



รายงานวิจัยฉบับสมบูรณ์

โครงการ “ฟุตพริ้นท์น้ำของพืชอาหาร อาหารสัตว์ พลังงาน และเส้นใย เพื่อ
จัดการทรัพยากรน้ำอย่างมีประสิทธิภาพ (ระยะที่ 2)”

Water footprinting of food, feed fuel and fibre for effective
water resource management (Phase II)

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|------------------------------|---|
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สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย (สกว.)
(ความเห็นในรายงานนี้เป็นของผู้วิจัย สกว. ไม่จำเป็นต้องเห็นด้วยเสมอไป)

EXECUTIVE SUMMARY

The project entitled “Water footprinting of food, feed, fuel and fibre for effective water resource management (Phase II)” has been performed by the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut’s University of Technology (KMUTT) in collaboration with Kasetsart University (KU) and supported financially by the Agricultural Division (Division 2) of the Thailand Research Fund (TRF) according to the contract no. RDG5620052. This 2nd phase of project aims to (1) continue the development of the water-use impact assessment method for Thailand by doing the detailed analysis of the temporal aspects of the water stress index (WSI) by using data from “bottom-up approach” to obtain the monthly and seasonal WSI of Thailand; and (2) continue the comprehensive assessment of freshwater used for field crops and trees grown in the selected provinces in different watersheds i.e. Mun, Chi, Chao Phraya and Tha Chin which were identified from the 1st phase as the water-hotspot watersheds. The impact assessment using the detailed WSI and the detailed freshwater used information especially for agriculture are performed. Recommendations for enhancing efficiency of freshwater use for future food and fuel crops production are identified and proposed. The monthly WSIs obtained from the project can be used as a tool for further promotion of crop water footprints (WFP) assessment in the agricultural sector of Thailand.

1) Research methodology

1.1 ISO-Water footprint assessment: The International Standard (ISO) has recently specified the principles, requirements and guideline related to water footprint assessment of products, processes and organizations or so called “ISO14046”. Under this ISO standard, the water footprint assessment will be based on a life cycle assessment aimed at assessing the magnitude of potential environmental impacts related to water resource. The impact of freshwater use for producing a product and its supply chain is therefore considered as a part of water footprint assessment. In the study, the impact of freshwater use for staple crop production in the selected regions/watersheds of Thailand is assessed by considering both the theoretical crop water requirement obtained from calculated evapotranspiration and the actual water use obtained from field data and irrigation practices of farmers.

1.2 Temporal Water Stress Index (WSI): is one of the indices widely used to explain the water vulnerability in terms of stress of each area. The WSI is derived from the ratio of annual total water withdrawals to hydrological availability of a watershed including variation related to monthly and annual rainfall. In the study, the temporal aspects of the water stress index (WSI) of 25 watersheds of Thailand have been evaluated based on the seasonal and monthly variations of water consumption in agriculture in each watershed due to the different cropping system and cycle. The WSI ranges from 0.01 (least water scarcity) to 1 (maximal water scarcity). The WSI at watershed level is an important characterization factors required for conducting the ISO-WF assessment because the impact of water use in different regions will be comparable. The crop water footprints can be calculated by multiplying seasonal/monthly WSI with seasonal/monthly crop irrigation water consumption and by summing the results over

the cultivation period. The obtained results from this calculation can be called as “water scarcity footprint”. The unit of water scarcity footprint is $m^3 H_2O_{eq}$ and it implies to the amount of water deficient to downstream human users and ecosystems or called as the “water deprivation impact potential”.

2. Summary results

2.1 Seasonal and Monthly WSI development

Figure 1 shows The extreme water stress reveals in areas of Chao Phraya and Tha Chin watersheds in dry season because large areas of second rice grown in both irrigated and non-irrigated areas of the Central region and its planting date starts in this period as well. In addition the amount of rainfall in dry season is generally less than in wet season. Thus the situation of these two watersheds becomes better in wet season. However this is different for the North-eastern part especially Mun and Chi watersheds. The low water stress is found in dry season and the level of stress increases in wet season. This is because the amount of rainfall in dry season of the North-eastern part is lower than other regions; therefore, this rainwater cannot be useful for meeting the water need of the crops. Moreover plantations of rice are in non-irrigated areas. Hence the amount of agricultural water in dry season depends on the amount of rainfall. For wet season, the levels of stress increase because the agricultural demand for water increases due to intensive major rice plantation in both irrigated and non-irrigated area, and lack of water storage in these two watersheds.

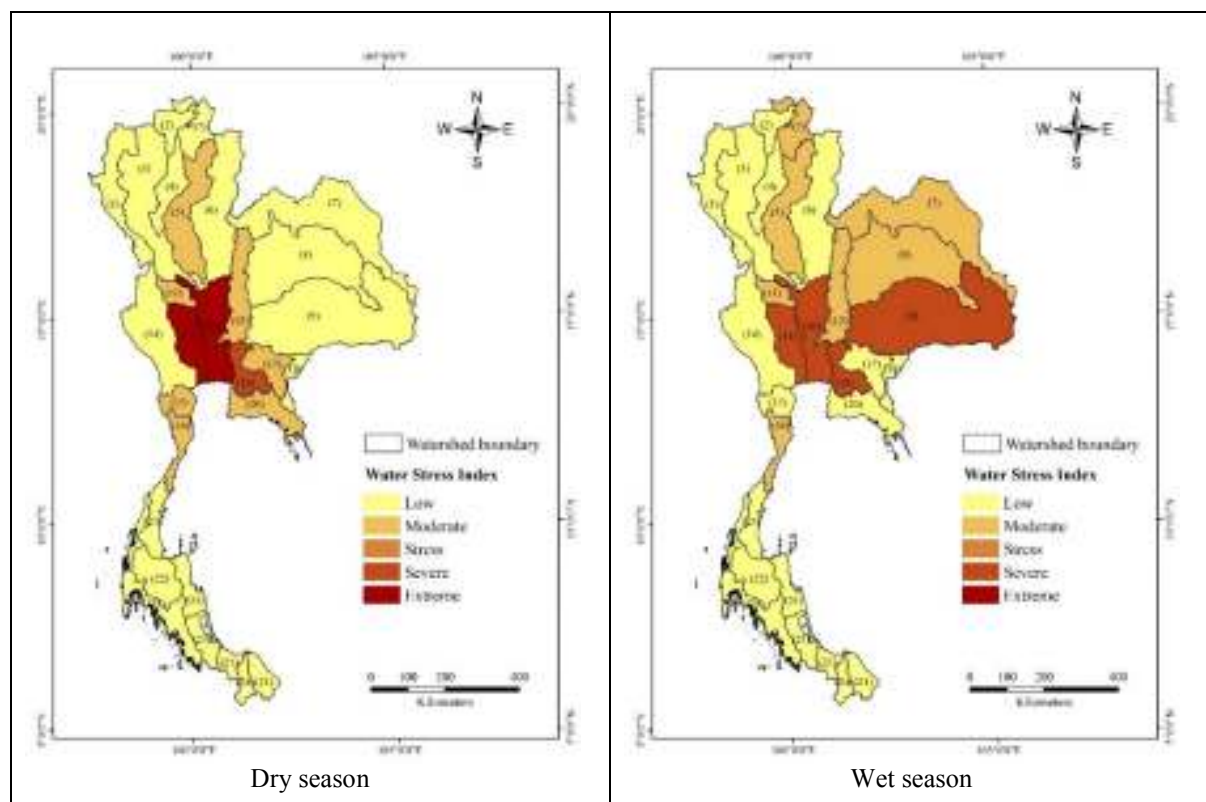


Figure 1 Seasonal WSI for 25 watersheds of Thailand

The reason of high stress on central regions of Thailand during dry season because of the higher areas of second rice plantations but the rainfall which is the major water availability is low. The water resource from other upstream watersheds therefore have to be managed as irrigation water for fulfilling the demands for agriculture in the central region during the dry season. The high water stress in the central region implies that the higher potential of water competition among other users and agriculture if the budget irrigation water is not enough to supply during the dry season.

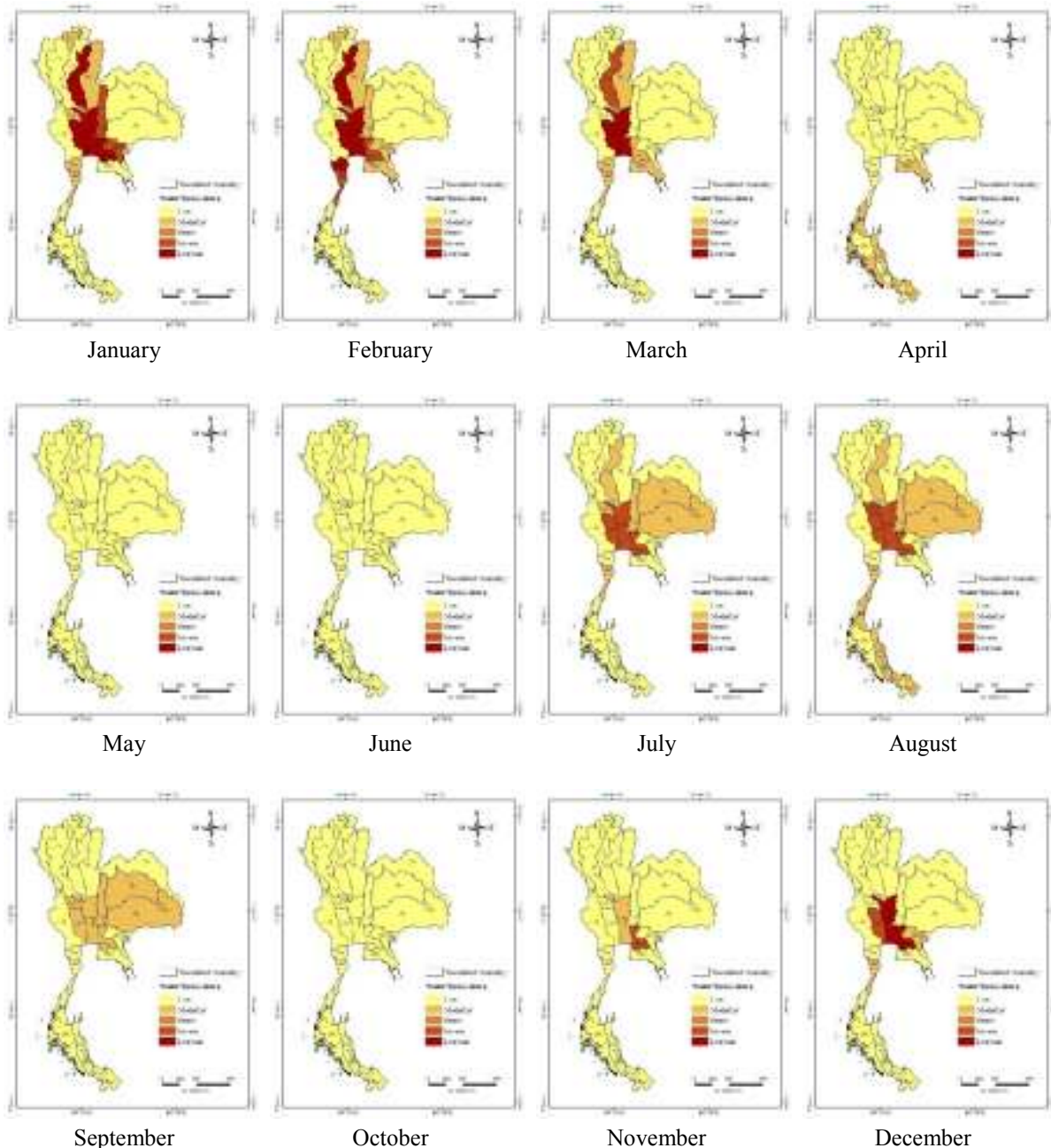


Figure 2 Monthly WSI for 25 watersheds of Thailand

The more variation of WSIs among the different month can be found in the monthly water stress maps as presented in **Figure 2**. To prevent the water competition and stress in severe watersheds, appropriate plan for water resource management is much required especially the cropping system and cropping calendar planning in each watershed. In addition, the plan of water

resource management for lower-watershed e.g. Chao Phraya should be correlated with the plan of the upper watershed. The different crop options can shift irrigation water consumption within a year which in turn can increase or decrease the related water stress.

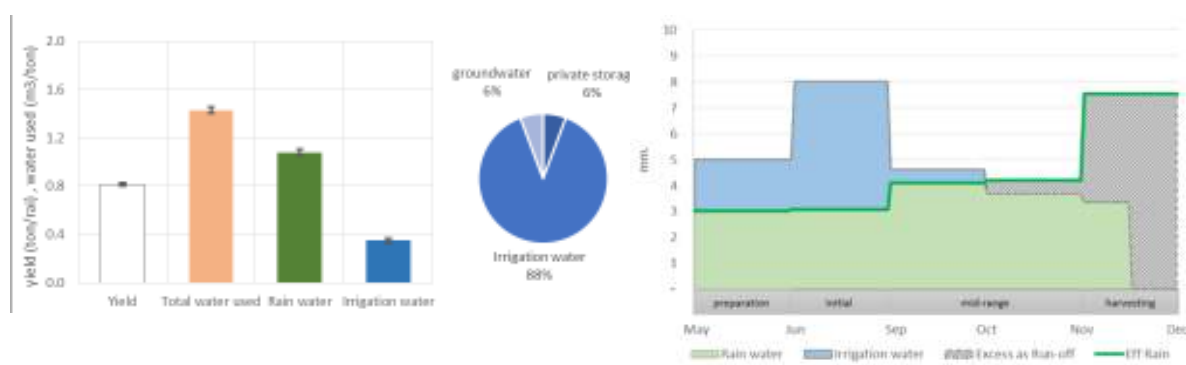
2.2 Crop water use in the studied areas

The theoretical water requirement and freshwater use from field data (deficit condition) for major crops cultivations including rice, sugarcane, cassava and maize in selected provinces under the Mun, Chi, Chao Phraya and Tha Chin are evaluated and compared. The water use assessment is estimated based on the crop evapotranspiration calculation complimenting with the rain fed and/or irrigated conditions of the planted areas as well as irrigation practices of farmers. Data on farming practices, irrigation technique and efficiency are primarily collected, complied and aggregated from farmers. The results show that there is a gap of water use and theoretical water requirement which in turn will respond into the crops' yields. Different location will require different amount of irrigation water use due to the irrigation technique and practices of farmers. Based on the collected data from many farmers, irrigation water help increase the yield of crops e.g. sugarcane and cassava. The example of specific crop water use obtained from assessment are as follows:

2.2.1 Rice

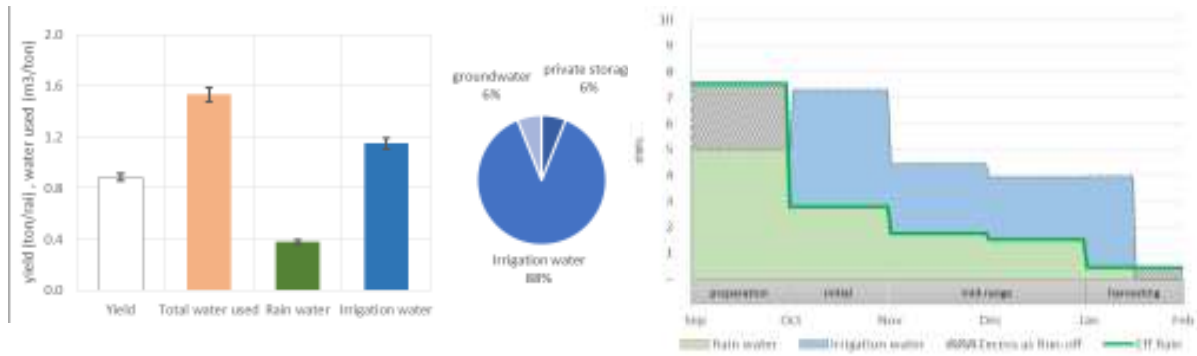
The comprehensive assessment of crop water use brings about the complete picture of total crop water demands and consumptions entire the major rice and second rice cultivation period as results shown in **Figure 3**. The results show that freshwater demand for rice cultivation will differ from theoretical crop water use which are generally referred as the water footprint value of crops in various studies so far. Water demand for rice cultivation can be either higher or lower than crop evapotranspiration depended on the irrigation availability and irrigation efficiency of the planted areas.

Based on average rice cultivation in Ayuthaya, the theoretical water requirements for major rice and second rice grown are about 1.2 and 1.15 m³/kg, respectively. However, total actual water used are about 1.43 and 1.53 m³/kg, respectively. The amount of rainwater used and irrigation water used in different period can be obtained from the assessment. The rainwater (green color in the Figure) is the major water source for major rice cultivation; meanwhile, the irrigation water (blue color) is the main water source for second rice cultivation. **Table 1** shows the ranges of total water use for rice cultivation in Mun, Chi, Chao Phraya and Tha Chin watersheds.



Major rice: Yields, Rainwater used, IRW used and sources

Major rice: Water used in different cultivation period



Second rice: Yields, Rainwater, IRW used and sources

Second rice: Water used in different cultivation period

Figure 3 Water use assessment for rice cultivation in Chao Phraya watershed (Ayuthaya)

Table 1 Total water used of rice cultivation in different watersheds

| Crop | Parameter | Unit | Chao Phraya | Tha Chin | Mun | Chi |
|---------------|-----------------------|--------------------|-------------|----------|------|------|
| Major | Yield | kg/rai | 814 | 923 | 427 | 479 |
| | Total water used | m ³ /kg | 1.43 | 0.97 | 2.81 | 2.27 |
| | Rain water used | m ³ /kg | 1.08 | 0.71 | 1.95 | 2.11 |
| | Irrigation water used | m ³ /kg | 0.35 | 0.26 | 0.85 | 0.15 |
| | Small storage | m ³ /kg | 0.02 | 0.02 | 0.05 | 0.02 |
| | Irrigation water | m ³ /kg | 0.31 | 0.23 | 0.81 | 0.13 |
| | Groundwater | m ³ /kg | 0.02 | 0.02 | 0 | 0 |
| Second | Yield | kg/rai | 884 | 848 | | |
| | Total water used | m ³ /kg | 1.53 | 0.89 | | |
| | Rain water used | m ³ /kg | 0.38 | 0.25 | | |
| | Irrigation water used | m ³ /kg | 1.15 | 0.64 | | |
| | Small storage | m ³ /kg | 0.07 | 0.01 | | |
| | Irrigation water | m ³ /kg | 1.01 | 0.59 | | |
| | Groundwater | m ³ /kg | 0.07 | 0.04 | | |

2.2.2 Sugarcane

Table 2 shows the average and ranges of freshwater used for sugarcane production in Chao Phraya and Chi watersheds. Sugarcane is able to grow for non-irrigated area; however, the irrigation water can help increase productivity of sugarcane. For example, the sugarcane planted areas in Chao Phraya used around 0.22 m³/kg sugarcane which is higher than sugarcane planted areas in Chi watershed which used only 0.14 m³/kg cane. Nevertheless, the sugarcane yields obtained for planted areas in Chao Phraya watershed are about 15 t cane/rai; meanwhile, the yields obtained for the planted areas in Chi area about 11.5 t cane/rai only.

Table 2 Total water used of sugarcane production

| Parameter | Unit | Chao Phraya | Chi |
|-----------------------|-------------------------|-------------|------|
| Yield | ton/rai | 15 | 11.5 |
| Total Water used | m ³ /kg cane | 0.22 | 0.14 |
| Rain water used | m ³ /kg cane | 0.11 | 0.12 |
| Irrigation water used | m ³ /kg cane | 0.11 | 0.03 |

2.2.3 Cassava

The averaged total water use for cassava is $0.63 \text{ m}^3/\text{kg}$ cassava (fresh root), comprising with 0.46 and $0.16 \text{ m}^3/\text{kg}$ cassava of rainwater and Irrigation water, respectively. The result obviously shows that the yields of cassava grown in Mun watershed is higher than Chi watershed around 40%. The Irrigation water used found for cassava growing in the Mun watershed come from shallow groundwater level with drip system. This type of watering has higher efficiency than the ground-pouring irrigation system. This means that there still have a gap of yield improving by increasing water use efficiency by installing the higher performance watering system.

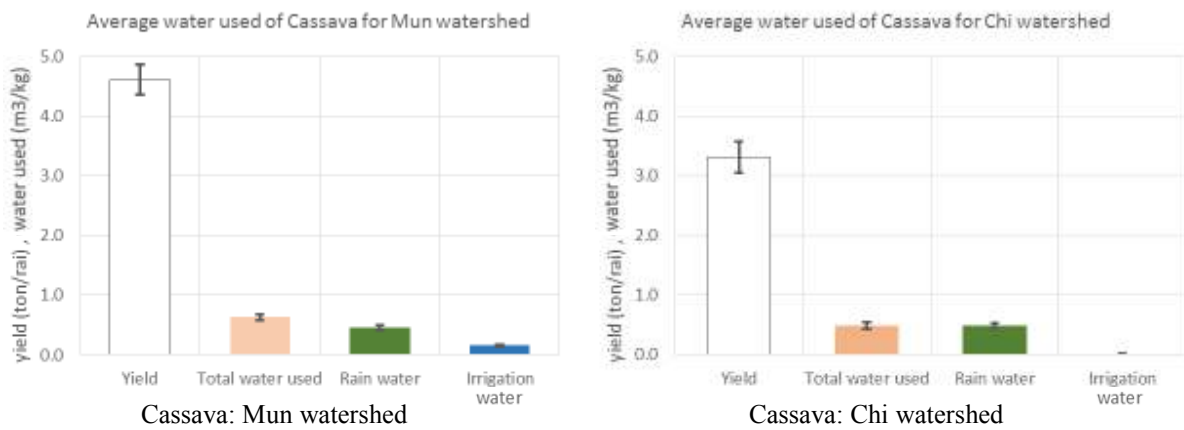


Figure 4 Water use assessment for cassava in Mun and Chi watersheds

2.2.4 Maize

The average freshwater used for cultivating maize in Chao Phraya watershed is about $1.48 \text{ m}^3/\text{kg}$ maize (Irrigation water shared about 10% of total water used); meanwhile, the water used for maize grown in Chi watershed is about $1.15 \text{ m}^3/\text{kg}$ (totally freshwater used from rainwater). The results are summarized as **Figure 5**.

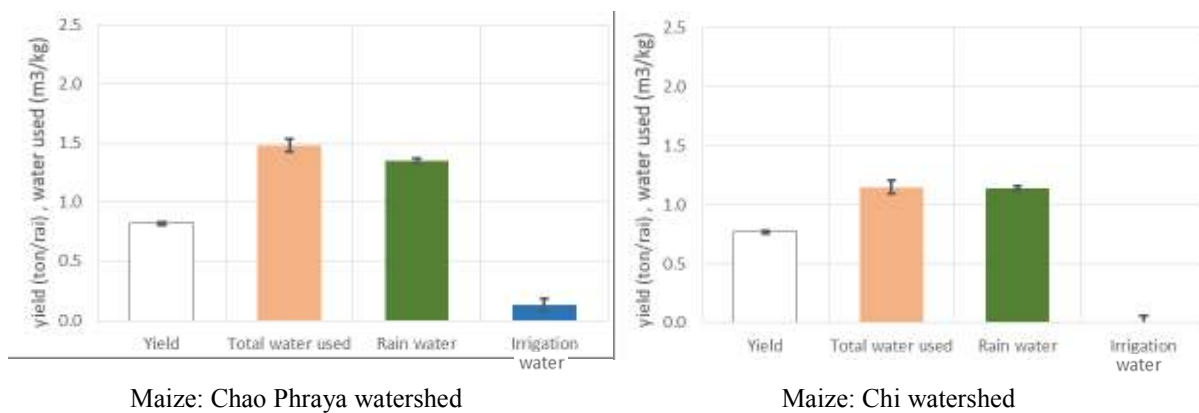


Figure 5 Water use assessment for cassava in Chao Phraya and Chi watersheds

2.3 WF and WSI Applications for Agricultural Policy Recommendations

2.3.1 Agricultural practices and freshwater use: Case study of Rice

The study shows the comparison of freshwater used for different rice cultivation systems including transplanting, dry ungerminated seed broadcasting, pregerminated seed broadcasting and alternate wetting and drying (AWD) based on crop evapotranspiration complemented with the actual water management practice of farmers in the central region (Ayuthaya province). **Tables 3** and **4** present the estimated water used for major and second rice cultivations. Major rice is grown during June – September and second rice is grown during October – January.

Table 3 Freshwater used for different major rice cultivation systems in Ayuthaya

| | Preparation (cm/day) | | ET (mm/day) | | Percolation (cm/day) | Standing water (cm/day) | CWU (m ³ /rai) | Total WU (m ³ /rai) | | |
|------------------------------------|----------------------|-----|-------------|-----|----------------------|-------------------------|---------------------------|--------------------------------|-----|-------|
| | RW | IRW | RW | IRW | | | | RW | IRW | Total |
| Transplanting | 3.0 | 3.7 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 751 | 444 | 1195 |
| Dry ungerminated seed broadcasting | 1.7 | 0 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 654 | 262 | 947 |
| Pregerminated seed broadcasting | 3 | 2 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 751 | 361 | 1112 |
| Alternate wetting and drying | 1.7 | 0 | 3.8 | 0.3 | 0.1 | 2.3 | 1013 | 666 | 166 | 832 |

*RW: Rainwater; IRW: Irrigation Water, CWU: Crop Water Use; WU: Water Use

Table 4 Freshwater used for different second rice cultivation systems in Ayuthaya

| | Preparation (cm/day) | | ET (mm/day) | | Percolation (cm/day) | Standing water (cm/day) | CWU (m ³ /rai) | Total WU (m ³ /rai) | | |
|------------------------------------|----------------------|-----|-------------|-----|----------------------|-------------------------|---------------------------|--------------------------------|-----|-------|
| | RW | IRW | RW | IRW | | | | RW | IRW | Total |
| Transplanting | 6.7 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 627 | 551 | 1178 |
| Dry ungerminated seed broadcasting | 1.7 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 385 | 545 | 930 |
| Pregerminated seed broadcasting | 5 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 547 | 548 | 1096 |
| Alternate wetting and drying | 1.7 | 0 | 2.8 | 0.7 | 0.1 | 2.3 | 1021 | 385 | 457 | 842 |

*RW: Rainwater; IRW: Irrigation Water, CWU: Crop Water Use; WU: Water Use

The results show that the transplanting method brings about the highest water used per rai, followed by pregerminated broadcasting, dry ungerminated broadcasting and AWD. The higher water used for transplanting and pregerminated broadcasting methods is due to the water requirement for land preparation and the standing water. AWD technique would help reduce irrigation water use; however, the limitation of implementation AWD method for large scale planted areas still be discussion by farmers because it seems to be difficult for controlling weeds.

2.3.2 Freshwater use and Irrigation efficiency: Case study of Sugarcane

Sugarcane is nowadays a staple crop playing an important role in the Thai economy not only for sugar production but also for bioenergy production. Under the AEDP, sugarcane is expected to play an important role as bioenergy feedstock for Thailand in the future because it has a high proportion of biomass especially in the form of readily fermentable sugars that can be used for biofuels. **Table 5** shows the theoretical water requirement and total freshwater used for

sugarcane cultivation under irrigation system (furrow) in Chao Phraya watershed. The results show that based on the sugarcane yield of about 15 ton cane/rai, the rainwater and irrigation water used are about 1100 and 1100 m³/rai/yr, respectively. The over irrigation water supplied to sugarcane field about 510 m³ as compared to the theoretical irrigation water requirement obtained from crop evapotranspiration which sugarcane will require only 590 m³/rai/yr is due to the irrigation efficiency. The irrigation efficiency of furrow system is about 54%. Nevertheless, the irrigation water used can be reduced by using the higher irrigation system such as big gun sprinkler, boom irrigator and sub-surface drip.

Table 4 Water requirements and water used for sugarcane cultivation in Chao Phraya watershed

| | Yield (ton/rai) | Theoretical CWR (m ³ /rai/yr) | | Total water used (m ³ /ton cane) | | IRW deficit (-)/over (+) |
|-----------------------|--------------------|---|-----|--|------|---|
| | | RW | IRW | RW | IRW | |
| Chao Phraya watershed | 15 | 1100 | 590 | 1100 | 1100 | (+) 510 m ³ /rai/yr Irrigation efficiency (furrow) = 55% |

RW: Rainwater; IRW: Irrigation water

Based on the theoretical irrigation water requirement of about 590 m³/rai/yr as above, **Table 6** shows the potential reduction of irrigation water use from different irrigation techniques. In order to achieve 15 t cane/rai as basis, the irrigation water would be saved around 310, 410 and 490 m³/rai/year if big gun sprinkler, boom irrigator and sub-surface drop were applied, respectively.

Table 5 Comparative irrigation water used for different irrigation technics for sugarcane plantation

| Irrigation system | Irrigation efficiency (%)* | IRW requirement for supply (m ³ /rai/yr) | Potential irrigation water use (m ³ /rai/yr) |
|------------------------------|----------------------------|---|---|
| Furrow | 55 | 1100 | - |
| Big gun sprinkler | 75 | 790 | 310 |
| Boom irrigator, Centre pivot | 85 | 690 | 410 |
| Sub surface drip | 97 | 610 | 490 |

*Source: OCSB (2014)

2.3.3 Application of WF and WSI for policy on expansion of sugarcane plantation areas

The government currently has initiated the policy on converting upland paddy fields with low productivity to sugarcane plantation in order to fulfil the excess capacity of current sugar millers along with the expectation to increase farmers' income. The Land Development Department (LDD) has identified the potential rice areas to be converted to sugarcane. The criteria for determining the substitution areas of LDD is as follows: (1) the current paddy field that located in the land classified as the low and non-suitable areas for rice; (2) the radius of about 50 km of 20 sugar factories that currently needs more sugarcane to fulfil their production capacity. Hence, the short-term target was set i.e. the total areas about 2.3 million rais as shown in **Figure 5**. **Table 7** shows the potential impacts of land-use change (LUC) policy on water resource availability.

Table 6 Impacts of land conversion from rice to sugarcane on water resource availability

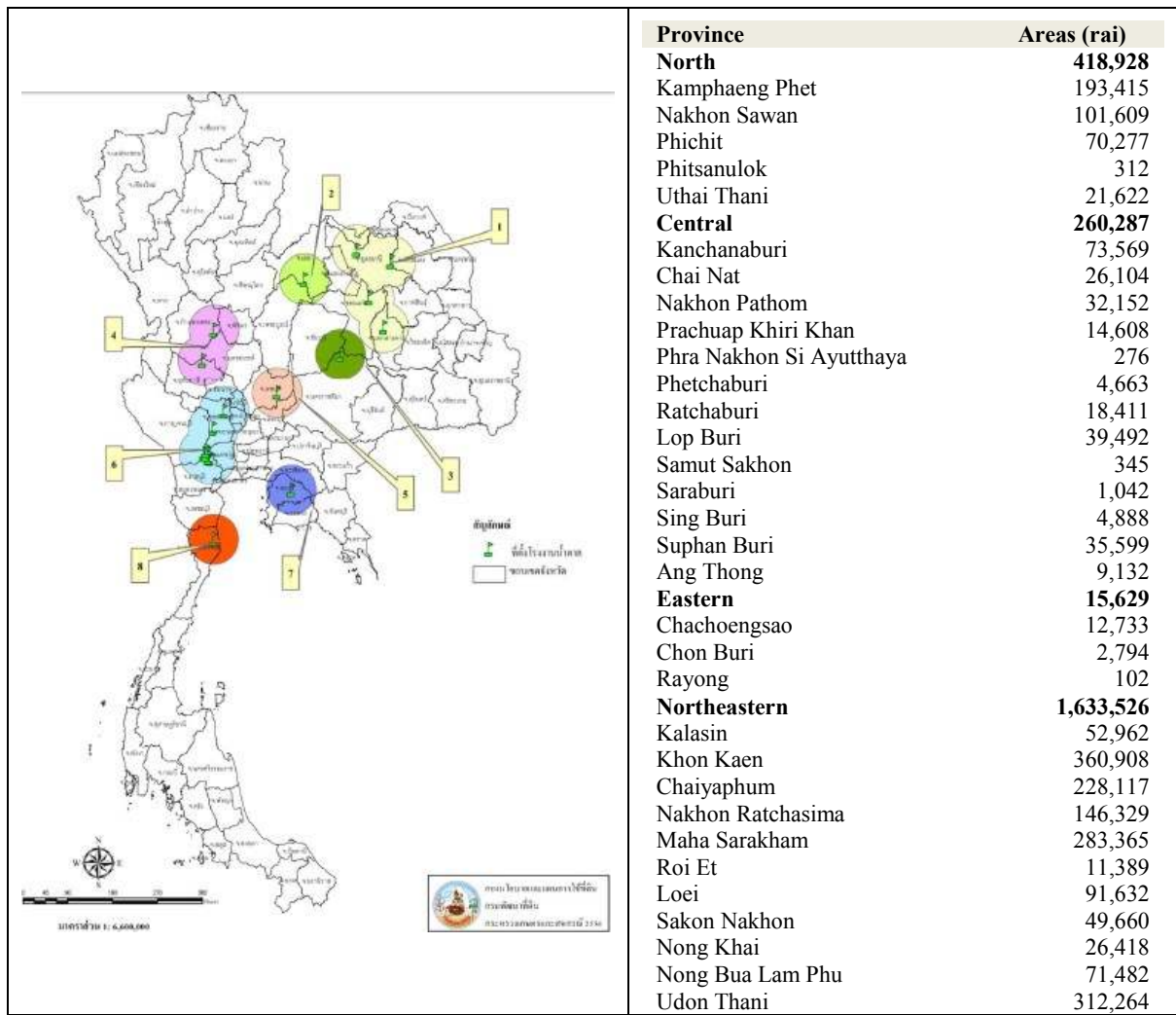
| Land type | Cropping change scenarios | Effect of land on irrigation water resource |
|--------------------|--------------------------------------|---|
| Non-irrigated area | Major rice → Sugarcane | <ul style="list-style-type: none"> • No affect to IRW resource because IRW is not used • Yield of major rice and sugarcane may not reach the baseline dataset i.e. 814 kg rice/rai and 15 t cane/rai (due to water deficit) |
| Irrigated area | Major rice → Sugarcane | <ul style="list-style-type: none"> • LUC will require additional irrigation water 940 m³/rai/yr (if irrigation efficiency is not improved) • LUC will require additional irrigation water 450 m³/rai/yr (if irrigation efficiency of sugarcane is improved to 97% by using sub surface dip) |
| Irrigated area | Major rice + Second rice → Sugarcane | <ul style="list-style-type: none"> • LUC will decrease irrigation water use 210 m³/rai/yr (if irrigation efficiency is not improved) • Reduce irrigation water used 750 m³/rai/yr (if irrigation efficiency is improved to 97% by using sub surface dip) |

*Cropping cycle: rice (4 months); sugarcane (9-10 months)

The implications of LUC policy of rice field conversion to the monthly water stress index of the relevant watersheds. The results reveals that the policy on converting 2.3 million rice planted areas to sugarcane potentially reduce the water withdrawal for agriculture which in turn will affect to the reduction of the water stress index of the relevant watersheds i.e. Mun, Choa Phraya, Bang Pakong, Tha Chin, Mae Klong, Sakae Krang, etc. The WSI of June – September would be reduced. The amounts of agricultural water required during June to September decreases around 62, 221, 144, and 122 million m³, respectively.

3. Dissemination Activities

- 1) Dissemination of the studied results to government organizations working on water resource management and agricultural and energy policies For example, the results obtained from the project has been presented to central and local government agencies that relevant to water resource management and agriculture e.g. RID, OAE, Provincial Agricultural Promotion and Extensions and etc. that water resource management for agriculture. The dissemination seminars have been organized for different regions i.e. Central region (Ayuthaya), Northeastern region (Buri Ram and Khon Kaen).
- 2) Dissemination by organizing the training/workshop about the developed WSI and WF tools and their application for government and public-sector organizations especially industrial sectors to apply in their water management.
- 3) The project has developed the WSI calculation templates and short guidelines which can be further used for updating WSI of all watersheds when the water withdrawal and water availability are updated. The update of WSI can be done regularly like every year or when the raw data has been revised by the government officers e.g. OAE and RID.
- 4) The research results have been disseminated via the international journal publication and the conference paper and oral presentation.



Source: LDD (2014)

Figure 7 Potential areas of paddy field conversion to sugarcane

ฟุตพริ้นท์น้ำและตัวชี้วัดความตึงเครียดด้านน้ำเป็นเครื่องมือที่สำคัญในการสนับสนุนการกระบวนการตัดสินใจของนักพัฒนานโยบายด้านการจัดการแหล่งทรัพยากรน้ำโดยเฉพาะอย่างยิ่งสำหรับประเทศไทยซึ่งมีการใช้น้ำเพื่อการเกษตรมากถึง 65-70% ของปริมาณการใช้น้ำรวมทั้งหมด โครงการฟุตพริ้นท์น้ำของพืชอาหารอาหารสัตว์ พลังงาน และเส้นใยเพื่อจัดการทรัพยากรน้ำอย่างมีประสิทธิภาพ (ระยะที่ 2) มีวัตถุประสงค์เพื่อ 1) ประเมินการเปลี่ยนแปลงเชิงเวลา (temporal aspect) ของค่าดัชนีความตึงเครียดด้านน้ำซึ่งใช้ข้อมูลโดยวิธีวิเคราะห์จากล่างขึ้นบน (Bottom-Up Approach) เพื่อให้ได้มาซึ่งค่าดัชนีความตึงเครียดด้านน้ำรายฤดูและรายเดือนของประเทศ 2) เพื่อประเมินความต้องการน้ำของพืชหลักที่สำคัญ พืชไร่และไม้ยืนต้นในพื้นที่ลุ่มน้ำมูล, ซี, เจ้าพระยา และท่าจีน ซึ่งเป็นลุ่มน้ำที่ถูกบ่งชี้ว่ามีค่าตัวชี้วัดความตึงเครียดด้านน้ำสูงอันเป็นผลการศึกษาจากโครงการระยะที่ 1 แผนที่ความตึงเครียดด้านน้ำรายฤดูและรายเดือน (Seasonal and monthly water stress maps) ที่ได้จากการศึกษาแสดงให้เห็นว่าการเปลี่ยนแปลงเชิงเวลานั้นมีผลกระทบต่อค่าตัวชี้วัดความตึงเครียดด้านน้ำอย่างมีนัยสำคัญ นอกเหนือจากนี้ผลการศึกษาที่ได้ยังสามารถใช้เป็นเครื่องมือสนับสนุนเพื่อส่งเสริมให้มีการประเมินวอเตอร์ฟุตพริ้นท์ของพืชในภาคเกษตรอีกด้วย ในส่วนของการประเมินความต้องการใช้น้ำและปริมาณการใช้น้ำของพืชในพื้นที่นั้น ผลการศึกษาพบความแตกต่างของปริมาณน้ำความต้องการใช้น้ำและปริมาณการใช้น้ำของพืชซึ่งผลดังกล่าวนี้สะท้อนให้เห็นเมื่อพิจารณาเทียบกับผลผลิต นอกเหนือจากนี้วิธีการและผลที่ได้จากการศึกษาในส่วนนี้สามารถใช้เป็นแนวทางในการส่งเสริมให้มีการประเมินวอเตอร์ฟุตพริ้นท์ของพืชในภาคเกษตรได้อีกเช่นกัน โดยการประยุกต์ใช้การประเมินวอเตอร์ฟุตพริ้นท์และตัวชี้วัดความตึงเครียดด้านน้ำในภาคเกษตรและเพื่อปรับปรุงประสิทธิภาพของการจัดการแหล่งทรัพยากรน้ำ ได้แก่ (1) การปรับปรุงวิธีการเกษตรและการใช้น้ำในการปลูกข้าว (2) การปรับปรุงประสิทธิภาพชลประทานในพื้นที่เพาะปลูกอ้อย (3) ข้อเสนอแนะสำหรับนโยบายการเปลี่ยนแปลงการใช้ประโยชน์ที่ดิน เช่น นโยบายการเปลี่ยนพื้นที่ปลูกข้าวที่ให้ผลผลิตต่ำไปเป็นพื้นที่ปลูกอ้อย โดยโครงการฯ ได้นำเสนอข้อเสนอแนะที่จะช่วยส่งเสริมให้เกิดประสิทธิภาพด้าน การใช้น้ำและการจัดการทรัพยากรน้ำสำหรับการผลิตอาหาร อาหารสัตว์ และพลังงานในอนาคต

Abstract

Water footprint (WF) and Water stress index (WSI) are gaining recognition as the important tools to support policy makers in their development of water resource management policy especially for Thailand which agriculture which accounts for about 65-70% of the water consumption. The project “Water footprinting of food, feed and fuel for effective water resource management (Phase II)” aims to (1) assess the temporal aspects of the water stress index (WSI) by using data from “bottom-up approach” to obtained the seasonal and monthly WSI of Thailand; and (2) continue the comprehensive assessment of freshwater used for field crops and trees grown in the selected provinces in different watersheds i.e. Mun, Chi, Chao Phraya and Tha Chin which were identified from the 1st phase as the water-hotspot watersheds. The seasonal and monthly WSIs assessment results show that that temporal aspect has a significant impact to the water stress index. The seasonal and monthly WSIs obtained from the project can be used as a tool for further promotion of crop water footprints (WFP) assessment in the agricultural sector of Thailand. For comprehensive water requirements and water use of crops and trees in the selected provinces/watersheds, the results show that there is a gap of total actual water use and theoretical water requirement which in turn will respond into the crops’ yields. The method and results obtained from the the project can be used as the tools for further crop water footprint assessment of agricultural products in Thailand. Several applications of WF assessment and WSI for improving efficiency of water resource management and use for agriculture have been conducted e.g. (1) agricultural practices and freshwater use improvement of rice production; (2) Irrigation efficiency improvement of sugarcane production; (3) WF and WSI for recommendations on land-use change (LUC) policy e.g. policy on changing low-productivity paddy field to sugarcane. Recommendations for enhancing efficiency of freshwater use for future food and fuel crops production are identified and proposed.

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CHAPTER 1

Introduction

1.1 Rationale

Water footprint (WF) and Water stress index (WSI) are gaining recognition as the important tools to support policy makers in their development of water resource management policy especially for Thailand which agriculture which accounts for about 65-70% of the water consumption. The project entitled “*Water footprinting of food, feed and fuel for effective water resource management*” was performed in 2012 – 2013 by the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut’s University of Technology (KMUTT) in collaboration with Kasetsart University (KU) and supported financially by the Agricultural Division (Division 2) of the Thailand Research Fund (TRF) to assess the water footprint of key agricultural food, feed, and fuel crops and to evaluate the situation and potential to affect the water stress in different regions of Thailand. The results showed that WF and WSI can provide the useful information for identification of the potential areas of water stress due to the expansion of agricultural activities and for determining the measures for improving water resource planning and management for sustainable food, feed, and fuel crops production in the future (Gheewala et al., 2013, 2014). However, due to the time limitation of that project, some factors that are able to influence to the WSI results were excluded from the investigation.

Phase II of the project “*Water footprinting of food, feed and fuel for effective water resource management*” is therefore proposed to (1) continue the development of the practical water impact assessment tool for Thailand; and (2) to continue the promotion of water footprint and water stress index as the tools for policy decision making in the promotion of food, feed, fuel production with the sustainable water and land use in Thailand.

1.2 Objectives and Targets

- (1) Improvement of WSI by using “bottom-up approach” to determine the variation factors i.e. seasonal and ability to manage the water resources of each watershed and their effects to the WSI.
- (2) Comprehensive assessment of freshwater used for field crops (rice, cassava, maize, sugarcane) and trees (oil palm, rubber and fruit) grown in the selected watersheds which revealed by the first phase of the project namely;
 - Chao Phraya: Nakhon Sawan, Lopburi and Ayutthaya
 - Tha Chin: Suphanburi, Kanchanaburi and Nakhon Pathom
 - Mun: Nakhon Ratchasima, Ubon Ratchathani and Buriram
 - Chi: Chaiyaphum, Khon Kaen and Kalasin

- (3) Impact assessment of freshwater used and recommendation on measures for enhancing efficiency of freshwater uses in the promotion of rice, cassava, sugarcane and oil palm grown in the selected watersheds.

1.3 Expected outcomes

- (1) Improved map of water stress index for various regions of Thailand by classifying into wet and dry season.
- (2) Water resource use and crop water requirement (CWR) of cash crops (rice, cassava and maize), perennial crops (sugarcane) and tree crops (oil palm, rubber and fruit) grown in the specific watersheds.
- (3) Impacts from water use due to policies to promote biofuels and area zoning
- (4) Recommendations of the strategies for reducing water stress from agricultural activities through improved water resource management.
- (5) An international journal publication and a conference paper on the studied topic.

1.4 Other outcomes

- (1) Implementing the appropriate agricultural policies and suitable irrigation will deliver actual benefits to farmers
- (2) Dissemination of the studied results to government organizations working on water resource management and agricultural and energy policies.
- (3) Dissemination by organizing the training/workshop about the developed WSI and WF tools and their application for government and public-sector organizations especially industrial sectors to apply in their water management.

1.5 Research framework

Figure 1.1 shows the research framework of the 2nd phase of the project “*Water footprinting of food, feed and fuel for effective water resource management*”. The outputs from the 1st phase i.e. CWR of staple crops in various provinces of Thailand and the WSI and water stress map of Thailand are used as the inputs for further investigations.

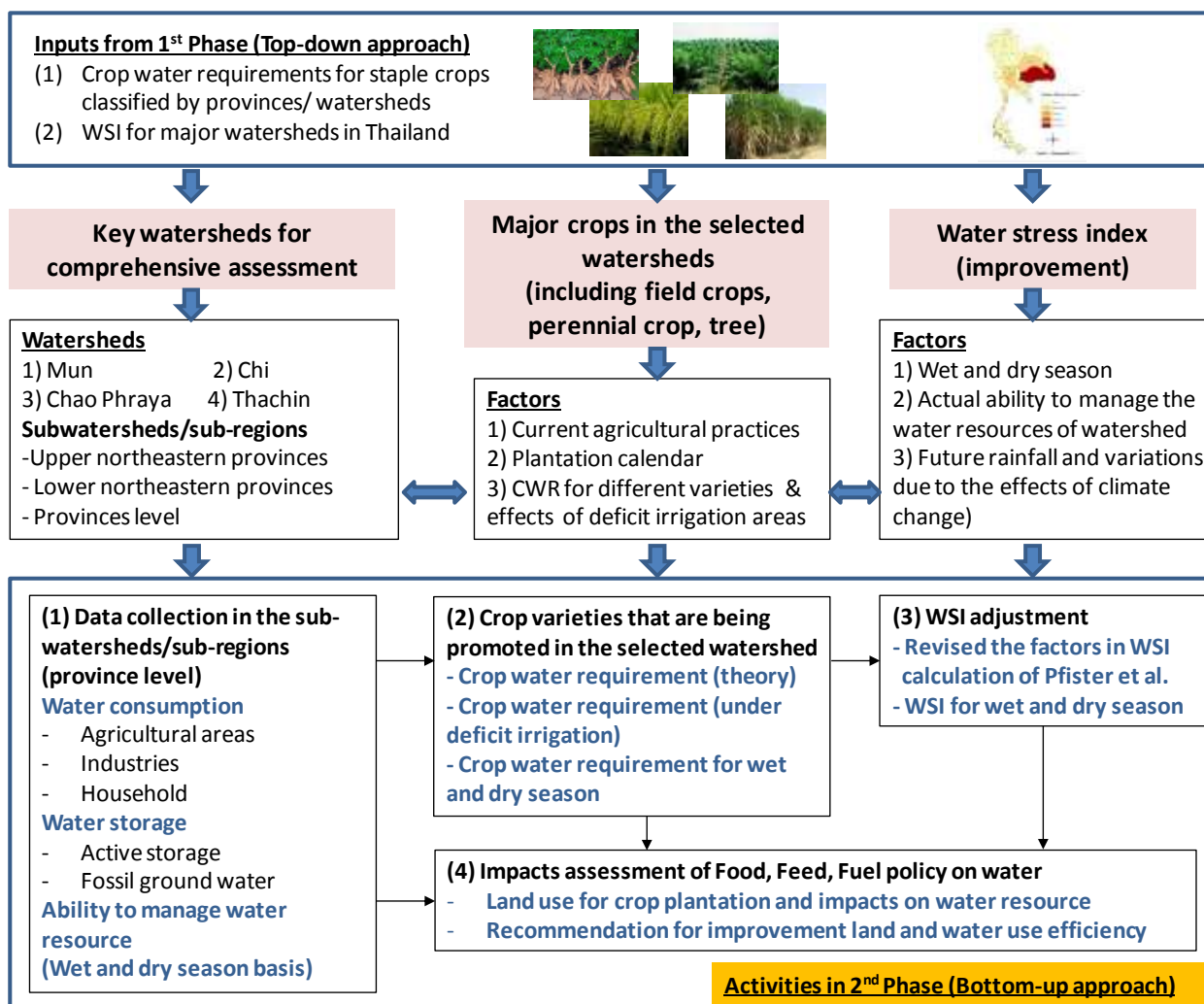


Figure 1.1 Research framework

Clarification of certain items in the research framework

- Bottom-up approach in Figure 1.1 refers to the approach where data is collected at a more detailed level (province and amphoe instead of just at the watershed level) in the identified critical zones. The data collection efforts will focus on collating information from local sources e.g. local governments, local irrigation department and other related organizations in the studied provinces/ watersheds. Data will be collected including water demand for various sectors in the studied provinces, water resource availability, and water resource management, existing crop cultivation practices and water use.
- Crop water requirement (CWR) in Figure 1.1 means the ‘theoretical water requirement’ over the period of crops cultivation in each regions/provinces. The general formula is as follows: $ET_{crop} = K_c \times ET_o$ [Unit: mm/day]; where ET = crop evapotranspiration i.e. the amount of water evapotranspired by the crops in a specific climate regime and adequate soil water is maintained by rainfall and/or irrigation; K_c = Crop coefficient of Penman-

Monteith; and ET_o = the reference crop evapotranspiration of Penman-Monteith (Allen et al., 1998).

- Crop water requirement under the deficit irrigation means the total irrigation over the period of crops cultivation in both the designated irrigated as well as non-irrigated areas. This is considered in the study because, in practice, there are many crops e.g. cassava and sugarcane that grown in the designated non-irrigated areas which therefore generally consume lesser amount of water as compared to the theoretical water requirement. The study therefore aims to investigate the total crop water use in the plantation areas and comparing with the theoretical water requirement in order to determine the effect on the yield as well as revealing trade-off between reduced water use and yield. This could be important information for the agriculture policy. The assessment will be done by using data from the sample plantation areas selected from the studied sites.

CHAPTER 2

Overview of Water resources in Thailand

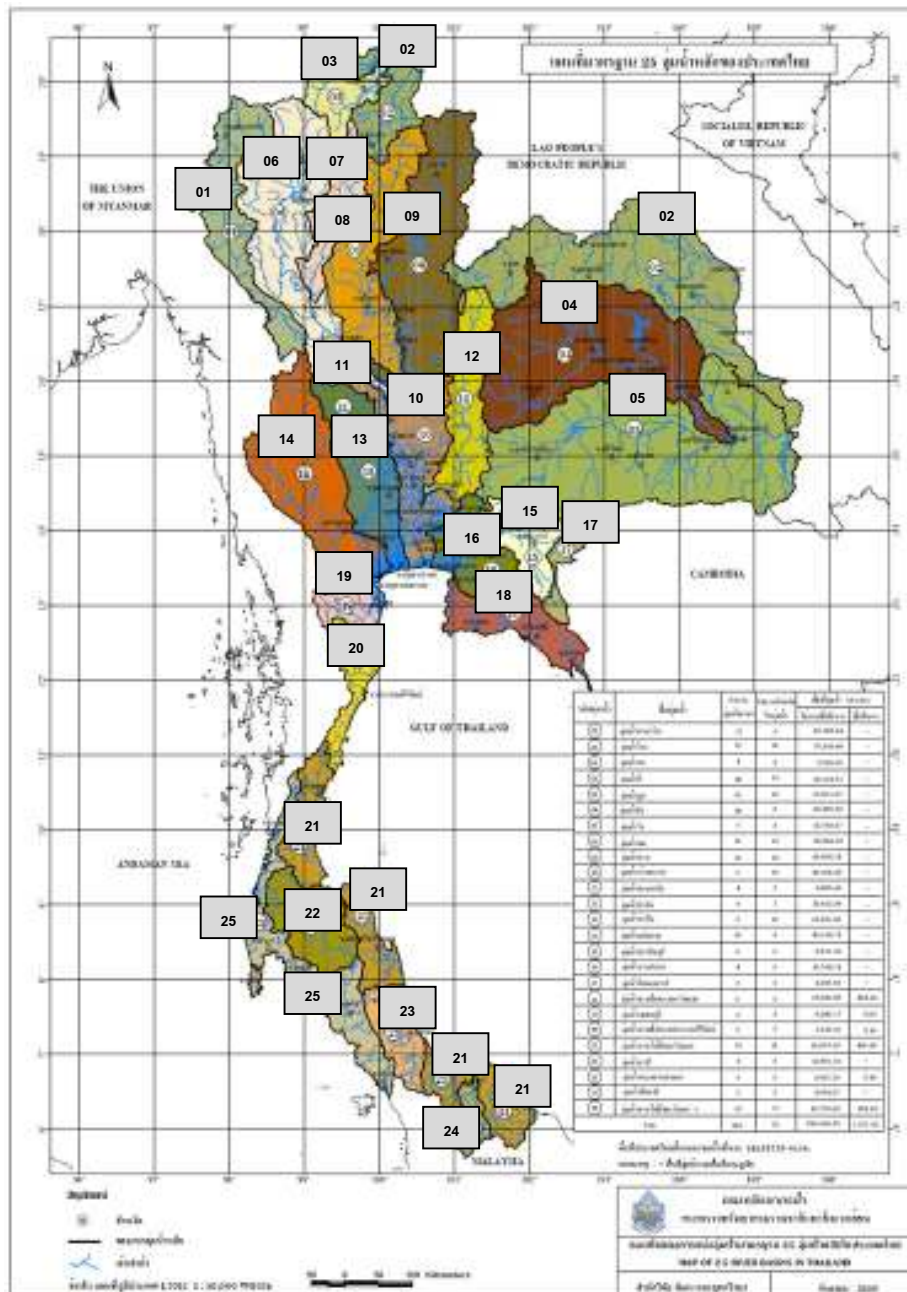
2.1 Watersheds

Thailand is located in the South Eastern region of Asia at the geographical coordinates of about 15° 0' 0" N latitude and 100° 0' 0" E longitude; the country's climate is therefore mainly tropical i.e. exhibiting hot and humid conditions throughout the year. For hydrological purposes, the office of the national water resources committee has divided Thailand into 25 major river basins based on hydrological criteria covering the catchment areas of about 515,837 km² (including islands and Phuket). In addition, the 25 watersheds can also be regrouped into 9 basin groups based on the flow of water as shown in Table 2.1.

Table 2.1 Major basin groups in Thailand

| 9 basin groups | Catchment areas (km ²) | 25 major basins | Numbers of sub-basins |
|--|------------------------------------|--|-----------------------|
| 1. Mekong Sub-basin Group | 188,775.80 | 1. Khong, 2. Kok, 3. Chi 4. Mun, 5. Thole Sap | 95 |
| 2. Salawin Sub-basin Group | 19,105.94 | 6. Salawin | 17 |
| 3. Chao Phraya-Tha Chin Basin Group | 158,586.58 | 7. Ping, 8. Wang, 9. Yom 10. Nan, 11. Sakae Krang 12. Pasak, 13. Chao Phraya 14. Tha Chin | 70 |
| 4. Mae Klong Basin Group | 30,180.71 | 15. Mae Klong | 11 |
| 5. Bang Prakong Basin Group | 20,372.81 | 16. Prachin Buri 17. Bang Prakong | 8 |
| 6. East-Coast Gulf Basin Group | 13,497.51 | 18. East-Coast Gulf | 6 |
| 7. West-Coast Gulf Basin Group | 13,398.20 | 19. Petchaburi 20. Prachuap Khiri Khan Coast* | 8 |
| 8. South-eastern Basin Group (Gulf of Thailand's side) | 52,192.37 | 21. Peninsula-East coast 22. Tapi, 23. Thale sap Songkhla, 24. Pattani | 26 |
| 9. South-western Basin Group (Andaman Sea's Side) | 19,727.23 | 25. Peninsula-West Coast | 13 |
| Total | 515,837.15 | 25 major basins | 254 |

Source: Bureau of Research, Development and Hydrology (2009)



| | | | | | |
|-------------|------------------------|----|-----------------------------|----|----------------------------|
| Code | Watershed | 09 | Mae Nam Nan | 18 | East-Coast Gulf |
| 01 | Mae Nam <u>Salawin</u> | 10 | Mae Nam Chao Phraya | 19 | Mae Nam <u>Petchaburi</u> |
| 02 | Mae Nam <u>Khong</u> | 11 | Mae Nam Sakae Krang | 20 | <u>Prachuap Khiri Khan</u> |
| 03 | Mae Nam <u>Kok</u> | 12 | Mae Nam <u>Pasak</u> | | <u>Coast*</u> |
| 04 | Mae Nam Chi | 13 | Mae Nam <u>Tachin</u> | 21 | Peninsula-East Coast |
| 05 | Mae Nam Mun | 14 | Mae Nam <u>Mae Klong</u> | 22 | Mae Nam <u>Tapi</u> |
| 06 | Mae Nam Ping | 15 | Mae Nam <u>Prachin Buri</u> | 23 | <u>Thale sap Songkhla</u> |
| 07 | Mae Nam Wang | 16 | Mae Nam <u>Bang Prakong</u> | 24 | Mae Nam <u>Pattani</u> |
| 08 | Mae Nam Yom | 17 | <u>Thole Sap</u> | 25 | Peninsula-West Coast |

Source: Bureau of Research, Development and Hydrology (2009)

Figure 2.1 Maps of major river basins in Thailand

2.2 Freshwater resources

2.2.1 Surface Water by Watershed

The natural input to surface water system is rainfall. Thailand's average annual rainfall is around 1,500 mm ranging from 1,200 mm in the north and the central plain to 2100-2300 mm in the western part of the south and the eastern part of the country. However, the rainfall has been varied in each year; in 2011 the country average value was around 1,974 mm which is significantly higher than the normal average rainfall and this led to the severe floods in Thailand. The total volume of water from rainfall in all river basins in Thailand is estimated at 728,027 – 800,000 million m³, around 70-75 percent of which or around 514,604 million m³ is lost through evaporation, evapotranspiration and infiltration; the remaining 25-30 percent or around 213,423 million m³ constitutes the runoff that flows in rivers and streams (Table 2.2). About 30-34% of the surface runoff or approximately around 72,560 million m³ annually will be stored in the reservoirs. However, due to the continual improvement and development of irrigation projects in Thailand, in year 2010, the total capacity of large and medium scale of irrigation project is 73,712 million m³ covering around 24.17 million rai or 3.7 million hectare of irrigated areas. The total capacity of small-scale water resources development projects all over the country is around 1,753 million m³ covering the beneficial areas of about 10.12 million rai or 1.6 million hectare (OAE, 2011).

2.2.2 Water storage by Watersheds

According to development of irrigation projects in Thailand, three scales (large, medium, small) water reservoirs, electric water pumps, and water retention areas are referred to water storage covering irrigated areas around 29.78 million rai or 4.8 million hectare with 76,103 million m³ of total stored water in 2013 as detailed in Table 2.3. Approximately 97% of the total stored water is collected by large and medium scale of irrigation projects and provided to 82% of the total irrigated areas. Moreover two large scale reservoirs were constructed during 2011-2013 contributing to increasing the total capacity of water storage from 72,862 to 74,524 million m³ (RID, 2013). Regarding the large-scale of water reservoirs, there are 33 active reservoirs over the country under responsibilities of Electricity Generating Authority of Thailand (EGAT) and Royal Irrigation Department (RID) via Regional Irrigation Offices (RIO) as can be seen in Table 2.4 (RID, 2012a; 2012b).

Table 2.2 Thailand's surface water resources in 2011

| | Range of rainfall ² (mm) | Average annual rainfall ² (mm/year) | Average annual rainfall during Apr 2007- Mar 2008 ¹ (mm/year) | Amount of rainfall ² (million m ³) | Amount of rainfall during Apr 2007- Mar 2008 ¹ (million m ³) | Amount of run off ² (million m ³) | Amount of run off during Apr 2007-Mar 2008 ² (million m ³) |
|----------------------|--|---|--|--|--|---|--|
| Northern | 900-3,100 | 1,248 | 7,712.60 | 156,967 | 162,749.65 | 38,567 | 42,277.76 |
| Salawin | 900-3,100 | 1,354 | 1,748.7 | 24,257 | 31,333.21 | 8,376 | 13,159.95 |
| Kok | 1,100-2,200 | 1,478 | 1,356.70 | 11,668 | 10,711.15 | 4,177 | 3,695.35 |
| Ping | 900-1,900 | 1,125 | 1,050.10 | 38,118 | 35,594.19 | 8,725 | 7,368.00 |
| Wang | 900-1,400 | 1,099 | 1,020.30 | 11,856 | 11,011.08 | 1,617 | 1,651.66 |
| Yom | 1,000-1,600 | 1,159 | 1,212.40 | 27,375 | 28,632.04 | 3,657 | 4,581.13 |
| Nan | 1,000-1,800 | 1,273 | 1,324.40 | 43,693 | 45,467.98 | 12,015 | 11,821.67 |
| Northeastern | 800-2,900 | 1,329 | 4,246.40 | 235,237 | 248,975.23 | 61,513 | 49,573.72 |
| Khong | 900-2,900 | 1,548 | 1,711.10 | 88,904 | 98,258.21 | 30,769 | 34,007.17 |
| Chi | 900-1,700 | 1,174 | 1,285.40 | 58,083 | 63,597.74 | 11,244 | 7,377.34 |
| Mun | 800-2,500 | 1,266 | 1,249.90 | 88,250 | 87,119.28 | 19,500 | 8,189.21 |
| Central | 800-2,200 | 1,145 | 7,782.10 | 116,378 | 113,531.32 | 24,975 | 33,106.35 |
| Chao Phraya | 800-1,600 | 1,084 | 881.30 | 21,813 | 17,737.04 | 1,732 | 3,192.67 |
| Sakae Krang | 1,000-1,500 | 1,234 | 1,095.80 | 6,405 | 5,688.30 | 1,125 | 1,251.43 |
| Pasak | 900-1,800 | 1,213 | 901.10 | 19,764 | 14,679.82 | 2,897 | 1,908.38 |
| Tha Chin | 800-1,500 | 1,041 | 977.30 | 14,239 | 13,370.44 | 1,364 | 1,283.56 |
| Mae Klong | 900-2,200 | 1,334 | 1,522.60 | 41,131 | 46,952.42 | 15,129 | 20,424.30 |
| Petchaburi | 900-1,400 | 1,064 | 972.20 | 5,961 | 5,447.24 | 1,385 | 2,342.31 |
| West-Coast Gulf | 800-1,600 | 1,048 | 1,431.80 | 7,065 | 9,656.06 | 1,343 | 2,703.70 |
| Eastern | 800-4,400 | 1,649 | 5,929.70 | 63,380 | 59,028.62 | 23,882 | 23,366.43 |
| Prachin Buri | 1,100-2,600 | 1,584 | 1,394.50 | 16,603 | 14,614.36 | 5,164 | 3,945.88 |
| Bang Prakong | 1,100-2,600 | 1,346 | 1,019.90 | 10,738 | 8,136.76 | 3,344 | 2,533.79 |
| Thole Sap | 800-3,000 | 1,516 | 1,274.60 | 6,293 | 5,290.86 | 2,394 | 2,013.17 |
| East-Coast Gulf | 1,100-4,400 | 2,151 | 2,240.70 | 29,746 | 30,986.64 | 12,980 | 14,873.59 |
| Southern | 1,400-4,400 | 2,121 | 8,381.50 | 156,065 | 123,042.02 | 64,486 | 48,761.20 |
| Peninsula-East coast | 1,400-3,800 | 2,052 | 1,642.40 | 54,081 | 43,280.52 | 22,261 | 18,610.63 |
| Tapi | 1,400-3,900 | 2,061 | 1,119.80 | 25,195 | 13,688.44 | 10,530 | 6,022.91 |
| Thale sap Songkhla | 1,500-2,900 | 1,992 | 1,509.30 | 16,923 | 12,821.50 | 6,628 | 3,461.81 |
| Pattani | 1,600-2,500 | 1,939 | 1,859.20 | 7,478 | 7,170.93 | 2,670 | 3,155.21 |
| Peninsula-West coast | 1,600-4,400 | 2,559 | 2,250.80 | 52,388 | 46,080.63 | 22,397 | 17,510.64 |
| Total | | 1,499 | 34,052.30 | 728,027 | 707,326.84 | 213,423 | 197,085.46 |

Remarks: ¹Bureau of Research, Development and Hydrology (2009); ²Department of Water Resources (2008)

Table 2.3 Water storage by watershed

| Watershed | Large project | | | Medium project | | | Small project | | | | Electrical water pump project | | | | Detention storage project (Kaem Ling project) | | | |
|--------------------|---------------|-------------------------------------|----------------------|----------------|-------------------------------------|----------------------|---------------|-------------------------------------|----------------------|--------------------|-------------------------------|-------------------------------------|----------------------|--------------------|--|-------------------------------------|----------------------|--------------------|
| | No. | Stored water (M.m ³) | Irrigated area (rai) | No. | Stored water (M.m ³) | Irrigated area (rai) | No. | Stored water (M.m ³) | Irrigated area (rai) | Command area (rai) | No. | Stored water (M-m ³) | Irrigated area (rai) | Command area (rai) | No. | Stored water (M-m ³) | Irrigated area (rai) | Command area (rai) |
| Salawin | - | - | - | 16 | 13.83 | 41,260 | 307 | 10.87 | 31,670 | 114,262 | 23 | - | 21,376 | - | - | - | - | - |
| Khong | 4 | 633.00 | 401,895 | 130 | 526.73 | 620,140 | 1,894 | 436.36 | 101,170 | 1,327,435 | 436 | - | 686,961 | 25,574 | 51 | 138.71 | 800 | 22,880 |
| Kok | 1 | - | 166,000 | 4 | 73.00 | 100,200 | 196 | 23.88 | 47,530 | 262,675 | 12 | - | 17,740 | - | - | - | - | - |
| Chi | 7 | 1,661.50 | 1,130,496 | 82 | 348.65 | 337,760 | 1,527 | 252.04 | 17,970 | 641,228 | 603 | - | 1,303,618 | 60,775 | 19 | 17.62 | - | 28,150 |
| Mun | 9 | 1,269.38 | 928,285 | 149 | 906.15 | 662,520 | 2,341 | 333.34 | 20,175 | 1,203,898 | 296 | - | 507,365 | 153,540 | 42 | 38.14 | - | 175,920 |
| Ping | 3 | 528.80 | 423,000 | 42 | 130.87 | 1,118,541 | 941 | 28.29 | 176,827 | 1,200,723 | 190 | - | 291,203 | 70,440 | 4 | 9.64 | - | 6,365 |
| Wang | 2 | 282.00 | 177,000 | 8 | 66.23 | 132,067 | 260 | 105.99 | 32,596 | 182,593 | 80 | - | 101,599 | 24,876 | - | - | - | - |
| Yom | 3 | - | 480,540 | 32 | 305.89 | 271,900 | 508 | 75.98 | 83,577 | 610,405 | 125 | - | 121,540 | 80,208 | 19 | 68.12 | 3,000 | 76,119 |
| Nan | 4 | 769.00 | 631,883 | 51 | 75.38 | 421,781 | 602 | 48.62 | 80,843 | 461,596 | 316 | - | 557,271 | 8,900 | 15 | 23.50 | - | 67,250 |
| Chao Phraya | 22 | - | 5,955,245 | 10 | 15.01 | 135,821 | 313 | 9.44 | 19,918 | 529,533 | 30 | - | 73,379 | 2,000 | 14 | 38.21 | 44,100 | 513,150 |
| Sakae Krang | 1 | 160.00 | 143,500 | 5 | 70.00 | 128,148 | 120 | 1.71 | 2,500 | 161,810 | 16 | - | 38,400 | - | 1 | - | - | - |
| Pasak | 2 | 960.00 | 310,800 | 22 | 202.81 | 204,520 | 393 | 4.65 | 11,882 | 417,960 | 3 | - | 1,832 | 1,832 | 5 | 28.83 | 6,000 | 13,000 |
| Tha Chin | 9 | 240.00 | 2,328,550 | 7 | 54.48 | 112,576 | 387 | 26.28 | 28,000 | 598,055 | 11 | - | 31,150 | - | 4 | 1.89 | 3,500 | 12,000 |
| Mae Klong | 7 | - | 1,343,600 | 19 | 123.11 | 146,400 | 287 | 164.64 | 32,611 | 296,323 | 68 | - | 117,030 | 23,400 | - | - | - | - |
| Prachin Buri | 1 | - | 326,000 | 23 | 139.37 | 201,215 | 224 | 13.39 | 19,819 | 158,865 | 66 | - | 114,453 | 4,000 | 1 | 0.05 | - | 500 |
| Bang Prakong | 4 | 549.00 | 1,224,040 | 15 | 58.70 | 109,150 | 261 | 15.00 | 10,180 | 206,056 | 5 | - | 16,950 | - | - | - | - | - |
| Thole Sap | - | - | - | 3 | 137.01 | 97,900 | 150 | 2.65 | 1,950 | 68,670 | - | - | - | - | - | - | - | - |
| East-Coast Gulf | 3 | 522.00 | 213,500 | 35 | 256.50 | 296,300 | 282 | 20.66 | 23,090 | 196,690 | 53 | - | 125,080 | 7,150 | 6 | 8.43 | - | 37,750 |
| Petchaburi | 1 | 710.00 | 336,000 | 12 | 4.39 | 24,530 | 136 | 35.74 | 17,070 | 92,280 | 9 | - | 8,100 | 500 | 2 | 0.06 | - | 1,200 |
| West-Coast Gulf | 1 | 445.00 | 220,000 | 21 | 154.49 | 94,620 | 328 | 50.86 | 31,874 | 307,603 | 1 | - | 1,000 | - | - | - | - | - |
| Peninsula-East co. | 6 | 80.00 | 884,744 | 24 | 15.80 | 445,100 | 1,022 | 69.38 | 102,338 | 621,150 | 44 | - | 62,592 | 25,500 | 6 | 4.10 | 1,500 | 4,700 |
| Tapi | - | - | - | 20 | 161.18 | 61,615 | 108 | 0.06 | 15,712 | 88,430 | 20 | - | 30,138 | - | 1 | 0.18 | - | 1,200 |
| Thale sap Songkhla | 2 | - | 190,000 | 15 | 82.00 | 425,190 | 177 | 0.56 | 31,220 | 216,616 | 25 | - | 46,265 | 2,700 | 1 | 0.04 | - | 800 |
| Pattani | 1 | - | 241,850 | 2 | - | - | 199 | 0.54 | 8,870 | 55,974 | 1 | - | 800 | - | 4 | 2.65 | - | 3,000 |
| Peninsula-West co. | - | - | - | 20 | 32.80 | 148,710 | 533 | 24.07 | 53,417 | 210,552 | 25 | - | 49,600 | - | 5 | 0.66 | - | 880 |

Table 2.4 Large-scale water reservoirs in Thailand

| Large scale reservoirs | Capacity (million m ³) | | | Organization |
|----------------------------|------------------------------------|---------------|------------|--------------|
| | Max. Level | Storage level | Min. Level | |
| Bhumibol Dam | 13,462 | 13,462 | 3,800 | EGAT |
| Sirikit Dam | 10,640 | 9,510 | 2,850 | EGAT |
| Keaw Lom Dam | 112 | 112 | 4 | RIO 2 |
| Mae Ngad Somboon Chon Dam | 325 | 2,654 | 22 | RIO 1 |
| Mae Kuang Udom Thara Dam | 263 | 263 | 14 | RIO 1 |
| Keaw Kho Ma Dam | 209 | 170 | 6 | RIO 2 |
| Khwaee Noi Bamrung Dan Dam | 1,080 | 939 | 43 | RIO 3 |
| Kraseaw Dam | 363 | 240 | 40 | RIO 12 |
| Tup Salao Dam | 198 | 160 | 8 | RIO 12 |
| Pasak Cholasit Dam | 960 | 785 | 3 | RIO 10 |
| Nam Pung Dam | 166 | 165 | 9 | EGAT |
| Ubonrat Dam | 2,432 | 2,432 | 581 | EGAT |
| Lam Pao Dam | 2,450 | 1,980 | 100 | RIO 6 |
| Lam Takhong Dam | 445 | 314 | 27 | RIO 8 |
| Lam PraPloeng Dam | 242 | 110 | 1 | RIO 8 |
| Sirinthon Dam | 1,966 | 1,966 | 831 | EGAT |
| Chulaporn Dam | 207 | 164 | 44 | EGAT |
| Nam Uoon Dam | 780 | 520 | 43 | RIO 5 |
| Upper Mun Dam | 350 | 141 | 7 | RIO 8 |
| Huay Luang Dam | 135 | 135 | 7 | RIO 5 |
| Lam Nang Rong Dam | 182 | 121 | 3 | RIO 8 |
| Lam Chae Dam | 325 | 275 | 7 | RIO 8 |
| Kangkracharn Dam | 930 | 710 | 67 | RIO 14 |
| Parnburi Dam | 650 | 347 | 18 | RIO 14 |
| Sri Nakarin Dam | 18,850 | 17,745 | 10,265 | EGAT |
| Wachiralongkorn Dam | 11,000 | 8,860 | 3,012 | EGAT |
| Bangpra Dam | 120 | 117 | 12 | RIO 9 |
| Nong Plalai Dam | 187 | 164 | 14 | RIO 9 |
| Khlong Si Yat Dam | 420 | 420 | 30 | RIO 9 |
| Khun Dan Prakarn Chon Dam | 226 | 224 | 5 | RIO 9 |
| Prasae Dam | 322 | 248 | 20 | RIO 9 |
| Banglang Dam | 1,674 | 1,454 | 260 | EGAT |
| Ratcha Prapa Dam | 6,620 | 5,639 | 1,352 | EGAT |

2.2.3 Groundwater resources by Watersheds

Groundwater is an importance source of freshwater in Thailand as it is estimated that 75 percent of domestic water is obtained from groundwater sources (Ti and Facon, 2003). The volume of groundwater stored over the 27 groundwater basins is estimated to be around 1,144,289 million m³. The groundwater system in Thailand is mainly recharged by rainfall

and by seepage from the rivers and the hydrological balance studies estimate that around 13-18 percent of rainfall would infiltrate the soil and about 9% reach the aquifer (Ti and Facon, 2003). The water cycle balance of Thailand developed by the Department of Water Resources showed that the total of natural groundwater recharge is 103,626 million m³ per year or 9% of the stored groundwater (ONEP, 2010). Recently, the amount of natural groundwater recharge slightly increased to around 104,700 million m³ per year spreading over groundwater basins. Nevertheless, the performance of rainfall reaching the aquifer is valid only for basins under favourable geologic conditions, such as the basins in the Northern Highlands, the upper Central Plain and along the Gulf Coastal Plain. For the other basins, such as the lower Central Plain including Bangkok and on the Korat Plateau, it is estimated that only 5-6 percent of the rainfall reaches the aquifer. Even though a huge amount of groundwater available in Thailand for supporting and replacing surface water in the areas where tap water is not enough or is inaccessible, especially for agricultural sector in non-irrigation areas and industrial sector including dyeing factory. The Department of Groundwater Resource (DGR) categorizes sources of groundwater into 3 types including water pumping from 1) private wells for domestic, business and agricultural usage, 2) public wells (municipal water supply) and 3) village water supply as showed in Table 2.5 (Koontanakulvong et.al, 2012).

The utilization of groundwater needs to be carefully managed to avoid adverse impacts such as land subsidence, contamination of groundwater from saline water intrusion, and so on. The limitations have been found in several locations especially in Bangkok. Nowadays, the use of groundwater has continuously increased not only in the urban areas but also in the rural areas for agriculture, industries and households; however, the volume of groundwater used nowadays is just only 8,000 million m³ and still far from the total stored groundwater (DGR, 2012).

2.3 Water requirements by watersheds

Thailand is like other Asian countries where with increasing population and economic growth, fresh water resource management is important for sustaining future economic and social development. The rapid rural development, industrialization and income growth have raised water demand for domestic usage, agriculture and industries drastically. The statistics of water demand in 2009 revealed that the water demand for the whole country was around 76,564 million m³ which shared by agriculture, ecosystem balance, domestic consumption (households) and industries around 74%, 12%, 8% and 6%, respectively (HAI, 2010). Meanwhile, the available water supply on that time was only 73,563 million m³ including 55,563 million m³ of stored water in large and medium reservoirs and 18,000 million m³ of water downstream of dam and groundwater excluding natural water resources. The volume of water deficit found was around 3,001 million m³ per year. Table 2.6 shows the historic data on water requirements and water shortage classified by regions in Thailand. The results show that during 1993-2006, total water demand has increased from 61,507 million m³ to 87,495 million m³ per year as well as the volume of water shortage has increased from 4,756 to 12,560 million m³ per year. The central region which including of Chao Phraya, Sakae

Krang, Pasak, Tha Chin, Mae Klong, Petchaburi, and West-Coast Gulf basins is the region of largest water consumption in Thailand. Moreover, the volume of water requirement in 2014 is predicted to be increased to 79,685 million m³ whereas available water that can be accessed is estimated around 75,563 million m³ including the additional 2,000 million m³ of stored water from the large and medium reservoirs that are being constructed. Hence, the shortage is estimated to be around 4,122 million m³ (DWR, 2008).

Table 2.5 Groundwater wells and demand based on major groups of watershed in 2007

(a) Private Wells

| Groups of watershed | Domestic | | Business | | Agriculture | |
|-------------------------|---------------|----------------------------------|---------------|----------------------------------|--------------|----------------------------------|
| | Well | Demand (million m ³) | Well | Demand (million m ³) | Well | Demand (million m ³) |
| 1 Khong | 2,716 | 20.22 | 2,800 | 35.51 | 1,487 | 13.43 |
| 2 Salawin | 69 | 0.63 | 42 | 0.83 | 34 | 0.67 |
| 3 Chao Phraya -Tha Chin | 4,126 | 65.23 | 6,108 | 256.30 | 2,169 | 38.76 |
| 4 Mae Klong | 291 | 3.89 | 580 | 54.82 | 202 | 3.93 |
| 5 Bang Prakong | 392 | 7.57 | 636 | 15.49 | 325 | 6.76 |
| 6 East- Coast Gulf | 455 | 3.98 | 714 | 9.96 | 687 | 4.70 |
| 7 West-Coast Gulf | 177 | 1.75 | 232 | 9.85 | 60 | 1.11 |
| 8 South-eastern Basin | 2,446 | 7.81 | 2,026 | 40.49 | 177 | 1.82 |
| 9 South-western Basin | 576 | 5.48 | 966 | 13.59 | 87 | 1.17 |
| Total | 11,248 | 116.56 | 14,104 | 436.84 | 5,228 | 72.35 |

(b) Public wells and village water supply

| Groups of watershed | Public wells | | Village water supply |
|-----------------------------|----------------|--|--|
| | Number of well | Water demand (million m ³) | Water demand (million m ³) |
| 1 Khong | 100,631 | 275.56 | 219.70 |
| 2 Salawin | 1,022 | 2.77 | 4.56 |
| 3 Chao Phraya -Tha Chin | 54,943 | 271.58 | 147.43 |
| 4 Mae Klong | 6,615 | 35.03 | 12.32 |
| 5 Bang Prakong | 7,310 | 31.14 | 14.38 |
| 6 East-Coast Gulf | 4,616 | 11.40 | 6.27 |
| 7 West-Coast Gulf | 3,706 | 10.47 | 7.18 |
| 8 South-eastern Basin Group | 15,350 | 56.08 | 33.36 |
| 9 South-western Basin Group | 6,255 | 18.33 | 13.53 |
| Total | 200,448 | 712.36 | 458.73 |

Table 2.7 shows the water withdrawal for different basins in Thailand obtained from the Royal Irrigation Department (RID, 2011) and the water demand shared by different sectors (HAIL, 2010). The withdrawals are normally classified into six sectors, namely agriculture, domestic, industry, tourism, ecosystem and livestock. Although the water resources development programme has been implemented and developed continually, the country is still facing serious supply constraints especially during dry season due to several reasons such as lack of enough fresh water storage and good water resource management, low efficiency of water delivery and open channel systems. In addition, variations of water quantity due to locations and seasons also bring about the shortage of water in some watersheds (ONEP, 2010). In 2010, 65% of the total water demand was for agriculture with

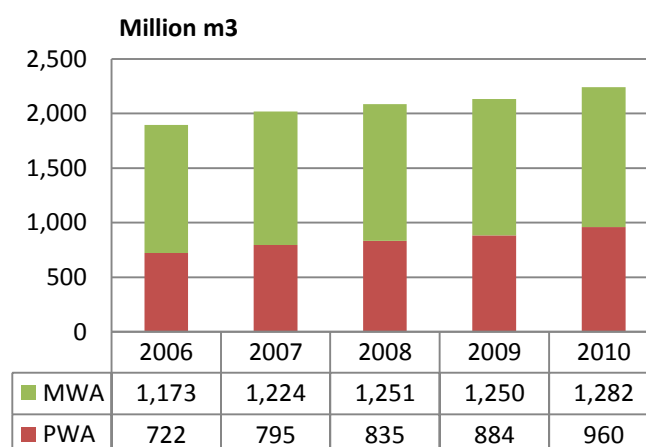
45,054 million m³ of water supplied in irrigated areas and 61,116 million m³ of water required by non-irrigated areas (RID, 2010).

Table 2.6 Water requirement classified by watersheds

| Regions and Watersheds | Water requirement* (million m ³ /year) | | | Water shortage* (million m ³ /year) | | |
|---|--|--------|--------|---|-------|-------|
| | 1993 | 1996 | 2006 | 1993 | 1996 | 2006 |
| North (Salawin, Kok, Ping, Wang, Yom, Nan) | 8,764 | 10,655 | 13,065 | 141 | 1,408 | 2,792 |
| North-East (Khong, Chi, Mun) | 6,389 | 8,409 | 11,814 | 961 | 1,003 | 2,637 |
| Central (Chao Phraya, Sakae Krang, Pasak, Tha Chin, Mae Klong, Petchaburi, West Coast Gulf) | 36,137 | 45,613 | 47,336 | 1,965 | 2,179 | 3,089 |
| East (Prachin Buri, Bang Prakong, Thole Sap, East-Coast Gulf) | 4,314 | 4,761 | 5,935 | 750 | 591 | 756 |
| South (Peninsula-East coast, Tapi, Thale sap Songkhla, Pattani) | 5,933 | 6,282 | 9,345 | 939 | 1,132 | 3,286 |

Source: DWR (2008)

The variations in season and location have the most significant impact to the agricultural sector in Thailand because nowadays the irrigated areas for agriculture are just only 35,200 km² requiring water supply around 59,900 million m³ per year; while, the non-irrigated areas are 174,400 km² (RID, 2012a). The water resources for agriculture today are therefore highly reliant on rainfall. For households, tap water is the major water supply source; Figure 2.2 shows that the amount of tap water provided by Metropolitan Waterworks Authority (MWA) (for Bangkok, Samut Prakan and Nonthaburi) and Provincial Waterworks Authority (PWA) (for the rest of country) has increased continuously.



Source: PWA (2010) and MWA (2010)

Figure 2.2 Water distributed by provincial and metropolitan waterworks authorities

Table 2.7 Water demand of 25 watersheds (RID, 2011)

| Watersheds | Water demands (million m ³ /year) | | | | | | | | | Total |
|----------------------|--|---|---------------------|------------------------|---------------------|----------|---------|-----------|-----------|-----------|
| | Domestic | Agriculture-Wet Season | | Agriculture-Dry Season | | Industry | Tourism | Livestock | Ecosystem | |
| | | Irrigated area | Non-Irrigated areas | Irrigated area | Non-Irrigated areas | | | | | |
| Salawin | 30.34 | 26.54 | 642.75 | 21.06 | 127.56 | 4.11 | 0.59 | 3.29 | 1838 | 2,694.24 |
| Khong | 238.66 | 0 | 0 | 377.17 | 1,116.21 | 24.85 | - | 54.06 | 3552.9 | 5,363.85 |
| Kok | 160.69 | 0 | 0 | 80.32 | 81.85 | 11.41 | - | 10.16 | 698.4 | 1,042.83 |
| Chi* | 213.81 | 4,295.02 (irrigated area) and 15,039.85 (non-irrigated areas) | | | | 33 | 3.91 | 62.39 | 1,884.70 | 21,532.68 |
| Mun* | 297.12 | 4,260.80 (irrigated area) and 33,892.00 (non-irrigated areas) | | | | 44.6 | 6.29 | 135.76 | 1,382.60 | 40,019.17 |
| Ping | 70.02 | 1,158.10 | 81.35 | 1,198.21 | 21.04 | 36.62 | - | 13.17 | 1,671.90 | 4,246.41 |
| Wang | 160.69 | 84.72 | 382.79 | 50.71 | 57.28 | 21.41 | - | 4.13 | 173.4 | 935.13 |
| Yom | 60.97 | 764.59 | 1,885.61 | 404.49 | 249.38 | 18.16 | 1.52 | 12.02 | 200.63 | 3,597.37 |
| Nan | 166 | 47.61 | 239.53 | 386.45 | 486.02 | 31.5 | 3.28 | 27.7 | 1172.4 | 2,560.49 |
| Chao Phraya | 652.2 | 1,812.68 | 1,239.55 | 1,316.92 | 225.13 | 896.65 | - | 18.23 | 1261.44 | 7,422.81 |
| Sakae Krang | 20.4 | 105.00 | 292.40 | 63.10 | 43.90 | 3.2 | - | 4.1 | 89.1 | 621.20 |
| Pasak | 86.01 | 158.14 | 1,058.71 | 178.59 | 298.9 | 103.26 | - | 27.73 | 894.8 | 2,806.14 |
| Tha Chin | 172.8 | 1,086.50 | 1,409.80 | 680.6 | 220.8 | 210.65 | - | 29.79 | 228.2 | 4,039.14 |
| Mae Klong | 112.6 | 134.88 | 196.9 | 412.55 | 150.56 | 96 | - | 35.33 | 1865.6 | 3,004.42 |
| Prachin Buri | 20.7 | 0 | 0 | 169.08 | 173.53 | 12.66 | - | 66.2 | 117.4 | 559.56 |
| Bang Prakong | 292.27 | 0 | 0 | 364.7 | 222.5 | 74.5 | - | 75.59 | 238 | 1,267.56 |
| Thole Sap | 23.62 | 16.86 | 248.64 | 26.02 | 95.96 | 6.5 | - | 3.62 | 262.2 | 683.43 |
| East-Coast Gulf | 117.06 | 0 | 0 | 109.1 | 279.4 | 161 | - | 52.13 | 1087.8 | 1,806.49 |
| Petchaburi | 42.02 | 0 | 0 | 111.38 | 136.91 | 6.1 | - | 5.95 | 463.6 | 765.96 |
| West-Coast Gulf | 40.27 | 116.99 | 753.67 | 35.10 | 56.53 | 989.6 | - | 5.6 | 318.2 | 2,315.95 |
| Peninsula-East coast | 265.37 | 768.82 | 4,227.14 | 282.70 | 388.58 | 1345.92 | - | 13.77 | 4466.7 | 11,759.00 |
| Tapi | 86.95 | 48.43 | 2,551.73 | 25.70 | 338.56 | 96.58 | - | 4.76 | 3,797.50 | 6,950.21 |
| Thale sap Songkhla | 93.09 | 0 | 0 | 142.31 | 139.87 | 73.79 | - | 6.37 | 740.9 | 1,196.33 |
| Pattani | 31.58 | 81.72 | 291.17 | 66.70 | 59.42 | 9.41 | - | 1.08 | 1527.1 | 2,068.18 |
| Peninsula-West coast | 150.51 | 0 | 0 | 44.87 | 309.74 | 44.19 | 11.60 | 6.54 | 3807.33 | 4,374.78 |

Remarks "0" means The amount of effective rainfall is higher than agricultural uses, *Water demands for agriculture in Mun and Chi watersheds cannot be separated into wet and dry season

CHAPTER 3

Monthly and Seasonal Water Stress Index (WSI) for Thailand

Water resource management nowadays becomes the essential issue to satisfy the increasing demand of agriculture with rising population and consequent increased demand of food. In addition, the proliferation of bioenergy and biofuels derived from crops promises to increase stress on water, an already scarce resource in many countries. This is of particular concern to Thailand which is a large agricultural base both for food for local consumption and export as well as for feed and biofuels. The study therefore aims to (1) continue the development of the practical water impact assessment tool for Thailand; and (2) continue the promotion of water footprint and water stress index as the tools for policy decision making in the promotion of food, feed, fuel production with the sustainable water and land use in Thailand. In this chapter, the methodology for development of monthly water stress index (WSI) and the results of monthly water stress map are explained and discussed.

3.1 Definition of Water Stress Index (WSI)

“Water Stress Index (WSI)” or so called “Water Scarcity Index” is commonly referred the indices that are developed to quantitatively evaluate water resources vulnerability (e.g. water stress or water scarcity). Although, there were many water stress indices proposed over the past decades; however, the general indicator would be defined as the ratio of total annual freshwater withdrawals to hydrological availability (Brown and Matlock, 2011). Water stress index is the important information for assessing the impact of freshwater use since one litre of water consumed in the water stress region would have the higher impact than the water rich region.

In Life Cycle Assessment (LCA) studies, one of the water stress index (WSI) used for assessing the environmental impacts of freshwater use is the WSI developed by Pfister et al. (2009). The method used the modified WSI as the characterization factor for the midpoint category so called “Water deprivation” (Pfister et al., 2009; Pfister et al., 2011).

3.2 Annual Water Stress Index (WSI)

From the 1st Phase of the project, the annual water stress index (WSI) of 25 major basins of Thailand has been evaluated based on the modified water assessment methodology of Pfister and colleagues (2009) and Ridoutt and Pfister (2010) as well as the annual water stress map of Thailand has been developed as shown in Figure 3.1. Although the annual WSI index and Water stress map obtained from the 1st phase of project can be extensively used e.g. assessing water deprivation potential or the impact of water consumption or water use for food, feed and fuel crops production; assessing the biofuel policy implications on water resource use and impact; enhancing the LCA researches on life cycle impact assessment of water use in Thailand. However, there still have the limitations of the WSI and the water stress map e.g. the map was developed based on yearly average map which cannot explain for the details of stress situation such as the seasonal effect. The objective of the 2nd phase is to improve the WSI and water stress map by using more comprehensive data on seasonal variables based on the “bottom-up data collection approach”. This

chapter presents improvement of WSI and water stress map by using more comprehensive data on seasonal variables. Details information of monthly WSI and water stress map are revealed.



| Watersheds | WSI |
|---------------------------|-------|
| (1) Salawin | 0.017 |
| (2) Kok | 0.018 |
| (3) Ping | 0.023 |
| (4) Wang | 0.021 |
| (5) Yom | 0.044 |
| (6) Nan | 0.015 |
| (7) Khong | 0.014 |
| (8) Chi | 0.471 |
| (9) Mun | 0.927 |
| (10) Chao Phraya | 0.339 |
| (11) Sakae Krang | 0.031 |
| (12) Pasak | 0.050 |
| (13) Tha Chin | 0.287 |
| (14) Mae Klong | 0.018 |
| (15) Phetchaburi | 0.022 |
| (16) West Coast Gulf | 0.158 |
| (17) PrachinBuri | 0.016 |
| (18) Bang Pakong | 0.026 |
| (19) Thole Sap | 0.019 |
| (20) East-Coast Gulf | 0.015 |
| (21) Peninsula-East coast | 0.067 |
| (22) Tapi | 0.060 |
| (23) Thale sap Songkhla | 0.014 |
| (24) Pattani | 0.025 |
| (25) Peninsula-West coast | 0.012 |

Figure 3.1 Water stress map of Thailand classified by 25 watersheds (1st phase of the project)

3.3 Monthly water stress index calculation in the 2nd Phase

Table 3.1 shows the comparison of general equations for annual and monthly water stress index calculations (Pfister et al., 2009; Pfister and Bayer, 2013). The key principal for WSI calculation is the same i.e. the water stress is calculated based on the withdrawal to availability as well as the same levels of water stress are classified. The main contrary is the baseline water withdrawal and water availability data used in the calculations. These will be annually and monthly based which in turn bring about the change in the coefficient use in the formula as shown in Table 3.1.

Table 3.1 Comparison between regionalised water stress and monthly water stress

| | Annual Water Stress Index | Monthly Water Stress Index |
|----------------------------------|---|---|
| General formula | $WSI = \frac{1}{1 + e^{-6.4WTA^* \left(\frac{1}{0.01} - 1\right)}}$ | $WSI_{month} = \frac{1}{1 + e^{-9.8WTA^*_{month} \left(\frac{1}{0.01} - 1\right)}}$ |
| Withdrawal to Availability (WTA) | Annual WTA | Monthly WTA |

| | Annual Water Stress Index | Monthly Water Stress Index |
|-----------------------|--|--|
| Variation Factor (VF) | <ul style="list-style-type: none"> Annual and monthly variability of water availability (S_{month}^* and S_{year}^*) Flow regulation by water reservoirs (SRF and non-SRF)[#] | <ul style="list-style-type: none"> Annual variability of rainfall (S_{year}^*) |
| Constant factor | -6.4 | -9.8 |

Remark: [#]SRF is a strongly regulated flow and non-SRF is a non-strongly regulated flow. These flows are classified based on flow regulation as detailed in 3.3.1-3.3.2

Followings are the terminology used in the study:

Water Availability refers to the amount of freshwater available at a location (UN-Water, 2009 and UN-ESCAP, 2011). Availability may vary a lot over the year, or even between one year and another depending on many factors e.g. seasonal, climate conditions and variations, and the capacity of the installed facility to withdraw the freshwater from the freshwater resources. In the other words, water availability can be defined as the amount of freshwater available for human uses.

Water withdrawal refers to the amount of freshwater removed from freshwater resources. It is sometimes called as the “Water abstraction”.

Regarding Table 3.1, the step-by-step WSI index calculations are briefly detailed as follows:

3.3.1 Withdrawal-to-Availability (WTA) and WTA* Calculations

(1) The WTA has to be initially calculated for each watershed/basin i . The WTA indicator is alternatively called as “Withdrawal-to-Availability (WTA)” index has been estimated from the ratio of total water withdrawals to hydrological availability of a basin by Equation (1):

$$WTA_i = \frac{\sum_j W_{ij}}{WA_i} \quad (\text{Eq. 1})$$

Where WTA_i represents to the water withdrawal to availability ratio for each watershed i ; W_{ij} represents to the water withdrawal from watershed/basin i by each sector j (or commonly referred as the sum of estimated water used for industrial, agricultural, and domestic sectors); WA_i represents to the water availability of the watershed/basin. The difference between annual and monthly WSI calculation is that the WTA and W_{ij} data used in the calculation will be yearly and monthly based, respectively.

(2) Applying the factor regarding seasonal variations to the flows and availability of water as the weighting factor for *WTA*. Hence the weighted *WTA* is then will be expressed as *WTA**.

For annual WSI calculation

Annual *WTA** can be calculated by Equation (2) and (3), respectively. Equation (2) shows the simple formula to determine the *WTA** i.e. the WTA in Equation (1) have been adjusted by the variation factor (VF) which was introduced to account for seasonal variations in water availability

in relation to regulation effects of water reservoir on flow regime. Thus the effect of VF will reduce if river flows are regulated by water reservoir. This criterion is defined as a strongly regulated flow (SRF). In contrast, a non-strongly regulated flow (non-SRF) is classified if river flows naturally, then the effect of VF is fully taken into account in the ratio of WTA. Equation (3) shows the formula to calculate the VF by using the standard deviations of monthly average (S_{month}^*) and annual rainfall (S_{year}^*).

$$WTA^* = \begin{cases} \sqrt{VF} \times WTA & \text{for SRF} \\ VF \times WTA & \text{for non-SRF} \end{cases} \quad (\text{Eq. 2})$$

$$VF = e^{\sqrt{\ln(S_{month}^*)^2 + \ln(S_{year}^*)^2}} \quad (\text{Eq. 3})$$

For monthly WSI calculation

Monthly WTA^* can be calculated by Equation (4) i.e. to determine the monthly WTA^* with regard to the variation factor which is considered only annual variability of rainfall (S_{year}^*). The geometric standard deviation is applied due to more suitable measure of a lognormal distribution than the arithmetic standard deviation.

$$WTA_{month}^*(i) = S_{year}^*(i) \cdot WTA_{month}(i) \quad (\text{Eq. 4})$$

Since the weighted WTA or WTA^* in Equation (4) is the monthly basis; therefore, the variation factor considered will be only the annual variability of rainfall. Equation (5) shows the formula to calculate the geometric standard deviation of annual rainfall (S_{year}^*).

$$S_{year}^* = \exp(\text{stdev}(\ln(\text{annual rainfall}))) \quad (\text{Eq. 5})$$

3.3.2 WSI Calculation

For annual WSI calculation

Equation (6) is a general formula used to calculate the annual WSI of Pfister et al. (2009) for each basin. The advantage of using the proposed water index by Pfister et al. (2009) is that the variation of rainfall is concerned in the WTA as well as the factors regarding the strongly regulated flow (SRF) and non-strongly regulated flow (non-SRF) of the basins/water storages. As Equation (2), the water storage is supposed to be dam or large and medium reservoirs and the adjusted WTA ratio is categorized into SRF if water is delivered from the water storages; otherwise, the adjusted WTA ratio is classified as non-SRF. In case of Thailand, water reservoirs ranging from large to small scales are built in all 25 watersheds; therefore, most of them are classified into SRF. In addition, obtained result of water stress index will be ranged from 0 to 1, which is essential to serve as a characterization factor for the suggested midpoint impact category “water deprivation” in life cycle impact assessment (LCIA).

$$WSI = \frac{1}{1 + e^{-6.4WTA^* \left(\frac{1}{0.01} - 1\right)}} \quad (\text{Eq. 6})$$

For monthly WSI calculation

Since the monthly WTA^* calculation has a lower variation factor in the calculation as compared to the annually WTA^* calculation, the general formula for explaining the relation between the WSI and the monthly WTA^* has been revised by Pfister and Bayer (2013) as shown in Equation (7).

$$WSI_{month}(i) = \frac{1}{1 + e^{(-9.8) \cdot WTA^*_{month}(i) \left(\frac{1}{0.01} - 1\right)}} \quad (\text{Eq. 7})$$

where $WTA_{month}(i)$ represents to the monthly water withdrawal to availability for watershed i ; $S^*_{year}(i)$ represents the annual variability by means of geometric standard deviation of annual rainfall for watershed i ; $WTA^*_{month}(i)$ represents the monthly WTA^* relating to annual variability of watershed i ; $WSI_{month}(i)$ represents to the monthly water stress index for each watershed i .

Hence, if comparing between WSI formula for annual and monthly WSI as Equation (6) and Equation (7), the revision lead to the change in the constant factor i.e. “6.4” to “9.8”. Nevertheless, the classifications of level of water stress using WSI values for both annual and monthly WSI are still be the same. The levels of water stress can be classified into five categories as shown in Table 3.2.

Table 3.2 Levels of water stress classified by Pfister et al. (2009)

| WSI | Category/Condition |
|-------------|--------------------|
| > 0.9 | Extreme |
| < 0.9 | Severe |
| 0.5 | Stress |
| 0.1 – < 0.5 | Moderate |
| < 0.1 | Low |

In this 2nd phase project, the monthly WSI shown in Equation (7) has been applied for improving the WSI and water stress map obtained from the 1st Phase. Thus, the WSI of 25 major basins of Thailand will be recalculated and adjusted based on the monthly WSI of Pfister and Bayer (2013). Since the monthly WSI is calculated based on a monthly basis; therefore, a variation of monthly rainfall is already addressed. Thus a variation of annual rainfall is fully accounted as VF for the monthly WSI while SRF and non-SRF are neglected. Accordingly, the VF values of monthly WSI are smaller than that of annual WSI. Although different equations are used to calculate annual and monthly WSI, levels and classifications of WSI results are the same as showed in Table 3.2. A logistic function is applied for converting the values of WTA ratio to the range of WSI values from 0 to 1. A range of water stress thresholds from 20% to 60% is employed for determining classification of water stress. The critical threshold of water stress is defined at the WTA of 0.4 which is equal to the WSI of 0.5 (Pfister and Bayer 2013; Pfister et al. 2009).

3.3.3 Working steps for water stress index calculation in the 2nd Phase

The activities for WSI improvement can be summarized as follows:

1. Development of template for WSI calculation
2. Data collection with various local data sources e.g. local government, Provincial agricultural promotion office, Sub-division of the Royal Irrigation Department (RID), Provincial waterworks authority (PWA), etc.

3. Testing the template
4. Data verification by checking with the local government/officers
5. Literature review and data collection on the future rainfall and variations due to the effects of climate change
6. WSI calculation modification by adapting from the existing WSI of Pfister et al. and the variation factors of Thailand
7. Development of water stress map classified by wet and dry season
8. Finalize the template for WSI calculation

In the 2nd phase, the template for the WSI calculation is developed and used for evaluating the monthly WSI of 25 major watersheds of Thailand. Details of the template are presented in this chapter. Nevertheless, the terms used in the WSI calculation as well as in the template will be defined here to facilitate the understanding of the users.

Table 3.3 shows the data requirements and sources for the WSI calculation. For freshwater availability, the rainfall and stored water in dams at the beginning of the year are taken into account as the monthly amount of freshwater availability. For water withdrawals, the work manual of Royal Irrigation Department for estimating the water quantities of four main economic sectors is applied in the study to estimate the amount of water withdrawal for each sector (as defined in Table 3.3). The data were collected from relevant organizations e.g. Royal Irrigation Department (RID), Department of Industrial Works (DIW), Office of Agricultural Economics (OAE), Department of Agricultural Extension (DOAE).

Table 3.3 Data requirements and sources for WSI calculation

| Parameters | Terms | Data Source |
|--------------------------|--|--|
| Water availability: | | |
| Rainfall | Monthly rainfall (10 years monthly average data during 2002-2011) by station | Thai Meteorological Department (TMD) |
| Stored water | Monthly stored water in water reservoirs by watershed | Royal Irrigation Department (RID) |
| Water withdrawal: | | |
| $W_{\text{Household}}$ | Water withdrawal for household sector by province is estimated from the number of population multiply with water consumption rate per person | RID; Provincial Waterworks Authority (PWA); National Statistical Office Thailand (NSO) |
| W_{Industry} | Water withdrawal for industrial sector by watershed is assessed based on types of industries and their areas. | Royal Irrigation Department (RID); Department of Industrial Works (DIW) |
| $W_{\text{Agriculture}}$ | Water withdrawal for agricultural sector by province is estimated from crop water requirements and cultivated areas | RID; Office of Agriculture Economics (OAE) |
| $W_{\text{Livestock}}$ | Water withdrawal for livestock sector by province is estimated from the number of each livestock multiply with water consumption rate per head of each livestock | RID; Department of Livestock Development (DLD) |

3.3.4 Verification

Data and information as well as literature related to data requirement in Table 3.3 are firstly reviewed. Data, criteria and standards obtained from different sources are analyzed and compared with statistical records in order to obtain the most reasonable and consistent data. In addition, discussion with expertise at RID, DIW, etc. are arranged for clarifying and confirming data required for developing the WSI template. After that, consultation meetings are performed for validating the monthly and seasonal WSI results obtained and receiving comments and suggestions from stakeholder, local governments, and related organizations.

3.4 Template for WSI Calculation

The template for calculating Monthly WSI as shown in Eq. (7) has been prepared in the MS Excel format. The template consists of two main parts; A and B. The A part refers to a workbook (file) named “A-Input”. The B part contains a main workbook called “B-Calculation and five supporting workbooks i.e. “B-WW_AgN”, “B-WW_AgNE”, “B-WW_AgC”, “B-WW_AgE”, and “B-WW_AgS” as illustrated the flowchart of developing the template for WSI calculation in Figure 3.2. Accordingly the template is established based on seven workbooks. Data required for WSI calculation are needed for the A-Input workbook and linked to the B-Calculation workbook. The final results are displayed in a worksheet named “OUTPUT” depending on selected options. Details of the calculation sheets and description are presented in Appendix B.

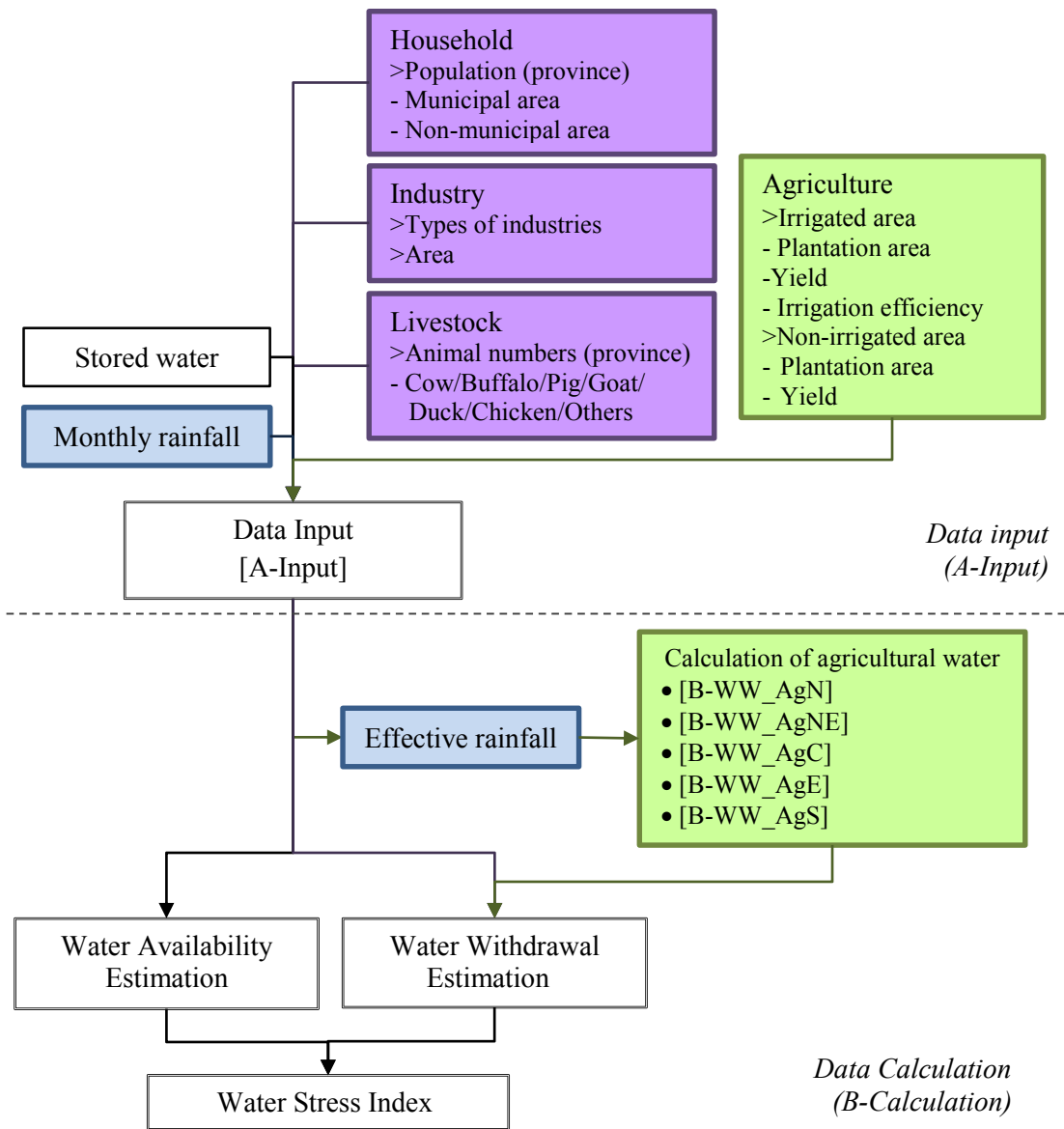


Figure 3.2 Flowchart of template for the monthly WSI Calculation

3.4.1 Water availability

Water availability is defined as the total of rainwater and stored water in water reservoirs in order to cover all sources of available water. The 10-year of rainfall data is accounted for calculating variables in the WSI equation as mentioned in the previous section. Referred to the 25 watersheds, annual rainfall based on statistical data during 1973-2008 is approximately 1,450 mm covering 5-6 months in the wet season; May to October. Table 3.4 shows the average monthly rainfall over the past ten years (2002-2011); meanwhile, Figure 3.3 shows the comparison of monthly rainfall by watershed. The annual rainfall during 2002-2011 is about 1,600 mm.

Table 3.4 Monthly average rainfall (mm/month) during 2002-2011

| Region | Watershed | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------|----------------------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| N | Salawin | 16.6 | 7.0 | 28.1 | 58.7 | 195.3 | 193.1 | 213.4 | 227.7 | 234.2 | 143.1 | 30.4 | 13.9 |
| | Kok | 21.1 | 20.0 | 37.9 | 80.8 | 214.1 | 176.4 | 247.7 | 305.7 | 296.5 | 113.0 | 55.2 | 18.5 |
| | Ping | 10.1 | 6.8 | 28.6 | 67.6 | 190.0 | 163.6 | 160.6 | 190.4 | 262.7 | 132.2 | 50.3 | 22.1 |
| | Wang | 11.3 | 11.6 | 34.4 | 79.7 | 202.9 | 140.8 | 154.3 | 199.5 | 246.3 | 105.7 | 32.7 | 14.1 |
| | Yom | 13.5 | 11.3 | 34.1 | 83.9 | 177.9 | 172.0 | 167.4 | 206.8 | 269.1 | 126.7 | 29.5 | 19.6 |
| | Nan | 14.4 | 15.3 | 35.9 | 85.0 | 179.7 | 202.6 | 214.2 | 275.4 | 288.9 | 109.4 | 27.7 | 19.6 |
| NE | Khong | 13.3 | 28.4 | 52.3 | 89.8 | 216.3 | 216.7 | 272.2 | 323.8 | 289.3 | 104.6 | 22.8 | 11.6 |
| | Chi | 17.5 | 24.9 | 57.0 | 94.7 | 172.1 | 161.4 | 179.6 | 253.4 | 264.8 | 110.2 | 19.8 | 8.8 |
| | Mun | 15.7 | 27.1 | 51.5 | 102.5 | 192.4 | 164.3 | 196.4 | 229.9 | 266.6 | 129.3 | 16.6 | 7.1 |
| C | Chao Phraya | 17.5 | 33.2 | 54.8 | 79.3 | 147.5 | 154.5 | 145.6 | 156.0 | 251.6 | 136.1 | 33.1 | 21.3 |
| | Sakae Krang | 36.8 | 86.7 | 85.5 | 93.9 | 137.5 | 183.9 | 159.1 | 116.9 | 159.5 | 97.5 | 26.3 | 27.9 |
| | Pasak | 20.8 | 34.8 | 62.6 | 92.7 | 148.6 | 162.5 | 133.3 | 163.9 | 228.2 | 101.4 | 22.2 | 19.9 |
| | Tha Chin | 20.3 | 51.8 | 65.6 | 72.9 | 142.6 | 142.6 | 136.3 | 114.4 | 179.5 | 132.4 | 37.3 | 23.3 |
| | Mae Klong | 9.9 | 31.2 | 64.7 | 84.1 | 199.8 | 169.4 | 199.4 | 188.0 | 214.0 | 160.9 | 30.8 | 17.0 |
| | Phetchaburi | 49.4 | 10.6 | 51.0 | 45.1 | 118.5 | 98.8 | 100.2 | 79.2 | 148.5 | 271.6 | 35.0 | 18.8 |
| | West Coast Gulf | 21.5 | 11.3 | 66.8 | 59.7 | 147.0 | 94.3 | 111.6 | 93.5 | 126.7 | 228.2 | 67.9 | 26.4 |
| E | PrachinBuri | 13.7 | 32.7 | 56.3 | 116.1 | 196.2 | 194.4 | 250.0 | 247.5 | 322.0 | 168.2 | 27.9 | 8.8 |
| | Bang Pakong | 31.1 | 77.9 | 122.5 | 151.6 | 178.5 | 181.5 | 148.8 | 128.3 | 194.8 | 112.5 | 28.6 | 16.5 |
| | Thole Sap | 13.8 | 38.7 | 58.6 | 123.9 | 263.1 | 269.2 | 313.2 | 288.9 | 345.9 | 213.0 | 29.9 | 12.4 |
| | East Coast Gulf | 27.9 | 56.8 | 90.4 | 139.8 | 335.2 | 381.6 | 505.2 | 388.8 | 476.6 | 273.6 | 40.8 | 23.2 |
| S | Peninsula East coast | 95.0 | 43.6 | 158.5 | 96.3 | 187.9 | 151.4 | 168.2 | 171.5 | 190.8 | 272.3 | 391.5 | 283.7 |
| | Tapi | 74.4 | 32.3 | 159.6 | 89.3 | 178.6 | 157.8 | 159.3 | 155.6 | 186.0 | 265.8 | 351.5 | 193.1 |
| | Thale sap Songkhla | 85.5 | 36.0 | 135.4 | 120.0 | 162.7 | 161.9 | 183.6 | 153.1 | 197.3 | 254.1 | 380.5 | 226.7 |
| | Pattani | 116.1 | 49.5 | 136.3 | 94.0 | 219.8 | 141.2 | 184.1 | 222.2 | 177.2 | 288.2 | 343.5 | 419.6 |
| | Peninsula West coast | 48.8 | 27.8 | 133.8 | 131.9 | 299.8 | 332.2 | 324.6 | 377.8 | 383.2 | 370.7 | 208.4 | 130.6 |

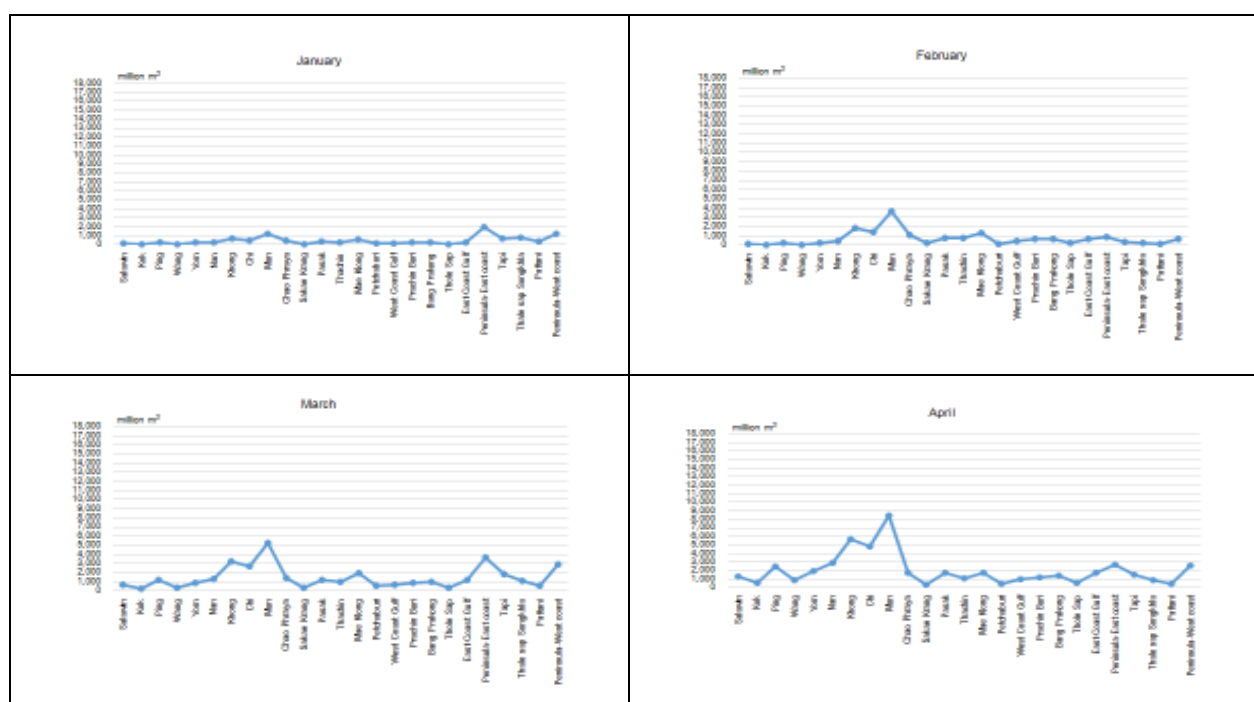


Figure 3.3 Monthly average rainwater resource (during 2002-2011) by watershed

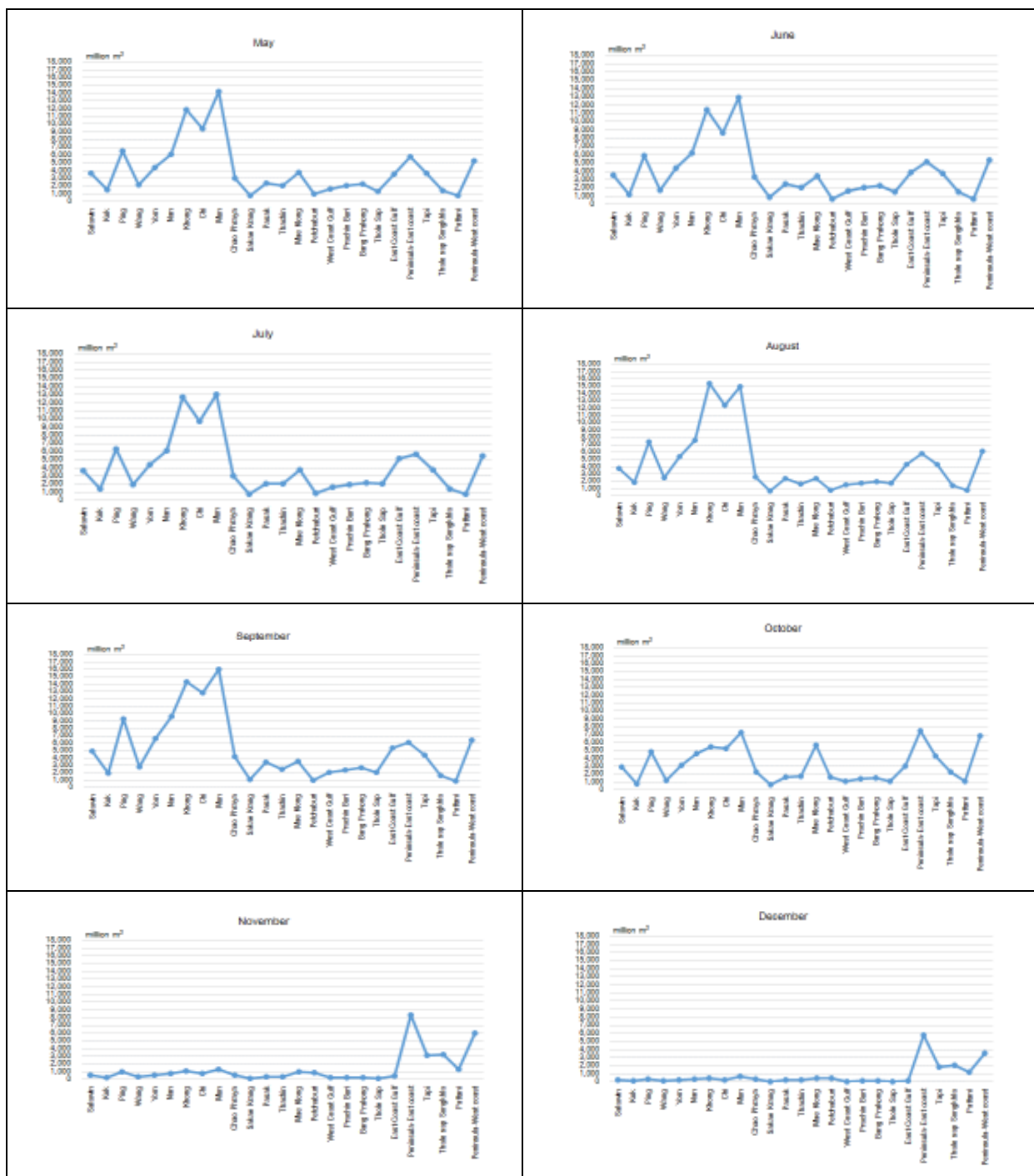


Figure 3.3 Monthly average rainwater resource (during 2002-2011) by watershed (continue)

3.4.2 Water withdrawal for household sector

The water withdrawn by the household sector is estimated based on the number of population in the province multiplied with the basic minimum water requirement for humans based on literature. The amounts of basic minimum water requirement for people who live in and outside the municipal area are 200 and 100 liters/person/day. The number of population classified into living in municipal and non-municipal is available at National Statistical Office. In addition, the sensitivity of these criteria is investigated and the results revealed that these criteria are sufficient

to provide a reasonable estimate for this sector. The result of sensitivity analysis is attached in Appendix A.

3.4.3 Water withdrawal for industrial sector

To quantify water for the industrial sector, there are many factors related to water used in industries. Three approaches for estimating water for industrial sector have been reviewed including horse power (Koontanakulvong S., 2007), industrial area (RID, 2011), and production capacity (PCD, 2005 and PCD, 2011). However to maintain a consistency with the previous study, water demand for industry is assessed based on types of industries and their areas. Data obtained based on a watershed boundary refers to 10 major industries classified by the Department of Industrial Works (DIW). Tourism is accounted as one of the industrial sectors in this assessment and the water intensity of tourism sector will be assessed based on number of tourist and excursionist (RID, 2011).

3.4.3 Water withdrawal for industrial sector

To quantify water for the industrial sector, there are many factors related to water used in industries. Three approaches for estimating water for industrial sector have been reviewed including horse power (Koontanakulvong S., 2007), industrial area (RID, 2011), and production capacity (PCD, 2005 and PCD, 2011). However to maintain a consistency with the previous study, water demand for industry is assessed based on types of industries and their areas. Data obtained based on a watershed boundary refers to 10 major industries classified by the Department of Industrial Works (DIW). Tourism is accounted as one of the industrial sectors in this assessment and the water intensity of tourism sector will be assessed based on number of tourist and excursionist (RID, 2011).

3.4.4 Water withdrawal for livestock sector

The amount of water withdrawal for this sector is estimated from the number of head of livestock multiplied with a coefficient (an average water use per animal) (RID, 2010 and RID, 2011). Livestock refers to dairy cow, beef cattle, buffalo, pig, goat and poultry. Thus the number of head of livestock is classified by province.

3.4.5 Water withdrawal for agriculture

Water required by crop or so called “crop water requirement (CWR)” refers to the volume of water lost via evapotranspiration process including evaporative water from soil and crop surfaces and transpired water from crop to atmosphere. In other word, CWR is denoted as crop evapotranspiration (ET_c). This term can be quantified either empirical measured at a field or theoretical estimated via formula or model. Results obtained from a field experiment are specific and cannot be applied to another area because weather conditions, soil characteristics, and crop variety affecting to volume of water used by crop. Therefore ET_c or CWR is practically computed by theoretical estimated formula or model simulation. This theoretical approach is established based on two terms of weather and crop specifics for each crop cultivated in different location. The general formula (Eq. 8) used for estimating crop water use is expressed as follows (Allen et al., 1998 and FAO, 2010).

$$ET_c = K_c \times ET_0 \quad (\text{Eq. 8})$$

Variations of weather and crop species are taken into account through a reference crop evapotranspiration (ET_0) and crop coefficient (K_c). These two terms are developed to be related to estimate the ET_c or CWR of any crops cultivated in any area and time. Penman Monteith method is applied with particular meteorological data for calculating the ET_0 . Accordingly CWR of 10 staple crops (rice (major and second), maize, cassava, sugarcane, oil palm, mungbean, soybean, peanut, coconut, para rubber and pineapple) is estimated in this study based on crop calendar. K_c values of crops are referred from RID.

Two scenarios are made for assessing the amount of agricultural water.

- Scenario 1 (theoretical CWR): refers to water is fully supplied to meet the theoretical CWR
- Scenario 2 (deficit condition): refers to water deficit condition i.e. estimated the water used for crops based on existing irrigated and rain-fed (non-irrigated) areas

Water required for growing crops in non-irrigated areas is supposed to be equal to the amount of rainfall used by crop so-called effective rainfall. If CWR is higher than effective rainfall, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of effective rainfall. On the other hand, if effective rainfall is higher than CWR, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of CWR. Water required for growing crops cultivated in irrigated areas are expected to meet total amount of crop water requirement. Thus, a sum of effective rainfall and irrigation water is accounted as the total water withdrawal for crops cultivated in irrigated areas. This irrigation water is defined as the additional amount of water required to reach the total amount of crop water requirement. In general, to calculate the amount of irrigation water requirement for irrigated agriculture, irrigation efficiency and water loss through percolation are taken into account as can be expressed in the Eq. 9 (RID, 2011).

$$\text{Irrigation water} = \frac{(\text{crop water requirement} - \text{effective rainfall}) + \text{water loss (percolation)} \times 100}{\text{Irrigation efficiency}^*} \quad (\text{Eq. 9})$$

Remark: *Irrigation efficiency = 0.65 derived from (efficiency of water conveyance = 0.9)*(efficiency of irrigation system = 0.9)*(efficiency of irrigation = 0.8)

Even though the irrigation efficiency at 0.65 is suggested by the specialist from RID using a rule of thumb approach, this factors depends not only on those three relative factors but also geographical conditions. Besides, each individual irrigation project also uses different values of these factors. As a result, a rough estimate of the total irrigation water may be obtained by using this value. Accordingly the irrigation efficiency is not taken into account in calculating the amount of irrigation water in this study. To estimate the total agricultural water withdrawal based on the 10 staple crops, crop plantation by province and irrigated and non-irrigated areas are employed in the calculation. The final results of total water withdrawal for agriculture by province are obtained in two scenarios. The first scenario is considered based on the full CWR and the second scenario is based on the crop water use.

3.4.6 Monthly WSI results

The results of monthly WSI can be obtained from the “mWSI” worksheet in the B-Calculation workbook as shown in Figure 3.4.

Figure 3.4 The “mWSI” worksheet in the B-Calculation workbook

3.5 Limitations of water stress index calculation

- Water demands for household, industrial, livestock, and agricultural sectors are estimated based on recommendations in the Work Manual of RID.
- Rainwater in form of effective rainfall and irrigation water excluding efficiency are classified as sources of available water.
- Criteria for evaluating water demands of household, industrial and livestock sectors will require updates due to social and technology changes influencing on water conservation and efficiency.
- Irrigation efficiency is neglected for calculating the monthly and seasonal WSI in this study. The efficiency of irrigation system is different based on geographical location and soil characteristics.

Consequently, these limitations are addressed in the WSI template by allowing to adjust all factors and assumptions made in this study.

3.5.1 Monthly Water Stress Index (WSI) of Thailand

The template for WSI calculation was developed for providing the WSI results based on different basis. Therefore the “mWSI” worksheet (Figure 3.4) was created in the B-Calculation workbook for calculation of monthly WSI.

The results of monthly WSI are presented into two scenarios as a result of water withdrawal for agriculture based on the 11 staple crops and their plantation areas. Agricultural sector is the most water intensive sector as compared to others. Thus the monthly WSI is considered based on the

full CWR for agriculture (Scenario 1: Agri = CWR) and the total crop water use due to location of plantation areas (Scenario 2: Agri = Total).

Table 3.5 and Figure 3.5 illustrate the monthly WSI results by watersheds and the monthly water stress map based on WSI results, respectively. The results obtained reflect more variation of WSI values among the different month as can be noticed from the monthly WSI maps in Figure 3.5. The WSI results of Scenario 1 are worse than that of Scenario 2 because of fully CWR provided. The amount of water requirement considered in Scenario 2 depend on areas inside and outside irrigation projects leading to less water required than Scenario 1. The results of Scenario 2 showed that the potentially critical areas of water stress are found particularly from December, January, February, and March in some parts of the North and Central regions. This is because intensive second rice production during these months in the Central region while rainfall in this period is less than in the wet season. The second rice fields are found in both irrigated and non-irrigated areas. To mitigate water stress, water taken from upper watersheds is considered as other sources of water during this period for the Central region. This possibly leads to increase the water stress levels of some watersheds in the North region which are connected to the Central part. Hence to manage the upper watersheds for providing additional water will help to minimizing water stress for the Central region. This however will lead to increase higher potential of water competition among other users and agriculture if water is not enough to satisfy all demands.

Oppositely, the Northeastern part is noticed as the moderate level of water stress during July to September. This is because intensive rice production in this region begins when the wet season starts and the production takes place in both irrigated and non-irrigated areas. The situation becomes better after this period because there is very less or none of rice production take place when entering into the dry season. Less rainfall during the dry season as well as geographical conditions are limitations of this region that lead to insufficient rainwater and lack of water storages. Therefore there is very less or none of rice production take place during this period. These results obtained reveal that determining crop water use by accounting for the total data of irrigated and non-irrigated crops significantly affect to the WSI results because the non-irrigated agricultural areas in Thailand is higher than the irrigated areas. Accordingly appropriate plan for water resource management especially for the dry season is much required for preventing the water problems. The focuses are recommended to place on cropping system and crop calendar of each watershed. Although the different crop options can shift irrigation water consumption within a year, it is in turn can increase or decrease the related water stress. Additionally, the plan for lower watershed such as Chao Phraya should be correlated with the plan of the upper watersheds such as Yom and Nan.

Table 3.5 Monthly WSI resulted from the template for WSI Calculation

Scenario 1: Monthly WSI based on crop water requirement

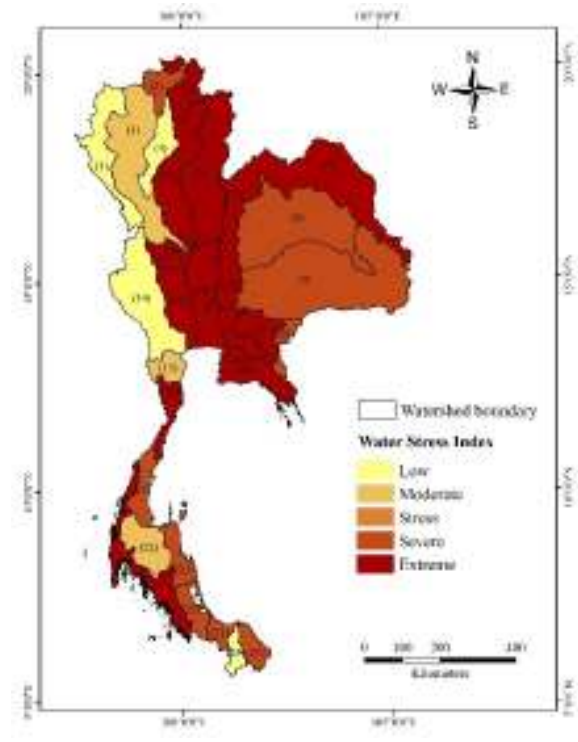
| Watershed | Monthly WSI | | | | | | | | | | | |
|----------------------|-------------|------|------|------|------|------|------|------|------|------|------|------|
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| Salawin | 0.02 | 0.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| Kok | 0.85 | 0.89 | 0.24 | 0.02 | 0.01 | 0.05 | 0.04 | 0.03 | 0.04 | 0.03 | 0.02 | 0.11 |
| Ping | 0.11 | 0.12 | 0.04 | 0.01 | 0.01 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 |
| Wang | 0.08 | 0.07 | 0.02 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 |
| Yom | 1.00 | 1.00 | 0.90 | 0.02 | 0.01 | 0.12 | 0.28 | 0.17 | 0.08 | 0.03 | 0.08 | 0.32 |
| Nan | 0.94 | 0.89 | 0.34 | 0.02 | 0.01 | 0.05 | 0.08 | 0.06 | 0.05 | 0.03 | 0.03 | 0.05 |
| Khong | 0.99 | 0.57 | 0.17 | 0.05 | 0.02 | 0.12 | 0.14 | 0.09 | 0.10 | 0.05 | 0.59 | 0.93 |
| Chi | 0.77 | 0.46 | 0.08 | 0.03 | 0.02 | 0.54 | 0.79 | 0.39 | 0.22 | 0.04 | 0.50 | 0.67 |
| Mun | 0.73 | 0.34 | 0.08 | 0.03 | 0.02 | 0.73 | 0.85 | 0.63 | 0.29 | 0.03 | 0.44 | 0.75 |
| Chao Phraya | 1.00 | 1.00 | 1.00 | 0.10 | 0.04 | 0.72 | 0.96 | 0.94 | 0.30 | 0.07 | 0.81 | 1.00 |
| Sakae Krang | 1.00 | 0.62 | 0.39 | 0.05 | 0.03 | 0.35 | 0.81 | 0.95 | 0.39 | 0.07 | 0.77 | 0.58 |
| Pasak | 0.99 | 0.71 | 0.14 | 0.03 | 0.02 | 0.13 | 0.42 | 0.27 | 0.13 | 0.15 | 0.70 | 0.71 |
| Tha Chin | 1.00 | 1.00 | 0.95 | 0.07 | 0.03 | 0.54 | 0.87 | 0.94 | 0.30 | 0.04 | 0.34 | 0.94 |
| Mae Klong | 0.05 | 0.03 | 0.02 | 0.02 | 0.01 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 |
| Phetchaburi | 0.20 | 0.99 | 0.13 | 0.03 | 0.02 | 0.05 | 0.09 | 0.13 | 0.04 | 0.01 | 0.03 | 0.08 |
| West Coast Gulf | 1.00 | 1.00 | 0.72 | 0.80 | 0.10 | 0.29 | 0.20 | 0.28 | 0.10 | 0.03 | 0.35 | 0.99 |
| Prachin Buri | 0.99 | 0.34 | 0.09 | 0.02 | 0.02 | 0.07 | 0.08 | 0.08 | 0.04 | 0.03 | 0.41 | 0.97 |
| Bang Pakong | 1.00 | 0.92 | 0.38 | 0.07 | 0.05 | 0.28 | 0.65 | 0.75 | 0.16 | 0.09 | 0.99 | 1.00 |
| Thole Sap | 0.86 | 0.11 | 0.07 | 0.03 | 0.02 | 0.04 | 0.05 | 0.06 | 0.04 | 0.03 | 0.68 | 0.95 |
| East-Coast Gulf | 0.99 | 0.58 | 0.31 | 0.12 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.03 | 0.94 | 1.00 |
| Peninsula-East coast | 0.71 | 1.00 | 0.39 | 0.84 | 0.16 | 0.25 | 0.21 | 0.21 | 0.12 | 0.06 | 0.03 | 0.05 |
| Tapi | 0.34 | 0.90 | 0.15 | 0.37 | 0.08 | 0.08 | 0.09 | 0.10 | 0.06 | 0.03 | 0.02 | 0.05 |
| Thale sap Songkhla | 0.78 | 1.00 | 0.36 | 0.42 | 0.15 | 0.12 | 0.10 | 0.15 | 0.07 | 0.05 | 0.03 | 0.07 |
| Pattani | 0.05 | 0.21 | 0.06 | 0.10 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 |
| Peninsula-West coast | 1.00 | 1.00 | 0.71 | 0.60 | 0.07 | 0.06 | 0.06 | 0.05 | 0.04 | 0.04 | 0.10 | 0.45 |

Scenario 2: Monthly WSI based on crop water use for agriculture (deficit condition)

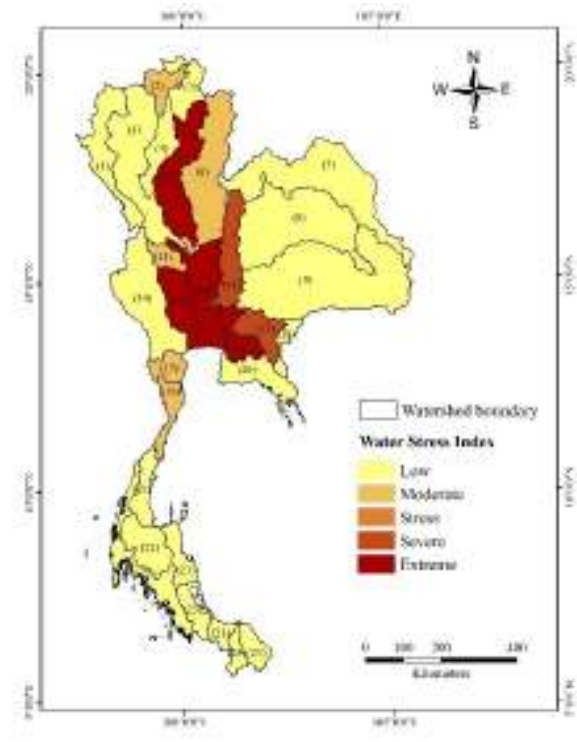
| Watershed | Monthly WSI | | | | | | | | | | | |
|----------------------|-------------|------|------|------|------|------|------|------|------|------|------|------|
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| Salawin | 0.02 | 0.05 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Kok | 0.17 | 0.11 | 0.09 | 0.01 | 0.01 | 0.04 | 0.03 | 0.03 | 0.04 | 0.02 | 0.01 | 0.02 |
| Ping | 0.04 | 0.04 | 0.03 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| Wang | 0.06 | 0.04 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 |
| Yom | 0.98 | 0.99 | 0.60 | 0.02 | 0.01 | 0.10 | 0.17 | 0.10 | 0.07 | 0.02 | 0.02 | 0.05 |
| Nan | 0.11 | 0.12 | 0.14 | 0.01 | 0.01 | 0.04 | 0.06 | 0.05 | 0.05 | 0.02 | 0.02 | 0.02 |
| Khong | 0.06 | 0.07 | 0.04 | 0.03 | 0.02 | 0.10 | 0.09 | 0.07 | 0.08 | 0.04 | 0.02 | 0.03 |
| Chi | 0.10 | 0.07 | 0.03 | 0.02 | 0.02 | 0.21 | 0.34 | 0.18 | 0.20 | 0.03 | 0.02 | 0.03 |
| Mun | 0.08 | 0.07 | 0.02 | 0.02 | 0.02 | 0.37 | 0.36 | 0.34 | 0.25 | 0.03 | 0.01 | 0.04 |
| Chao Phraya | 1.00 | 1.00 | 0.99 | 0.08 | 0.04 | 0.52 | 0.90 | 0.86 | 0.28 | 0.05 | 0.35 | 0.98 |
| Sakae Krang | 0.38 | 0.05 | 0.09 | 0.04 | 0.03 | 0.13 | 0.43 | 0.70 | 0.33 | 0.05 | 0.06 | 0.04 |
| Pasak | 0.83 | 0.37 | 0.08 | 0.03 | 0.02 | 0.06 | 0.21 | 0.14 | 0.13 | 0.05 | 0.06 | 0.08 |
| Tha Chin | 1.00 | 1.00 | 0.94 | 0.04 | 0.03 | 0.42 | 0.76 | 0.82 | 0.28 | 0.04 | 0.06 | 0.69 |
| Mae Klong | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 |
| Phetchaburi | 0.16 | 0.97 | 0.11 | 0.02 | 0.01 | 0.04 | 0.07 | 0.10 | 0.03 | 0.01 | 0.02 | 0.04 |
| West Coast Gulf | 0.38 | 0.65 | 0.30 | 0.06 | 0.05 | 0.13 | 0.17 | 0.12 | 0.04 | 0.03 | 0.03 | 0.26 |
| Prachin Buri | 0.77 | 0.19 | 0.06 | 0.02 | 0.02 | 0.06 | 0.05 | 0.06 | 0.04 | 0.03 | 0.02 | 0.13 |
| Bang Pakong | 1.00 | 0.79 | 0.28 | 0.06 | 0.05 | 0.23 | 0.51 | 0.67 | 0.16 | 0.09 | 0.51 | 0.98 |
| Thole Sap | 0.03 | 0.04 | 0.04 | 0.03 | 0.02 | 0.04 | 0.04 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 |
| East-Coast Gulf | 0.05 | 0.19 | 0.15 | 0.10 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.07 | 0.07 |
| Peninsula-East coast | 0.06 | 0.06 | 0.04 | 0.22 | 0.07 | 0.13 | 0.09 | 0.15 | 0.09 | 0.03 | 0.02 | 0.02 |
| Tapi | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 | 0.04 | 0.05 | 0.07 | 0.04 | 0.02 | 0.01 | 0.01 |
| Thale sap Songkhla | 0.02 | 0.02 | 0.01 | 0.08 | 0.06 | 0.06 | 0.04 | 0.11 | 0.05 | 0.02 | 0.01 | 0.01 |
| Pattani | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 |
| Peninsula-West coast | 0.03 | 0.04 | 0.01 | 0.11 | 0.05 | 0.04 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 |

January

Scenario 1

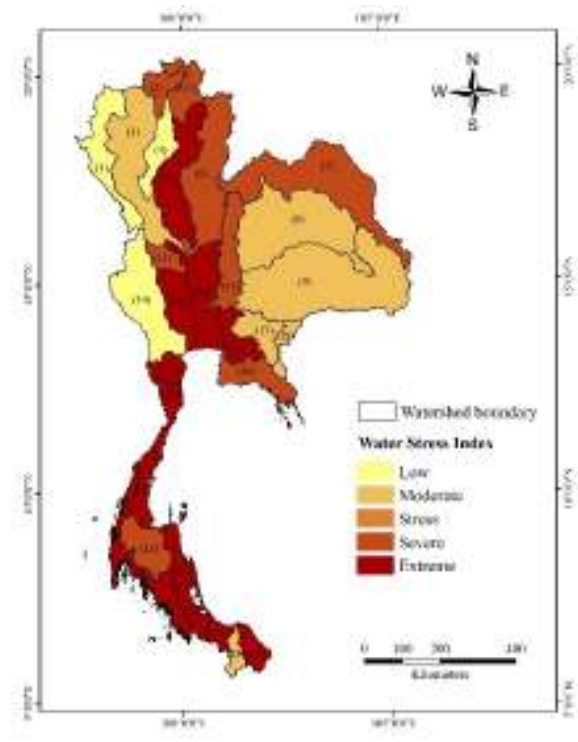


Scenario 2



February

Scenario 1



Scenario 2

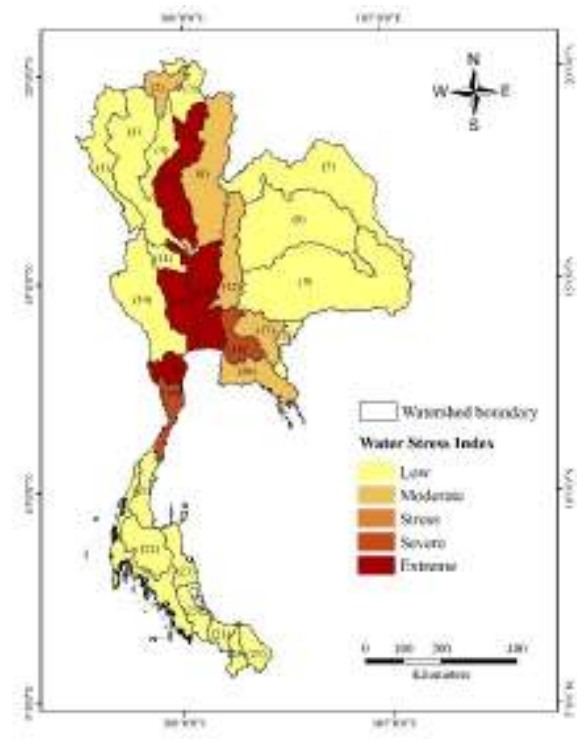
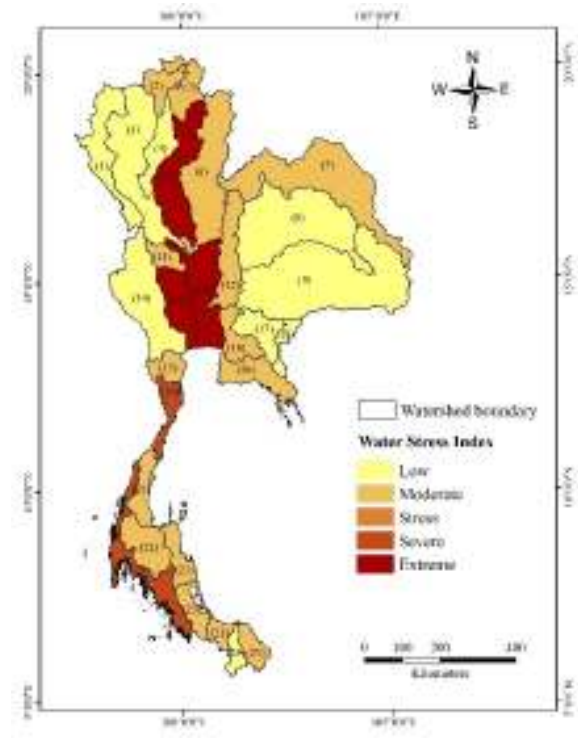


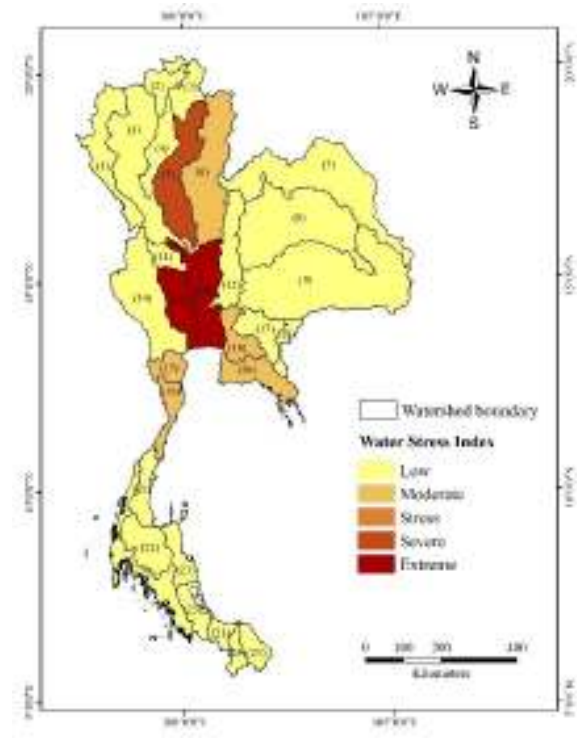
Figure 3.5 Monthly Water Stress Map

March

Scenario 1

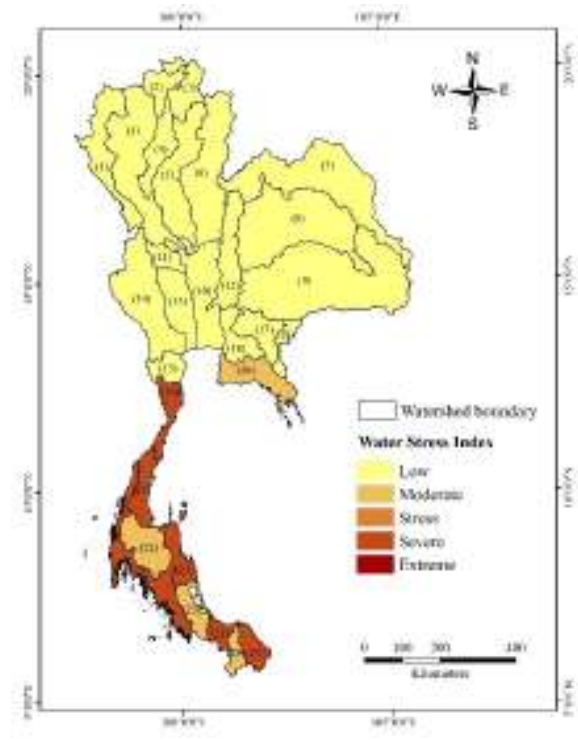


Scenario 2



April

Scenario 1



Scenario 2

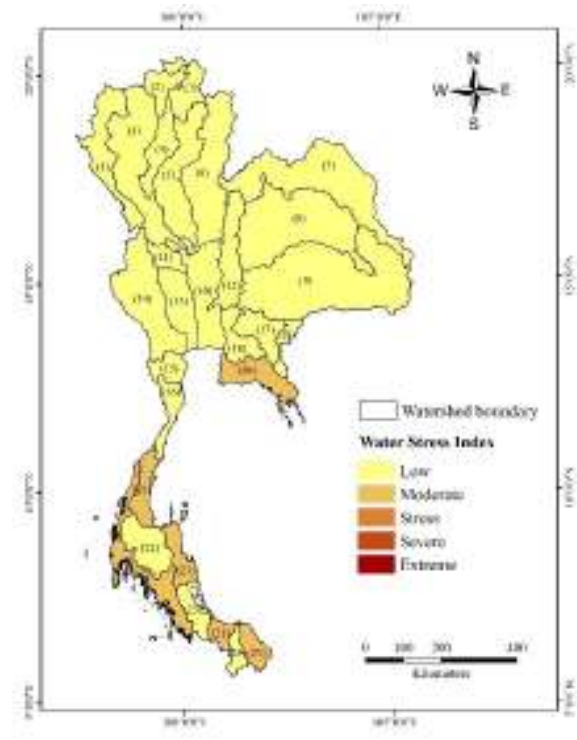
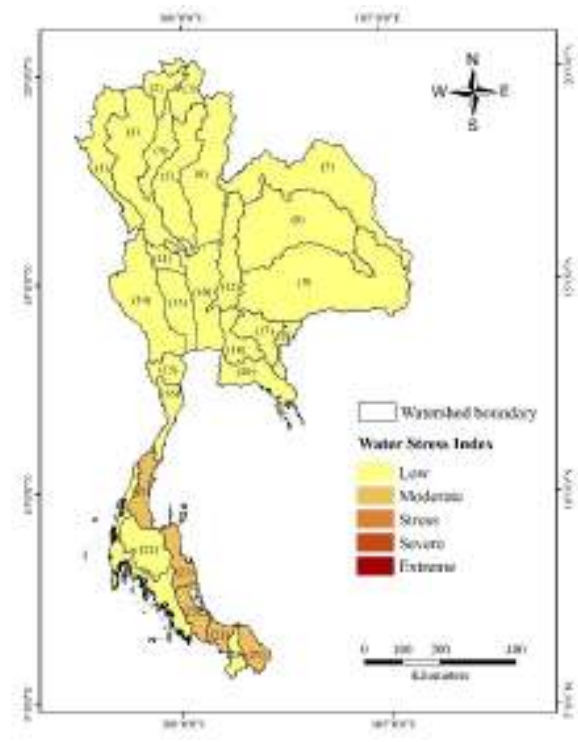


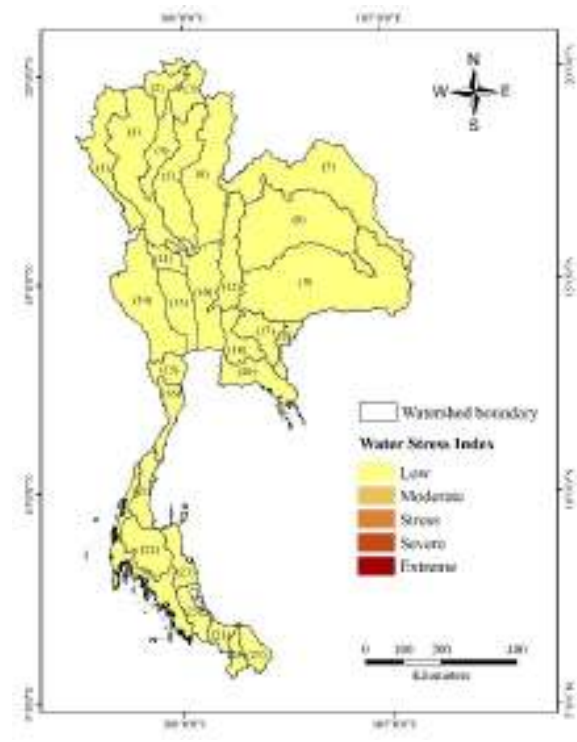
Figure 3.5 Monthly Water Stress Map (continue)

May

Scenario 1

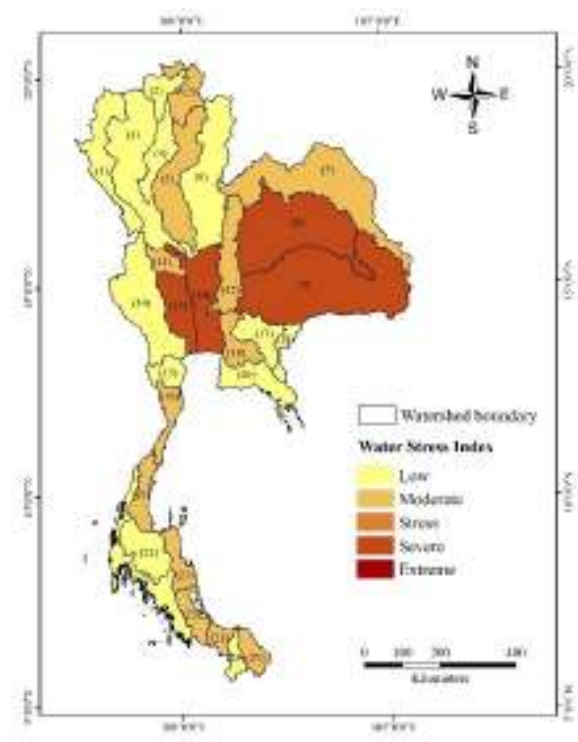


Scenario 2



June

Scenario 1



Scenario 2

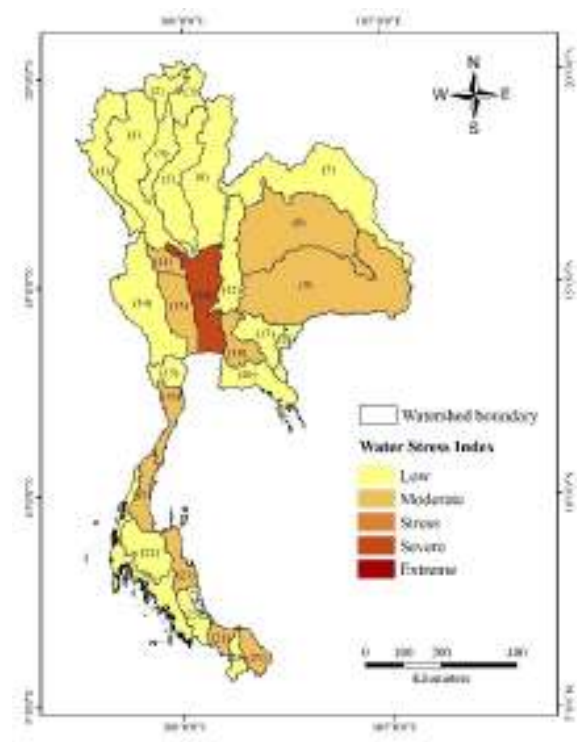
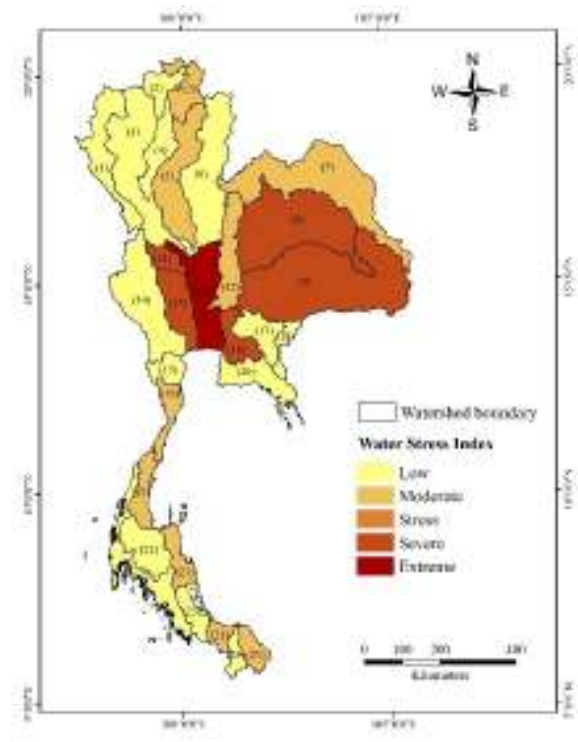


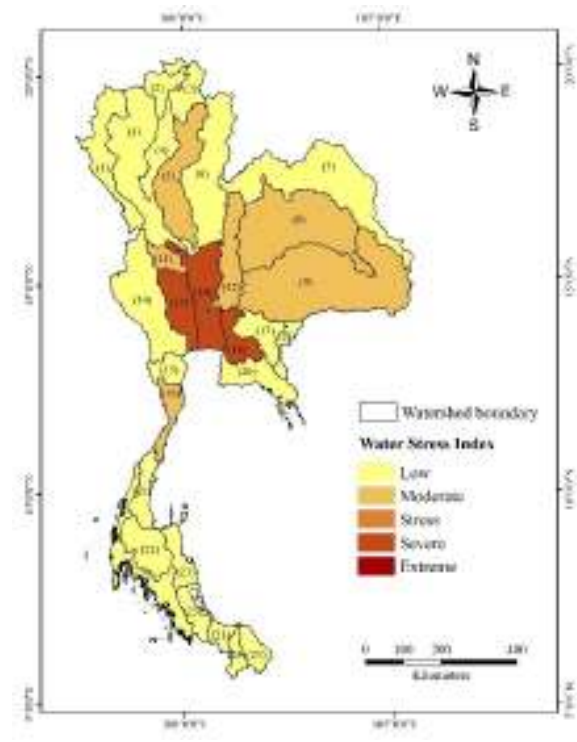
Figure 3.5 Monthly Water Stress Map (continue)

July

Scenario 1

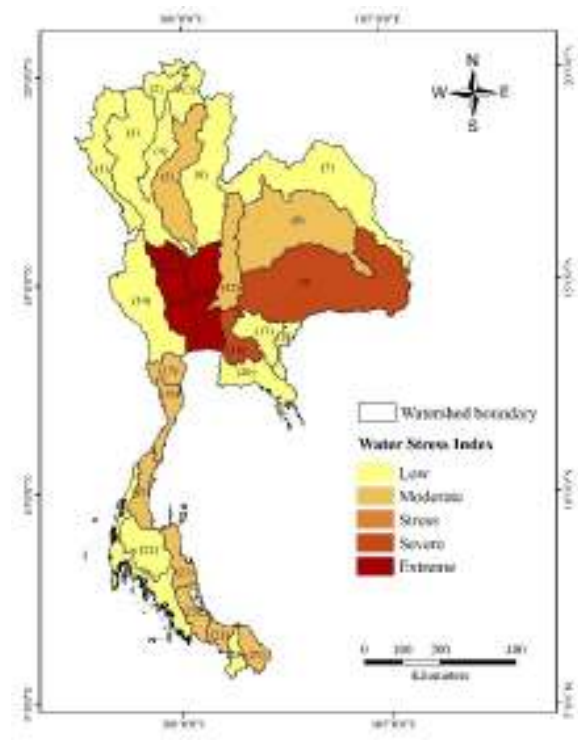


Scenario 2



August

Scenario 1



Scenario 2

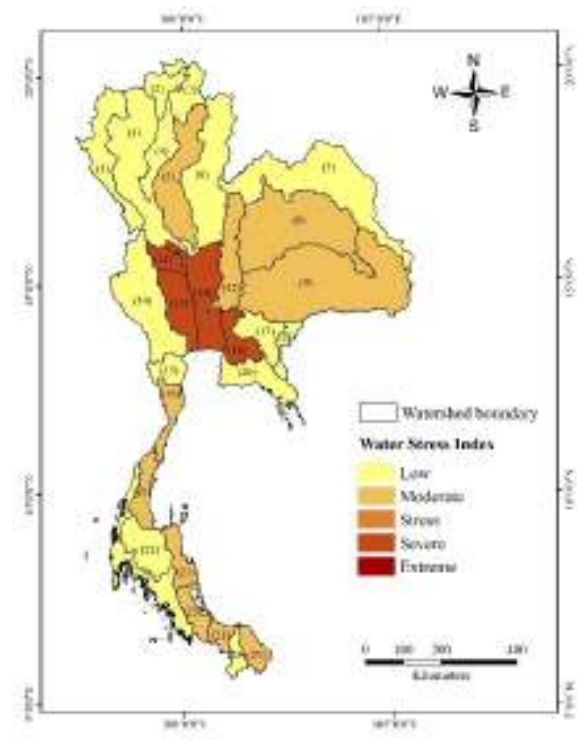
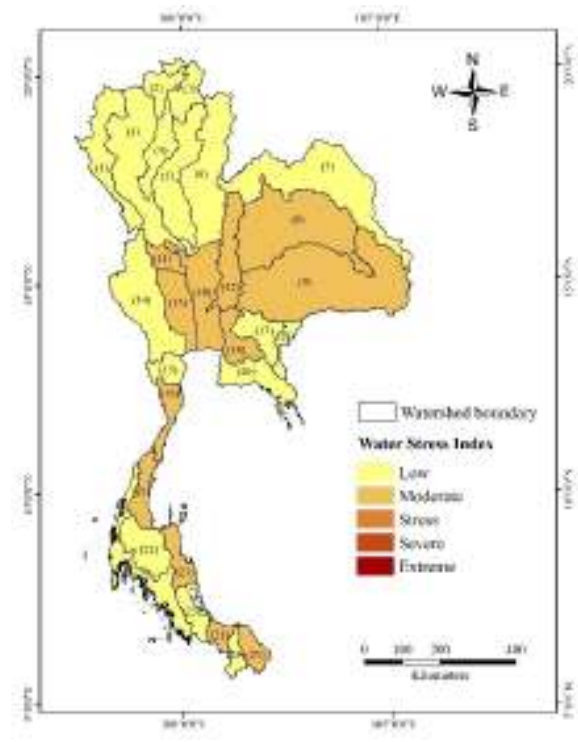


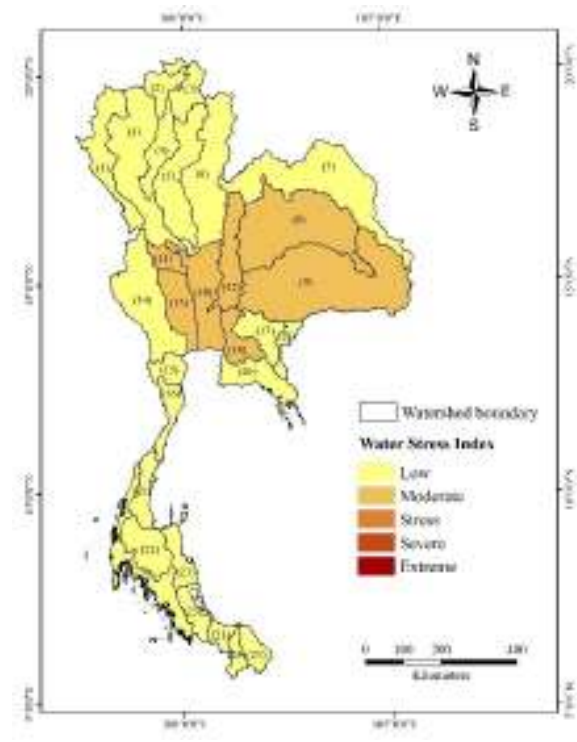
Figure 3.5 Monthly Water Stress Map (continue)

September

Scenario 1

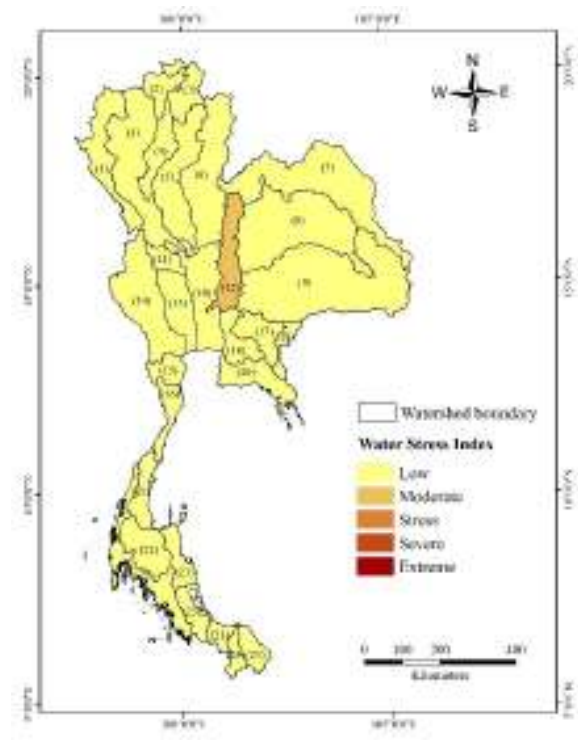


Scenario 2



October

Scenario 1



Scenario 2

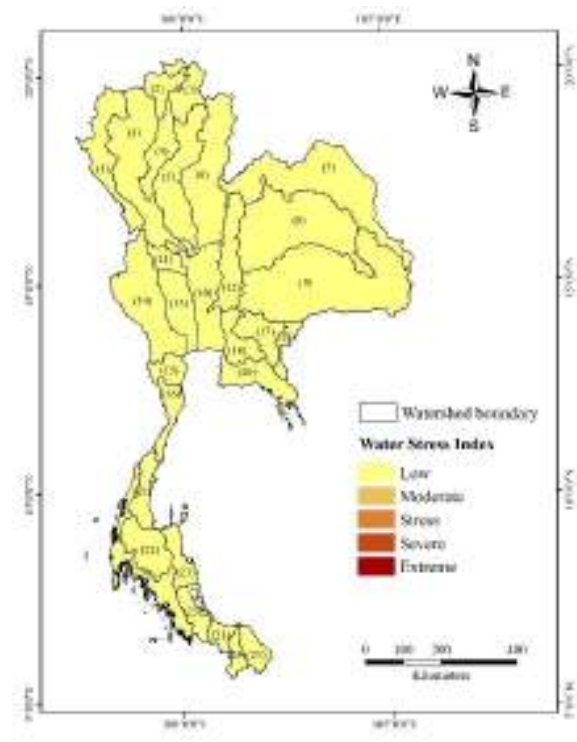
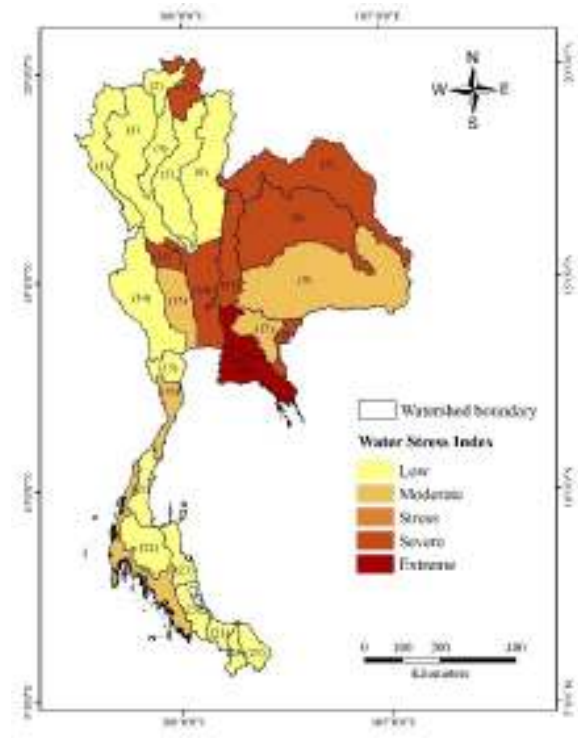


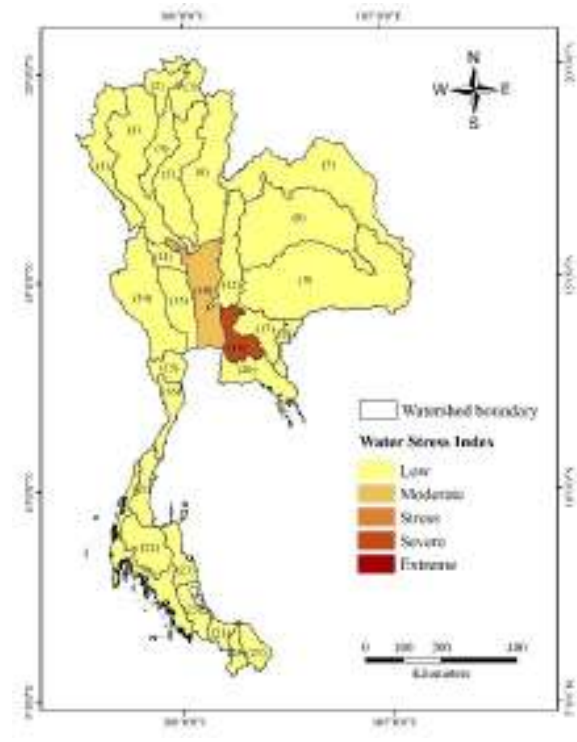
Figure 3.5 Monthly Water Stress Map (continue)

November

Scenario 1

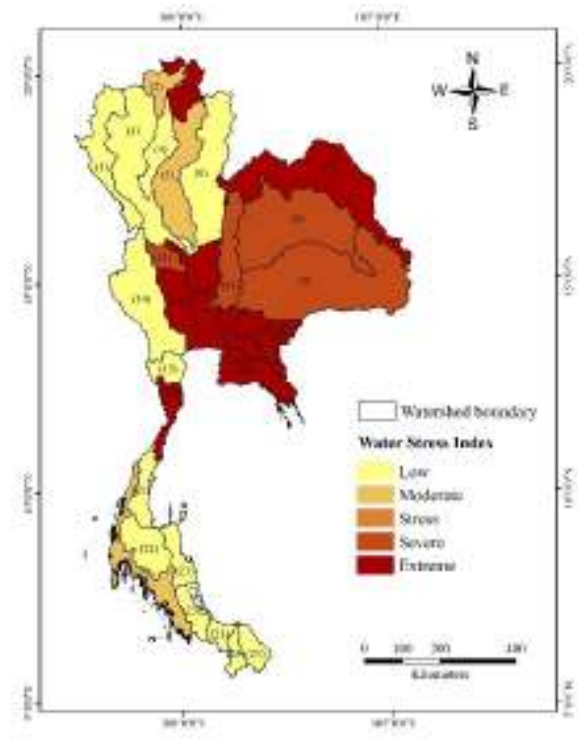


Scenario 2



December

Scenario 1



Scenario 2

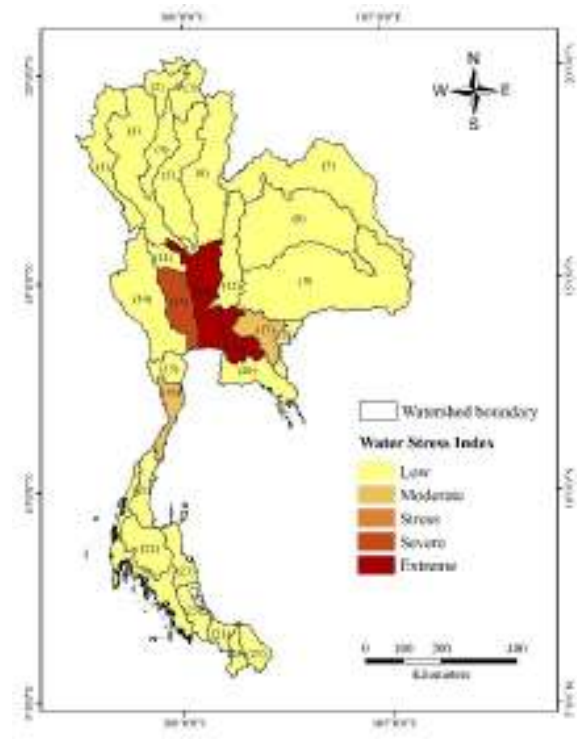


Figure 3.5 Monthly Water Stress Map (continue)

3.5.2 Seasonal WSI

The template for WSI calculation was developed for providing the WSI results based on seasons; therefore, the “sWSI” worksheet (Figure 3.6) was created in the B-Calculation workbook.

Figure 3.6 The “sWSI” worksheet in the B-Calculation workbook

The results of seasonal WSI based on two scenarios are showed in Table 3.6 and Figure 3.7. As similar to the results of monthly WSI obtained, most of the results from Scenario 1 are greater than that of Scenario 2 and the results of season WSI from Scenario 2 is applicable to a wide range of the current agricultural situation. Chao Phraya and Tha Chin are found as the most critical watersheds during the dry season as seen in the results of Scenario 2. The same reasons as provided for the results of monthly WSI are large areas of second rice cultivated in both irrigated and non-irrigated areas of the Central region and its planting date starts in the dry season. These lead to the extreme level of water stress occurring in those two watersheds. Additionally, this situation becomes better when entering into the wet season. On the other hand, the situation is different for the Northeastern part. The low level of water stress is revealed in the dry season and the situation becomes worse in the wet season as noticed in Mun and Chi watersheds. When the wet season starts, the agricultural demand for water also increases because of intensive major rice cultivated in both irrigated and non-irrigated areas. Furthermore less rainfall and lack of water storages are limitations of this region as detailed earlier.

Table 3.6 Seasonal WSI resulted from the template for WSI Calculation

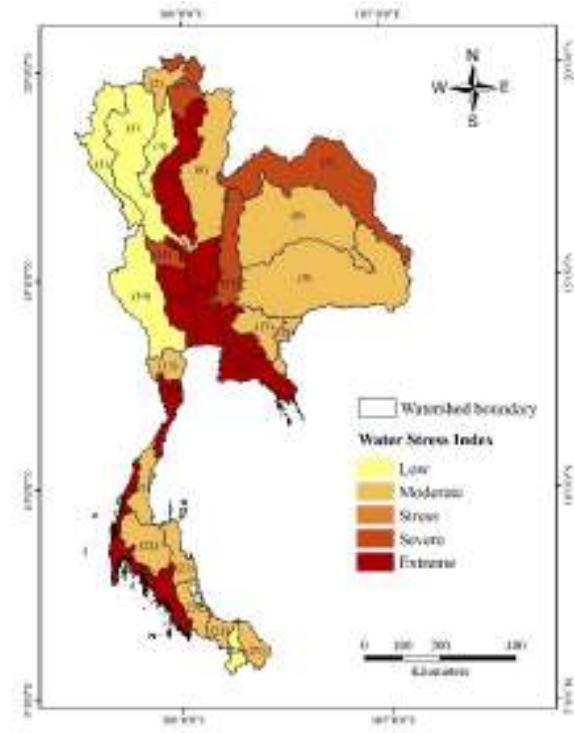
| Watershed | Scenario 1 | | Scenario 2 | |
|----------------------|------------|------|------------|------|
| | Dry | Wet | Dry | Wet |
| Salawin | 0.02 | 0.01 | 0.02 | 0.01 |
| Kok | 0.23 | 0.05 | 0.05 | 0.04 |
| Ping | 0.05 | 0.03 | 0.03 | 0.03 |
| Wang | 0.03 | 0.02 | 0.02 | 0.02 |
| Yom | 0.97 | 0.23 | 0.36 | 0.16 |
| Nan | 0.41 | 0.09 | 0.07 | 0.07 |
| Khong | 0.76 | 0.25 | 0.07 | 0.18 |
| Chi | 0.46 | 0.72 | 0.05 | 0.41 |
| Mun | 0.39 | 0.84 | 0.05 | 0.57 |
| Chao Phraya | 1.00 | 0.85 | 1.00 | 0.74 |
| Sakae Krang | 0.79 | 0.66 | 0.11 | 0.38 |
| Pasak | 0.69 | 0.37 | 0.23 | 0.21 |
| Tha Chin | 1.00 | 0.67 | 0.99 | 0.55 |
| Mae Klong | 0.04 | 0.03 | 0.03 | 0.03 |
| Phetchaburi | 0.26 | 0.04 | 0.17 | 0.04 |
| West Coast Gulf | 1.00 | 0.24 | 0.30 | 0.12 |
| Prachin Buri | 0.34 | 0.09 | 0.11 | 0.07 |
| Bang Pakong | 0.97 | 0.58 | 0.83 | 0.50 |
| Thole Sap | 0.29 | 0.06 | 0.05 | 0.05 |
| East-Coast Gulf | 0.90 | 0.03 | 0.25 | 0.03 |
| Peninsula-East coast | 0.18 | 0.15 | 0.03 | 0.08 |
| Tapi | 0.11 | 0.07 | 0.01 | 0.04 |
| Thale sap Songkhla | 0.17 | 0.10 | 0.02 | 0.05 |
| Pattani | 0.03 | 0.03 | 0.01 | 0.02 |
| Peninsula-West coast | 0.90 | 0.07 | 0.03 | 0.05 |

In conclusion, the results of monthly and seasonal WSI obtained from the two scenarios are provided. This is to illustrate the difference between an ideal scenario (Scenario 1) and a realistic scenario (Scenario 2). Scenario 1 can also be used to represent as the worst-case scenario, it is assumed enough water is fully supplied to reach the total amount of theoretical CWR. Besides, Scenario 2 represents the existing situation of agriculture. In reality, the amount of crop water use depends on cultivated areas. If crops are cultivated in irrigated area, it is possible to provide enough water to fully meet the theoretical CWR. This event hardly takes place in non-irrigated areas. However, it is generally impossible to determine the exact worst-case scenario or existing situation because there are several factors related to the amount of water required by crops such as soil quality, crop species, weather conditions, farming practices and so on.

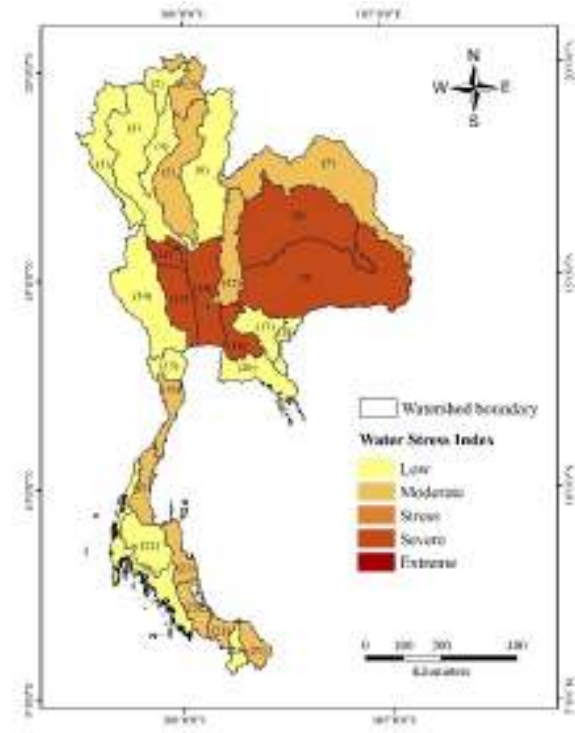
Consequently the results of monthly and seasonal WSI obtained from Scenario 2 can be applied to existing agricultural situation. Irrigated and non-irrigated areas play an important role in this Scenario. In addition, if the irrigation efficiency is taken into account, the actual amount of irrigation water requirement is definitely greater than the results obtained in this study. Moreover the results of monthly WSI obtained are not used to derive the summary value on an annual basis in this study because it may lead to misinterpretation. Besides, the annual and monthly WSI are estimated based on different equations as expressed in Table 3.1. Hence it is more reasonable to compare the monthly WSI to the annual WSI obtained from the 1st phase.

Scenario 1

Dry

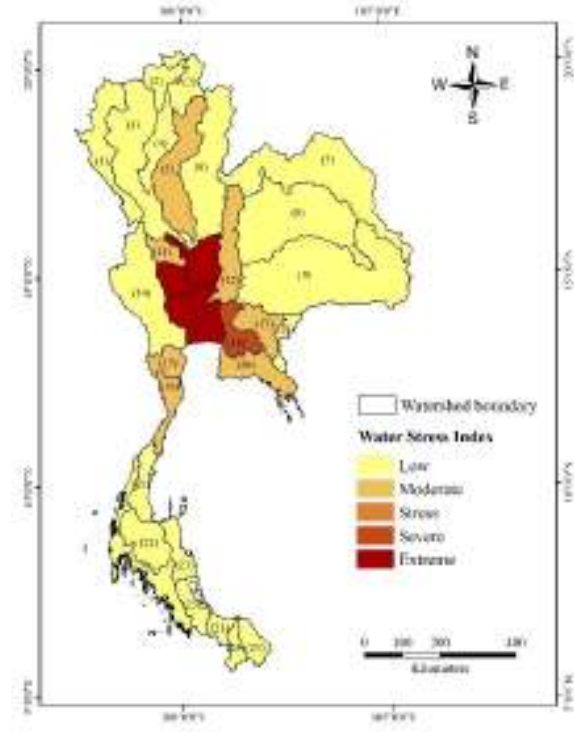


Wet



Scenario 2

Dry



Wet

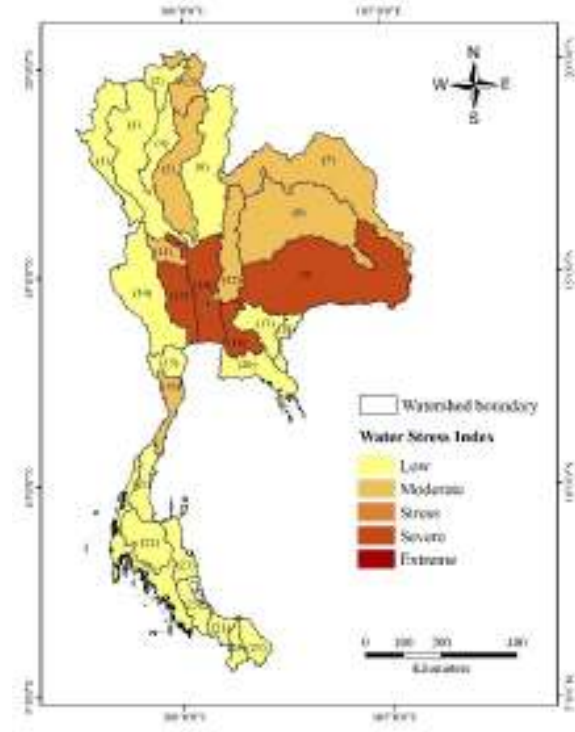


Figure 3.7 Seasonal Water Stress Map

3.5.3 Comparison between the WSI results from the 1st phase and the 2nd phase

The potential areas of water stress revealed from the annual WSI of the 1st phase include Mun, Chi, Chao Phraya and Tha Chin. These four significant watersheds are in a focus of the 2nd phase. The monthly WSI as the outcome of this 2nd phase refers to the results obtained from Scenario 2 because this scenario is considered based on existing irrigated and non-irrigated (rainfed) areas.

The results of this 2nd phase also found that the four critical watersheds as indicated in the 1st phase are still in crisis. The results of monthly WSI indicate that Chao Phraya and Tha Chin, water stress is still a serious concern especially from December to March and July to August as a water stress level is classed as severe. In contrast, the annual WSI values of Mun and Chi are greater than Chao Phraya and Tha Chin. The moderate level of monthly water stress is spotted over Mun and Chi during June to September. Other than these four significant areas, areas that need more attentions include Yom and Bang Pakong. Although the annual WSI of these two watersheds are indicated as a low level, the monthly water stress levels obtained during January to February reach an extreme level as can be seen the comparison between annual and monthly WSI in Table 3.7. Overall, the monthly WSI shows that the situation of water stress in the dry season particularly during January to February become worse than the situation in the wet season.

Agricultural water demand and available water are the key drivers of water stress situation as the influence of rice plantations and rainfall variation on the results of monthly and seasonal WSI are noticed from this study. Rice cultivated in both irrigated and non-irrigated areas as well as cropping calendar are two important factors affecting the results of monthly WSI. Additionally, lack of water storage and geographical condition are found as limitations for increasing water availability.

Furthermore to bring about sustainability in a water management policy, an important management strategy by means of target setting will be necessary for carrying out its monitoring and evaluation. Thus to indicate the target would be recommended at the critical threshold which is defined at WTA of 0.4. This threshold, internationally recognized and widely accepted, is implied as a severe water stress as well as a potential to cause deterioration of aquatic ecosystem will occur if water is withdrawn over 40% of total available water (Ecologic Institute and SERI, 2010; Alcamo et al, 2000 and 2003; Raskin et al, 1997; United Nations, 1999). However this recommended target includes a need of research to support and better understand direct and indirect impacts of this target. Hence this will be a good start moving toward sustainability because it is not only setting the target value to be achieved but also plans or measures for reaching target. There are several potential options related to agriculture or irrigation, for instance, maintaining agricultural land and crops, shifting crop calendar, improving crop varieties, building additional surface water storage, developing irrigation methods, changing agricultural practices and so on. Accordingly, the WSI template as the outcome of this 2nd phase can be used to evaluate impacts of those options on the results of WSI.

Table 3.7 Annual and monthly WSI of 25 watersheds

| | Annual | Monthly WSI ² | | | | | | | | | | | |
|----------------------|------------------|--------------------------|------|------|------|------|------|------|------|------|------|------|------|
| | WSI ¹ | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Salawin | 0.017 | 0.02 | 0.05 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Kok | 0.018 | 0.17 | 0.11 | 0.09 | 0.01 | 0.01 | 0.04 | 0.03 | 0.03 | 0.04 | 0.02 | 0.01 | 0.02 |
| Ping | 0.023 | 0.04 | 0.04 | 0.03 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| Wang | 0.021 | 0.06 | 0.04 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 |
| Yom | 0.044 | 0.98 | 0.99 | 0.60 | 0.02 | 0.01 | 0.10 | 0.17 | 0.10 | 0.07 | 0.02 | 0.02 | 0.05 |
| Nan | 0.015 | 0.11 | 0.12 | 0.14 | 0.01 | 0.01 | 0.04 | 0.06 | 0.05 | 0.05 | 0.02 | 0.02 | 0.02 |
| Khong | 0.014 | 0.06 | 0.07 | 0.04 | 0.03 | 0.02 | 0.10 | 0.09 | 0.07 | 0.08 | 0.04 | 0.02 | 0.03 |
| Chi | 0.471 | 0.10 | 0.07 | 0.03 | 0.02 | 0.02 | 0.21 | 0.34 | 0.18 | 0.20 | 0.03 | 0.02 | 0.03 |
| Mun | 0.927 | 0.08 | 0.07 | 0.02 | 0.02 | 0.02 | 0.37 | 0.36 | 0.34 | 0.25 | 0.03 | 0.01 | 0.04 |
| Chao Phraya | 0.339 | 1.00 | 1.00 | 0.99 | 0.08 | 0.04 | 0.52 | 0.90 | 0.86 | 0.28 | 0.05 | 0.35 | 0.98 |
| Sakae Krang | 0.031 | 0.38 | 0.05 | 0.09 | 0.04 | 0.03 | 0.13 | 0.43 | 0.70 | 0.33 | 0.05 | 0.06 | 0.04 |
| Pasak | 0.050 | 0.83 | 0.37 | 0.08 | 0.03 | 0.02 | 0.06 | 0.21 | 0.14 | 0.13 | 0.05 | 0.06 | 0.08 |
| Tha Chin | 0.287 | 1.00 | 1.00 | 0.94 | 0.04 | 0.03 | 0.42 | 0.76 | 0.82 | 0.28 | 0.04 | 0.06 | 0.69 |
| Mae Klong | 0.018 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 |
| Phetchaburi | 0.022 | 0.16 | 0.97 | 0.11 | 0.02 | 0.01 | 0.04 | 0.07 | 0.10 | 0.03 | 0.01 | 0.02 | 0.04 |
| West Coast Gulf | 0.158 | 0.38 | 0.65 | 0.30 | 0.06 | 0.05 | 0.13 | 0.17 | 0.12 | 0.04 | 0.03 | 0.03 | 0.26 |
| Prachin Buri | 0.016 | 0.77 | 0.19 | 0.06 | 0.02 | 0.02 | 0.06 | 0.05 | 0.06 | 0.04 | 0.03 | 0.02 | 0.13 |
| Bang Pakong | 0.026 | 1.00 | 0.79 | 0.28 | 0.06 | 0.05 | 0.23 | 0.51 | 0.67 | 0.16 | 0.09 | 0.51 | 0.98 |
| Thole Sap | 0.019 | 0.03 | 0.04 | 0.04 | 0.03 | 0.02 | 0.04 | 0.04 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 |
| East-Coast Gulf | 0.015 | 0.05 | 0.19 | 0.15 | 0.10 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.07 | 0.07 |
| Peninsula-East coast | 0.067 | 0.06 | 0.06 | 0.04 | 0.22 | 0.07 | 0.13 | 0.09 | 0.15 | 0.09 | 0.03 | 0.02 | 0.02 |
| Tapi | 0.060 | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 | 0.04 | 0.05 | 0.07 | 0.04 | 0.02 | 0.01 | 0.01 |
| Thale sap Songkhla | 0.014 | 0.02 | 0.02 | 0.01 | 0.08 | 0.06 | 0.06 | 0.04 | 0.11 | 0.05 | 0.02 | 0.01 | 0.01 |
| Pattani | 0.025 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 |
| Peninsula-West coast | 0.012 | 0.03 | 0.04 | 0.01 | 0.11 | 0.05 | 0.04 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 |

Remarks ¹Annual WSI from the 1st phase of the project; ²Monthly WSI from the 2nd phase of the project

CHAPTER 4

Agriculture and Freshwater used Assessment in the Selected Watersheds

This chapter presents the results on comprehensive assessment of freshwater used and freshwater requirements for major crops including rice, cassava, maize and sugarcane grown in the studied watersheds i.e. Mun, Chi, Chao Phraya and Tha Chin. The fresh water used is estimated based on the crop evapotranspiration calculation complimenting with the actual rainfed/irrigated conditions of planted areas as well as irrigation practices of farmers. The irrigation practices of farmers and irrigation water efficiency are collected and complied from field survey with the farmers in various provinces. The freshwater used results are analysed, aggregated and weighted to represent the average and ranges of actual freshwater used for crop growing under different cultivation conditions of farmers e.g. rainfed cultivation, irrigated cultivation with different irrigation practices. The results are expected not only to answer how much of freshwater consumed for crop growing but also where the freshwater source and how those freshwater used for crops will potentially affect to the water scarcity impact. This is particularly in the selected watershed when the water stress index was incorporated in the calculations. This can be called the “water scarcity footprint” assessment based on ISO14046. The obtained results would be useful information for policy decision making on water resource management for agriculture as well as for identification of improvement measures for effective water resource management for crop growing.

4.1 Water footprint assessment methodology and studied areas

The water used is a spatially and temporally explicit indicator of freshwater consumption. The water footprint assessment in this section aims to determine the freshwater used or so called “direct water used” per amount of production, focusing on the actual freshwater availability and irrigation practice of farmers. The source of freshwater is categorized into two components i.e. rainwater and irrigation water which will be sub-divided into surface water and groundwater. The watering practices of each crop are surveyed and analysed. The freshwater used by crop is supposed to be equivalent to the volume of water lost via evapotranspiration process including evaporative water from soil and crop surfaces and transpired water from crop to the atmosphere. In general the crop evapotranspiration (ET_c) term can be quantified either empirical measured at a field or theoretical estimated via formula or model. The general formula used for estimating crop water use is expressed as follows (Allen et al., 1998 and FAO, 2010).

$$ET_c = K_c \times ET_0 \quad (\text{Eq.8})$$

To obtain the ET_c by experiment, the result cannot be applied to another area because weather conditions, soil characteristics, and crop variety crop water use affect to volume of water used by crop. Therefore the ET_c is practically computed with regard to meteorological data and crop variety. According to variations of weather and crop species, a reference crop evapotranspiration (ET_0) and crop coefficient (K_c) are developed to be related to estimate the ET_c of any crops planted in any area and time. Regarding the K_c and ET_0 terms, the Penman Monteith method is mainly applied with particular meteorological data

Water demand for crop growing is assessed based on water required by crops and cultivated areas relating to effective rainfall, water loss via conveyance and irrigation efficiency as can be expressed in the Equation below (RID, 2011).

$$\text{Water demand for crop growing (m}^3/\text{rai)} = \frac{[\text{crop water requirement}] - [\text{effective rainfall}] + [\text{water loss}] \times 100}{[\text{irrigation efficiency}]}$$

Figure 4.1 shows the step of data collection and freshwater used calculation. The calculation sheets have been prepared in the MS Excel spreadsheet format. Assumptions and factors used in the calculations are as follows:

- The reference crop evapotranspiration (*ET_o*), crop coefficients and monthly average rainfall data for different provinces of Thailand are referred from RID. The crop evapotranspiration (*ET_c*) and the effective rainfall are calculated for the given set of data on *ET_o*, monthly rainfall, *K_c* and the crop calendar.
- Monthly data on rainfall and *ET_o* are assumed to distribute within the month. The effective rainfall is estimated based on RID recommendations as follows:
- To calculate amount of water used within direct freshwater uses including rain water source and irrigation water sources which divided into Irrigation water, in-situ stored, and groundwater. The detail of water demand calculation of each crop will be defined in further subtopics.

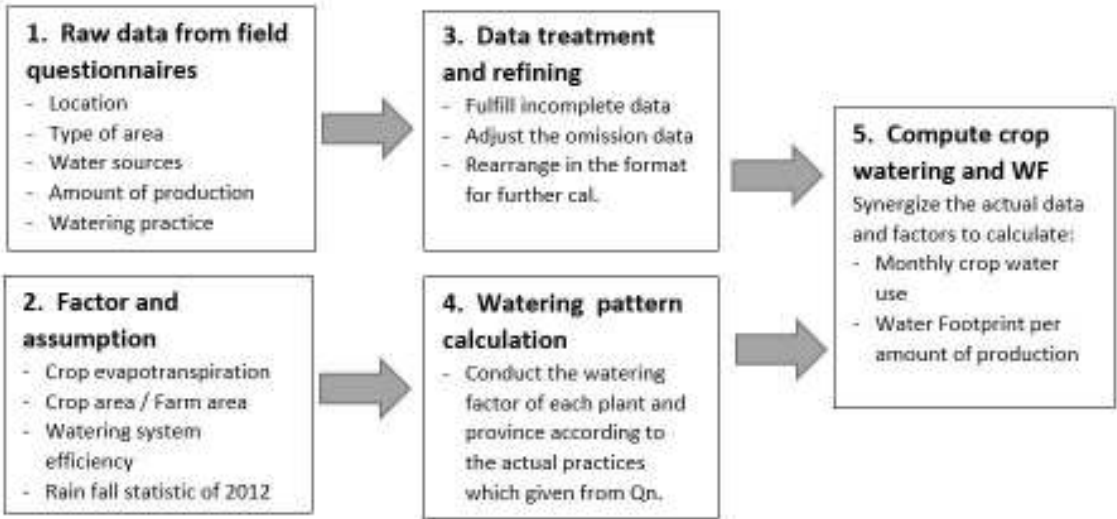


Figure 4.1 Calculation flowchart of field data template

- To collect data from surveying. The details of questionnaire used has been shown in Appendix III which will consist of the set of questions including farming general information, crop practices, crop calendar, watering pattern, watering practice e.g. watering system, production yield, water level in paddy field of each growing periods, supplement water sources and portion, etc.

- Farm-leveled water used is aggregated by weighted averaging of yield and representative or each province and then projected to for watershed by production, accordingly.
- To verify the analysed results, literature review as well as stakeholder consultations have been conducted in several steps. Firstly, field data obtained from literature review are used to calculate the preliminary water scarcity footprint in order to see the necessary assumptions and parameters that required for field data collection. Secondly, field data collection is performed. Target areas and sampling size of farmer surveys are recommended by local agricultural experts such as Provincial Agricultural Extension’s officers, Provincial Royal Irrigation Department, local government and farmers’ leaders. Questionnaires have also been developed based on their recommendation. The agricultural land for data collection include irrigated and non-irrigated areas, different watering patterns and agricultural practices. Lastly, the stakeholder meetings are conducted for validating the analyzed results and receiving comments and suggestions from stakeholders, local governments, and related organizations.

Table 4.1 shows the studied watersheds and their representative provinces as well as the related government offices that were interviewed and collected data.

Table 4.1 Data sources for agricultural practice in studied watersheds

| Studied watersheds | Province | Data source |
|--------------------|-------------------|--|
| Mun | Nakhon Ratchasima | Provincial Agricultural office: Nakhon Ratchasima Regional Irrigation Office 8 |
| | Ubon Ratchathani | Provincial Agricultural office: Ubon Ratchathani Regional Irrigation Office 7 |
| | Buri Rum | Provincial Agricultural office: Buri Rum |
| Chi | Chaiyaphum | Provincial agricultural office: Chaiyaphum |
| | Khon Kaen | Provincial agricultural office: Khon Kaen Regional Irrigation Office 6 |
| | Kalasin | Provincial agricultural office: Kalasin |
| Chao Phraya | Chai Nat | Provincial Agricultural office: Chai Nat Regional Irrigation Office 12 |
| | Nakhon Sawan | Provincial Agricultural office: Nakhon Sawan |
| | Lop Buri | Provincial Agricultural office: Lop Buri Regional Irrigation Office 10 |
| | Ayutthaya | Provincial Agricultural office: Ayutthaya |
| | Pathum Thani | Provincial Agricultural office: Pathum Thani |
| Tha Chin | Suphan Buri | Provincial Agricultural office: Suphan Buri Suphan Buri Rice Research Centre: Suphan Buri |
| | Karnchanaburi | Provincial Agricultural office: Karnchanaburi |
| | Nakhon Pathom | Provincial Agricultural office: Nakhon Pathom |

4.2 Freshwater used for rice production

Rice is the major economic crop of Thailand. Irrigation used as well as several irrigation projects for agriculture in Thailand are often planned and constructed based on the water demand for rice production in each area. The study determines the freshwater used for rice cultivation in different practices in the studied areas i.e. Mun, Chi, Chaophraya and Tha Chin watersheds. In the assessment, the freshwater used for rice cultivation is classified into two terms i.e. rainwater and

irrigation water. Rainwater implies to the effective rainfall that rice can be used, irrigation water implies to the freshwater that is withdrawn from surface or ground water for rice cultivation.

4.2.1 Description of rice cultivations in Thailand

In Thailand, rice growing is mainly in the wet systems i.e. rice fields are prepared and the soil is kept saturated. There are three major types of rice cultivations found in the studied areas i.e. transplanting, dry ungerminated seed broadcasting and pregerminated seed broadcasting. Generally, the cultivation system begins with the land preparation by puddling. This is done by saturating the soil layer for one month prior to sowing. The volume of water that is necessary for saturated soil is about 200 mm (Brouwer and Heiblowem, 1986). For upland rice growing, a standing layer of water may not be used due to the geographical limitation. However, for the lowland rice growing, the standing layer of water generally will be required for weed control. This wet system will have a constant percolation and seepage loss during this period. Since the percolation loss is primarily a function of soil texture, the study refers the percolation loss factor based on RID which is about 1 mm/day for central region of Thailand and 1.5 mm/day for the other regions. This standing water is assumed to be used for the entire period of rice cultivation except for the last 15 days when the field is left to dry out for easy harvesting. A water layer is assumed to be established during transplanting or sowing and maintained throughout the growing season but the level of water layer can differ depending on the farmers' practices. The volume of water needed for maintaining the water layer will be accounted in the percolation losses and evaporative demand of the crop during the last phase of paddy growth, it is necessary to get this volume of water at the beginning of the crop period. The study assumes that the water layer is established in the month of sowing. The total freshwater demand for rice cultivation is therefore calculated from the summation of ET_c , standing water, and percolation for each time step. For the last 15 days prior to the harvesting when the land is left to dry out, the volume of water required for evaporation is supplied by the effective rainfall in the period and any residual soil moisture maintained from the previous stages.

To determine the proportion of rainwater and irrigation water used for crops growing, the effective rainfall is given as the first prioritized water resource used for crops; however, if the effective rainfall is less than the evapotranspiration value, the irrigation water is supposed to be added to fulfilled the deficit amount of water requirement (if the planted areas are irrigated). However, if the planted areas are the rain water only, only the effective rainfall is considered as the water used for crops. Irrigation water sources are divided into three types i.e. 1) Irrigation water 2) small water storage e.g. pond and 3) groundwater in place. The amount of each water source consumption calculated from interviewing as portion and watering practice. Though, some farmers had only use Irrigation water as supplement but the supply is not appropriate to their watering pattern that means the water shortage occurrences in some period. The amount of irrigation water is determined as only available supply amount.

4.2.2 Studied areas for data collection

The studied areas for determining the freshwater used of rice production are listed in Table 4.2. The specific simple sites include both non-irrigation and irrigation areas (with different watering practices) are identified as per recommended by the provincial agricultural officers to representing

various practices of farmers in the studied provinces/watersheds. It was found that the planted areas of in Tha Chin and Chao Phraya watersheds are generally the lowland paddy rice which farmers are able to cultivate with irrigation water. Meanwhile, the cultivated areas in the Mun and Chi watersheds mostly relied on rainwater due to the lower numbers of irrigation projects available.

The geographical location of Chao Phraya and Tha Chin watershed is of central region, the rain band striations since mid-May to mid-August due to southwest monsoon and another with northwest monsoon in mid-October to end of November. Therefore the rice is generally grown more than one crop if farmers have enough supplement water for land preparation. It was found that in Ayuthaya, Nakhon Pathom, Pathum Thani, farmers are able to grow crop rather than twice per year. However, in case of the northeastern region (i.e. Mun and Chi watershed), the rainy season generally come a bit later than the central region and those areas have not fully irrigation system, so that, farmers are generally start to prepare their rice field since the mid-July and then sowing in mid-August in order to use the rainwater. Nowadays, the non-irrigated rice field have been promoted by DOA to cultivate the mungbean or other beans in order to improve soil quality. For some repeated drought areas, the groundwater use has being supported to use or subsidised to quit growing rice by government campaign due to water scarcity problem.

Table 4.2 List of Amphoe and provinces included in data collection on rice production

| Watershed | Province | Amphoe district | Data collecting area (rai) | |
|-------------|--------------|--------------------------|----------------------------|-------------|
| | | | Major crop | Second crop |
| Chao Phraya | Pathum Thani | Lat lum kaeo | 1,037 | 984 |
| | | Nong Suea | 814 | 789 |
| | Ayutthaya | Tha Ruea | 679 | 591 |
| | | Nakhon Luang | 749 | 645 |
| | | Bang Sai | 393 | 393 |
| | | Bang Sai | 1,394 | 1,349 |
| | | Bang Ban | 353 | 304 |
| | | Bang Pahan | 1,109 | 635 |
| | | Bang Pa-in | 21 | 21 |
| | | Ban Phraek | 1,059 | 906 |
| | | Phak Hai | 1,272 | 1,087 |
| | | Phra Nakhon Si Ayutthaya | 499 | 477 |
| | | Phachi | 829 | 649 |
| | | Maharat | 792 | 565 |
| | | Lat Bua Luang | 966 | 966 |
| | | Wang Noi | 1,002 | 996 |
| | | Sena | 1,027 | 945 |
| | Uthai | 1,115 | 878 | |
| | Nakhon Sawan | Chum Saeng | 1,573 | 1,554 |
| | | Tak Fa | 20 | 20 |
| Chai Nat | Wat Sing | 390 | 213 | |
| | Sankhaburi | 423 | 217 | |
| | Sapphaya | 197 | 60 | |
| | | Nong Mamong | 227 | - |
| | | Mueang Chai Nat | 423 | 156 |
| | | Hankha | 327 | 93 |
| | | Manorom | 174 | 174 |
| | | Nong Mamong | 124 | 34 |
| Lop Buri | | Ban mi | 816 | 371 |

| Watershed | Province | Amphoe district | Data collecting area (rai) | |
|--------------|-------------------|---------------------|----------------------------|---------------|
| | | | Major crop | Second crop |
| | | Sa Bot | 632 | 18 |
| | | Khok samrong | 409 | - |
| | | Mueang Lop Buri | 423 | 156 |
| | | Tha Wung | 249 | 50 |
| Tha Chin | Suphan Buri | Si Prachan | 30 | - |
| | | Doem Bang Nang Buat | 732 | 660 |
| | Kanchanaburi | Phanom Thuan | 544 | 488 |
| | Nakhon Pathom | Kamphaeng Saen | 221 | 221 |
| Bang Len | | 488 | 488 | |
| Mun | Ubon Ratchathani | Sawang Wirawong | 76 | 20 |
| | | Na Chaluai | 70 | - |
| | | Sawang Wirawong | 111 | - |
| | | Na Yia | 166 | - |
| | | Nam Yuen | 30 | - |
| | | Trakan Phuet Phon | 78 | - |
| | | Muang Sam Sip | 153 | - |
| | | Samrong | 103 | - |
| | Nakhon Ratchasima | Chok Chai | 5,441 | 2,242 |
| | Buri Ram | Mueang Buri Ram | 150 | - |
| Chi | Nakhon Ratchasima | Dan Khun Thot | 1,472 | - |
| | Chaiyaphum | Bamnet Narong | 247 | 129 |
| | | Kaset Sombun | 400 | 30 |
| | Kalasin | Somdet | 665 | - |
| Khong Chai | | 984 | 984 | |
| Khon Kaen | Ban Phai | 730 | - | |
| | Mueang Khon Kaen | 680 | 389 | |
| Total | | | 35,082 | 21,945 |

4.2.3 Results on freshwater used for rice

The assessment results on freshwater used (average and ranged values) for rice production can be summarized as Table 4.3.

Table 4.3 Sumnerized result of yield and water used of rice production

| Crop | Parameter | Unit | Chao Phraya | Tha Chin | Mun | Chi |
|---------------|-----------------------|--------|--------------------|--------------------|--------------------|--------------------|
| Major | Yield | kg/rai | 814 (803 - 825) | 923 (883 - 1061) | 427 (411 - 443) | 479 (467 - 491) |
| | Total water used | m3/kg | 1.43 (1.4 - 1.46) | 0.97 (0.92 - 1.13) | 2.81 (2.59 - 3.03) | 2.27 (2.2 - 2.34) |
| | Rain water used | m3/kg | 1.08 (1.05 - 1.11) | 0.71 (0.67 - 0.85) | 1.95 (1.74 - 2.16) | 2.11 (2.05 - 2.17) |
| | Irrigation water used | m3/kg | 0.35 (0.33 - 0.37) | 0.26 (0.22 - 0.39) | 0.85 (0.69 - 1.01) | 0.15 (0.12 - 0.18) |
| | Small storage | m3/kg | 0.02 (0.02 - 0.02) | 0.02 (0 - 0.07) | 0.05 (0.02 - 0.08) | 0.02 (0.01 - 0.03) |
| | Irrigation water | m3/kg | 0.31 (0.29 - 0.33) | 0.23 (0.19 - 0.36) | 0.81 (0.65 - 0.97) | 0.13 (0.1 - 0.16) |
| | Groundwater | m3/kg | 0.02 (0.01 - 0.03) | 0.02 (0.01 - 0.06) | 0 (0 - 0) | 0 (0 - 0) |
| Second | Yield | kg/rai | 884 (856 - 912) | 848 (775 - 1101) | | |
| | Total water used | m3/kg | 1.53 (1.48 - 1.58) | 0.89 (0.8 - 1.2) | | |
| | Rain water used | m3/kg | 0.38 (0.36 - 0.4) | 0.25 (0.18 - 0.48) | | |
| | Irrigation water used | m3/kg | 1.15 (1.11 - 1.19) | 0.64 (0.57 - 0.89) | | |
| | Small storage | m3/kg | 0.07 (0.06 - 0.08) | 0.01 (0 - 0.13) | | |
| | Irrigation water | m3/kg | 1.01 (0.97 - 1.05) | 0.59 (0.52 - 0.84) | | |
| | Groundwater | m3/kg | 0.07 (0.05 - 0.09) | 0.04 (0.01 - 0.13) | | |

1) Chao Phraya watershed

The water used for major rice cultivation of Chao Phraya watershed average of 1.43 m³ per kg paddy rice with 814 kg/rai of production. That comprises rainwater and irrigation are 1.08 (75%) and 0.35 (25%) m³/kg respectively. Second rice have higher production yield due to its variety and water use which sourced by irrigation water. The water used total 1.53 m³/kg consisting of rainwater used 0.38 m³/kg (25%) and irrigation water 1.15 m³/kg (75%) those that is adverse to major rice. The irrigation water is majority portion farmer uses in result of central plain has been covered by abundant irrigation system. The groundwater and private storage e.g. pond, small reservoir are other sources that found to be enable as supplementary water where are inaccessible to irrigation distribution system. The results illustrate in Figure 4.2.

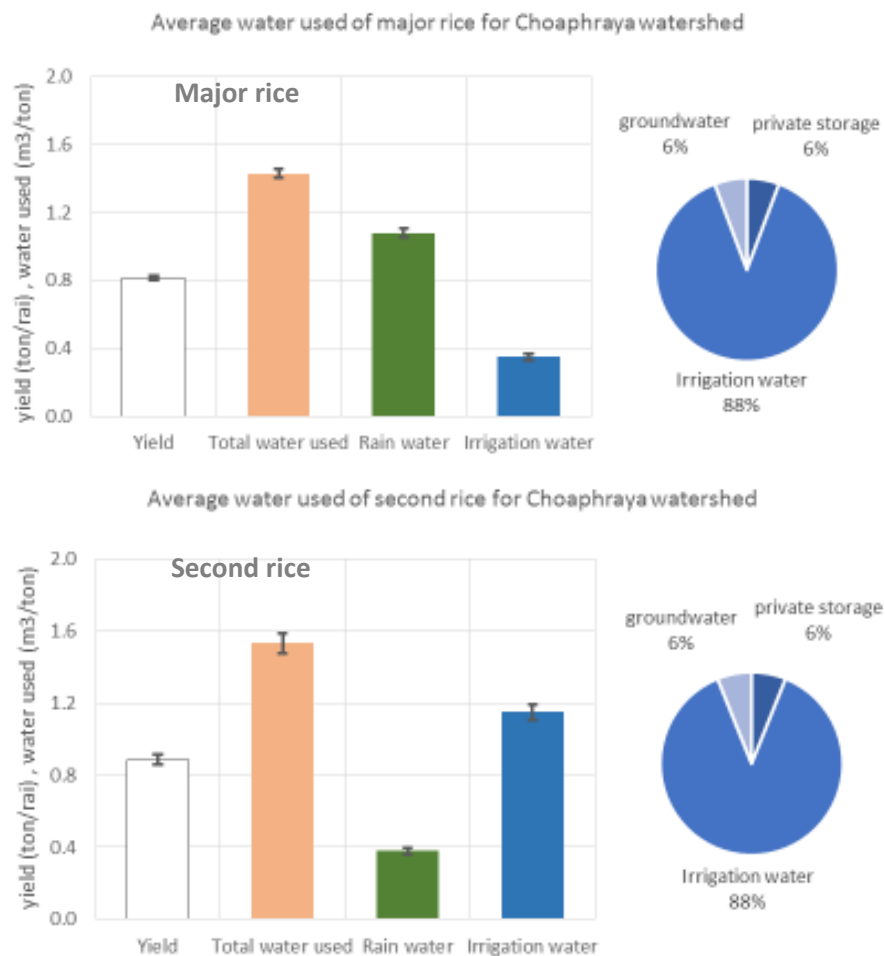


Figure 4.2 Production yield and water used for major and second rice of Chao Phraya watershed

Figure 4.3 presents the water demand for major and second rice cropping with common watering practice of Ayuthaya. The diagram divided as four growing periods across mode crop month. The farmer starts to land preparing in May comprising of water-use activity i.e. plough, harrows, soil drying and tillage as consequence. Then sowing in Jun when farmer have to fill and contain water in rice field to prevent herbicides growing up. These stages require large water due to insufficient rainfall. In mid-range, the water demand almost equivalent to rain fed. After August entering the monsoon season, the excess rain fall have to be taken out the field and then dried out the rice filed for harvesting in end of September. When the second rice will immediately start after

finished major crop in October. All growing stages of second crop have to add irrigation water due to the end of monsoon season. Initial stage probably still have some rainwater remain due to the delay of monsoon season; however, after November, it would enter to drought season and farmers will need fully irrigation water for rice flowering and development stage until harvested in January.

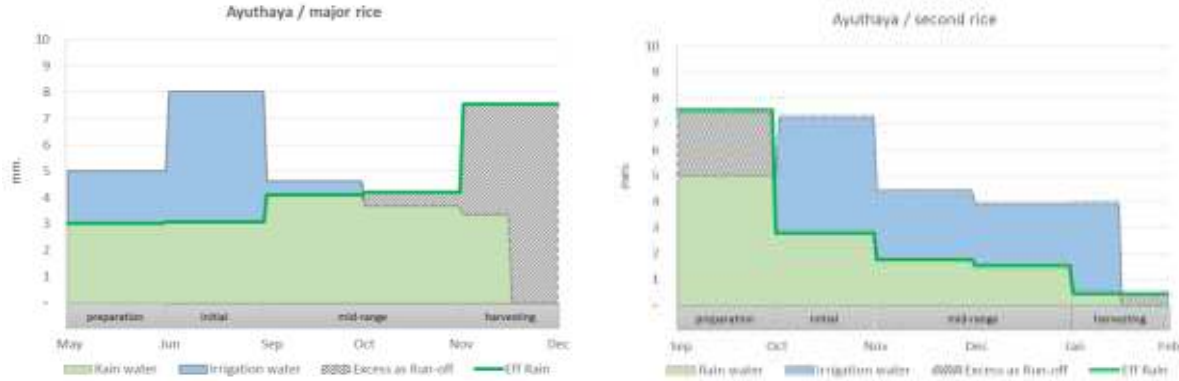


Figure 4.3 Water demand of common practice for major and second rice in Ayuthaya

2) Tha Chin watershed

Tha Chin watershed located in central plain where it is the largest agricultural area. Suphan Buri is the major rice cultivation province and use modern practice in order to improving production yield. The average freshwater used for major rice cultivation of Tha Chin watershed average of 0.93 m³/kg with the highest yield of 923 kg/rai. The portion of water used comprises rainwater and irrigation as 0.71 (73%) and 0.26 (27%) m³/kg respectively. Second rice yield is about 848 kg/rai. The total water used is then around 0.89 m³/kg rice consisting of rainwater 0.25 m³/kg (28%) and irrigation water 0.64 m³/kg (72%). The irrigation water is the majority portion farmer uses for both major and second rice cultivation. The groundwater was highly used in the Pathum Thani because of the areas have shallow groundwater level that can easily be pumped up for supplying the remote farms. Moreover, by recently government campaign for more using groundwater in drought season for substituting irrigation water that causes increasing trend to open the new well. Hence, risky to salty groundwater problem in future. The results illustrate distinguish of major rice and second rice in Figure 4.4.

Figure 4.5 shows the total water demand of major and second rice crops in Suphan Buri based on common practices. Major rice crop starts in May for land preparing before wet seeded sowing in June. For initial stage, rice growers would maintain water level at averaged 9.8 mm. which lowest level compared with other growing place. After that water increase at 13-15 mm. until are drained out for harvesting in September. However the referenced effective rain fall statistics that be used in this considering is rather low in particular Jun to August. Irrigation water are therefore required around 4 mm./day in June then, would be deceased in mid-range growing stages as 1-2 mm./day. Second rice are grown after harvesting major crop suddenly. It requires higher irrigation water of all growing stage around 3-4 mm. /day. The flowering and development in December to January stage are particularly much higher water demand.

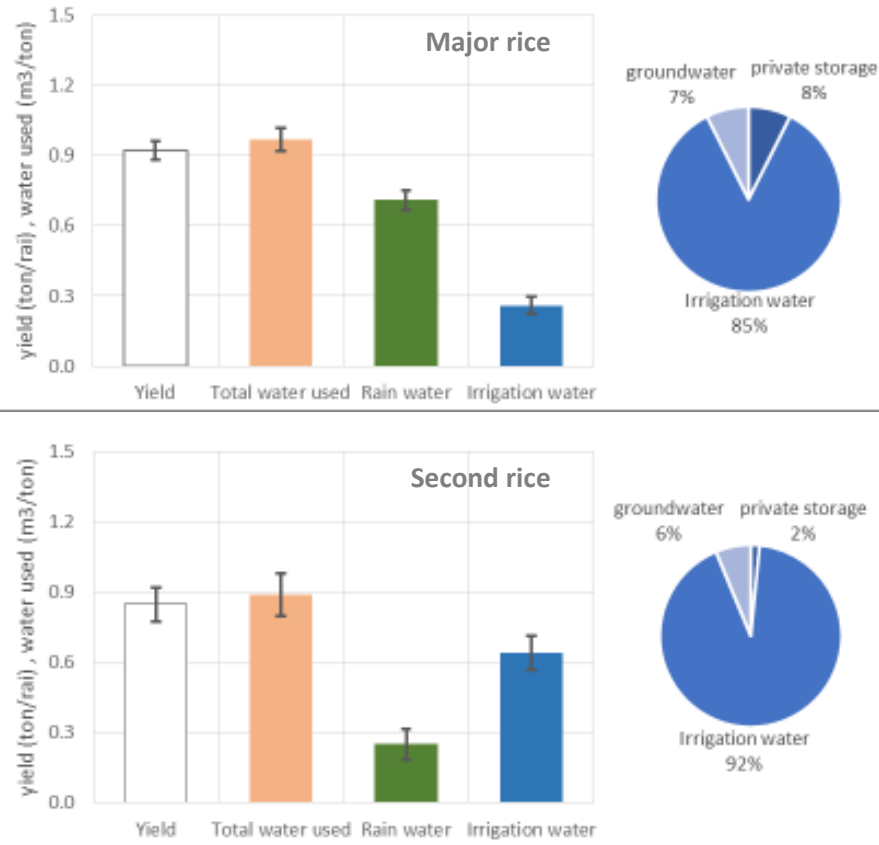


Figure 4.4 Production yield and water used for major and second rice of Tha Chin watershed

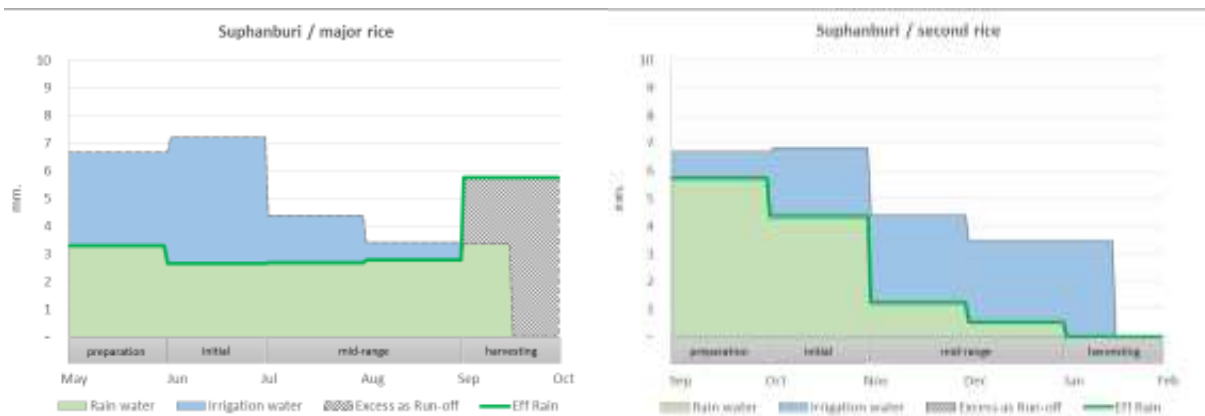


Figure 4.5 Water demand of common practice for major and second rice in Suphan Buri

3) Mun watershed

Mun watershed originates a famous Hom Mali rice (Thai jasmine rice) due to prevailing grown. However, this watershed locates in northeastern region as plateau area by lags of irrigation system. Moreover, the Hom Mali variety's yield has lower than ordinary rice. The production yield is 427 kg/rai by total water used is 2.81 m³/kg (even considering based on area that is higher Chao Phraya and Tha Chin watershed). Most rain water are mainly provided by 1.95 m³/kg (70%) and other irrigation water are 30%. The irrigation water can be used for only rice field where near and accessible to irrigation canals. Due to the survey data on second rice growing is very low samples

due to lack of irrigation water in this region, the freshwater used for second rice cannot be interpreted. The result illustrates in Figure 4.6.

The water consumption for major rice in Ubon Rachathani show in Figure 4.7. It is likely to the results of other provinces that almost freshwater used are rainfall. The survey found that farmers started preparing land in July and then ready to sowing in August. Though, the virtual graphic shows the late mid-range and harvesting state need some irrigation water, those required water can be acquired from excess rain fall of earlier months and remaining in the field.

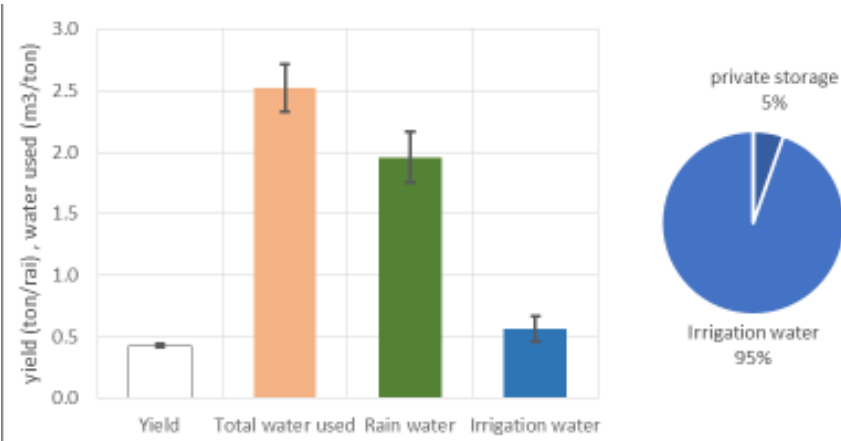


Figure 4.6 Production yield and water used for major rice of Mun watershed

The level of standing water is highly influence to freshwater used of rice cultivation, the common practice of this province likely prefer to control at high water level, 12 mm. for initial stage and 20 mm. for mid-range and harvesting stages, comparing to central farmer. Although, government officers have tried to encourage standing water use reduction to farmers; however, it is still difficult to change the farmers’ practices.

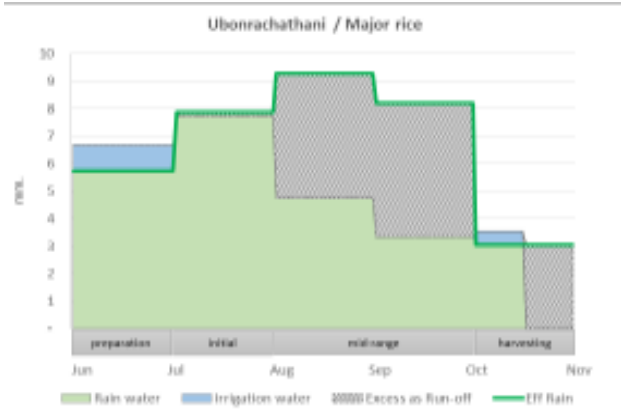


Figure 4.7 Water demand of common practice for major rice in Ubon Rachathani province

4) Chi watershed

Same situation as Mun watershed, rice cultivation in Chi watershed largely relied on rainwater. Although, Chi river has lot of sub rivers covered of large area; however, the lack of irrigation

system bring about the deficit water available for second crop growing. Some private storage would be enabled in some places that owners divided area for water storage or granted by government programs. The production yield is 479 kg/rai by total water used is 2.27 m³/kg. Most of freshwater used are the rainwater i.e. 2.11 m³/kg (93%). The irrigation water just accounted for about 7%. Since the data on second rice growing is rarely found from the survey (only Kalasin and some amphoes of Khon Kaen) and those cannot be a reliable representative value of water used. The freshwater used results in Chi watershed therefore will show only major rice as illustrated in Figure 4.8.

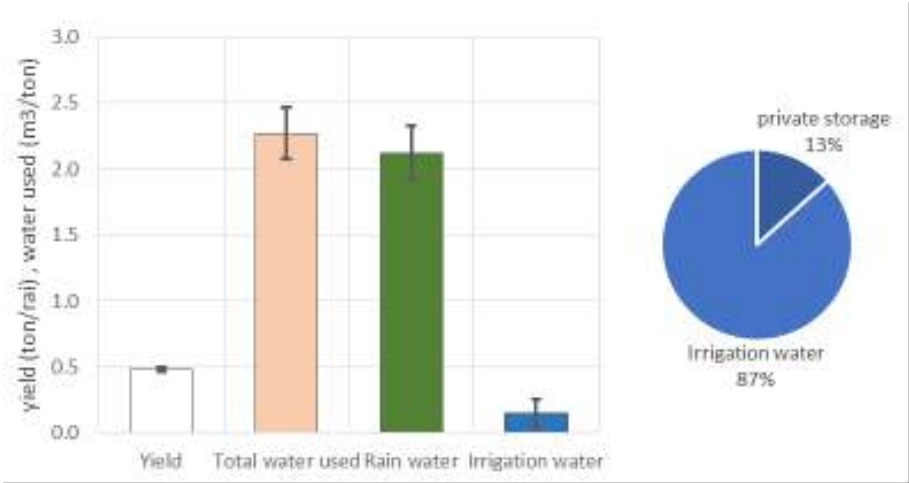


Figure 4.8 Production yield and water used for major rice of Chi watershed

The common practice for major rice crop in Kalasin province shown in Figure 4.9. Kalasin province has a large water body, Lum Pao dam, to supply the supplement water for major rice crops. So, farmers have therefore opportunity to shift the crop calendar up to the water availability which managed by RID. Both crop periods also required irrigation water but in different stage viz. earlier crop requires initial stage and later crop requires late mid-range and harvesting stage, so the irrigation water can be efficiently allocated to planned area. The watering practice of farmers are weak as Ubon Ratchathani farmer, higher water level cause to higher water used and loss. However, eventually mainly depending on available rainfalls.

The shifting of cultivation calendar is the one of the options that were suggested for the farmers by RID in order to reduce the irrigation water use for major rice cultivation. For example, traditionally, farmers start land preparing on July, broadcasting in August, then harvesting in mid-to-late October. That their common practice requires irrigation water in late growing stage. If they were shifted up to starting on June, it would be less irrigation water due to heavy rainfall in July and August. This can be saved the water use around 6 mm (equivalent to 10 m³ per rai) or 6 percent of the total irrigation water uses. The study also found that the paddy rice cultivations in Mun and Chi are mainly rainfed which it is quite different from the paddy rice cultivations Thachin and Chao Phraya watersheds where are the lower-watersheds and have abundant freshwater from the upper as well as fully covered by water irrigation systems. Hence, the total water use for rice cultivations in Thachin and Chao Phraya watersheds are higher than the Mun and Chi watersheds.

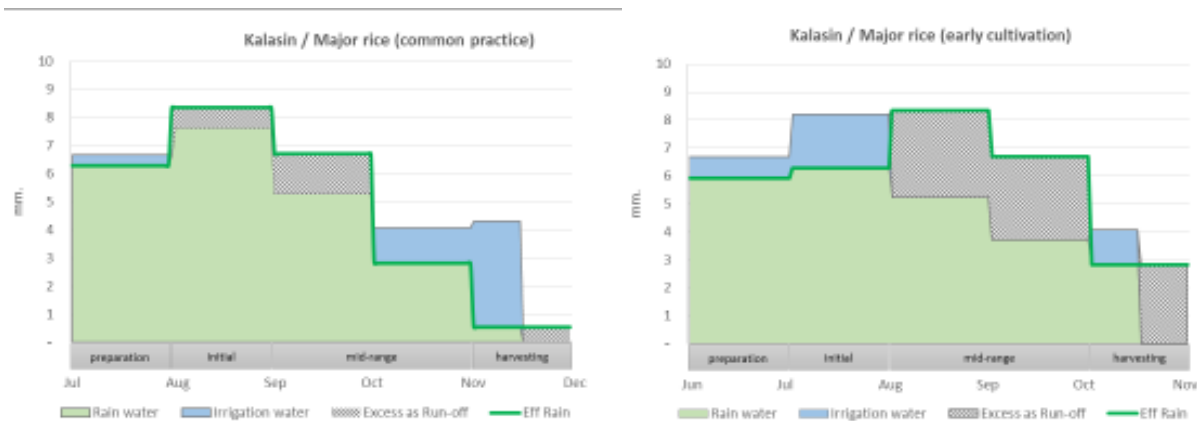


Figure 4.9 Water demand of common practices for major rice in Kalasin province

4.3 Freshwater used of sugarcane production

The selected area for data collecting is identified based on the provinces where highly produced sugarcane and participated sugar mills. Two watersheds i.e. Chao Phraya and Chi have the large areas of sugarcane cultivation. Table 4.4 shows the provinces and sugarcane planted areas involved in the data collection. The key factors for determining the crop water used e.g. water level in each farm location, watering technology and practices, source of supplement water (if applicable), etc. are surveyed by the questionnaire and face-to-face interview to farmers.

Table 4.4 Data collection area for sugarcane cultivation

| Watershed | Province | Collecting data area (rai) |
|-------------|-------------------|----------------------------|
| Chao Phraya | Nakhon Sawan | 1,819 |
| | Lop Buri | 1,658 |
| Chi | Nakhon Ratchasima | 1,282 |
| | Chai yaphum | 886 |
| | Kalasin | 701 |
| | Khon Kaen | 1,195 |

Farmers begin to planting sugarcane at the end of rainy season in order to use the remaining moisture in the soil for land preparing. Along the growing stage of sugarcane, they require supplement water in just growing period, the remaining period of growing will be mainly relied on the rainwater. The survey indicated that farmers generally started to replant the cane ratoon during the mid of January. Another practice of cane planting started before rainy season in May or June. The harvesting will take place in November until the next January. After that, farmers still maintain the ratoon for replanting. The replanted cane be ranged from three to five crops. Many farmers nowadays have installed the drip irrigation system in their field. So, the yield is obviously increased due to the irrigation system installation especially the sugarcane planted areas in Chao Phraya area. Table 4.5 shows the summary of freshwater used for sugarcane production in the studied areas.

Table 4.5 Summnerized result of yield and water used of sugarcane production

| Parameter | Unit | Chao Phraya | Chi |
|-----------------------|-------------------------|----------------------|-----------------------|
| Yield | ton /rai | 14.99 (14.48 - 15.5) | 11.45 (11.11 - 11.79) |
| Total water used | m ³ /kg cane | 0.22 (0.2 - 0.24) | 0.14 (0.13 - 0.15) |
| Rain water used | m ³ /kg cane | 0.11 (0.11 - 0.11) | 0.12 (0.11 - 0.13) |
| Irrigation water used | m ³ /kg cane | 0.11 (0.09 - 0.13) | 0.03 (0.02 - 0.04) |

The water use of sugarcane planted in Chao Phraya are 0.22 m³/kg cultivated sugarcane, higher than Chi watershed 0.14 m³/kg. That help to more production yield as consequently. Although, sugarcane is a plant which recommended for non-irrigated area. Higher demand of production to serve more consumption of sugar and even ethanol substrate demand increase. So, sugarcane are expanded to irrigation area substitute other lower economic crops i.e. paddy rice, beans, etc. that result obviously present in Chao Phraya watershed, sugarcane consumes irrigation water as much as rain water. Irrigation water is main source which shared with rice and other crops. The irrigation water allocation are planned by RID that sugarcane as one to be accounted. Meanwhile, Chi lacks of irrigated system, uses irrigation only 20% of total water used, the small water storage is major. As comparing results of Chao Phraya and Chi produced show the significant of increase yield when input of irrigation water. Nevertheless, other crop factors e.g. variety, soil quality, pest control, other practices are still relevant to output as well.

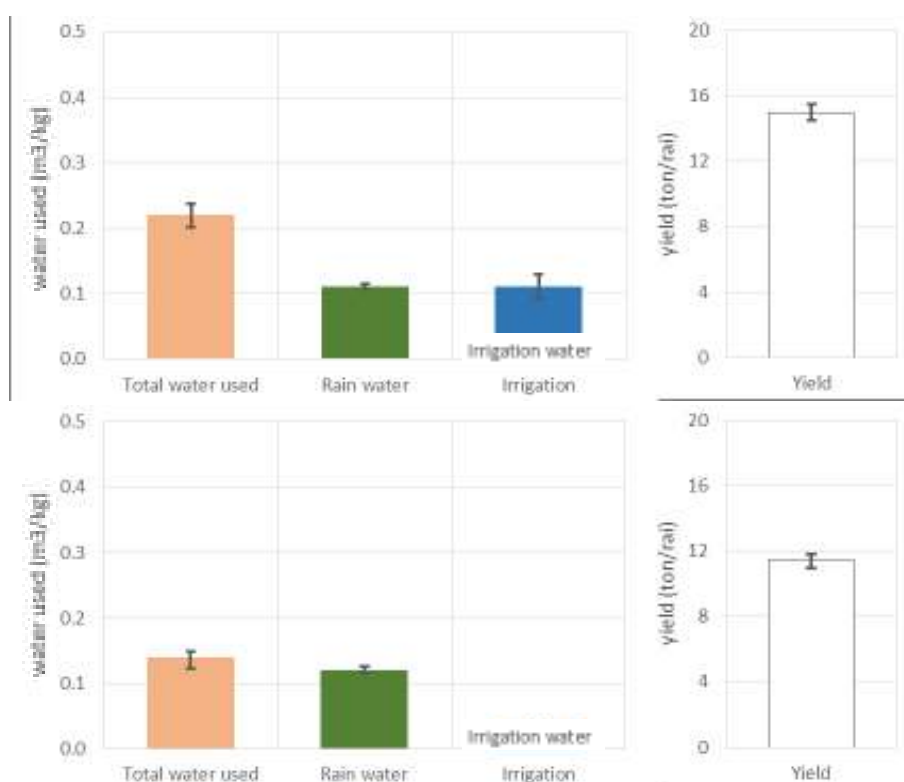


Figure 4.10 Production yield and water used for sugarcane in Chao Phraya and Chi watershed

4.4 Freshwater used of cassava production

Cassava is one of the energy crop that is being promoted to ethanol production. The cassava plantation areas have increased from 7.2 to 8.4 million rai during 2011 to 2014 consisting of 52%, 26% and 22% in the northeastern, central and northern regions, respectively. The study areas of

cassava plantation is listed in Table 4.6. Nakhon Ratchasima Khon Kaen and Buri Rum are the focal areas of cassava that data are collected by surveying and direct interviewing with farmers as well as the provincial DOAE officers. With reason of promoted plant as mentioned above, the advance technology has been applied for increasing yields, e.g. variety, soil quality improvement, and also watering system.

Cassava can be grown all year round but the common practice is started before raining season (around March or April, depended on climate region). After clearing land of previous crop, farmers may plough taken place to remove whether underground roots of cassava or others and also soil quarrying. Organic fertilizers e.g. cassava mill residue, manure are applied before planting with cassava cuttings. Rainwater is the major source for cassava growing (since age 3-10 months) for the conventional cropping. Most of cassava are grown in rainfed areas. However, nowadays, modern farmers prefer to use affordable drip irrigation system if they able to access irrigation water, i.e. stored water or groundwater. This is to avoid the risk of low yield due to long-term lacking of rain falls. The harvesting period take place in February to March.

Table 4.6 Data collection area for cassava cultivation

| Watershed | Province | Collecting data area (rai) |
|--------------|-------------------|----------------------------|
| Chao Phraya* | Nakhon Sawan | 1,061 |
| Chi | Nakhon Ratchasima | 1,184 |
| | Chaiyaphum | 1,143 |
| | Kalasin | 679 |
| | Khon Kaen | 1,671 |
| Mun | Ubon Ratchathani | 781 |
| | Buri Rum | 1070 |

* Noted that the field sampling is not enough to be analysed

The averaged total water uses for cassava is 0.63 m³/kg, comprising with 0.46 and 0.16 m³/kg of rainwater and irrigation water, respectively. The result obviously showed that the yields of cassava grown in Mun watershed is higher than Chi's around 40%. The irrigation water used found in cassava growing in the Mun watershed due to shallow groundwater level with drip underground system. This type of watering perform the high efficiency at 0.07-0.10 m³/kg comparing with ground-pouring which more than 1.20 m³/kg. This means there are some gap of yield improving by increase water utilized efficiently for considered the supplement water uses and watering system. The detail of result shows in Table 4.7.

Table 4.7 Summery result of yield and water used of cassava cultivation

| Parameter | Unit | Mun | Chi |
|-----------------------|----------------------------|--------------------|--------------------|
| Yield | ton/rai | 4.61 (4.35 - 4.87) | 3.31 (3.19 - 3.43) |
| Total Water used | m ³ /kg cassava | 0.63 (0.58 - 0.68) | 0.49 (0.48 - 0.5) |
| Rain water used | m ³ /kg cassava | 0.46 (0.42 - 0.5) | 0.49 (0.48 - 0.5) |
| Irrigation water used | m ³ /kg cassava | 0.16 (0.14 - 0.18) | 0 (0 - 0) |

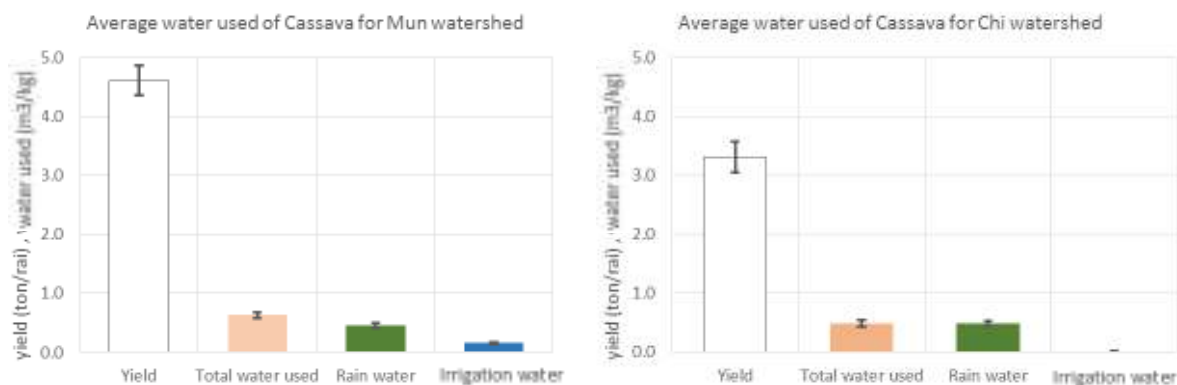


Figure 4.11 Production yield and water used for cassava in Mun and Chi watershed

4.5 Freshwater used of maize production

Maize is normally planted on highland where lack of water supplied. Upper Chao Phraya and Chi watersheds are selected to collect the data. About 3,180 rais of maize planted areas in Chao Phraya and 1,846 rais in Chi watersheds have been surveyed as listed in Table 4.8.

The survey found that farmers use a very few irrigation water and practice of growing are generally the same. Therefore, the amount of field data can be used to represent the water consumption of maize production.

Table 4.8 Data collection area for maize cultivation

| Watershed | Province | Collecting data area (rai) |
|-------------|-------------------|----------------------------|
| Chao Phraya | Nakhon Sawan | 1,320 |
| | Lop Buri | 1,860 |
| Chi | Nakhon Ratchasima | 1,361 |
| | Chaiyaphum | 485 |
| Mun* | Ubon Ratchathani | 270 |

* Noted that the field sampling is not enough to be analysed

Early raining season is the suitable period for start growing maize. Although, maize is mainly planted in the non-irrigated area, but water is still be the important factor to the crop yields. After harvesting of crop, farmers will start preparing the land again by ploughing roughly and then fallowing for first rain. Then, furrow plowing and sowing the seed for growing. After four months, the fully corn cob developed and farmers will prepare to harvest. The some corn stem will be left in the field for returning some nutrients to soil. However, cultivating in sloped land may occur the soil erosion and losing the nutrient and organic matter rapidly. Farmer so have to use further fertilizers to be adequate for next crops. The study found that in Nakhon Sawan and Lop Buri provinces have the higher yields of maize due to the irrigation water applied when comparing to Chaiyaphum cultivated in Chi watershed. The average freshwater used for cultivating maize in Chao Phraya is about 1.48 m³/kg maize (irrigation water shared about 10% of total water used); meanwhile, the water used for maize grown in Chi watershed is about 1.15 m³/kg (totally freshwater used from rainwater). The results are summarized in Table 4.9 and Figure 4.12.

Table 4.9 Summeryzed result of yields and water used of maize cultivation

| Parameter | Unit | Chao Phraya | Chi |
|-----------------------|--------------------------|--------------------|--------------------|
| Yield | ton/rai | 0.82 (0.81 - 0.83) | 0.77 (0.73 - 0.81) |
| Total Water used | m ³ /kg maize | 1.48 (1.42 - 1.54) | 1.15 (1.08 - 1.22) |
| Rain water used | m ³ /kg maize | 1.35 (1.33 - 1.37) | 1.14 (1.05 - 1.23) |
| Irrigation water used | m ³ /kg maize | 0.13 (0.08 - 0.18) | 0.01 (0 - 0.06) |

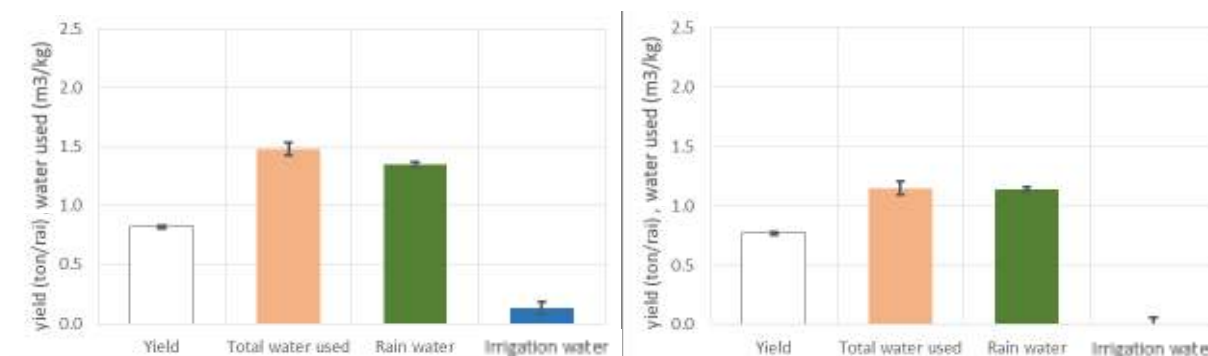


Figure 4.12 Production yield and water used for maize in Chao Phraya and Chi watersheds

Maize is nowadays become one of the dry-season crops that farmers select for cultivating in highland and non-irrigated area. This is because it consumes less supplement water comparing with the paddy rice or other cash crops. The result obviously shows that growing maize in those two regions are normally under water deficit condition i.e. the use of freshwater lower than the theoretical water requirement. Rain water is only the major source for maize cultivation in both Chao Phraya and Chi watersheds.

4.6 Agriculture and freshwater requirements in Chao Phraya watershed

Chao Phraya watershed have the major area covering in central and some parts in northern Thailand. The total area of Chao Phraya watershed is 20,266 km² (or 12.7 million rai). Its major area is located in 11 provinces including Nakhon Sawan, Chai Nat, Sing Buri, Lop Buri, Ang Thong, Ayutthaya, Saraburi, Pathum Thani, Nonthaburi, Samut Prakan and Bangkok. The upper part consists of steep mountains with plains along the banks. A large low flat alluvial plain called the Delta Plain. It consists of 2 sub-watersheds: Buengboraphet and Chao Phraya River plain. The average annual rainfall of this watershed is approximately 1,140 mm in which, around 3,786 million m³ is accounted for the average annual runoff. In case of the total capacity of runoff of catchment, there is around 253 million m³ (accounting for 7% of the annual natural runoff in Chao Phraya watershed). The cultivated area in irrigating project is 5,461,945 rai from the total cultivated areas around 9,103,544 rai (accounting for the 60% of the total cultivated areas). The agricultural water use is 8,342 million m³ per year (RID, 2010; OAE, 2011). Table 4.10 shows the water demands by sectors. The main water demand is agricultural sector that was about 8,342 million m³/year. The second water demand is ecosystem sector for protecting inland seawater that was about 1,261 million m³/year. The industrial water demand is 897 million m³/year. The domestic water demand is 652 million m³/year. The livestock water demand is 18 million m³/year (RID, 2010).

Table 4.10 Cropping calendar for the Central Region (RID, 2010)

| Watershed | Water demand by sectors (million m ³ /year) | | | | | Total |
|-------------|--|----------|-----------|-------------|-----------|--------|
| | Domestic | Industry | Livestock | Agriculture | Ecosystem | |
| Chao Phraya | 652 | 897 | 18 | 8,342 | 1,261 | 11,171 |

Source: RID (2010)

Figure 4.13 shows the cropping calendar for the central region of Thailand which can be referred as the baseline for estimating crop water requirements for agriculture in Chao Phraya and Tha Chin watersheds.

The study selected four provinces in Chao Phraya watershed i.e. Chai Nat, Nakhon Sawan, Lop Buri and Ayutthaya for comprehensive assessment of freshwater used for field crops and trees. To estimate freshwater requirement per ton product of staple crops (i.e. Table 4.30 for Chai Nat) is also quantified based on the calculation showed in Figure 4.14.

| Major crops | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Major rice (UW) | | █ | | | | | | | | | | |
| Major rice (LW) | █ | | | | | | | | | | | |
| Second rice (UW) | | | | | | █ | | | | | | |
| Second rice (LW) | | | | | | █ | | | | | | |
| Sugarcane | █ | | | | | | | | | | | █ |
| Cassava | █ | | | | | | | | | | | |
| Maize | | | | | █ | | | | | | | |
| Soybean | | | | | █ | | | | | | | |
| Oil palm | █ | | | | | | | | | | | |
| Fruits/Standing timber | █ | | | | | | | | | | | |

LW: Lower-watershed provinces, UW: Upper-watershed provinces

Figure 4.13 Cropping calendar for the Central Region based on the survey of farmers

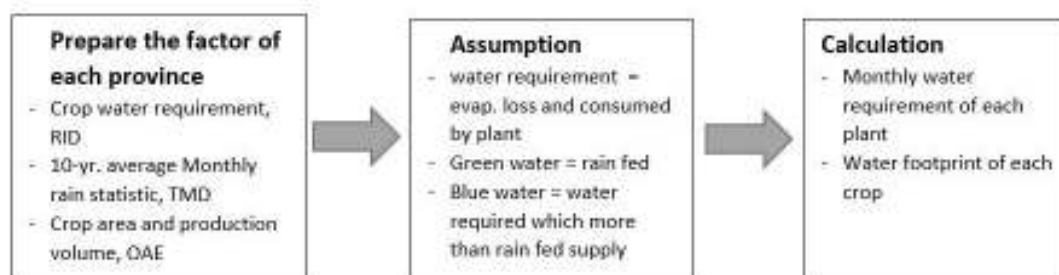


Figure 4.14 Calculation steps of freshwater used per ton production

4.6.1 Chai Nat

Chai Nat province occupies 1,543,591 rai in Chao Phraya watershed, and has a cultivated area of 1,617,308 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.11. The freshwater used for staple crops is shown in Figure 4.15. In wet season, rainwater is mainly used for major rice, cassava and sugarcane. In dry season, irrigation water is mainly required for second rice. Table 4.12 shows freshwater requirement per ton crop product.

Table 4.11 Irrigated and non-irrigated agricultural area crop in Chai Nat

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 794,856 | 659,184 | 135,672 |
| Second rice | 676,402 | 560,949 | 115,453 |
| Maize | 2,704 | - | - |
| Cassava | 65,424 | - | - |
| Sugarcane | 76,587 | 122 | 76,465 |
| Peanut | 530 | - | - |
| Coconut | 805 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, (RID)

2. Agricultural information of Chai Nat 2014, Agricultural Office of Chai Nat province

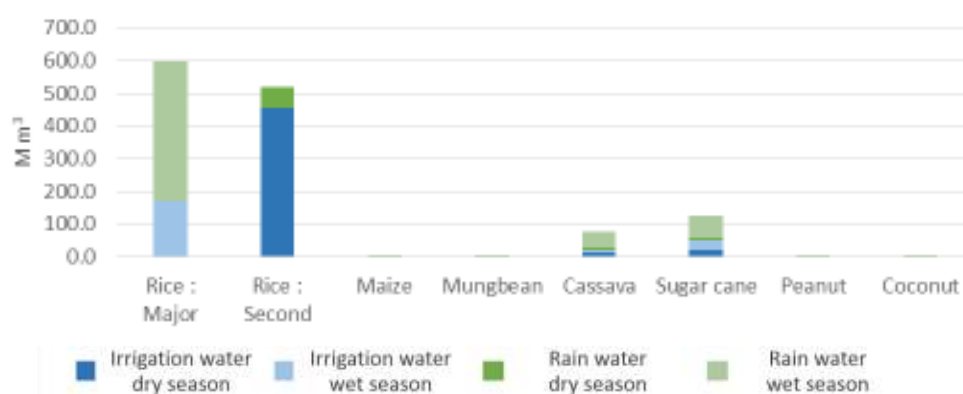


Figure 4.15 Freshwater requirement for stable crops in Chai Nat (Yr 2010/2011)

Table 4.12 Freshwater requirement per ton product in Chai Nat

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rainwater (m ³ /ton) |
|-------------|-------------------------------------|-------|-------|------------------------------|-------|-------|----------------|--------------------|--|---------------------------------|
| | dry | wet | Total | dry | wet | total | | | | |
| Major rice | - | 169.8 | 169.8 | - | 428.8 | 428.8 | 653 | 0.48 | 1,005 | 141 |
| Second rice | 454.5 | - | 454.5 | 63.76 | - | 63.76 | 707 | 0.45 | 780 | 153 |
| Maize | 2.08 | - | 2.08 | 0.12 | 0.29 | 0.41 | 615 | 0.00 | 1,393 | 698 |
| Mungbean | 0.34 | - | 0.34 | 0.06 | 0.11 | 0.17 | 112 | 0.00 | 150 | 421 |
| Cassava | 13.13 | 6.86 | 20.00 | 7.46 | 48.63 | 56.09 | 2,237 | 0.13 | 55 | 82 |
| Sugarcane | 21.53 | 28.68 | 50.21 | 6.30 | 69.19 | 75.48 | 12,372 | 0.92 | 1,334 | 268 |
| Peanut | 0.21 | - | 0.21 | 0.01 | 0.03 | 0.04 | 298 | 0.00 | 1,145 | 967 |
| Coconut | 0.92 | 0.22 | 1.15 | 0.12 | 0.85 | 0.97 | 1,036 | 0.00 | 1,005 | 141 |

4.6.2 Nakhon Sawan

Nakhon Sawan province occupies 5,998,548 rai in Chao Phraya watershed, and has a cultivated area of 4,992,035 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.13. The assessment results of freshwater used for staple crops are shown in Figure 4.16. In wet season, rainwater is mainly used for major rice, cassava and sugarcane. In dry season, the irrigation water is mainly required for second rice, maize and mungbean. Table 4.14 shows freshwater requirement per ton crop product.

Table 4.13 Irrigated and non-irrigated agricultural area in Nakhon Sawan

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 2,440,206 | 75,387 | 2,364,819 |
| Second rice | 1,268,874 | 39,200 | 1,229,674 |

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Maize | 247,788 | - | - |
| Cassava | 414,009 | - | - |
| Sugarcane | 605,602 | 22,896 | 582,706 |
| Oil palm | 1,068 | - | - |
| Peanut | 6,080 | - | - |
| Coconut | 2,010 | - | - |
| Para rubber | 6,398 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, (RID)

2. The "Agricultural Statistics of Thailand 2013", Office of Agricultural Economics (OAE)

Table 4.14 Freshwater requirement per ton product in Nakorn Sawan

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rainwater (m ³ /ton) |
|-------------|-------------------------------------|-------|-------|------------------------------|-------|-------|----------------|--------------------|--|---------------------------------|
| | dry | wet | Total | dry | wet | total | | | | |
| Major rice | - | 182.8 | 182.8 | - | 1,270 | 1,270 | 476 | 1.19 | 154 | 1,071 |
| Second rice | 993.9 | - | 993.9 | 84.57 | - | 84.57 | 610 | 0.66 | 1,501 | 128 |
| Maize | 148.9 | - | 148.9 | 11.38 | 20.21 | 31.59 | 693 | 0.20 | 762 | 162 |
| Mungbean | 36.99 | - | 36.99 | 4.02 | - | 4.02 | 97 | 0.01 | 3,173 | 345 |
| Cassava | 65.55 | 5.99 | 71.54 | 60.53 | 286.6 | 347.1 | 3,172 | 0.98 | 73 | 356 |
| Sugar cane | 183.9 | 174.2 | 358.0 | 71.09 | 642.3 | 713.4 | 13,586 | 8.06 | 44 | 89 |
| Oil palm | 0.48 | 0.05 | 0.53 | 0.09 | 0.45 | 0.53 | - | - | - | - |
| Peanut | 2.66 | - | 2.66 | 0.25 | 0.34 | 0.59 | 220 | 0.00 | 1,986 | 439 |
| Coconut | 3.77 | 0.40 | 4.17 | 0.68 | 3.52 | 4.21 | 917 | 0.00 | 1,312 | 1,325 |
| Para rubber | 13.48 | 1.42 | 14.90 | 2.45 | 12.60 | 15.05 | - | - | - | - |

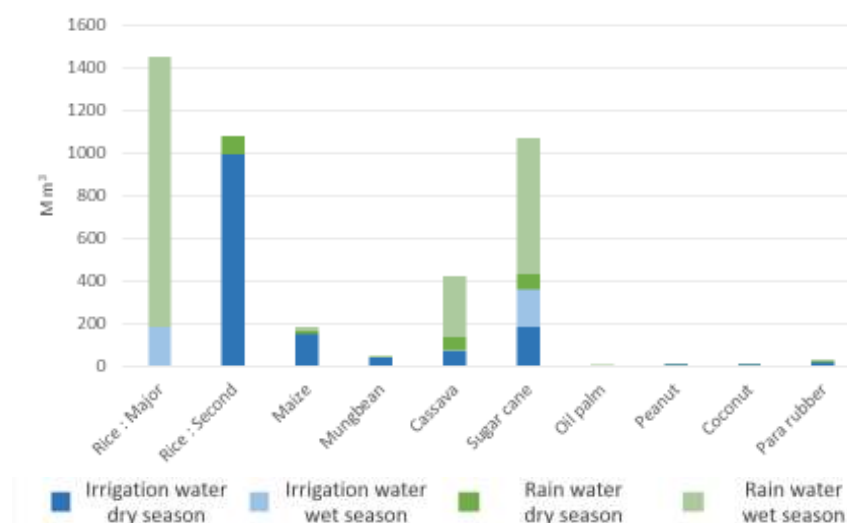


Figure 4.16 Freshwater used for stable crops in Nakhon Sawan (Yr 2010/2011)

4.6.3 Lop Buri

Lop Buri province occupies 3,874,846 rai in Chao Phraya watershed, and has a cultivated area of 1,960,157 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.15. The assessment results of freshwater used for staple crops are shown in Figure 4.17.

Table 4.15 Irrigated and non-irrigated agricultural area in Lop Buri

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 745,476 | 30,211 | 715,265 |
| Second rice | 413,414 | 16,754 | 396,660 |

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Maize | 234,535 | - | - |
| Cassava | 206,972 | - | - |
| Sugarcane | 353,569 | 23,430 | 330,139 |
| Oil palm | 2,010 | - | - |
| Peanut | 3,710 | - | - |
| Para rubber | 471 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, (RID)

2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

In wet season, rainwater is mainly used for major rice, sugarcane and cassava. In dry season, the irrigation water is required for second rice and maize. Table 4.16 shows the freshwater requirement per ton crop product.

Table 4.16 Water footprint per ton product in Lopburi

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rain water (m ³ /ton) |
|-------------|-------------------------------------|-------|-------|------------------------------|-------|-------|----------------|--------------------|--|----------------------------------|
| | dry | wet | total | dry | wet | total | | | | |
| Major rice | - | 128 | 128 | - | 421.4 | 421.4 | 495 | 0.35 | 369 | 1,216 |
| Second rice | 356.1 | - | 356.1 | 69.72 | - | 69.72 | 692 | 0.31 | 1,144 | 224 |
| Maize | 165.3 | - | 165.3 | 11.67 | 21.66 | 33.33 | 625 | 0.18 | 899 | 181 |
| Mungbean | 1.59 | - | 1.59 | 0.29 | 0.52 | 0.81 | 107 | 0.00 | 1,687 | 856 |
| Cassava | 36.72 | 10.93 | 47.65 | 30.71 | 138.6 | 169.3 | 3,111 | 0.52 | 92 | 327 |
| Sugar cane | 101.2 | 111.9 | 213.1 | 49.63 | 330.4 | 380.0 | 11,652 | 4.05 | 53 | 94 |
| Peanut | 1.73 | - | 1.73 | 0.15 | 0.21 | 0.36 | 234 | 0.00 | 1,989 | 417 |
| Para rubber | 0.93 | 0.14 | 1.07 | 0.18 | 0.79 | 0.97 | - | - | - | - |

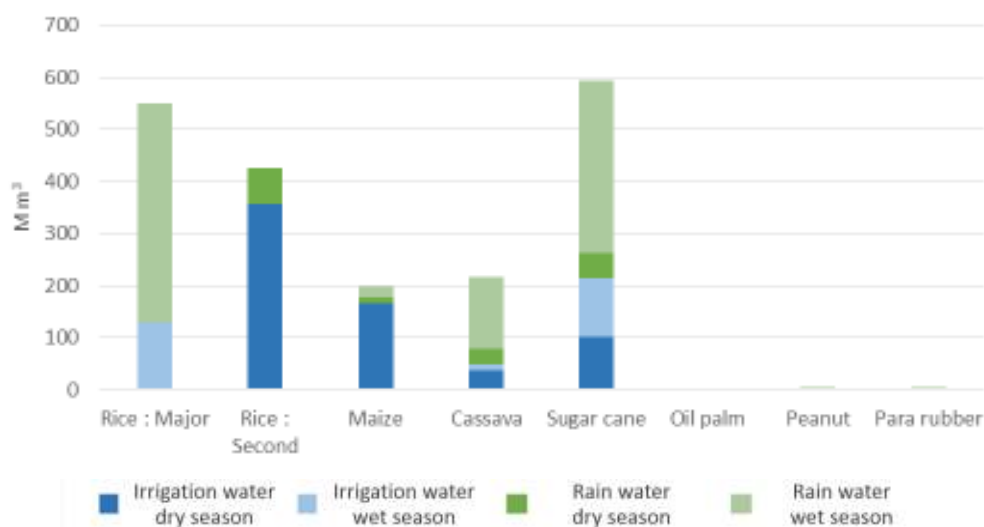


Figure 4.17 Freshwater used for stable crops in Lop Buri (Yr 2010/2011)

4.6.4 Ayutthaya

Ayutthaya province occupies 1,579,900 rai in Chao Phraya watershed, and has a cultivated area of 1,777,236 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.17. The assessment results of freshwater used for staple crops are in

Figure 4.18. In wet season, the rainwater is mainly used for major rice. In dry season, the irrigation water is mainly required for second rice. Table 4.18 shows freshwater requirement per ton crop product.

Table 4.17 Irrigated and non-irrigated agricultural area in Ayutthaya

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 922,179 | 196,123 | 726,056 |
| Second rice | 854,362 | 181,700 | 672,662 |
| Coconut | 695 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, RID
2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

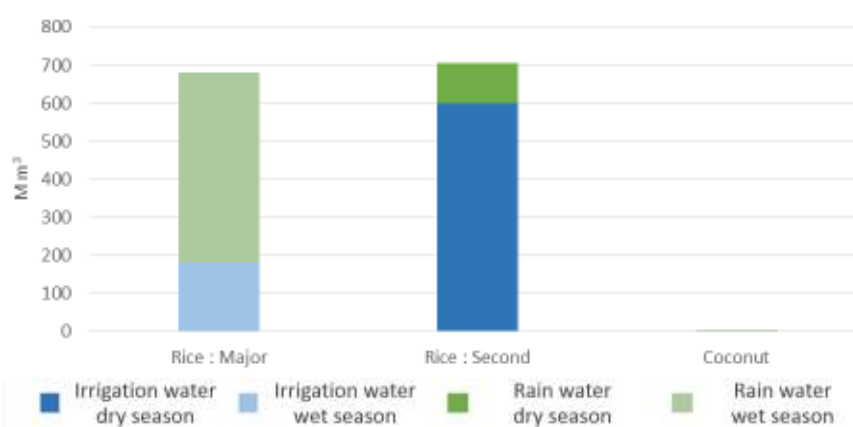


Figure 4.18 Freshwater used for stable crops in Ayutthaya (Yr 2010/2011)

Table 4.18 Freshwater requirement per ton product in Ayuthaya

| Crops | Irrigation water (Mm³) | | | Rainwater (Mm³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m³/ton) | Rainwater (m³/ton) |
|-------------|------------------------|------|-------|-----------------|------|-------|----------------|--------------------|---------------------------|--------------------|
| | dry | wet | total | dry | wet | total | | | | |
| Major rice | - | 181 | 181 | - | 498 | 498 | 602 | 0.50 | 364 | 999 |
| Second rice | 599.7 | - | 599.7 | 106.2 | - | 106.2 | 705 | 0.57 | 1,060 | 188 |
| Coconut | 0.88 | 0.20 | 1.08 | 0.17 | 0.75 | 0.92 | 1,507 | 0.00 | 828 | 706 |

4.6.5 Pathum Thani

Pathum Thani province occupies 953,660 rai in Chao Phraya watershed, and has a cultivated area of 726,928 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.19. The cultivation areas for second rice are higher than major rice followed the data of Agricultural Statistics of Thailand 2013 collected by Office of Agricultural Economics (OAE). The assessment results of freshwater used for staple crops are shown in Figure 4.19. In wet season, rainwater is mainly used for major rice. In dry season, irrigation water is mainly required for second rice. Table 4.20 shows freshwater requirement per ton crop product.

Table 4.19 Irrigated and non-irrigated agricultural area in Pathum Thani

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|------------|------------------------|----------------------|--------------------------|
| Major rice | 328,031 | 252,340 | 75,691 |

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Second rice | 387,326 | 297,953 | 89,373 |
| Oil palm | 10,919 | - | - |
| Coconut | 652 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, RID

2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

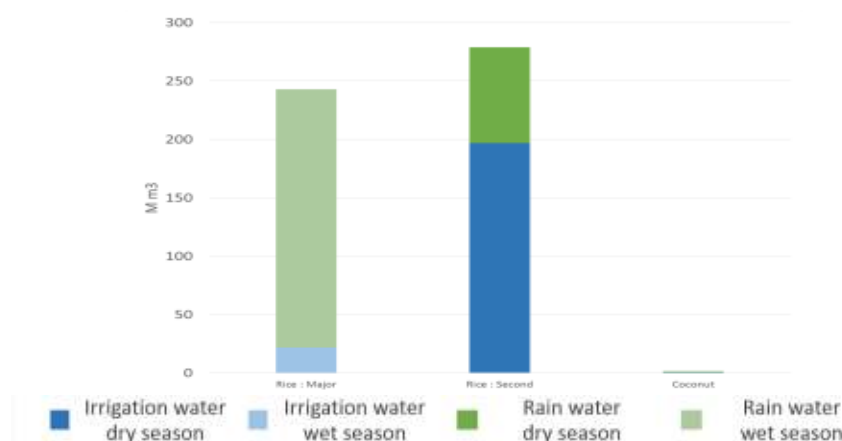


Figure 4.19 Freshwater used for stable crops in Pathum Thani (Yr 2010/2011)

Table 4.20 Freshwater requirement per ton product in Pathumthani

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rain water (m ³ /ton) |
|---------------|-------------------------------------|-------|--------|------------------------------|--------|--------|----------------|--------------------|--|----------------------------------|
| | dry | wet | Total | dry | wet | Total | | | | |
| Rice : Major | - | 21.64 | 21.64 | - | 221.45 | 221.45 | 713 | 0.22 | 99 | 1,016 |
| Rice : Second | 196.95 | - | 196.95 | 81.94 | - | 81.94 | 672 | 0.22 | 879 | 366 |
| Oil palm | 2.77 | - | 2.77 | 1.23 | 3.68 | 4.91 | 2,923 | 0.01 | 272 | 483 |

4.7 Agriculture and freshwater requirements in Tha Chin watershed

Tha Chin watershed is located in central of Thailand, place on the right side of Chao Phraya River. The total area of Tha Chin watershed is 13,492 km² (or 8.43 million rai). Its major area is covered in 8 provinces including Uthai Thani, Chai Nat, Suphan Buri, Nakhon Pathom, Samut Sakhon, Ang Thong, Ayutthaya and Nonthaburi. The geographical area is similar to Chao Phraya watershed as a large low flat alluvial plain. It consists of two sub-watersheds: Kraseaw and Tha Chin River plain. The average annual rainfall of this watershed is approximately 1,046 mm in which, around 3,890 million m³ is accounted for the average annual runoff. In case of the total capacity of runoff of catchment, there is around 330 million m³ (or account for 8% of the annual natural runoff in Tha Chin watershed). The cultivated area in irrigating project is 2,789,400 rai from the total cultivated areas around 6.4 million rai (or account for the 43% of the total cultivated areas). The agricultural water use is 3,177 million m³ per year (RID, 2010; OAE, 2011).

Table 4.21 shows the water demands by sectors. The main water demand is agricultural sector that was about 3,177 million m³/year. The second water demand is ecosystem sector for protecting inland seawater that was about 228 million m³/year. The industrial water demand is 211 million m³/year. The domestic water demand is 173 million m³/year. The livestock water demand is 30 million m³/year (RID, 2010).

Table 4.21 Water demand according to activities in Tha Chin watershed

| Watershed | Water demand by sectors (million m ³ /year) | | | | | Total |
|-----------|--|----------|-----------|-------------|-----------|-------|
| | Domestic | Industry | Livestock | Agriculture | Ecosystem | |
| Tha Chin | 173 | 211 | 30 | 3,177 | 228 | 3,818 |

Source: RID (2010)

The provinces that located in Tha Chin watershed were selected including Suphan Buri, Kanchanaburi and Nakhon Pathom for assessment of freshwater requirement for crops and tress.

4.7.1 Suphan Buri

Suphan Buri occupies around 3,348,755 rai in Tha Chin watershed, and has a cultivated area of 2,901,240 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.22. The assessment results of freshwater used for staple crops are shown in Figure 4.20. In wet season, rainwater is mainly used for major rice, sugarcane and cassava. In dry season, irrigation water is required mainly for second rice and maize. Table 4.23 shows freshwater requirement per ton crop product.

Table 4.22 Irrigated and non-irrigated agricultural area in Suphan Buri

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 1,218,261 | 145,737 | 1,072,524 |
| Second rice | 1,104,439 | 132,121 | 972,318 |
| Maize | 47,025 | - | - |
| Cassava | 36,478 | - | - |
| Sugarcane | 486,562 | - | - |
| Oil palm | 2,427 | - | - |
| Coconut | 608 | - | - |
| Para rubber | 1,132 | - | - |
| Pineapple | 4,308 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, RID
2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

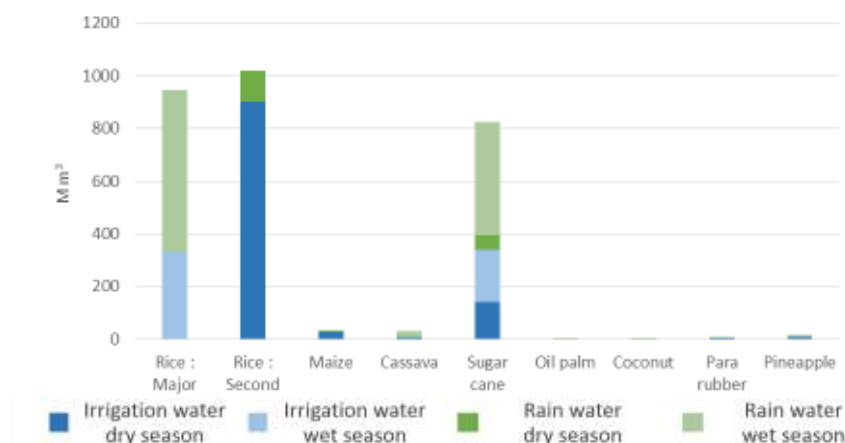


Figure 4.20 Freshwater used for stable crops in Suphan Buri (Yr 2010/2011)

Table 4.23 Freshwater requirement per ton product in Suparn Buri

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rainwater (m ³ /ton) |
|-------------|-------------------------------------|------|-------|------------------------------|------|-------|----------------|--------------------|--|---------------------------------|
| | dry | wet | total | dry | wet | total | | | | |
| Major rice | - | 333 | 333 | - | 612 | 612 | 678 | 0.80 | 414.88 | 763.24 |
| Second rice | 900 | - | 900 | 121 | - | 121 | 695 | 0.81 | 1,113.16 | 149.17 |
| Maize | 27.6 | - | 27.6 | 2.72 | 3.94 | 6.65 | 709 | 0.04 | 696.50 | 167.98 |
| Cassava | 5.48 | 3.58 | 9.06 | 3.70 | 18.8 | 22.5 | 2,811 | 0.07 | 131.29 | 326.00 |
| Sugar cane | 142 | 196 | 338 | 54 | 434 | 488 | 14,196 | 6.94 | 48.75 | 70.33 |
| Oil palm | 0.12 | 0.03 | 0.15 | 0.02 | 0.10 | 0.11 | - | - | - | - |
| Coconut | 0.89 | 0.21 | 1.10 | 0.13 | 0.73 | 0.87 | 1,021 | 0.00 | 1,234.97 | 970.72 |
| Para rubber | 2.51 | 0.59 | 3.10 | 0.37 | 2.07 | 2.44 | - | - | - | - |
| Pineapple | 6.19 | 1.46 | 7.65 | 0.92 | 5.10 | 6.02 | 3,374 | 0.02 | 373.71 | 293.75 |

4.7.2 Kanchanaburi

Kanchanaburi province occupies 12,176,968 rai in Tha Chin watershed, and has a cultivated area of 2,029,106 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.24. The assessment results of freshwater used for staple crops can be shown in Figure 4.21. In wet season, the rainwater is mainly used for major rice, sugarcane, cassava, oil palm, pineapple and para rubber. In dry season, the irrigation water is required for second rice and maize. Table 4.25 shows freshwater requirement per ton crop product.

Table 4.24 Irrigated and non-irrigated agricultural area in Kanchanaburi

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 421,162 | 341,521 | 79,641 |
| Second rice | 238,225 | 193,177 | 45,048 |
| Maize | 92,601 | - | - |
| Cassava | 452,758 | - | - |
| Sugarcane | 692,733 | 9,188 | 683,545 |
| Oil palm | 14,009 | - | - |
| Coconut | 899 | - | - |
| Para rubber | 88,757 | - | - |
| Pineapple | 27,962 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, RID

2. The "Agricultural Statistics of Thailand 2013", Office of Agricultural Economics (OAE)

Table 4.25 Freshwater requirement per ton product in Kanchanaburi

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rainwater (m ³ /ton) |
|---------------|-------------------------------------|-------|-------|------------------------------|-------|-------|----------------|--------------------|--|---------------------------------|
| | dry | wet | total | dry | wet | total | | | | |
| Rice : Major | - | 44.88 | 44.88 | - | 225 | 225 | 574 | 0.21 | 214.89 | 1,077.64 |
| Rice : Second | 164.7 | - | 164.7 | 46.79 | - | 46.79 | 734 | 0.17 | 942.94 | 267.83 |
| Maize | 47.78 | - | 47.78 | 3.79 | 6.34 | 10.13 | 689 | 0.07 | 715.43 | 151.71 |
| Cassava | 42.74 | - | 42.74 | 65.16 | 238.5 | 303.6 | 2,888 | 0.83 | 51.65 | 366.91 |
| Sugar cane | 173.9 | 24.42 | 198.4 | 105.7 | 793.1 | 898.9 | - | - | - | - |
| Oil palm | 12.69 | - | 12.69 | 3.56 | 13.62 | 17.18 | 1,712 | 0.02 | 539.63 | 730.86 |
| Coconut | 0.87 | - | 0.87 | 0.24 | 0.93 | 1.18 | 1,019 | 0.00 | 906.62 | 1,227.90 |
| Para rubber | 122.3 | - | 122.3 | 34.33 | 131.3 | 165.7 | - | - | - | - |
| Pineapple | 30.65 | - | 30.65 | 8.60 | 32.91 | 41.51 | 3,395 | 0.11 | 272.12 | 368.55 |

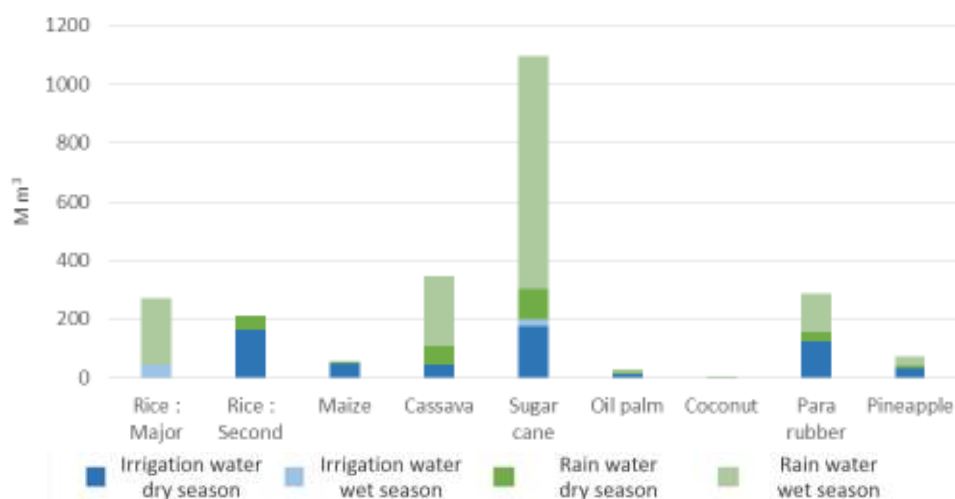


Figure 4.21 Freshwater used for stable crops in Kanchanaburi (Yr 2010/2011)

4.7.3 Nakhon Pathom

Nakhon Pathom province occupies 1,355,204 rai in Tha Chin watershed, and has a cultivated area of 907,447 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.26. The cultivation areas for second rice are higher than major rice followed the data of Agricultural Statistics of Thailand 2013 collected by Office of Agricultural Economics (OAE). The assessment results of freshwater used for staple crops can be shown in Figure 4.22. In wet season, the rainwater is the major freshwater resource used for major rice, sugarcane and coconut. In dry season, the irrigation water is required mainly for second rice. Table 4.27 shows freshwater requirement per ton crop product.

Table 4.26 Irrigated and non-irrigated agricultural area in Nakhon Pathom

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 398,750 | 185,791 | 212,958 |
| Second rice | 409,495 | 190,798 | 218,697 |
| Sugarcane | 95,901 | - | - |
| Coconut | 3,301 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, RID
 2. Agricultural areas in Mae Klong-irrigation project in the year 2013/2014, RID
 3. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

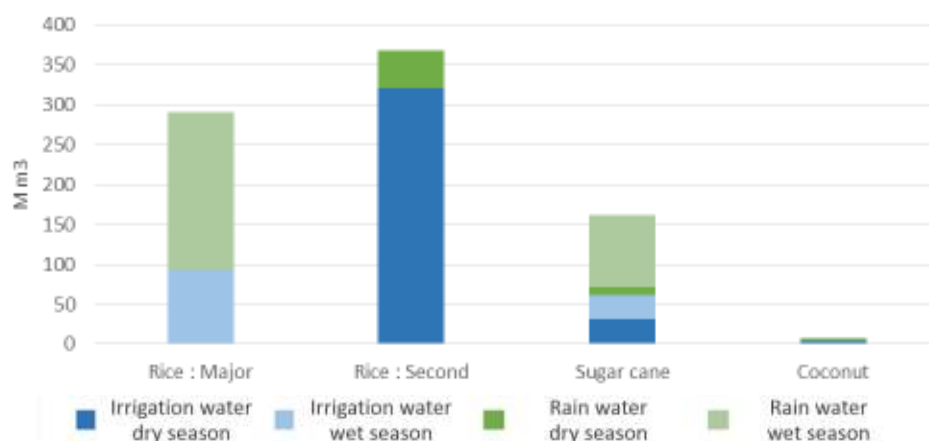


Figure 4.22 Freshwater used for stable crops in Nakhon Pathom (Yr 2010/2011)

Table 4.27 Freshwater requirement per ton product in Nakhon Pathom

| Crops | Irrigation water (Mm ³) | | | Rainwater (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Irrigation water (m ³ /ton) | Rainwater (m ³ /ton) |
|-------------|-------------------------------------|-------|-------|------------------------------|------|-------|----------------|--------------------|--|---------------------------------|
| | dry | wet | total | dry | wet | total | | | | |
| Major rice | - | 92.90 | 92.9 | - | 198 | 198 | 682 | 0.25 | 368 | 784 |
| Second rice | 321 | - | 321 | 47.1 | - | 47.1 | 729 | 0.29 | 1,106 | 163 |
| Sugar cane | 31.2 | 30.3 | 61.5 | 9.5 | 90.6 | 100 | - | - | - | - |
| Coconut | 3.80 | 0.59 | 4.39 | 0.57 | 3.17 | 3.73 | 759 | 0.00 | 1,656 | 1,408 |

4.8 Agriculture and freshwater requirements in Mun watershed

Mun watershed is located in north eastern of Thailand, and to be the part of Mekong River. The total area of Mun watershed is 71,072 km² (or 44.4 million rai). Its major area is covered in 11 provinces including Buri Ram, Surin, Khon Kaen, Maha Sarakham, Roi Et, Yasothon, Ubon Rachathani, Amnat Charoen, Mukdahan, Nakhon Ratchasima and Si Sa Ket. It consists of 31 sub-watersheds that can be categorized into three major part including upper part, middle part and lower part of Mun watershed. The average annual rainfall of this watershed is approximately 1,268 mm in which, around 17,118 million m³ is accounted for the average annual runoff. In case of the average runoff in wet season, there is around 13,597 million m³ (accounting for 79% of the annual runoff in Mun watershed) while the average runoff in dry season is around 3,520 million m³ (or account for 21% of the annual runoff in Mun watershed). The cultivated area in irrigating project is 2.3 million rai from the total cultivated areas around 21.8 million rai (or account for the 10% of the total cultivated areas).

Table 4.28 shows the water demands by sectors. The main water demand is agricultural sector that was about 38,153 million m³/year. The second water demand is ecosystem sector for protecting inland seawater that was about 1,383 million m³/year. The livestock water demand is 136 million m³/year. The industrial water demand is 45 million m³/year. The domestic water demand is 6 million m³/year (RID, 2010). Figure 4.23 shows the cropping calendar for the Northeastern region of Thailand which can be referred as the baseline for estimating crop water requirements for agriculture in Mun and Chi watersheds. The dry season runs from November through April (shaded in the figure).

Table 4.28 Water demand according to activities in Mun watershed

| Watershed | Water demand by sectors (million m ³ /year) | | | | | Total |
|-----------|--|----------|-----------|-------------|-----------|--------|
| | Domestic | Industry | Livestock | Agriculture | Ecosystem | |
| Mun | 6 | 45 | 136 | 38,153 | 1,383 | 39,723 |

Source: RID (2010)

| Major crops | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|
| Major rice | ■ | | | | | ■ | | | | | | | |
| Second rice | | | | | | | | ■ | | | | | |
| Sugarcane | ■ | | | | | | | | | ■ | | | |
| Cassava | ■ | | | | | | | | | | | | |
| Maize | | | | | ■ | | | | ■ | | | | |
| Soybean | | | | | ■ | | | | ■ | | | | |
| Oil palm | ■ | | | | | | | | | | | | |
| Fruits/Standing timber | ■ | | | | | | | | | | | | |

Figure 4.23 Cropping calendar for the North-Eastern Region (RID, 2010)

The selected provinces in Mun watershed including Nakhon Ratchasima, Ubon Ratchathani and Buri Ram for comprehensive assessment of freshwater used for field crops (rice, cassava, sugarcane and maize), and trees (oil palm, rubber and fruit).

4.8.1 Nakhon Ratchasima

Nakhon Ratchasima province occupies 12,808,728 rai in Mun watershed, and has a cultivated area of 6,790,869 rai.

Table 4.29 shows the irrigated and non-irrigated agricultural areas. Figure 4.24 shows the assessment results of freshwater used for major rice, second rice, maize, cassava and sugarcane. In wet season, rainwater is the main freshwater resource used for major rice, cassava and sugarcane. In dry season, the irrigation water is mainly required for second rice and maize. Table 4.30 shows freshwater requirement per ton crop product.

Table 4.29 Irrigated and non-irrigated agricultural area in Nakhon Ratchasima

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 3,564,491 | 3,408,852 | 155,638.68 |
| Second rice | 280,027 | 267,800 | 12,227 |
| Maize | 689,313 | - | - |
| Cassava | 1,598,405 | - | - |
| Sugarcane | 658,633 | 8,250 | 650,383 |

Source: 1. Water management plan for agriculture in dry season 2013/2014 (RID)

2. The "Agricultural Statistics of Thailand 2013", Office of Agricultural Economics (OAE)

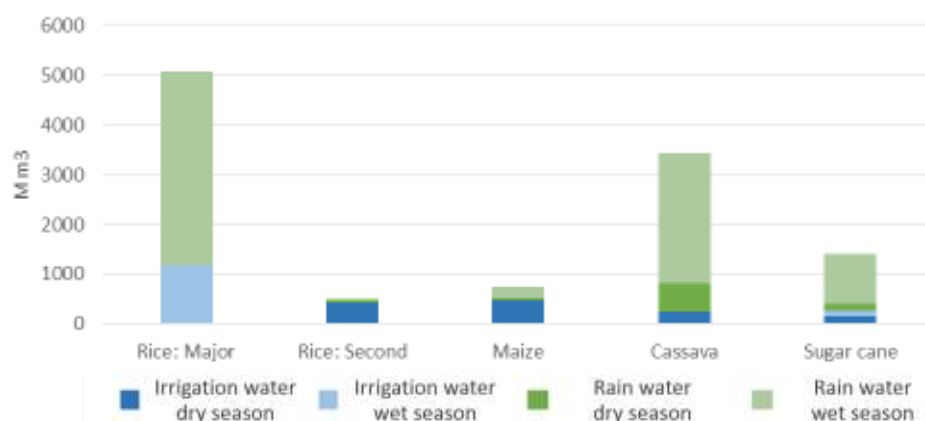


Figure 4.24 Freshwater used for stable crops in Nakhon Ratchasima (Yr 2010/2011)

Table 4.30 Freshwater requirement per ton product in Nakhon Ratchasima

| Crops | Rainwater (Mm ³) | | | Irrigation water (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Rain water (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|------------------------------|----------|----------|-------------------------------------|----------|----------|----------------|--------------------|----------------------------------|--|
| | dry | wet | Total | dry | wet | Total | | | | |
| Major rice | - | 2,743.41 | 2,743.41 | - | 1,315.61 | 1,315.61 | 285 | 1.09 | 2,524.47 | 1,210.62 |
| Second rice | 264.34 | - | 264.34 | 219.07 | - | 219.07 | 582 | 0.30 | 878.58 | 728.12 |
| Maize | 447.26 | - | 447.26 | 67.65 | 61.35 | 129.00 | 618 | 0.54 | 834.02 | 240.55 |
| Mungbean | 3.76 | - | 3.76 | 0.39 | - | 0.39 | 93 | 0.00 | 3,482.53 | 360.09 |
| Cassava | 185.35 | 643.86 | 829.21 | 472.32 | 987.75 | 1,460.07 | 3,054 | 5.19 | 159.87 | 281.51 |
| Sugarcane | 159.17 | 409.56 | 568.73 | 112.80 | 493.17 | 605.97 | 11,978 | 7.79 | 73.00 | 77.78 |
| Oil palm | 0.46 | 0.30 | 0.76 | 0.44 | 0.54 | 0.99 | 469 | 0.00 | 2,172.09 | 2,833.82 |
| Peanut | 1.15 | - | 1.15 | 0.41 | 0.16 | 0.56 | 241 | 0.00 | 1,697.02 | 830.90 |
| Coconut | 0.59 | 0.38 | 0.97 | 0.57 | 0.70 | 1.26 | - | - | - | - |
| Para rubber | 25.43 | 16.50 | 41.93 | 24.58 | 30.12 | 54.70 | - | - | - | - |

4.8.2 Ubon Ratchathani

Ubon Ratchathani province occupies 10,299,063 rai in Mun watershed, and has a cultivated area of 4,699,860 rai. Table 4.31 shows the irrigated and non-irrigated agricultural areas. The freshwater requirements for major rice, second rice, cassava, oil palm and para rubber are assessed and shown in Figure 4.25. In wet season, rainwater is the major freshwater resource for major rice, cassava. In dry season, the irrigation water is required for second rice and para rubber. For cassava and oil palm, the freshwater used relies on seasoning rainwater. Table 4.32 shows freshwater requirement per ton crop product.

Table 4.31 Irrigated and non-irrigated agricultural area in Ubon Ratchathani

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 3,891,535 | 3,229,610.85 | 661,924.15 |
| Second rice | 163,181 | 135,425 | 27,756 |
| Maize | 6,602 | - | - |
| Sugarcane | 12,187 | - | - |
| Cassava | 424,132 | - | - |
| Para rubber | 202,223 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014 (RID)
2. The "Agricultural Statistics of Thailand 2013", Office of Agricultural Economics (OAE)

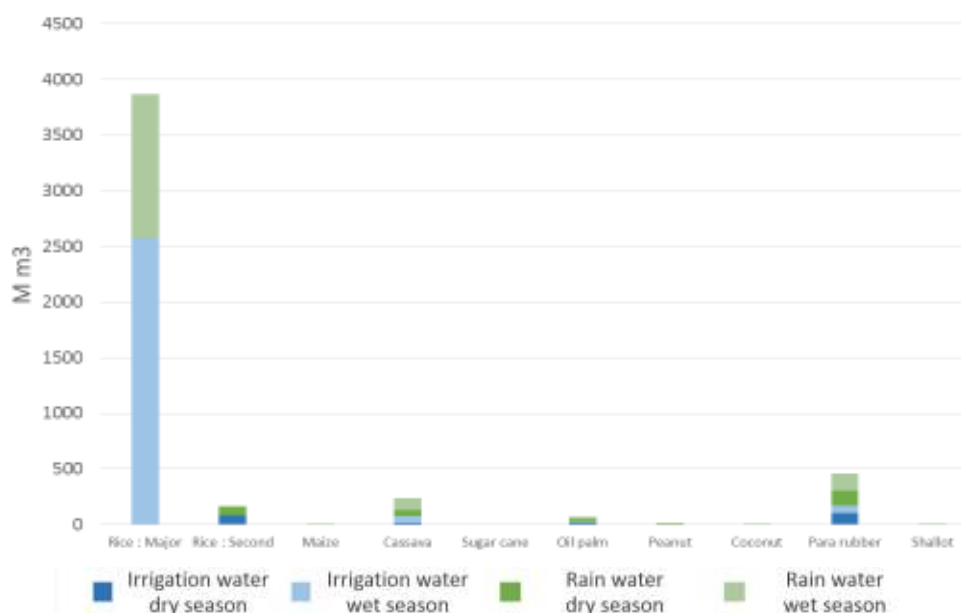


Figure 4.25 Freshwater requirement for stable crops in Ubun Ratchathani (Yr 2010/2011)

Table 4.32 Freshwater requirement per ton product in Ubun Ratchathani

| Crops | Rainwater (Mm ³) | | | Irrigation water (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Rain water (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|------------------------------|----------|----------|-------------------------------------|----------|----------|----------------|--------------------|----------------------------------|--|
| | dry | wet | Total | dry | wet | Total | | | | |
| Major rice | - | 2,577.55 | 2,577.55 | - | 1,291.25 | 1,291.25 | 301 | 1.18 | 2,187.35 | 1,095.78 |
| Second rice | 81.16 | - | 81.16 | 79.35 | - | 79.35 | 463 | 0.08 | 999.75 | 977.47 |
| Maize | 0.79 | - | 0.79 | 0.17 | 0.11 | 0.28 | 694 | 0.00 | 714.56 | 255.95 |
| Mungbean | - | - | - | - | - | - | - | - | - | - |
| Cassava | 15.28 | 61.92 | 77.20 | 55.18 | 103.16 | 158.35 | 3,048 | 0.56 | 137.76 | 282.56 |
| Sugar cane | - | - | - | - | - | - | - | - | - | - |
| Oil palm | 15.78 | 9.70 | 25.48 | 20.94 | 22.94 | 43.88 | 2,283 | 0.07 | 364.20 | 627.32 |
| Soybean | - | - | - | - | - | - | - | - | - | - |
| Peanut | 4.44 | - | 4.44 | 1.83 | 0.62 | 2.45 | 248 | 0.00 | 1,598.60 | 884.26 |
| Coconut | 0.39 | 0.24 | 0.63 | 0.51 | 0.56 | 1.08 | 741 | 0.00 | 1,122.10 | 1,932.76 |
| Para rubber | 104.13 | 64.01 | 168.14 | 138.23 | 151.39 | 289.62 | - | - | - | - |

4.8.3 Buri Ram

Buri Ram province occupies 6,451,178,125 rai in Mun watershed, and has a cultivated area of 3,352,160 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.33 and Figure 4.26 shows the freshwater requirement for staple crops. In wet season, rainwater is the major freshwater resource for major rice, cassava, sugarcane and para rubber. In dry season, irrigation water is required mainly for second rice. Table 4.34 shows freshwater requirement per ton crop product.

Table 4.33 Irrigated and non-irrigated agricultural area in Buri Ram

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 2,735,624 | 1,561,581 | 1,174,043 |
| Second rice | 49,314 | 28,150 | 21,164 |
| Cassava | 210,006 | - | - |
| Sugarcane | 206,388 | 7,080 | 199,308 |
| Para rubber | 150,828 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014 (RID)
2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

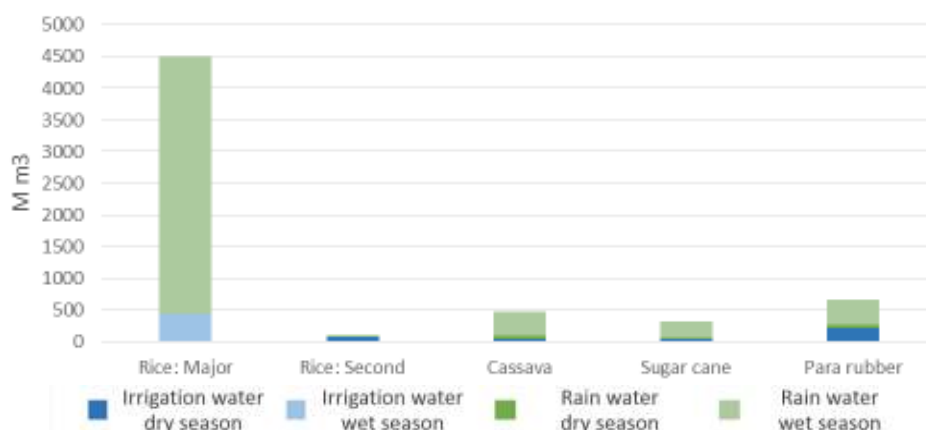


Figure 4.26 Freshwater used for stable crops in Buri Ram (Yr 2010/2011)

Table 4.34 Freshwater requirement per ton product in Buri Ram

| Crops | Rainwater (Mm ³) | | | Irrigation water (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Rainwater (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|------------------------------|-------|-------|-------------------------------------|-------|-------|----------------|--------------------|---------------------------------|--|
| | dry | wet | total | dry | wet | total | | | | |
| Major rice | - | 2,249 | 2,249 | - | 1,079 | 1,079 | 368 | 1.15 | 1,949.61 | 935.16 |
| Second rice | 47.13 | - | 47.13 | 41.4 | - | 41.41 | 474 | 0.04 | 1,086.67 | 954.79 |
| Maize | 0.33 | - | 0.33 | 0.07 | 0.05 | 0.12 | 612 | 0.00 | 815.39 | 301.12 |
| Cassava | 17.55 | 79.29 | 96.83 | 66.64 | 124.2 | 190.8 | 3,113 | 0.64 | 151.04 | 297.67 |
| Sugar cane | 29.59 | 78.37 | 108 | 29.73 | 113.9 | 143.6 | 12,493 | 1.68 | 64.26 | 85.50 |
| Oil palm | 0.66 | 0.44 | 1.10 | 0.77 | 0.89 | 1.66 | 488 | 0.00 | 1,998.66 | 3,023.00 |
| Peanut | 3.50 | - | 3.50 | 1.43 | 0.53 | 1.95 | 231 | 0.00 | 1,733.72 | 968.53 |
| Coconut | 0.06 | 0.04 | 0.11 | 0.08 | 0.09 | 0.16 | 1,282 | 0.00 | 760.80 | 1,150.72 |
| Para rubber | 123.5 | 81.56 | 205 | 144.5 | 165.6 | 310.1 | - | - | - | - |

4.9 Agriculture and freshwater requirements in Chi watershed

Chi watershed is located in north eastern of Thailand, and to be the part of Mekong River. The total area of Chi watershed is 49,130 km² (or 30.7 million rai). Its major area is covered in 12 provinces including Chaiyaphum, Khon Kaen, Kalasin, Maha Sarakham, Roi Et, Yasothon, Ubon Ratchathani, Nakhon Ratchasima, Loei, Nong Bua Lam Phu, Udon Thani and Si Sa Ket. The average annual rainfall of this watershed is approximately 1,208 mm in which, around 11,160 million m³ is accounted for the average annual runoff. The cultivated area in irrigating project is 2.5 million rai from the total cultivated areas around 20 million rai (accounting for 12% of the total cultivated areas). The total of agricultural water use is 19,647 million m³ per year accounted for irrigated area 4,600 million m³ and non-irrigated area 15,040 million m³. The water demands by sectors are shown in Table 4.35. The main water demand is agricultural sector that was about 19,335 million m³/year. The second water demand is ecosystem sector for protecting inland seawater that was about 1,885 million m³/year. The domestic water demand is 218 million m³/year. The livestock water demand is 62 million m³/year. The industrial water demand is 33 million m³/year (RID, 2010).

The provinces in Chi watershed selected in this assessment include Chaiyaphum, Khon Kaen and Kalasin for assessment of freshwater requirement for field crops and trees.

Table 4.35 Water demand according to activities in Chi watershed

| Watershed | Water demand by sectors (million m ³ /year) | | | | | Total |
|-----------|--|----------|-----------|-------------|-----------|--------|
| | Domestic | Industry | Livestock | Agriculture | Ecosystem | |
| Chi | 218 | 33 | 62 | 19,335 | 1,885 | 21,533 |

Source: RID (2010)

4.9.1 Chaiyaphum

Chaiyaphum province occupies 7,986,429 rai in Chi watershed, and has a cultivated area of 2,797,446 rai.

Table 4.36 shows the irrigated and non-irrigated agricultural areas. The freshwater requirements for major rice, second rice, maize, cassava, sugarcane, soybean and para rubber are shown in Figure 4.27. Rainwater is the major freshwater resource for major rice, cassava, sugarcane and para rubber in wet season. In dry season, irrigation water is required for second rice and maize. Table 4.37 shows freshwater requirement per ton crop product.

Table 4.36 Irrigated and non-irrigated agricultural area in Chaiyaphum

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 1,617,366 | 290,273 | 1,327,093 |
| Second rice | 165,485 | 29,700 | 135,785 |
| Maize | 123,896 | - | - |
| Cassava | 422,766 | - | - |
| Sugarcane | 429,194 | 5,170 | 424,024 |
| Soybean | 5,405 | - | - |
| Para rubber | 33,334 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014 (RID)

2. The "Agricultural Statistics of Thailand 2013", Office of Agricultural Economics (OAE)

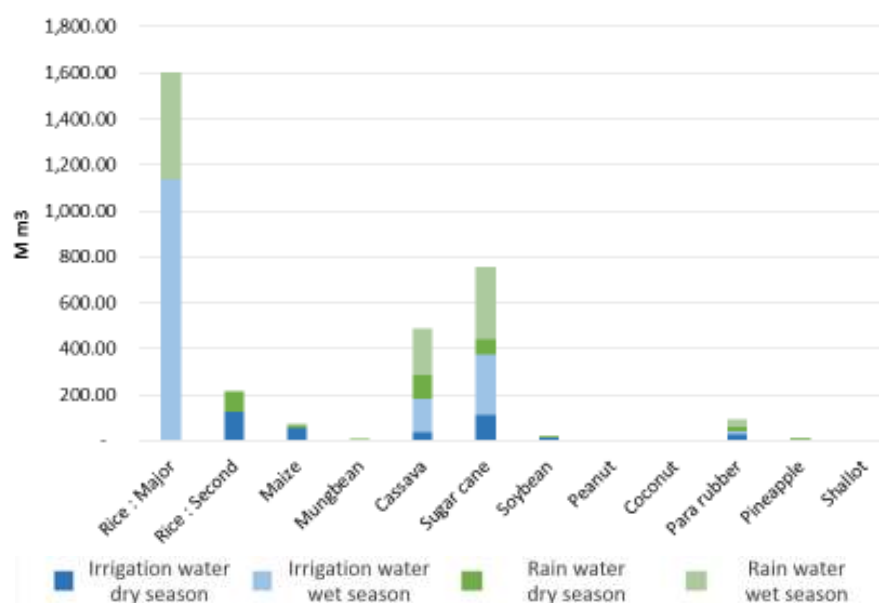


Figure 4.27 Freshwater requirement for stable crops in Chaiyaphum (Yr 2010/2011)

Table 4.37 Freshwater requirement per ton product in Chaiyaphum

| Crops | Rainwater (Mm ³) | | | Irrigation water (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Rainwater (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|------------------------------|-------|-------|-------------------------------------|-------|-------|----------------|--------------------|---------------------------------|--|
| | dry | wet | Total | dry | wet | Total | | | | |
| Major rice | - | 1,137 | 1,137 | - | 463 | 463 | 279 | 0.43 | 2,634.48 | 1,073.53 |
| Second rice | 127 | - | 127 | 87 | - | 87 | 506 | 0.12 | 1,090.08 | 749.19 |
| Maize | 56.67 | - | 56.67 | 8.89 | 8.69 | 17.58 | 590 | 0.07 | 842.29 | 261.31 |
| Mungbean | 2.11 | - | 2.11 | 0.25 | - | 0.25 | 96 | 0.00 | 3,240.30 | 378.97 |
| Cassava | 37.72 | 147 | 184 | 103 | 198 | 301 | 3,115 | 1.11 | 165.45 | 270.42 |
| Sugar cane | 111 | 263 | 375 | 65 | 315 | 379 | 12,196 | 5.05 | 74.14 | 75.07 |
| Soybean | 13.03 | - | 13.03 | 4.58 | 2.01 | 6.59 | 250 | 0.01 | 1,566.10 | 792.00 |
| Peanut | 0.40 | - | 0.40 | 0.14 | 0.06 | 0.20 | 228 | 0.00 | 1,728.17 | 866.44 |
| Coconut | 0.31 | 0.17 | 0.48 | 0.24 | 0.34 | 0.59 | - | - | - | - |
| Para rubber | 26.76 | 15.10 | 41.86 | 20.90 | 29.64 | 50.53 | - | - | - | - |

4.9.2 Khon Kaen

Khon Kaen province occupies 6,803,125 rai in Chi watershed, and has a cultivated area of 3,247,503 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.38. Figure 4.28 shows the freshwater used for major rice, second rice, maize, sugarcane and soybean. In wet season, rainwater is the major freshwater resource for major rice and sugarcane. In dry season, irrigation water is required for second rice. Table 4.39 shows freshwater requirement per ton crop product.

Table 4.38 Irrigated and non-irrigated agricultural area in Khon Kaen

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 2,487,781 | 1,916,093 | 571,688 |
| Second rice | 149,914 | 115,464 | 34,450 |
| Maize | 12,571 | - | - |
| Sugarcane | 575,671 | - | - |
| Soybean | 21,566 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, (RID)

2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

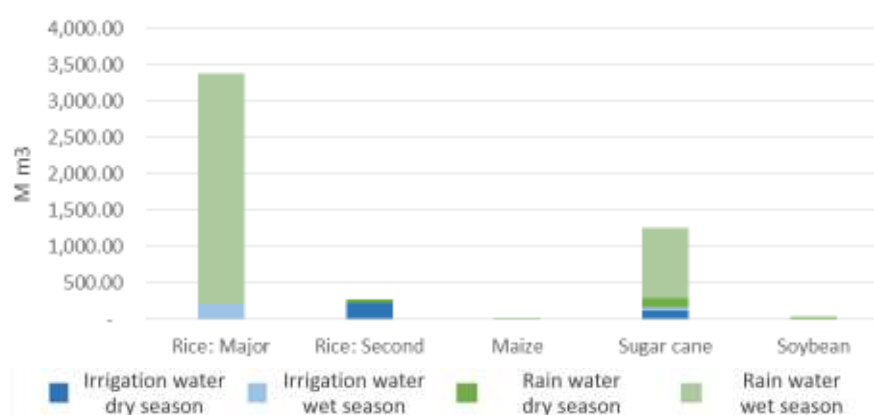


Figure 4.28 Freshwater used for stable crops in Khon Kaen (Yr 2010/2011)

Table 4.39 Freshwater requirement per ton product in Khon Kaen

| Crops | Rainwater (Mm ³) | | | Irrigation water (Mm ³) | | | Yield (kg/rai) | Production (M ton) | Rainwater (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|------------------------------|-------|-------|-------------------------------------|-------|-------|----------------|--------------------|---------------------------------|--|
| | dry | wet | Total | dry | wet | Total | | | | |
| Major rice | - | 1,829 | 1,829 | - | 722.2 | 722.2 | 310 | 0.77 | 2,390.50 | 943.98 |
| Second rice | 133.5 | - | 133.5 | 129.6 | - | 129.6 | 574 | 0.17 | 792.84 | 769.56 |
| Maize | 2.26 | - | 2.26 | 0.41 | 0.36 | 0.78 | 592 | 0.00 | 782.96 | 268.64 |
| Mungbean | 0.43 | - | 0.43 | 0.07 | - | 0.07 | 80 | 0.00 | 3,576.91 | 563.48 |
| Sugar cane | 120.9 | 380.9 | 501.8 | 110.6 | 412.1 | 522.8 | 12,674 | 7.26 | 69.10 | 71.99 |
| Soybean | 9.51 | - | 9.51 | 3.71 | 1.54 | 5.25 | 256 | 0.01 | 1,420.07 | 783.31 |
| Peanut | 1.74 | - | 1.74 | 0.69 | 0.28 | 0.97 | 248 | 0.00 | 1,465.88 | 816.39 |
| Coconut | 0.29 | 0.25 | 0.53 | 0.39 | 0.42 | 0.80 | - | - | - | - |

4.9.3 Kalasin

The total area of Kalasin province occupies 4,409,418 rai in Chi watershed, and has a cultivated area of 2,166,272 rai. The irrigated and non-irrigated agricultural areas are shown in Table 4.40. Figure 4.29 shows the freshwater requirements for staple crops. In wet season, rainwater is the major freshwater resource for major rice, cassava, sugarcane and para rubber. In dry season, the irrigation water is required for second rice. Table 4.41 shows freshwater requirement per ton crop product.

Table 4.40 Irrigated and non-irrigated agricultural area in Kalasin

| Crops | Cultivation area (rai) | Irrigated area (rai) | Non-irrigated area (rai) |
|-------------|------------------------|----------------------|--------------------------|
| Major rice | 1,484,044 | - | - |
| Second rice | 53,295 | - | - |
| Cassava | 248,801 | - | - |
| Sugarcane | 297,578 | 550 | 297,028 |
| Para rubber | 82,554 | - | - |

Source: 1. Water management plan for agriculture in dry season 2013/2014, (RID)

2. The “Agricultural Statistics of Thailand 2013”, Office of Agricultural Economics (OAE)

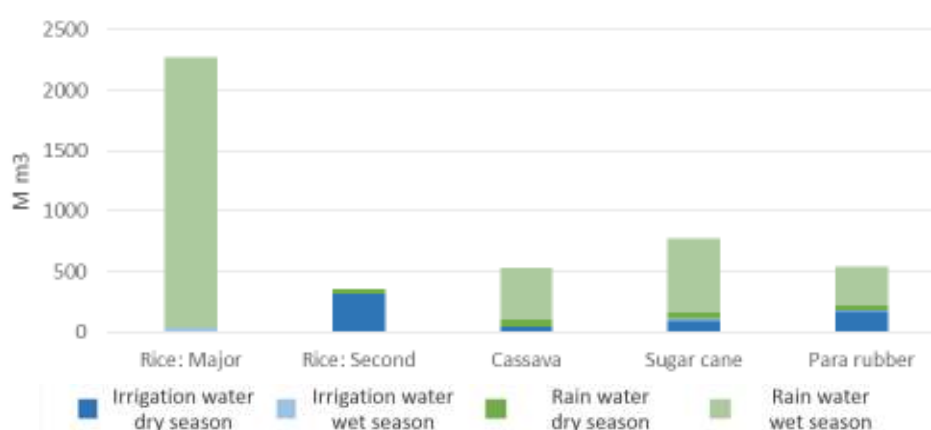


Figure 4.29 Freshwater requirement for stable crops in Kalasin (Yr 2010/2011)

Table 4.41 Freshwater requirement per ton product in Kalasin

| Crops | Rainwater (M m ³) | | | Irrigation water (M m ³) | | | Yield (kg/rai) | Production (M ton) | Rainwater (m ³ /ton) | Irrigation water (m ³ /ton) |
|-------------|-------------------------------|--------|--------|--------------------------------------|--------|--------|----------------|--------------------|---------------------------------|--|
| | dry | wet | Total | dry | wet | Total | | | | |
| Major rice | - | 1,105 | 1,105 | - | 374.35 | 374.35 | 356 | 0.49 | 2,268.95 | 768.28 |
| Second rice | 189.61 | - | 189.61 | 165.44 | - | 165.44 | 607 | 0.21 | 902.89 | 787.77 |
| Cassava | 26.50 | 98.55 | 125.05 | 64.94 | 114.78 | 179.72 | 3,111 | 0.65 | 192.02 | 275.96 |
| Sugar cane | 79.83 | 220.63 | 300.45 | 57.95 | 212.40 | 270.36 | 12,100 | 3.55 | 84.60 | 76.13 |
| Oil palm | 0.06 | 0.05 | 0.11 | 0.07 | 0.07 | 0.15 | 444 | 0.00 | 2,516.54 | 3,292.83 |
| Soybean | 0.33 | - | 0.33 | 0.08 | 0.04 | 0.12 | 216 | 0.00 | 2,252.86 | 842.25 |
| Peanut | 3.92 | - | 3.92 | 0.94 | 0.52 | 1.45 | 262 | 0.00 | 1,868.32 | 692.51 |

4.10 Limitations of crop water use assessment (based on field survey data)

- The field survey on agricultural practices and water use of farmers are mainly focused on the four staple crops of the studied watersheds i.e. rice, sugarcane, maize, and cassava. Although, there are the other crops which researchers interested to do the survey e.g. oil palm, rubber, and legumes. However, the study excludes because of the time limitation and they were found to be not significant to the freshwater consumptions in the selected watersheds because of the less planted areas after consulting with the local stakeholders.
- The water footprint assessment approach used in the study is based on the concept of water scarcity footprint of ISO 14046. Therefore, the volumetric freshwater consumption for crop cultivations (classified by rainwater and irrigation water) as well as the WSI of the regions where crops are grown will be focused. This approach differs from the water footprint assessment based on the Water Footprint Network concept which will separate the water into three types i.e. green, blue and gray water. The gray water is really not the real freshwater amount consumed rather it is a virtual amount calculated for diluting pollutants to meet specific water quality standard. This is based on the critical volume concept that was used in the past for characterizing pollutants. However, there are now more sophisticated methods available for characterizing water pollution in LCA, examples, eutrophication, acidification, ecotoxicity, etc. Hence, gray water is not used for this purpose anymore in ISO-water footprint.
- The monthly rainfall statistics were obtained from secondary sources and freshwater consumption from field surveying are the single average-value of specific month. These are used for the water footprint calculating and to be represented as an aggregated results. This uncertain time variance is not to be accounted due to the lack of gathered data resolution.

CHAPTER 5

WF and WSI Applications for Agricultural Policy Recommendations

This section aims to present the implications of water footprint assessment and monthly water stress index developed in the project for agricultural policy application. The analysis is based on the water footprint results and monthly WSI results obtained from the previous chapters to show how they can be applied for water used impact assessment. The recommendations and measures for enhancing efficiency of freshwater used in the food and fuel crops production e.g. rice, sugarcane are discussed. The policy on land conversion from low productivity rice field to sugarcane has been used as a case study to analyse its potential impacts on water resource.

5.1 Agricultural practices and freshwater use

5.1.1 Rice

Rice is the major economic crop of Thailand. Irrigation used as well as several irrigation projects for agriculture in Thailand are often planned and constructed based on the water demand for rice production in each area. The study determines the freshwater used for rice cultivation in different practices in the studied areas i.e. Mun, Chi, Chao Phraya and Tha Chin watersheds. In the assessment, the freshwater used for rice cultivation is classified into two terms i.e. rainwater and irrigation water. Rainwater implies to the effective rainfall that rice can be used, irrigation water which can be either surface water or groundwater. Freshwater (both rainwater and irrigation water) is used for growing rice with the two main reasons i.e. (1) maintain soil moisture and (2) control weeds for wet cultivation which the standing layer of water will be maintained over the field. Although, the standing freshwater in the rice fields will percolate and recharge to groundwater and surface water which will not be accounted as water consumption; however, the much standing freshwater used will affect to the much irrigation water requirement for rice growing too which in turn can cause affect to the water deprivation with other users in the basins. Hence, percolation is considered as a loss to rice field, but for the catchment area it is not considered as a loss because the freshwater can be captured and reused downstream (Bouman et al., 2007).

The study shows the comparison of freshwater used for rice cultivations based on crop evapotranspiration complemented with the survey data on actual water management practice in the rice field of farmers in the central region (Ayuthaya province). The percolation is also estimated and accounted for estimating the total freshwater requirement for rice growing. The different rice cultivation systems including transplanting, dry ungerminated seed broadcasting, pregerminated seed broadcasting and alternate wetting and drying (AWD) have been compared.

(1) Description of rice cultivation systems

In Thailand, rice growing is mainly in the wet systems i.e. rice fields are prepared and the soil is kept saturated. There are three major types of rice cultivations found in the studied areas i.e. transplanting, dry ungerminated seed broadcasting and pregerminated seed broadcasting. Table 5.1 and Table 5.2 show the major and second rice cultivated areas in the northeastern and central regions of Thailand classified by types of cultivation system.

Generally, the cultivation system begins with the land preparation by puddling. This is done by saturating the soil layer for one month prior to sowing. The volume of water that is necessary for saturated soil is about 200 mm (Brouwer and Heiblowem, 1986). For upland rice growing, a standing layer of water may not be used due to the geographical limitation. However, for the lowland rice growing, the standing layer of water generally will be required for weed control. The wet system will have a constant percolation and seepage loss during this period. Since the percolation loss is primarily a function of soil texture, the study refers the percolation loss factor based on RID which is about 1 mm/day for central region of Thailand and 1.5 mm/day for the other regions. This standing water is assumed to be used for the entire period of rice cultivation except for the last 15 days when the field is left to dry out for easy harvesting. A water layer is assumed to be established during transplanting or sowing and maintained throughout the growing season but the level of water layer can differ depended on the farmers' practices.

Table 5.1 Major rice cultivation systems

| Rice cultivation systems | Planted areas by cultivation types (rai) | | % of planted areas by cultivation types | |
|------------------------------------|--|-----------|---|---------|
| | Northeast | Central | Northeast | Central |
| Transplanting | 20,539,142 | 754,071 | 56% | 8% |
| Dry ungerminated seed broadcasting | 15,680,912 | 1,587,042 | 42% | 17% |
| Pregerminated seed broadcasting | 782,940 | 7,047,243 | 2% | 75% |
| Direct seeding | 63,635 | 7,010 | 0% | 0% |

Source: OAE (2013)

Table 5.2 Second rice cultivation systems

| Rice cultivation system | Planted areas by cultivation types (rai) | | % planted areas by cultivation types | |
|------------------------------------|--|-----------|--------------------------------------|---------|
| | Northeast | Central | Northeast | Central |
| Transplanting | 116,123 | 79,523 | 7% | 1% |
| Dry ungerminated seed broadcasting | 26,006 | 9,281 | 1% | 0% |
| Pregerminated seed broadcasting | 1,539,739 | 6,826,502 | 92% | 99% |
| Direct seeding | - | - | - | - |

Source: OAE (2013)

Recently, the “*Alternate wetting and drying (AWD) system*”, a water-saving technic for rice cultivation, is encouraged to farmers in order to reduce irrigation water use in rice fields by without decreasing yields. In AWD, irrigation water is applied a few days after the disappearance of the ponded water. Hence, the field is alternately flooded and non-flooded. The number of days of non-flooded soil between irrigations can vary from 1 to more than 10 days depending on a number of factors such as soil type, weather and crop growth stage. To implement AWD, a “field water tube” is used to monitor the water depth on the field.

AWD can be started a few weeks (1-2 weeks) after transplanting. However, if there are weeds presented, AWD should be postponed for 2-3 weeks to assist suppression of the weeds by the ponded water and improve the efficacy of herbicide. After irrigation, the water level will gradually decrease. When the water level has dropped to about 15 cm below the surface of the soil, irrigation should be reapplied to flood the field to a depth of about 5 cm. From one week before to a week after flowering, the field should be kept flooded and the water level should be increased to 7-10

cm. When the rice's age is about 35-45 days, the water input can be stopped for 14 days until the water level has dropped to about 10-15 cm below the surface of the soil before re-irrigation. Local fertilizer recommendations can be used. Apply N fertilizer preferably on the dry soil just before irrigation. AWD in rainfed rice is not recommended due to uncertain water availability when fields have to be re-flooded.

(2) Comparative freshwater used for rice cultivations

The volume of water needed for maintaining the water layer is will be accounted in the percolation losses and evaporative demand of the crop during the last phase of paddy growth, it is necessary to get this volume of water at the beginning of the crop period. The study assumes that the water layer is established in the month of sowing. The total freshwater demand for rice cultivation is therefore calculated from the summation of ET_c , standing water, and percolation for each time step. For the last 15 days prior to the harvesting when the land is left to dry out, the volume of water required for evaporation is supplied by the effective rainfall in the period and any residual soil moisture maintained from the previous stages. Table 5.3 and Table 5.4 present the estimated freshwater used for major and second rice cultivation for different practices. The analysis based on the average data of major and second rice cultivations in Ayuthaya province. Major rice is grown during June – September and second rice is grown during October – January. The average common practices of farmers for water management in the rice field are as follows:

- **Major rice cultivation:** the average water used for preparation period (30 days) is 11.5 cm/day; for growing stage (60 days) is 16.8 cm/day and for the last period (60days) is 17.6 cm/day
- **Second rice cultivation:** the average water used for preparation period (30 days) is 11.2 cm/day; for growing stage (60 days) is 13.8 cm/day and for the last period (60days) is 14.3 cm/day

Table 5.3 Freshwater used for different major rice cultivation systems in Ayuthaya

| | Preparation (cm/day) | | ET (mm/day) | | Percolation (cm/day) | Standing water (cm/day) | CWU (m ³ /rai) | Total WU (m ³ /rai) | | |
|------------------------------------|----------------------|-----|-------------|-----|----------------------|-------------------------|---------------------------|--------------------------------|-----|-------|
| | RW | IRW | RW | IRW | | | | RW | IRW | Total |
| Transplanting | 3.0 | 3.7 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 751 | 444 | 1195 |
| Dry ungerminated seed broadcasting | 1.7 | 0 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 654 | 262 | 947 |
| Pregerminated seed broadcasting | 3 | 2 | 3.8 | 0.3 | 0.1 | 3.8 | 1013 | 751 | 361 | 1112 |
| Alternate wetting and drying | 1.7 | 0 | 3.8 | 0.3 | 0.1 | 2.3 | 1013 | 666 | 166 | 832 |

*RW: Rainwater; IRW: Irrigation Water

Table 5.4 Freshwater used for different second rice cultivation systems in Ayuthaya

| | Preparation (cm/day) | | ET (mm/day) | | Percolation (cm/day) | Standing water (cm/day) | CWU (m ³ /rai) | Total WU (m ³ /rai) | | |
|------------------------------------|----------------------|-----|-------------|-----|----------------------|-------------------------|---------------------------|--------------------------------|-----|-------|
| | RW | IRW | RW | IRW | | | | RW | IRW | Total |
| Transplanting | 6.7 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 627 | 551 | 1178 |
| Dry ungerminated seed broadcasting | 1.7 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 385 | 545 | 930 |
| Pregerminated seed broadcasting | 5 | 0 | 2.8 | 0.7 | 0.1 | 3.7 | 1021 | 547 | 548 | 1096 |

| | Preparation (cm/day) | | ET (mm/day) | | Percolation (cm/day) | Standing water (cm/day) | CWU (m ³ /rai) | Total WU (m ³ /rai) | | |
|---------------------------------|-------------------------|-----|----------------|-----|-------------------------|-------------------------------|------------------------------|--------------------------------|-----|-------|
| | RW | IRW | RW | IRW | | | | RW | IRW | Total |
| Alternate wetting and drying | 1.7 | 0 | 2.8 | 0.7 | 0.1 | 2.3 | 1021 | 385 | 457 | 842 |

*RW: Rainwater; IRW: Irrigation Water

The results show that the transplanting method brings about the highest water used per rai, followed by pregerminated seed broadcasting, dry ungerminated seed broadcasting and alternate wetting and drying. The higher water used for transplanting and pregerminated broadcasting method is due to the water requirement for land preparation and the standing water requirement during cultivation period. AWD method can help reduce freshwater used. This is especially for the major rice cultivation which the results in Table 5.3 shows that the AWD method would significantly reduce the irrigation water requirement. The reductions of irrigation water used when the AWD method is applied to replace the pregerminated seed broadcasting method for major rice and second rice cultivations in the central region (Ayuthaya) are about 195 and 91 m³/rai, respectively. Nevertheless, the limitation of implementation AWD method for large scale planted areas still be discussion by farmers because it seems to be difficult for controlling weeds.

5.1.2 Sugarcane

Sugarcane is nowadays a staple crop playing an important role in the Thai economy not only for sugar production but also for bioenergy production. Thailand is ranked as the 2nd largest sugar exporter by exporting about 8 M.ton sugar/year. The demands for sugarcane for food (sugar) and energy (bioelectricity and bioethanol) are increasing continuously due to the increase of population as well as the policy on bioenergy promotion worldwide. The Thai Government has launched the 10-Year Alternative Energy Development Plan (AEDP) by setting a target that renewables will contribute 25% of the country's energy mix by 2021. Under the AEDP, different types of renewable energy sources are promoted including bioenergy such as electricity from biomass and biofuels like bioethanol. Sugarcane is expected to play an important role as bioenergy feedstock for Thailand in the future because it has a high proportion of biomass especially in the form of readily fermentable sugars that can be used for biofuels.

In 2014, the total sugarcane planted areas is about 8.5 M.rais and total sugarcane production is around 103 M.ton. The growing period can vary between 9-12 months with harvest. Plant crop is normally followed by 2 to 3 ratoon crops. For freshwater used, the adequate available moisture throughout the growing period is important for obtaining maximum yields because cane growth is directly proportional to the water transpired. Depending on climate, water requirements of sugarcane are around 1500-2500 mm evenly distributed over the growing season. Table 5.5 shows the average theoretical water requirement and actual freshwater used for sugarcane cultivation under irrigation system (furrow) in Chao Praya watershed. The results show that based on the sugarcane yield of about 15 ton cane/rai, the rainwater and irrigation water used are about 1100 and 1100 m³/rai/yr, respectively. The over irrigation water supplied to sugarcane field about 510 m³ as compared to the theoretical irrigation water requirement obtained from crop evapotranspiration which sugarcane will require only 590 m³/rai/yr is due to the irrigation efficiency. The assessment shows that the irrigation efficiency of furrow system is about 54%. Nevertheless,

the irrigation water used can be reduced by using the higher irrigation system such as big gun sprinkler, boom irrigator and sub-surface drip.

Table 5.5 Water requirements and water used for sugarcane cultivation in Chaophraya watershed

| | Yield (ton/rai) | Theoretical CWR (m ³ /rai/yr) | | Total water used (m ³ /t cane) | | IRW deficit (-)/over (+) |
|-----------------------|--------------------|---|-----|--|------|---|
| | | RW | IRW | RW | IRW | |
| Chao Phraya watershed | 15 | 1100 | 590 | 1100 | 1100 | (+) 510 m ³ /rai/yr Irrigation efficiency (furrow) = 55% |

RW: Rainwater; IRW: Irrigation water

Based on the theoretical irrigation water requirement of about 590 m³/rai/yr as indicated in Table 5.5, Table 5.6 shows the potential reduction of irrigation water used if the existing irrigation system like the furrow has been changed to others in order to achieve 15 tons cane/rai. The amount of irrigation water that can be saved is estimated to be around 310, 410 and 490 m³/rai/year for big gun sprinkler, boom irrigator and sub-surface drop, respectively.

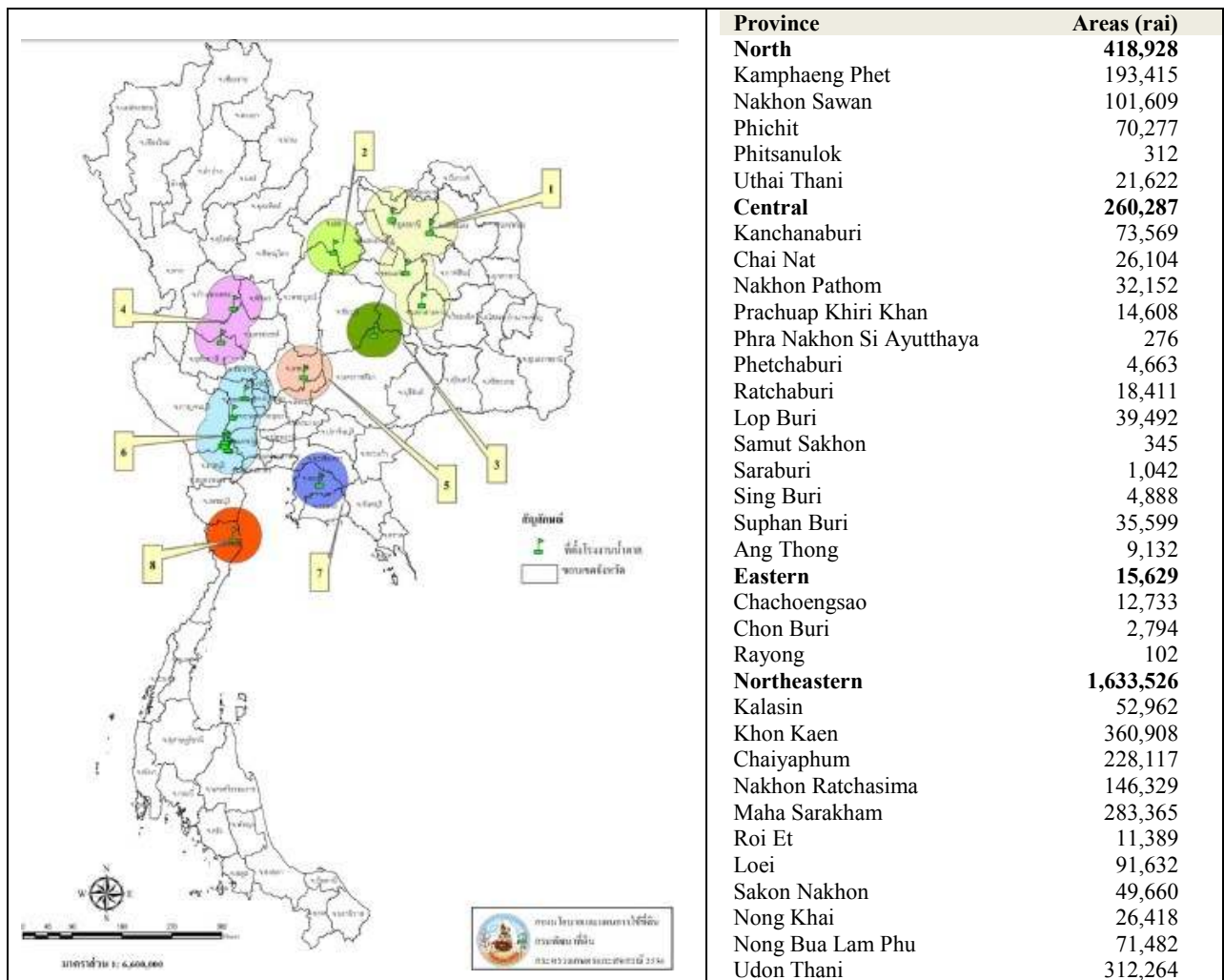
Table 5.6 Comparative irrigation water used for different irrigation technics for sugarcane plantation

| Irrigation system | Irrigation efficiency (%)* | IRW requirement for supply (m ³ /rai/yr) | Potential reduction of irrigation water used after replacing the existing irrigation system by “sub surface drip system” (m ³ /rai/yr) |
|------------------------------|----------------------------|---|---|
| Furrow | 55 | 1100 | - |
| Big gun sprinkler | 75 | 790 | 310 |
| Boom irrigator, Centre pivot | 85 | 690 | 410 |
| Sub surface drip | 97 | 610 | 490 |

*Source: OCSB (2014)

5.2 Application of WF and WSI for land-use policy for agriculture

The government currently has initiated the policy on converting upland paddy fields with low productivity to sugarcane plantation in order to fulfil the excess capacity of current sugar millers along with the expectation to increase farmers’ income. The current target is set to about 2.1 M.rai that will be converted to sugarcane focusing on the Northeast and Central regions of Thailand. The Land Development Department (LDD) has developed the map of potential areas for substituting low productivity paddy field by sugarcane. The criteria for determining the substitution areas is as follows: (1) the current paddy field that located in the land classified as the low and non-suitable areas for rice; (2) the radius of about 50 km of 20 sugar factories that currently needs more sugarcane to fulfil their production capacity. The results found that, for short-termed target, the potential areas found are 2.3 million rais covering 3 provinces in the eastern region, 11 provinces in Northeastern region, 6 provinces in north and 13 provinces in central region as shown in Figure 5.1.



Source: LDD (2014)

Figure 5.1 Potential areas of paddy field conversion to sugarcane

Based on the information of potential rice planted areas to convert to sugarcane as shown in Figure 5.1 and the amount of rainwater and irrigation water used for growing rice and sugarcane which would be different in each province, the impacts of land-use change policy on water resource availability can be evaluated. The potential impacts of LUC policy for rice field conversion to sugarcane is shown in Table 5.7. The assessment has been conducted into potential scenarios i.e. non-irrigated rice field conversion, irrigated land rice field conversion (with one crop basis), and irrigated land rice field conversion (with two crops basis). The results can be summarized as follows:

- If non-irrigated rice field is converted to sugarcane: there will have no affect to irrigation water resource because it doesn't used. However, the yield of major rice and sugarcane may not reach the baseline yield in calculation i.e. 814 kg rice/rai and 15 t cane/rai (due to water deficit)
- If irrigated rice field (one crop basis) is converted to sugarcane: LUC will require the additional irrigation water about 940 m³/rai/yr (if irrigation efficiency is not improved) and 450 m³/rai/yr (if sub surface dip is applied for sugarcane irrigation)

- If irrigated rice field (two crops basis) is converted to sugarcane: LUC will decrease the irrigation water used about 210 m³/rai/yr (if irrigation efficiency is not improved) and 750 m³/rai/yr (if sub surface dip is applied for sugarcane irrigation)

Table 5.7 Potential impacts of policy on land conversion from rice field to sugarcane on water resource availability

| Land type | Cropping change scenarios | Theoretical CWR (m ³ /rai/crop) | | Total water used (m ³ /rai/crop) | | Effect of land on irrigation water resource |
|--------------------|--------------------------------------|---|--|---|--|---|
| | | RW | IRW | RW | IRW | |
| Non-irrigated area | Major rice → Sugarcane | Major rice = 1,080; Sugarcane = 1,100 | Major rice = 80 Sugarcane = 590 | Major rice = 1,080; Sugarcane = 1,100 | Major rice = 0 Sugarcane = 0 | <ul style="list-style-type: none"> • No affect to IRW resource because IRW is not used • Yield of major rice and sugarcane may not reach the baseline dataset i.e. 814 kg rice/rai and 15 t cane/rai (due to water deficit) |
| Irrigated area | Major rice → Sugarcane | Major rice = 1,080; Sugarcane = 1,100 | Major rice = 80 Sugarcane = 590 | Major rice = 1,080; Sugarcane = 1,100 | Major rice = 160 Sugarcane = 1,100 (54% irrigation efficiency) | <ul style="list-style-type: none"> • LUC will require additional irrigation water 940 m³/rai/yr (if irrigation efficiency is not improved) • LUC will require additional irrigation water 450 m³/rai/yr (if irrigation efficiency of sugarcane is improved to 97% by using sub surface dip) |
| | Major rice + Second rice → Sugarcane | Major rice = 1,080 Second rice = 380 <u>Total (rice)</u> = 1,460 Sugarcane = 1,100 | Major rice = 80 Second rice = 660 <u>Total (rice)</u> = 740 Sugarcane = 590 | Major rice = 1,080 Second rice = 380 <u>Total (rice)</u> = 1,460 Sugarcane = 1,100 | Major rice = 160 Second rice = 1,150 <u>Total (rice)</u> = 1,310 Sugarcane = 1,100 (54% irrigation efficiency) | <ul style="list-style-type: none"> • LUC will decrease irrigation water use 210 m³/rai/yr (if irrigation efficiency is not improved) • Reduce irrigation water used 750 m³/rai/yr (if irrigation efficiency is improved to 97% by using sub surface dip) |

*Cropping cycle: rice (4 months); sugarcane (9-10 months)

Table 5.8 shows the implications of LUC policy of rice field conversion to the monthly water stress index of the relevant watersheds. The results reveals that the policy on converting 2.3 million rice planted areas to sugarcane potentially reduce the water withdrawal for agriculture which in turn will affect to the reduction of the water stress index of the relevant watersheds i.e. Mun, Chao Phraya, Bang Pakong, Tha Chin, Mae Klong, Sakae Krang, etc. The WSI of June – September would be reduced. The amounts of agricultural water required during June to September decreases around 62, 221, 144, and 122 million m³, respectively. It can be concluded that the policy on converting 2.1 M.rai low-productivity rice field to sugarcane in the Northeast and Central regions of Thailand will help reduce the amount of water requirement for agriculture in that regions.

Although the changes of WSI results between two LUC scenarios is not significant in view of the whole watershed. For example, WSI of Chao Phraya watershed can be reduced just about 1% (during June – September); however, if looking at the volumetric water saving, it would totally be reduced around 549 million m³. This amount of water resource can be further used for the other crops which in turn will result in the increase economic benefits of other farmers. Hence, WSI can be used the reference indicator for policy decision making that the new policy on agricultural promotion in any particular region shall not exceed the critical WSI of each watershed. In principle, the recommended WSI baseline should not more than 0.5 which equivalent to WTA of about 0.4 of each particular region/watershed.

Table 5.8 WSI of June-September

| Watershed | WSI | | | | LUC policy | | | |
|----------------------|-------|-------|-------|-------|------------|-------|-------|-------|
| | JUN | JUL | AUG | SEP | JUN | JUL | AUG | SEP |
| Ping | 0.021 | 0.027 | 0.022 | 0.022 | 0.021 | 0.027 | 0.022 | 0.022 |
| Yom | 0.099 | 0.165 | 0.104 | 0.073 | 0.098 | 0.162 | 0.103 | 0.072 |
| Nan | 0.044 | 0.059 | 0.048 | 0.049 | 0.044 | 0.058 | 0.048 | 0.049 |
| Khong | 0.099 | 0.091 | 0.070 | 0.084 | 0.098 | 0.089 | 0.069 | 0.083 |
| Chi | 0.208 | 0.344 | 0.183 | 0.197 | 0.202 | 0.319 | 0.175 | 0.190 |
| Mun | 0.367 | 0.359 | 0.342 | 0.255 | 0.366 | 0.354 | 0.339 | 0.253 |
| Chao Phraya | 0.520 | 0.898 | 0.864 | 0.282 | 0.516 | 0.893 | 0.860 | 0.279 |
| Sakae Krang | 0.134 | 0.428 | 0.698 | 0.333 | 0.132 | 0.413 | 0.688 | 0.327 |
| Pasak | 0.063 | 0.210 | 0.144 | 0.129 | 0.063 | 0.207 | 0.143 | 0.128 |
| Tha Chin | 0.419 | 0.757 | 0.824 | 0.281 | 0.415 | 0.747 | 0.818 | 0.277 |
| Mae Klong | 0.022 | 0.024 | 0.026 | 0.023 | 0.022 | 0.024 | 0.025 | 0.023 |
| Phetchaburi | 0.042 | 0.075 | 0.096 | 0.031 | 0.042 | 0.074 | 0.095 | 0.031 |
| West Coast Gulf | 0.132 | 0.170 | 0.125 | 0.040 | 0.131 | 0.167 | 0.123 | 0.039 |
| Prachin Buri | 0.063 | 0.053 | 0.060 | 0.039 | 0.063 | 0.053 | 0.060 | 0.039 |
| Bang Pakong | 0.227 | 0.506 | 0.674 | 0.158 | 0.227 | 0.504 | 0.673 | 0.158 |
| East-Coast Gulf | 0.024 | 0.020 | 0.026 | 0.020 | 0.024 | 0.020 | 0.026 | 0.020 |
| Peninsula-East coast | 0.129 | 0.089 | 0.154 | 0.087 | 0.129 | 0.089 | 0.154 | 0.087 |

5.3 Climate change and water stress index

Figure 5.2 shows the example of potential effects of climate change on water resource and crop water requirement. Climate change can bring about the change of rainfall pattern which will affect to the water availability in both spatial and temporal dimensions. Increased temperature can lead to the increase of crop water requirement in order to compensate the increased evaporative loss.

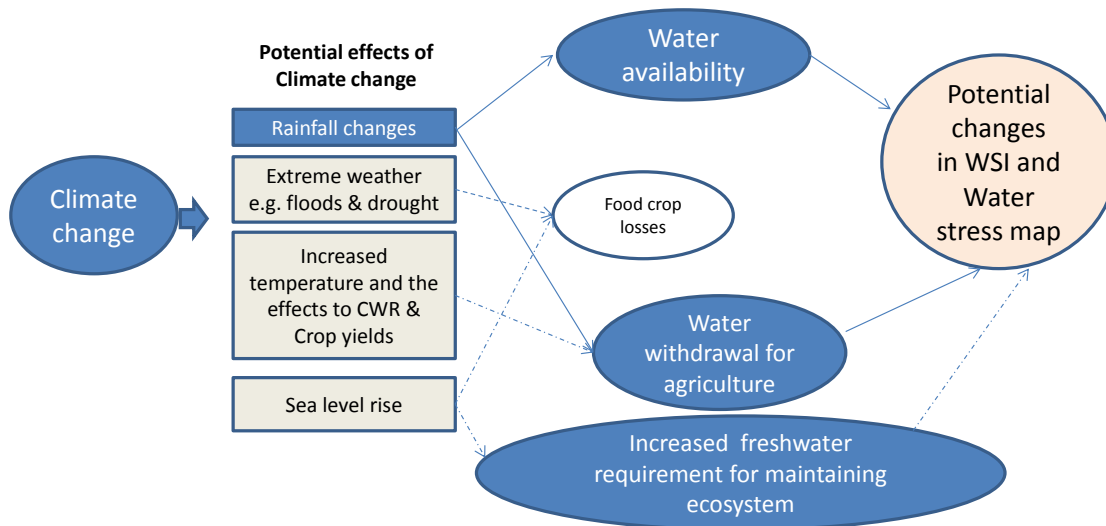
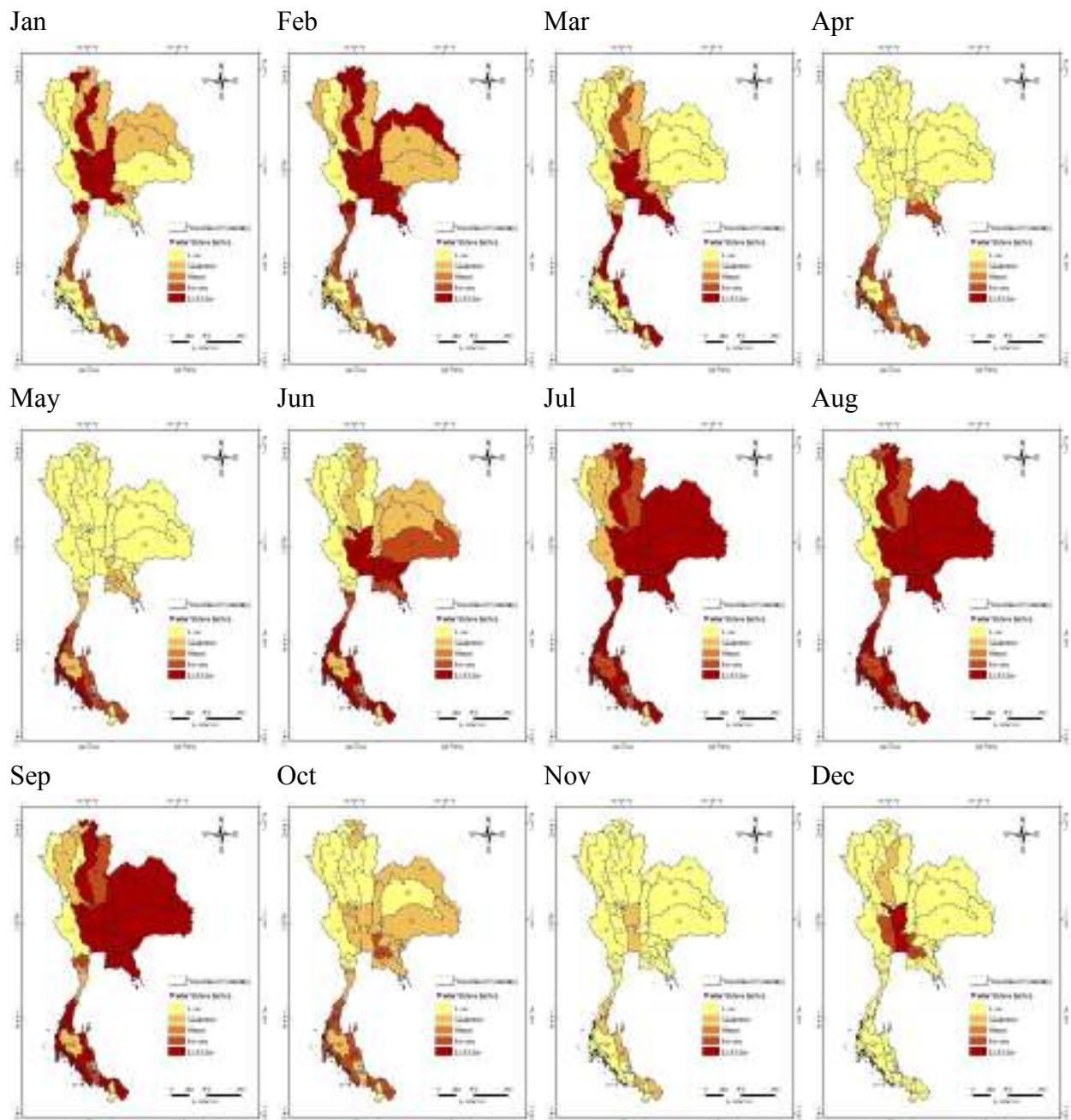


Figure 5.2 Climate change and its effects on water availability and WSI

IPCC (the Intergovernmental Panel on Climate Change) is the international body for assessing the science related to climate change. IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies. One of the results from IPCC assessment is the projections of future climate change based on different scenarios and the risks that climate change poses. Based on the 5th IPCC assessment report (AR5) in 2014, there are four possible climate futures so called Representative Concentration Pathways (RCP) used for climate modelling and research. All of which are considered possible depending on how much greenhouse gases are emitted in the years to come. To determine the climate change and its effects on water availability and WSI in this project, the projection of rainfall for the future under IPCC scenario has been made to see their influence to the water stress index of Thailand. The forecasted rainfall in Thailand during 2015-2025 based on RCP4.5¹ is provided by Asst. Prof. Dr. Jerasorn Santisirisomboon under the project on “Downscaling of GCMs for the impacts study of climate change on rice production in Thailand”. The results show that forecasted rainfall data in 2025 decrease in every watersheds that lead to changes of water stress index in several watersheds of Thailand. It is found that there will have an increase of the levels of monthly and seasonal water stress as the results showed in Figure 5.3 and Figure 5.4.

¹ RCP4.5 (used in CMIP5 and in the IPCC-AR5) refers to the GHG and aerosols concentrations changes in a way that lead to an additional radioactive forcing equal to +4.5 Wm⁻² (~650 ppm CO₂ equivalent) at the end of the 21st century with respect to the pre-industrial climate. This scenario is taken into account as an optimist scenario with respect to the GHG concentration (Tramblay, et al., 2013)



Source: The forecasted rainfall in 2025 is provided by Asst. Prof. Dr. Jerasorn Santisirisomboon under the project on “Downscaling of GCMs for the impacts study of climate change on rice production in Thailand”

Figure 5.3 Monthly WSI based on the forecasted rainfall in 2025

For monthly WSI, the comparison of monthly water stress map under climate change condition (Figure 5.3) and the current water stress map (Figure 3.5) revealed the significant increase in water stress for all watersheds during June to August. Nevertheless, as the overall, the water stress will increase nationwide due to the climate change but the severe of the impact will be varied by the month and the region. For seasonal WSI, the comparison of seasonal water stress map under climate change condition and the current water stress map are shown in Figure 5.4. It is also obviously seen that water stress becomes a serious concern in the wet season as a result of dramatic decreases in the amount of rainfall in 2025. This implies that the based on the existing agricultural planted areas currently as well as the current demands for water of all sectors, the climate change

can cause the decrease in rainfall in Thailand and potentially cause the increase water stress. However, the effects will be varied differently depended on which month and which watershed.

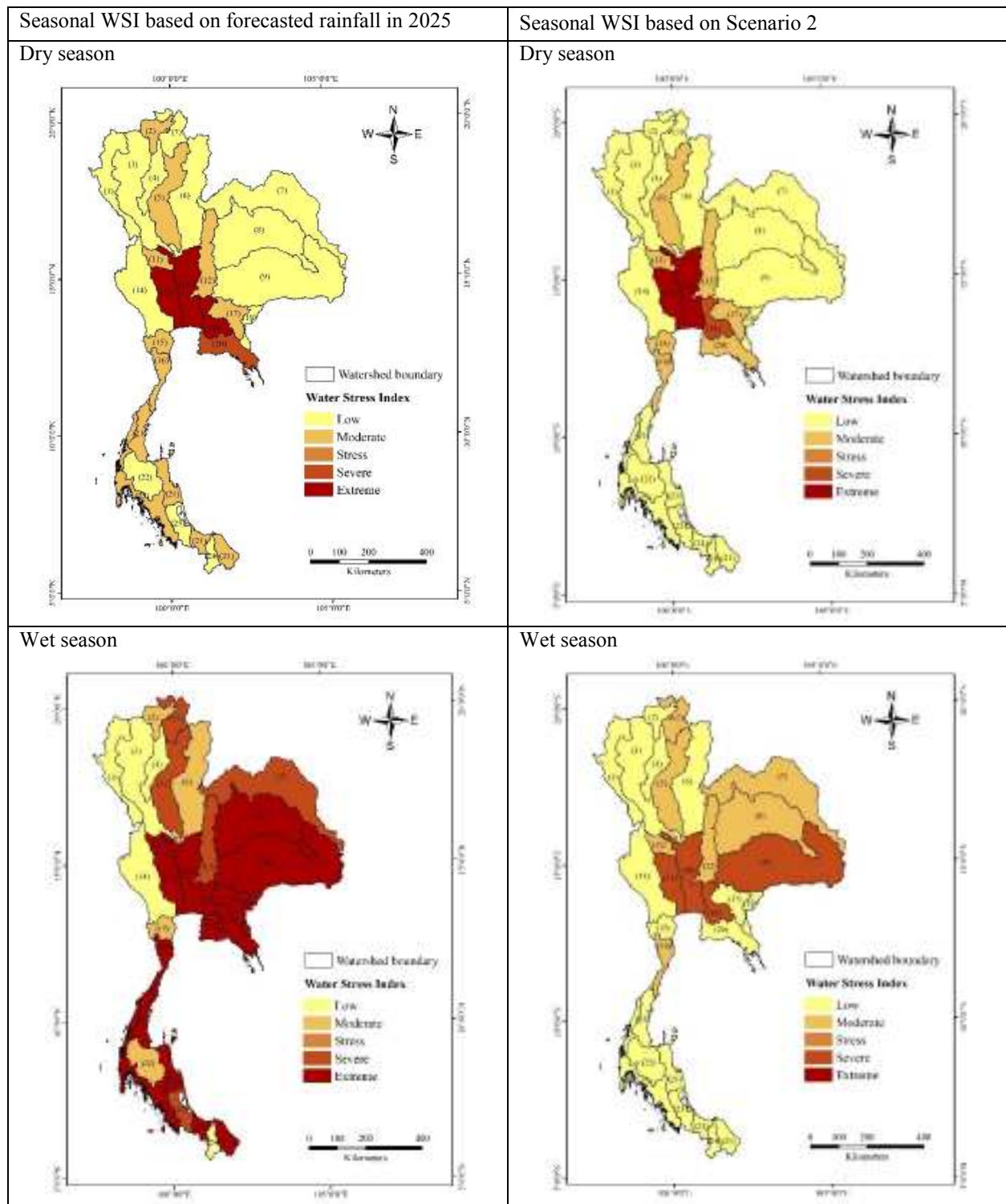


Figure 5.4 Seasonal WSI based on the forecasted rainfall in 2025 and Scenario 2 (using 10-year average rainfall)

The results can also be concluded that there would have the potential to have less water during wet season due to the climate change. Meanwhile, the current agricultural practices in Thailand

are mainly relied on rainfall. Thus, there would potentially have the high risk on water scarcity for agriculture in wet season which in turn will directly affect to farmers especially major rice cultivation. The appropriate water management policies e.g. water storage, efficient irrigation system promotion and expansion, as well as the appropriate agricultural cropping calendar for each needs to be implemented. The long-term plan should also look at the potential effect on climate change in the future. Also, the plan should not only focus on dry season water resource management but also wet season which potentially have less rainfall in the foreseeable year.

Water stress index and water footprint is therefore become an important tool for policy decision makers to identify the potential impact on water scarcity due to the agricultural policy on the agricultural areas expansion or switching from one crop to another crop. The reference WSI indicator that can be used for policy decision makers is that if the total demands for freshwater in that studied areas exceed 40% of the total available water. That studied area would potentially have the impact on water scarcity i.e. the water resource that naturally required for ecosystem will be deficit which in turn will cause the problem to ecosystem, economic activity and society. Hence, the Water Stress Index (WSI) at critical level in the study i.e. 0.5 or equivalent to the Withdrawal-to-Availability (WTA) about 0.4 can be used as a target by government in order to mitigate the impact of water scarcity and water competition among water users in each region.

5.4 Water Scarcity Footprint of Crops

Although the annual WSI obtained from the 1st phase of the project is useful and nowadays widely referred for water scarcity footprint assessment of various agricultural products in Thailand as seen from several recent studies on water footprint (Gheewala et al., 2013; 2014); however, the monthly WSI results show the different of water stress in different months in each region. This section shows therefore the implications of monthly WSI (developed in this 2nd Phase of the WF project) and annual WSI (developed in the 1st Phase of the project) on water scarcity footprint assessment of agricultural product. According to ISO-Water footprint, since the environmental impacts of water consumed are heavily dependent on spatial conditions; therefore, using only the quantitative value of water consumption of product does not enough to interpret the level of impact on water consumption. The water scarcity footprint therefore has been recommended as the proxy indicator to show the “water deprivation impact potential” or some studies called as the “RED (Relevant for Environmental Deficiency) water”. In this case, the water scarcity footprint can be calculated from the multiplication of irrigation water use with the water stress index (WSI) in the specific location: Water deprivation = Blue water × WSI. This water scarcity footprint is measured in m³ water equivalents (m³eq) and represents a surrogate indicator for the amount of water deficiency to downstream human users and ecosystems (Pfister et al., 2009).

Table 5.9 shows the comparison of water scarcity footprint of sugarcane cultivation (m³H₂Oeq/t cane) in Chao Phraya and Chi watersheds based on the total water use and yields that obtained from the survey data as shown in Table 4.5. The results show that, for the case of Chao Phraya watershed, the water scarcity footprint's value of sugarcane using would increase from 38 to 66 m³H₂Oeq/t cane or increase about 16%. However, it is not necessary that the water scarcity footprint would be always increase after using the monthly WSIs in the calculation. As for the case of Chi watershed, the water scarcity footprint results would decrease from 14 to 3 m³H₂Oeq/t cane. This implications mean that there still have the gap of results using annual and monthly WSIs in

water scarcity footprint. It is therefore necessary to interpret the water scarcity footprint results carefully. The comparison of water scarcity footprint results must be based on the same degree of water stress index basis. Annual WSI may be useful for the top-down vision for quickly determine the potential impact from agricultural policy on water scarcity in different region. However, monthly water footprint may be useful for comprehensive assessment in order to see the potential stress and how affect if the shifting crop calendar policy is implemented. This is because the variation of WSI in each month has been considered. As monthly WSI values of Chao Phraya and Chi in Table 5.9, the stress level will not be found over the entire year. For Chao Phraya watershed, the high WSI are found in two periods i.e. December to March and May to July due to high water demands for second rice and major rice, respectively. This is consistent to the cropping calendar of rice in Chao Phraya watershed as shown in Figure 4.13.

Table 5.9 Comparison on water scarcity footprint of sugarcane cultivations in Chi and Chao Phraya watersheds using annual and monthly WSIs

| Parameter | Unit | Chao Phraya | Chi |
|--|---|-------------|------------|
| Yield | ton /rai | 15 | 11.5 |
| Total water used | m³/t cane | 220 | 150 |
| Rain water used | m ³ /t cane | 110 | 120 |
| Irrigation water used | m ³ /t cane | 110 | 30 |
| WSI value | | | |
| Annual WSI value (1 st Phase) | - | 0.339 | 0.471 |
| Monthly WSI value (2 nd Phase) | | | |
| • January | - | 1.00 | 0.10 |
| • February | - | 1.00 | 0.07 |
| • March | - | 0.99 | 0.03 |
| • April | - | 0.08 | 0.02 |
| • May | - | 0.04 | 0.02 |
| • June | - | 0.52 | 0.21 |
| • July | - | 0.90 | 0.34 |
| • August | - | 0.86 | 0.18 |
| • September | - | 0.28 | 0.20 |
| • October | - | 0.05 | 0.03 |
| • November | - | 0.35 | 0.02 |
| • December | - | 0.98 | 0.03 |
| Water scarcity footprint | m³H₂Oeq/t cane | | |
| • Water scarcity footprint based on annual WSI (1 st Phase) | m ³ H ₂ Oeq/t cane | 38 | 14 |

5.5 Recommendations for agricultural policy decision makers in using WSI and Water scarcity footprint

Based on the results of monthly WSIs in 25 watersheds of Thailand and the crop water use (both theoretical crop water requirement and deficit condition) obtained from the projects, it was found that water stress index (WSI) and crop water use information are essential to support the future agricultural policy decision making in various applications. Descriptions are as follows:

Based on the results of monthly WSIs in 25 watersheds of Thailand and the crop water use (both theoretical crop water requirement and deficit condition) obtained from the projects, it was found that water stress index (WSI) and crop water use information are essential to support the future agricultural policy decision making in various applications. Descriptions are as follows:

- (1) Water stress index (WSI) should be used as one of the criteria for further agricultural zoning. Even though the zoning agricultural areas must be based on geographical and climate conditions e.g. soil series, soil quality, land slope, rainfall, temperature and etc. as so far has been done by Land Development Department and Ministry of Agricultural and Cooperatives. However, in reality, apart from the agricultural sector there are other water use sectors in the society such as domestic, ecosystem and industries. Since WSI has already considered the relationship of total water demands and total water availability of a particular area, the applications can be as followed:
 - a. WSI can be used as the indicator for monitoring the potential impacts due to the policy on land use conversion. For instance, the LUC policy from converting low-productivity rice field to sugarcane about 2.1 M.rais (as section 5.2) has been evaluated. The results show that this policy can help reduce the amount of water requirement for agriculture in the selected areas proposed by LDD which in turn result in the decrease in WSI values of the relevant watersheds. Although the changes of WSI results are found to be not significant in view of the whole watershed. For example, WSI of Chao Phraya watershed can be reduced just about 1% (during June – September); however, WSI still be at least used as the indicator for ensuring that the new policy will not cause the impact on water stress in the promoted areas.
 - b. WSI can be used as the target for future land use policy. For conservative, all regions should avoid to exceed the critical WSI value i.e. 0.5 which will be equivalent to the WTA of about 0.4 for each region/watershed. For the areas/watersheds where the WSI values are classified as the severe (>0.5 and <0.9) and the extreme severe (>0.9), the measures such as the shifting of cropping calendar, finding new water resources, cropping system changes, efficient irrigation system and practices need to be applied appropriately by consulting with the all stakeholders in the region.
- (2) The promotion of the appropriate agricultural practices as well as efficient irrigation system must be more encouraged to farmers in nationwide especially in the Central and Northeastern regions. For examples:
 - a. As section 5.1.1, the AWD method can help reduce freshwater used. Nevertheless, the limitation of implementation AWD method for large scale planted areas still be discussion by farmers because it seems to be difficult for controlling weeds. Also, the water storage may be required for controlling the water in the rice field.
 - b. As section 5.1.2, the input of irrigation water can affect to the increase of sugarcane yields. However, it was found that using the low irrigation efficiency as furrow system can bring about the over water consumption as compared to the theoretical requirement. The reduction of irrigation water used can be reduced by using the higher irrigation system such as big gun sprinkler, boom irrigator and sub-surface drip.
- (3) WSI obtained from the project will be the national baseline data for further assessment of the water footprint of agricultural products in Thailand. The promotion of water footprint assessment and water footprint label of agricultural products is an important policy that needs to be implemented in Thailand to encourage the sustainable food production and trade. This will also be the preparation stage for Thai food industries to compete in the international

markets which nowadays environmental sustainability aspects such as GHG emission and water use are likely become the criteria for trade.

- (4) Climate change is found to be the factor that cause the water scarcity problem for agriculture in Thailand (as section 5.3). The policies on water resource management policies including water storage, efficient irrigation system, agricultural land zoning, as well as the good agricultural practices needs to be parallel implemented by taking in to account the future rainfall from the climate change modelling. The water management plan must be focused not only for the dry season but also for the wet season which it was forecasted to have the lower rainfall.

5.6 Limitations of the results and Recommendations for further researches

- The 1st and 2nd phases of research project focus on the water footprint methodology and background information development for further use of agricultural policy decision makers on assessing impacts of water use. However, the study still lack of considering the nexus of arable land, freshwater resource, food and energy production in the areas. Further stage, it is therefore necessary to integrate the whole those impacts of all agricultural activities in the selected watershed by combining with several life cycle sustainability assessment indicators in the study e.g. water scarcity footprint, carbon footprint, land productivity as well as energy performance.
- The LUC Policy Impact in the study is focused only on the potential impacts on the freshwater use, water resource availability, and water stress that would be happen in the studied region where LUC occurs. However, the other impacts such as economic and socio-economic impacts resulted from the LUC policy are not included in the scope of the project. The further research therefore should expand the scope of the assessment from the water consumption and water availability basis to determine the economic value of water in different watersheds or so called “externality of water”. Also, the economic and socio-economic impacts of LUC policy should also be included in the assessment in order to support the decision makers in development of sustainable agricultural land use policy.
- Research on climate change modelling need to be continue promoted for Thailand. This is to have the more reliable information of forecasted rainfall in the future which it is the important information for agricultural policy development.

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APPENDIX A: Sensitivity of household criteria

The criteria for estimating water withdrawal for household sector is defined at 200 liters/person/day for people who live in a municipal area and 100 liters/person/day for people who live outside a municipal area. Sensitivity analysis is carried out to investigate how much will the seasonal WSI results change if the criteria values are adjusted as showed in Appendix A (Table 1). The results of both Scenario 1 and 2 are presented in Appendix A (Figure 1). Even if the value of seasonal WSI change slightly, the classifications remain the same. As a result, these criteria is sufficient to provide a reasonable estimate of the water withdrawal for this sector.

Table 1 Water withdrawal for household sector when changing the criteria values

| | Criteria values | 75% decreased | 50% decreased | 50% increased | 100% increased |
|--|------------------------|----------------------|----------------------|----------------------|-----------------------|
| <i>(L/person/day for municipality)</i> | 200 | 50 | 100 | 300 | 400 |
| <i>(L/person/day for non-municipality)</i> | 100 | 25 | 50 | 150 | 200 |
| Monthly water withdrawn (million m³) | | | | | |
| Salawin | 1.77 | 0.44 | 0.89 | 2.66 | 3.54 |
| Kok | 2.90 | 0.72 | 1.45 | 4.35 | 5.80 |
| Ping | 11.49 | 2.87 | 5.74 | 17.23 | 22.97 |
| Wang | 2.79 | 0.70 | 1.39 | 4.18 | 5.58 |
| Yom | 8.07 | 2.02 | 4.03 | 12.10 | 16.13 |
| Nan | 8.20 | 2.05 | 4.10 | 12.31 | 16.41 |
| Khong | 23.19 | 5.80 | 11.60 | 34.79 | 46.39 |
| Chi | 23.31 | 5.83 | 11.66 | 34.97 | 46.62 |
| Mun | 32.01 | 8.00 | 16.00 | 48.01 | 64.01 |
| Chao Phraya | 78.65 | 19.66 | 39.32 | 117.97 | 157.29 |
| Sakae Krang | 1.40 | 0.35 | 0.70 | 2.10 | 2.80 |
| Pasak | 6.42 | 1.60 | 3.21 | 9.62 | 12.83 |
| Thachin | 15.22 | 3.81 | 7.61 | 22.83 | 30.45 |
| Mae Klong | 8.53 | 2.13 | 4.27 | 12.80 | 17.07 |
| Phetchaburi | 2.28 | 0.57 | 1.14 | 3.41 | 4.55 |
| West Coast Gulf | 2.11 | 0.53 | 1.06 | 3.17 | 4.22 |
| Prachin Buri | 3.50 | 0.87 | 1.75 | 5.24 | 6.99 |
| Bang Prakong | 7.30 | 1.82 | 3.65 | 10.95 | 14.60 |
| Tonle Sap | 1.28 | 0.32 | 0.64 | 1.91 | 2.55 |
| East Coast Gulf | 10.43 | 2.61 | 5.21 | 15.64 | 20.86 |
| Peninsula East Coast | 13.78 | 3.44 | 6.89 | 20.67 | 27.56 |
| Tapi | 4.65 | 1.16 | 2.32 | 6.97 | 9.29 |
| Thale sap Songkhla | 5.17 | 1.29 | 2.59 | 7.76 | 10.35 |
| Pattani | 1.71 | 0.43 | 0.85 | 2.56 | 3.41 |
| Peninsula West Coast | 8.64 | 2.16 | 4.32 | 12.95 | 17.27 |

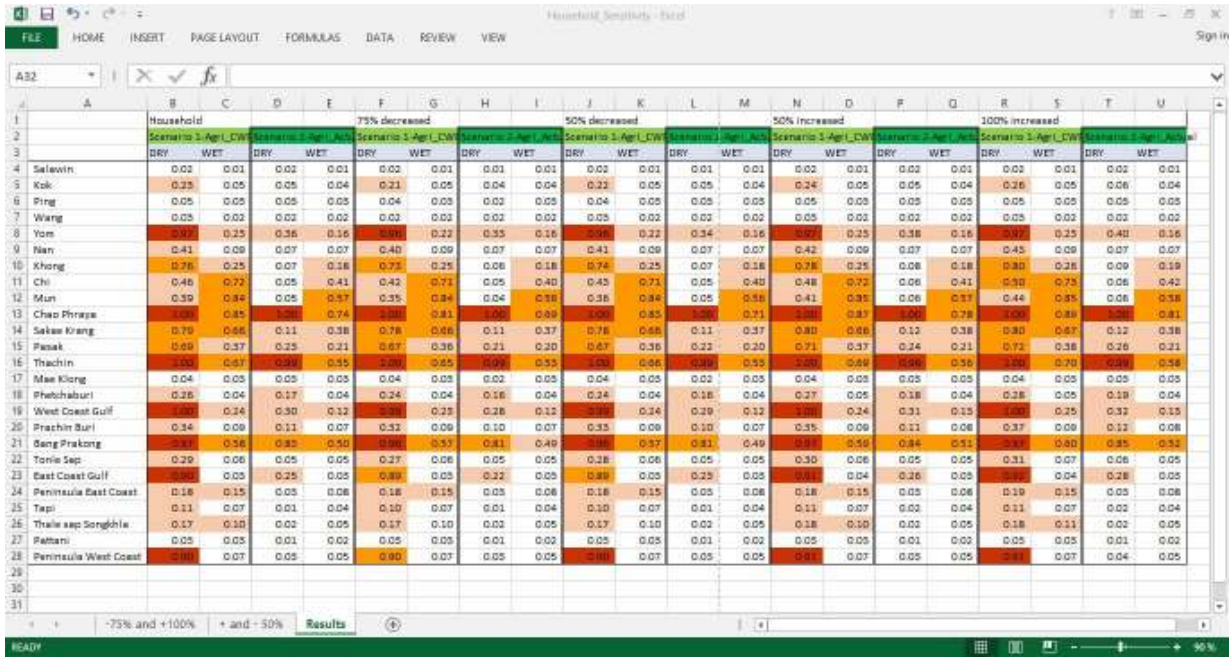


Figure 1 Seasonal WSI of Scenario 1 and 2 when changing the values of water demand criteria for household sector

APPENDIX B:

Template for WSI Calculation

The template for calculating Monthly WSI as shown in Eq. (7) has been prepared in the MS Excel format. The template consists of two main parts; A and B. The A part refers to a workbook (file) named “A-Input”. The B part contains a main workbook called “B-Calculation and five supporting workbooks i.e. “B-WW_AgN”, “B-WW_AgNE”, “B-WW_AgC”, “B-WW_AgE”, and “B-WW_AgS” as illustrated the flowchart of developing the template for WSI calculation in Figure 3.2. Accordingly the template is established based on seven workbooks. Data required for WSI calculation are needed for the A-Input workbook and linked to the B-Calculation workbook. The final results are displayed in a worksheet named “OUTPUT” depending on selected options.

The A-Input workbook contains six worksheets of data requirement for rainfall, stored water, household, agricultural, livestock and industrial sectors. The required data are simply classified into data for assessing water availability and water withdrawal. These data have been recorded and provided by official national sources (Table 3.3); therefore, data input templates are designed based on a record format of each data. Most of the data input are collected based on administrative boundary (province) except the stored water and industrial data which are reported based on hydrological boundary (watershed).

The B-Calculation workbook includes data calculations for estimating water withdrawal and available water. Criterion for assessing water withdrawal and factors required for calculating WSI values are embedded in this workbook. Details of each criterion are provided in the following section. To assess water withdrawal for agricultural sector, five supporting workbooks are separately created by region. The results of these five workbooks and agricultural data filled in the A-Input are linked to the B-Calculation for computing the total amount of agricultural water withdrawal. Calculations of water withdrawal for household, industrial and livestock sectors are also automatically calculated from filled data in the A-Input based on each criteria. The rainfall and stored water data filled in the A-Input are linked to calculate water availability. To evaluate a value of WSI for each watershed, all data based on provincial boundary are converted into the watershed boundary. Thus two worksheets named “Weight-Area” and “Basin-Data” are created for this conversion. Calculation of variables in the WSI equation embedded in a worksheet called “Factors” is evaluated based on variability of 10 years rainfall data (2002-2011). WSI values based on a monthly and seasonal basis are separately computed in worksheets; mWSI and sWSI. In case of the seasonal WSI, the calculation is based on the annual WSI equation (Eq.6) because of annual and monthly variabilities of rainfall. Finally, the results of WSI, water withdrawal, and water availability are linked to a “SUMMARY” worksheet. Then the final results to be shown in an “OUTPUT” worksheet is selected by users.

The template for WSI calculation is designed for general use and development modes. The general use mode is allowed only for filling data required in the A-Input workbook. The B-Calculation and five supporting workbooks (the B part) are protected by password in this mode. Thus the A-Input workbook and the “OUTPUT” worksheet of the B-Calculation workbook are visible for the general use mode. The B part can be unlocked in the development mode. This mode allows authorized users to update and modify the entire data and calculation in the B part.

A.1 Water availability

Water availability is defined as the total of rainwater and stored water in water reservoirs in order to cover all sources of available water. Hence monthly rainfall and stored water data are required to fill in worksheets named “Rainfall” and “Stored water” of the A-Input workbook as illustrated in Appendix B (Figure 1). The monthly rainfall data is linked to the “Weight-Area” worksheet and the stored water data is connected to the “Basin-Data” worksheet in the B-Calculation workbook. The historical rainfall data embedded in the “Factors” worksheet of the B-Calculation workbook are used for determining the geometric standard deviation according to the Eq. (5).

[A-Input workbook/Rainfall]

| Location | Year | Rainfall (mm) | | | | | | | | | | | |
|------------|-----------|---------------|------|------|------|-------|-------|-------|-------|-------|-------|-------|------|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1000000000 | 2002-2011 | 21.0 | 8.8 | 22.8 | 48.4 | 183.8 | 393.0 | 323.0 | 294.4 | 238.8 | 181.6 | 101.0 | 22.8 |
| 1000000000 | 2002-2011 | 51.0 | 18.0 | 48.4 | 88.8 | 220.0 | 388.8 | 281.2 | 258.8 | 204.0 | 134.8 | 80.2 | 24.4 |
| 1000000000 | 2002-2011 | 20.8 | 8.8 | 38.2 | 88.8 | 198.2 | 327.2 | 248.4 | 220.2 | 220.4 | 121.2 | 10.8 | 27.8 |

[A-Input workbook/Stored water]

| Project Name | Stored water (m3) | Other Metrics |
|--------------|-------------------|---------------|
| 1000000000 | 13200 | 52.87 |
| 1000000000 | 51144 | 48.58 |
| 1000000000 | 21.48 | 0 |
| 1000000000 | 4113.3 | 181.04 |
| 1000000000 | 5055.98 | 591.34 |
| 1000000000 | 13880.8 | 28.28 |
| 1000000000 | 281 | 189.39 |
| 1000000000 | 0 | 988.17 |
| 1000000000 | 80076 | 48.62 |
| 1000000000 | 0 | 87.71 |
| 1000000000 | 160 | 1.11 |
| 1000000000 | 482 | 188.47 |
| 1000000000 | 240 | 84.48 |
| 1000000000 | 35605 | 125.11 |
| 1000000000 | 0 | 141.72 |
| 1000000000 | 840 | 38.7 |
| 1000000000 | 0 | 157.02 |
| 1000000000 | 822 | 258.88 |
| 1000000000 | 728 | 89.94 |
| 1000000000 | 445 | 154.49 |
| 1000000000 | 81 | 89.88 |
| 1000000000 | 1888 | 181.18 |
| 1000000000 | 0 | 52.42 |
| 1000000000 | 1484 | 0.84 |
| 1000000000 | 0 | 24.07 |

Figure 1 Data requirement worksheets for water availability in the A-Input workbook

A.2 Water withdrawal for household sector

The water withdrawn by the household sector is estimated based on the number of population in the province multiplied with the basic minimum water requirement for humans based on literature. The number of population classified into living in municipal and non-municipal areas are required to fill in a worksheet named “Household” of the A-Input workbook. Then the filled data is linked to compute the amount of water withdrawal for this sector in a “Household” worksheet of the B-Calculation workbook. A criteria for this sector is also included in the same worksheet. The household worksheets in the A-Input and B-Calculation workbooks related to this sector are shown in Appendix B (Figure 2).

[A-Input workbook Household]

| Province | Municipal area | Non-municipal area | Total |
|-------------------|----------------|--------------------|-----------|
| 1. Aceh | 42,818 | 178,228 | 221,046 |
| 2. Sumatra Utara | 498,730 | 777,086 | 1,275,816 |
| 3. Sumatra Tengah | 311,000 | 195,217 | 506,217 |
| 4. Sumatra Barat | 867,632 | 770,021 | 1,637,653 |
| 5. Jambi | 377,494 | 870,880 | 1,248,374 |
| 6. Lampung | 570,800 | 549,808 | 1,120,608 |
| 7. Bengkulu | 178,088 | 271,290 | 449,378 |
| 8. Riau | 98,278 | 293,818 | 392,096 |
| 9. Kepulauan Riau | 250,647 | 287,501 | 538,148 |
| 10. Aceh Tenggara | 148,768 | 878,822 | 1,027,590 |
| 11. Aceh Selatan | 200,488 | 771,261 | 971,749 |
| 12. Aceh Tenggara | 172,178 | 767,800 | 939,978 |
| 13. Aceh Tenggara | 211,778 | 889,877 | 1,101,655 |
| 14. Aceh Tenggara | 188,782 | 862,830 | 1,051,612 |
| 15. Aceh Tenggara | 150,088 | 430,908 | 581,000 |
| 16. Aceh Tenggara | 218,900 | 788,888 | 1,007,788 |
| 17. Aceh Tenggara | 310,788 | 588,700 | 899,488 |
| 18. Aceh Tenggara | 508,188 | 381,848 | 889,036 |
| 19. Aceh Tenggara | 680,017 | 808,808 | 1,488,825 |
| 20. Aceh Tenggara | 200,148 | 281,881 | 482,029 |
| 21. Aceh Tenggara | 915,297 | 630,811 | 1,546,108 |
| 22. Aceh Tenggara | 128,738 | 860,808 | 989,546 |
| 23. Aceh Tenggara | 700,117 | 1,808,807 | 2,508,924 |
| 24. Aceh Tenggara | 188,608 | 1,240,790 | 1,429,398 |
| 25. Aceh Tenggara | 188,738 | 870,880 | 1,059,618 |
| 26. Aceh Tenggara | 418,818 | 290,880 | 709,698 |

[B-Calculation workbook Household]

| Province | Population | Municipal area | Non-municipal area | Total | Water demand (liters/day/ha) |
|-------------------|------------|----------------|--------------------|-----------|------------------------------|
| 1. Aceh | 30,818 | 178,228 | 208,338 | 386,566 | 3.19 |
| 2. Sumatra Utara | 458,730 | 777,086 | 1,275,816 | 2,503,632 | 2.15 |
| 3. Sumatra Tengah | 172,062 | 188,817 | 827,878 | 1,188,757 | 2.82 |
| 4. Sumatra Barat | 381,000 | 770,021 | 1,739,041 | 3,290,062 | 2.81 |
| 5. Jambi | 571,460 | 570,880 | 749,140 | 1,891,480 | 1.11 |
| 6. Lampung | 242,800 | 149,808 | 112,744 | 505,352 | 0.88 |
| 7. Bengkulu | 168,098 | 271,280 | 427,298 | 866,676 | 1.79 |
| 8. Riau | 98,198 | 555,638 | 452,614 | 1,106,450 | 1.86 |
| 9. Kepulauan Riau | 182,087 | 287,501 | 438,818 | 908,406 | 1.77 |
| 10. Aceh Tenggara | 148,768 | 878,822 | 338,382 | 1,365,972 | 1.14 |
| 11. Aceh Tenggara | 191,488 | 771,261 | 811,817 | 1,774,566 | 2.35 |
| 12. Aceh Tenggara | 172,178 | 767,800 | 860,678 | 1,702,656 | 2.80 |
| 13. Aceh Tenggara | 211,778 | 889,877 | 989,807 | 2,101,462 | 1.70 |
| 14. Aceh Tenggara | 188,782 | 862,830 | 1,051,612 | 2,103,224 | 1.89 |
| 15. Aceh Tenggara | 150,088 | 430,908 | 581,000 | 1,161,996 | 2.12 |
| 16. Aceh Tenggara | 218,900 | 788,888 | 1,007,788 | 2,015,576 | 1.25 |
| 17. Aceh Tenggara | 310,788 | 588,700 | 899,488 | 1,799,076 | 2.30 |
| 18. Aceh Tenggara | 508,188 | 381,848 | 889,036 | 1,779,072 | 1.33 |
| 19. Aceh Tenggara | 680,017 | 808,808 | 1,488,825 | 3,177,650 | 2.42 |
| 20. Aceh Tenggara | 200,148 | 281,881 | 482,029 | 964,058 | 1.85 |
| 21. Aceh Tenggara | 915,297 | 630,811 | 1,546,108 | 3,092,216 | 1.88 |
| 22. Aceh Tenggara | 128,738 | 860,808 | 989,546 | 2,019,102 | 1.74 |
| 23. Aceh Tenggara | 700,117 | 1,808,807 | 2,508,924 | 5,127,754 | 3.11 |
| 24. Aceh Tenggara | 188,608 | 1,240,790 | 1,429,398 | 2,859,196 | 1.81 |
| 25. Aceh Tenggara | 188,738 | 870,880 | 1,059,618 | 2,169,276 | 1.84 |
| 26. Aceh Tenggara | 418,818 | 290,880 | 709,698 | 1,429,396 | 1.19 |
| 27. Aceh Tenggara | 188,114 | 708,780 | 896,894 | 1,894,788 | 2.26 |

Figure 2 Worksheets of household sector in the templates for WSI calculation

A.3 Water withdrawal for industrial sector

To quantify water for the industrial sector, there are many factors related to water used in industries. Three approaches for estimating water for industrial sector have been reviewed including horse power (Koontanakulvong S., 2007), industrial area (RID, 2011), and production capacity (PCD, 2005 and PCD, 2011). However to maintain a consistency with the previous study, water demand for industry is assessed based on types of industries and their areas.

[A-Input workbook\Industry]

| Industry | Water Withdrawal (MCM) |
|----------------------|------------------------|
| Salween | 4.7 |
| Chong | 33.4 |
| Yan | 33.8 |
| Chk | 23.8 |
| Man | 38.7 |
| Ping | 34.9 |
| Wiang | 34.8 |
| Yon | 30.8 |
| Nan | 50.8 |
| Chao Phraya | 665.7 |
| Sakae Krong | 8.2 |
| Opakh | 555.5 |
| Thachin | 220.7 |
| Mae Krong | 86.2 |
| Phrae Bur | 5.1 |
| Stung Treng | 889.8 |
| Yon | 33.7 |
| East Coast Gulf | 74.5 |
| Phra Pradaeng | 8.8 |
| West Coast Gulf | 181.8 |
| Peninsula East Coast | 1,845.8 |
| Tan | 86.8 |
| Thaeng Sangkhro | 75.8 |
| Paran | 9.4 |
| Peninsula West Coast | 33.8 |

[B-Calculation workbook \Industry]

| Industry | Area | Water Demand (MCM) |
|----------------------|---------|--------------------|
| Salween | 4.7 | 8.38 |
| Chong | 33.4 | 2.71 |
| Yan | 33.8 | 2.80 |
| Chk | 23.8 | 2.07 |
| Man | 38.7 | 3.00 |
| Nan | 50.8 | 4.34 |
| Ping | 34.9 | 3.97 |
| Wiang | 34.8 | 2.78 |
| Yon | 30.8 | 2.78 |
| Man | 38.7 | 3.38 |
| Ping | 34.9 | 3.38 |
| Wiang | 34.8 | 3.38 |
| Yon | 30.8 | 3.38 |
| Nan | 50.8 | 3.38 |
| Chao Phraya | 665.7 | 74.71 |
| Sakae Krong | 8.2 | 8.23 |
| Opakh | 555.5 | 8.81 |
| Thachin | 220.7 | 17.85 |
| Mae Krong | 86.2 | 8.90 |
| Phrae Bur | 5.1 | 19.47 |
| Stung Treng | 889.8 | 8.71 |
| Yon | 33.7 | 8.27 |
| East Coast Gulf | 74.5 | 8.11 |
| Phra Pradaeng | 8.8 | 117.46 |
| West Coast Gulf | 181.8 | 8.29 |
| Peninsula East Coast | 1,845.8 | 8.25 |
| Tan | 86.8 | 8.78 |
| Thaeng Sangkhro | 75.8 | 8.43 |
| Paran | 9.4 | 8.43 |
| Peninsula West Coast | 33.8 | 8.43 |

Figure 3 Worksheets of industrial sector in the templates for WSI calculation

Data obtained based on a watershed boundary refers to 10 major industries classified by the Department of Industrial Works (DIW). Tourism is accounted as one of the industrial sectors in

this assessment and the water intensity of tourism sector will be assessed based on number of tourist and excursionist (RID, 2011). Hence a worksheet named “Industry” is designed based on a pattern of data recorded by watershed. Then the filled data is linked to an “Industry” worksheet of the B-Calculation workbook as can be seen these two templates in Appendix B (Figure 3).

A.4 Water withdrawal for livestock sector

The amount of water withdrawal for this sector is estimated from the number of head of livestock multiplied with a coefficient (an average water use per animal) (RID, 2010 and RID, 2011). Livestock refers to dairy cow, beef cattle, buffalo, pig, goat and poultry. Thus the number of head of livestock classified by provinces is required to fill in a “Livestock” worksheet of the A-Input workbook, then the filled data is linked to compute the amount of water withdrawal for this sector in a “Livestock” worksheet of the B-Calculation workbook. A criteria for this sector is stored in the same worksheet. The livestock worksheets in the A-Input and B-Calculation workbooks related to this sector are shown in Appendix B (Figure 4).

[A-Input workbook\Livestock]

| Province | Cows | Buffalo | Pig | Sheep | Goat | Chicken | Others |
|------------------------|---------|---------|---------|-----------|---------|---------|--------|
| 1 Aceh | 10,288 | 11,331 | 11,231 | 100,768 | 1,329 | 911 | 73 |
| 2 Sumatra Utara | 39,141 | 11,207 | 149,432 | 1,982,638 | 118,119 | 1,223 | 688 |
| 3 Sumatra Tengah | 10,288 | 1,129 | 14,971 | 1,021,688 | 11,278 | 106 | 81 |
| 4 Sumatra Selatan | 148,111 | 28,878 | 101,811 | 9,238,189 | 71,388 | 1,028 | 109 |
| 5 Jawa Barat | 82,178 | 8,124 | 10,111 | 2,102,127 | 11,196 | 811 | 141 |
| 6 Jawa Tengah | 11,187 | 1,111 | 148,882 | 1,148,191 | 11,122 | 178 | 11 |
| 7 Jawa Timur | 38,811 | 1,111 | 14,811 | 1,111,172 | 1,111 | 11 | 11 |
| 8 Kalimantan Barat | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 9 Kalimantan Tengah | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 10 Kalimantan Selatan | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 11 Sulawesi Utara | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 12 Sulawesi Tengah | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 13 Sulawesi Selatan | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 14 Sulawesi Tenggara | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 15 Maluku Utara | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 16 Maluku | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 17 Papua Barat | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 18 Papua | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |
| 19 Nusa Tenggara Barat | 10,111 | 1,111 | 11,111 | 1,111,111 | 1,111 | 111 | 111 |

[B-Calculation workbook \Livestock]

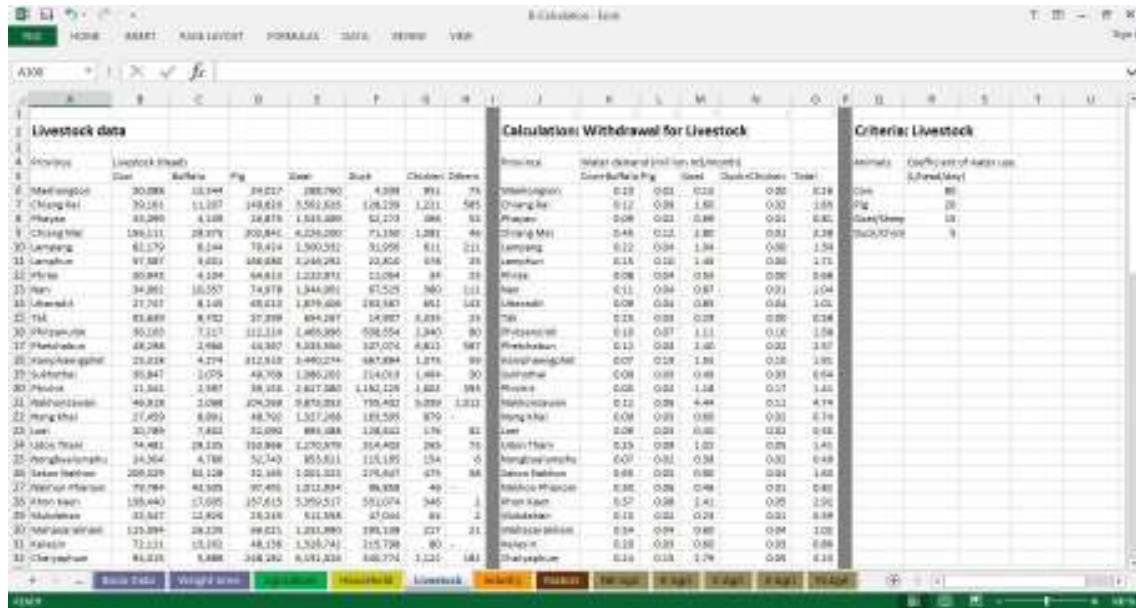


Figure 4 Worksheets of livestock sector in the templates for WSI calculation

A.5 Water withdrawal for agriculture

Water required by crop or so called “crop water requirement (CWR)” refers to the volume of water lost via evapotranspiration process including evaporative water from soil and crop surfaces and transpired water from crop to atmosphere. In other word, CWR is denoted as crop evapotranspiration (ET_c). This term can be quantified either empirical measured at a field or theoretical estimated via formula or model. Results obtained from a field experiment are specific and cannot be applied to another area because weather conditions, soil characteristics, and crop variety affecting to volume of water used by crop. Therefore ET_c or CWR is practically computed by theoretical estimated formula or model simulation. This theoretical approach is established based on two terms of weather and crop specifics for each crop cultivated in different location. The general formula (Eq. 8) used for estimating crop water use is expressed as follows (Allen et al., 1998 and FAO, 2010).

$$ET_c = K_c \times ET_0 \quad (\text{Eq. 8})$$

Variations of weather and crop species are taken into account through a reference crop evapotranspiration (ET_0) and crop coefficient (K_c). These two terms are developed to be related to estimate the ET_c or CWR of any crops cultivated in any area and time. Penman Monteith method is applied with particular meteorological data for calculating the ET_0 . Thus these two factors (ET_0 values by province and K_c values by crop) are embedded in worksheets named “Kc” and “ET0” of the five supporting workbooks (see a case of North-Eastern region in Appendix B Figure 5). Accordingly, CWR of 11 staple crops (rice (major and second), maize, cassava, sugarcane, oil palm, mung bean, soybean, peanut, coconut, para rubber and pineapple) is estimated in this study

based on crop calendar. K_c values of 40 crops are referred from RID, calculation of CWR for the 40 crops also added in the five supporting workbooks.

Two scenarios are made for assessing the amount of agricultural water.

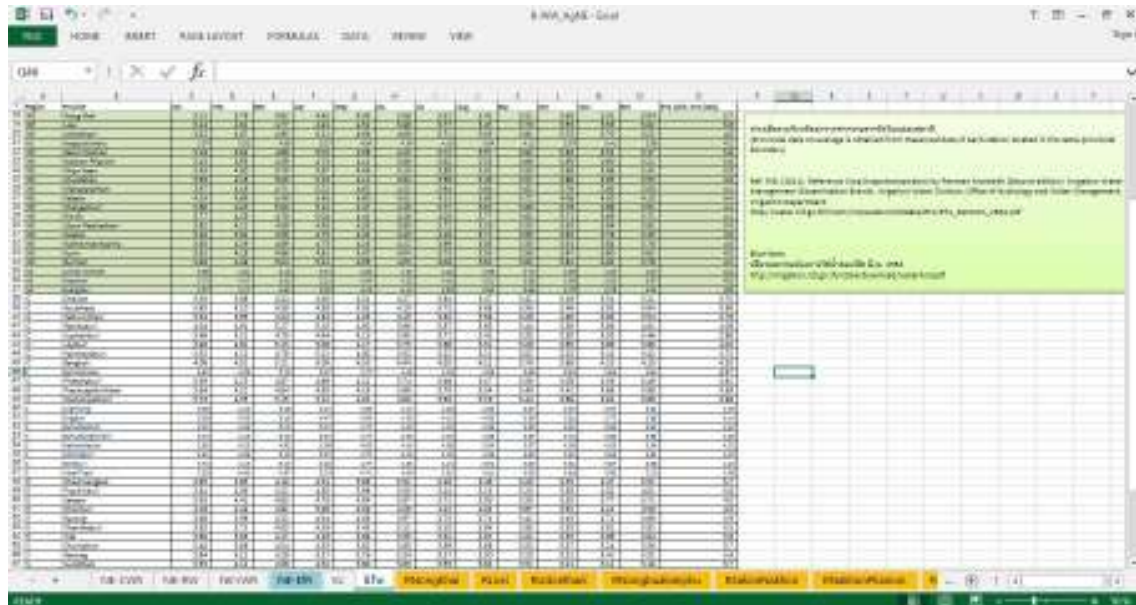
- Scenario 1: refers to water is fully supplied to meet the theoretical CWR
- Scenario 2: refers to water deficit scenario i.e. estimated the total water used for crops based on existing irrigated and rain-fed (non-irrigated) areas

Water required for growing crops in non-irrigated areas is supposed to be equal to the amount of rainfall used by crop so-called effective rainfall. The effective rainfall is automatically computed (from the rainfall data filled in the A-Input workbook) in a worksheet called “-EfR” of the five supporting workbooks (see a case of North-Eastern region in Appendix B Figure 5). If CWR is higher than effective rainfall, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of effective rainfall. On the other hand, if effective rainfall is higher than CWR, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of CWR. Water required for growing crops cultivated in irrigated areas are expected to meet total amount of crop water requirement. Thus, a sum of effective rainfall and irrigation water is accounted as the total water withdrawal for crops cultivated in irrigated areas.

[B-WW_AgNE workbook\Kc]

| Crop | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1. Cereals | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 2. Legumes | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 3. Oilseeds | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 4. Fodder | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 5. Horticulture | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 6. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 7. Cashew | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 8. Coconut | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 9. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 10. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 11. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 12. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 13. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 14. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 15. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 16. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 17. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 18. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 19. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 20. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 21. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 22. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 23. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 24. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 25. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 26. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 27. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 28. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 29. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 30. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 31. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 32. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 33. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 34. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 35. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 36. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 37. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 38. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 39. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| 40. Rubber | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |

[B-WW_AgC workbook\ETo]



[B-WW_AgC workbook\C-Efr]

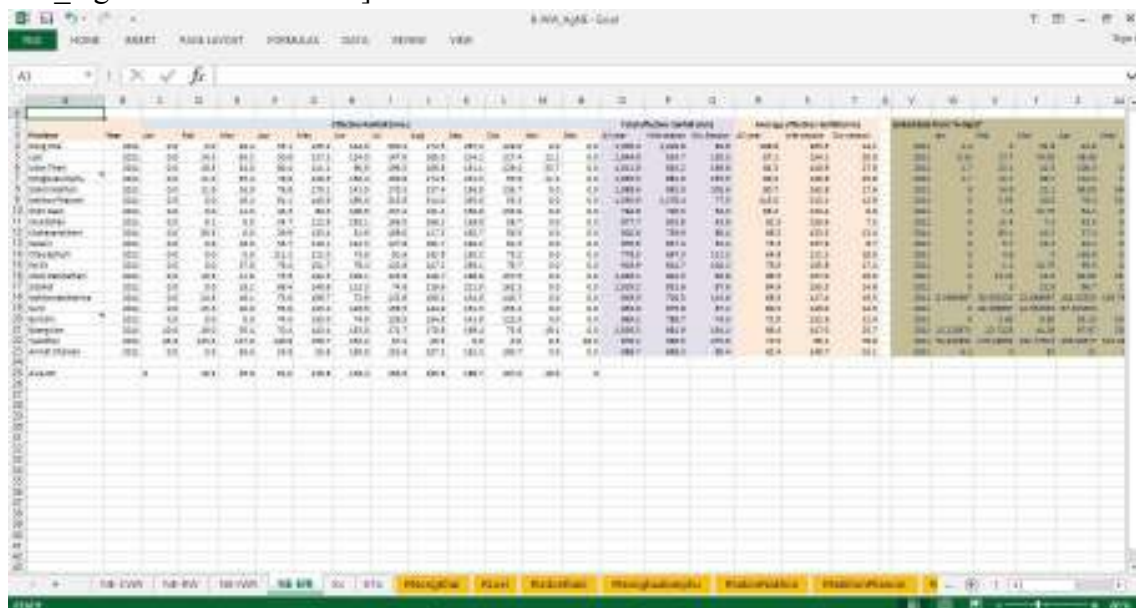


Figure 5 Examples of worksheets for agricultural water calculation of North-eastern region (B-WW_AgNE), one of the supporting workbooks

The outcomes of the five supporting workbooks include CWR, rainwater (effective rainfall), and irrigation water of the 40 crops. These results are stored in worksheets named “-CWR”, “-RW” and “-IWR” and also linked to the B-Calculation workbook (see a case of North-Eastern region in Appendix B Figure 6).

To estimate the total agricultural water withdrawal based on the 11 staple crops, crop plantation by province, irrigated and non-irrigated areas, and irrigation efficiency are required to fill in an “Agriculture” worksheet in the A-Input workbook as showed in Appendix B Figure 7. The irrigation efficiency at 0.65 (Equation 9) is not taken into account in calculating the amount of irrigation water in this study; therefore, 100% is defined instead. Then these filled data is linked

to worksheets called “E-Agri”, “C-Agri”, “N-Agri”, “NE-Agri” and “S-Agri” of the B-Calculation workbook). These five worksheets contain the results obtained from the five supporting workbooks associated with plantations (see a case of North-Eastern region in Appendix B Figure 8). Consequently, the final results of total water withdrawal for agriculture by province (in an “Agriculture” worksheet shown in Appendix B Figure 9) are obtained in two scenarios. The first scenario is considered based on the full CWR and the second scenario is based on the total crop water use.

[B-WW_AgNE]

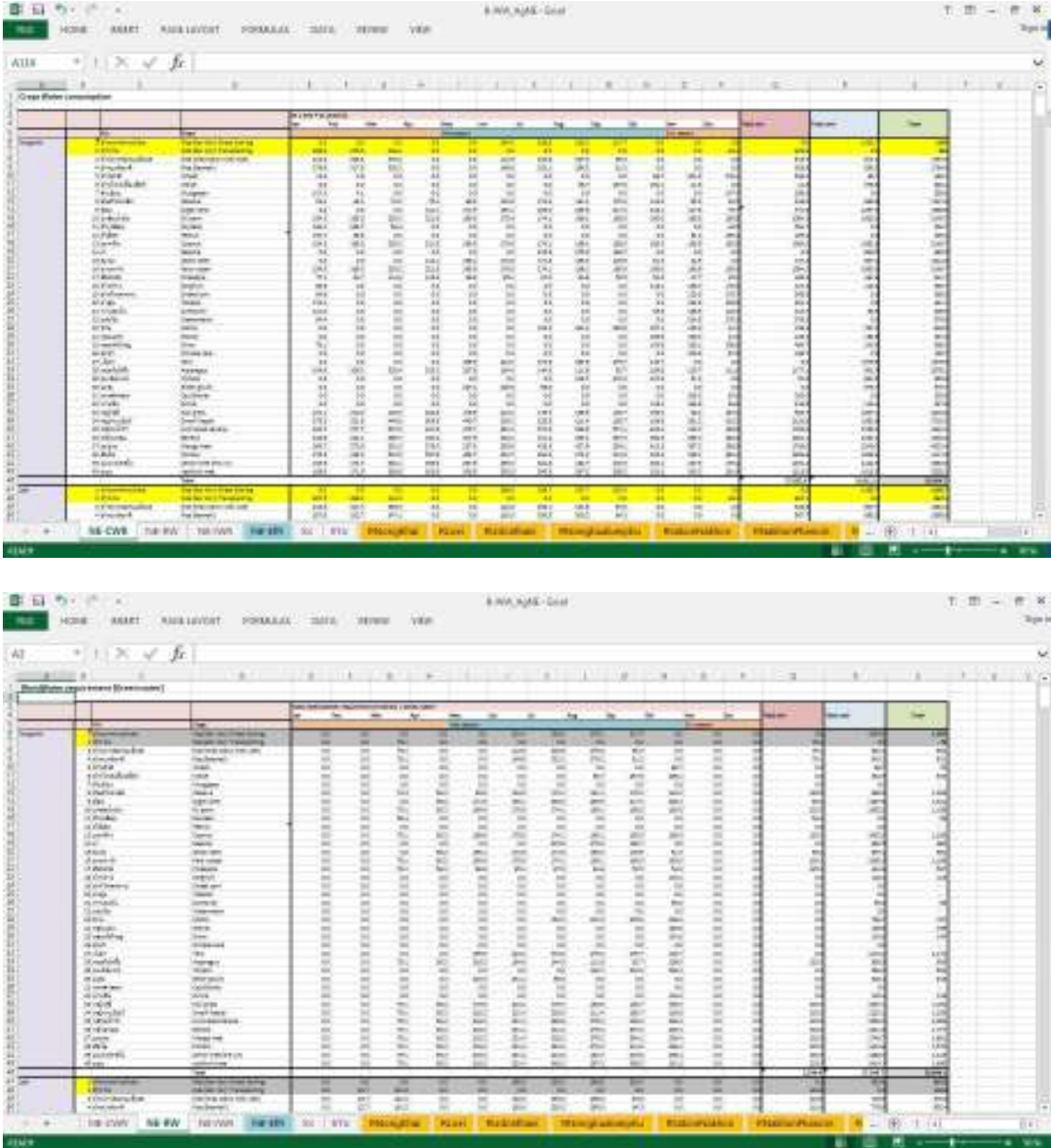


Figure 6 Three worksheets named “NE-CWR”, “NE-RW” and “NE-IWR” of the B-WW_AgNE workbook (Results of the supporting workbook)

[A-Input workbook\Agriculture]

Figure 7 Worksheet for agricultural data in the A-Input workbook

[B-Calculation workbook\NE-Agri]

Calculation - Irrig

HOME RESET RASLEVERIT FORMULAE DATA REVIEW VIEW

DA10

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Crop water requirement

| Crop | Area (ha) | Crop water requirement (mm) | | | | | | | | | | | | Total (mm) |
|--------|-----------|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------------|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Calculation - Irrig

HOME RESET RASLEVERIT FORMULAE DATA REVIEW VIEW

DA10

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

(Rain)Water requirement

| Crop | Area (ha) | Water requirement (mm) | | | | | | | | | | | | Total (mm) |
|--------|-----------|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------------|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Irrigated

Calculation - Irrig

HOME RESET RASLEVERIT FORMULAE DATA REVIEW VIEW

DA10

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Irrigated water requirement

| Crop | Area (ha) | Irrigated water requirement (mm) | | | | | | | | | | | | Total (mm) |
|--------|-----------|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------------|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| Wheat | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1200 |
| Barley | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 600 |
| Maize | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

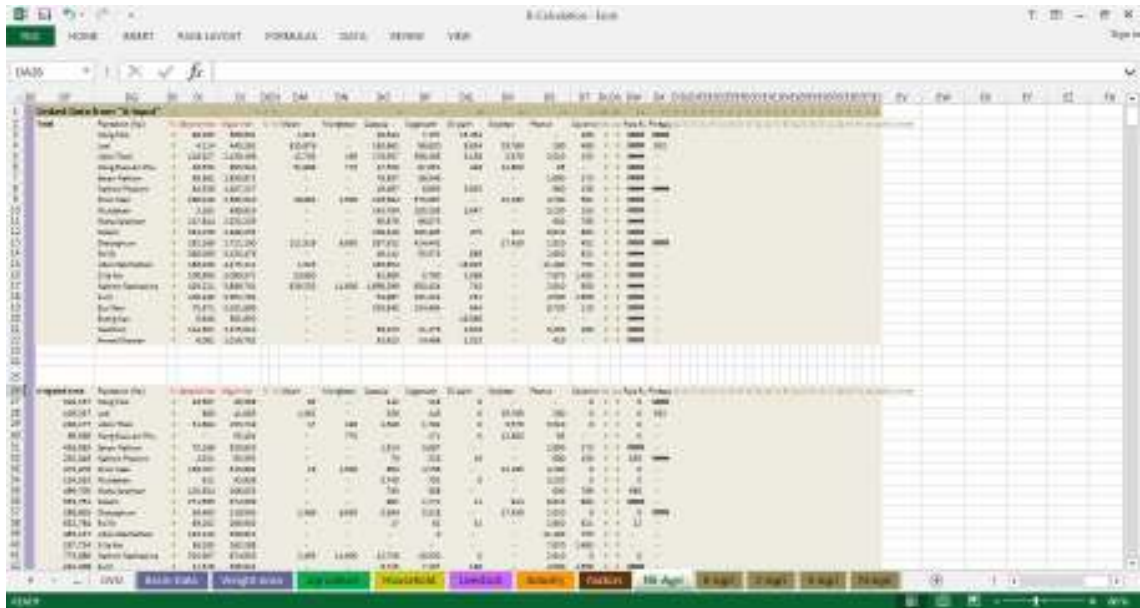


Figure 8 Worksheet of agricultural data by region in the B-Calculation workbook (a case of North-Eastern region)

[B-Calculation workbook\Agriculture]

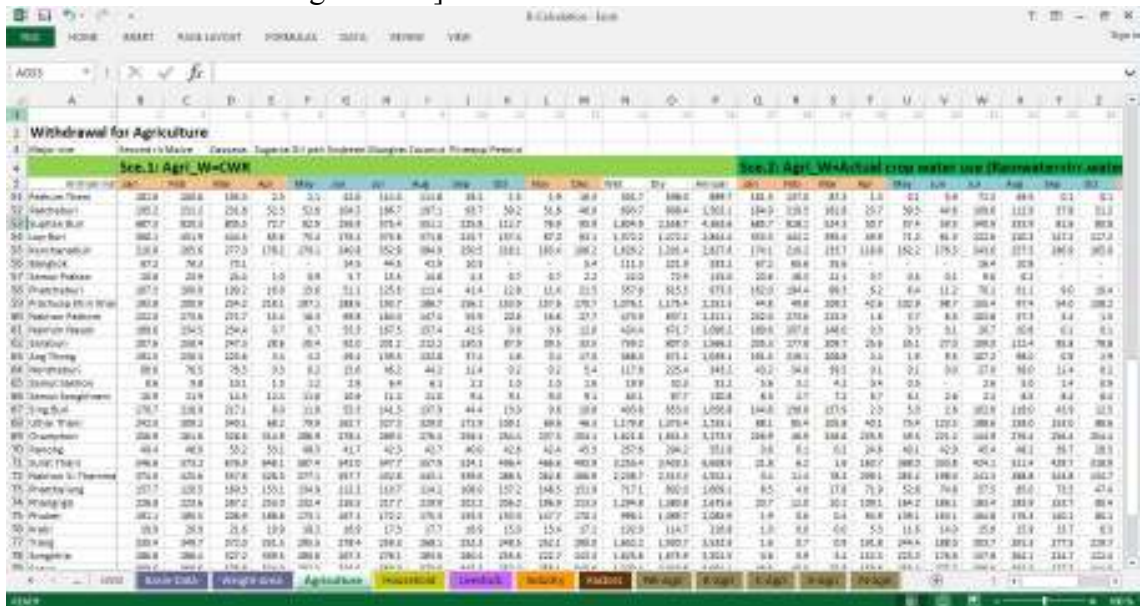


Figure 9 Worksheets for agricultural water results of two scenarios in the B-Calculation workbook

**APPENDIX C:
Minutes on Consultation Panel**

Consultation Panel

Water Footprinting of Food, Feed, Fuel and Fibre for Effective Water Resources Management
(Phase II)

27 July 2015 at Mamaison hotel, Burirum

Seminar program

| | | |
|---------------|---|-------------------------------------|
| 09.30 – 10.00 | - | Registration |
| 10.00 – 10.30 | - | Presentation of the studied results |
| 10.30 – 10.45 | - | Coffee Break |
| 10.45 – 12.00 | - | Discussion |
| 12.00 – 12.30 | - | Summary |
| 12.30 – 13.30 | - | Lunch |

Participant registration

| Government organization | Name | Position / Division |
|---|-----------------------------|---|
| Nakhon Ratchasima Provincial Agricultural Extension Office | Mr.Cherdchaichana Yutthagla | Agricultural Extensionist |
| | Mr.Nathanat Sunthadphom | Agricultural Extensionist |
| Non Suwan District Agricultural Extension Office, Nakhon Ratchasima | Mr.Somnuek Watthaklang | Professional level of Agriculture |
| Buri Ram Provincial Agricultural Extension Office | Mr.Kangsadarn Sawaschai | Director of Buri Ram Provincial Agricultural Extension Office |
| Buri Ram , Office of the rubber replanting aid fund | Mr.Somchart Gaysorn | Director of the rubber replanting aid fund office |

Key findings:

- The main problem that affects to cassava production is the shifting of rain season. Normally, the rain season in Nakhon Ratchasima regions should be in March to April. However, there are some years found that may be late in May to June.
- Currently, the rice farmer can effectively use their agricultural area by applying multicultural practice. A rice field can also use to grow cassava instantly when the farmer finished the harvesting period for rice. The multicultural practice can increase the income to farmer in dry season.
- There are supports from government to invest in pond construction in individual agricultural area. It helps to reduce the burden of providing water from irrigation system in dry season. However it need to consider the geographical locations, some agricultural areas are remote from irrigation system, surface water and also out of rain-fed area. The farmer can't supply the water to their pond.

Consultation Panel

Water Footprinting of Food, Feed, Fuel and Fibre for Effective Water Resources Management
(Phase II)

24 July 2015 at Pullman Khon Kaen Raja Orchid, Khon Kaen

Seminar program

| | | |
|---------------|---|-------------------------------------|
| 09.30 – 10.00 | - | Registration |
| 10.00 – 10.30 | - | Presentation of the studied results |
| 10.30 – 10.45 | - | Coffee Break |
| 10.45 – 12.00 | - | Discussion |
| 12.00 – 12.30 | - | Summary |
| 12.30 – 13.30 | - | Lunch |

Participant registration

| Government organization | Name | Position / Division |
|--|--------------------------------|--|
| Khon Kaen Provincial Agricultural Extension Office | Mr.Thammanoon Boonkraisorn | Director of Khon Kaen Provincial Agricultural Extension Office |
| | Mr.Krittayaporn Somranphat | Agricultural Extensionist |
| Mueang District Agricultural Extension Office, Khon Kaen | Mr.Sayan Khaokaeng | Director of Mueang District Agricultural Extension Office, Khon Kaen |
| | Mrs.Pissamai Munsri | Agricultural Extensionist |
| Ban Phai District Agricultural Extension Office, Khon Kaen | Mr.Weerasak Angpinich | Agricultural Extensionist |
| Royal Irrigation Department 6 | Mr.Sompong Chankramol | Water management and maintenance |
| Kalasin Provincial Agricultural Extension Office | Miss Oranuch Katsanchai | Agricultural Extensionist |
| | Mrs.Sopis Bunguthum | Agricultural Extensionist |
| Chaiyaphum Provincial Agricultural Extension Office | Mr.Phuset Pomsopol | Agricultural Extensionist |
| | Mr.Surat Ditchaowalit | Agricultural Extensionist |
| Khon Kaen Rice Research Center | Mrs.Jirawan Sungsomrang | Agricultural Extensionist |
| Faculty of Environment, Maharakham University | Asst.Prof.Dr.Jittima Prasara-A | Assistant Professor |
| KSL Sugar factory | Mr.Sompong Kamngao | Agricultural Extensionist |
| | Mrs.Chanok Yensabai | Agricultural Extensionist |
| Office of the rubber replanting aid fund | Mr.Somchart Gaysorn | Director of the rubber replanting aid fund office |
| | Mr.Dithadet Watthanaporn | Assistant director of the rubber replanting aid fund office |

Key findings:

- Water shortage in the future can be resulted from domestic demand due to urban growth. It is important to build up an awareness of water used in agricultural sector because of a low-efficiency and inappropriate plan on water management remains.
- Another factor is land use allocation. The population increase while the land is limitation. So, it needs to set a policy like agricultural zoning consisted with water resource management in district scale.

- Due to urban growth and market demand, the practice of planting on water management in field crops is more important than that of crop expansion.
- Changing attitudes and cultural practices of farmers are very important for implementing any water management plan properly. There are still misunderstanding for agricultural practices on water management by farmers. The improvement of practice on water management can help to reduce unnecessary water consumption.
- Planting techniques for rice should be changed to dry seed broadcasting, or alternate wetting and drying. Alternate wetting and drying (AWD) rice system is promoted by government confirmed that it can reduce water used. However additional areas for water transfer is an obstacle of this technique. Because it need an area for water storage that ready to irrigate to paddy field any time.
- Shortening the rice growing season can reduce water used for rice production but the weight of rice grain may not reach the standard.
- Groundwater is mainly used as a source of water supply. Solar cell or LPG are alternative choices of an energy supply for groundwater pumping system in rural areas without access to electricity. However, to install the solar cell has a rather high investment cost while using the LPG also increases costs of crop production.
- A drip irrigation system has already proved that it helps to reduce water used for growing crop. However, a power supply is also a major problem of a drip irrigation system for agricultural plantations in rural areas.

Consultation Panel

Water Footprinting of Food, Feed, Fuel and Fibre for Effective Water Resources Management
(Phase II)

4 August 2015 at Woraburi Ayothaya convention resort, Ayutthaya

Seminar program

| | | |
|---------------|---|-------------------------------------|
| 09.30 – 10.00 | - | Registration |
| 10.00 – 10.30 | - | Presentation of the studied results |
| 10.30 – 10.45 | - | Coffee Break |
| 10.45 – 12.00 | - | Discussion |
| 12.00 – 12.30 | - | Summary |
| 12.30 – 13.30 | - | Lunch |

Participant registration

| Government organization | Name | Position / Division |
|---|---------------------------|---|
| Ayutthaya Provincial Agricultural Extension Office | Mr. Wutthichai Jittrikarn | Agricultural Extensionist |
| | Miss Parindhorn Piyarak | Agricultural Extensionist |
| Lop Buri Provincial Agricultural Extension Office | Mr. Charoeng Pimkhan | Agricultural Extensionist |
| | Mr. Thavorn Sangiamwong | Agricultural Extensionist |
| Pathum Thani Provincial Agricultural Extension Office | Miss Jamriang Muenwan | Agricultural Extensionist |
| | Miss Orapim Suriya | Agricultural Extensionist |
| Royal Irrigation Department 13 | Mr. Pirat Tupprasert | Director of water management |
| Office of Agricultural Economics 7 | Mrs. Unchana Tracho | Director of office of Agricultural Economics 7 |
| | Miss Chonlada Phetsisuk | Plan and policy analyst |
| Office of Agricultural Economics 12 | Mr. Kosit Wirojphet | Director of office of Agricultural Economics 12 |

Key findings:

- Water scarcity in some areas should be separately defined to water scarcity for agricultural, industrial, household demand, etc. Because the difference of land use have an effect in different ways.
- The irrigation and non-irrigation area should be considered in this study. In non-irrigation area may not be stressed from a large water use for rice because there have rainwater enough for growing. In contrast, cultivation of rice in irrigation area may be stressed from water use as the result from lack of water supply and rainwater in dry season.
- This study should be more considerate about the water consumption from increasing of population and decreasing of forestation in the future. Climate change is one of the crucial factors that impact to water availability aspect; however, the trend of population and forestation is also the major impact to water withdrawal aspect.
- This study should be added the study of water crisis as the worst case scenario in order to see the impact of water use in different sectors and find the solution to deal with this situation when it may occur in the future.

- The calculation of stress index should be divided in term of water stress for agricultural, industrial, household, ecosystem sectors. Then these calculation would be compared to see which sector is the hotspot for water consumption.
- This study can support the policy for crop zoning strategy that will be consistent with water management for agriculture.