agencies in Thailand and around the world use the WRF model as summarized in Table A7.

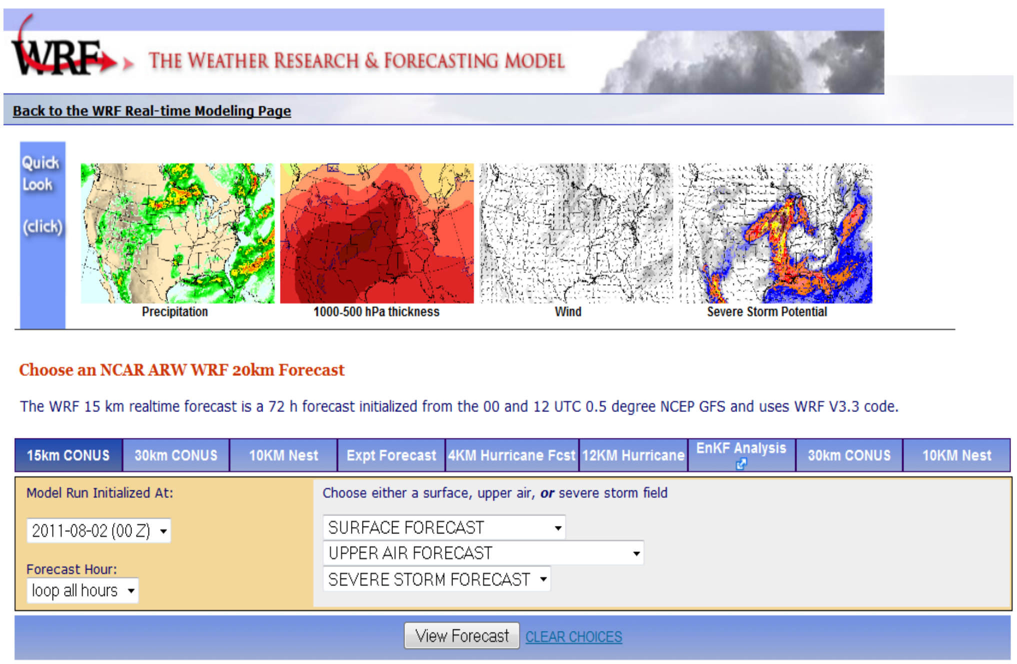


Fig A 11- Overview of real-time forecasting
Source: The Weather Research & Forecasting Model (The Weather Research & Forecasting Model)

Table A 7: Organizations and governmental agencies in Thailand and around the world using the WRF model

Organization in Thailand	International Organization
Faculty of Science, King Mongkut's University of Technology Thonburi (KMUTT)	The National Center for Atmospheric Research (NCAR)
Thai Meteorological Department	National Oceanic and Atmospheric Administration (NOAA)
Atmospheric Physics Research Unit, Faculty of Science, Chiang Mai University	US Universities • University of Illinois • Millersville university • Jackson State University • University of Washington • NCEP/EMC HiResWindow forecasts
National Disaster Warning Center	The National Taiwan Normal University
	The Unidad de Meteorologia, Instituto de Fisica
	The National Observatory of Athens
	The Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR)
	Slovenian Meteorological Amateur Research Team
	The Institute of Astronomy and Meteorology of the University of Guadalara, Mexico
	C-DAC, India
	Meteo Riccione, Italy
	Mexican Institute of Water Technology (IMTA)
	Vietnam and Southeast Asia by AMI Environmental
	The National Atmospheric Research Laboratory of India
	North Atlantic and Iceland by the Institute for Meteorological Research, Reykjavik, Iceland
	Earth Sciences Department, Barcelona Supercomputing Center, Spain
	Department of Physics and Department of Meteorology, University of Athens

Annex 2: Project ideas for international support

2.1 Agricultural sector

Project 1: Formulation of graduate courses to promote capacity building for technology diffusion and transfer in agricultural sector through international collaboration and networking (5 years plan)

This is to formulate graduate courses with the emphasis on technology diffusion and transfer in agricultural sector through a consortium of leading international universities, local universities, research centers, and private companies for the purpose of human resource capacity building. This could be achieved using the framework of the Thailand Advanced Institute of Science and Technology (THAIST), an institute dedicated to develop Thai human resources.

An Example of a Successful Consortium for Capacity Building Thailand Advanced Institute of Science and Technology and Tokyo Institute of Technology (TAIST) under THAIST framework lead a consortium involving the National Science and Technology Development Agency (NSTDA) and partner universities both domestic (include King Mongkut's University of Technology Thonburi (KMUTT) and Mahidol University (MU)) and international to develop Thai human resources. TAIST serves as a virtual institution and focal point. NSTDA provides researchers to act as adjunct professors and supplies research projects and scholarships for graduate students. The participating institutions or universities from overseas provide world class background, expertise and experience, academic instruction, and research supervision. Also, the TAIST Tokyo Tech project aims to attain the world-class performance by mobilizing the whole institutional resources based on the long academic and research history of Tokyo Tech, NSTDA, KMITL, SIIT and other participating universities. Tokyo Tech and TAIST Tokyo Tech share the same philosophy of education and research - "HRD by promoting cutting-edge research activities".

Requirements for international support

A financial support of 10 million USD is estimated to support the travel expenses of leading experts to teach courses in Thailand and to equip learning materials as well as learning facilities to support approximately 150 students.

Project 2: Establishment of an ASEAN training hub for adaptation technologies in agriculture (5 years plan)

This aims to establish a national training center in Thailand as an ASEAN training hub in the context of south-south collaboration, linking with international organizations and experts with the ultimate goal of ensuring the world's food security. The activities of the knowledge and training hub for adaptation technologies may include providing various short training courses for practitioners such as a 3-5 days workshop, a short term research training (3 months), and an advanced research training (6 months). The center will emphasize on multi-disciplinary lessons in related fields. Research projects and internships with farmers and agribusiness parties will provide practical experience and collaboration they need for future success. Areas of emphasis include simulation models for forecasting and early warning, marker assisted selection, risk assessment on GM product, and precision farming skills. Agricultural practitioners should be able to use and develop innovative techniques and gain an access to the top of the line equipments and facilities including both hardware and software. The center would also host an international workshop on adaptation technologies to be applied in the agricultural sector, attracting academics and industry representatives from many countries to share their expertise and experience, with a strong emphasis on the real world applications. This program could also follow the successful model of the Molecular Rice Breeding Program for the Mekong Region (in the box below)**.**

Requirements for international support

Thailand would need a sufficient funding/ grant/ scholarship in the key areas, along with high efficiency training equipments. A subsidy of 35,000 US dollars is estimated for operating a comprehensive hands-on training course on selected technologies for approximately 20 persons/ year. In addition, collaboration with prestigious overseas academic/ research institutes from overseas to design the training courses is imperative. Similarly, collaboration on research and development of adaptation technologies, especially customization of the techniques to meet the country's specific needs, is essential. This can also build a network of researchers/ practitioners/ experts in related fields (such as simulation, phenotyping-genotyping association, high throughput screening, and precision farming) both domestically and internationally. Consequently, this network will provide training skills and forums to exchange ideas in a self-sustained manner.

The Molecular Rice Breeding Program for the Mekong Region

An example of this type of project is the "Molecular Rice Breeding Program for the Mekong Region" project, which aimed at promoting the implementation of Marker Assisted Selection (MAS) for rice breeds in the Mekong region, particularly in Laos, Cambodia and Myanmar, through a comprehensive hands-on training program and through the sharing of genomic information and research facility. The first phase of the project took place in 2004-2006 with a financial support from the Rockefeller Foundation, Kasetsart University, and BIOTEC/ NSTDA. During 2007-2008, the project obtained another funding from the Generation Challenge Program (GCP) under the project title "Community of Practices". The concept applied to rice production in the Mekong Region with emphasis on drought, salinity and grain quality improvement to continue the development of backcross introgression lines.

Partners of this program included the Cambodian Agricultural Research and Development Institute (CARDI) from Cambodia, National Agricultural and Forestry Institute (NAFRI) from Laos, the Department of Agricultural Research (DAR) from Myanmar, and the Ubon Ratchathani University from Thailand.

2.2 Water Resource Management Sector

Project 1: the Water Resource Management Capacity Development and International Knowledge Networking Project

1. Motivation

The main objectives of Thailand water development and management are to increase security in terms of capital water supply, to build flexibility for management in all types of supply, to minimize damage from disasters, to maximize water usage efficiency, to involve all sectors in the management, and to build knowledge/know-how and data for management. Overall, the main obstacles of technology transfer and diffusion in Thailand to achieve these goals are institutional framework and lack of knowledge and vigorous capability development of personnel involved in water resource management. To be able to build a strong technological foundation for Thailand, these issues need to be concretely approached.

These proposed project ideas are suggested as short-term action plans, offering immediate actions and rapid outcomes, for the three prioritized technologies. The focus is on human resource capability development, i.e. to create learning opportunities and to get ready to receive new knowledge and new technologies. The main tools of the project ideas are activities related to the first national conference on climate change and national water resource management in Thailand. The target participants include water resource personnel and climate change experts from all sectors. The conference also enables knowledge exchange among overseas experts and local personnel.

2. Objectives

1. To vigorously and systematically develop the capability of Thailand's human resources in water resource management, from government agencies to educational institutes, and from the private sector and to local communities.
2. To create an international knowledge network which enables the exchange of knowledge and research work as well as the transfer of technologies among water resource management agencies around the world.
3. To create skilful human resources in water resource management through international collaborative research scholarships at the master and Ph.D. levels.

3. Benefits

1. Exchange of knowledge and technology that benefit the climate change adaptation of the water resource management
2. Awareness of the benefits of the systematic application or utilization of water resource management technology among personnel in the government sectors, academic institutes, and private sectors
3. Increase in water resource management manpower within the government sectors and academic institutes that would help create a strong foundation for the country

4. Project Scope and Possible Implementation

This project aims at the systematic capability development of human resources in water resource management and climate change. The government is assigned as a main driver who pushes forward national workshops or conferences in order to motivate vigorous and concrete development of water resource knowledge. The operation includes four main activities as shown in Table A 8. The outcomes of activities in the 1st step are an input for the 2nd step and so on. Table A 8 also provides the target groups, the details, and the outcomes of each step as an input for the next step.

Table A 8-Activities, target groups, details, and outcomes of each step as an input for the next step

Activity	Target group	Detail	Outcome as an input for the next step
1) Organizing a seminar on climate change and water resource management	▪ Government agencies, private sectors, educational institutes, and local administers and communities ▪ Participants from Thailand as well as overseas representatives from agencies within the water resource network	<u>Conference sessions</u>; Sessions of the conference would relate to three prioritized technologies: ▪ Networking & management of infrastructures ▪ Seasonal climate prediction ▪ Sensor web for warning system <u>Number of participants</u> ▪ Thai : 400–500 ▪ foreigners: 100–200 <u>Duration</u> ▪ 3– 4 consecutive days	▪ Collaborative network of experts with different water management skills ▪ Knowledge needed by the target groups in order to organize an international workshop programme
2) Organizing technical training/workshops on climate change and water management in the form of a network of knowledge and international training scholarships	▪ Government officers, university students, educational institutes, local administrative officers, and representatives from the communities	<u>Workshop programmes</u>: Programmes of the workshop should be set to enhance the capability of each of the three prioritized technologies: 1) Networking & management of infrastructures ▪ Management of large water structure networks ▪ Management of small water structures connected to the irrigation systems ▪ Application of innovation and local wisdom to community water resource management 2) Seasonal climate prediction ▪ Data analysis to predict water situation and climate ▪ Techniques in data completion and modification of data definition ▪ Long-range climate forecast modelling 3) Sensor web for a warning system ▪ Technologies used in monitoring and detecting flood disasters and landslides	▪ The use of case studies from agencies where the participants are from and the application of techniques/knowledge / concepts learned from the workshop ▪ The application/further development of operational knowledge concepts in the form of papers/research proposals

Activity	Target group	Detail	Outcome as an input for the next step
		▪ The design of a database system and warning system from the supervisor level to the operator level ▪ Flood modelling <u>Location</u> ▪ Each programme will be organized in one of the network member countries. The selection of the country is based on the readiness and the success of the country in that particular field of study. <u>Duration</u> ▪ Approximately 1-2 months per each programme in which participants use case studies from their own agencies	
3) Presentation of papers/research proposals	▪ Participants previously attended activity 2)	▪ Select suitable papers or research proposals that truly benefit the country's water management to be granted research scholarships or international collaborative research scholarships	▪ Papers/ research proposals being selected to receive research scholarships or international collaborative research scholarships
4) Granting research scholarships and international collaborative research scholarships	▪ Selected participants from activity 3)	▪ Provide domestic research scholarships for research work which requires short research duration but which produces fast results ▪ Provide international collaborative scholarships in suitable fields according to the readiness of the member countries	▪ Increase the number of personnel capable of water management in Thailand ▪ Increase research work in water and climate-related subjects which is practical in various circumstances

5. Timelines

Activities	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1) Organizing seminars on climate change and water management												
2) Organizing workshops on climate change and water management in the form of a network of international knowledge and training scholarships												
3) Presenting papers/research proposals												
(4Granting research scholarships and international collaborative research scholarships*												
Tentative Budget (baht)	**10,515,000**				**31,255,000**				-*			

* Subject to the research domains/topics and sponsoring countries.

6. Budget/Resource requirements

Expense details		Cost (baht)	Total (baht)
1)Seminar/Conference			**10,515,000**
	Seminar organizing fees 4 days (500 persons/day)	2,400,000	
	International travelling expenses (30 speakers)	2,700,000	
	Allowances (30 speakers)	375,000	
	Accommodations (50 rooms)	750,000	
	Domestic travelling expenses	750,000	
	Brochures/Documentation (1500 sets)	825,000	
	PR expenses	1,400,000	
	Souvenirs	350,000	
	Administrative costs	965,000	
2)Programme held in Thailand			**28,075,000**
Only one programme will be held in Thailand in the relevant topic of "Application of innovation and local wisdoms into community water resource management". More technical programmes can be organized in other member countries.			
	Local programme		1,575,000
	Tuition fees (30 persons)	750,000	
	Instructors (5 lecturers/15days)	225,000	
	Domestic travelling expenses	300,000	
	Administrative costs	300,000	
	International programme		26,500,000
	Travelling expenses (50 persons)	4,000,000	
	Allowances (2-3 months/person)	9,000,000	
	Accommodations (2-3 months/person)	13,500,000	
3)Selection papers/ research proposals			**3,180,000**
	Subject matter experts (5-6 persons)	2,700,000	
	Administrative costs	480,000	
4)Grant research scholarships		-	-
* Subject to the research domains/topics and sponsoring countries.			

7. Thai national organizations involved in the project

Science and technology policy

- National Science Technology and Innovation Policy Office, Ministry of Science and Technology

Research and development

- Hydro and Agro Informatics Institute, Ministry of Science and Technology
- Department of Science Service, Ministry of Science and Technology
- King Mongkut's University of Technology Thonburi
- Kasetsart University
- Chulalongkorn University

Operations

- Royal Irrigation Department, Ministry of Agriculture and Cooperatives
- Department of Water Resources, Ministry of Natural Resources and Environment
- Thai Meteorological Department, Ministry of Information and Communication Technology
- Department of Ground Water Resources, Ministry of Natural Resources and Environment
- Land Development Department, Ministry of Agriculture and Cooperatives
- Department of Drainage and Sewerage

Disaster Prevention and Warning

- Department of Disaster Prevention and Mitigation, Ministry of Interior
- National Disaster Warning Center, Ministry of Information and Communication Technology

2.3 Modeling Sector

Project 1: Improving climate change modeling capability of Thailand by establishing an integrated national data center equipped with the implementation of integrated national data transfer/management

1. Introduction

Climate change is known to cause increasing frequency and intensity of hydro-meteorological hazards (e.g., floods, droughts, heat waves, and storm surge), which potentially put quality of life, social system, and economic system under jeopardy. Climate change also affects the onset, duration, and variability of seasonal rainfall, which introduces uncertainty in natural ecosystems (including fisheries spawning and bird migration) and traditional cropping calendars. The social and economic impacts of these increasing vulnerabilities often vary among communities, stakeholders, and vulnerable groups. Climate change impact modeling is an essential tool for climate change adaptation and mitigation for various sectors including water resource management, agricultural, energy, health, transportation sectors. As thoroughly discussed in the barrier identification and the possible solutions to address the barriers of climate change modeling for Thailand, an integrated national data center equipped with an effective integrated national data transfer/management process is imperative and is proposed here as a project idea for international support.

2. Objectives

Implied by the project title, the main objectives of the project idea are

1) To establish a national data center for data collection, integration, and distribution to uses of all the sectors

2) To implement effective mechanisms to collect, transfer, and manage domestic, regional, and international data relevant for the climate change impact modeling

3. Relationship to the Thailand sustainable development priorities

This project is essential for the success of Thailand sustainable development priorities, especially for the water resource management and agricultural sectors which require a lot of modeling tools, database, and data center.

4. Project Benefits

This project is beneficial for both governmental agencies and private institutes of all the sectors utilizing climate change modeling for planning and decision making. The national data center maximizes the data utilization efficiency, promotes cross-sectoral coordination and data exchange, and minimizes the total cost of the country regarding data transfer/management due to the reduction of data transfer/management repetition and redundancy. Last but not least, this initiation will strengthen Thailand's potential to become a hub of climate change knowledge in the region.

5. Project Scope and Possible Implementation

This project is proposed to address the barrier identification and the TAPs discussed in this report. Thus, the project scope, possible implementation, timeline activity, and estimated budget can be seen from. These can be summarized as in Fig A 12 Fig A 13for the national data center establishment and the national data transfer/management process, respectively

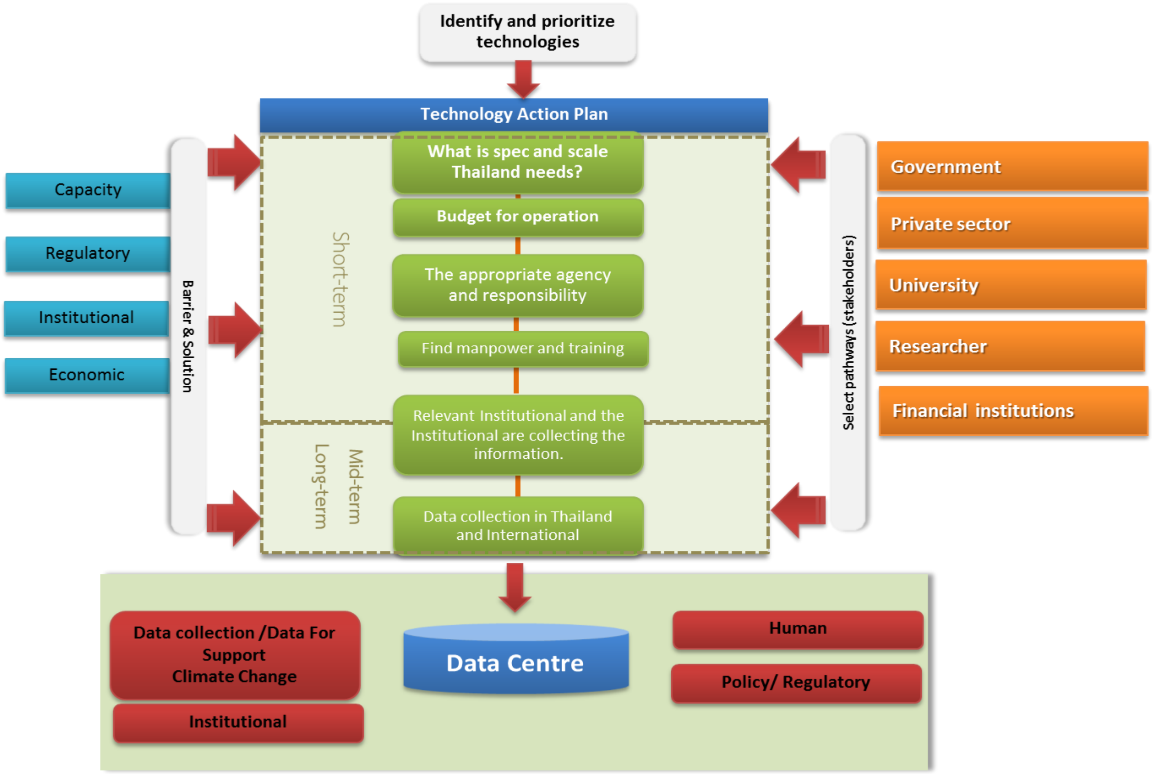


Fig A 12-Technology action plan for the national data center

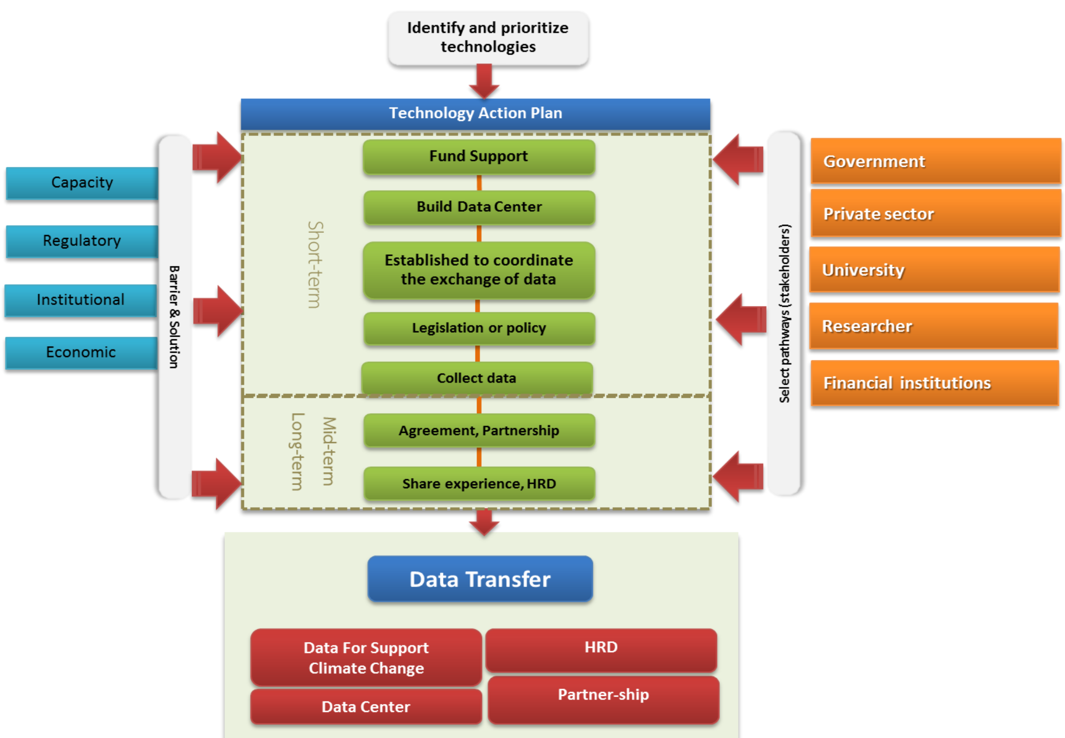


Fig A 13-Technology action plan for the national data center

6. Budget/Resource requirements

Data center: 5,000,000 THB
Data Transfer: 10,000,000 THB

7. Measurement/Evaluation

Evaluation of the success of the project can be done by

1) Surveying user rating of the data center performance,
2) Accounting the number of domestic and international partners of the center,
3) Verifying the improvement of climate change forecast accuracy,
4) Measuring the number of the members or the subscribers of the data center

8. Responsibilities and Coordination

The potential responsible institutes and coordinators of the project include, but not limited to, the Center of Excellence for Climate Change Knowledge Management (CCKM) at Chulalongkorn University, Thailand and the Thai Meteorological Department.

Annex 3: List of stakeholders involved

3.1 List of experts and stakeholders in the First Meeting for the Thailand Technology Needs Assessment project on July 12, 2010

No.	Name	Organization
1	Ms. Dusita Krawanchid	Stockholm Environment Institute - Asia (SEI-Asia) Chulalongkorn University
2	Mr. Suppakorn Chinvanno	Southeast Asia System for Analysis, Research and Training Regional Center (SEA-START-RC), Chulalongkorn University
3	Assoc. Prof. Dr. Jiemjai Kreasuwan	Faculty of Science, Chiang Mai University
4	Mr. Pongsak Noophan	Faculty of Engineering, Kasetsart University
5	Assistant Professor Dr. Surat Bualert	College of Environment, Kasetsart University
6	Mr. Chanawut Iemprasertkul	King Mongkut’s University of Technology Thonburi
7	Mr. Nathawoot Setkit	King Mongkut’s University of Technology Thonburi
8	Mr. Sukawat Tuntara	King Mongkut’s University of Technology Thonburi
9	Dr. Nathsuda Pumijumnong	Faculty of Environment and Resource Studies, Mahidol University
10	Mr. Siam Arunsrimorakot	Faculty of Environment and Resource Studies, Mahidol University
11	Ms. Duangrat Inthorn	Faculty of Public Health, Mahidol University
12	Dr. Poranee Pataranawat	Faculty of Public Health, Mahidol University
13	Ms. Duangta Dejkaew	Faculty of Public Health, Mahidol University
14	Dr. Kraichat Tantrakarnapa	Faculty of Public Health, Mahidol University
15	Dr. Sarintip Tantanee	Faculty of Engineering, Naresuan University
16	Dr. Wirachai Roynarin	Mechanical engineering department, Rajamangala University of Technology Thanyaburi
17	Mr. Nipat Somkleeb	Faculty of Science, Ramkhamhaeng University
18	Ms. Kanchana Supapol	Faculty of Engineering, Thammasat University
19	Ms. Nutthika Upanasak	Faculty of Engineering, Thammasat University
20	Ms. Siripang Kaewsunthon	Faculty of Engineering, Thammasat University
21	Dr. Paritud Bhandhubanyong	Technology Promotion Association (Thailand-Japan)
22	Mrs. Chutithorn Praditphet	Office of Transport and Traffic Policy and Planning
23	Ms. Wipada Unlumlert	Office of Transport and Traffic Policy and Planning
24	Ms. Jarinporn Tipapornmongkol	Pollution Control Department
25	Ms. Parichat Borkhum	Department of Water Resources
26	Ms. Nidalak Sitthipon	Department of Environment Quality Promotion
27	Ms. Kanyarat Promupatum	Department of Marine and Coastal Resources
28	Ms. Suthasinee Bhothisuntorn	Royal Forest Department
29	Mr. Thanit Pulivekin	Siam City Cement Public Co., Ltd
30	Mrs. Patsharee Congtrakultien	Charoen Pokhand Group
31	Mr. Somjettana Pasakanon	The Thai Chamber of Commerce
32	Dr. Teerin Vanichseni	The Thai Chamber of Commerce
33	Ms. Sukanya Chaichuen	The Thai Chamber of Commerce
34	Ms. Rampueng Swangduen	Bank for Agriculture and Agricultural Co-operatives

No.	Name	Organization
35	Mr. Pinij Siripuekpong	Electricity Generating Authority of Thailand
36	Mr. Supatpong Sikkhabandit	Electricity Generating Authority of Thailand
37	Ms. Piyathip Eawpanich	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
38	Mr. Prasert Aungsuratana	Bureau of Royal Rainmaking and Agriculture Aviation
39	Ms. Duangchai Amornkul	Hydro and Agro Informatics Institute
40	Ms. Chirapaporn Laima	Energy Policy and Planning Office
41	Dr. Kasititorn Pooparadai	National Science and Technology Development Agency
42	Dr. Thumrongrut Mungcharoen	National Science and Technology Development Agency
43	Ms. Sumavasee Salasuk	National Science and Technology Development Agency
44	Mr. Bancha Dokmai	National Science and Technology Development Agency
45	Dr. Charnwit Udomsakdigool	National Science and Technology Development Agency
46	Ms. Kulwarang Suwansri	National Science and Technology Development Agency
47	Ms. Yuwanan Santitaweeroek	National Science and Technology Development Agency
48	Dr .Sornthep Vannarat	National Science and Technology Development Agency
49	Ms. Araya Nuntapotidech	Office of National Resources and Environmental Policy and Planning
50	Ms. Sunee Piyapanpong	Office of National Resources and Environmental Policy and Planning
51	Dr. Natthanich Asvapoositkul	Office of National Resources and Environmental Policy and Planning
52	Dr. Nares Damrongchai	National Science Technology and Innovation Policy Office
53	Dr. Surachai Sathitkunarat	National Science Technology and Innovation Policy Office
54	Ms. Tipawan Tangjitpiboon	National Science Technology and Innovation Policy Office

3.2 List of experts and stakeholders of the agricultural sector in the stakeholder meeting for the Thailand technology needs assessment on July 17, 2011

No.	Name	Organization	e-mail
1	Prof. Dr. Arun Puttanothai	Khon Kaen University	aran@kku.ac.th
2	Mr. Sookwat Chandraparnik	Department of Agriculture	sookwat1@hotmail.com
3	Dr.Peeradet Tongumpai	The Thailand Research Fund	peeradet@trf.or.th
4	Mr. Chatta Udomwongsa	FXA Company Limited	chattau@fxagroup.com, soonthac@fxagroup.com
5	Assoc. Prof. Chalor LIMSUWAN	Kasetsart University	ffiscll@ku.ac.th
6	Dr. Putth Songsangjinda	Department of Fisheries	putthsj@yahoo.com
7	Dr. Theerayut Toojinda	Kasetsart University	Theerayut@dna.kps.ku.ac.th
8	Dr. Rachaporn Keinprasit	National Electronics and Computer Technology Center	rachaporn.keinprasit@nectec.or.th
9	Dr. Amnat Chidthaisong	King Mongkut's University of Technology Thonburi	amnat_c@jgsee.kmutt.ac.th
10	Prof. Dr. chareinsak Rojanaridpiched	Kasetsart University	agrcsr@ku.ac.th
11	Assoc. Prof Dr Padermsak Jarayabhan	Chulalongkorn University	padermsakj@yahoo.com
12	Dr. Nuchnart Tangchitsomkid	Department of Agriculture	nuchanar@doa.go.th
13	Dr. Anek Silapapan	Crop Integration Business C.P. Group	
14	Mr. Pisuth Paiboonrat	National Science and Technology Development Agency	
15	Mr. Chavalit Nitkasakoon	Applied Chem (thailand) Co., Ltd	n_chavalit@hotmail.com
16	Ms. Sukanya Chaichuen	The Thai Chamber of Commerce	sukanya@cpf.co.th
17	Mr. Somjettana Pasakanon	The Thai Chamber of Commerce	somjettana.pas@gmail.com
18	Mrs. Parichart Burns (Sithisarn)	National Center for Genetic Engineering and Biotechnology	p.burns@biotec.or.th
19	Mr. Sarawut Sukmueng	Office of The Cane and Sugar Board	sarawut@ocsb.go.th
20	Mr. Tawatchai Veerapornvanichkul	Thai Sugar Mill Co.,Ltd	tawatchai@sugarmaill.thmail.com

No.	Name	Organization	e-mail
21	Ms. Supawan Petsri	Ministry of Agriculture and Cooperatives	spetsri@yahoo.com
22	Ms. Sudarat Wangmee	Ministry of Agriculture and Cooperatives	
23	Dr. Noppadon Khiripet	National Electronics and Computer Technology Center	
24	Dr. Chayakrit Charoensiriwat	National Electronics and Computer Technology Center	
25	Dr. Royboon Rassameethes	Hydro and Agro Informatics Institute	royboon@haii.or.th
26	Dr.Sujin Patarapuwadol	Kasetsart University	agrsujp@ku.ac.th
27	Mr. Sutep Sahaya	Department of Agriculture	sahaya_s@hotmail.com
28	Mr. Sithichoke Tangphatsornruang	National Center for Genetic Engineering and Biotechnology	sithichoke.tan@biotec.or.th
29	Ms. Rachanee Sonkanok	Office of Agricultural Economics	rachanee@oae.go.th
30	Assoc Prof Prasert Chatwachirawong	Kasetsart University	
31	Dr. Jarunya Narangajavana	Faculty of Science Mahidol University	scjnr@mahidol.ac.th
32	Mr. Watcharapong Noimunwai	Center of Excellence for Climate Change Knowledge Management	watcharapong@cckm.or.th
33	Mr. Suthiporn Chirapanda	Thai Tapioca Development Institute	chirapanda@yahoo.com
34	Mr. Aekachai Kheuenmanee	Ministry of Science and Technology	ackachai@most.go.th
35	Mr. Prem Na Songkhla	House Agricultural Magazine	prempree@hotmail.com
36	Mr. Poonlarb Chatchawalkhosit	Chareon Pokphand Group	
37	Dr. Suraphol Chandrapatya	International Water Management Institute	

3.3 Water resource management sector

Two national public hearing workshops for water resource management sector were held together with workshops for mitigation and other adaptation sectors. The first workshop was focused on presenting the draft of TNA report and the second was focused on the draft of TAP report. Prior to each workshop, a focus group meeting or e-communication with a small group of water resource management experts was arranged to exchange ideas and to review the preliminary draft or outlines of TNA and TAP reports.

Fig A 14-Steps of national public hearing workshops

3.3.1 Focus Group

Three small focus group meetings in the water sector were on June to discuss report outlines and to prepare a water management technology list for prioritization before the 1st nation public hearing on 24 June, 2011 (Table A 9).

Table A 9- Focus group meetings

Date	Place	Stakeholder
10 June, 2011	Meeting Room 2, Floor 8, Hydro and Agro Informatics Institute.	Asian Institute of Technology. Kasetsart University.
14 June, 2011	Meeting Room 1, Floor 14, Hydro and Agro Informatics Institute.	ASDECON Corporation.
20 June, 2011	Office of Project Management, Royal Irrigation Department of Thailand	Royal Irrigation Department of Thailand.

3.3.2 The National Public Hearing Workshops

The 1st national public hearing workshop on technology needs assessment for water resource management was held on 24 June, 2007 at Boardroom 1, Queen Sirikit National Convention Center Bangkok in Thailand. The 29 stakeholders from the public sectors, the private sectors, and specialists met to brainstorm on the list of technology groups and technologies, to discuss criteria and processes for technology prioritization, and to prioritize technology groups and technologies (Fig A 15).

Stakeholders included

- Royal Irrigation Department of Thailand
- Marine Department of Thailand.
- The National Water Resources Board.
- Agriculture, Natural Resource and Environment Planning Office (ANEO).
- Department of Environment, Bangkok Metropolitan Administration.
- Thailand International Development Cooperation Agency, Ministry of Foreign Affairs.
- Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand
- The Industrial Environment Institute, The Federation of Thai Industries.
- National Science Technology and Innovation Policy Office.
- ASDECON Corporation Co., Ltd.
- Eastern Water Resources Development and Management Public Company Limited.
- Charoen Pokphand Group.
- DHI Thailand.

Fig A 15 The 1st national public hearing workshop

The 2nd national public hearing workshop on technology needs assessment for water resource management was held on 24 August, 2007 at the Twin Towers Hotel Bangkok in Thailand. The 30 stakeholders from the government (top down & bottom up), research and educational institutes, agricultural communities, and public-private partnerships brainstormed on technology maps for prioritized technologies as well as barriers and solutions.

Stakeholders included.

- Royal Irrigation Department of Thailand
- Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand
- Industrial Estate Authority of Thailand
- Metropolitan Waterworks Authority
- Provincial Waterworks Authority
- Department of Water Resources
- The Federation of Thai Industries
- Department of drainage and sewerage, Bangkok Metropolitan Administration.

- Department of Environment, Bangkok Metropolitan Administration.
- Department of Science Service
- Local Government such as Nong Bot Subdistrict Administrative Organization, Burrirum Province, Namkhaw Subdistrict Administrative Organization, Trat Province and Klongchaun Municipality , Surat Thani Province .
- National Disaster Warning Center
- National Science Technology and Innovation Policy Office.
- Thammasat University
- Naresuan University
- Kasetsart University
- Mitr Phol Sugarcane Research Center
- ASDECON Corporation Co., Ltd.
- Eastern Water Resources Development and Management Public Company Limited.

Fig A 16 The 2nd national public hearing workshop

Thailand TNA Coordinator
National Science Technology and Innovation Policy Office (STI)
Ministry of Science and Technology

Advisor

1 Dr. Pichet Durongkaveroj	Secretary General, STI
2 Dr. Yada Mukdapitak	Deputy Secretary General, STI
3 Dr. Somchai Chatratana	Deputy Secretary General, STI
4 Dr. Nares Damrongchai	Senior Director, STI
5 Dr. Aweewan Mangmeechai	Editor, Ramkhumhaeng University
6 Dr. Tanapon Phenrat	Editor, Naresuan University
7 Miss Akiko Uyeda	Editor, Chulalongkorn University

TNA Coordinators

8 Dr. Surachai Sathitkunarat	Lead coordinator
9 Mr. Asira Chirawithayaboon	Assistant to lead coordinator
10 Ms. Supak Virunhakarun	Assistant to lead coordinator
11 Dr. Piengpen Butkatanyoo	Coordinator
12 Dr. Jakapong Pongthanaisawan	Coordinator
13 Dr. Srichattra Chaivongvilan	Coordinator
14 Ms. Ubontit Jungtiyanont	Coordinator
15 Ms. Nirada Werasopon	Coordinator
16 Ms. Pattarawan Charumilin	Coordinator

National TNA Committee

1 Professor Dr. Naksitte Coovattanachai	Chairman, Senior Advisor to Secretary-General, STI
2 Dr. Thumrongrut Mungcharoen	National Science Technology Development Agency
3 Ms. Somying Kunanopparat	Representatives from Department of Industrial Works
4 Dr. Pongpisut Jongudomsuk	Representatives from Health Systems Research Institute
5 Ms. Araya Nuntapotidech	Representatives from Office of Natural Resources and Environment Policy and Planning
6 Ms. Rachanee Sonkanok	Representatives from Office of Agricultural Economics
7 Mr. Chetphong Butthep	Representatives from National Research Council of Thailand
8 Ms. Sukanya Chaichuen	Representatives from The joint Standing Committee on Commerce Industry and Banking
9 Dr. Kopr Kritayakirana	National Science Technology Development Agency
10 Dr. Qwanruedee Chotichanathawewong	Thailand Environment Institute Foundation
11 Mr. Chavalit Pichalai	Energy Policy and Planning Office, Ministry of Energy
12 Dr. Chatri Sripaipan	National Science Technology Development Agency
13 Dr. Bundit Fungtammasan	The Joint Graduate School of Energy and Environment
14 Mr. Buntoon Wongseelashote	The joint Standing Committee on Commerce Industry and Banking
15 Dr. Prasert Sinsukprasert	Department of Alternative Energy Development and Efficiency
16 Ms. Prasertsuk Chamornmarn	Thailand Greenhouse Gas Management Organization (Public Organization)
17 Dr. Morakot Tanticharoen	National Science Technology Development Agency
18 Dr. Supranee Jongdeepaisarz	Thailand Research Fund
19 Dr. Sirintornthep Towprayoon	The Joint Graduate School of Energy and Environment
20 Dr. Suvit Tia	National Science Technology Development Agency
21 Dr. Anond Snidvongs	Center of Excellence for Climate Change Knowledge Management
22 Dr. Pichet Durongkaveroj	National Science Technology and Innovation Policy Office

Secretariat of National TNA Committee

23 Dr. Nares Damrongchai	National Science Technology and Innovation Policy Office
24 Dr. Surachai Sathitkunarat	National Science Technology and Innovation Policy Office
25 Ms. Supak Virunhakarun	National Science Technology and Innovation Policy Office
26 Mr. Sittapong Rattanakit	National Science Technology Development Agency

National Consultants - Water Resource Management Sector
Hydro and Agro Informatics Institute (HAII)

1. Dr. Royol Chitradon	Project Manager (Director of HAII)
2. Asst. Prof. Sutat Weesakul	Consultant (Water Engineering and Management Program, AIT)
3. Dr. Somkiat Prajamwong	Consultant (Office of Project Management, Royal Irrigation Department)
4. Mr. Somruthai Tasaduak	Consultant (Water Resource Engineering, Kasetsart University)
5. Dr. Royboon Rassameethes	Subject Matter Expert (Community Water Resource Management Researcher, HAII)
6. Dr. Porranee Thanapakpawin	Researcher (Head of Hydro Informatics and Assessment Section, HAII)
7. Dr. Surajate Boonya-aroonnet	Researcher (Head of Hydro Modeling Section, HAII)
8. Ms.Pakarat Danusatianpong	Contributor, HAII
9. Ms.Jittiporn Chantarojsiri	Contributor, HAII
10. Ms.Karnjana Saengprapai	Contributor, HAII
11. Ms. Aisawan Chankarn	Contributor, HAII
12. Ms. Pintip Vajarothai	Contributor and Project Coordinator, HAII
13. Ms. Aungkana Pratumthong	Contributor and Project Coordinator, HAII

National Consultants - Agricultural Sector
National Science Technology Development Agency (NSTDA)

1. Professor Dr.Aran Pattanothai	Expert Consultant
2. Mr.Sookwat Chandraparnik	Expert Consultant
3. Assoc. Prof. Dr.Peeradet Tongumpai	Expert Consultant
4. Mr.Pornsil Patchrintanakul	Expert Consultant
5. Mr.Chetta Udomwong	Expert Consultant
6. Professor Dr. Morakot Tanticharoen	Project Leader
7. Dr.Charnwit Udomsakdigool	Team Member/ Project Coordinator
8. Mr.Bancha Dokmai	Team Member
9. Dr.Chalinee Kongsawat	Team Member
10. Miss Kasama Kongsmak	Team Member
11. Dr.Kasititorn Pooparadai	Team Member
12. Miss Kulwarang Suwanasri	Team Member
13. Miss Nuchjaree Pisamai	Team Member
14. Mrs. Siriporn Wattanasrirungkul	Team Member
15. Miss Tanapon Glingaysorn	Team Member
16. Miss Tipawan Tangjitpiboon	Team Member
17. Mrs.Uthaiwan Grudloyma	Team Member
18. Miss Viraporn Mongkolchaisit	Team Member
19. Miss Watcharin Meerod	Team Member

National Consultants - Modeling Sector
Center of Excellence for Climate Change Knowledge Management (CCKM)

1. Dr. Anond Snidvongs	Principal Investigator (Director of CCKM)
2. Mr. Suppakorn Chinvanno	Consultant (SEA START Regional Center)
3. Dr. Charlie Navanugraha	Consultant (Mahasarakham University)
4. Dr. Narumon Wiangwang	Consultant (Department of Fisheries)
5. Mr. Watcharapong Noimunwai	Researcher, CCKM
6. Mr. Jaturong Rakdee	Researcher, CCKM
7. Mr. Eksura Nantanaworakul	Researcher, CCKM
8. Mr. Chalermwut Noisopa	Researcher, CCKM
9. Ms. Rommanee Anujit	Researcher, CCKM