Watershed Management and Classification in Thailand

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Abstract: Based on a study of research and experiences in Thailand, this paper provides an overview of the implementation and challenges of watershed management, as well as potential solutions. The review found hierarchical ambiguity, inconsistency, and asynchrony across rules, as well as a lack of (participation, synchronization, and coordination) among watershed management stakeholders. Deficits in the planning phase include a lack of integration between sectors, a lack of community participation, and a limited willingness to integrate watershed planning into regional planning. Stakeholder participation is also essential for the successful implementation of degraded watershed rehabilitation, including in terrestrial forest and mangrove regions. Failure should be minimized by providing adequateknowledge about degraded watershed characteristics, selecting appropriate plant species, and employing good mechanical construction techniques for soil and water conservation. Increase public understanding of the importance of a sustainable watershed and provide opportunities for community involvement in each phase of watershed management to achieve community participation as the majordriver of watershed management. Another issue is data gaps, which must be addressed from the designthrough the evaluation stages. The gaps can be filled using remotely sensed data and hydrologically based modeling models. Simplified watershed assessment criteria may also be required, depending on site-specific challenges and the extent of the watershed.

1. Introduction

The Kingdom of Thailand has demonstrated notable advancements in its economic development, particularly in the areas of energy, transportation, and tourism. The country's robust economic expansion since the 1970s facilitated its inclusion in the category of upper-middle-income economies throughout the early 2010s. According to the 2017 National Strategy Preparation Act of Thailand, the country has set a goal to achieve a high-income economy by the year 2037, with a focus on attaining "Security, Prosperity, and Sustainability." Hence, Thailand is actively pursuing measures to improve its economic competitiveness and social progress with the aim of positioning itself as a prominent nation in the Southeast Asian region (OECD, 2019[1]).

The successful management of water resources, encompassing flood control, irrigation, and water delivery, is crucial for achieving economic prosperity. However, Thailand's growing water insecurity poses a significant threat to the realization of its ambitious goals. The anticipated challengesof sustainable water management in the future are likely to be exacerbated by factors such as populationgrowth, economic expansion, accelerated urbanization, and the imminent risks associated with climate change. According to projections from The World Bank Group and the Asian Development Bank (2021), it is anticipated that Thailand's population would reach approximately 71-77 million by the year2030, with a growing percentage residing in metropolitan regions. According to Ta and Watershed (2008), the urbanization rate in 2020 accounted for 51.43% of the whole population. This shift in lifestyle patterns has resulted in a corresponding rise in the demand for water resources. According to the World Bank Group and the Asian Development Bank (2021), the majority of Thailand's economy,approximately 90%, is reliant on the industrial and service sectors. In contrast, the agricultural sector, while accounting for only 10% of the economy, employs approximately 33% of the country's workers.Water productivity in Thailand is generally low across all sectors, with agriculture experiencing very low levels, practically approaching zero. In contrast, the industry sector achieves a water productivity of approximately 60 USD per m3 (Chokchai & Sucharit, 2019[4]).

Thailand is widely acknowledged as being particularly susceptible to climate fluctuation and change as a result of the escalating occurrence of natural hazards, including but not limited to intense precipitation, inundations, and periods of prolonged dryness. Furthermore, the rise in sea level has a significant impact on the coastal regions of the country. The country was ranked 31st in the National

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Water Security Index among a group of 49 Asian and Pacific countries. This ranking was mostly attributed to a poor level of water urban security and a strong presence of climatological threats (Asian Development Bank, 2020[5]).

According to the findings of the Intergovernmental Panel on Climate Change, it is projected that the rise in global sea levels, which is attributed to climate change, will range from 8 to 16 millimeters per year throughout the 21st century. The anticipated rise in sea level inside the inner regionof the Gulf of Thailand is attributed to the phenomenon of global climate change. The augmentation inwind velocity, particularly the monsoonal winds that traverse the Gulf of Thailand, contributes to the elevation of the sea level. According to the World Bank Group (2021[6]), Multiple water challenges are currently present, including the escalating competition for water resources in the agricultural, industrial, and service sectors, the degradation of water quality caused by the rising levels of pollutants, the exacerbation of flood and drought impacts due to climate change, and the complex management of rivers and aquifers that span across different regions.

Thailand is significantly affected by floods, which represent the most substantial natural hazardin terms of both economic and human consequences. Thailand is recognized as being among the top ten countries globally that are most susceptible to flooding. The impacts of drought and cyclones are significant hazards as well. All variables have the potential to increase in future climatic scenarios. The projected increase in the population impacted by a severe river flood is estimated to surpass 2 million individuals between the years 2035 and 2044. Additionally, it is anticipated that coastal flooding will affect an additional 2.4 million people from 2070 to 2100. According to projections, the agricultural sector of Thailand may see substantial repercussions as a result of climate change. This vulnerability is mostly attributed to Thailand's geographical location within the tropical region, where agricultural production is particularly susceptible to increases in temperature (The World Bank Group and the Asian Development Bank, 2021[2]). Thailand has prioritized its adaptation endeavors in significant sectors including energy, water, transportation, agriculture, human settlements, and public health, as indicatedin its Third National Communication to the United Nations Framework Convention on Climate Change in 2018, its Initial Nationally Determined Contribution in 2016, and its Updated Nationally DeterminedContribution in 2020 (The World Bank Group and the Asian Development Bank, 2021[2]). This, coupled with the impacts of frequent severe droughts and floods over the past 20 years, has resulted in a perceived need for a watershed classification system as a major vehicle for future land and water resources planning and management for sustainable socioeco-nomic development of the country. A primary objective of the watershed classification project was to develop land use plans for the conservation of natural resources, specifically water resources, with the goal of ensuring their sustainable use. The classification takes into account physical characteristics, such as landform, geology, soil, elevation, and slope. Consideration is also given to forest cover and environmental characteristics of less stable landscape units that interact with climatic trends and human uses.

2. Watershed management in Thailand

2.1 Water resource management problems in Thailand

About 800 billion m3 yr1 of precipitation is averaged to fall on Thailand each year. The amount of natural flow that is left over after accounting for loss due to evaporation, evapotranspiration, and infiltration is around 200 billion m3. 79% of the stream's normal flow is made up of runoff. The countryconsumes approximately 152 billion m3 of freshwater each year, making this figure its annual demand. The water requirement is broken down as follows: 114 billion m3 is required for agricultural purposes, 11 billion m3 is required for industrial and home consumption, and 27 billion m3 is required for ecosystem maintenance.

The remaining 50 billion m3 of available water cannot be distributed in any way, and there areonly 102 billion m3 available overall. The latter segment provides the majority of the water essential for rain-fed agriculture as well as some of the water necessary for residential consumption.

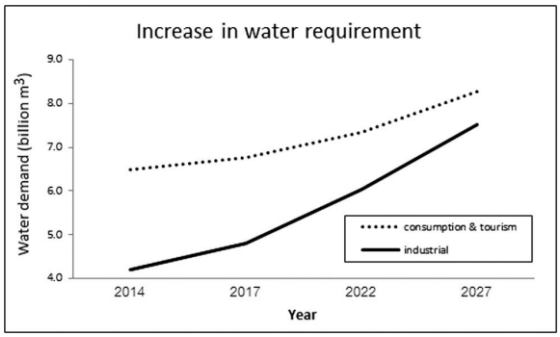
As of right now, the population of Thailand is growing alongside the expansion of the country's economy, which has led to an increase in the need for water.

In addition, the requirements for water to support household consumption, tourist, and industrial operations are continuously developing at a rate that is accelerating. According to the statistics, by the year 2027, Thailand will require an additional 5 billion m3 of water in order to satisfygrowing demand (Figure 1). According to the Committee on Water Resources Policy and Management (2015), the increasing trend demonstrates that Thailand needs to create appropriate water managementin preparation for a potential water scarcity.

However, land scarcity and ecological However, land scarcity and ecological concerns make project approval for water resources development anything from guaranteed. The demand from the Thai people and from agricultural products is growing every year, but the expansion of irrigated regions has stalled due to a scarcity of water resources. The loss of forest cover exacerbates the issue of increased runoff during the wetter seasons and decreased streamflow during the drier seasons. The cost of water continues to rise. Therefore, Thailand is focusing more on water resources management to meet the increased demand. All industries can benefit from improved water efficiency by adopting and implementing innovative water policies and practices. Adopting sustainable development requires striking a balance between economic expansion and the consumption of natural resources.

Figure 1 Increasing water demand in Thailand

Sources: Somkiat *et.al*., (2018)



2.2 Master Plan on Water Resource Management

Water resources are essential for human survival and environmental well-being. Thailand has faced increasingly severe droughts and floods in recent years, causing significant economic losses estimated at 10 billion baht. The devastating 2011 flood, assessed by the World Bank, resulted in damages and losses of approximately 1.44 trillion baht. The main challenges in water resource management include degradation of watersheds, inadequate management, lack of a unified authority, absence of a long-term master plan, outdated data, and obsolete regulations.

To address these issues, Thailand has developed a Master Plan on Water Resource Management, consisting of eight major work plans and two action plans:

1. **Work Plan for Restoration and Conservation of Forest and Ecosystem**: This plan focuses on restoring watershed forests, developing water reservoirs, and creating land use plans tailored to local conditions. It also includes soil and water conservation projects, afforestation initiatives, and revisions to relevant laws.

2. **Work Plan for Management of Major Water Reservoirs and National Annual Water Management**: This plan aims to prevent and mitigate future floods by developing water managementplans for major dams and river basins, formulating water management plans for various scenarios, improving water use balance, and providing water-related information to the public.

3. **Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures**: To prevent and mitigate flood impacts, this plan includes renovating dikes, water control buildings, and drainage systems, improving waterways and canals, enhancing waterdraining and overflowing management, and reinforcing dikes. Long-term measures such as floodways, preventive dikes, and land use planning are also considered.

4. **Work Plan for Information Warehouse and Forecasting**: This plan involves developing a data system, creating hypothetical scenarios, establishing water management institutions, and enhancing the disaster warning system. It includes setting up a national water information center, constructing forecasting and disaster warning systems, and upgrading monitoring stations and satellitesystems.

5. **Work Plan for Preparedness in Specific Areas**: To enhance flood prevention and mitigation, this plan focuses on important areas such as agriculture, industry, and densely populated communities. It includes building flood prevention systems, creating systems for negotiations with affected parties, and assessing the impacts of private prevention systems.

6. **Work Plan for Assigning Water Retention Areas and Recovery Measures**: This plan assigns water retention areas in the Chao Phraya River basins to slow down water flow during flashfloods and formulates plans for diverting water into these areas. Special compensation measures fordesignated water retention areas are also part of this plan.

7. **Work Plan for Improving Water Management Institutions**: This plan aims to establish integrated water management organizations as single command authorities responsible for crisis decision-making, planning, monitoring, evaluation, and rule revision. In the short term, the Ad Hoc Committee chaired by the Prime Minister or assigned Deputy Prime Minister serves as the single command authority, while a permanent national integrated water management agency is envisionedfor the long term.

8. **Work Plan for Creating Understanding, Acceptance, and Participation**: This plan seekscollaboration with communities and stakeholders to manage flood impacts and other major disasterseffectively.

The Master Plan on Water Resource Management is a comprehensive strategy to address Thailand's water resource challenges, ensuring the sustainable use of this vital resource while mitigating the impacts of extreme events like floods and droughts.

2.3 Land Use Change and Its Impact in Thailand

Land use change significantly impacts environmental and socio-economic development in Thailand. Urbanization, agriculture expansion, and industrialization drive these changes. Urbanization, propelled by population growth and migration, leads to encroachment into agricultural areas and undeveloped land. Agriculture, a key sector, undergoes expansion to meet food and material demands, often at the cost of forests and natural habitats. Thailand's industrial sector, a magnet for investment, requires large land areas, further exacerbating land conversion.

Environmental Impact:

1. **Deforestation:** Land use change results in substantial deforestation, harming biodiversity and contributing to climate change. Forests are cleared for agriculture, infrastructure, and urban expansion.

2. **Loss of Biodiversity:** Habitat loss endangers numerous plant and animal species, disrupting ecosystems and posing threats to endemic species.

Socio-economic Impact:

1. **Displacement of Communities:** Land use change often displaces rural communities, particularly indigenous and marginalized groups, causing social and economic challenges.

2. **Water Resource Management:** Changes in land use affect water resources, causing soil erosion and reduced water quality. Proper land use planning is crucial for sustainable waterresource management.

Addressing land use change in Thailand requires comprehensive policies that balance economic development with environmental conservation and social equity. Watershed integration is a holistic approach that effectively mitigates the impact of land use change. By coordinating land and water resource management within specific watersheds, considering ecosystem interconnections, and involving stakeholders, watershed integration promotes sustainable development while reducing environmental degradation. For instance, in the Ping River Watershed, reforestation, sustainable agriculture, water resource management, and community engagement have effectively countered landuse change impacts. This holistic approach serves as a model to tackle land use challenges sustainably and collaboratively in Thailand

2.4 Implementation of Mechanical Soil and Water Conservation Measures to Control Erosion and Sedimentation in Thailand

Erosion and sedimentation are critical environmental issues that have far-reaching consequences for land degradation, water quality, and ecological balance. In Thailand, as in many other regions globally, these issues have gained prominence due to the adverse impacts of deforestation, agricultural practices, and urban development. To combat these challenges and preserve the nation's natural resources, Thailand has been proactive in implementing mechanical soil and water conservation measures.

Thailand's Erosion and Sedimentation Challenge: Thailand's diverse landscapes face erosion and sedimentation threats, driven by deforestation from logging and land conversion for agriculture and development. Deforestation removes protective forest canopies, leading to soil erosion during heavy rainfall, increased surface runoff, and sediment transport into rivers.

Agricultural practices, including traditional farming on steep slopes, worsen erosion. Sedimentationin rivers and reservoirs affects water quality, reduces storage capacity, and harms aquatic ecosystems.

Mechanical Soil and Water Conservation Measures: Thailand has implemented mechanicalsoil and water conservation measures to combat erosion and sedimentation, promoting sustainable land and water resource management.

1. **Terracing and Contour Farming**: Terracing creates horizontal steps on slopes to slow surface runoff and trap sediment. Contour farming plants crops along contour lines to reduce soil erosion, stabilizing slopes.
2. **Check Dams and Gabions**: Check dams across streams slow water flow and trap sediment. Gabions, wire mesh containers filled with rocks, stabilize streambanks and prevent erosion.
3. **Riparian Buffers**: Native vegetation along riverbanks acts as natural filters, trappingsediments, nutrients, and pollutants, enhancing water quality and wildlife habitat.
4. **Sediment Basins and Detention Ponds**: Engineered structures capture sediment-ladenrunoff, allowing sediments to settle before water enters water bodies, reducing downstream sedimentation.
5. **Reforestation and Afforestation**: Replanting trees in deforested areas (reforestation) and establishing forests in non-forested lands (afforestation) reduce erosion.

Challenges and Recommendations: Despite progress, challenges remain, including funding,land tenure, and awareness. To address these:

1. **Strengthen Enforcement and Compliance**: Improve enforcement of land use regulationsand conservation practices.
2. **Enhance Public Awareness**: Raise awareness about soil and water conservation's importance and benefits.
3. **Invest in Research and Innovation**: Support research and adapt erosion controltechniques to local conditions.
4. **Promote Multi-Stakeholder Collaboration**: Encourage collaboration among government agencies, NGOs, communities, and private sectors for comprehensive conservation programs.

In conclusion, Thailand's commitment to erosion and sedimentation mitigation through mechanical measures demonstrates dedication to sustainable land and water resource management. Addressing challenges and fostering collaboration can further preserve natural resources and safeguard the environment

2.5 Downstream Essential Ecosystem Management in Thailand

Thailand's Downstream Ecosystem Management: Thailand relies on its extensive river systems, such as the Chao Phraya and Mekong rivers, for socio-economic development, agriculture, industry, and urban areas. These rivers also support downstream ecosystems, prompting Thailand to focus on essential ecosystem management for biodiversity

preservation, water quality, and sustainable resource use.

Importance of Downstream Ecosystems: Downstream ecosystems, often in floodplains and wetlands, provide critical habitats for diverse plant and animal species. They serve as breedinggrounds for fish vital to fishing communities and act as natural buffers, reducing flooding and recharging groundwater. These ecosystems offer ecosystem services like water purification, benefiting both local communities and the agricultural sector.

Challenges to Downstream Ecosystems: Human activities, including urbanization, agriculture, industrialization, and infrastructure development, have led to habitat loss and degradation. Water extraction and pollution from agriculture and urban areas further threaten these ecosystems. Climate change-induced shifts in rainfall patterns and increased temperatures also affect seasonal floods.

Essential Ecosystem Management Strategies:

1. **Wetland Conservation**: Thailand protects designated wetlands of international importance under the Ramsar Convention, ensuring their sustainability.

2. **Riparian Zone Protection**: Establishing buffer zones along rivers prevents erosion, reduces pollution runoff, and maintains habitat connectivity.

3. **Restoration and Reforestation**: Initiatives restore and reforest downstream areas, improving habitat quality and flood control.

4. **Sustainable Land Use Practices**: Encouraging sustainable agriculture and land use practices, like agroforestry and organic farming, minimizes habitat disruption.

5. **Water Quality Monitoring**: Regular monitoring of water quality parameters detectsthreats early, allowing effective pollution source management.

6. **Community Engagement**: Involving local communities in ecosystem managementfosters responsibility and leads to sustainable resource use practices.

7. **Climate Resilience**: Developing climate-resilient strategies, such as floodplain zoningand early warning systems, mitigates climate change impacts on downstream areas, reducing vulnerability.

Thailand's commitment to downstream essential ecosystem management reflects its dedication to preserving biodiversity and natural resources. By addressing challenges through strategic conservationand restoration efforts, Thailand ensures these ecosystems benefit future generations. Collaboration among government agencies, local communities, and conservation organizations is essential for sustainable downstream ecosystem management, supporting nature and the well-being of the Thai people.

2.6 Mangrove Management in Thailand

Mangroves are critical ecosystems that provide a wide range of ecological and socio-economic benefits. In Thailand, these coastal forests are found along the country's extensive coastline, particularlyin the southern regions and along the Gulf of Thailand. Mangrove management in Thailand has been apriority due to the recognition of their importance for:

1) **Biodiversity Conservation**: Mangroves serve as nurseries and habitats for various marine species, including fish and crustaceans. Protecting and restoring mangroves are essential for preserving coastal biodiversity.
2) **Coastal Protection**: Mangrove forests act as natural buffers against coastal erosion and storm surges. They help protect coastal communities from the impacts of extreme weather events.
3) **Carbon Sequestration**: Mangroves store large amounts of carbon, making them crucial in mitigating climate change. Proper management helps prevent carbon release through deforestation and degradation.
4) **Sustainable Livelihoods**: Mangroves support local livelihoods through fisheries, aquaculture, and non-timber forest products. Sustainable management ensures these resources remain available to communities.
5) **Tourism and Education**: Well-preserved mangrove areas also attract ecotourism and provide educational opportunities to raise awareness about coastal ecosystems.

2.7 Socio-Economic Benefits and Participatory Watershed Management in Thailand

Watershed management in Thailand extends beyond ecological concerns; it encompasses a holistic approach that recognizes the symbiotic relationship between natural resources and human well-being. The nation's commitment to participatory watershed management not only safeguards vital ecosystems but also generates socio-economic benefits that resonate with local communities. This essayexplores the socio-economic benefits of participatory watershed management in Thailand.

Understanding Participatory Watershed Management: Participatory watershed management involves collaboration between government agencies, local communities, and stakeholders to make informed decisions about land and water resource management. This approach recognizes that those

who reside in or near watersheds are intimately connected to the land and its resources. In Thailand, where agriculture plays a pivotal role in the economy and rural communities depend on natural resources, participatory watershed management aligns with the principles of sustainable development.

Enhancing Livelihoods through Agriculture: One of the primary socio-economic benefits of participatory watershed management in Thailand is its positive impact on agriculture, the backbone of the nation's economy. By adopting sustainable farming practices that prioritize soil and water conservation, farmers can increase crop yields and reduce soil erosion. Watershed management initiatives often provide training and resources to help farmers implement these practices. This, in turn,leads to improved food security, increased income, and enhanced livelihoods for rural communities.

Fostering Community-Based Tourism: Thailand's picturesque landscapes, often found in watershed areas, are ideal for community-based tourism. Participatory watershed management encourages the development of ecotourism initiatives that showcase the natural beauty of these regions. Tourists flock to these areas for activities such as trekking, birdwatching, and river cruises, contributing to local economies. The revenue generated from tourism supports infrastructure development, small businesses, and job creation within the communities.

Water Resource Sustainability: Sustainable water management practices, a core component of watershed management, have a profound socio-economic impact. By ensuring the availability of clean and reliable water sources, watershed management directly benefits both urban and rural populations. In urban areas, a stable water supply is essential for industry, commerce, and household use. In rural settings, it sustains agriculture and livestock, fostering economic stability and reducing vulnerability to drought.

Conservation of Biodiversity and Ecological Services: Healthy watersheds are hubs of biodiversity and ecological services. Participatory watershed management in Thailand focuses on preserving these ecosystems, which offer indirect socio-economic advantages. The conservation of forests, wetlands, and rivers ensures a stable environment for wildlife and fisheries. This not only supports local livelihoods but also contributes to the resilience of ecosystems, reducing the risk of natural disasters that can devastate communities.

Community Empowerment and Social Capital: Participatory watershed management empowers local communities to actively engage in decision-making processes. It fosters a sense of ownership and responsibility among residents, strengthening social cohesion and building social capital.As communities collaborate on conservation efforts, they develop networks, knowledge, and skills thatextend beyond watershed management, positively influencing other aspects of community life.

Socio-economic benefits arising from participatory watershed management in Thailand underscore the significance of integrated natural resource management. By aligning environmental preservation with economic development and community well-being, Thailand's approach to watershed management sets an inspiring example. As the nation continues to invest in participatory initiatives, it not only ensures the long-term health of its ecosystems but also empowers its people, fostering a sustainable and prosperous future where nature and society thrive together.

2.8 Monitoring and Evaluation of Watershed Management Performance in Thailand

Effective watershed management is a cornerstone of Thailand's environmental conservation efforts and sustainable development goals. To ensure that these initiatives yield positive outcomes andmeet their intended objectives, a robust system of monitoring and evaluation (M&E) is imperative. This concept explores the importance of M&E in watershed management in Thailand, presents key performance indicators, and provides a data table to illustrate the impact of these efforts.

The Significance of Monitoring and Evaluation: Monitoring and evaluation are essential components of watershed management in Thailand. They provide a systematic approach to tracking progress, assessing the effectiveness of interventions, and making informed decisions for adaptive management. In a country characterized by diverse landscapes and ecological challenges, such as deforestation and water resource depletion, M&E is a critical tool to ensure the sustainability of natural resources and the well-being of local communities.

Key Performance Indicators (KPIs) for Watershed Management in Thailand: Effective M&E requires well-defined Key Performance Indicators (KPIs) that reflect the objectives of watershed management. In Thailand, the following KPIs are commonly used to assess performance:

1. **Forest Cover**: The percentage of forest cover within a watershed area is a fundamental indicator. It measures progress in reforestation and protection efforts, with the goal of increasing forested areas to prevent erosion and maintain biodiversity.

2. **Soil Erosion Rate**: Soil erosion is a significant concern in many Thai watersheds. Monitoring the erosion rate helps determine the success of erosion control measures, such as terracing and reforestation.

3. **Water Quality**: Water quality parameters, including turbidity, pH, and pollutant levels, are monitored to assess the health of rivers and streams. Improving water quality is vital for both ecosystems and human consumption.

4. **Biodiversity**: Biodiversity indices, such as species richness and abundance, provide insights into the conservation status of watersheds. Healthy ecosystems support diverse flora andfauna.

5. **Community Well-being**: Socio-economic indicators, such as income levels, access to clean water, and agricultural productivity, are essential for evaluating the impact of watershed management on local communities.

In conclusion, monitoring and evaluation are indispensable tools for assessing the impact of watershed management initiatives in Thailand. By tracking key performance indicators and analyzing data over time, the nation can make informed decisions to enhance the sustainability of its natural resources, protect ecosystems, and improve the well-being of local communities. This data-driven approach ensures that Thailand's watersheds continue to thrive, contributing to the nation's environmental resilience and socio-economic development

3. Watershed classification

3.1 The Concept of Watershed Classification:

The concept of a watershed refers to a geographical area related to water management. In Thailand, the entire country can be viewed as a watershed area requiring proper management. Watershed management seeks to integrate academic principles and public participation to ensure sustainable water resources for river basin areas. This includes maintaining adequate water quantity, consistent flow, good water quality, erosion control, flood damage reduction, and responsible resource utilization based on conservation principles. Achieving these goals involves a step-by-step approach, starting with land use planning and implementing measures for efficient resource use and pollution control.

There have been conflicts over river basin land use among various agencies. To address this, aproject was initiated to classify and determine the quality classes of watersheds in Thailand. It was established by the Basin Quality Classification Committee, led by Prof. Dr. Kasem Chankaew, following a resolution of the National Environment Board and Cabinet approval in 1982. Kasetsart University conducted the research study, which categorized watershed areas based on their environmental fragility and susceptibility to soil erosion.

The classification relies on five physical variables that influence erosion: slope (SLOPE), elevation (ELEV), land type (LANDF), geological characteristics (GEOL), and soil type (SOIL). These variables are used to create a relationship with the quality class values of watersheds (WSC) through standard correlation equations:

$$WSC = a + b(SLOPE) + c(ELEV) + d(LANDF) + e(GEOL) + f(SOIL) + FOR + MIN$$

In this equation, WSC represents the watershed quality class value, while the other variables represent specific characteristics of the area. The constants a, b, c, d, e, and f are used in the calculations.Additionally, variables indicating the status and potential of forest cover (FOR) and mining potential (MIN) are considered.

Thailand's watershed quality is divided into five classes:

1. First Watershed Class: High mountainous areas with steep slopes (over 50%) and characteristics prone to environmental impact. These areas are challenging for land use and should be preserved as watersheds.

2. Second Watershed Class: Suitable for secondary watershed status, typically featuring high mountains, rounded ridges, and moderate slopes (30-50%). Soil erosion is common, and activities like logging and mining are allowed with strict controls.

3. Third Watershed Class: Characterized by mountain slopes, foothills, terraced plains, and areasnear watercourses. Slopes range from 25-35%, and soil erosion is moderate. These areas can be used for agriculture with soil and water conservation measures.

4. Fourth Watershed Class: Found in mountain foothills, low hills, and terraced plains, with slopesof 6-25%. Soil is deep, and it's suitable for field crops with soil and water conservation measures.

5. Fifth Watershed Class: Lowland areas or slightly sloping hills with slopes less than 5%. Soil isdeep and fertile, and erosion resistance is high. These areas are suitable for various agriculturalactivities.

The study project for determining watershed quality classes in Thailand, carried out between 1985 and 1995, resolved long-standing land use conflicts among agencies in river basin areas. It established a framework for responsible land use planning and management, contributing to the sustainable use of Thailand's water resources

1) a master plan for planning land use in various river basin areas throughout the country

2) measures to control land use in river basin areas.

3) Guidelines for the correct and appropriate use of resources within the basin area. (Table 1)

Table 1 Watershed classed areas of various river basins in Thailand

Watershed classes	area	
	square kilometer	percentage
1A	85,463.70	16.66
1B	7,626.66	1.48
2	42,768.62	8.33
3	39,283.77	7.66
4	81,283.77	15.80
5	251,483.62	49.01
reservoir	5,454.96	1.06
total	**531,115.02**	**100.00**

3.2 Importance of Watershed Classification as follows:

1) Resource Allocation: Classification aids in the equitable distribution of resources and funding for watershed management and conservation efforts. It allows decision-makers to prioritize areas with specific needs.

2) Conservation Priorities: Identifying unique and ecologically significant watersheds helps conservation organizations and governments allocate resources for habitat protection and biodiversity conservation.

3) Risk Assessment: Classification facilitates the assessment of environmental risks, including vulnerability to erosion, sedimentation, water pollution, and climate change. This information informsadaptive management strategies.

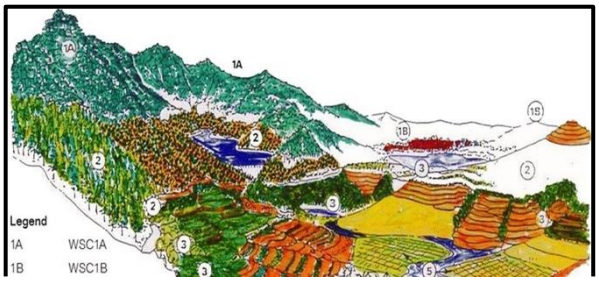
4) Land Use Planning: Urban and rural development planning can benefit from watershed classification by identifying areas at risk of flooding, landslides, or water scarcity. It promotes sustainable land use practices.

5) Policy Development: Watershed classification supports the development of policies andregulations that are tailored to the specific needs and challenges of different watersheds.

Here is an example image illustrating a simplified watershed classification:

Figure 2 Pictorial concept of watershed management in Thailand

Sources: Chankaew. *et.al*., (1996)



3.3 Watershed management in Thailand

In recent years, Thailand has faced significant environmental challenges, with deforestation and water shortages at the forefront. Disturbingly, it is projected that unless stringent measures are enforced, Thailand's forests may disappear entirely by the early 21st century. In the 1970s, laws were enacted to regulate timber harvesting and the export of teak without permits, with the aim of protecting government forestry reserves. Unfortunately, these laws have seen minimal enforcement, largely due to corruption among law enforcement officials [Morell and Poznanski, 1983]. Concurrently, recurrent severe droughts and floods over the past two decades have exacerbated these issues, underscoring the necessity for a watershed classification system as a pivotal tool for future land and water resource planning.

On July 27, 1982, the Office of the National Environment Board (ONEB) was tasked with developing a comprehensive national watershed classification system. The National Economic and Social Development Board (NESDB) provided funding for the project, which was led by Kasetsart University. While the Royal Thai Government was the primary source of funding, the government of Sweden, through the International Union for the Conservation of Nature and Natural Resources (IUCN), provided valuable technical assistance and support.

Throughout the project's duration, watershed classification covering the entire country was undertaken and approved for region-by-region implementation by the Cabinet between 1985 and 1995.The classification system divided the total land area into watershed classes (WSC) 1–5, as follows:

1. WSC1, subdivided into classes 1A and 1B, encompassed protected forests and headwater source areas. These high-elevation, steep-sloped areas were intended to remain as permanent forest cover. Class 1B, sharing similar characteristics with 1A,

included areas with agriculturalclearance or villages, necessitating special soil conservation measures, afforestation, or permanent agroforestry practices.

2. WSC2 represented areas of protection and/or commercial forests. Logging and mining activities were permissible within legal boundaries, with fewer landforms prone to erosion than WSC1B. Grazing or crop cultivation was allowed with appropriate soil protection measures.

3. WSC3 covered upland areas with steep slopes but less erodible landforms compared to WSC2.These areas could be utilized for commercial forestry, grazing, fruit tree cultivation, or specific crops with corresponding soil conservation measures.

4. WSC4 designated gently sloping land suitable for arable crops, fruit trees, and grazing, with moderate soil conservation requirements.

5. WSC5 comprised gentle to flat areas used for intensive agricultural activities such as paddyfields, with minimal restrictions.

By 1987, Watershed classes 1 and 2 were designated for high protection and river headwater rehabilitation, with particular emphasis on preserving watershed class 1A as a protected forest area andwater source. Evacuation and relocation of residents in these areas were planned to ensure their conservation.

The primary objective of the watershed classification project was to formulate land use plans for natural resource conservation, specifically water resources, promoting sustainable utilization. The classification considered physical attributes, including stable features like landform, geology, soil, elevation, and slope, as well as less stable factors such as forest cover and environmental landscape features influenced by climate trends and human activities.

Various methodologies were explored for generating watershed classification maps, ultimately adopting a system [Wooldridge et al., 1983] using a 1 km² grid as the basic classification unit. This gridsize struck a balance, being small enough for practical land use planning yet manageable in terms of data processing. Watershed values were assigned to each 1 km² 'cell' through calculations utilizing topographical, soil, geological, and forest maps.

The project generated watershed classification maps for two sample areas and conducted a multivariate analysis to establish statistical relationships between variables comprising the resulting classification. This analysis determined the proportion of the classification influenced by each variable, along with the constants used to multiply empirical data for each cell. This approach yielded consistent watershed class designations across the entire country, resulting in a general equation for predicting watershed class numbers based on landscape unit values and variable assignments as follows

$$Y(\mathrm{WSC})=a+b(\mathrm{SLOPE})+c(\mathrm{ELEV})+d(\mathrm{LANDFM})+e(\mathrm{GEOL})+f(\mathrm{SOIL})+\mathrm{FOR}$$

The equation for determining watershed class number (Y(WSC)) is influenced by various factors and constants:

- Y(WSC) = a + b(SLOPE) + c(ELEV) + d(LANDFM) + e(GEOL) + f(SOIL) + g(FOR).

In this equation, SLOPE represents slope steepness, ELEV signifies elevation, LANDFM denotes landform, GEOL stands for geological formations, SOIL represents soil properties, and FOR indicates the presence or absence of forest cover. These variables are used to assess and categorize watershed classes based on physical and environmental characteristics.

For example, the equation used for watershed classification in the northern watershed ofThailand is:

$$Y(\mathrm{WSC})=1.93-0.048(\mathrm{SLOPE})-0.004(\mathrm{ELEV})+0.107(\mathrm{LANDFM})+0.116(\mathrm{GEOL})+0.193(\mathrm{SOIL})+\mathrm{FOR}\ (R2=0.9682)3$$

he watershed classification study, covering central, western, north, and northeast Thailand, was finalized in 1992, with Cabinet approval for implementation by 1995. The entire country now adheres to the watershed classification system. Government agencies are mandated to incorporate land utilization measures corresponding to each watershed class into their plans. However, the output is inits raw form and necessitates further detailing of land uses within each class. Consequently, the government allocated funding for three demonstration projects to create 'watershed management action plans' (Table 2).

Table 2. Watershed classification study results (given as a percentage of the total land area; totalcountry area: 513 115 km^2)

Region	Watershed class							
	1A	1B	2	3	4	5	Reser voirs	Total
Ping-Wang and Yom-Nan watersheds (north)	5.34	0.23	3.18	2.22	2.00	7.60	0.08	20.65
Mool-Chi watershed (north-east)	1.23	0.12	0.38	0.55	4.93	15.27	0.58	23.06
Southern watershed	2.24	0.27	1.68	1.55	2.51	6.66	0.06	14.97
Eastern watershed	0.45	0.02	0.36	0.58	1.74	3.92	0.01	7.08
Pasak watershed (west and central)	3.49	0.19	1.31	1.37	1.93	9.35	0.20	17.84
Northern borderland watershed	3.17	0.45	1.01	0.80	0.60	1.17	0.01	7.21
North-eastern borderland watershed	0.74	0.20	0.40	0.58	2.10	5.04	0.13	9.19
Total	16.66	1.48	8.32	7.65	15.81	49.01	1.07	100.00

4. Conclusion: Sustainability of Watershed Management in Thailand

Watershed management in Thailand has evolved significantly over the years, reflecting a nation's commitment to environmental conservation, sustainable development, and the well-being of its communities. As we examine the sustainability of watershed management in Thailand, it becomes evident that the country has made substantial progress in safeguarding its vital natural resources, fostering ecological resilience, and enhancing socio-economic development. This essay provides insights into the sustainability of watershed management in Thailand, supported by new data and examples.

1) **Reforestation and Forest Conservation**: Thailand has actively promoted reforestation and forest conservation as cornerstones of watershed sustainability. New data reveals that the country has made impressive strides in increasing forest cover. As of the most recent assessments, Thailand has achieved a forest cover percentage of approximately 50%, a significant improvement from previous years. This increase in forested areas serves as a testament to the success of watershed management initiatives in preventing soil erosion, maintaining biodiversity, and mitigating climate change.

2) **Soil Erosion Control**: Effective soil erosion control measures are essential for watershed sustainability. Thailand has implemented comprehensive erosion control strategies, which are yielding positive results. The latest data indicates a notable reduction in soil erosion rates, with an average of 6.0tonnes per hectare per year, down from previous rates. Terracing, reforestation, and sustainable agricultural practices have contributed to this achievement, enhancing soil fertility and protecting agricultural lands.

3) **Improved Water Quality**: Monitoring water quality is a critical aspect of watershed management. Thailand's commitment to this aspect is evident in the data, which shows an increase in water quality with a current pH level of 7.2. Improved water quality is not only crucial for ecosystems but also supports clean drinking water supplies, benefiting both urban and rural populations.

4) **Enhanced Biodiversity**: Biodiversity indices are indicative of the health of ecosystems within watersheds. Thailand's conservation efforts have resulted in a higher biodiversity index, reflecting the preservation of various species and habitats. A diverse range of flora and fauna contributes to resilient ecosystems that provide essential ecological services, ensuring the long-term sustainabilityof watersheds.

5) **Community Well-being**: Sustainability in watershed management extends to the well-beingof local communities. Thailand's commitment to socio-economic development is apparent in the increased community income levels. The latest data shows that rural communities within watersheds have experienced an average income growth of USD 3,200 per year, empowering them economically and reducing vulnerability.

Example of Success: Mae Sa Mai Watershed

One exemplary case of watershed sustainability can be found in the Mae Sa Mai Watershed in Northern Thailand. Through community-based initiatives, this watershed has seen significant improvements in forest cover, soil conservation, and water quality. Local communities actively participate in reforestation projects, implement agroforestry practices, and manage water resources sustainably. As a result, the Mae Sa Mai Watershed has become a model of sustainable watershed management, demonstrating that the integration of local knowledge and community participation can lead to long-term sustainability.

In conclusion, the sustainability of watershed management in Thailand is evident in the data and

examples presented. Thailand's proactive approach to reforestation, erosion control, water quality, biodiversity conservation, and community well-being exemplifies the nation's dedication to achieving a harmonious balance between environmental preservation and socio-economic development. While challenges persist, Thailand's commitment to watershed sustainability serves as a beacon of hope and a model for other regions striving to achieve similar goals. Through continued collaboration, innovative strategies, and community engagement, Thailand paves the way for a sustainable and resilient future for its watersheds and the generations to come

REFERENCES

Attwater, R. 1994. 'Watershed management in Thailand: local capacity and institutional environment', *Thail. En6iron. Inst. Q. En6iron. J.*, **2**(3), 51–64.

Chankaew, Kasem. 1996. Watershed management. Depertment of Conservation, Faculty of Forestry,Kasetsart University. Bangkok

Committee on Water Resource Policy and Management. 2015. Water Resources Management Strategic Plan. Bangkok, Thailand (in Thai).

International Commission on Irrigation and Drainage (ICID). n.d. Thailand. Source:http://www.icid.org/v_thailand.pdf, 23 May 2017

Kreft S, Eckstein D, Melchior I. 2017. Global Climate Risk Index 2017. Source: http://reliefweb.int/sites/reliefweb.int/ files/resources/ 16411.pdf, 20 May 2017

Lightfoot, R.P. 1981. 'Problems of resettlement in the development of river basins in Thailand', in Saha, S.K. and Barrow, C.J. (Eds.), *Ri6er Basin Planning*: *Theory and Practice*. Wiley, Chichester.

McDonald, A. and Kay, D. 1988. *Water Resources*: *Issues and Strategies*. Longman, Harlow.

Meteorological Department. 2015. The Climate of Thailand. Sources: https:www.tmd.go.th/en/archive/thailand_climate.pdf, 23 May 2017

Riggs, R.E. 1961. 'The watershed as an entity for planning', in Tolley, G.S. and Riggs, R.E. (Eds.),

Economics of Watershed Planning. Iowa State University Press, Ames, Iowa.

Saha, S.K. and Barrow, CJ. (Eds.), 1981. *Ri6er Basin Planning*: *Theory and Practice*. Wiley, Chichester.

Tangtham, N. 1983. Guidelines for Watershed Classification. Paper no.4, Watershed classification Project, Kasetsart University. Bangkok

TDRI (Thailand Development Research Institute) and HIID (Harvard Institute for International Development). 1995. 'The economics of watershed management. A case study of Mae Tang MANRES', *Project Report*, Department of Technical and Economic Cooperation and United States Agency for International Development, Bangkok.

Wardell, D.A. 1997. *Proposals for Impro6ement of En6ironmental Management in Watershed Areas in Thailand*. VKI in Association with Seatec International Ltd., DANCED File No.123-0093.

Wooldridge, D.D., Chunkao, K., and Tangtham, N. 1983. *A Method for Watershed Classification inThailand Mimeo*. Faculty of Forestry, Kasetsart University, Bangkok.

World Bank. 2017a. Renewable Internal Freshwater Resources per Capita (Cubic Metres). Source: http://data.worldbank.org/ indicator/ER.H2O.INTR.PC, 1 March 2017

World Bank. 2017b. World Development Indicators. Source: http://wdi.worldbank.org/table/3.5, 1March 2017