

PROJECT REPORT 3

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RECOMMENDATIONS ON THE FURTHER DEVELOPMENT OF REMOTE SENSING AND WATER ACCOUNTING TO SUPPORT SUBBASIN AGRICULTURAL WATER MANAGEMENT IN ASIA





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1 EXECUTIVE SUMMARY

The main aim of this small research activity was to assess the utility of freely-available, or low cost, remotely sensed data to provide relevant timely hydrological information for agricultural water management – including use in tools such as water accounting, in low/middle income countries. The project aimed to identify existing and emerging remote sensing data products, derived-hydrological information and associated water accounting tools, and describe their applicability to decision-making by agriculture and water decision-makers in Viet Nam. It aimed to cover all scales from basin to local (e.g. subbasin, irrigation district), with a specific focus on the smallest scale at which water managers operate. And, we applied a user-centred approach to maximise the outcomes for water managers, in particular those working at subbasin scales, making decisions influencing water availability and quality for agriculture, in the context of water security to meet all needs.

The methods and findings of the Viet Nam pilot project are described in Project Report 2: *Understanding The Role Of Remote Sensing And Water Accounting In Supporting Agricultural Water Management In Viet Nam*. The research proved the concept and feasibility of subbasin agricultural water management, and there is very strong interest from stakeholders to continue to refine the approaches (by extending to new types of crops and geologies), and to develop the skills required by a team within MAE to acquire remote sensing and other data, process this and generate water accounting data, and, to develop the skills of provincial and district MAE staff, and IMC staff, to interpret, interrogate and apply water accounting output to improving subbasin water management.

The research process and results have generated results, insights and lessons that may be useful for other research endeavouring to improve the application of water accounting for agricultural water management. These relate to:

- The user-centred research approach
- Downscaling water accounting to subbasin scales

Additionally, the research project sought to position these insights and lessons within the broader space of water accounting research and application to meet subbasin water management data needs in our region.

User-centred research process

The application of Water Accounting, including the use of remote sensing to contribute data to these analyses, to improve water management is not new, including to the case study country of this research project, Viet Nam. This project sought to improve the demand for, and willingness to uptake, these advanced water management tools, by those water managers making planning, management and operational decisions. The user-centred approach adopted here aimed to:

- Understand the existing governance arrangements relating to surface and groundwater management, such as the roles and responsibilities of different agencies, the relationships between agencies, and with irrigation operators.
- Appreciate the water issues or problems being experienced, and identify the range of water resources management tasks being undertaken, or that should/need to be undertaken, especially at subbasin scales, and, assess the status of use of data to inform these decisions (i.e. the maturity of data-informed water resources management)
- Understand the existing capacities, both individual and institutional, for the technical skills required for remote sensing and water accounting, and, if needed, the interest in acquiring these capacities

- Draw on this knowledge of the governance and management regimes, and capacities, to identify specific water data needs that might be met with remote sensing and down-scaled water accounting tools and guide the format of such tools and outputs.
- Assess the usefulness, usability, accessibility and feasibility, and interest, in the water accounting tools developed in the project.

These aims were supported by the application of two frameworks to assist in the design and analysis of qualitative data:

1. Maturity of Data-informed Water Resources Management

The project involved the development and application of a framework and method to assess the maturity of data-informed water resource management. The application of a localised water resources management maturity framework was useful (i) in identifying existing strengths and weaknesses of data-informed water resources management, and (ii) as a structured, participatory and deliberative process for stakeholder self-assessment of current water resource practices and data availability.

The research confirmed that many core water resources management tasks are already being undertaken across planning, management, and operations of water resources infrastructure. However, the extent to which these tasks were systematically informed by water data varied considerably, with stronger application in surface water operation and management, including flood and drought, and weaker application in groundwater management, monitoring of allocation, water-use efficiency and productivity and water accounting.

The participants reflected several benefits of this process:

- The framework provided structure and ensured important aspects of water resources management were not overlooked, but the process allowed for localisation of this framework to ensure it made sense to Viet Nam.
- The in-person and small group process supported a deliberative process that was inclusive, overcoming some of the challenges of large groups of stakeholders within which seniority and types of organisations can reduce the opportunities for some participants to voice their opinions.
- The rare opportunity to gather and share experiences and knowledge with others from across Viet Nam, particularly from different provinces with different water resources contexts, and from different types of organisations. Reflecting this benefit, a key recommendation, repeated by many participants, was the need for a more coordinated approach to water data and water management

2. Assessing Usefulness, Usability, Accessibility, Interest

To improve the outcomes of this research activity, particularly with regard to the demand and interest to adopt subbasin water accounting approaches, the project assessed the usability, usefulness, accessibility and feasibility, and interest. These were defined as follows:

- Usability - the potential for stakeholders to use the tools in their current form
- Usefulness – the potential to use the outputs from the tools to assist with water resources management
- Accessibility & Feasibility – the potential for stakeholders to acquire the resources, facilities and systems to implement and use remote sensing / water accounting tools e.g. to acquire the required input data, to access required computing equipment to use the tools.

- Interest – the attitude of stakeholders to adopt remote sensing / water accounting approaches. Here stakeholders include the potential users of the tools, the potential users of the outputs, and the senior managers of these units with governance and management decision-making powers.

Taking an intentional approach to assessing these 4 dimensions for scaling up gave the research team a deeper insight into the likely barriers needing attention in order to progress this project goals.

Downscaling water accounting to subbasin scales

Subbasins can range in size, as they represent a smaller watershed, drainage area, or geological basin located within a larger one. The type and complexity of management decisions also vary with scale, ranging from the management of transnational water issues, involving national governments and international treaties, down to management of water supplies to, and within, irrigation scheme areas (or irrigation clusters as they are known in Viet Nam), involving irrigation management companies. As the basins became smaller the decisions being made went from planning to more operational in nature. The decision-making being made at subbasin scales falls naturally across the 'neoclassical' and 'classical' approaches to agricultural water management. Subbasin water accounting could therefore provide a bridge to link the two approaches to agricultural water management, where irrigation district scale interventions could be evaluated for possible impacts on the broader subbasin scale.

The research demonstrated there were many water accounting and related parameters that can be produced by drawing upon remotely sensed data, which have the potential to be useful for water resources management including at subbasin scales, in Viet Nam and more broadly in the region. However, depending upon the spatial scale, and methodology involved for each parameter, there are varying levels of complexity in acquiring and computing the datasets. These ranged from; least complex where the required data layers could be obtained from the web and easily incorporated and interpreted in GIS, to moderate complexity that required some calculations in GIS to derive desired indicators and the most complex that requires some kind of modelling to generate the desired indicators.

Positively, the availability and accessibility of remote sensing data, relevant to application to subbasin water accounting is rapidly evolving. The next generation of free and accessible remote sensing satellite missions promises to provide more accurate, higher-resolution, and more frequent information on water availability, directly addressing some of the limitations of current satellite datasets, for example, the Mass Change mission under NASA's Earth System Observatory, SMAP with higher resolution and frequency, and Copernicus High Priority Candidate Missions (such as the L-band radar mission ROSE-L), which will be particularly important for Southeast Asia. Optical and radar imaging capacity is also set to improve e.g. NISAR (radar satellite for soil moisture and crop conditions), SWOT (surface water elevation), and the increased spectral bands of Landsat Next mission.

Hydrological datasets are also becoming more available through cloud computing platforms, such as CSIRO's Basin Futures and EASI platforms, however the resolution and complexity involved in processing these sets will likely limit their immediate applicability to the subbasin water managers in low and middle income countries.

On water accounting, IHE Delft continue to make improvements to Water Accounting Plus tools and methods, such incorporation of a new Soil Water balance model (though this requires programming skills to effectively use) and are developing Irrigation Performance Indicators using WaPOR data, which are freely available. Another key developer of water accounting is the International Institute for Water Management (IWMI). IWMI is working on high resolution evapotranspiration and Irrigation Scale Accounting, and have also developed the Scale Invariant Water Accounting Plus method, which enables the development of Water Accounts for different administrative units and areas.

These developments demonstrate the increasing availability of high-resolution ET tools, but most applications remain limited to pilot regions. In Southeast Asia, operational adoption remains limited, highlighting the need for user-centric approaches such as those explored in this study.

2 WATER ACCOUNTING RESEARCH AND DEVELOPMENT

This research project applied a user-centred approach to maximise the outcomes for water managers, in particular those working at subbasin scales, making decisions influencing water availability and quality for agriculture, in the context of water security to meet all needs. The research process and results have generated results, insights and lessons that may be useful for other research endeavouring to improve the application of water accounting for agricultural water management. These relate to:

- The user-centred research approach
- Downscaling water accounting to subbasin scales

Additionally, the research project sought to position these insights and lessons within the broader space of water accounting research and application to meet subbasin water management data needs in our region. The following sections summarise these findings.

2.1 A USER-CENTRED APPROACH TO RESEARCH AND DEVELOPMENT OF WATER ACCOUNTING

The application of Water Accounting, including the use of remote sensing to contribute data to these analyses, to improve water management is not new, including to the case study country of this research project, Viet Nam. Many such projects are successful in building awareness of the potential of both remote sensing and water accounting to support data-informed water management. This project sought to improve the demand for and willingness to uptake these advanced water management tools, by those water managers making planning, management and operational decisions. Rather than developing a set of tools, then engaging with stakeholders to determine their usefulness and make refinements, the user-centred approach adopted here aimed to:

- Understand the existing governance arrangements relating to surface and groundwater management, such as the roles and responsibilities of different agencies, the relationships between agencies, and with irrigation operators.
- Appreciate the water issues or problems being experienced, and identify the range of water resources management tasks being undertaken, or that should/need to be undertaken, especially at subbasin scales, and assess the status of use of data to inform these decisions (i.e. the maturity of data-informed water resources management)
- Understand the existing capacities, both individual and institutional, for the technical skills required for remote sensing and water accounting, and, if needed, the interest in acquiring these capacities
- Draw on this knowledge of the governance and management regimes, and capacities, to identify specific water data needs that might be met with remote sensing and down-scaled water accounting tools and guide the format of such tools and outputs.
- Assess the usefulness, usability, accessibility and feasibility, and interest, in the water accounting tools developed in the project

These aims were met through a series of qualitative research activities, and water management engagement in the research process. This project research process is summarised in Figure 2.1.

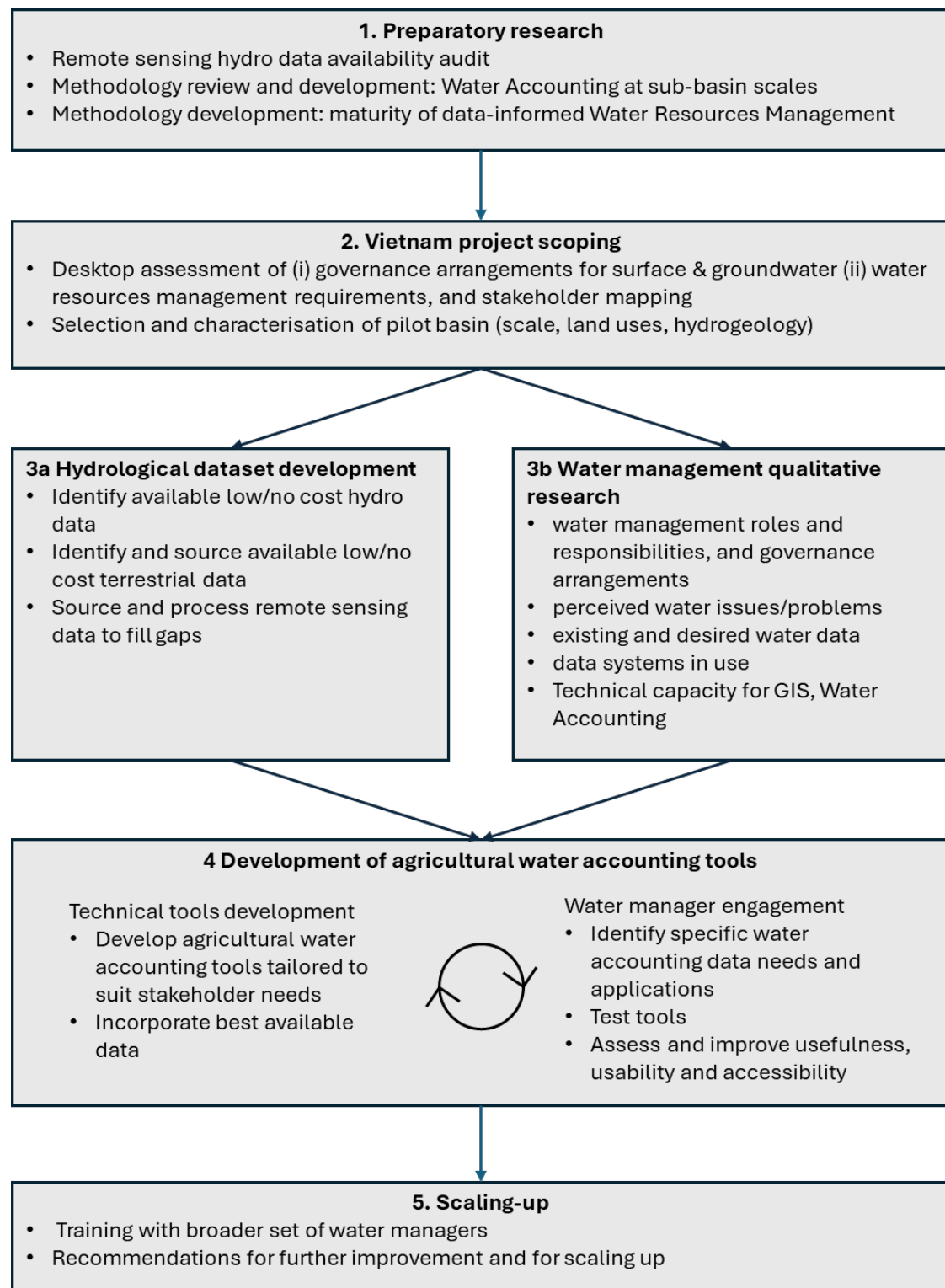


FIGURE 2.1 OVERVIEW OF THE USER-CENTRED PROJECT APPROACH TO SUBBASIN WATER ACCOUNTING

The key steps of this process were designed to meet the aims described above were steps 2, 3b, 4 and 5.

The project implemented a dynamic and interactive user-centred approach, fostering an iterative dialogue to ensure all potential users had an equitable opportunity to contribute. This approach allowed researchers to comprehensively investigate user needs and capacities from multiple perspectives, directly informing the final product design. Participants highlighted that being genuinely consulted and heard throughout the development process is a best practice that should be scaled up to ensure all products are fit-for-purpose and responsive to real-world demands.

The project team included social researchers to ensure a structured and robust approach to these parts of the research approach. A range of qualitative research methods were used, with research ethics approval, to generate this information:

- Document analyses, especially of policy and regulatory documents
- Semi-structured interviews, usually with 1 individual, sometimes two individuals together (documented and analysed)
- Surveys (anonymous and individual), disaggregated by different regions of Viet Nam
- Self-assessment using a water resources management framework, conducted in person, in small groups
- Open group discussions

The full report provides a summary of these methods and results. Here we draw attention to two frameworks that have proved especially helpful.

FRAMEWORK AND PROCESS TO ASSESS THE MATURITY OF DATA-INFORMED WATER RESOURCE MANAGEMENT

The application of a localised water resources management maturity framework was useful (i) in identifying existing strengths and weaknesses of data-informed water resources management, and (ii) as a structured, participatory and deliberative process for stakeholder self-assessment of current water resource practices and data availability.

The Research brief [Assessing The Maturity Of Data-Informed Water Resources Management – Viet Nam Case Study](#), provides a more complete account of this framework and it's development, and it's use in assessing the situation in Viet Nam. The key steps involved:

- Development of a generic framework, based on literature describing subbasin water resources management tasks (Box 1).
- Localisation of this framework to the Viet Nameese context, through workshopping with water managers
- Self-assessment against the framework, using a small group format to enable inclusive participation of all at the workshop, and to identify items needing broader discussion to resolve.

TABLE 1: WATER RESOURCES MANAGEMENT TASKS, ORGANISED BY HIGH-LEVEL FUNCTIONAL CATEGORIES

PLANNING

- Water resources assessments to inform capacity for future / additional economic development / productivity in specific subbasins
- Water resources capacity assessments to guide investment and design of water infrastructure
- Designing irrigation systems
- Designing water supply systems (community, towns, cities)
- Input to (environmental, drinking) water quality guidelines (alongside other ecosystem health, human health & values-based inputs)
- Determining water discharge license conditions and fees
- Designing flood control works
- Basin / Subbasin level allocations for major water use groups (subbasin level totals for each water user type e.g. agriculture, hydroelectricity, forestry, mining, industry, urban/domestic, environment, etc)
- Annual license allocations for major individual water users (agriculture, industry, hydroelectricity), including extraction locations
- Informing/forecasting Urban / domestic water supply service levels; Guiding (urban) demand management need & actions
- Measuring and predicting impacts of externalities such as climate change, population growth, industrial changes (à forecasting future water resource regimes)
- Determine groundwater/Surface Water extraction licensing fees

MANAGEMENT & OPERATIONS

- Enforcing extraction allocations / compliance monitoring
- Guiding water infrastructure operations decisions e.g. opening or closing storage regulators, timing of pumping or irrigation or irrigation headworks operations, or access restrictions
- Identifying pollution problems for attention (evidence base for managers and polluters; spatial and temporal scale important)
- Compliance monitoring enforcing pollution requirements
- Monitoring sustainability/appropriateness of water allocations (comparing actual to projected balances to identify adjustments)
- Inform water markets / trading
- Determine location and number of groundwater extraction points

RISK & DISASTER MANAGEMENT

- Monitoring crop productivity (early warning food insecurity)
- Drought early warning and management
- Flood early warning and management

The self-assessment process involved the self-formed small groups providing the following information or opinions:

- Water resources management task status – is this task being conducted in Viet Nam?
- Spatial and temporal scales at which this task is performed
- Agencies/ organisations involved
- Score (max 5) of the current use of water data to support each water resources management task
- Types of water-related data being used

This process enabled the research team, as well as the participants, to identify specific water resources management tasks that could be strengthened in their implementation, and opportunities to strengthen the use of data to support these tasks.

The research confirmed that many core water resources management tasks are already being undertaken across planning, management, and operations of water resources infrastructure. However, the extent to which these tasks were systematically informed by water data varied considerably, with stronger application in surface water operation and management, including flood and drought, and weaker application in groundwater management, monitoring of allocation, water-use efficiency and productivity and water accounting.

A very high-level summary of the maturity of water resources management and the use of water-related data can be represented by averaging the above scores, for each functional grouping of water resources management tasks (Figure 1). Although only a very high-level assessment, this indicated there are opportunities to further strengthen the implementation of water resources management – the tasks considered as relevant to Viet Nam – and more scope to strengthen the application of water-related data to support evidence-based water resources management.

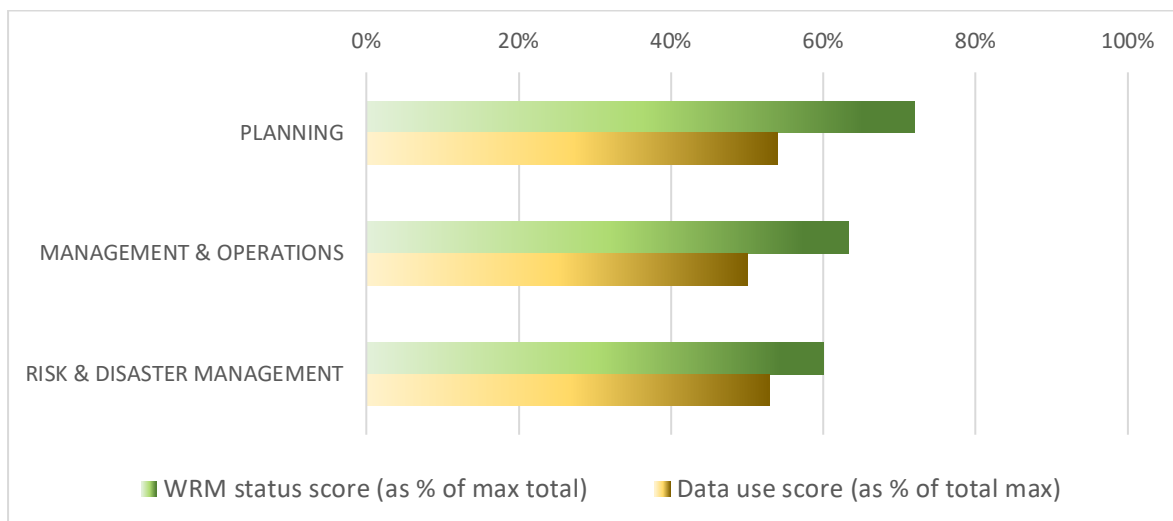


FIGURE 2.2. AVERAGE % OF MAXIMUM SCORE FOR THE CURRENT STATUS OF WATER RESOURCES MANAGEMENT TASKS, AGGREGATED BY FUNCTIONAL GROUP, AND AVERAGE % MAX SCORES FOR WATER-DATA USE TO SUPPORT WATER RESOURCES MANAGEMENT, AGGREGATED BY FUNCTIONAL GROUP. THE SCORES ARE BASED ON SELF-ASSESSMENT BY STAKEHOLDERS, ARRIVED AT THROUGH A GROUP-BASED DELIBERATIVE PROCESS.

The participants reflected several benefits of this process:

- The framework provided structure and ensured important aspects of water resources management were not overlooked, but the process allowed for localisation of this framework to ensure it made sense to Viet Nam.
- The in-person and small group process supported a deliberative process that was inclusive, overcoming some of the challenges of large groups of stakeholders within which seniority and types of organisations can reduce the opportunities for some participants to voice their opinions.
- The rare opportunity to gather and share experiences and knowledge with others from across Viet Nam, particularly from different provinces with different water resources contexts, and from different types of organisations. Reflecting this benefit, a key recommendation, repeated by many participants, was the need for a more coordinated approach to water data and water management.

A key recommendation of the participants, during the discussion of steps required to progress water accounting, related to collaboration. Strong interest was expressed in continued pilot testing, feedback loops, and joint problem-solving amongst practitioners, and between researchers and practitioners, to ensure solutions are practical and scalable.

The disconnect between agencies, levels of agencies, and with on-ground water managers / operators, especially between surface and groundwater management, is not unique to Viet Nam. Using a framework describing water resources management tasks that spans these boundaries, and especially through a process that brings together representatives from across these organisations, is likely to be beneficial in any context where there is a paucity of coordination and communication.

The framework developed and used here provides a useful starting point, and through a similar process of localisation, could be usefully applied to other countries where there is an aim to improve the use of data for water resources management.

ASSESSING USEFULNESS, USABILITY, ACCESSIBILITY, INTEREST

To improve the outcomes of this research activity, particularly with regard to the demand and interest to adopt subbasin water accounting approaches, the project assessed the usability, usefulness, accessibility and feasibility, and interest. These were defined as follows:

- Usability - the potential for stakeholders to use the tools in their current form

- Usefulness – the potential to use the outputs from the tools to assist with water resources management
- Accessibility & Feasibility – the potential for stakeholders to acquire the resources, facilities and systems to implement and use remote sensing / water accounting tools e.g. to acquire the required input data, to access required computing equipment to use the tools.
- Interest – the attitude of stakeholders to adopt remote sensing / water accounting approaches. Here stakeholders include the potential users of the tools, the potential users of the outputs, and the senior managers of these units with governance and management decision-making powers.

All four of these dimensions are necessary if any an innovative or new tool or approach, such as subbasin water accounting, is to be successfully adopted on a national or large scale.

Qualitative data to guide this assessment was extracted from the range of research activities that followed training / exposure to the developed tools, but particularly drew upon:

- surveys of individual water managers
- small group, and plenary, discussions
- an open, semi-anonymous opportunity to provide feedback specifically against these 4 criteria (through a sticky note and poster activity, left up for the duration of a training and post-training workshop).

Taking an intentional approach to assessing these 4 dimensions for scaling up gave the research team a deeper insight into the likely barriers needing attention in order to progress this ambition. Their key findings that emerged from this analysis included:

- The outputs of the water accounting and GIS tools were **considered highly useful**, provided much needed data to support to meet legal requirements, support operational activities, and provide independent data that can validate efficiency and performance of operations
- **Demand and interest in the GIS and water accounting tools to support acquisition of water data is high**, as it is seen as a necessary and appropriate advancement to meet the needs listed above. Through engagement in this project, awareness about the potential usefulness and availability of remote sensing data was improved and created stronger demand and interest for new technologies to improve water data.
- While the shared acknowledgment of the tools' usefulness and interest is high among all participants, **the perceived usability, accessibility, and feasibility of the products vary significantly across different user groups**. This diversity reflects differences in human capacity, financial resources, and the level of autonomy among organizations of the same type or at the same level of management. For example, there is currently **insufficient technical capacity** and practical experience, for both remote sensing and water accounting, especially at provincial and commune levels. This makes the existing tools **less usable by all interested staff in their current forms**.
- Demand for **simplified tools** was expressed, however, a complimentary approach discussed was an internal **service-provider model**, in which mandated units / teams within Ministry of Agriculture and Environment, or Irrigation Management Companies, nationally or in provincial offices (where essential levels of skills exists), act as 'data suppliers or producers' - acquiring and processing data, operating GIS and water accounting tools, and distributing data outputs to data users in local level government and IMC offices. This could **increase the end usability of tools**, although some simplification to user interfaces is still required.

- **Accessibility and feasibility to scale-up** to national adoption is **hampered** by limited access to no cost but high resolution (spatial and temporal) datasets. Some datasets, particularly larger, lower resolution datasets are easy and inexpensive to access, while datasets at smaller scales often require a higher skill level to access and process the data including modelling capabilities. Access to computing equipment is moderate, although much monitoring and data management is currently manual; better access and skills in IT would assist with efficiency of accessing data. The feasibility to scaleup implementation requires the development of capacities of data producers and data users, and systems to enable the requesting/sharing of data outputs for water resources management use.

3 APPLYING WATER ACCOUNTING TO SUBBASIN SCALES

3.1 THE NEED FOR SUBBASIN WATER ACCOUNTING – BRIDGING BASINS TO IRRIGATION SYSTEM LEVELS

The literature review (included in Report 1), indicated that there are two distinct approaches to agricultural water efficiency and management, distinguished primarily by their scale: *classical* approaches focus on irrigation system levels to improve efficiency, such as improving how much water reaches the crop root zone; in contrast, the *neoclassical* approach takes a basin perspective, where losses (like seepage or runoff) are often reused downstream, meaning local efficiency improvements do not automatically equal basin-level water savings (Perry, 2007; Perry, 2011; Perry and Steduto, 2017; Seckler, 1996; Seckler et al., 2003; Van Opstal et al., 2021). Consequently, organisations working in the Water Accounting and/or remote sensing spaces are usually either working at larger basin scales, or irrigation district levels.

There is still a widespread perception that improving water efficiencies in irrigation areas through water conservation technologies alone will save water, whereas perversely it increases water usage (Perry and Steduto, 2017; Van Opstal et al., 2021). The FAO has developed programs such as REWAS to address this misconception about water conservation technologies. The purpose of these programs is to assess interventions in a broader basin context to better understand what impact these interventions will have on basin water balances.

This research project worked at different subbasin scales. As the basins became smaller the decisions being made went from planning to more operational in nature. The decision-making being made at subbasin scales falls naturally across the ‘neoclassical’ and ‘classical’ approaches to agricultural water management. Therefore, subbasin water accounting could provide a bridge to link the two approaches to agricultural water management (Figure 2) where irrigation district scale interventions could be evaluated for possible impacts on the broader subbasin scale.

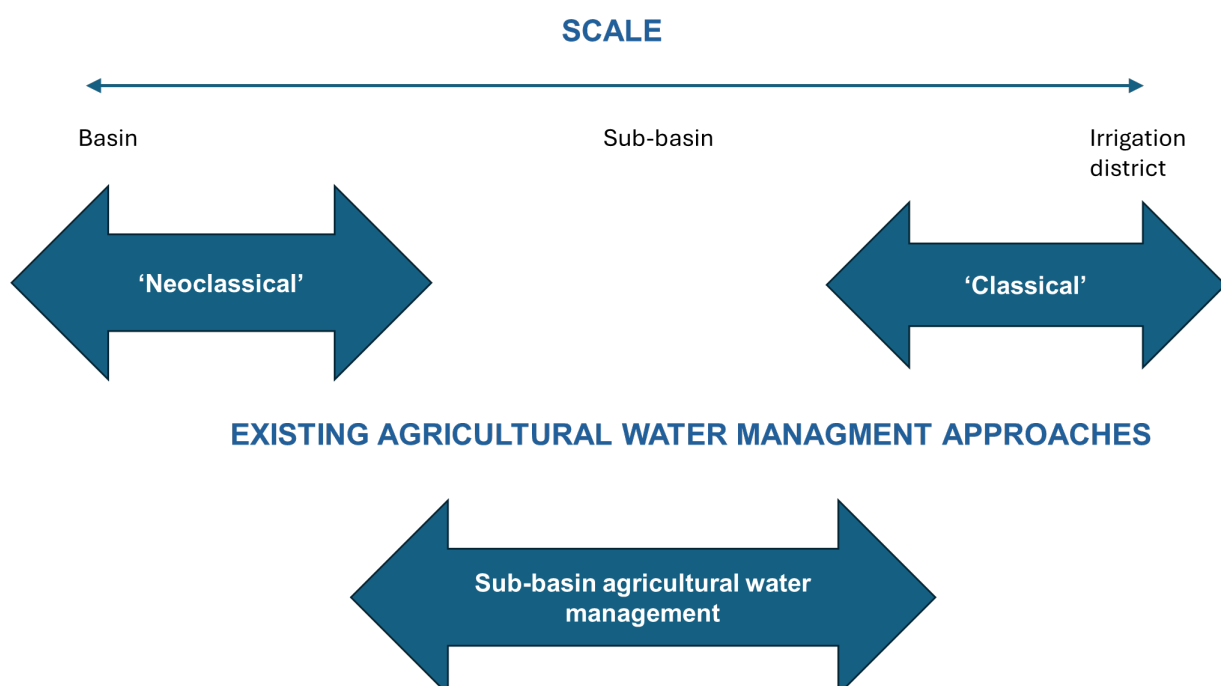


FIGURE 3.1. ADDRESSING THE GAPS IN AGRICULTURAL WATER MANAGEMENT

There are two ways to use Water Accounting to assess the possible impacts of management interventions on the broader subbasin hydrology, monitoring and modelling (Lillicrap, 2015). Water Accounting Plus uses models at larger basin scales to determine surface and groundwater outflows (Mul

et al., 2020). Due to issues in scaling and lack of data for calibration, the existing WA+ models are not suitable at subbasin scales. This will be described further in the next section.

3.2 DOWNSCALING DATA AND METHODS FOR SUBBASIN WATER ACCOUNTING

Subbasins can range in size, as they represent a smaller watershed, drainage area, or geological basin located within a larger one. Using the Mekong-Lancang River Basin as an example, subbasins vary in size from transnational subbasins such as the SrePok, 30,757 km² in area, to headwater subbasins where reservoirs provide water for irrigation scheme areas such as Krong Buk, 464 km² in area.

The type and complexity of management decisions also vary with scale, ranging from the management of transnational water issues, involving national governments and international treaties, down to management of water supplies to, and within, irrigation scheme areas (or irrigation clusters as they are known in Viet Nam), involving irrigation management companies.

Due to the range in scales of subbasins and the difference in data needs at the different scales, the pilot study consisted of three study areas at different scales. The largest study area was the Ban Don subbasin, 10,850 km² in area, the second study area was the Krong Buk subbasin, a headwater subbasin providing water for irrigation and domestic needs, and the third was an irrigation cluster. The range of subbasin scales provided the opportunity to investigate the different data needs as well as the ability and limitations of remote sensing data to provide hydrological data at these different scales.

The research indicated there were many water accounting and related parameters that can be produced by drawing upon remotely sensed data, which have the potential to be useful for water resources management including at subbasin scales, in Viet Nam and more broadly in the region (summarised Table 2).

TABLE 2 POSSIBLE SOURCES AND USES OF SUB-BASIN HYDROLOGICAL DATA / INDICATORS

Useful Parameters	Temporal and spatial scale of input datasets and scale of application	Examples of water resources management tasks for which these indicators are useful, and scale of application	Level of complexity in generating the parameters / indicators
1. Precipitation	• CHIRPS / WaPOR, daily 0.05° (~5.5 km). – Applicable to all subbasin scales	• Irrigation planning, allocation and management • Domestic and industrial water supply planning and allocation and management • Reservoir operations • Management of irrigation clusters • Flood and disaster management	Least complex
2. Evapotranspiration	• SSEBop dekadal (10 days), monthly, annually, ~ 1km – applicable to basins ~ > 9000 km² • WaPOR Level 1, dekadal (10 days), monthly annually, ~ 300m – applicable to basins ~ > 900 km² • SSEBop / EEFlux dependent on Landsat Passover and cloud cover, ~30 m > Applicable to irrigation clusters and larger • ETLook – modelling ET data at all scales	• Crop water demand • Irrigation cluster and scheme operations (identifying over- or under-irrigated areas) • Catchment water balances • Drought preparedness and response • Prioritisation of water distribution during dry season	SSEBop / WaPOR; Least complex ETLook; Most complex
3. Change in storage	• GRACE – Downscaled, monthly, annual, ~ 10 km resolution – applicable to basins > 10,000 km²	• Basin water balances • Groundwater risk screening - changes in groundwater storage • Targeted monitoring assessment • Supporting groundwater level commune assessment	Most complex
4. Rainfall deficit (Precipitation minus actual evapotranspiration)	• Depends on rainfall and actual ET data	• Irrigation cluster / scheme operations - Used to estimate irrigation or withdrawals from storage for different land use classes	Moderate complexity
5. Land use land cover	• Land use Land cover, annually, 10m - applicable to all scales	• Identify water depletion for different land uses	Least complex
6. NVDI (Normalised difference vegetative index)	• USGS composite, dekadal, 1000 m – applicable to basins > 10,000 km² • Landsat limited by passover and cloud cover, ~30 m – applicable to irrigation clusters and larger	• Productivity of biomass	Least complex
7. Net primary production	• WaPOR Level 1, dekadal (10 days), monthly annually, ~ 300m – applicable to basins > 900 km² • ETLook – modelling ET data at all scales	• Combined with land use maps to identify unproductive areas	Moderate complex
8. Yield	• Depends on resolution of net primary production and land use datasets	• Crop productivity and identification of underperforming areas	Moderate complexity
9. Water productivity	• WaPOR Level 1, annually, ~ 300m (Gross and Net primary production only) – applicable to basins > 900 km² • ETLook – modelling data at all scales	• Assessing irrigation efficiency and effectiveness • Supporting agricultural water use optimisation • Informing investment and extension priorities	Net biomass water productivity – Least complexity ETLook – Most complex
10. Basin water balance (Precipitation – evapotranspiration +/- change in storage)	• Dependent on input datasets	• Provides estimation of water surplus / deficit (scarcity) can be on monthly or annual time steps	Moderate complexity
11. System outflows	• Requires modelling of input data	• Provides projections of surface and groundwater outflows	Most complex

3.3 ADVANCES TO REMOTE SENSING AND WATER ACCOUNTING METHODOLOGIES

The first report of this project, *Review of Remote Sensing and Water Accounting Supporting Agricultural Water Management in Subbasins*, outlined the current status of remote sensing data for water management, and the current methodologies for water accounting.

REMOTE SENSING

Looking forward, the next generation of free and accessible remote sensing missions promises to provide more accurate, higher-resolution, and more frequent information on water availability, directly addressing some of the limitations of current satellite datasets. For changes in terrestrial water storage, the planned Mass Change mission under NASA's Earth System Observatory (ESO) will continue the legacy of GRACE and GRACE-FO. This mission is expected to improve both the spatial resolution (potentially finer than the current ~300 km footprint) and the robustness of monthly gravity-based water storage measurements (Wiese et al., 2020; Wiese et al., 2022). For soil moisture, the continuation of SMAP and the planned development of enhanced passive-active systems will ensure higher-resolution coverage and shorter revisit times. ESA's upcoming Copernicus High Priority Candidate Missions (such as the L-band radar mission ROSE-L) will be particularly important for Southeast Asia (Torres et al., 2020). With spatial resolution below 10 m and revisit cycles of only a few days, these missions will significantly improve the monitoring of soil moisture variability at the basin and farm scale, offering a capability that current global missions cannot deliver (Khanal et al., 2020). Also, precipitation monitoring will benefit from continuity and refinement. The NASA Global Precipitation Mission constellation is expected to be maintained and expanded through additional partner satellites, ensuring high-frequency rainfall estimates at resolutions of ~5km or better (Kidd et al., 2021; Kummerow et al., 2020). Further, missions like the Meteostat Third Generation (MTG) and next-generation Japanese Himawari satellites (Bessho et al., 2016; Lee et al., 2017; Miura and Nagai, 2019) will provide rapid-refresh observations that can improve early warning for extreme rainfall events and floods across South-East Asia's monsoon-driven climate.

Optical and radar imaging capacity is also set to grow. The new and ongoing NISAR mission (radar satellite) will improve field to management-scale monitoring of soil moisture and crop conditions and irrigation water use, with repeat coverage typically every ~6-12 days, supporting assessment of irrigation timing and effectiveness. SWOT is now operational and will strengthen surface water accounting by mapping surface water elevation to track seasonal changes in rivers as well as large irrigation storages that supply irrigation, informing water allocation decisions in managed agricultural systems. The Landsat Next mission, scheduled for launch in the early 2030s, will triple the number of spectral bands while retaining 30 m spatial resolution and increasing revisit frequency to every 6-8 days. This will enhance the monitoring of crop water use, evapotranspiration, and vegetation stress. Meanwhile, the Sentinel Expansion missions, including Sentinel-1 Next Generation and Sentinel-2 Next Generation, will preserve continuity of existing programs while offering improved resolution and shorter revisit times. This will ensure an uninterrupted data stream for mapping agricultural and irrigation activities in regions like South-East Asia.

Datasets

CSIRO are producing hydrological datasets and cloud computing platforms. CSIRO has developed the web-based Basin Futures platform. The lowest level on the platform is Basin Scale 5 which when zoomed to the study area used in the pilot project, covered 79,000 km² whereas the study areas used were 10,000 km² or less. Therefore, the data on the Basin Futures portal is at too broader scale for use in subbasin water accounting. CSIRO also has the Earth Analytics Science & Innovation Platform (EASI) a powerful cloud-based computing platform, however its use is beyond the capacity of most people

surveyed in project. It is likely to be beyond, not applicable, to most people working in subbasin scale water management.

WATER ACCOUNTING METHODOLOGIES

IHE Delft

IHE Delft are making improvements to Water Accounting Plus tools and methods. IHE Delft have introduced a new Soil Water Balance Model, that is a grid based, physically oriented model that integrates land cover, soil characteristics, slope and root depth. The model uses remote sensed derived actual evapotranspiration (ET) as the driver, allocating green or rainfall ET when soil moisture can supply ET needs and supplied or Blue ET when additional water must come from irrigation or groundwater. The model is available via GitHub, with continuous updating though requires programming skills to use and lacks predictive capability. IHE Delft is developing Irrigation Performance Indicators, using WaPOR ET and rainfall data to calculate adequacy, equity, uniformity and ET green/ET blue split. The tool is available via; Jupyter notebooks, Streamlit dashboards and open-access code.

With WaPOR data, WaPOR v3 has global coverage at 300 m. High resolution (30–100 m) products available only where funded. The geographic and capacity building focus for IHE Delft has been a long-term investment in Middle East & North Africa (MENA) through Dutch-funded Water and Development Partnership Programme, though with newer expansions into Pakistan, Colombia and parts of Asia. Capacity building now follows a blended model with online sessions, intensive in country work and follow-up support. All capacity building must be project funded. IHE Delft works closely with FAO HQ (Rome) on Water Accounting Plus studies and remote sensing-based monitoring. It has less alignment with regional FAO offices, who may contract other consultants creating some tension where consultants replicate methods without full understanding.

International Water Management institute (IWMI)

IWMI is working on high resolution evapotranspiration and Irrigation Scale Accounting. It is based on SEEBop evapotranspiration that is generated on demand through a web interface using Landsat 30 m data. They also have developed a QGIS plugin (not yet publicly released) for SEEBop. The new tool generates irrigation performance indicators: blue/green ET separation, supply adequacy, efficiency, spatial irrigation equity. The tool is used in Africa; Ethiopia, Ghana, Burkina Faso and Zambia. IWMI has also developed the Scale Invariant Water Accounting Plus method. It can be applied to any administrative unit, not only hydrologic basins with publication pending and the method is to be released on GitHub. Currently it available via web interface for Africa. The tool uses a hydrological/phenology based model (VegET) that estimates water balances for 1 km² grids and is linked with a routing model to estimate streamflow. This enables the development of Water Accounts for different administrative units and areas.

IWMI has previously worked in the Mekong and Southeast Asia with past WA+ analyses for Mekong Basin. IWMI is currently working on a DFAT/ADB project in Laos and Cambodia on a project that incorporates groundwater into hydrological models. They are using the SWAT+ gwflow model (Bailey et al., 2020) which is a surface water model with a simplified groundwater process routines.

IWMI is also doing climate related work developing climate scenario ET datasets using the Budyko framework (linking P, PET, and ET) with the aim to enable climate informed water accounting and assessment of impacts on agriculture. They are also developing user-oriented tools and dashboards in R Shiny, Tableau and Power BI simplifying WA+ outputs. The tools are for: irrigation performance monitoring, nature-based solutions (e.g., water harvesting, MAR) and transboundary water dependency metrics. IWMI are developing a new tool that will classify water service levels that are linked to

(WHO/UNICEF Joint Monitoring Program) using surface/groundwater availability, discharge, distance and travel time to sources.

These developments demonstrate the increasing availability of high-resolution ET tools, but most applications remain limited to pilot regions. In Southeast Asia, operational adoption remains limited, highlighting the need for user-centric approaches such as those explored in this study.

3.4 ADDRESSING THE MISMATCH IN CAPACITY AND DATA AVAILABILITY

As indicated in Table 2 above, depending upon the spatial scale, and methodology involved for each parameter, there are varying levels of complexity in acquiring and computing the datasets. These ranged from; least complex where the required data layers could be obtained from the web and easily incorporated and interpreted in GIS, to moderate complexity that required some calculations in GIS to derive desired indicators and the most complex that requires some kind of modelling to generate the desired indicators.

Larger basins had freely available remote sensing data available, smaller basins (e.g. Ban Don - ~ 10,000 km²) had freely available precipitation and evapotranspiration data but changes in storage, using GRACE needed to be downscaled and calculated. With even smaller basins such (e.g. Krong Buk - 464 km²), and irrigation clusters, finer scale remote sensing data was not always available due to cloud cover so the required data had to be computed using algorithms like ETLook, which required higher skill levels not available within smaller basins (Figure 2).

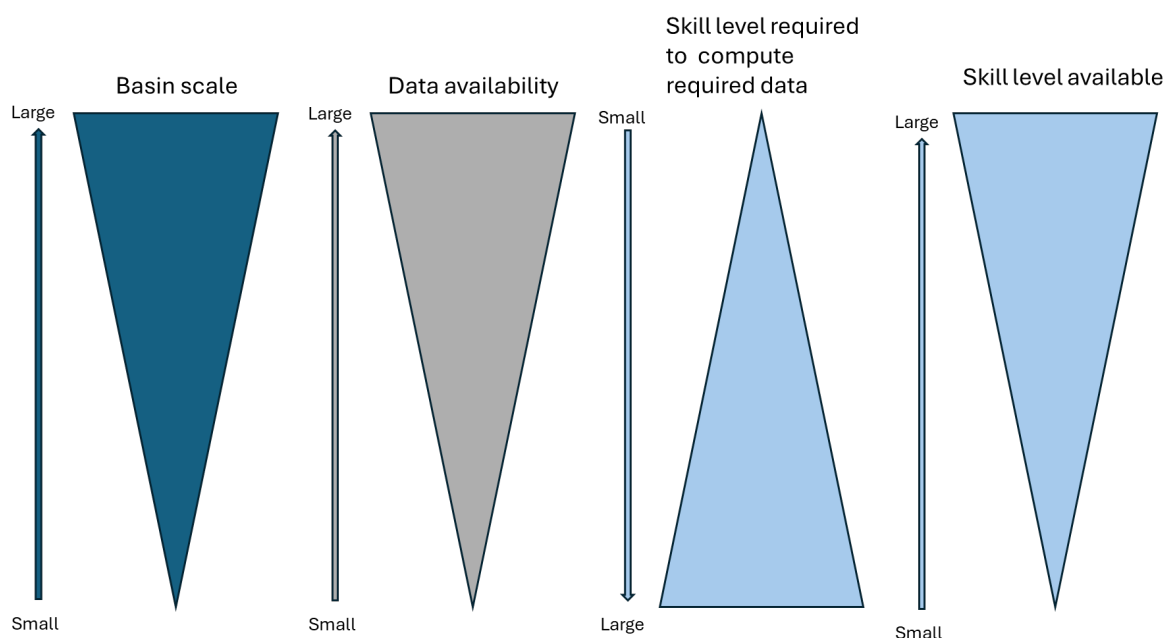


FIGURE 3.2. SUMMARY OF LINKS BETWEEN BASIN SIZE, DATA AVAILABILITY, COMPLEXITY TO COMPUTE DATA, AND CAPACITY AVAILABLE. GENERALLY, LARGE BASINS HAVE HIGH DATA AVAILABILITY WITH LOWER SKILL LEVELS NEEDED TO CALCULATE WATER BALANCES, THOUGH WITH HIGH SKILL LEVELS AVAILABLE. CONVERSELY, SMALL BASINS HAD LIMITED DATA AVAILABILITY AND REQUIRED ADVANCED SKILL LEVELS TO COMPUTE THE REQUIRED DATA TO DERIVE WATER BALANCES BUT HAD LIMITED CAPACITY.

With Water Accounting Plus, estimating detailed basin-scale surface or groundwater flows ultimately requires the application of hydrological models. The ability of remote sensing data to provide insights into hydrological processes means it could be used to develop hydrological models in ungauged and low data availability areas. In developed countries, hydrological model-based decision support systems are obligatorily used to support water resource decision making. The combination of open-source

hydrological models and remote sensing data provides an opportunity to develop similar modelling capacity in low- and middle-income countries. In basins with significant surface water-groundwater interactions, such as Ban Don, an integrated surface water groundwater modelling approach (e.g., SWAT+ gwflow) would be needed to evaluate effects of agricultural clearing of native forests, conjunctive water use, climate change impacts and extreme event scenarios

In addition to a lack of capacity at the commune and IMC operations level to use GIS and water accounting tools, there was also less interest to gain those skills, but a high interest to use the data outputs. There was a strong preference for a “service-provider model”, whereby mandated units / teams within national or provincial government / irrigation company offices, act as ‘data producers’ - acquiring and processing data, operating GIS and water accounting tools, and distributing data outputs to data users in local level government and IMC operations offices. The water accounting outputs could be visualised in two practical formats: (i) standardized spreadsheets summarizing key metrics and maps for spatial display; (ii) simple interactive dashboards/webs that allow users to filter by the level of details and administrative boundaries.

For such a service delivery model to be effective, capacity development would be required for the data producers, as well as the data users. The capabilities of those ‘data producers’ would likely need to include basic hydrological modelling, which would give the capability to (i) fill data gaps at smaller scales of application and (ii) assess the impact of seasonal and longer climate projections on water resources.

4 BROADER APPLICABILITY OF RESEARCH OUTCOMES

The study demonstrated that integrating remote sensing-based information with water accounting approaches and validating through local decision-making realities can formulate practical and meaningful inputs into subbasin water management. In contexts where in-situ hydrological and biophysical measurements are absent, inaccessible or ad hoc, for example, agricultural water usage, crop yield, drought conditions, publicly available remote sensing products offer a viable source of data for water management decisions.

Pilot testing of down-scaled water accounting, supported by remote sensing, applied to basin, subbasin and irrigation cluster levels, indicates strong potential to enhance robust information of water availability and use, support seasonal and annual planning, and improve transparency in allocation and compliance discussions. The research demonstrated there are many water accounting and related parameters that can be produced by drawing upon remotely sensed data, and which are useful to water resources management.

The sections above, on the user-centred approach to researching and developing water accounting, and the findings relating to the downscaling to subbasin water accounting, are applicable not only to Viet Nam but to other contexts.

Many river basins across southeast Asia share similar characteristics with the study areas in Viet Nam, including strong seasonal rainfall patterns, limited groundwater monitoring and fragmented institutional responsibilities for water resource management. These conditions increase the potential value of remote sensing and water accounting information.

Work to progress water accounting continues in other Southeast countries. As mentioned above in Viet Nam, FAO had introduced water accounting to relevant government ministries. This awareness-raising work helped to create a ready context into which the user-centred research and development of this research project, was able to be successfully applied. This explicit user-centred approach proved especially useful in building, essentially from the “user-up” (rather than “top-down”), understanding and demand for basin and subbasin water accounting, and remote sensing for water management. It may

therefore make sense to explore the utility of such an explicit user-centred approach to support adoption of water accounting particularly when a more top-down approach has laid the foundation of awareness and interest.

Water accounting, as well as evapotranspiration management, and improving governance, are three goals of FAO's inter-Regional Technical Platform on Water Scarcity (iRTP-WS), that are aligned with the work of this research project. The iRTP-WS has a mission to strengthen knowledge exchange and support the development of innovative methods, pilot and develop tools to scale-up action and address complex development challenges on water and food security towards the achievement of SDGs with a special focus on goals 6 and 2. FAO's Asia Pacific Water Scarcity Action Program

In [Indonesia](#), the FAO's Indonesia Water Scarcity Programme, steered by the National Development Planning Agency (BAPPENAS), includes a focus on water accounting of river basins, particularly through River Basin Organisations (RBOs). With support also from Australian Water Partnership, there has been development of a roadmap that evolves existing water allocation practices, towards the adoption of basin Water Accounting, 2024. The adoption of water accounting, including with use of remote sensing and GIS, appears well underway in Indonesia, at least at basin scales, and for surface waters. Anecdotally, there appears to be some technical capacity at the RBO levels for remote sensing, GIS and water accounting. There may remain a gap in groundwater accounting, though a pilot project is currently underway in Serayu Opak basin (AWP). A case study application in Cimanuk-Cisanggurung basin, did consider some subbasin applications of water accounting, due to district-level issues identified, affecting basin water balances.

Similarly in Thailand, FAO worked with partners and the Government of Thailand to develop a Water Accounting Roadmap, 2025. The process to develop this included a pilot application in the Pa Sak River Basin. Interestingly, their consultations with users of water accounting articulated strong support for establishing a Water Accounting Unit (WAU) within the Office of the National Water Resources, which is a similar concept to that described in Viet Nam where it was suggested as a mechanism to address the technical capacity gaps at the subbasin levels. As in Viet Nam, the Thai stakeholders also requested integration of surface and groundwater data.

FAO has also recently introduced Water Accounting to Cambodia and Laos, where there is also interest by government in applying such advancements to improved water management.

There would be potential value from sharing key lessons from this ACIAR research project with others in Southeast Asia – both regarding the technical down-scaling aspects, especially regarding the need for applying hydrological modelling to smaller scale water accounting, as well as the user-centred processes to define useful subbasin water accounting needs.

The recommendation arising from the Viet Nam work, or knowledge exchange between Southeast Asia countries would appear particularly relevant at this time of much interest and demand in Water Accounting.

5 RECOMMENDATIONS

The report *Understanding The Role Of Remote Sensing And Water Accounting In Supporting Agricultural Water Management In Viet Nam* (Report 2, this project), contains recommendations arising from this research, specifically relating to the progress of subbasin water accounting in Viet Nam. This Report (3) relates to recommendations applicable to continuing to develop and scaled up regionally, subbasin water accounting.

1. Use research and development processes that are user-centred and collaborative to ensure that the further development of subbasin water accounting tools is guided by clearly defined use cases. In particular:
 - a. Recognise that subbasin water managers and operators have not a homogenous group and have different water data needs, and their use cases – in particular, the spatial and temporal resolution, and the format, of water accounting data – should be distinguished and described.
 - b. The use of localised, comprehensive data-informed water resources management frameworks, such as that used in this project, can enable a deliberative process amongst water planners/managers - including across surface and groundwater divides – that assists in identifying priority data gaps and case uses for developing water accounting.
 - c. Explicit processes to assess user accessibility, usefulness, usability and interest in developed/developing tools can support a collaborative process that improves the tool development and builds greater interest and commitment in the use of tools.
- This user-centred approach should utilize diverse platforms, methodologies, and communication channels to ensure inclusive stakeholder engagement that is rooted in the principles of equality and participation. The process should foster an environment of goodwill that encourages diverse respondents to share their perspectives openly, effectively overcoming participation barriers and capturing data from all relevant user levels and locations.
2. Consider whether a ‘service delivery’ model to the preparation and application for water accounting, may be best suited, given subbasin level technical capacity. In contrast to all water managers / operators at subbasin levels being trained in preparing water accounting data, this alternative model this entails a dedicated unit or team in central government undertaking preparation of water accounting data outputs, for use by subbasin water managers. In such situations, a number of specific recommendations are made:
 - a. Attention should be given to developing, again using user-centred processes, the format of water accounting ‘user reports’ that are shared with subbasin water managers / operators. The capacity for GIS at subbasin levels is variable, and so a diversity of output formats may be necessary to promote the use of water accounting data.
 - b. Capacity development of subbasin water staff would still be required at subbasin levels, in the interpretation and application of water accounting data to subbasin water management.
 - c. An explicit Quality Assurance process is needed to give confidence in data accuracy to subbasin water managers, including a validation process involving feedback from those subbasin water managers/operators that is considered and used by the “service providers” for data quality improvement.
 - d. Capacity of the water accounting “service providers” (unit within central government), for hydrological modelling is required for subbasin water accounting, due to the lack of remotely sensed data at this scale, for some water accounting parameters. An enhanced modelling capability would also enable more predictive types of water resources assessments, such as testing different management or climate scenarios.

3. To improve the accuracy and resolution of subbasin water accounting, a number of strategies should be considered:
 - a. Localise remote sensing algorithms to local agricultural and hydrogeological contexts, in particular to local crops.
 - b. Integrate surface and groundwater datasets to support conjunctive water management and encourage integrated governance processes
 - c. Integrated field-based and remotely sensed data, and where possible using real-time data
 - d. Promote cross-regional sharing of data sources, remote sensing and water accounting methods and tools, and application case studies.
4. Capacity Development should take several forms and recognise that developing the knowledge and skills of staff needs to be complemented with developing the institutional systems and processes, as well as the interest of agencies and staff. Future programs/projects should consider a mix of pedagogies and approaches to capacity development design:
 - a. Use structured training short courses, with durable learning resources that provide an ongoing reference for 'how to' information. Such structured training should build on local preferences and effective adult education pedagogies, but at a minimum should include hands-on practical exercises using relevant use cases, with sufficient opportunity for peer-to-peer learning.
 - b. Use pilot projects to develop, demonstrate and build trust in processes to integrate remote sensing, modelling and water accounting data in priority areas such as agriculture water allocation (e.g., for coffee plantations), reservoir regulation, and urban water supply planning.
 - c. Consider opportunities for regional community-of-practice types of activities for peer-to-peer learning to enable, as described above to improve water accounting methods, through sharing of data sources, remote sensing and water accounting methods and tools, and application case studies. Such activities could be held as side events to other existing fora, until support for dedicated regional learning activities is available.
 - d. Capacity Development should be integral to any water accounting projects, with intentional objectives and design during the project development stage
 - e. Capacity Development should be guided by structured feedback processes to inform the continuous improvement of capacity development activities, given the diversity of participant experiences
 - f. Capacity Development should be recognised as an opportunity further research and development of subbasin water accounting tools, systems and approaches, such as through the identification and documentation of more unique use cases, and the use of user experience frameworks, such as the usefulness, usability, accessibility and feasibility, and interest framework used here.

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