POLICY RECOMMENDATIONS FOR WATER MANAGEMENT ENHANCEMENT THROUGH SCIENCE, TECHNOLOGY, AND INNOVATION (STI)

SPEARHEAD RESEARCH PROGRAM FOR SOCIAL STRATEGIC GOALS ON WATER MANAGEMENT

Assoc. Prof. Dr. Sucharit Koontanakulvong
Faculty of Engineering, Chulalongkorn University and
Program Chair of NRCT Spearhead Research
Program on Water Management

Policy Recommendations for Water Management Enhancement through Science, Technology, and Innovation (STI)

Spearhead Research Program

for Social Strategic Goals on Water Management

Propose to

National Higher Education Science Research and Innovation Policy Council

by

Assoc. Prof. Dr. Sucharit Koontanakulvong
Faculty of Engineering, Chulalongkorn University

Policy Recommendations for Water Management Enhancement through Science, Technology, and Innovation (STI) Spearhead Research Program for Social Strategic Goals on Water Management

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Preface

This book aims to propose policy recommendations to enhance water management through science, technology, and innovation (STI). It involves a thorough review of international practices in utilizing STI, summarizing outcomes from three consecutive phases of the Spearhead Research Program to show the main research outcomes of each technologies developed. To enhance water management at the operational level, innovation can be created by systematic integrated design from developed technologies, which can improve water management to match with predefined goals effectively and efficiently in each study area. Four study areas applied for water management enhance are 1) pumping and storage efficiency improvement and water reuse/recycle improvement for industry in the Eastern Economic Corridor, 2) improvement of dam release control to increase dam water storage in the Central Plain, 3) improvement of water release control in an irrigation project to reduce conveyance water losses, and 4) development of water user group in a rainfed area via Geographic Information Systems for Community Water Management Planning linked with the Provincial Integrated Water Resources Plan.

The book presents existing water management issues and challenges, innovative technological advancements, review of technology-driven improvements to water management on an international level, Thailand's Sustainable Development Goals (SDGs) and water security status, and main research outcomes from the National Research Council of Thailand (NRCT) Spearhead Research Program. It also includes samples of innovative designs derived from new technologies developed from the NRCT Spearhead Research Program in four study areas and policy recommendations for further implementations.

The author hopes that this book will serve as a guideline in formulating policies that apply STI as tools to enhance water management. The aim is to fulfill SDGs and enhance Thailand's water security through the application of technological advancements. By focusing on practices that ensure efficient water usage, the book seeks to address water security issues and elevate water productivity of water utilization, aligning with the objectives outlined in the National Strategic Plan's master plan. Thanks to all researchers, supporting staff and agencies during the Spearhead Research Program.

Assoc. Prof. Dr. Sucharit Koontanakulvong
Faculty of Engineering, Chulalongkorn University
Program Chair of NRCT Spearhead Research Program on Water Management
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Content

1 Introduction

1.1 Problems in water management

Water resources are essential for daily life and are crucial factors in the production of goods and services, contributing significantly to economic and social development. They also support energy production and the creation of sustainable environmental systems. Therefore, highly efficient water management, achieved by balancing water demand, quantity, and quality, is of utmost importance. Currently, the risks and damages from water-related disasters tend to be more severe than before. The world faces high risks, particularly from the impacts of climate change, which is a predictable event. Therefore, disasters related to climate change can be anticipated and planned for mitigation (Visessri S., 2022). The conditions of water scarcity, water demand, value creation from water usage, and water stress in the main river basin follow the patterns depicted in Figure 1 and Figure 2.

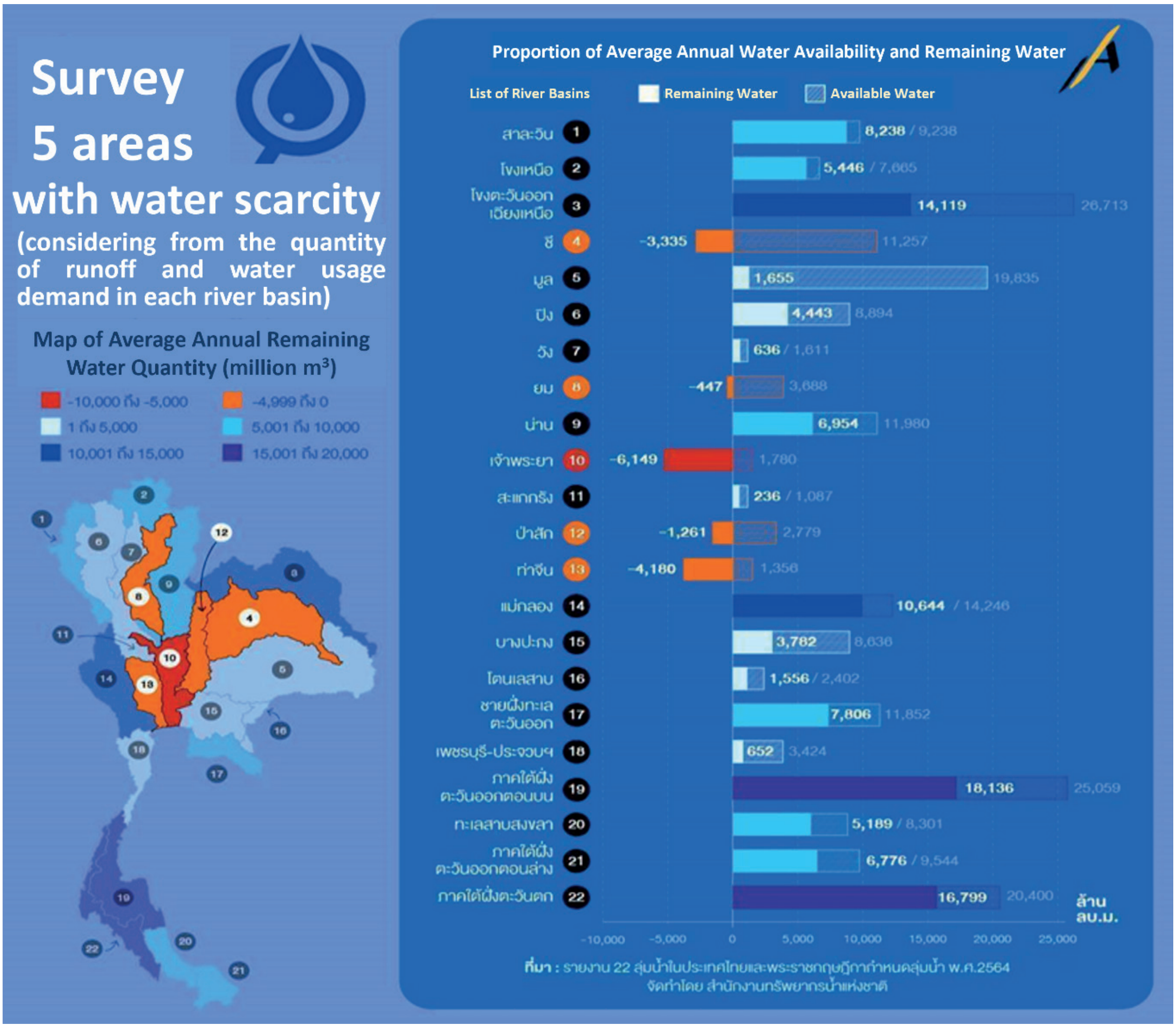


Figure 1 Water scarcity situations in each river basin.

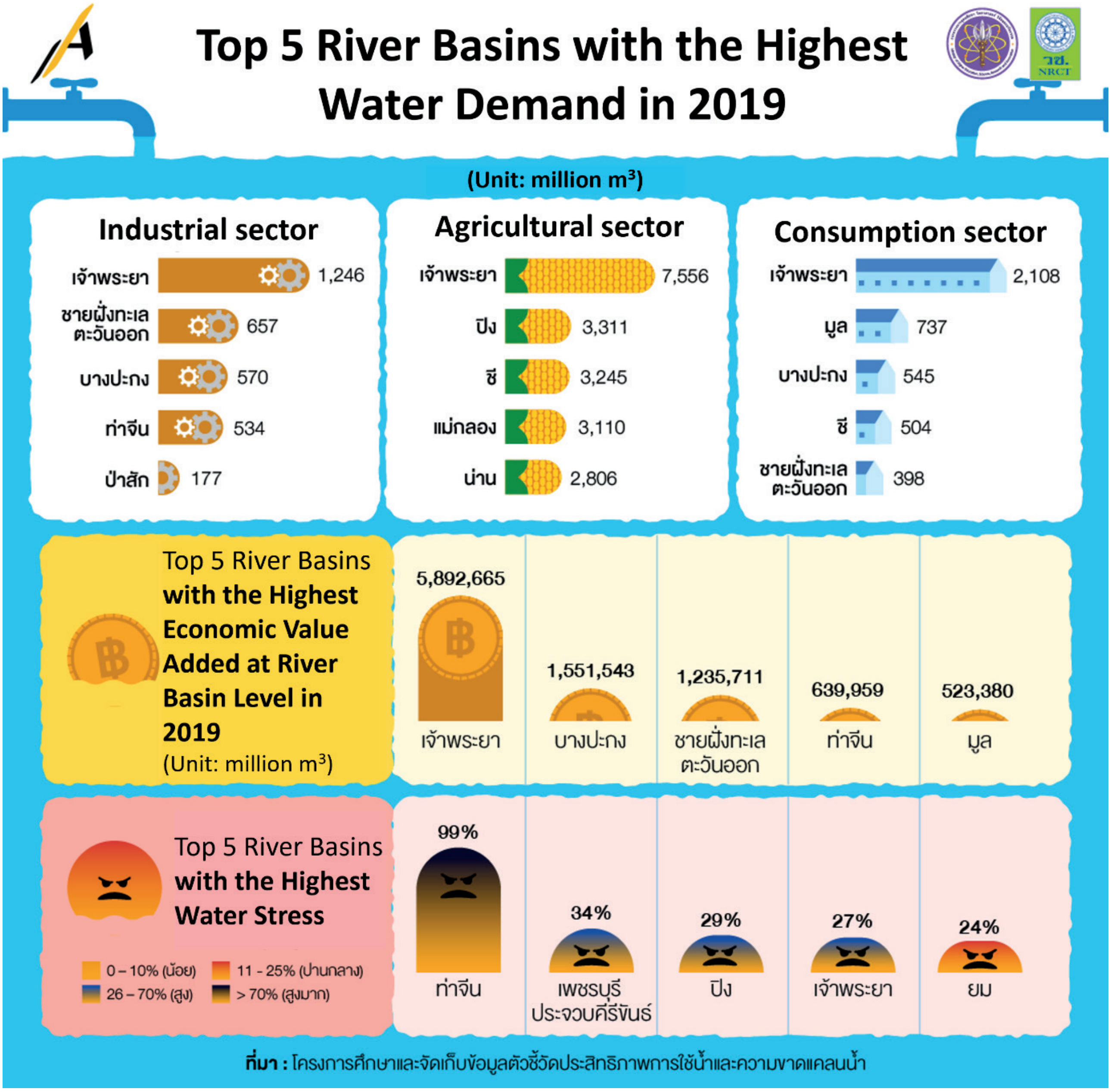


Figure 2 Water demand, value creation from water use, and water stress levels in the main river basin.

Climate change and disaster occurrence

Flooding and drought have widespread impacts on the global population. According to the statistics from the Center for Research on the Epidemiology of Disasters in 2018, the most frequent natural disaster is flooding, followed by drought. The cumulative statistics from 2000 to 2017 indicates that the number of people affected by flooding was 86.6 million, whereas drought impacted 58.7 million people (Visessri S., 2022).

In 2021, the annual rainfall in Thailand was below the average for two consecutive years. From 2004 to 2020, Thailand experienced fluctuating precipitation, with increased variability in quantity, raising the likelihood of drought. The water conditions in 2021 were a continuation from the relatively low rainfall in 2020 and 2021. Therefore, the Thai government has formulated strategies, plans, and state policies to mitigate the impacts of climate change and reduce the risks emerging from such disasters, as shown as follows:

1. Climate Change Master Plan (2015–2050) aligning with Sustainable Development Goals (SDGs).
2. Master Plan under the 20-Year National Strategy (2018–2037), aligning with Topic 19 of Comprehensive Water Management (2018–2037).
3. The 20-Year Water Resources Management Plan (2018–2037) consisting of six strategies. The substrategy specifically related to water disaster management is the Flood and Hydrological Disaster Management Master Plan, which is the third substrategy.
4. The 13th National Economic and Social Development Plan highlights key responses to climate change, specifically Goal 10: Promoting Circular Economy and Low-carbon Society and Goal 11: Reducing Risks from Natural Disasters and Climate Change.
5. The Ministry of Natural Resources and Environment, in collaboration with the Ministry of Energy, has established carbon neutrality targets to be achieved by 2065.

Furthermore, Thailand has participated in the third United Nations (UN) World Conference on Disaster Risk Reduction held in Sendai, Japan. During the conference, Thailand endorsed the Sendai Framework for Disaster Risk Reduction for the years 2015–2030. With this regard, building resilience through research and development is crucial to support water management, risk management, and proactive planning by using high-quality, reliable, and timely decision-making data. This philosophy has been successfully demonstrated by countries such as Malaysia and Japan.

Malaysia's water management

Malaysia faces a range of critical issues regarding water resources, such as water scarcity, high water demand from various sectors, high non-revenue water, water pollution, segregated management practices, flooding, environmental degradation, impacts from climate change, and dependence on government budgets. To resolve these challenges, Malaysia initiated the National Artificial Intelligence (AI) Roadmap in 2017, building upon the National Big Data Analytics Framework introduced in 2015. Despite having plans and frameworks for AI, Malaysia still needs to enhance readiness, focusing on various aspects, particularly investment and data. The IDC Asia Pacific Data Center Group revealed that Malaysia's readiness scores for investment and data are lower than the regional average. Key challenges for AI in Malaysia include a lack of leadership in investment, insufficient skills and resources, lack of continuous learning programs, and inadequacies in infrastructure (M Zaki M Amin, 2022).

Japan's water management

Fukuoka is a major city in the southwestern region of Japan with an average rainfall of 1,612 mm per year. However, when considering the population, given its substantial population of 1.52 million people, the per capita rainfall is 361 m^3/year/person, which is significantly lower compared with the national average of 5,030 m^3/year/person and the global average of 15,085 m^3/year/person. In 1978, the city of Fukuoka underwent a severe drought due to factors such as urban expansion, population growth, and transition to flush toilets, leading to an increase in water consumption.

Japan is the first country in Asia and the second country after Canada to develop a national strategy for AI. The National Parliament of Japan, which formulated the strategy, consists of personnel from the government, education, and industry sectors. They collaborated to establish guidelines, research objectives, and development goals for the AI industry. The national AI strategy was implemented in 2017 and has gained a reputation for its approach to driving the AI industry. The strategy views AI as a service and has been applied in three crucial sectors, namely, manufacturing, healthcare, and transportation and logistics. In addition to the national strategy, supportive policies in other aspects include research investment, building personnel capabilities, public data disclosure, and support for startups.

1.2 Progress in science, technology, and innovation (STI) in water management

The progress in technology and the emergence of big data have led to a significant increase in the volume of water-related data. This development allows for the application of big data analysis techniques to filter useful information for diverse water management purposes, such as disaster warning, mitigation of disaster impacts, and engineering design. It enhances the efficiency of water management and enables real-time decision making through obtaining, transmitting, storing, processing, and utilizing data promptly.

Currently, the world is in the Industry 4.0 era, where innovations and digital technologies are driving organizations to survive and gain a competitive advantage. The digital transformation of organizations is essentially occurring across various industries, including the water sector. Examples of water reforms in Malaysia include implementing plans to incorporate technology in water management. Japan is placing increased focus on the role of river basin groups. Meanwhile, South Korea adopts global technologies in water management.

Moreover, the concepts and operational approaches to water management have undergone transformation in several periods. Presently, an emphasis has been placed on institutional water management (Allan, 2003), encompassing water organizations, policies, strategies, and laws by focusing on the allocation and collaborative management of water resources among all stakeholders. The utilization of modern technologies is crucial in enhancing the efficiency and sustainable growth of water management. Therefore, a study of institutional water management, encompassing policies, laws, and organizations, with concrete practices nationally and internationally, is crucial to serve as a guideline for effective water management practices in the current era.

The UN-CSTD meeting in March 2023 identified the current global situation entering an era that necessitates adaptation. There exists a shift from growth-oriented approaches to one that focuses on reducing greenhouse gas emissions to mitigate the impacts of climate change over an appropriate timeframe within the framework of sustainable development. Incorporating green technologies, which include the use of modern digital technologies, is considered a solution to address development challenges and simultaneously reduce greenhouse gas emissions. This approach will contribute to the emergence of a new economy in the near future.

The report on "Solution through STI," prepared by the UN-CSTD working group, aims to ensure safe water and sanitation for all. It highlights the role and potential of STI as a catalyst for change to achieve SDGs, particularly Goal 6, which is linked to the revolution of green technology.

Examples of building water resilience and producing green outcomes demonstrate the benefits of digital technology for improvement. The green technology revolution is a phenomenon occurring in developed countries, and developing nations should prepare for such changes. This phenomenon involves establishing suitable innovation, fostering research and innovation capabilities, and having a sufficient workforce to adapt to the transition, domestically and internationally. Several countries provide valuable learning experiences of this journey (Koontanakulvong S., 2023).

It can be seen that water-related challenges are complicated and are expected to become more intensified due to climate change and increasing water demand. Many countries had introduced new technologies to assist the analysis, preparing adaptive strategies to be put in the action plan and prepared for supportive driving measures, which will be discussed in the next section.

2

Modern Technology and Water Management for Achieving SDGs

When examining how the development of new technologies has enhanced water management and helped achieve SDGs, the key points can be summarized as follows.

2.1 Weather and typhoon forecasting system

2.1.1 Seasonal weather forecasting

Forecasting seasonal weather conditions relies on the understanding of the air–sea interaction. This process involves the heat content from tropical oceans, which affect large-scale atmospheric dynamics through distant forces. Such forces subsequently affect tropical atmospheric circulation and teleconnections in mid-latitude areas. Key phenomena such as the

El Niño–Southern Oscillation (ENSO) in the Pacific Ocean and the Indian Ocean Dipole (IOD) in the Indian Ocean are crucial in this context. These phenomena are characterized by abnormal sea surface temperatures, which serve as major drivers of variability in the atmospheric system, with a lead time of 3–6 months. As a result, these anomalies are frequently utilized in seasonal weather forecasting (Doi, JAMSTEC/APL, 2021).

2.1.2 System development for estimating typhoon damage

Prof. Dr. Yasuto Tachikawa, from Kyoto University in Japan, who serves as the Chair of the Cross Ministerial Strategic Innovation Promotion Program, has presented a research framework under Theme 6 Development of Super Typhoon Damage Prediction System. This initiative involves collaborative research across various institutions in Japan, with a focus on reducing damage caused by disasters while developing a new hazard prediction system to support real-time short-term and long-term early warning. It also provides new hazard forecast information to support timely warnings and evacuation planning. In addition, it involves advancing technologies for maximizing the utilization of hydraulic facilities for flood control (Tachikawa Y., 2021).

2.1.3 Tracking and predicting drought conditions

Taiwan experienced severe drought from May 2020 to April 2021, which was considered the worst the nation has experienced in the past century. This drought led to many reservoirs having water levels below the standard. Drought is a natural disaster caused by a decrease in rainfall from the average, typically resulting in soil moisture deficits. Therefore, the agricultural sector is the first to be affected. Given their slow onset, droughts can be predicted. In this regard, the Standardized Precipitation Index (SPI) is employed to measure meteorological drought as it can efficiently summarize abnormal rainfall patterns over specific time intervals. According to a survey conducted between 2010 and 2014, 35 out of 43 countries used the SPI to monitor drought conditions (Ke-Sheng Cheng, 2021).

In addition, the WMO (World Meteorology Organization) referred to consultations and operational meetings involving 54 experts from 22 countries, recommending that many countries utilize the SPI for meteorological drought monitoring due to its simplicity and the widespread availability of precipitation data as the essential information (Visessri S., 2022).

2.2 Dam management

2.2.1 Flood and sediment management of dams under climate change

Challenges on flood and sediment management of dams under changing climate in Japan are categorized into three main points: 1) urgent action plan to safe and effective dam operation to cope with extreme flood events, 2) increase flood mitigation function and sediment management for reservoir sustainability, and 3) rainfall-driven optimization of flood and sediment management (Sumi T., 2021).

2.2.2 Real-time dam management for drought mitigation

Dr. Daisuke Nohara, a lecturer and researcher from Technical Research Institute in Japan, presented on the topic "Real-time Reservoir Operation for Drought Management Considering Operational Ensemble Predictions of Precipitation in Japan." The presentation emphasized the importance of managing dams and reservoirs in real-time and incorporating mid-term and long-term operational ensemble predictions of precipitation in dam and reservoir management.

Dr. Nohara also discussed the utilization of rainfall forecast data for predicting inflow into reservoirs by developing the Hydrological River Basin Environment Assessment Model, which is a distributed model. He also developed an optimization model to identify the optimal daily water release schedule, with a specific emphasis on minimizing damage caused by drought through the utilization of stochastic dynamic programming (SDP) and sampling SDP techniques. A case study of the Sameura reservoir on the Yohino River in Japan was presented as an example, showcasing the effectiveness of the approach in water management (Nohara D., 2021).

2.3 Crop cultivation management policy

Taiwan is facing drought conditions that adversely affect farmers and agricultural production due to climate change and COP26 measures. To mitigate these effects, Taiwan necessarily requires supportive policies, undertake policy adaptations, and strategize agricultural plans (Lin, Yu-Pin, 2021).

In a study, the EcoCrop model was employed to assess the risk for each type of crop, and the CropWat model was utilized to calculate water requirements. The four types of crop included in the study were rice, soybeans, potatoes, and sweet potatoes. Data from the years 2004, 2015, and 2020 were utilized to evaluate the crop risks associated with climate change. In addition, experiments were conducted by using a sensor/Internet of Things (IoT) system in irrigation projects in collaboration with private companies. The study also proposed guidelines for planning irrigation systems and cultivating crops suitable for the country's topography and soil types in Taiwan, contributing to the development of future agricultural policies and plans.

2.4 Community water management

Taiwan's water management system emphasizes the importance of water user groups (in the form of associations), legal frameworks connecting various agencies, case studies, and operational results. The management methods, success factors, challenges, and future trends of water user groups are addressed to cope with severe impacts and climate change.

The water management structure is divided into two groups, namely, water users and water-related disasters. The water user group, particularly, in the agricultural sector, falls under the Council of Agriculture, whereas other water user activities are overseen by the Department of Economic Affairs. Water-related disasters are managed by the Environmental Protection Administration, which operates under the Cabinet. The overall situation regarding the development of water user groups in Taiwan is continuously evolving, encompassing structural and legal aspects.

The Irrigation Association, which utilizes 12 billion m^3 of water (65% of the allocated water quantity), has 1.5 million members. Taiwan's water laws involve 17 agencies related to water management. The water user groups in the irrigation areas will cover approximately 150 ha per group, with representatives selected by farmers in that specific area.

In the mission of the water user association under various notable laws, the Farmland Water Law of 2020 plays a crucial role. This legislation has led to 1) efforts to improve water usage efficiency through the maintenance of various infrastructure; 2) no specific area restrictions within the irrigation area, with comprehensive care provided to all farmers; and 3) monitoring of water quality and tracking of pollutants discharged from this agricultural area.

Taiwan's irrigation system undergoes significant adjustments in two main patterns. First is the rotational allocation, where water is distributed from left to right, allowing water to flow to the end before being directed back to the source, to reduce the volume of water needed for cultivation. Another pattern is the rotation of rice cultivation during years with insufficient rainfall for cultivation in a normal year by alternating with the cultivation of other crops to minimize water usage (Ming Daw SU, 2021).

Moreover, success factors in water management in Taiwan depend on human-related factors, such as the active participation of farmers, research and technology in collaboration with educational institutions, and the integration of technology. Challenges faced by Taiwan are similar to many countries in the region, such as financial issues, water rights disputes among different sectors leading to conflicts in water usage, and competition in water management. The increasing number of aging farmers is also a common concern shared by Taiwan with several countries, including Thailand.

Taiwan has implemented various measures, such as promoting high-value crops that demand less water as an alternative to rice cultivation, saving water in irrigation systems through canal improvements, adopting drip irrigation systems, utilizing IoT to enhance water management, and developing water delivery plan during dry periods with regional fallow pattern. Such measures allow small-scale cultivation, with water supplied during the daytime for cultivation and returned to storage areas during the night. In addition, the use of small-scale water reservoirs distributed throughout the area helps collect excess water and bring to use during periods of insufficient rainfall. Taiwan has been increasingly cautious in adopting technology. To gather data, it relies heavily on many sensors to cover extensive areas, ensuring precise information for cost-effective investments.

International efforts have been made to develop technology for water management, enhance resilience, reduce risks, formulate supportive policies and plans, and strategize for community adaptation. Such efforts are accomplished by utilizing data and forecasting future conditions.

3

Evaluation Concepts and Driving Strategies

3.1 SDGs

SDGs are initiated by the UN for countries worldwide to use as a national development framework. They consist of 17 key goals.

The goals related to addressing poverty and reducing inequality are in SDG 1: “End poverty in all its forms everywhere,” and SDG 10: “Reduce inequality within and among countries.” The goals related to water resources are in SDG 6: “Ensure availability and sustainable management of water and sanitation for all.”

SDG 1: End poverty in all its forms everywhere

SDG 1 aims to eradicate all forms of poverty by 2030. This goal is related to identifying target groups living in risky situations with limited access to resources and basic services. It also includes providing assistance to communities affected by conflicts and disasters related to climate conditions.

SDG 10: Reduce inequality within and among countries

Income inequality is a global problem that requires interventions. This problem is related to improving regulatory frameworks, financial market oversight, and financial institution scrutiny. It involves promoting development assistance and directing foreign investments to regions that need them the most. Facilitating safe migration and the movement of people is also crucial in addressing the problems of territorial division.

SDG 6: Clean water and sanitation

Ensuring access to water and sanitation for all and sustainable management is the overarching goal that encompasses issues related to safe drinking water access (6.1), access to adequate and equitable sanitation and hygiene (6.2), water pollution and wastewater treatment (6.3), water use efficiency, and addressing water scarcity (6.4), integrated water resources management (IRWM) within and between countries (6.5), and protecting and restoring water-related ecosystems (6.6). It also covers international collaboration and support for capacity-building for activities and plans related to water and sanitation, which also include reservoirs, desalination, water use efficiency, and wastewater treatment technologies (6.a). In addition, it includes supporting and strengthening the engagement of local communities in water and sanitation development (6.b).

For IWRM within and between countries (6.5), it involves implementing comprehensive water management at all levels, which also includes cross-border cooperation, as appropriate, by 2030. This goal consists of the following:

1. Level of implementation of IWRM (0–100).
2. Proportion of transboundary river basin areas with operational management for water cooperation.

The SDG index is used as a measure for the level of sustainable development. In the past, the global average SDG index (encompassing 193 UN member countries) showed an increasing trend. It indicated that countries were approaching the set development goals. However, in 2020, the global average SDG index decreased for the first time since 2015. This decline is attributed to increased poverty rates and unemployment following the COVID-19 pandemic.

3.2 Water security concepts and driving strategies

3.2.1 Water security assessment of Asian Development Bank (ADB)

The concept of developing the Water Security Index was initiated by the ADB to assess water sustainability in terms of quantity. It was reported in the Asian Water Development Outlook (AWDO) 2007 during the First Asia Pacific Water Summit held in Japan on December 3–4, 2007 (ADB, 2007). Subsequently, in 2013, the ADB published the AWDO 2013 report titled "Measuring Water Security in Asia and the Pacific," presenting the calculation of the Water Security Index and providing guidelines on governance, investment, capacity building, monitoring, and reporting (ADB, 2013). In 2016, a review of the framework and assessment methods for water security was published, evaluating 48 countries in Asia. It presented a water security assessment framework covering multiple dimensions to reflect five dimensions of water security, namely, household water security, economic water security, urban water security, environmental water security, and resilience to water-related disasters (Visessri S., 2022).

3.2.2 Driving strategies

"The Water Dialogs for Results, Bonn 2021: Accelerating cross-sectoral SDG 6 implementation" is a policy-oriented dialog aimed at supporting member countries in accelerating actions to achieve sustainable water-related goals by 2030. Spearheaded by the Federal Republic of Germany, this conference produced outcome documents conveying a political message that is not legally binding among participating countries. The outcome documents will be among the recommendations presented at the UN Conference on the Midterm Comprehensive Review of the Implementation of the International Decade for Action, "Water for Sustainable Development" (2018–2028), scheduled to take place in 2023.

The political message "From Dialog to Results–Key messages for accelerating cross-sectoral SDG 6 implementation" is a document expressing the political commitment of the endorsing countries at the end of the political message. The objective is to emphasize the determination to accelerate actions to achieve sustainable water-related development goals by 2030 under the Sustainable Development Agenda. This program covers cooperation in the operation of the government, service providers, civil society organizations, and the UN system. The content encompasses guidelines for action in five areas covered: 1) new approach in financial management, 2) data-based decision making, 3) capability building, 4) fostering innovation by integrating traditional knowledge with modern technologies, and 5) collaborating to create good governance at all levels.

Thailand has presented challenges and best practices in operations, particularly during the COVID-19 pandemic in 2019. The country is prepared to drive operations toward achieving SDGs in the water sector by 2030 by applying the Principles of Sufficiency Economy, recognizing the importance of development amid the impacts of climate change. The goal is to ensure universal access to water, ensuring no one is left out. The approach involves incorporating principles of sustainability and innovation, applying knowledge and technology in operations, and promoting collaboration at all levels.

The international water assessment criteria encompass SDGs, water security, and driving strategies, covering financial arrangement, data-driven decision making, capacity building, innovation development, and promoting good governance at all levels.

4

Research Achievements in the Development of Water Management Technologies

In the Spearhead Research Program on Water Management (Phase 1–3), significant technologies have been developed to enhance water management. The eight main issues are summarized as follows.

4.1 Technology development for weather forecasting

In the field of weather forecasting technology, a two-week rainfall forecasting system has been developed by using the WRF–ROMS coupled model. This approach involves dynamical downscaling with rainfall forecast data from the Climate Forecast System Version 2 (CFSv2) provided by the National Centers for Environmental Prediction. Moreover, the research team has implemented this forecasting system as an operational tool to support water management (Sarinnapakorn K., 2022).

1) An analysis of the forecast data, which supports water management covering the period from September 2018 to August 2021, reveals that the overall monthly rainfall forecasts at a national level for 1 to 6 months ahead showed a relatively good correlation with the observed data, with correlation coefficients ranging from approximately 0.6 to 0.8. These forecasts were issued by the Thai Meteorological Department and the Hydro Informatics Institute (Public Organization) and were cross-verified using OneMap. The Thai Meteorological Department exhibited slightly greater forecast accuracy (PBIAS = 7%–15%) compared with the Hydro Informatics Institute (PBIAS = 20%–34%). Nonetheless, the integration of rainfall forecasts between the Thai Meteorological Department and the Hydro Informatics Institute through OneMap improved the forecast accuracy, narrowing the margin of error. The rainfall forecasts from the Thai Meteorological Department utilized the Climate Predictability Tool software developed by the International Research Institute for Climate and Society at Columbia University, USA. This statistical method typically results in rainfall distribution patterns and quantities close to the 30-year normal values, with a deviation of no more than 10%. Conversely, the Hydro Informatics Institute forecasts rainfall based on the actual rainfall amounts from the year with the highest correlation with long-distance teleconnection indices (i.e., ONI, IOD, and PDO) of the preceding 12 months.

2) From January 2020 to November 2021, the rainfall forecast was evaluated over a six-month period using eight models, namely, CCSM4, CFSv2, CMC1, CMC2, GFDL, GFDL_FLOR, NASA, and NMME. These models are utilized by the Thai Meteorological Department in generating its forecasts. The results indicate that the rainfall forecasts during the upcoming rainy season from May to October, initialized in April, exhibit values that are close and have a correlation with the highest observed values. The forecast accuracy is at its minimum deviation. For initial times from June to September, the models demonstrate a good ability for predicting rainfall quantities for a six-month period. However, for other initial times, a high deviation is observed, and the proportion of accurate forecasts is at a low level. The evaluation of the six-month forecast results, averaged across all stations, reveals that the forecast outcomes are relatively correlated with the measured data, but with high deviations. Furthermore, the CMC1 and NMME models provide forecasts exhibiting higher correlation with the measured data and lower deviations compared with other models. However, the short-term (2 years) evaluation might not fully cover the models’ capabilities for long-term applications.

4.2 Technology development for estimating water demands

Satellite imagery technology, which can continuously track changes in resource data with high reliability, has been applied to monitor changes in cultivation areas within the Greater Chao Phraya Basin. It is used to estimate historical and current irrigation water demands and predict future irrigation water requirements. Rainfall forecast data are incorporated to estimate the anticipated irrigation water demand by considering forecasted rainfall amounts. The actual irrigation water demand information is fundamental in determining dam release schedules to align with the variable irrigation water demand during different growing seasons. Findings of the study indicate that the estimated average irrigation water requirement in the Chao Phraya Dam Irrigation Project area is estimated to be around 10,865 million m^3 per year.

The application of satellite imagery technology for assessing water demand quantities aims to achieve results that closely resemble the actual conditions in watershed areas. It involves adjusting potential inaccuracies that may arise from satellite imagery results. In addition, the accuracy of the results is verified through ground truth data. The obtained outcomes can specify cultivated areas and the growth stages of crops, enabling the evaluation of plant water use efficiency and the spatial water demand of crops comprehensively within watershed boundaries (Chompuchan C., 2020).

4.3 Flow modeling development, data tracking, and decision making for water releases and water use

The operational management of dams and reservoirs relies on modern technology, and information database management plays a crucial role in driving stability and sustainability of water resources in short and long terms (Rittima A., 2022).

In addition to using satellite data to assess water demand (as outlined in Section 4.2), widely used mathematical models have also been employed in simulating meteorological conditions occurring in watersheds. In a research, the DWCM-AgWU model was applied in conjunction with the MIKE Hydro Basin model to simulate rainfall and reservoir conditions in the Lower Chao Phraya River Basin. This simulation was conducted to assess the potential of the side flow volume at the tail of the dam. It intends to use the information obtained to reduce the water discharge volume from the dam if the potential side flow volume at the dam's tail is sufficient (Theppasit C. and Vongphet J., 2022).

4.4 Development of AI for dam water release management

AI technology is applied to develop predictive models for reservoir inflow and create dam management models to determine discharge schedules for the four main dams in the Chao Phraya River Basin–Bhumibol Dam, Sirikit Dam, Kwai Noi Bumrung Dan Dam, and Pasak Chonlasit Dam. The objective is to increase the long-term water storage capacity of the reservoir system by 15% based on the current data. The process aims to mitigate the risk in water resources management due to water scarcity issues affecting agricultural production in the area. It involves developing predictive models for reservoir inflow volume by using machine learning (ML) techniques. Dam management models (or reservoir operation models) are developed by utilizing AI technology in two formats: 1) reinforcement learning technique (RL) and 2) constraint programming (CP) (Rittima A., 2022).

4.5 Tool development for groundwater management

The development of tools and technologies for groundwater management comprises two main components. First, groundwater management systems are developed to assess the groundwater potential for planning, enhancing the efficiency of operational management systems in conjunction with surface water. The goal is to reduce damage to agricultural areas experiencing water shortages during drought. Second, utilization of groundwater is appropriated in conjunction with surface water patterns, aligning with the groundwater levels and reservoir water while considering the hydrogeological conditions of a groundwater aquifer (Kitpaisalkul T., 2022).

4.6 Development of sensor technology and automated system for water gate control

The development of an automatic water release control system for the Thorthongdaeng Operation and Maintenance Project and the Kamnan Aar Pump Drainpipe has been implemented. This system allows for remote control through a website, integrated with water level data tracking in the canal supplying water to the Thorthongdaeng Operation and Maintenance Project. The development of an operational system for managing water and agricultural areas has been implemented, along with tracking current soil moisture data. This system enables operational staff to recommend appropriate water release amounts to reduce excess water supply to agricultural areas by an average of 15%, thereby meeting the target. However, in agricultural areas with water scarcity issues in the middle and end of the canal, a water status tracking system and an automatic gate control system in the subarea remain lacking. Consequently, this absence led to the development of a water management and agricultural area management system, focusing on hardware tools. This system was established by installing a control system covering the water supply section of the project and connecting it to the operational system (software) for full management. It also includes an assessment of irrigation water usage, along with groundwater usage, to propose weekly water allocation that aligns with actual water needs (Pinthong P., 2022).

The comprehensive technological development aims to improve the efficiency of an agricultural water management operational system in irrigation through integration and synergy, allowing for systematic water management. This development includes the consideration of surface water (irrigation water) and groundwater at the agricultural plot level, leading to the development of a tracking and evaluation system. The Thorthongdaeng Operation and Maintenance Project was conducted by installing water management tools in the canal network, subcanals, and natural waterways and linking the tracking system, processing, and automatic control tools to the original system. The project serves as a pilot area for experimenting with the fully integrated water management system at the irrigation project and agricultural plot levels.

4.7 Development of geographic information systems (GIS) for community participatory water management

The water management information system (MIS) was developed to facilitate the collaboration among various stakeholders in water management, including the leader of irrigation management group, water user groups, farmers, irrigation officials, local government officials, and relevant agencies in the area. The collaborative model emphasizes driving activities by applying a seven-step research process tailored to the local context, which includes: 1) identifying the leader of water users at the local level, 2) developing water management issues, 3) designing operations, 4) promoting mutual understanding (both in terms of goals and work processes), 5) managing data, 6) utilizing data, and 7) extracting/summarizing lessons learned (Maneesrikum C., 2022).

The research process adopts a participatory action research method for local development, with the goal of building relationships and enhancing coaching capabilities among officials and personnel engaged in the Thorthongdaeng Operation and Maintenance Project and partner organizations. The data collection process is collaborative, encompassing activities such as the creation of waterway maps and production timelines. In addition, tools such as Google Forms and a GIS management system are utilized for surface and groundwater water management. A powerful and insightful data analysis was conducted to formulate an action plan for creating income by enhancing the efficiency of water management. Transitioning the guidance into practical implementation involves networking meetings among leaders of irrigation management groups, relevant organizations, and summarizing the lessons learned and the results. It also includes changes and insights gained from operational practices in the area for presenting research outcomes to the public. The activities cover Subareas 1–3 of the Thorthongdaeng Operation and Maintenance Project in Kamphaeng Phet Province, encompassing upstream, midstream, and downstream of Kamphaeng Phet and Sukhothai Provinces, covering 20 subdistricts. Only 10 subdistricts were selected as representatives.

4.8 3R+ system for water saving in industries

The utilization of the 3R system, along with IoT technology, in the industrial sector has shown that various industrial estates and factories can decrease water usage and attain water recycling rates of up to 15%. The cost of recycled water is also lower than tap water in the Eastern Economic Corridor (EEC) area. Some water-intensive factories, particularly those in the food and beverage sector, have experienced substantial water savings exceeding 15% after investing in recycled water systems. Furthermore, recycled water contributes to cost savings in water utility expenses (Kwanyuen B., 2022).

For the 3R measures in the service sector, water savings at the source for large business buildings, hotels, accommodation services, and department stores, can be significantly enhanced by installing water-saving fixture sets. This improvement can contribute to an additional water usage reduction efficiency of approximately 5%–15%, and even more if innovative water-saving fixtures are further developed in the EEC area.

For information on the potential water savings in water-intensive industries, this research analyzed data from the Federation of Thai Industries to track the operations of prototype industries by using the 3Rs + IoT measures to enhance 15%–36% of the overall water usage efficiency (Ratanatamskul C., 2022).

The eight technologies developed as part of the water management research program include 1) weather forecasting, 2) water demand estimation, 3) river runoff simulation, 4) groundwater potential assessment, 5) dam management with AI, 6) sensor and automation systems in irrigation projects, 7) community-based GIS, and 8) 3R+ technique for water saving in the industrial sector.

5 Case Studies of Innovation Design

In this section, examples illustrate the application of the developed technologies (under Section 4) in designing innovations to address water management challenges in specific areas. The goal is to improve water management and enhance efficiency in water conveyance and usage. Four targeted areas were selected, namely, the EEC, dam management in the central region, irrigation project in the Thorthongdaeng Operation and Maintenance Project, and community water management outside irrigation areas. These examples are outlined as follows.

5.1 Water management case in the EEC

In the EEC area, an information system was developed for water management, particularly to facilitate water pumping into the area. This system utilizes weather forecasting technology and simulates water runoff conditions, assisting decision making in pumping water into the main reservoir prior to the expected dry season. It helps save electricity costs for water pumping, reduce water usage, and reuse water in industrial estates and factories. The application of the developed 3R + IoT technology has contributed to a water usage reduction of more than 20%.

5.1.1 Water MIS prototype

The water allocation and criteria for water allocation have been developed to promote efficient and cost-effective water usage. In this context, the research plan created an MIS prototype. This system uses the application programming interface to automatically link data from databases, covering the data of weather conditions, weather forecasting, runoff situation modeling, and reservoir water situations. The implementation of the MIS system for water allocation and early pumping management, for pumping and variable speed systems, has led to increased convenience in managing water resources and variable speed systems. The system also contributes to electricity savings.

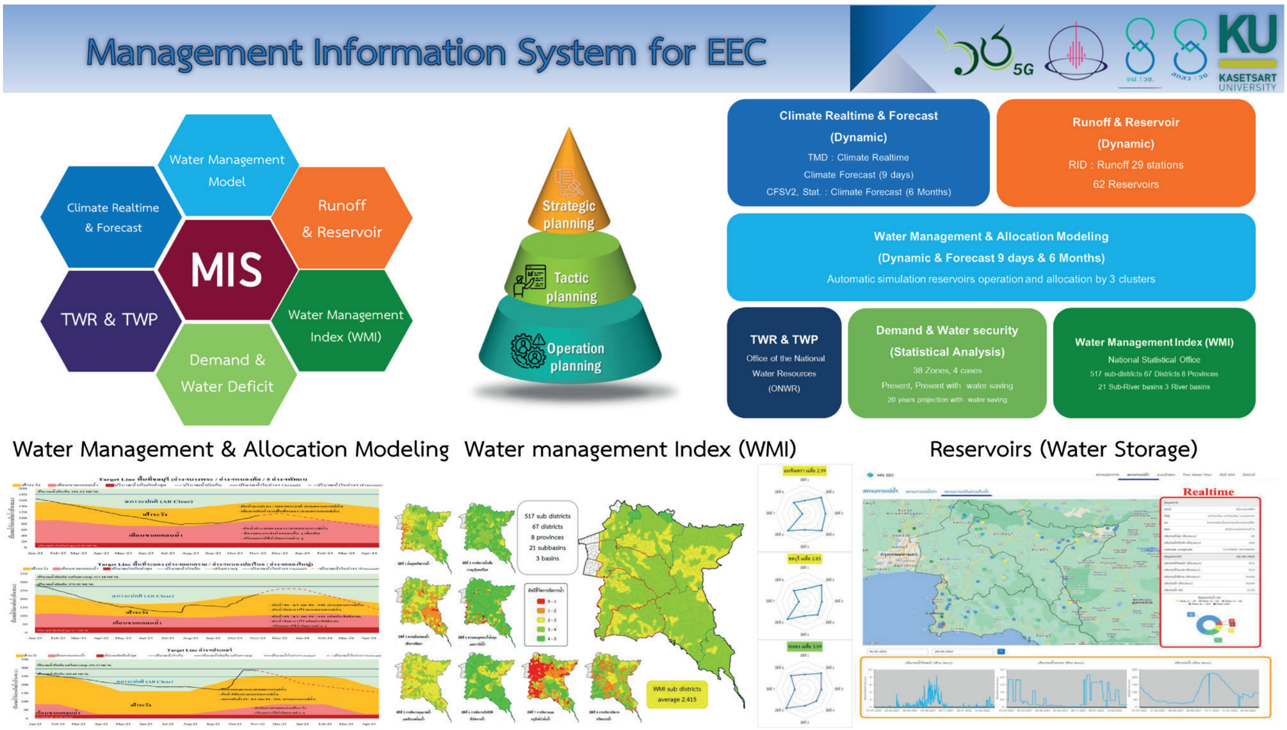


Figure 3 Information system for water management in the EEC area (including water pumping into irrigation; Thepprasit C., Vongphet J., 2022).

5.1.2 Application of 3R technology and IoT

In terms of engineering, a smart water management system (3R + IoT) can be applied to service and industrial sector buildings in the EEC. This intelligent system is designed to treat wastewater from these service buildings using a combination of biological processes, ozone, and sand filtration. The system incorporates sensors and IoT devices to monitor and report the treated water quality in real time, ensuring that the reclaimed water meets the required standards for reuse. The treated water can be reused without a direct human contact (nonportable reuse).

In the case of reducing water usage in industrial estates, the process involves reclaiming water by reusing the discharged water from the wastewater system. This water is treated to compensate for the raw water used in producing tap water. The treated water is then supplied as Grade 2 tap water to industrial plants. The treated water is also used for watering plants in the area. In the case study of the industrial estate, water savings of up to 20% can be achieved, and the labors needed for tracking the results can be saved.

In the case of water reclamation in the service sector, the process is implemented by taking wastewater from the building to be treated to meet the standard. Then, the wastewater is utilized for toilet flushing, watering plants, and cleaning specific areas.

5.2 Dam Management in the Central Plain

Managing dams to increase water supply for the next dry season can be achieved by using a set of technologies. This process includes rainfall forecasting, estimating water demand from satellite data, simulating conditions of water runoff and groundwater, estimating inflow into the dam using AI, and applying decision-making techniques for dam water release. Integrating these technologies into a single system can significantly increase the water supply of the main dams in the central region before entering the dry season, resulting in an average of 15% increase in water supply. The technologies used in this process include the following.

5.2.1 Rainfall forecasting technology

The use of modern rainfall prediction technology enhances the effectiveness of short- and long-term rainfall forecasts, ensuring accuracy and precision. It is beneficial for planning and operational activities related to reservoir management, such as using forecasted rainfall data to analyze and assess water situations for appropriate water allocation from the dam in terms of quantity and timing. This technology helps mitigate damages from floods and droughts. The study developed a two-week (short-term) rainfall prediction model for operational dam activities and a six-month (long-term) rainfall prediction model for water management planning. These models are presented through three techniques: 1) CFSV2-BC, which uses statistical methods to adjust forecast results; 2) ML-SimlDXV2, which utilizes ML to create models from various indices; and 3) ensemble DL, which combines different and independent learning models.

5.2.2 Satellite imagery technology for estimating irrigation water requirements

Satellite imagery technology, which can consistently track changes in resources with high reliability, has been applied to monitor changes in cultivation areas within the Greater Chao Phraya Basin. It has been utilized for estimating irrigation water demand from the past to the present. It also forecasts the upcoming irrigation water needs by considering rainfall forecast data to estimate the quantity of rainfall needed to compensate for irrigation water allocated from the dam.

5.2.3 Mathematical models for estimating runoff volumes

A mathematical model is used to simulate hydrological conditions within a watershed. In this research, the DWCM-AgWU model, coupled with the MIKE Hydro Basin model, was applied to simulate rainfall and runoff conditions in the Lower Chao Phraya River Basin. The aim is to evaluate the potential side flow volumes of runoff at the downstream of the dam and provide information for adjusting the water discharge volume from the dam if the potential side flow water volume is sufficient.

The study showed that the estimated side flow volumes at the C.2 runoff water gauge station between December and April averaged 1,430 million m^3. In addition, the study assessed the potential use of water from other sources in the irrigation project area, with an annual average of 2,020 million m^3 (655 million m^3 during the rainy season and 1,365 million m^3 during the dry season). This estimation included approximately 804 million m^3 of usable groundwater annually and 1,216 million m^3 from small water sources.

5.2.4 Technology for the development of groundwater database systems and groundwater management, coupling with surface water

The development of tools and technology to assess the potential of groundwater sources in the area is aimed at using them in planning to enhance the efficiency of groundwater management, combining it with surface water, and reducing damage from agricultural water scarcity issues. The suitable patterns for utilizing groundwater along with surface water are also evaluated based on groundwater and dam water level conditions. According to the study results on groundwater in the northern part of the Lower Central Plain, the average groundwater consumption during 2010–2021 was 404 million m^3 per year; the average potential groundwater availability was 804 million m^3 per year; and the average recharge of groundwater from rainfall, runoff, and adjacent aquifers was 557 million m^3 per year.

5.2.5 Management of dam water release

AI technology is applied to develop predictive models for reservoir inflow and create dam management models to determine discharge schedules for the four main dams in the Chao Phraya River Basin–Bhumibol Dam, Sirikit Dam, Kwai Noi Bumrung Dan Dam, and Pasak Chonlasit Dam. The process aims to mitigate the risk in water resources management due to water scarcity issues affecting agricultural production in the area. It involves developing predictive models for reservoir inflow volume by using ML techniques.

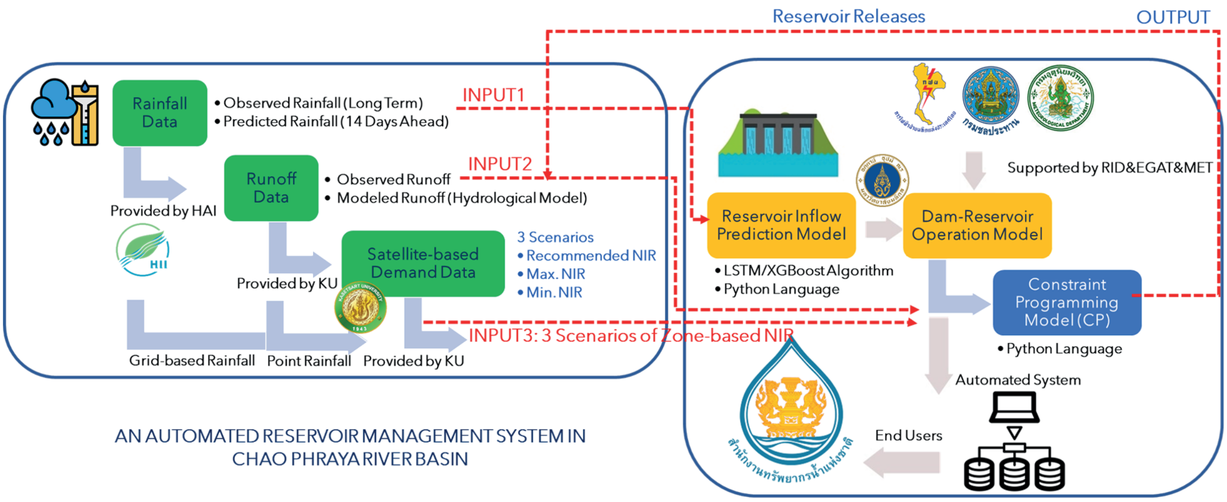


Figure 4 Innovation system for dam management (Rittima A., 2022).

5.3 Water management case in the Thorthongdaeng irrigation area

The water management strategies in irrigation areas for minimizing water losses encompass various techniques. These methods include estimating water requirements, evaluating groundwater potential, implementing automated systems for managing water releases, and establishing water user groups. The data on soil moisture from paddy fields and water levels in the main canal support the determination of automated gate control. This innovation results in a significant reduction of more than 15% in water losses from canal releases. The technology set comprises the following.

5.3.1 Predictive data utilization for demand estimation

To forecast water demand, the research devised a decision support system (DSS) that incorporates collecting water balance data, leveraging integrated land use, utilizing a water application, gathering groundwater data, and establishing a Data Studio system in conjunction with a smart water management system.

5.3.2 Monitoring water situations and modeling surface water and groundwater flow conditions

The water delivery in accordance with demand, water demand management, and precision agriculture guidelines are implemented through real-time monitoring using IoT technology. This implementation involves automated control of water discharge gates, accessing current canal water level data, and checking real-time soil moisture data in agricultural plots via mobile/tablet/computer. The testing results of IoT technology systems have demonstrated a significant reduction in irrigation water usage in agricultural plots, achieving a minimum reduction of 15%.

5.3.3 Automatic gate control for water release management

An electronic operating system that can control and command automatic water release from the website and control panel was developed. All data collected from the monitoring tools were integrated into the network, connected to the situational data processing system and the water management operations system. The implementation of water management operations would enhance the operational efficiency for the water delivery officials involved in the Thorthongdaeng Operation and Maintenance Project. The implementation of these tools is anticipated to streamline and simplify processes, enabling effective water delivery planning and optimal allocation based on current conditions.

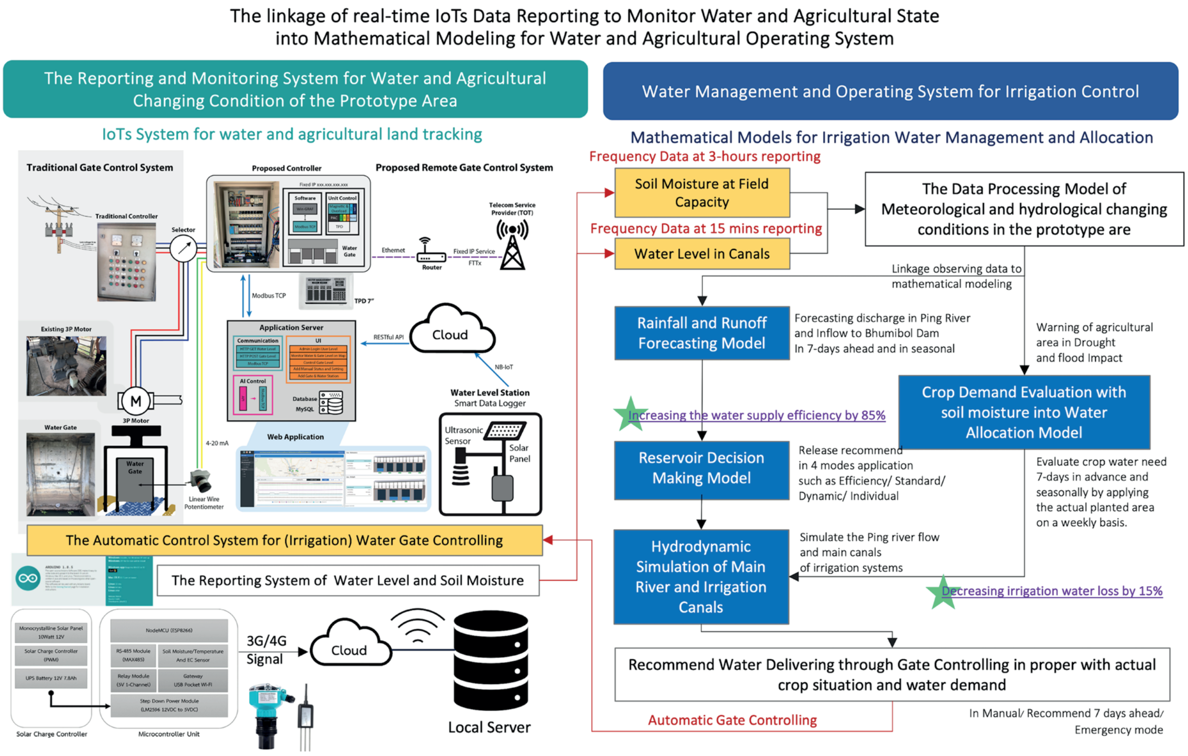


Figure 5 Water monitoring, analysis, and decision-making system for water release, along with automatic dam gate open-close system (Pinthong P., 2020).

5.3.4 Development of water user group

- **Creation of mechanisms for collaboration between irrigation water user groups and irrigation officers**

Water management efficiency can be enhanced by creating a network and building the capacity of human resources. This process involves forming a team of local coaches, establishing teams of water users at the village/district level, and connecting with the network of organizations. This team formation leads to the emergence of community leaders/water user groups, connecting upstream, midstream, and downstream areas. The development also includes improving the efficiency of the mentoring mechanism, where irrigation officials work collaboratively with all stakeholders continuously. This collaborative effort aims to reduce conflicts in water allocation among upstream, midstream, and downstream areas.

- **Development of water and land management plan for alternative occupations**

Creating water and land management plans involves training people or communities (peopleware) for group management; establishing rules, regulations, and guidelines (software); developing infrastructure (hardware); and specifying measures to cope with droughts and floods under climate change. In terms of rules and regulations, collaborative efforts are made between water user groups and irrigation officials to report the water usage needs for agriculture in each season. This process includes joint water tracking, establishing a water management fund, and collaboratively addressing obstacles/barriers that affect water management. The goal is to ensure equal access to water resources for everyone.

5.4 Water management case in non-irrigated areas

A community-level water data management system was established through collaboration between water users and the subdistrict administrative organization. This initiative utilizes GIS software, designed for collecting, analyzing, and preparing project proposals submitted to higher authorities (provincial level through the Thai Water Plan system). The system further supports the equitable sharing of available water for suitable crop cultivation to reduce conflicts and generate additional income for the community after the rice farming season.

5.4.1 Development of water user group

Water user organizations are established to enhance the water management planning capability in the target area, with a focus on exploring water management knowledge aligned with the local context. This development connects to the establishment of water user organizations and the creation of local community water management planning. This process has led to the formation of GIS for community water data system management. Academic recommendations for driving community water management have also emerged. These efforts are implemented through a local research methodology consisting of seven steps, integrated with the application of information technology systems related to water to support the project's activities. The implementation of research results in the following.

1) Knowledge on water management and guidelines for enhancing the capacity of water user organizations for area-based water resource planning involves a three-phase operational process, namely, human resource development, data development, and development of a participatory community water plan. The execution of these phases involves relying on a series of training courses, comprising four key courses: (1) Developing collaborative data collection skills through applications; (2) Collecting data in the area by water user organizations, community leaders, and officials from local administrative; (3) Integrating data into the community water system (Data Studio); and (4) Developing the "Community Water Plan" project linked with local development plans (local administrative).

2) An information system for water management was developed to support decision making. In this research project, the data collection process was divided into four sections, namely, general information of community, data on quantity of water supply, community water demand data, and local community development data, focusing on projects related to the area's water management, to be utilized in assessing future community participatory water plan guidelines.

3) A water user organization was established to plan a water management framework at the local level. It aims to enable water user organizations to have their own water management plans derived from the active participation of members and local stakeholders to collectively formulate plans based on comprehensive data for informed decision making. Such organizations have evolved into a community enterprise involved in alternative agriculture, contributing to increased income and diversification beyond traditional rice cultivation.

5.4.2 Development of water information systems at the subdistrict level linked to the provincial water plan

The development of a collaborative mechanism between the irrigation water use management group and development organizations aims to enhance the efficiency of water management. This enhancement is achieved through the human resource development and network creation. The focus is on developing the capacity of the mentoring mechanism, where irrigation officers collaborate with all stakeholders continuously. This development involves the establishment of water user groups, coupled with the utilization of modern technology to extend the project’s outcomes to other irrigation initiatives in collaboration with the province. The goal is to summarize the lessons learned before formulating the provincial master plan. This continuous approach aims to encourage participation in every step of the operational processes.

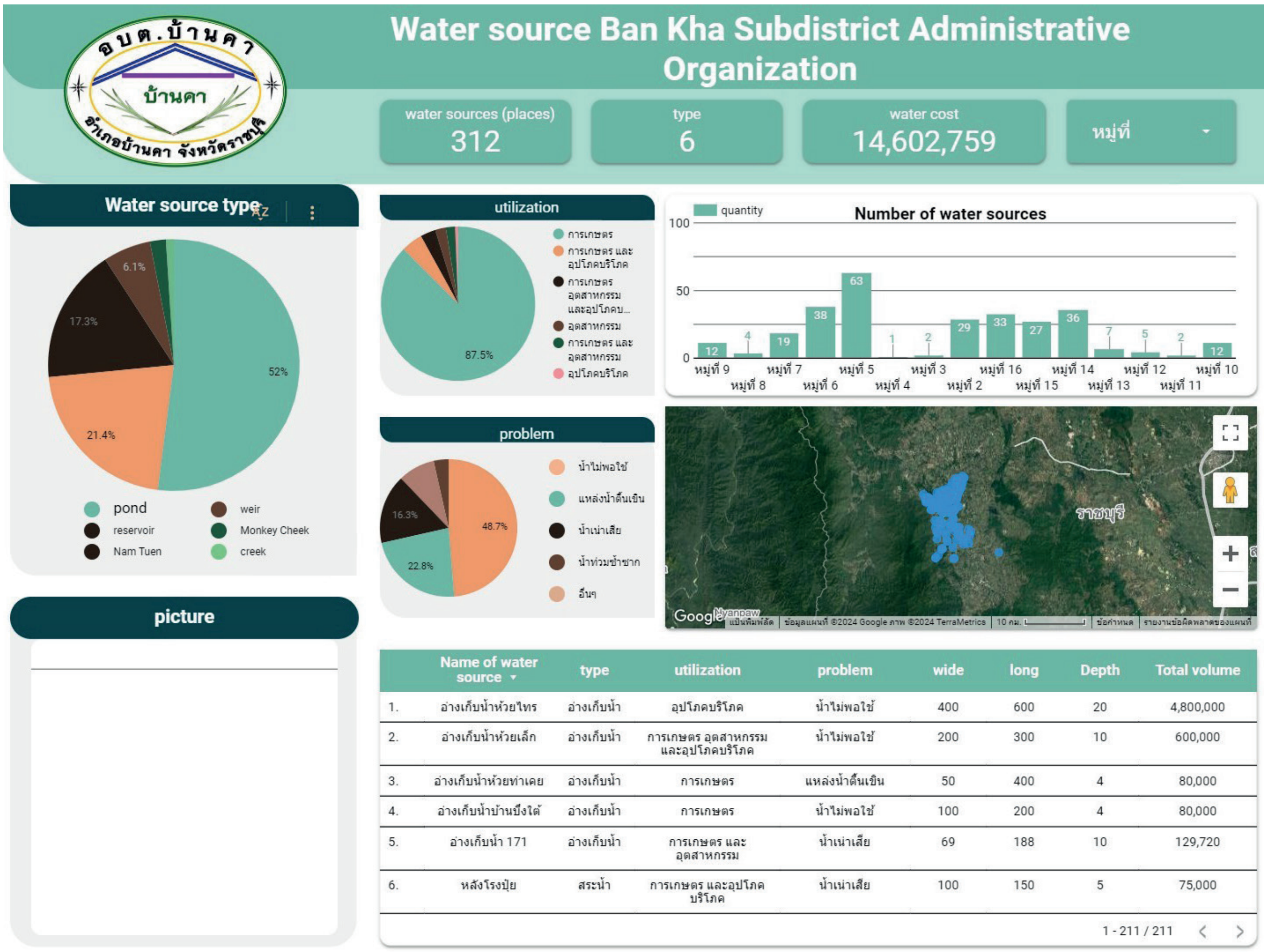
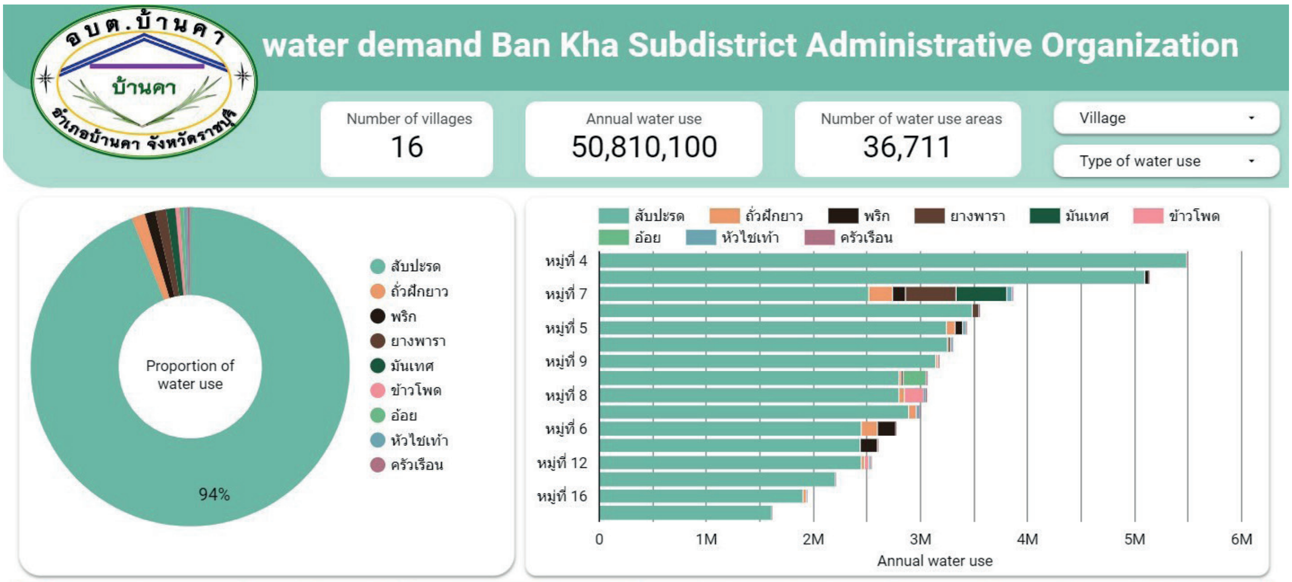


Figure 6 GIS of water sources for community water management (Maneesrikum C., 2022).



Village	Jan.	Feb.	Mar.	April	May	June	July	August	August	Oct.	Nov.	Dec.	Water usage/year
หมู่ที่ 9	629,639	629,639	629,639	140,728	144,859	143,826	140,728	144,859	143,826	140,728	144,859	142,793	3,176,120
หมู่ที่ 8	561,230	561,230	567,256	132,705	142,894	133,317	157,795	167,985	165,437	186,995	153,385	130,770	3,060,998
หมู่ที่ 7	524,373	524,373	914,923	185,805	269,869	209,291	212,243	256,307	229,811	208,373	176,437	154,405	3,866,214
หมู่ที่ 6	507,113	507,113	507,113	109,748	140,042	154,141	131,420	161,714	132,469	126,002	156,296	141,149	2,774,321
หมู่ที่ 5	656,109	656,109	665,008	155,370	171,618	166,462	154,275	170,524	157,174	151,953	168,202	160,078	3,432,882
หมู่ที่ 4	1,098,674	1,098,674	1,098,674	244,985	244,985	244,985	244,985	244,985	244,985	244,985	244,985	244,985	5,500,885
หมู่ที่ 3	1,023,675	1,023,675	1,023,675	227,263	227,263	231,907	231,907	231,907	227,263	230,746	230,746	230,746	5,140,771
หมู่ที่ 2	578,501	578,501	587,771	140,258	154,579	140,183	129,443	143,764	140,183	129,443	143,764	136,603	3,002,992
หมู่ที่ 16	381,754	381,754	381,754	85,141	91,199	89,685	85,141	91,199	89,685	85,141	91,199	88,170	1,941,821
หมู่ที่ 15	441,511	441,511	441,511	98,511	98,511	98,511	98,511	98,511	98,511	98,511	98,511	98,511	2,211,132
รวมทั้งหมด	9,648,715	9,648,715	10,072,0...	2,265,8...	2,448,519	2,382,427	2,363,344	2,514,761	2,405,826	2,397,213	2,376,523	2,286,161	50,810,100

Note: The color shown in each row indicates the amount of water used. And villages cannot be sorted by village.

Figure 7 GIS of water demand for community water management (Maneesrikum C., 2022).

The innovation design stems from integrating advanced technologies into a systematic framework and implementing operations to achieve management objectives. Table 1 illustrates the technology-based innovation design for specific sample areas. The outcomes are illustrated in Figure 8.

Table 1 Innovation design from technology development in study areas

List of innovations	EEC Area	Reservoir management	Irrigation water management	Non-irrigation water management
Rainfall prediction technique	✓	✓	✓	
Water demand estimation technique		✓	✓	
Runoff simulation technique	✓	✓	✓	
Groundwater assessment technique		✓		

List of innovations	EEC Area	Reservoir management	Irrigation water management	Non-irrigation water management
Dam water release technique		✓		
3R+ technique	✓			
Water user group development technique			✓	✓
Information system for community water planning			✓	✓

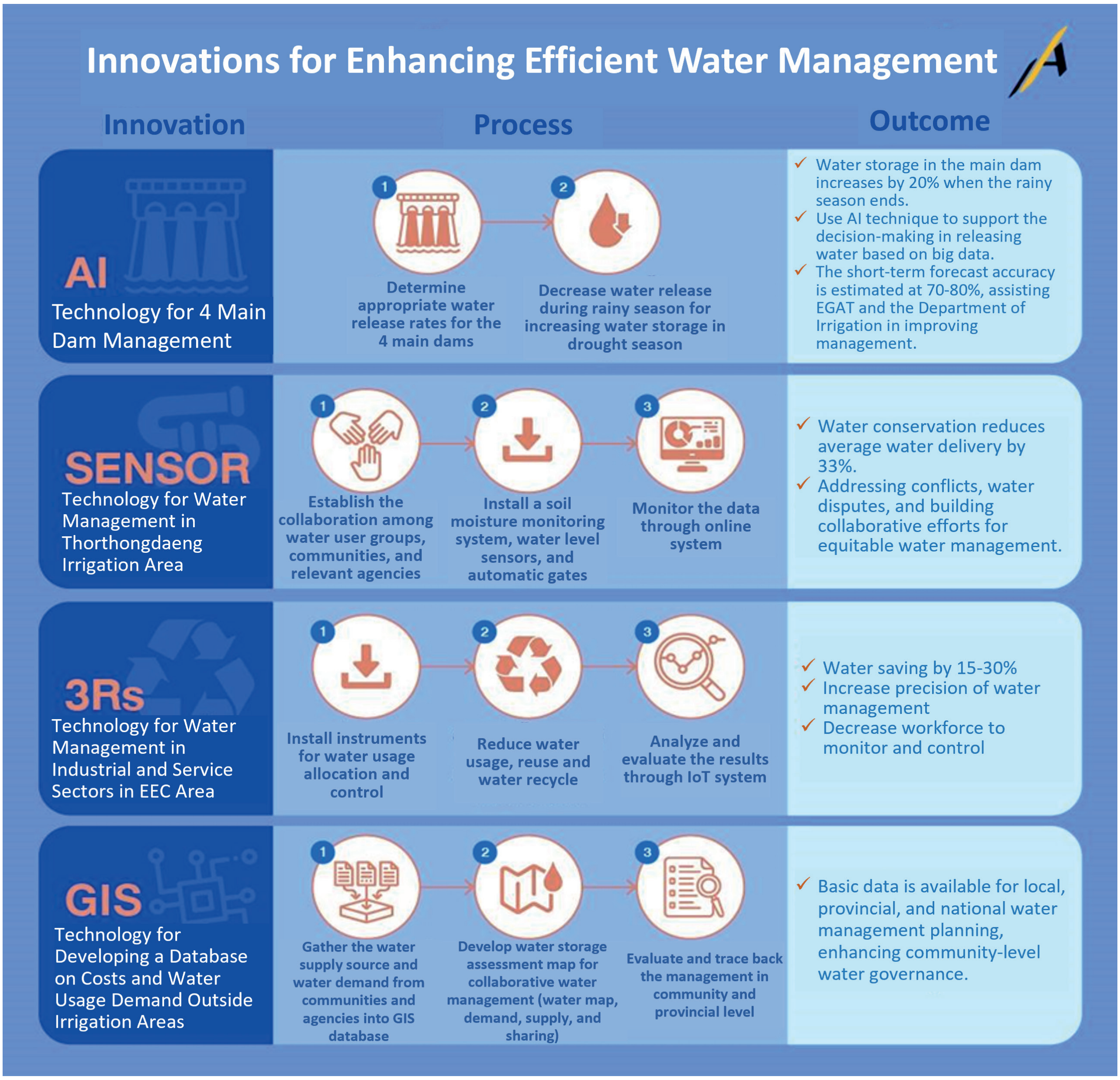


Figure 8 Innovations from research findings, processes, and outcome (Soralump S., 2023).

6

Environmental Economics Assessment Results and Strategic Direction for Enhancing Water Security

6.1 Economic valuation of water management systems development with technology for the industrial, service, and urban sectors

6.1.1 Case study in the central region

The feasibility study comprises four scenarios: Case 1, where the construction material prices and water costs remain constant; Case 2, where construction material prices increase and water costs remain constant; Case 3, where the construction material prices remain constant and water costs increase; and Case 4, where the construction material prices and water costs increase. All these scenarios have economic viability. However, the most economically viable possibility is in Case 3 due to the investment in technology development to save water and promote water reuse in the Chao Phraya River Basin area. Case 3 involves implementing water management systems in dams and technologies to enhance the efficiency of water management practices in the Thorthongdaeng irrigation area (expansion section) (Attavanich W., 2022).

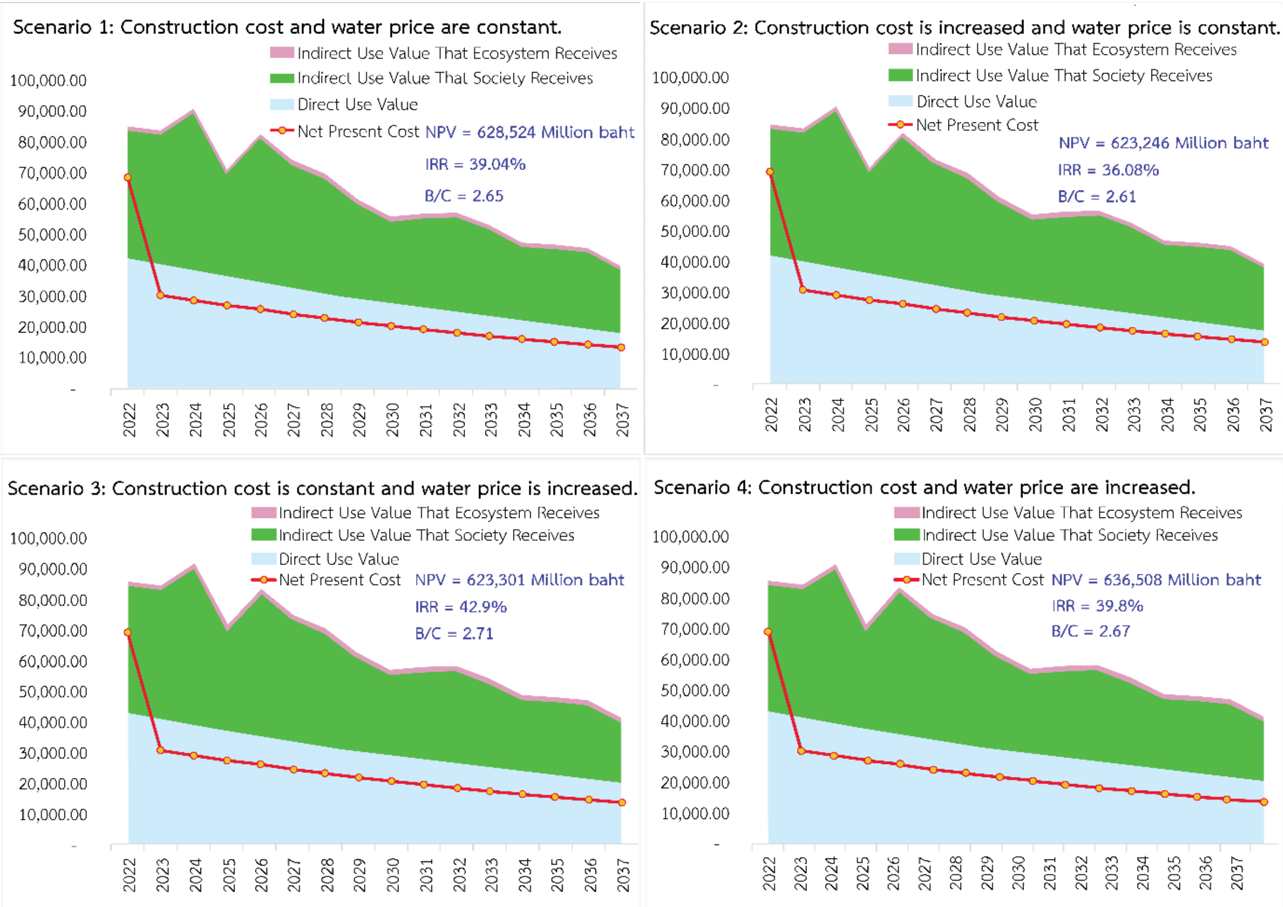


Figure 9 Economic feasibility analysis results for investing in the development of technologies in the Chao Phraya Basin area.

Table 2 Economic viability in water management strategies for the central region

Economic viability in management	Net Present Value (NPV) (million baht)	Internal rate of return (IRR) (percentage)	Benefit–cost ratio (time)
Investment in the dam water management system.	115,443.57	52.52	
Investment in technology for enhancing the efficiency of water management systems in the Thorthongdaeng irrigation area (expansion section).	6,815.82	32.24	

Economic viability in management	Net Present Value (NPV) (million baht)	Internal rate of return (IRR) (percentage)	Benefit–cost ratio (time)
Investment in technology for water conservation and reuse in the Chao Phraya River Basin area, encompassing industrial, service, and urban community sectors.	567,616.89	96.5	2.65
Investment in developing 3R and IoT technologies for water management to reduce water consumption and promote water reuse in the industrial sector.	162,604.30	38.6	2.08
Investment in developing technology for water management based on the principles of the 3Rs in the service sector.	68,234.64		2.69
Investment in the service sector (enterprise).	20,481.19		2.67
Hotel industry sector.	14,602.21		2.17
Increasing investment in water management systems with the 3R technology (large hotels).	6,253.91	44.1	2.01
Investment in community-based wastewater treatment technology for producing Grade 2 water for municipal use in the community.	299,252.12	40.7	2.57

Findings from economic research, which includes the assessment of water savings quantity and the evaluation of benefits from market and non-market perspectives across the economic, social, and environmental dimensions, indicate that investing in technology development to reduce water consumption and promote water reuse according to the 3R+ principles yields significant direct economic benefits. Such investments include 3R and IoT technologies for water management in the industrial sector, technology for smart water management following the 3R+ principles in the service sector, and community-based wastewater treatment technology for producing Grade 2 water in urban communities. Moreover, society and the environment benefit from reduced water consumption resulting from the implementation of these technologies in each sector. Research findings also indicate that the dry season yields higher benefits compared with the rainy season. In addition, when considering investments in dam water management systems and technologies to enhance the efficiency of water management systems in the agricultural area in the Thorthongdaeng irrigation area (phase 2 study area), the study indicates that economic, social, and environmental benefits are increased. Hence, the investment in technology for water management following the 3R+ principles in the Chao Phraya River Basin is economically viable.

6.1.2 Case study in the EEC area

Water resources play a crucial role in production and are essential for people's livelihoods. However, the EEC area is currently facing imbalances between water demand and supply due to constraints in water resources and urban expansion associated with industrial development and population migration. Therefore, efficient management of water demand is a critical factor for development in this area. It reflects the benefits derived from developing water management systems based on technology with the 3R+ in the industrial, service, and urban community sectors, covering economic, social, and environmental values. An economic pricing mechanism for water allocation among different economic sectors is essential. Thus, the design of economic-based water pricing mechanism for water allocation will contribute to water savings and optimal water use in the EEC, finally leading to a balanced use of water and ensuring effective water management in the long term (Attavanich W., 2022). The details are shown in Table 3.

Table 3 Potential water savings from the water management systems based on the 3R+ in the EEC

Quantity of water savings from the water management systems based on 3R+	Percentage of potential water savings (percentage)
Investment in the development of water management system with the 3R+ in the industrial, service, and urban sectors	
Utilizing 3R and IoT technologies for water management in the industrial sector	60–63
Applying community wastewater treatment technologies to produce Grade 2 tap water in urban communities	32–34
Using technology for water management according to the 3R+ in the service sector	3–8
Percentage of water savings per volume of water demand segmented by economic sector	
Urban communities	60.3
Industrial sector	23.3
Service sector	11.9–43.1

Table 4 Economic value of developing water management systems with technology in the EEC

Economic value of developing water management systems with technology	Value (million baht/year)	Ratio (percentage)
Economic viability across the industrial, urban community, and service sectors		
Overall economic benefits	300.67–1,348.65	-
Social benefits	9,041.0–9,598.8	-

Economic value of developing water management systems with technology	Value (million baht/year)	Ratio (percentage)
Ecosystem services benefits creation	368.0–389.9	-
Value-added to society	-	80.63–93.64
Economic benefits	-	1.25–14.91
Ecosystem services benefits	-	4.46–5.10
Investment in 3R and IoT technologies for water management in the industrial sector		
Economic benefits	237.65–1,050.64	-
Social benefits	2,969.54	-
Ecosystem services benefits	234.52	-
Investment in developing community-based wastewater treatment technology for producing Grade 2 water in urban communities		
Economic benefits	46.92–95.13	-
Social benefits	1,596.24	-
Ecosystem services benefits creation	125.48	-
Investment in technology for water management following the 3R+ in the service sector		
Economic benefits	16.10–202.88	-
Social benefits	106.80–387.37	-
Ecosystem services benefits	8.04–29.89	-

Table 5 Economic viability of water management in the EEC

Economic viability in management	NPV (million baht)	IRR (percentage)	Benefit–cost ratio (time)
Investment for the development of water management systems with technology in the EEC in 2022–2037.	83,740–104,876	21.82–49.06	1.98–2.22
Investment in 3R and IoT technologies for water management in the industrial sector.	3,802.43–16,810.30	-	1.07–1.30
Investment in the development of community-based wastewater treatment technology for producing Grade 2 water in urban communities.	750.78–1,522.08	3.27–6.60	1.03–1.06
Investment in technology for water management following the 3R+ in the service sector.	479.98–3,246.01	1.92–39.75	1.16–1.89

6.2 Guidelines for enhancing water security via modern technology

(Case study in the central region and the EEC)

The assessment of water security status according to the development of water management systems with technology in the central region and the EEC aims to evaluate the water security status from enhanced agricultural productivity resulting from implementing technology-based water management systems compared with the current water resilience status.

The ADB has established a multidimensional assessment of water security, comprising five dimensions: 1) water security for household consumption, 2) water security for economic purposes, 3) water security for urban areas, 4) environmental water security, and 5) water security for disaster recovery. In the AWDO reports of 2013, 2016, and 2020, the water security index scores in the dimensions of urban water security, environmental water security, and water security for disaster recovery are only 2 out of 5. These dimensions are interconnected with societal, environmental, and integrated management systems.

The water security of Thailand is assessed within the international frameworks, including SDG 6 and AWDO 2013, 2016, and 2020. Thailand has reported data on SDG 6 for 10 dimensions out of 12. In terms of sanitation, 26% of the population has access to safely managed sanitation services. Regarding hygiene, 85% of the population has access to proper handwashing practices, and 24% of households have wastewater treatment. In terms of water quality, 36% of water sources have good quality. The value added from water resource utilization efficiency is $7/m^3. The water stress level is 23% (the proportion of water use to the circulating water resource quantity). About 53% of water management indicates the level of integrated water resource management implementation. In terms of the ecosystem, a 1% change exists in water resource ecology in 2016 compared with that in 2001–2005. Moreover, the financial assistance for water and hygiene amounts to 3 million dollars. The comparison of the subtarget indicators under SDG 6 for Thailand with the global average indicates that the proportion of safely treated wastewater in Thailand is 24%, whereas the global average is 56%; the proportion of high-quality water sources in Thailand is 36%, whereas the global average is 72%. The water use efficiency in Thailand is $7/m^3, whereas the global average is $19/m^3.

Table 6 Technologies for water use reduction in the industrial sector

Technologies for water use reduction in the industrial sector	Water use reduction (percentage)	Water use reduction in the industrial sector (baht/m^3)	Water productivity in the industrial sector of the province
The use of 3R and IoT technologies for water management to save water consumption and reuse.	23.2	-	-
Water productivity in the industrial sector in the EEC in 2017			
Chachoengsao Province	-	5,592	7,262
Chonburi Province	-	2,854	3,706
Rayong Province	-	2,243	2,913

The development of water management systems with technology has resulted in increased productivity in the industrial and agricultural sectors due to water conservation and reuse. This development contributes to higher scores in the water security dimension for economy. The outcomes demonstrate that innovation from developed technologies can create valuable economic benefits and enhance water security.

Therefore, when the new technologies were introduced to the Greater Central Plain Basin (via the water release scheme of the main dams) and the EEC area (via smart pumping scheme and water saving in the industries via 3R+). The advancement leads to an increase in water productivity, a boost in water reuse from community wastewater, and a reduction in wastewater reintroduced into water bodies. All these measures contribute to valuable economical returns.

7

Policy Recommendations for Expansion and Achieving SDGs

The challenges in water management tend to increase due to growing water demand, changing patterns of water use, natural variability, and limitations in existing infrastructure and tools. An integrated approach to problem solving is crucial by considering structural and nonstructural aspects and management at various levels, such as community (subdistrict), watershed (province), major river basins (22 river basins), and national and international levels. The global trend in addressing challenges involves attempting to address global warming, along with the use of modern technologies that integrate with traditional knowledge (or called as green and smart) to address global warming issues and reduce operational costs simultaneously.

The research and innovation development from the Spearhead Research Program on Water Management has led to the creation of new technologies (8 topics) and the design of innovations to address specific problems (4 area-based models). These developments stem from field experiments (during the research phase) and have proven economically valuable for widespread implementation across the entire area. Therefore, policies that utilize STI to elevate water management must be established. This approach aims to achieve SDGs and global water security, starting by addressing crucial issues in specific areas.

The drive for the utilization of developed innovations should consider financial management, data management, capacity development, and good governance. Fundamentally, financial management should consider factors beyond regular budget allocations. In situations requiring swift action, the utilization of mechanisms such as funds or collaboration with international organizations or the private sector becomes imperative. Regarding data management, an interconnected (or automated) system of innovation that aligns or integrates with the existing water information system network must be established. This system should enhance mutual benefits at the national level (downward and upward) and at the local level. The development of capabilities at various levels, in addition to existing mechanisms within departments, divisions, and local administrative organizations, may be considered to establish livable learning centers. These centers can draw benefits from well-implemented projects and involve active personnel as mentors, enabling immediate practical application and time efficiency. In terms of ethics, it involves integrating innovative work boundaries into routine tasks, collaborating with capacity building (reskilling, retraining, or outsourcing) under the government's policy to limit the workforce. The details of each job descriptions are outlined as follows.

7.1 Policy formulation for utilizing STI in water management

1) Water management in the Special Development Area (from the EEC case)

1. Water allocation and criteria for efficient and sustainable water use is established by utilizing a developed MIS to simulate various scenarios for policy and criteria formulation (by the Royal Irrigation Department and the Office of the National Water Resources).
2. Smart water pumping management into the main reservoir of the area is operated by using a smart water pumping system (by the Royal Irrigation Department).
3. Promoting the use of the 3R+ measures (in collaboration with IoT technology) for the industrial sector can reduce water consumption and recycle wastewater up to 15% of the total water usage. The recycled water contributes to cost savings in water supply (by the EEC Office in collaboration with the Department of Industrial Works and the Industrial Estate Authority of Thailand).
4. Promoting the use of the 3R+ measures (in collaboration with IoT technology) for the service sector involves enhancing water savings at the source for large-scale business buildings, hotels, and accommodation services. This promotion can be achieved by installing water-saving sanitary wares, resulting in an increased efficiency of water

reduction at the source, approximately 5%–15%. The efficiency can be further elevated with the extended development of innovative water-saving sanitary wares in the EEC (by the EEC Office and the Department of Public Works and Town and Country Planning).

2) Dam management (from the central region case)

1. Developing an automated water management system (based on the developed Spearhead Research Program) under pre-agreed regulations aims to reduce decision-making time and limited workforce. It includes establishing an integrated water management system, encompassing surface water and groundwater to manage the quantitative and qualitative aspects of water. Moreover, efforts are exerted to improve dam management systems (by the Royal Irrigation Department, Electricity Generating Authority of Thailand, and the Ministry of Higher Education, Science, Research, and Innovation).
2. Integrating collaborative planning to establish an extensive network for water management in the Chao Phraya River Basin involves coordination with other provinces, particularly those interconnected with shared river basins and coordinated water distribution. This collaborative effort is supported by the implementation of dam management technology (dam sets; led by the Royal Irrigation Department and the Office of the National Water Resources).
3. Adjusting the management of surface water, starting in the lower central region, involves the utilization of modern and advanced techniques, integration of interconnected or automated systems, and delivery of effective and timely notifications/alerts to communities (supported by the Royal Irrigation Department and the Ministry of Higher Education, Science, Research, and Innovation).
4. Procuring reservoirs for emergency water storage is crucial to develop an interconnected water management system by applying technology for utilization during the process. This strategy generates significant indirect benefits in the agricultural sector, as well as other sectors (led by the Royal Irrigation Department and provincial authorities).

3) Water management in irrigated areas

1. The learning and collaborative work processes for efficient water management are expanded by utilizing modern technologies within the Thorthongdaeng Operation and Maintenance Project area, reaching other irrigation areas (led by the Royal Irrigation Department).

2. Precise agricultural methods are developed under the collaborative management of surface water and groundwater by pumping groundwater for utilization during suitable periods without exceeding the natural groundwater recharge balance (led by the Ministry of Agriculture and Cooperatives, Department of Groundwater Resources, and the Ministry of Higher Education, Science, Research, and Innovation).
3. Knowledge transfer is comprehensively disseminated, and water user groups are established in the Thorthongdaeng irrigation area while simultaneously increasing economic value. This implementation should be expanded to five community enterprise groups that generate additional income from improving water management efficiency. Moreover, shifting to water-efficient crop cultivation and creating community water plans that align with climate change will lead to the enhancement of the quality of life, in alignment with the bio-circular-green (BCG) policy (led by the Royal Irrigation Department and Provincial Agriculture Office).
4. A community economic system is created to address poverty by adjusting livelihoods and occupations that align with water resources and climate changes. Community enterprises and community funds generate jobs and create new occupations based on community resources. Community products and goods are elevated through the development of GIS for community participatory water management and scientific knowledge from research (agricultural sector; led by the Royal Irrigation Department and Provincial Agriculture Office).

4) Water management in non-irrigated (rainfed) areas

1. Applying GIS for community water management has been developed to enable local administrative organizations to collaborate with water user organizations in storing, analyzing, planning, and operationalizing water-related activities at the subdistrict level (by the Ministry of Interior).
2. Developing supplementary occupation plans aims to increase income for water user groups, particularly in alternative agriculture, by utilizing scientific knowledge derived from research findings. The educational institutions in the area act as mentors (by the Ministry of Interior, Ministry of Agriculture and Cooperatives, and the Ministry of Higher Education, Science, Research, and Innovation).
3. Connecting the local administrative subdistrict water operational plan and income creation development plan with the main provincial integrated water resources plan is achieved by using the Water GIS as a supporting tool (by the Office of the National Water Resources and provincial authorities).

7.2 Driving strategies

1) Water management in EEC

1. A water management fund in the EEC is established based on feedback from various organizations and water users in different sectors. According to the research program, several sectors require the establishment of a water management fund in the EEC. Therefore, the research program proposes guidelines for establishing the aforementioned fund by utilizing the authority under the EEC Act of 2018.
2. An organization/mechanism for water management should be established, covering short-, medium-, and long-term periods, by relying on authority according to the Water Resources Act through River Basin Committees and National Water Resources Committee, as well as the authority according to the EEC Development Act. This approach ensures the existence of a water allocation mechanism and regulates the operation after allocating the water to water-related enterprises in the area by utilizing modern technologies for assistance.
3. The establishment of a working group to formulate comprehensive water management guidelines for the EEC requires collaborative efforts between the Office of the National Water Resources and the Office of EEC Policy Committee. This collaboration aims to develop a water management plan that encompasses all dimensions, including the demand side, supply side, and operation. Furthermore, the operation of water supply by managing reservoirs within the EEC area will enhance water retention capabilities.
4. The Regional Office of Water Resources 2 has responsibilities covering nine river basins (in the central, eastern, and western regions). This extensive coverage presents challenges in terms of coordination and problem solving, in policy and practice. To improve capabilities, responsiveness, and operational efficiency in the area, the Office of Eastern Water Resources should be established for quick, efficient, and timely responses to issues on policy and operational levels.

2) Dam management

1. Allocating resources toward the development of dam water management systems, coupled with the integration of advanced technology, substantially enhances the efficiency of agricultural water management practices in irrigation projects. The implementation of technology-driven water management systems for the industrial, service, and urban community sectors in the Chao Phraya Basin also plays a pivotal

role in conserving water. These investments not only contribute to water conservation but also provide economic, social, and environmental benefits. Moreover, society and the environment derive increasing benefits from the reduction in water usage. Therefore, investing in technology development to decrease water consumption and promote water reuse following the 3R+ is economically worthwhile, providing tangible benefits in terms of economics, society, and environmental sustainability throughout the year.

2. Investing in community wastewater treatment technology to produce Grade 2 tap water in urban communities generates direct economic benefits, reflecting a high proportion of net benefits, highlighting that businesses directly benefit from investing in this technology.
3. The development of technology into a long-term DSS for dam and reservoir management can be advanced by relevant operational agencies. These agencies can develop the technologies used in dam and reservoir management beyond the scope of research projects to establish a DSS. This system integrates all relevant technologies and models employed in dam management. The developed system can present input data, display results from applied technologies, and illustrate recommended forecasting runoff patterns from the models. Moreover, it should generate reports for operational personnel at all levels, enhancing effective, relevant, and timely decision making in water management, specifically for the community.

3) Water management in irrigated areas

1. Applying a tracking system with measurement system and sensors in irrigation projects can enhance water delivery efficiency and reduce losses during distribution.
2. The establishment of an institution or water user group aims to develop knowledge and techniques and utilize the developed water information system. This initiative is designed to create a continuous learning experience and serve as a collaborative workspace for water user groups, organizations, and relevant agencies, thereby supporting water management planning in the area.

4) Water management outside the irrigated area

1. Promoting the use of the developed GIS for water management among water user groups in collaboration with the Office of the National Water Resources aims to plan and manage water resources in the area. Moreover, this system is linked with the plans and projects of the Office of the National Water Resources to align with the provincial water master plan, as outlined in the developed guidelines.

2. A master plan for developing water user organizations is established to improve the quality of life and enhance economic and income stability. This initiative seeks to foster sustainable water management within and outside irrigation areas, in collaboration with provincial authorities.

7.3 Supporting measures

7.3.1 Measures for innovation promotions

1) Water management in EEC

1. Strengthening the River Basin Committees, including collaboration between the East Coast Gulf and the Bang Pakong River Basin, involves utilizing the mechanisms of the Office of the National Water Resources and establishing compensation mechanisms for water transfers among river basins.
2. Drafting a water management plan to support operations in the EEC area involves overseeing water transfer across river basins and managing water through pipeline systems. This plan also incorporates crisis management to ensure water security and prevent the risk of water shortages.
3. Supporting and monitoring water conservation and efficient water usage are conducted in industrial and consumer sectors.
4. Expanding the influence by applying the study results in the area, in the form of a Sandbox, is made possible through local administrators' establishment of a centralized wastewater treatment system. The design may include treated water that meets the quality standards, allowing it to be reused in accordance with policies and master plans defined in that area. Moreover, municipalities, starting from two or more, may collaboratively establish a cooperative to operate wastewater treatment and reuse the treated water to enhance water security in the relevant municipal areas. The treated water can be supplied to the demands of industries or agricultural sectors with approval from the Ministry of Interior. The cooperative may receive government support and seek financial assistance.
5. Support is also given to the Department of Public Works and Town and Country Planning, as well as the Wastewater Management Authority, in establishing guidelines for separating water pipe systems and storage reservoirs from the recycled water, distinct from the water pipe and tap water system. Efforts are also being made for the elimination of

barriers in management for the water discharge from the recycled system. Research is also underway to identify low-cost treatment methods or implement a collection pipe system to direct wastewater to treatment facilities designed for effective processing.

6. The pilot project is expanded to test the use of technology along with incentive measures to assess feasibility and cost-effectiveness. This expansion includes (1) transferring high-quality recycled water from the community from local government organizations to industrial estates and (2) diverting high-quality recycled water from the community from local government organizations to the agricultural sector for ongoing operations.
7. Systems for sharing information and providing training on water conservation and reuse are being developed, targeting crucial sectors.
8. Mechanisms or agencies are established to support and monitor water conservation and reuse in all sectors.

2) Dam and water management in the Central Plain Region

1. Researching groundwater recharge involves studying various methods such as aquifer recharge from rainwater and runoff. The study encompasses the use of structures such as weirs in rivers, recharge from water-receiving areas, recharge wells, reservoir recharge, and water pumping to recharge groundwater wells. This research aims to ensure accuracy and monitor the effectiveness of multiple groundwater recharge methods.
2. Economic research agencies should establish dedicated units responsible for studying innovative economic tools tailored to specific water management conditions. These tools aim to meet the growing demand for productive water in alignment with the country's development goals. Moreover, these instruments can be used for continuous monitoring and evaluation.
3. Promoting entrepreneurs in industrial, service, and urban community sectors to invest in developing water management systems with technology is being prioritized due to its economically viability, covering economic, social, and environmental dimensions. Regarding the current unchanged water tariff rates, the government should consider additional incentive measures to attract industrial sector investment in water management systems, such as low-interest loans or various tax benefits.

4. Database system development
    - Expand observation wells to measure groundwater levels widely across the area adequately and continuously recording groundwater levels from observation wells to monitor the situation and changes promptly.
    - Expand the installation of real-time groundwater level measurement devices covered across the study area to provide real-time data for integration with groundwater models, especially in hot spot areas.
    - Connect real-time canal level measurement systems along the entire length of key rivers or canals in the study area to assess the replenishment of groundwater from the river to the aquifer.
    - Integrate data on surface water usage, satellite information, and soil moisture to assess cultivated areas and water demands for the soil.
5. Dissemination of information and advanced public warning system
    - Regularly report groundwater level data, as well as rainfall and runoff data, to the public on a weekly or monthly basis through various communication channels accessible to water users and relevant organizations in the area. Ensure ease of data access and real-time updates through platforms such as websites, mobile applications, and LINE.
    - Provide early warning of groundwater conditions, similar to flood and drought warnings, to inform whether the groundwater level is falling near or below the critical level. If it exceeds this level, warnings should be issued to cease or reduce groundwater use, allowing the people to prepare by decreasing groundwater consumption, reducing planting, and minimizing damage from water shortages due to excessive cultivation. This strategy ensures groundwater balance and facilitates groundwater recovery to normal levels in the following seasons or years.
    - If the groundwater level consistently decreases over a period of 10–20 years, then the groundwater consumption exceeds the recharged volume. Therefore, measures should be implemented to prevent further decline of groundwater by reducing the use of groundwater, utilizing water from alternative sources, and implementing groundwater recharge methods such as rainwater and runoff, as well as other groundwater recharge measures.

3) Water management in irrigated areas

1. Implementation of water resource management activities according to the Water Resource Act of 2018 at the district, subdistrict, and provincial levels.
   - Establishment of a Precision Agriculture Learning Center utilizing IoT technology within the Thorthongdaeng Operation and Maintenance Project area aims to serve as a knowledge dissemination hub and foster continuous development in other areas with similar conditions for sustainability.
   - Creating a provincial water resource utilization master plan and a flood and drought operation plan, along with establishing a supporting data system for integration into the River Basin Master Plan, is done through strategic issues/major plans under the River Basin Master Plan.
   - Collaboratively enhancing the capabilities of farmer water user groups and governmental officials in developing water projects to be proposed for budget support is made possible through the Provincial Water Subcommittee, River Basin Committee, and National Water Resources Committee.
2. Guidelines for improving water management in irrigation areas with modern technology
   - Short-term: Continuously monitor and evaluate the performance of the installed systems and equipment to assess usage and benefits. Be an example for other irrigation projects to study and apply.
   - Long-term: Expand the results to other irrigation projects with master plans to enhance modern water management in irrigation projects, integrating with production and marketing.
3. Data support should be conducted by creating participatory awareness for encouraging community data collection for use in driving the local operations.
4. Community empowerment should be implemented through promoting community in adopting an integrated market mechanism (production–processing–marketing) connecting with the BCG economy concept.

4) Water management outside the irrigated area

1. Developing data focuses on creating awareness on the importance of having community water data for efficient planning.

2. Developing a community participatory water plan requires utilizing relationships, active participation, and data to support decision making, ultimately leading to the creation of a water plan that effectively addresses the area's operations.

3. Building capabilities is performed through four training programs, including (1) skill development in community-based data collection–application; (2) data collection in the area by water user organizations, community leaders, and government officials; (3) data input into the community water system (Data Studio); and (4) development of "Community Water Project Planning" linked to a local administrative development plan.

4. Developing competencies is related to three main input factors:
   - Community water user organizations need financial resources.
   - State agencies should support community-level organizations and water user groups by providing tools and technology for diverse water allocation.
   - Community-level organizations and water user groups should receive competency development and be able to utilize essential data, such as water source maps, crop production calendars, and water quantity data, to manage information effectively.

5. Developing competencies in the operational process comprises three main factors:
   - State agencies should promote the concept of participation as a fundamental idea in the operational process.
   - State agencies should support organizations/water user groups in developing an empowerment process by emphasizing the acquisition and enhancement of skills and competencies for teamwork.
   - State agencies should promote organizations/water user groups to develop an information presentation that is disclosed to all members based on the principle of transparency.

6. Developing human resources includes empowering the water user organization committee, local government officials, and community members to be ready for organizational management and have skills in various operations.

7. Water user organizations are created for area-based water management planning. These organizations are allowed to develop their water management plans through the active participation of members and local residents, collaboratively determining the plan based on comprehensive data for decision making.

8. Plans/projects at the local administrative organization level are integrated with the provincial water management plans to enable coordination and system alignment with water systems at the local, subbasin, and basin levels.

7.3.2 Legal and regulatory measures

1) Water management in the EEC

1. Setting water prices and wastewater treatment fees should be determined based on the understanding of the supply chain by a water price regulatory committee (regulator). A water price regulatory committee should be initially established in the EEC and then gradually expand it nationwide.
2. Criteria for setting water prices must be determined to reflect the actual costs of water and be fair to everyone and every group. The regulator should explain to the public the principles and reasons for adjusting prices, including the actual costs of water.
3. Ministerial regulations or rules to facilitate investments in water treatment systems, the discharge of treated water, and water reclamation are formulated through collaboration with the Board of Investment of Thailand, the Department of Public Works and Town and Country Planning, the Department of Pollution Control, the Office of the National Water Resources, and the Office of the EEC Policy Committee. This process should be accompanied by the issuance of local regulations.
4. Accelerate the review and improvement of relevant laws

   The Building Control Act, various municipal regulations, environmental and energy-related laws, and specific building-related acts should be revised to mandate the installation of water-saving and water reuse equipment in service sector buildings constructed after 2021. This revision is highly economically viable and can alleviate water scarcity issues in the EEC area.
5. Amend the Investment Promotion Act of 1977

   The existing investment promotion measures for water treatment and recycling service providers, as well as other businesses within the promoted scope, need to be improved for increased efficiency. Economic-based investment promotion measures should be enhanced. Publicizing the rights and benefits of businesses should be conducted to allow entrepreneurs to acknowledge their rights and benefits received from investment promotion. The types of business eligible for investment promotion should also be expanded, particularly certain types of business that use a large quantity of water in their production processes but do not receive investment promotion. This expansion includes industrial factories that use an amount of water, factories using more than 100 m^3 per day, and service sectors that consume more than 100 m^3 per day.

6. Amend the Water Resources Act of 2018

   Establishing a fund is possible, following the preliminary legislative framework. However, the clauses related to the fund's establishment have been removed in the initial stages as the Water Resources Act is under consideration by the Parliament. Thus, it is not within the authority of the Water Resources Act. Moreover, the Water Resources Act should be amended to enable the establishment of a water management organization (water agency) to serve as a water regulator. This organization is responsible for developing a sustainable water management framework within the EEC and other operations, such as setting water usage rates in various sectors under normal and crisis conditions. In addition, the River Basin Committees must operate between the East Coast Gulf and the Bang Pakong River Basin by using mechanisms established by the River Basin Committees through the Office of the National Water Resources. Establishing effective mechanisms for compensating water diversion across river basins is also imperative. Moreover, a water management plan should be developed to support operations in the EEC. This plan should encompass the management of water diversion across river basins, oversight of pipeline systems, and crisis management. The EEC is an area that requires water security with no risk of water shortages. It should also support and monitor water use reduction in the industrial and consumption sectors.

7. To promote measures for water saving and water recycling in the short term under the Water Resources Act of 2018, the Office of the National Water Resources may propose the establishment of a Regional Water Resource Management Subcommittee in the central region, following the directive of the National Water Resources Committee (Order No.: 17/2565, dated August 18, 2022). The creation of these regional subcommittees is intended to establish guidelines for water demand management, particularly in the EEC area. Their primary objectives include developing a draft master plan for water saving and reuse in the EEC. This process involves establishing objectives and target areas to be presented sequentially to the River Basin Committee, the National Water Resources Committee, and the Special Eastern Economic Zone Development Policy Committee. The purpose is to formulate policies, measures, or consider amendments to laws, regulations, rules, announcements, or orders. Furthermore, promotion measures should be devised to encourage water saving and reuse within the existing framework of benefits, as analyzed and proposed above.

8. Providing voluntary compensation to the agricultural sector for refraining from cultivating crops during the drought season allows the diversion of water toward consumption and the industrial sector.
9. Compensation in cases of water diversion across river basin during crisis periods and water shortages, such as water diversion during severe droughts with significant water scarcity, will be provided.
10. Funds should be allotted to support water management or provide water resources according to future needs.
11. Economic incentive measures are recommended to align with the proposed supporting measures under the Investment Promotion Act of 1977. This involves improving existing investment promotion measures and providing information and education to entrepreneurs in the industrial and service sectors about their rights and benefits. Furthermore, the research team has proposed to expand the types of business eligible to receive an investment promotion by including industrial or service sectors that use an amount of water but are not currently covered by existing promotion measures.
12. Promote incentive benefits

    A proposal to the Board of Investment must be drafted to provide financial benefits, tax deductions, and tax exemptions for machinery and equipment, with additional coverage for activities related to water recycling, water production, and water-saving equipment.

    In addition to the mechanism of promoting water saving through investment promotion by the Board of Investment, the EEC Policy Committee also has the authority to establish benefits in the form of a Sandbox within the EEC area.
13. The "Eastern Water Security Fund" and/or the "Drought Relief Fund in the EEC Area" must be established by the Office of the EEC Policy Committee. The objective is to support water management for water security. The funds are collected from raw water charges, local taxes, or voluntary contributions from entrepreneurs to address drought-related problems.

2) Dam and water management in the Central Plain Region

1. Expedite the review and improvement of relevant laws to support the installation of water-saving and water recycling instruments and systems, which have been found to have high economic worthiness and can alleviate water scarcity issues in the Chao Phraya River Basin area.
2. Establish criteria for integrated use of surface water and groundwater in the study area under various water scenarios, and assess the effectiveness of these criteria in mitigating water scarcity.

3) Water management in the irrigated areas

Improve the scope of work for provincial irrigation projects to allow participation in water planning and operations in alignment with the province's main water plan and water operation plan.

4) Water management in the non irrigated area

1. Improve the scope of responsibilities for the Provincial Water Resource Subcommittee to develop water operation plans (pre-drought and pre-rainy season) and the main provincial water plan (aligned with the timeline of the River Basin Master Plan).
2. Enhance the scope of responsibilities for the local administration to develop water operation plans (pre-drought and pre-rainy season) and link these plans with the main provincial water plan and water operation plan.

7.4 International collaboration measures for continuous development

7.4.1 Development of predictive systems for typhoon and seasonal weather situations

Predicting seasonal weather conditions relies on the understanding of the air–sea interaction. The processes involve the heat content from tropical oceans, affecting large-scale atmospheric processes through remote forcing. This influence subsequently affects tropical atmospheric circulation and teleconnections in mid-latitude area, particularly the ENSO phenomena in the Pacific Ocean and the IOD in the Indian Ocean. These phenomena are characterized by abnormal sea surface temperatures, which serve as major drivers of variability in the atmospheric system, with a lead time of 3–6 months. As a result, these anomalies are utilized in seasonal weather forecasting.

Prediction of temperatures during the periods of 1983–2020 demonstrates accurate forecasting during December to February in the western Indian Ocean and the eastern Pacific Ocean. However, some deviations exist in land areas. For Thailand, the accuracy of predictions varies across regions from June to August. For rainfall, predictions can be less accurate than for temperature. The temperature predictions are generally highly accurate in the Western Pacific Ocean region. Moreover, for Thailand, some deviations are observed from June to August. Regarding the forecasts from August to October 2021, the results indicate increased temperatures in the Western Pacific and increased rainfall in the Maritime Continent, aligning with the development of the La Niña phenomenon. Overall, the SINTEX-F system can predict temperatures and rainfall that closely resemble measured data in the ocean and cover oceanic phenomena but tend to have lower accuracy for land areas (such as participating in the S2S Working Group).

7.4.2 Big data analysis system for water management planning

A large-scale rainfall data analysis model is being developed for water management planning, utilizing ML to predict rainfall in collaboration with international and foreign organizations. This initiative aims to enhance personnel capabilities in developing a rainfall prediction process for water management planning through training in large-scale data analysis. It involves studying weather forecasting using technology systems and analyzing and developing large-scale rainfall data analysis systems to predict rainfall for a period of 14 days to 3 months. Furthermore, the project incorporates the use of weather forecasting technology, preparing a numerical weather prediction model to study mechanisms during the dry and rainy seasons and utilizing ML data management tools (as found on the kit-weather.de website).

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Appendix A

Curriculum Vitae of Program Chair

Personal Information

Name	:	Dr. Sucharit Koontanakulvong
Position	:	Associate Professor
Website	:	www.ksucharit.com
Current Job Responsibilities and Affiliation	:	Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University

Educational Background

Degree	Department	Year of Graduation	Education Institution
Bachelor's Degree	Chemical Engineering	1978	Kyoto University
Master's Degree	Agricultural Engineering (Civil Engineering)	1980	Kyoto University
Doctoral Degree	Agricultural Engineering (Civil Engineering)	1983	Kyoto University

Professional Experience

1984–Present	Associate Professor at Water Resources Engineering Department Faculty of Engineering, Chulalongkorn University
2003–2018	Head of Water Resource Management System Research Unit, Chulalongkorn University
2004–2007	Vice Dean for Special Affairs, Faculty of Engineering, Chulalongkorn University
2011–2015	Head of the Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University
2011–2012	Working member under Water Management Strategic Committee, Thai Government
2017–2019	Vice Chairman of the Subcommittee on Water Resources in the National Strategy Committee on Sustainable Growth for Environmentally Friendly Quality of Life

2017–2021	Expert Committee in Groundwater Committee at Groundwater Resources Department
2017–Present	Expert Committee in National Climate Change Policy Committee, Ministry of Natural Resources and Environment
2018–Present	Expert Committee in Subcommitee on Water Resource Management Masterplan Driving Committee, ONWR
2019–Present	Subcommittee on Poverty and Inequality Reduction: Water and Land Resource Management, House of Senate Committee
	Chairman of Spearhead Research Program for Social Strategic Goals on Water Management
2022–Present	Distinguished Scholar in Water Management, Chulalongkorn University

Research

2014–2017	Climate Change Impact, Vulnerability and Adaptation Study in the critical sectors, Technical Report submitted to Office of National Environmental Board under UNDP support
2015	Study on the Analysis and Synthesis of Climate Change-Related Water Resource Management under TRF support
2015–2016	Analysis Report of Thailand's Water Situation: Water Resources and Economic Development under TRF support
	Development of Information Systems to Support Provincial Budget Planning in the Water and Agricultural Sectors under TRF support
2016–2018	Development of Mechanisms to Support Budget Planning in Water and Agriculture through Information Systems Integration under TRF support
2017	Conceptual Framework for Research on Water–Food–Energy Nexus toward Sustainable Development Planning under TRF support
2018–2019	Roadmap for Strategic Research Issue of Water Management to Support National Water Strategy under TRF support
	Analysis of Water Security, Water Productivity and Water-related Disaster for Water Resources Master Plan under TRF support
2020	Academic Seminar of National Research Council of Thailand (NRCT) on the 2020 Drought Situation and Future Management Strategies

Appendix B

List of Executive Committee Members, Project Managers, and Research Management Team

Spearhead Research Program website: www.sip-water.com

List of Executive Committee Members

Phase 1

1.	Secretary General of the National Research Council of Thailand (NRCT)	Committee Advisor
2.	Director of Thailand Science Research and Innovation	Committee Advisor
3.	Deputy Secretary General of the NRCT (Ms. Wiparat De-ong)	Committee Advisor
4.	Assoc. Prof. Dr. Sucharit Koontanakulvong	Chairman
5.	Prof. Surichai Wankaew	Vice Chairman
6.	Assoc. Prof. Dr. Jessada Keawkallaya	Committee Member
7.	Dr. Somchai Baimuang	Committee Member
8.	Mr. Worawut Tantiwanit	Committee Member
9.	Ms. Ladawan Kumpa	Committee Member
10.	Mr. Surajit Chirawate	Committee Member
11.	Secretary General of the Office of the National Water Resources or Representative	Committee Member
12.	Director General of the Royal Irrigation Department or Representative	Committee Member
13.	Director General of the Thai Meteorological Department or Representative	Committee Member
14.	Chairman of the National Farmers' Council or Representative	Committee Member
15.	Representative of the Federation of Thai Industries	Committee Member
16.	Director of the Planning and Budgeting Division or Representative, NRCT	Committee Member
17.	Dr. Krissanapong Kirtikara	Committee Member
18.	Director of the Public Welfare Division (Division 3), The Thailand Research Fund	Secretary General

19. Project Management Officer, The Thailand Research Fund — Assistant Secretary General
20. Policy and Planning Analyst, The Thailand Research Fund — Assistant Joint Secretary General

Phase 2

1. Director of the NRCT	Committee Advisor
2. Assoc. Prof. Dr. Sucharit Koontanakulvong	Chairman
3. Prof. Surichai Wankaew	Vice Chairman
4. Assoc. Prof. Dr. Jessada Keawkallaya	Committee Member
5. Ms. Ladawan Kumpa	Committee Member
6. Dr. Somchai Baimuang	Committee Member
7. Mr. Worawut Tantiwanit	Committee Member
8. Secretary General of the Office of the National Water Resources or Representative	Committee Member
9. Director General of the Royal Irrigation Department or Representative	Committee Member
10. Director General of the Thai Meteorological Department or Representative	Committee Member
11. Representative of the Federation of Thai Industries	Committee Member
12. Plan and Policy Specialist, NRCT	Committee Member
13. Director of the Management and Results Delivery Unit, NRCT	Secretary General
14. Plan and Policy Analyst, NRCT	Assistant Secretary General

Phase 3

1. Director of the NRCT	Committee Advisor
2. Assoc. Prof. Dr. Sucharit Koontanakulvong	Chairman
3. Prof. Surichai Wankaew	Vice Chairman
4. Assoc. Prof. Dr. Jessada Keawkallaya	Committee Member
5. Ms. Ladawan Kumpa	Committee Member
6. Dr. Somchai Baimuang	Committee Member
7. Mr. Worawut Tantiwanit	Committee Member
8. Secretary General of the Office of the National Water Resources or Representative	Committee Member

9.	Director General of Royal Irrigation Department or Representative	Committee Member
10.	Director General of Thai Meteorological Department or Representative	Committee Member
11.	Representative of the Federation of Thai Industries	Committee Member
12.	Director of the Research and Innovation Management Division 1, NRCT	Committee Member
13.	Director of the Management and Results Delivery Unit, NRCT	Secretary General
14.	Plan and Policy Analyst, NRCT	Assistant Secretary General

List of Research Projects and Project Heads

Research Project	Project Manager	Affiliation
Water Management Group in the Eastern Economic Corridor (EEC)		
1. Administration and Synthesis of the Research Projects on Water Balance and Water Saving for Sustainable Development in the EEC	Assoc. Prof. Dr. Bancha Kwanyuen	Kasetsart University
2. Analysis and Management of water balance in EEC	Dr. Jutithep Vongphet	Kasetsart University
3. Guidelines for Water Efficiency Enhancement for Water Users in Community to Support the Development of the EEC	Assoc. Prof. Dr. Chaisri Suksaroj	Kasetsart University
4. Development of Industrial and Urban Areas by Wastewater Reclamation in EEC Area	Assoc. Prof. Dr. Chavalit Ratanatamskul	Chulalongkorn University
5. Study of Agricultural Water Requirement under Changing Environmental to Supporting the EEC Development	Dr. Songsak Puttrawutichai	Kasetsart University
6. Development of Water Management Systems to Enhance Water Efficiency in the Industrial Sector within the EEC	Ms. Panrat Phechpakdee	The Federation of Thai Industries
7. Development of Smart Water Management Systems for Service Sector in EEC	Asst. Prof. Dr. Tanapon Phenrat	Naresuan University

Research Project	Project Manager	Affiliation
8. Conflict Prevention and Management in Water Consumption: A Case Study of the EEC and Related Areas	Dr. Somnuck Jongmeewasin	Silpakorn University
9. Learning and Knowledge Transfer Center for Treated Wastewater Management	Dr. Chanyut Kalakan	Burapha University
10. Study and Development of Green Area Sensor and Information System for Field Level	Asst. Prof. Dr. Sanphet Chunithipaisan	Chulalongkorn University
11. Administration and Syntheses on the Study of Research Projects to Support on Water Saving in the EEC	Assoc. Prof. Dr. Bancha Kwanyuen	Kasetsart University
12. Development of Information System for Water Operating in the EEC	Dr. Jutithep Vongphet	Kasetsart University
13. Feasibility Study and Roadmap for Initiating the Specialized Organization for Water Development and Management in the EEC	Assoc. Prof. Dr. Chaisri Suksaroj	Kasetsart University
14. Development of Ministerial Regulations Framework on Water Savings and Water Reclamation in EEC by Integration of Technical and Socioeconomical Measures	Assoc. Prof. Dr. Chavalit Ratanatamskul	Chulalongkorn University
15. Progress Report on Water Efficiency Initiatives in the 1st Year of Operation of the Exemplary Industry and Comprehensive Survey of Water Sources and Industrial Water Usage Data in the EEC	Ms. Panrat Phechpakdee	The Federation of Thai Industries
16. Economic Valuation of Water Management Systems Development with Technology for the Industrial, Service, and Urban Sectors in the EEC	Assoc. Prof. Dr. Witsanu Attavanich	Kasetsart University
17. Technology Transfer and Entrepreneurship Incubation for Bio- and Agro-industries based on Recirculation Usage of Community Treated Wastewater	Dr. Chanyut Kalakan	Burapha University
18. Development of Smart Sensor Systems for Smart Park System with Water Hydration Training for the Service and Industrial Sectors to Reduce Water Consumption in the EEC	Asst. Prof. Dr. Sanphet Chunithipaisan	Chulalongkorn University

Research Project	Project Manager	Affiliation
19. Refining Water Management Adjustments within the EEC Development Zone and Advancing Implementation	Assoc. Prof. Dr. Bancha Kwanyuen	Kasetsart University
20. Development of Social Policies for Water Conservation and Efficient Water Use Based on Scientific Research Findings	Dr. Pavisorn Chuenchum	Chulalongkorn University
Smart Dam Management Group		
21. Adaptation Strategy toward Reservoir Re-operation for Long-term Water Supply Management of Bhumibol Dam (Phase 1)	Asst. Prof. Dr. Areeya Rittima	Mahidol University
22. Study and Assessment of Water Supply (Runoff, Surface Water, and Groundwater) in the Lower Chao Phraya River Basin	Asst. Prof. Dr. Chaiyapong Thepprasit	Kasetsart University
23. Development of Groundwater Management System to Improve Conjunctive Use Water Management System	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University
24. Development of a Two-week Rainfall Forecasting System for Water Management in the Chao Phraya River Basin Area	Dr. Kanoksri Sarinnapakorn	Hydro Informatics Institute (Public Organization)
25. Big Data Analysis System for Water Management Planning	Asst. Prof. Sukree Sinthupinyo	Chulalongkorn University
26. Training on Big Data-driven Rainfall Analysis for Water Management Planning	Dr. Piamchan Doungmanee	Chulalongkorn University
27. Assessment of Water Demand in the Central Plains Region (Phase 1)	Dr. Chuphan Chompuchan	Kasetsart University
28. Water Resources Study for Strategic Flood Risk Management in the Ping-Nan and Chao Phraya River Basin	Dr. Sanit Wongsa	King Mongkut's University of Technology Thonburi
29. Economic and Social Risk Assessment of Flood and Drought	Dr. Pongsak Suttinon	Chulalongkorn University
30. Chao Phraya Delta 2040	Assoc. Prof. Dr. Suttisak Soralump	Kasetsart University
31. Water Management Plan Data Lab	Assoc. Prof. Dr. Phisan Santitamnont	Chulalongkorn University
32. Integrated Water Resource Management for Drought Risk Reduction	Asst. Prof. Dr. Chaiwat Ekkawatpanit	King Mongkut's University of Technology Thonburi

Research Project	Project Manager	Affiliation
33. Research and Development of Rainfall Forecasting Systems to Support Water Management in the Chao Phraya River Basin	Dr. Kanoksri Sarinnapakorn	Hydro Informatics Institute (Public Organization)
34. Operation of New Reservoir Systems for Long-term Water Supply Management in the Upper Chao Phraya River Basin by Using AI Techniques (Phase 2)	Asst. Prof. Dr. Areeya Rittima	Mahidol University
35. Assessment of Water Demand and Surface Water Quantities for Water Management in the Chao Phraya River Basin	Asst. Prof. Dr. Chaiyapong Thepprasit	Kasetsart University
36. Groundwater Management System Development for Integrated Planning to Enhance Water Management Efficiency with Surface Water in the Northern Part of Lower Central Plains Region	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University
37. Development of a Communication Platform for Raising Awareness and Collaboratively Addressing Water Issues (to Support the Conceptual Framework Development of Chao Phraya Delta 2040)	Assoc. Prof. Dr. Suttisak Soralump	Kasetsart University
38. Assessment of Economic Impacts and Social Perspectives on Drought	Mr. Arthittayapong Suchinroj	KlickerLab Co., Ltd.
39. Economic Evaluation of Developing Water Management Systems with Technology for the Industrial, Service, Tourism, and Urban Community Sectors in the Chao Phraya River Basin Area	Assoc. Prof. Dr. Witsanu Attavanich	Kasetsart University
40. Technology Development to Enhance Water Supply Capacity of Main Dams and Water Resource Management in the Central Plains Region	Asst. Prof. Dr. Chaiyapong Thepprasit	Kasetsart University
41. Development of Automatic Reservoir Management Systems in the Chao Phraya River Basin	Asst. Prof. Dr. Areeya Rittima	Mahidol University

Research Project	Project Manager	Affiliation
Irrigation Water Management Group		
42. Mathematical Modeling System of Utilizing Water Supply for Enhanced Agriculture Management	Asst. Prof. Dr. Panuwat Pinthong	King Mongkut's University of Technology North Bangkok
43. Development of Technology for Improved Water Management in Irrigation Projects	Assoc. Prof. Dr. Phayung Meesad	King Mongkut's University of Technology North Bangkok
44. Guidelines for Enhancing Water Efficiency Management in the Thorthongdaeng Operation and Maintenance Project in Kamphaeng Phet Province	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
45. Institutional Strengthening and Good Governance Mechanisms for Irrigation Management in the Irrigation Project Area, Kamphaeng Phet Province	Dr. Man Purotaganon	Foundation for Integration of Water Management (Thailand)
46. An extended of IoT and AI Development Technology for Water Management and Operation Improvement in Irrigated Area of Thorthongdaeng Operation and Maintenance Project	Asst. Prof. Dr. Panuwat Pinthong	King Mongkut's University of Technology North Bangkok
47. Assessment of the Potential and Utilization of Groundwater for Planning a Conjunctive Use Water Management System in the Thorthongdaeng Operation and Maintenance Project	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University
48. Development of Participatory Mechanisms between Irrigation Water Management Groups and Organization to Increase Water Management Efficiency at Thorthongdaeng Operation and Maintenance Project	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
49. Development of Area-Based Management Mechanisms for Water Planning to Support Provincial Agricultural and Marketing Target under the Spearhead Research Program for Social Strategic Goals on Water Management Phase 2	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University

Research Project	Project Manager	Affiliation
50. Development of GIS for Community-based Participatory Water Management to Propose a Community Water Management Plan at the Local Level, Kamphaeng Phet Province	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
51. Enhancing Efficiency in Water Management Planning for Water User Organizations through Collaborative Mechanisms with Government Agencies, Local Administrative Organizations, and the Provincial Water Resources Subcommittee, Kamphaeng Phet Province	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
52. Economic and Social Impact Assessment of Developing Water User Groups in the Thorthongdaeng Irrigation Area	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University
Water Management Group in Non-Irrigated Areas		
53. Guidelines for Enhancing the Capacity of Community Water User Organizations for Area-Based Water Management Planning	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
54. Capacity Building for Sustainable Water Management at Local Level: A Case Study of Participatory Assessment of Community Water	Dr. Surangrut Jumnianpol	Chulalongkorn University
55. Area-Based Water Management Planning through Collaborative Mechanisms between Water User Organizations and Local/Provincial Governmental Agencies in Sample Provinces to Promote Water Conservation, Water Usage Efficiency, and Scientific Utilization	Mr. Chitsanuwat Maneesrikum	Sangsan Panya Co., Ltd.
56. Economic and Social Impact Assessment of Developing Water User Groups Beyond Irrigation Area Boundaries	Assoc. Prof. Dr. Tuantan Kitpaisalkul	Chulalongkorn University
Driving, Management and Output Delivery		
57. Water Security Assessment based on Development of Water Management System using Technology in Central Region and The Eastern Economic Corridor (EEC)	Asst. Prof. Dr. Piyatida Ruangrassamee	Chulalongkorn University

Research Project	Project Manager	Affiliation
58. Organizing a Social Lab Workshop to Foster Collaborative Problem-Solving for Water Conservation, Efficient Water Use, and Science-Driven Solutions	Assoc. Prof. Dr. Suttisak Soralump	Kasetsart University
59. Supporting Research and Innovation Directions and Drive Policy Setup under Water Resources Management Spearhead Project	Dr. Supattra Visessri	Chulalongkorn University
60. Research to Drive the 2nd Year Water Resources Management Spearhead Research Plan	Dr. Supattra Visessri	Chulalongkorn University
61. Drive, Connect, Develop (Water Management)	Mr. Teetitorn Chullapram	Chulalongkorn University
62. Develop, Drive and Linkage for Water Management Improvement in TTD Project	Mr. Teetitorn Chullapram	Chulalongkorn University
63. Knowledge Communication of Water Management in Thailand	Ms. Wimonphon Baison	I&I Communication Co., Ltd.
64. Research and Innovation Supportive Activities Phase 3 Report	Assoc. Prof. Dr. Sucharit Koontanakulvong	Chulalongkorn University

Research Management Team

Phase 1

1. Program Chair

Assoc. Prof. Dr. Sucharit Koontanakulvong
Faculty of Engineering, Chulalongkorn University
sucharit.k@chula.ac.th
081-646-9750

2. Director of Operations and Delivery Unit (ODU)

Prof. Dr. Chanathip Pharino
Faculty of Engineering, Chulalongkorn University
chanathip.p@chula.ac.th
0-2218-6668

3. Manager of the Collaborative Office on Strategic Water Management Researches (Social Strategic Goals Research Program)

    Dr. Nuchcha Phonphoton
    Faculty of Science and Health Technology, Navamindradhiraj University
    nuchcha@nmu.ac.th
    0-2244-3000 ext. 5814

Phase 2

1. Program Chair

    Assoc. Prof. Dr. Sucharit Koontanakulvong
    Faculty of Engineering, Chulalongkorn University
    sucharit.k@chula.ac.th
    081-646-9750

2. Director of ODU

    Asst. Prof. Dr. Pongsak Suttinon
    Faculty of Engineering, Chulalongkorn University
    pongsak.su@chula.ac.th
    098-328-0234

3. Deputy Director of ODU

    Dr. Pavisorn Chuenchum
    Faculty of Engineering, Chulalongkorn University
    pavisornchuenchum@gmail.com
    080-809-1332

4. Research Driving Project Head

    Asst. Prof. Dr. Supattra Visessri
    Faculty of Engineering, Chulalongkorn University
    supattrav@hotmail.com
    081-694-6680

5. Secretary to the Program Chair

    Ms. Duenpen Punayangkool
    Faculty of Engineering, Chulalongkorn University
    fon_fon1@hotmail.com
    081-907-5513

Phase 3

1. Program Chair

    Assoc. Prof. Dr. Sucharit Koontanakulvong
    Faculty of Engineering, Chulalongkorn University
    sucharit.k@chula.ac.th
    081-646-9750

2. Program Advisor

    Dr. Supichai Tangjaitrong
    Chula Unisearch, Chulalongkorn University
    unisearch@chula.ac.th
    0-2218-2880

3. Director of ODU

    Assoc. Prof. Dr. Tuantan Kitpaisalkul
    Faculty of Engineering, Chulalongkorn University
    tuantan.k@chula.ac.th
    087-076-1119

4. Secretary to the Program Chair

    Ms. Duenpen Punayangkool
    Faculty of Engineering, Chulalongkorn University
    fon_fon1@hotmail.com
    081-907-5513

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