Australian Government
Australian Centre for International Agricultural Research

Final report

project	**Enhancing the resilience and productivity of rainfed dominated systems in Lao PDR through sustainable groundwater use**
project number	LWR/2010/081
date published	30 September 2016
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approved by	NA
final report number	FR2019-77
ISBN	978-1-925747-53-9
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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Contents

1 Acknowledgments

There have been a large number of individuals who have contributed towards this research and its achievements. The project has been administered by two ACIAR Programme Managers, namely, Dr. Andrew Noble at the formulation stage, and his successor, Dr. Evan Christen who has guided the project since its inception. Ms. Chiraporn Sunpakit and her successor, Ms. Dulce Carandang Simmanivong from the ACIAR Lao PDR office have provided excellent administrative support throughout the project. The two external reviewers to the project, namely, Dr. William Milne-Home (University of Technology Sydney) and Dr. Vanthong Phengvichith (National Agriculture and Forestry Research Institute) gave highly constructive inputs during the final review meeting and thereafter provided a detailed report noting areas for improvement.

Over the four year duration of the project there has been some degree of turnover of team members. Mr. Bounmee Maokhamphiou and Dr. C.T. Hoanh (IWMI), Mr. Vongsakda Vongxay and Mr. Pasonexay Insisiengmay (DOI), Dr. Yatsuka Kataoka (IGES) and Dr. Laa Archwichai (KKU-GWRC) contributed to the earlier stages of the research in a variety of capacities.

Collegial support was provided by Mr. Michael Victor and Ms. Elizabeth Weight (IWMI/WLE), Mr. John Dore (DFAT) and Dr. Palikone Thalongsengchanh (NAFRI) through valuable inputs at a number of project forums. Mr. Nicholas Lombardi, Mr. Suparerk Janprasart and Mr. Rien Dam from the NIWRMSP interacted closely with the research team, bringing benefits to both projects. The contributions from Ms. Chantha Souvannaxayyavong (DAFO, Phonhong), Dr. Lilao Bouapao and his team (MDC), Mr. Prayuth Senchai (Hydrogeosci) and Mr. Jens Laugen (THPC) are also gratefully acknowledged.

Finally, we wish to warmly thank the communities where we have worked, particularly the people of Ekxang and Phousan villages, for the hospitality, time and patience they have shown in allowing the research team to carry out the various field activities. We sincerely hope that this research will bring some gains to their lives and livelihoods in the longer term.

2 Executive summary

Owing to a high prevalence of rural poverty in Lao PDR, improving the livelihoods of smallholder farmers by increasing their productivity is a high priority for the Government. Smallholder farming relies primarily on rainfall, which is prone to shortfalls and occasional droughts during the crop planting season. Reliable irrigation supplies would allow farmers to overcome water deficits and boost crop and livestock production, offering great potential for poverty reduction and increasing food security and livelihoods. Irrigation in Lao PDR has traditionally involved the use of surface water resources. Groundwater could also play an important role for smallholder farmers lacking access to reliable surface water supplies if these resources can be adequately understood and sustainably developed.

Groundwater development and usage in Lao PDR has been unregulated and the weak institutions in place have been unable to implement effective management. Experience in groundwater-based irrigation is almost non-existent in the country. Recent policy initiatives by the Government have bolstered water resources management planning, including consideration of opportunities for groundwater irrigation as an important area for development. With groundwater governance in its early stages, there is a need to build capacity to assess and manage groundwater resources effectively and advance the use of groundwater for agriculture without compromising the users of the groundwater or the resource.

This project has focused on two inter-connected goals: (i) contributing towards the sustainable management of groundwater resources; and (ii) demonstrating the use of groundwater for small-scale irrigation. It naturally also had a strong capacity building and training component.

The project worked from the national scale down to the household scale. At the national level, the potential for groundwater development was mapped, policy analysis was conducted and capacity enhanced through formal training courses and studies linked to the research activities. At the catchment level, groundwater quantity and quality assessments were carried out. Groundwater irrigation demonstration sites were established with the active participation of local communities. Sites were chosen in lowland and upland areas to broadly reflect the different types of groundwater occurrence in the country. The lowland sites included the Vientiane Plain and southern province of Champasak whilst the upland site was in Bolikhamxay Province.

The major findings according to the major components of the project are as follows:

Sustainable management of groundwater resources:

At the national scale, groundwater potential and baseflow maps have been developed and validated using the available data. These maps highlight areas likely to be most suited for resource development. On the Vientiane Plain, studies have been conducted on groundwater recharge estimation at multiple scales, current groundwater use estimation, hydrogeology and flow systems, and soil and water quality. Similar, but less intensive studies have been carried out at the study sites in Bolikhamxay and Champasak provinces. Overall, the understanding of the hydrogeology and groundwater systems has been greatly improved and enabled the areas of fresh groundwater and suitable yield to be more clearly delineated. The data and tools can help guide future development and enable better management of the groundwater resources by government authorities. The local community (farmers, drillers, water user groups, etc.) and the wider community they serve would also benefit.

The alluvial deposits of the Vientiane Plain provide a significant potential resource for groundwater development for improving food production, with recharge rates in excess of 400 mm per annum and current use estimated to be less than 5 percent of the recharge. However careful management of the groundwater resources are required due to the importance of the resource for domestic supplies and the risks from underlying salt-bearing layers. A groundwater model for the Plain has been developed by the Natural Resources and Environment Institute and a Management Plan for the upper Vientiane Plain is under development by the Groundwater Division of the Department of Water Resources.

Use of groundwater for small-scale irrigation:

The first-ever community-managed groundwater irrigation trial has been established at Ekxang village, situated on the Vientiane Plain. Four male farmers have participated in dry season cropping with groundwater. Additional net incomes as high as LAK 4 million (AUD 670) per season were generated by the farmers who chose to grow cash crops and participated effectively. This provides encouragement for wider use of groundwater irrigation. Given the short duration of the evaluation (one dry season) and the limited adoption by farmers in the first year, further research would be beneficial to assess the longer-term uptake, sustainability and how benefits of the system could be maximized. Individual enterprising farmers have been utilising the groundwater resources for production of watermelon, long bean and other crops for the market using simple, low cost technologies. Investment costs for an open dug well, a pump and necessary pipes are as little as LAK 5 million (AUD 840) and can generate net incomes of LAK 20-30 million (AUD 3,400-5,000) per season from one hectare of land. Guidelines to establish groundwater irrigation schemes in Lao PDR are being prepared to help assist prospective implementing agencies.

Capacity building and training

There has also been a strong emphasis on strengthening the technical capacity of staff from government agencies in the water, agriculture and energy sectors and from academia. Over 100 Lao nationals have been trained through short courses, internships, on-the-job training and academic study. There have been around 15 undergraduate and graduate projects by Lao students completed or underway. The first demonstration of groundwater-based irrigation has been established at the NUOL Faculty of Water Resources campus at Tad Thong, which serves as an easily accessible experimental facility for education and training of staff and students testing crop productivity under a range of conditions. The site can also serve to demonstrate groundwater irrigation to prospective farmers and extension staff.

Through these activities the project has made several important achievements:

(i) increased the profile of groundwater to national authorities and raised awareness amongst a broader range of stakeholders;

(ii) provided a basis for improved capacity development within Government and at the National University; and

(iii) contributed to formulation of new national policies, including the National Groundwater Action Plan.

3 Background

3.1 Sustainable groundwater management in Lao PDR

Owing to the vast surface water resource potential of Lao PDR (per capita availability of 29,000 m^3/person/yr according to World Bank Statistics; the highest in the Greater Mekong Subregion), there has traditionally been limited dependence on groundwater resources and hence they have remained largely neglected. Although water-rich by any measure, Lao PDR is not immune to drought events and water scarcity emerges as a major issue at specific times and areas (Khamhung, 2002).

Groundwater resources offer a highly strategic niche resource that would compliment the more abundant, but highly seasonal and less evenly distributed surface water resources. Groundwater presents a reliable (well-buffered) supply of (generally) good quality water that is widely available on-demand, easy to distribute (even in rough terrain) and that can be developed incrementally. On the down side, energy is generally required for pumping and groundwater resources are susceptible to overuse and pollution from poor land use practices.

There are distinct risks/issues when developing groundwater resources and adequate scientific knowledge and understanding are needed to help support development and improve management. As a consequence of the previous lack of recognition of groundwater in Lao PDR, there are no formal mechanisms for data collection, compilation and storage, no protocols or government entities tasked with groundwater management or strategic planning. There is, as yet, no regulatory framework for groundwater usage and monitoring. Information on hydrogeological systems and groundwater resources (both quantity and quality) is very limited and monitoring and evaluation activities for groundwater are not carried out to any significant degree.

Groundwater is the main source of domestic supplies in many rural areas of Lao PDR (Johnston et al., 2010). Around 90 percent of the rural population rely on groundwater in the form of springs and wells. This includes some 20 percent for urban water supplies. Bottled water sold by small and large operators is the preferred source for drinking from public health as well as aesthetic viewpoints. Villages situated on upland terrain prefer groundwater drawn from locally available wells and springs to surface water which is often polluted by faecal contamination and clouded by sediment and organic matter. Soft drink and beer companies draw upon fresh groundwater reserves for production, whilst salt producers target the areas with saline reserves in parts of the Mekong floodplain for commercial salt production. Groundwater also supports environmentally sensitive ecosystems by feeding springs and base-flow to rivers, streams and wetlands that are habitats for aquatic plants and animals harvested by communities. In uplands areas where difficult terrain does not allow groundwater to be directly accessed, it is often the steady discharge of groundwater into streams and springs that can supply water for villages all year around.

Groundwater development for agricultural purposes is virtually absent in Lao PDR. Figures derived from FAO statistics for Lao PDR reveal that the extent of groundwater irrigation at the beginning of this decade was a mere 200 hectares, or just 0.1 percent of the total irrigated area (Siebert et al., 2010). This figure is likely to be an under-estimate as groundwater use by private and individual small- and micro-scale irrigators tends to go undetected in FAO survey data. Other studies also suggest that groundwater irrigation in Lao PDR is almost entirely absent for agricultural development (GHD, 2010). In Southern Lao LDR where drought risks are the highest in the country, groundwater is beginning to be commonly used by householders for livestock and garden-scale vegetable production within the electrified parts of the Champasak and Savannakhet areas, where groundwater is accessible at relatively shallow depths (Vote et al., 2015).

The lack of groundwater use for irrigation in Lao PDR is likely the result of multiple barriers which are broadly known to relate to limited (and fragmented) hydrogeological information, generally high establishment and operating costs of groundwater infrastructure, lack of access to credit and limited extension services, amongst others. Progress is reliant upon better understanding the key barriers that constrain development for policy development.

With the intensification of agricultural groundwater use comes the responsibility of ensuring that increased groundwater use is sustainable, and of avoiding the problems of over-exploitation that have emerged across many countries in both the developed and developing world (Siebert et al., 2010). Over-exploitation can lead to increased costs of drilling and pumping or even wells drying-out, reduced access to domestic supplies, failure of groundwater-dependent crops, reduced base-flow to rivers and wetlands, saline intrusion and land subsidence in some instances. The challenge is to find the right level of groundwater use for increased food production without creating unacceptable negative impacts and externalities. Good groundwater governance can help reduce these vulnerabilities. Experience worldwide has shown that reducing groundwater over-draft is an extremely challenging resource management problem, it ultimately affects the most vulnerable members of the community who do not have the resources to deepen their wells.

The most opportune time to develop policies promoting good resource management is well before the resource becomes over-allocated as is the case in Lao PDR at present. Although somewhat modified, this ecosystem, with its regular flood pulses, fisheries, sediment flows and floodplain productivity continues to be in-tune with natural regimes. Expanded use of groundwater must be fully cognisant of this sensitive balance, in particular of the interactions that take place between surface water and groundwater, and seek to identify and minimise the negative impacts associated with increased groundwater use.

3.2 Climate change as a driver for improving irrigation

The dominance of rainfed agricultural production makes agriculture particularly vulnerable to climate variability with significant risk of both floods and drought even under current climate conditions. It is argued that this will worsen as the impacts of climate change become evident in the region. Climate events in in the region including droughts in 2009/10 and the current 2015/16 El Nino- related drought amply served to illustrate just how sensitive the regional agricultural economy and water resources are, not only to precipitation shortfalls but also to temporary shifts in seasonal pattern, particularly to an uncharacteristic early end to the monsoon. As the Greater Mekong Sub-region (GMS) and other regions move into an era of enhanced climate uncertainty, building biophysical and economic resilience into smallholder farming systems, which also bring increased productivity and enhanced incomes, will significantly increase the viability and livelihoods of these producers.

In order to create new opportunities and enhanced resilience of smallholder farmers to climate variability/climate change, supplementary irrigation (to account for wet season deficits and for localised access to water during the dry season) is viewed as a key strategy in adaptation to change drivers (Johnston et al., 2010).

3.3 Small scale irrigation is a key intervention

The area under irrigation in Lao PDR is still low by the standard of most countries in the Greater Mekong Subregion (Hoanh et al., 2009). At same time, irrigation development is a vital and integral part of agricultural and rural development throughout Lao PDR. Areas under wet and dry season irrigation production have been steadily increasing in recent years and have more than doubled from 0.17 million ha in 1995 to 0.41 million ha in 2011, or approximately 14% of the total agricultural area (MAF, 2012). As a country rich in natural resources but limited in non-farm development, Lao PDR is still economically dependent on the agricultural sector for about 28% of GDP, and more critically to support livelihoods in rural areas.

The irrigation potential in Lao PDR has yet to be fully realised, with adequate land and water for expansion and intensification of irrigated agriculture in most provinces. Continued strong investments in irrigated agriculture are forecast in coming years, as reflected in the new (8^{th}) National Socio-Economic Development Plan for 2016-2020 and related high level policies (GoL, 2015). Major public and private investments are envisaged in areas with highest production potential (i.e. the large lowland plains and upland plains). Bold targets are set for expansion of irrigated rice production as well as other commercial crops to generate export earnings (MAF, 2015). These ambitious plans do not adequately recognise the major challenges that constrain irrigation system management.

Significant investments in large and medium size irrigation schemes in Lao PDR have been made in the past and are proposed for the future, however the performance of these systems has been mixed due to a range of constraining factors. Throughout the GMS, surface based irrigation systems have been shown to be underperforming due to a range of issues that include the high operational and maintenance costs, poor institutional structures, and lack of technical expertise (CES and AFD, 2007). In many cases, farmers cannot even afford the cost of electricity to operate the pumping stations for lift-operated irrigation schemes (Hoanh et al., 2009).

The key constraint to these smallholder production systems is the lack of access to water resources in the dry season to irrigate crops. This has significant implications in the ability of these farmers to enhance their livelihoods and increase incomes. Medium- and large-irrigation systems that are common to the region were designed for the production of rice. These systems have been shown to offer limited flexibility with respect to diversification of farming systems that is desirable for smallholder farmers. Diversification brings with it opportunities of increased and more reliable incomes, improved nutritional health associated with diversified crops/vegetables/livestock and reduced risk linked to climate and market uncertainty. In addition, these systems offer limited choices for smallholder farmers with respect to changing their cropping/livestock production systems to meet market demands.

To date there has been no serious consideration of the role and potential for groundwater in the development of an irrigation development strategy most appropriate for smallholder farmers in the country, although this has been discussed in public policy formulation for many years. Earlier reports have highlighted groundwater's potentially important role in socio-economic development across the GMS (e.g. Johnston et al., 2010). One way in which this may be realised is through the expansion and intensification of areas under irrigated agriculture, for a balanced production of staple crops for meeting basic needs, and cash crops directly linked to markets for boosting household incomes. Groundwater provides a buffer against the limitations and uncertainties in rainfall availability by supplementing surface water supplies – particularly during the dry season and in low rainfall years - or as a sole source in areas remote from surface water resources.

4 Objectives

This project focusses on two inter-connected goals associated with natural resources management and agricultural development, namely: (i) sustainable planning, development and management of groundwater resources; and (ii) use of groundwater for small-scale irrigation. Both have a major bearing in the socio-economic development of Lao PDR from the viewpoints of a range of drivers including water resources management, food & nutritional security, livelihood enhancement and climate change adaption. These goals are expressed in terms of six objectives.

Objective *1: Assessment and prioritization of typologies and hotspots most suited to the development of groundwater-based irrigation*

Activity 1.1 Conduct a comprehensive literature review, drawing upon data and other information from the project partners and from agencies currently or previously active in groundwater studies and develop a database on the state of knowledge of groundwater availability and suitability for agriculture and other purposes.

Activity 1.2 Prioritise areas within the study areas for more localised investigations, and pilot-scale testing using information gained from the above-described activity, together with other relevant key biophysical and socio-economic parameters.

Activity 1.3 Extend the analysis described above to other parts of Lao PDR to identify development opportunities at the national scale.

Objective *2: Demonstration and evaluation of on-farm pilot trials and groundwater resource characterization*

Activity 2.1 Review, design, setup and test infrastructure for abstraction and utilization of groundwater for irrigated agriculture at the individual farm-scale for up to 3 locations with similar conditions for each of the 3 hydrological configurations

Activity 2.2 Design and implement a monitoring program and evaluate the performance of the pilot trials from a range of perspectives, to establish the localised impacts on the livelihoods of the participating farmers through to the wider impacts on the quantity and quality of the groundwater resource and other groundwater users

Activity 2.3 Perform hydrogeological and hydrological assessments that provide an adequate conceptual understanding of the aquifer system and surface water – groundwater interaction assessments needed to undertake water resources sustainability assessments (Obj. 5)

Activity 2.4 Review, design and pilot a participatory model of groundwater monitoring and management that recognises the demand and supply constraints in relation to crop types and intensities and needs of the other sectors

Objective *3: Strengthening the understanding of opportunities and constraints for agricultural groundwater use*

Activity 3.1 Undertake comprehensive socio-economic surveys and investigations to identify and address unresolved questions that provide a constraining environment in developing viable strategies for expanded groundwater use for agriculture.

Activity 3.2 Work with local communities and institutions to identify farming systems and the forward/backward linkages needed to meet the multiple needs of higher food security, nutritional value and financial profitability of irrigation with groundwater.

Activity 3.3 Draw cross-comparisons and learnings from regions where groundwater use is more intensive (e.g. parts of Thailand and much of India) and other developing regions of *the world which are plagued by similar issues to Lao PDR (e.g. including eastern India and much of SSA).*

Objective *4: Groundwater governance, review of existing agricultural strategies within the broader context of water-land-energy nexus*

Activity 4.1 Undertake comprehensive reviews of existing groundwater institutions and policies (within and outside the water sector) and their relevance to a scenario of enhanced groundwater use.

Activity 4.2 Conduct cross-sectoral, multi-level institutional analysis to identify existing barriers, gaps, and potential for (future) groundwater application in agriculture within the context of the water-land-energy nexus.

Activity 4.3 Perform multi-country review of groundwater management policies that identify strategies relevant to Lao PDR to avoid over-exploitation problems

Objective *5: Sustainability assessment of the groundwater resources in relation to water requirements for higher productivity cropping systems*

Activity 5.1 Using data collected from Obj. 2, develop mathematical models that reliably describe the dynamics of the groundwater system and any transboundary and surface water / groundwater interactions present.

Activity 5.2 Predict a range of future scenarios for more intensified and diversified cropping systems in relation to conjunctive use and groundwater availability and sustainability, taking into account CC and the water requirements of, and impacts on, other water use sectors, including the environment/ecosystem services.

Activity 5.3 Identify suitable monitoring and management plans and implementation models that gauge the impacts of irrigation on the groundwater system, including groundwater-fed ecosystems.

Objective *6: Capacity building, training and institutional enhancement*

Activity 6.1 Identify the key stakeholders from the key sectors (government, donors, NGOs) and develop a process of ongoing engagement over the course of the project

Activity 6.2 Conduct targeted short courses in Lao PDR on practical groundwater development and management issues (e.g. aquifer assessment, groundwater development, water quality modeling and other issues identified as highest priority in the initial stages of the research).

Activity 6.3 Provide significant capacity building of Lao nationals through the engagement of at least 3 PhD, 5 MSc and a greater number or undergraduate students within the research portfolio.

Activity 6.4 Dissemination of scientific information and technologies at the village and provincial levels.

Activity 6.5 Undertake exposure visits to neighbouring Thailand to see small and large scale groundwater irrigation projects and approaches to effective groundwater management.

5 Methodology

5.1 Project implementation approach and scales

This project has involved a large number of activities owing to the wide interests of the project team, and the opportunities presented through it. Each activity relates to one or more of the Project Objectives. In order to gain a clear overview of the overall research an activity-based matrix is presented in Table 5.1. This framework partitions the activities in terms of the two major thrusts or domains of the project, namely the broad-spanning issue of 'groundwater resources assessment and governance' and the more specific issue of 'agricultural groundwater use technologies'.

Integration has been our goal wherever possible, and thus a feature of the majority of the project activities. The framework also indicates the thematic or disciplinary areas to which each activity contributes: namely (i) resource assessments & modeling; (ii) socio-economic and institutional; (iii) capacity building & training; (iv) communications (i.e. a derivation of the project objectives). Integration provides a means of value-adding and better serves the interests of informing policy makers and other users of the knowledge and tools provided.

The methods applied to each of the activities are indicated in very general terms in Table 5.1. A broad impression can be gained from this, and where necessary further details have been provided in Section 7. This is done in the interests of brevity, and those readers interested to know more should always refer to the relevant publication that is completed or pending for greater detail (refer to Section 8).

The project has operated at multiple locations and at a range of scales according to the specific requirements of each research activity and objective, as outlined in Table 5.1. This multi-scale approach is reflected in the schematic shown in Figure 5.1. The methods have included, but are not limited to, data collation and database development, desktop synthesis and evaluations, well drilling and testing, hydrogeological mapping; establishment of on-farm pilot sites; monitoring of the quantity and quality of the groundwater resources, remote sensing analysis, socio-economic and institutional evaluations of agricultural groundwater usage; construction of groundwater models for capacity building and operational purposes, running short courses and trainings.

Table 5.1. Matrix describing the major project activities

Activity Name	Thematic area	Province	Implem-enting Partners	Suppor-ting Partners	Methods Applied
Groundwater potential mapping & validation	RA&M	All	IWMI	DWR, NREI	weighted overlay analysis of key parameters - geology, rainfall, slope, soil, LULC, ET, drainage; drillhole data from project drilling, partner archives and other available sources
GW recharge estimation from baseflow separation	RA&M	All (LMB)	IWMI		baseflow separation of hydrograph records applied at regional scale
Hydrogeological assessment of the upper Vientiane Plain	RA&M	Vientiane	IWMI	DWR, NUOL-FWR	well inventory, aquifer testing, groundwater level monitoring, water quality testing
Detailed hydrogeological assessment and water balance of the Nam Panai watershed	RA&M	Vientiane	IWMI/NUOL-FES	DWR	field testing of borewells and dug wells to assess properties of the aquifers; coupled water budget and watertable fluctuation approach to estimate specific yield and mean annual recharge; household surveys to estimate groundwater use; and hydrograph separation of groundwater – surface water interactions
Soil and water quality conditions on the Vientiane Plain [2]	RA&M	Vientiane / Vientiane Capital	DWR, IWMI		soil and groundwater testing using laboratory kits and field analysers
Routine groundwater monitoring of the Vientiane Plain	RA&M / CB&T	Vientiane / Vientiane Capital	DWR/IWMI		training, groundwater monitoring, database development
Groundwater model development for the Vientiane Plain (and Nam Panai watershed)	RA&M / CB&T	Vientiane / Vientiane Capital	NREI/KKU-GWRC	DWR, IWMI	review & interpretation of available data, conceptual model development, collection of new field data, selection & construction of numerical model
Surface water - groundwater interactions in Sukhuma district, southern Laos [2]	RA&M / CB&T	Champasak	NUOL-FWR/UTS	IWMI	data compilation and data base, groundwater and surface water monitoring, GRACE
Groundwater resource assessment and waterbalance of Khiat Ngong village [2]	RA&M / CB&T	Champasak	NUOL-FE/IWMI	PHDC	well inventory, aquifer testing, groundwater level monitoring, water quality testing, socio-economic surveys
Feasibility studies for establishing a village-scale groundwater irrigation scheme at the THXP site, Bolikhamxay province	RA&M, SE*&I, CB&T	Bolikham-xay	KKU-GWRC/Hydrogeosci	IWMI	review & interpretation of available data, field reconnaissance study, well & irrigation design, pre-pilot trial testing, economic analysis, exposure visit
Opportunities and constraints of agricultural groundwater use in two contrasting villages in the Vientiane Plain	SE&I	Vientiane	IWMI	MDC	farming systems and HH characterization & perception study for given farming systems and households typology through HH surveys, FGDs, statistical analysis
Community Groundwater Management: The case of Phousan village	SE&I	Vientiane	IWMI	DWR	literature review, field work (KIIs, FGDs, SSIs)
Emerging Groundwater Management Plan for the Upper Vientiane Plain	SE&I	Vientiane	DWR	IWMI, NREI	stakeholder consultations, synthesis reporting, formulating new regulations, communications
Privately managed irrigation with dug-out wells for cash crops at Ekxang village	AGWUT	Vientiane	IWMI		site selection, participatory monitoring of irrigation practices, semi-structured interviews

Community groundwater irrigation - technical & non technical aspects	AGWUT, CB&T	Vientiane	DOI/IWMI/IGES		well/pump maintenance, water delivery, irrigation technologies, WUG processes & protocols
Short Course on Hydrogeology I: "Fundamentals of Groundwater Resources"	CB&T	NA	KKU-GWRC	IWMI	lecture notes, reading materials, powerpoint slides, well drilling and testing practicals, field excursion with notes
Short Course on Hydrogeology II: "Groundwater Modeling and Application"	CB&T	NA	KKU-GWRC	IWMI	lecture notes, presentations, essential reading material, laboratory exercises.
Follow-up workshops on groundwater modelling	CB&T	NA	KKU-GWRC	IWMI	technical support and guidance through practical workshops over 18 month period
Capacity building of Lao nationals as well as Australian/international students [1]	CB&T	NA	IWMI		Disseminate information to prospective applicant, postgraduate application support and research supervision, research internships, on-the-job training,
Exposure visits to groundwater irrigation projects in NE Thailand [1]	CB&T, AGWUT	Khon Kaen, UdonThani	KKU-GWRC	IWMI	site visits, discussions with key stakeholders from water and agricultural sectors, document findings and lessons

RA&M: resource assessments & modelling; AGWUT: agricultural groundwater use technologies; SE&I: socio-economic and institutional; CB&T: capacity building & training; CO: communications; [1] cross cutting activity; [2] post graduate student projects

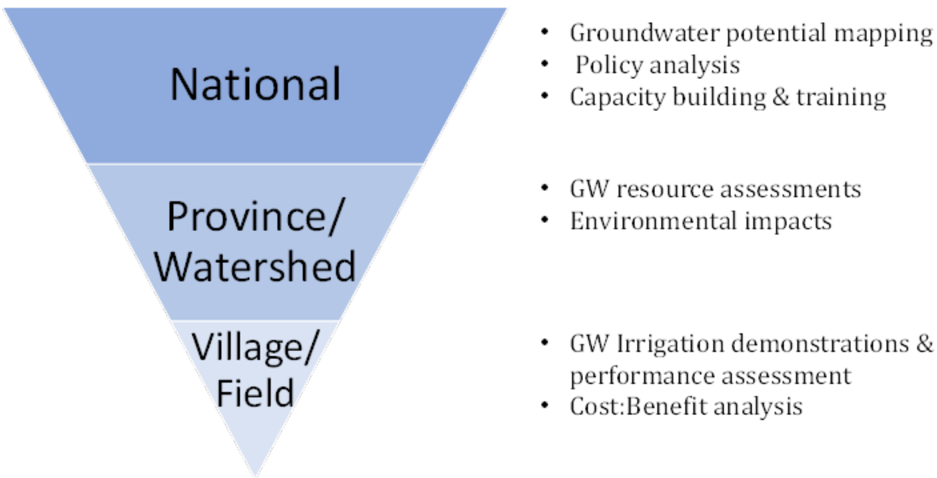

Figure 5.1 Multi-scale approach indicating activities addressed at each of the three scales

5.2 Focal areas

The field-based research has focused on three areas, namely: Vientiane/Vientiane Capital, Champasak and Bolikhamxay provinces.

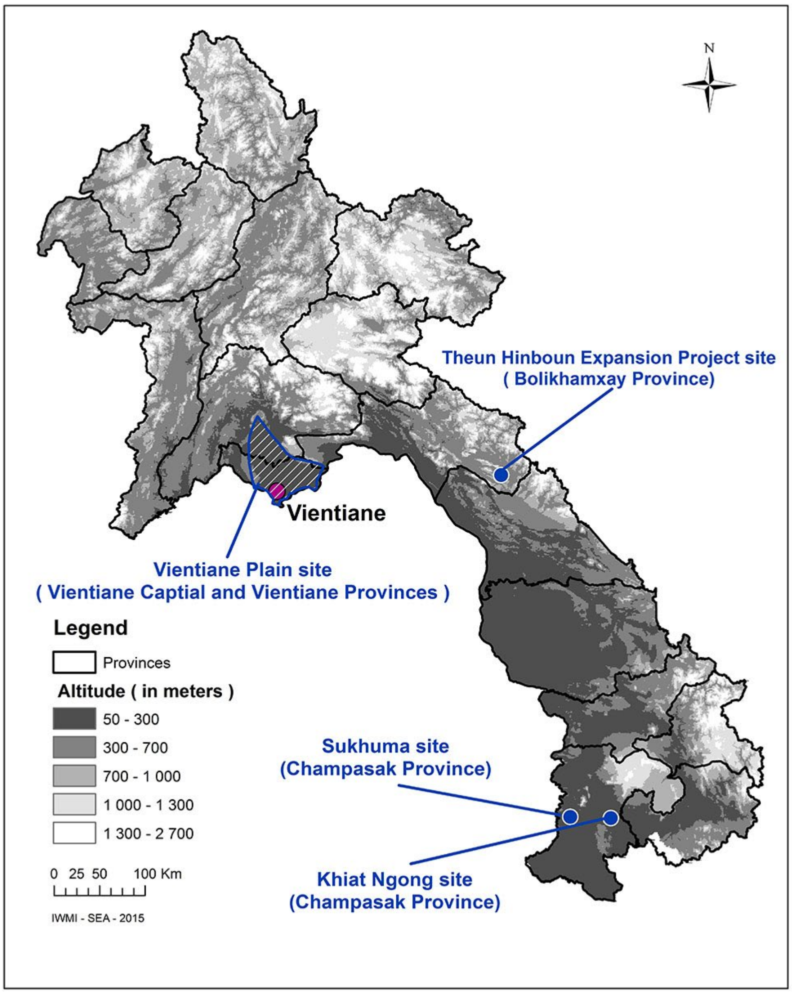

Figure 5.2 Project study areas

5.2.1 Vientiane Plain

The first of the three focal areas is the Vientiane Plain, extending across the two neighbouring provinces of Vientiane and Vientiane Capital. The significance of this site is reflected in the breadth of work carried out there, as indicated in Table 5.1. The Vientiane Plain, as one of seven major lowland plains of Lao PDR, is one of the most important agricultural production areas, with plans to further expand the area under irrigated agriculture, and which has not yet seriously considered making greater use of groundwater for irrigation. The proximity to large domestic markets (principally Vientiane) and high degree of rural electrification makes it worthwhile to examine if utilizable reserves of groundwater can be identified; particularly in areas remote from major surface water courses. The proximity to the Vientiane Capital City also made it logistically convenient for field work, and from the viewpoint of developing new irrigation technologies in particular, a necessary pre-requisite. The Vientiane Plain lies on the northern margin of the Khorat Plateau and knowledge of the hydrogeological systems on the Lao part of the Plateau is extremely limited relative to the more intensively studied work in Thailand (Landon, 2011). The widespread presence of marine deposits and poorly defined areas of low permeability impact the success of drilling efforts, due to salinity and yield constraints.

5.2.2 Champasak province

Studies have been carried out at Sukhuma and Pathoumphone districts in Champasak province through the work of one PhD student and one Masters student respectively. Sukhuma district is located on the southeastern margin of the Khorat Plateau and the lowland is one of the poorest and most drought-prone of the lowland districts in Lao PDR (Vote et al., 2015). The work at the Sukhuma District site took into account the work of ACIAR Project No CSE/2009/004 which had started earlier and had yet to be completed at the commencement of this project. This project team worked with the CSE/2009/004 team in 2012 to select sites for the transect of piezometers, and were aware of the activities underway in that project to ensure that any new work under the auspices of this project was value-adding. Activities at this site became possible after Mr Sinxay Vongphachanh was awarded a John Allwright Fellowship in 2013 to undertake PhD studies at University Technology Sydney (his studies only started in early 2015 after passing the necessary English literacy standards to enroll at an Australian university). His study is focusing on a quantitative hydrogeological assessment of the Huay Khamouan watershed which drains into the Mekong River, with particular emphasis on the spatial and temporal nature of surface water – groundwater interactions. The study at Pathoumphone District has focused on Khiat Ngong village where groundwater presents the only source of water supply and major water quality issues (in relation to arsenic in particular) have been raised by local authorities. The area is hydrogeologically quite distinct from Sukhuma (basalts overlying a sandstone formation) and is situated adjacent to the Beung Khiat Ngong wetland, it is Ramsar-listed and of great environmental, social and cultural significance. Mr Khamkieo Phommavong undertook a one-year study of the groundwater resources in the village as part of his Masters . Since the successful completion and defence of the Thesis he has been carrying out a one-year research internship with IWMI to expand the study to the watershed scale to better reflect the groundwater – wetland interactions.

5.2.3 Bolikhamxay Province

Opportunity to undertake scoping studies at Bolikhamxay province in central Lao PDR was at the invitation of the Theun-Hinboun Power Company (THPC) through the Theun-Hinboun Expansion Project, associated with the construction of the Nam Gnouang dam on the Gnouang River (a tributary of the Nam Theun) for power generation and which has resulted in resettlement of around 4,000 people into four new resettlement sites. The resettlement program seeks to ensure that resettled communities have an improved standard of living and sustainable livelihoods, including improved housing, household plots for vegetable gardens, fruit trees and small livestock, one hectare of rice fields and half a hectare of upland fields for cash crops and trees. THPC has invested in groundwater infrastructure to serve domestic needs and has approached the project team to explore if groundwater could also cost-effectively provide irrigation water supplies for the lowland rice fields, to increase agricultural productivity by providing water during the dry season and supplement rainfall during the wet season.

6 Achievements against activities and outputs/milestones

Objective 1: Assessment and prioritization of typologies and hotspots most suited to the development of groundwater-based irrigation

No.	Activity	Outputs/ milestones	Com. date	Comments
1.1	Conduct a comprehensive literature review, drawing upon data and other information from the project partners and from agencies currently or previously active in groundwater studies and develop a database on the state of knowledge of groundwater availability and suitability for agriculture and other purposes.	A comprehensive and accessible electronic database that includes all known available hydrogeological information in the areas investigated.	Dec.'15	Databases at the national and more localised scales have been compiled from data collected during the project as well as secondary data. They are used for various forms of analysis in the project and have been shared with next end users.
1.2	Prioritise areas within the study areas for more localised investigations, and pilot-scale testing using information gained from the above-described activity, together with other relevant key biophysical and socio-economic parameters.	Report detailing the ranking and delineation of areas most suited to the development of smallholder groundwater irrigation within the study regions.	Jul.'16	Focal areas for detailed investigations/pilot-scale testing have been identified. A wide range of biophysical, socio-economic and institutional studies have been carried out across the focal areas.
1.3	Extend the analysis described above to other parts of Lao PDR to identify development opportunities at the national scale.	Local/regional level prospects maps and associated reporting of the mapping techniques used to assess the status of groundwater availability and suitability for development.	Jul.'16	A national scale assessment of groundwater potential has been carried out based on multilayer RS/GIS analysis. Major effort has gone into securing data and the map is being validated before being published and disseminated.

Objective 2: Demonstration and evaluation of on-farm pilot trials and groundwater resource characterization

No.	Activity	Outputs/ milestones	Comp. date	Comments
2.1	Review, design, setup and test infrastructure for abstraction and utilization of groundwater for irrigated agriculture at the individual farm-scale for up to 3 locations with similar conditions for each of the 3 hydrological configurations	Documented evidence that initial farmer liaison conducted successfully and pilot trial sites selected. Report reviewing the relevant agricultural water management technologies with recommendations on design options most suitable to Laos.	Jul.'16	A community-managed groundwater irrigation trial setup and being evaluated at Ekxang village. A demonstration site (0.2 Ha) has also been setup at NUOL-FWR and is used for studies by students carried. Assessments made of individual farmer managed dug wells used for dry season cash cropping. A small trial at THXP sie carried out unsuccessfully and scaling up is deemed uneconomic.

2.2	Design and implement a monitoring program and evaluate the performance of the pilot trials from a range of perspectives, to establish the localised impacts on the livelihoods of the participating farmers through to the wider impacts on the quantity and quality of the groundwater resource and other groundwater users	Report describing the groundwater irrigation pilot trial with farmers' cultivation during the wet and dry seasons. Report containing monitoring data on the impacts of irrigation on hydrology, agricultural production and livelihoods.	Jul.'16	GW monitoring network setup in September 2014 across the upper Vientiane Plain and managed by DWR. Farmers have been trained and are monitoring climate and water use at the Ekxang trial site.
2.3	Perform hydrogeological and hydrological assessments that provide an adequate conceptual understanding of the aquifer system and surface water – groundwater interaction assessments needed to undertake water resources sustainability assessments (Obj. 5)	Detailed and systematic documentation of the hydrogeological systems (and hydrological systems where relevant) for the study areas in each province.	Jul.'16	Evaluation of the groundwater flow and hydrochemistry of the Vientiane Plain on a variety of scales is complete and publications are being prepared. Assessment of groundwater recharge and baseflow in gauged catchments across Laos and neighbouring countries is underway.
2.4	Review, design and pilot a participatory model of groundwater monitoring and management that recognises the demand and supply constraints in relation to crop types and intensities and needs of the other sectors	Documentation of the experiences gained in piloting the most appropriate participatory practices	Jul.'16	Groundwater User Group formed based on extensive consultation with famers and local officials. Useful lessons about how to and how not to establish such groups is being gained.

Objective 3: Strengthening the understanding of opportunities and constraints for agricultural groundwater use

No.	Activity	Outputs/ milestones	Comp. date	Comments
3.1	Undertake comprehensive socio-economic surveys and investigations to identify and address unresolved questions that provide a constraining environment in developing viable strategies for expanded groundwater use for agriculture.	Detailed workplans developed outlining approach and study areas.	Dec.'14	The role of groundwater access in shaping farming households' livelihood strategies has been investigated in two nearby but strongly contrasting villages. One journal paper has been accepted for publication taking one village as a case study. Other publications will also emerge based on both villages.
3.2	Work with local communities and institutions to identify farming systems and the forward/backward linkages needed to meet the multiple needs of higher food security, nutritional value and financial profitability of irrigation with groundwater.	Documentation of the socio-economic, gender and livelihood impact of present and potential groundwater use at different scales and in various geographic settings.	Jul.'16	The viability of privately managed irrigation has been evaluated. An evaluation for community systems is in advanced stages.

3.3	Draw cross-comparisons and learnings from regions where groundwater use is more intensive (e.g. parts of Thailand and much of India) and other developing regions of the world which are plagued by similar issues to Lao PDR (e.g. including eastern India and much of SSA).	Documentation of the similarities and differences between the situation in Lao PDR and that of other regions where groundwater is highly over-utilised and underutilised for livelihood improvement.	Jul.'16	Review of groundwater use and management has been carried and the lessons for Lao PDR drawn out. A publication is under preparation.

Objective 4: Groundwater governance, review of existing agricultural policy and strategies within the broader context of water-energy nexus

No.	Activity	Outputs/ milestones	Comp. date	Comments
4.1	Undertake comprehensive reviews of existing groundwater institutions and policies (within and outside the water sector) and their relevance to a scenario of enhanced groundwater use.	Synthesis report on the different rationales to either position groundwater as part of the country's national strategies in agricultural development or to merely focus on its role as farmers' additional means to get access to water.	Jul.'16	A policy brief is being prepared synthesizing the findings. After knowing that groundwater was inadequately addressed in the existing policy documents, the scope of this work was scaled down and more focus was given on identifying the policy entry points and on other activities (4.2. and 4.3). MONRE, MEM and MAF were identified as key ministries to engage in the development and management of groundwater irrigation in future. A journal paper is being prepared by compiling inputs from 4.1, 4.2 and 4.3.
4.2	Conduct cross-sectoral, multi-level institutional analysis to identify existing barriers, gaps, and potential for (future) groundwater application in agriculture within the context of the water-land-energy nexus.	Documentation of key actors and institutions in current and future groundwater development and proposed instruments and approaches for effective groundwater management.	Jul.'16	A horizontal and vertical mapping of key institutions and actors involved in water-land-energy was conducted. A two way information flow should be enhanced to strengthen the vertical linkage within a ministry. Similarly, across three sectors, an inclusive decision making needs to be promoted to maximise synergy and manage trade-off.
4.3	Perform multi-country review of groundwater management policies that identify strategies relevant to Lao PDR to avoid over-exploitation problems	Assessment of the success or otherwise of alternative models of groundwater governance to feed into the groundwater Irrigation Strategy.	Jul.'16	Policy brief in 4.1 will incorporate lessons from international experiences that could be applied in the Lao context. Experiences from 4.1, 4.2 and 4.3 will complement preparation of the "Guideline for establishing community groundwater user group". A country paper focussing on issues and ways forward for improving groundwater governance has been published.

Objective 5: Sustainability assessment of the groundwater resources in relation to water requirements for higher productivity cropping systems

No.	Activity	Outputs/ milestones	Comp. date	Comments
5.1	Using data collected from Obj. 2, develop mathematical models that reliably describe the dynamics of the groundwater system and any transboundary and surface water / groundwater interactions present.	Documented understanding of groundwater processes and availability under current conditions and future scenarios of climate, crop type/pattern and groundwater development.	Jul.'16	This activity proved to be much more challenging than envisaged and required major investments in capacity building and data collection. As part of #6.2, prospective modelers from partner agencies have been trained in numerical groundwater modeling and two teams are developing models under the guidance of KKU. Publications are in progress.
5.2	Predict a range of future scenarios for more intensified and diversified cropping systems in relation to conjunctive use and groundwater availability and sustainability, taking into account CC and the water requirements of, and impacts on, other water use sectors, including the environment/ecosystem services.	Report that assesses the sustainable limits of groundwater utilization in the study areas, taking future climate predictions into account.	Jul.'16	This could not be achieved in full despite the major efforts made by the modeling team and trainers. The outputs include a working model for the Vientiane Plain, and ongoing competency to progress on the existing model.
5.3	Identify suitable monitoring and management plans and implementation models that gauge the impacts of irrigation on the groundwater system, including groundwater-fed ecosystems.	Development of tools and other forms of guidance needed by key stakeholders to identify decision pathways for development.	Jul.'16	The DWR is developing a GW Management Plan for the upper districts of the Vientiane Plain (a first in Laos), building upon the work that has been carried out in the area through the project and merging regulatory framework. This Plan will be one of the major tools to support planning and decision making.

Objective 6: Capacity building, training and institutional enhancement

No.	Activity	Outputs/ milestones	Comp. date	Comments
6.1	Identify the key stakeholders from the key sectors (government, donors, NGOs) and develop a process of ongoing engagement over the course of the project	Documentation of stakeholder engagement that identifies the key groundwater knowledge needs.	Jul.'16	Stakeholder mapping is well established. We have been reaching out through targeted communication activities.
6.2	Conduct targeted short courses in Lao PDR on practical groundwater development and management issues (e.g. aquifer assessment, groundwater development, water quality modeling and other issues identified as highest priority in the initial stages of the research).	Focussed trainings for national partners and other stakeholders covering the multidisciplinary aspects of groundwater and irrigation management.	Jul.'16	Two major short courses held successfully at KKU for project team members and other invitees. A working group on groundwater modeling formed and regular trainings were carried out over an 18-month period to progress on project activities and develop longer term capacity in this area.

6.3	Provide significant capacity building of Lao nationals through the engagement of at least 3 PhD, 5 MSc and a greater number or undergraduate students within the research portfolio.	Demonstrated postgraduate and other on-the-job training opportunities for project participants from national partner agencies. A number of Master and PhD qualified Lao nationals as a result of the research project.	Jul.'16	Significant advancements has been made: two Lao team members have received JAF's for PhD studies to study in Australian universities; three members have carried out MSc studies (2 complete), and numerous Bachelor theses at NUOL.
6.4	Dissemination of scientific information and technologies at the village and provincial levels.	Information sharing and capacity building through the involvement of national counterpart institutions and presentation of new knowledge at meetings and workshops.	Jul.'16	Active engagement with provincial, district and village level authorities has been led by DWR for the development of the upper Vientiane Plain Management Plan.
6.5	Undertake exposure visits to neighbouring Thailand to see small and large scale groundwater irrigation projects and approaches to effective groundwater management	Report documenting the insights and value gained from the exposure visits.	Dec.'14	Completed. Three exposure visits to Khon Kaen and Nong Khai provinces have been carried out over the course of the project to see groundwater irrigation projects and meet stakeholders from the water and agriculture sectors. The outcomes of these visits have been documented.

PC = partner country, A = Australia

7 Key results and discussion

Owing to the large number of activities undertaken through the project, only a brief synopsis of the key results from each can be provided here. Readers are directed to specific publications for more detailed information.

7.1 National level studies

7.1.1 Groundwater potential mapping

Hydrogeological maps at the national scale does not exist for Lao PDR, with only regional maps available at 1:1,000,000 scale produced by Landon, (2011) based on the earlier work of Charuratna and Phu, (1992). Given the general paucity of data, generating a defensible hydrogeological map through this project was not considered feasible. Instead, the mapping of likely potential (or prospects) was thought to be an achievable and useful result. Such approaches have been used at the country level with success in other data scarce environments such as Ghana (e.g. Gumma and Pavelic, 2013).

A GIS-based approach was used as it provides a useful tool to integrate a wide range of spatial data types. GIS and RS dataset analysis included 7 specific layers: geology, rainfall, slope, soil clay content, land use/land cover, evapotranspiration and distance from river banks. Major efforts were put into securing data from published and unpublished reports, and contacting various government departments, NGOs and the private sector to attempt to validate the map within the constraints mentioned above. This has yielded a modest dataset. Borewell and aquifer data were aggregated into a database of 256 wells from various studies and data for 40 pumping tests has been used to characterise aquifer units. Each of the 7 layers were classified based on data and literature and integrated through a weighted overlay analysis. Information on the classifications and weights used can be found in Viossanges et al., (in prep).

Result is expressed as a Groundwater Potential Index (GPI). The resulting map given in Figure 7.1 shows the areas of highest potential to develop groundwater resources. The validation process has been difficult owing to the scarcity of field data and the heterogeneity of aquifer properties at the local scale. Thus the map is intended to provide a broad overview of the anticipated groundwater potential rather than a precise map, and a basis for more detailed field investigations.

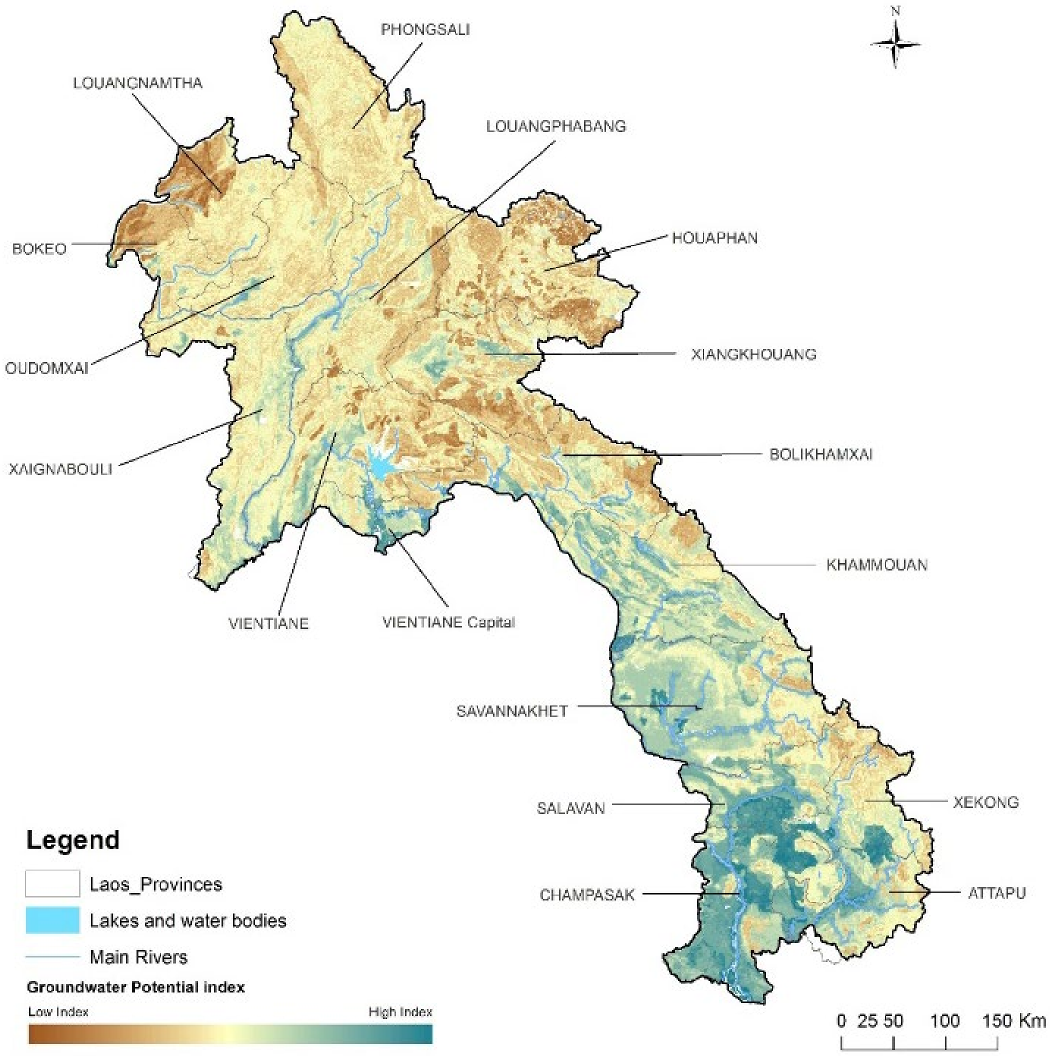

Figure 7.1 Groundwater potential index map for Lao PDR (from Viossanges et al., in prep)

7.1.2 Groundwater recharge estimation from base-flow separation

Groundwater recharge- the process by which aquifers are replenished through seepage derived from rainfall, rivers, drains etc. - is an important first step in defining the quantities of groundwater that can be reliably and sustainably extracted for human use. Recognizing this, and given that the mechanisms and fluxes for recharge are poorly understood in Lao PDR, some effort was put into better understanding recharge at the regional scale (as described in this section), and at more local scales in far more detail (as indicated in some of the sub-sections below).

Groundwater recharge rates are estimated throughout the Lower Mekong Basin, including Lao PDR, using a base-flow separation method. This method is appropriate due to the climate and regional hydrology of the region: shallow watertables, gaining streams, groundwater usually discharged mainly through base flow to streams, dominant diffuse recharge. The approach opted for was the local minimum method which tends to under-estimate recharge rates rather than over-estimate (Eckhardt, 2008). Daily flow data from 65 locations along the tributaries of the Lower Mekong River was used. Mean areal recharge rates over the sub-catchment areas were spatially interpolated using multi-variate regression analyses, resulting in the gridded map (Fig. 7.2). This analysis showed that the spatial variability of groundwater recharge (Re, [mm/year]) rates are predominantly and log-linearly correlated to the geographic location, latitude (La, [decimal degrees]) and longitude (Lo [decimal degree]), annual rainfall (Ra [mm/year]) and standard evapotranspiration (ET [mm/year]) as formulated in this exponential equation:

$$Re = \exp(76.56) \times La^{-2.79} \times Lo^{-11.01} \times ET^{-4.12} \times Ra^{2.43} \qquad (1)$$

These four explanatory variables (La, Lo, ET and Ra) were selected among a range of catchment characteristics including soil texture and depth, land-use, geomorphological features (slope, drainage density, and elevation) and meteorological variables (rainfall, temperature and standard evapotranspiration). The selection was made by the combination of 'best subset regression' and 'step-wise regressions'. The prediction R-squared was 66.4%. Note the exponents for Ra (2.43) and ET (-4.12) are positive and negative, respectively, meaning that the groundwater recharge consistently increases as annual rainfall increases and the standard evapotranspiration decreases. The inclusion of the geographic coordinates (La and Lo) in equation (1) is difficult to explain at this stage. It is tempting, but overly simplistic, to conclude that they are a surrogate for the environmental variable(s) controlling recharge rates such as geology not yet included in the list of candidate explanatory variables. The reason for omitting geology is the unavailability of quantitative data when the analysis was completed. Although the omission of geology-related variable(s) in equation (1) could result in lower predictive performance, this gap does not bias the magnitude of the recharge rates and their overall spatial variability over the study area.

Figure 7.2 indicates that mean annual recharge rates vary between less than 170 mm/yr in Northeast Thailand (15% of mean rainfall) and more than 800 mm/yr in the sub-catchment of the Nam Ngum River in Lao PDR (Phou Khao Khouay mountain) and South-eastern Lao PDR (equivalent to >50% of mean rainfall).

These recharge rates are above the global average due to the humid tropical conditions (Döll and Fiedler, 2008) and in line with results obtained by different methods in other parts of the world (Rutledge and Daniel 1994). Scanlon et al., (2002) warns of the high uncertainty of the results obtained by applying digital filters to river flow. However, in this case, since a conservative approach known to provide underestimates was applied, this may be still of some benefit for resource managers.

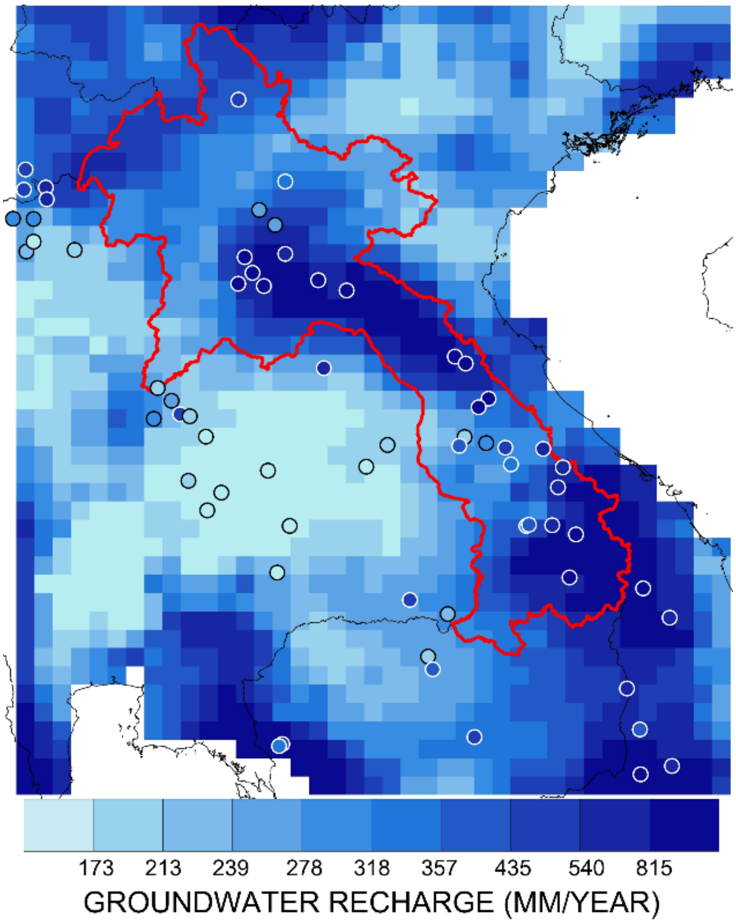

Figure 7.2 Recharge rates in the Lower Mekong Basin. *Coloured cells are estimated by multi-variate interpolations. Coloured circles are estimated from streamflow records and located in the centroid of the gauged sub-catchments* (from Lacombe et al., in prep)

7.2 Biophysical, socio-economic and institutional studies in the Vientiane Plain

7.2.1 Hydrogeology and flow systems of the Upper Vientiane Plain

The geologic materials that lie beneath the entire Vientiane Plain were laid down between 65 and 200 million years ago during the Jurassic and Cretaceous periods. Since that time sediment has been converted to rock (sandstones and siltstones). In the last stage of sedimentation, during a period of high sea level, evaporation of a shallow sea resulted in the formation of rocksalt (*Tha Ngone formation*). These rocks were then folded and fractured to form the hills of actual Phou Phanang and Phou Khao Khouay mountains respectively in the west and east of the upper (northern) Vientiane Plain. Along the north-south axis, the valley has been filled with alluvium (sands, gravels and clays) deposited from the Nam Lik and Nam Ngum Rivers. In general, the geology can be simplified as hard rocks (sandstones) and alluvium (sand, silts and clay) (Fig. 7.3). The sandstones of the *Tha Ngone*, *Champa*, *Phupanang* and *Namset* formations have a combined depth of several hundred meters. The alluvium is non-existent or less than 2 meters thick in the hills of Phonhong, Thoulakhom and Keo-oudom districts. In the plains, the thickness of alluvium is limited near the hills and increases towards the Nam Ngum River. Alluvium thickness is highest is Viengkham district where it has a maximum depth of around 40 metres.

The sandstones in the hilly areas have low storage capability and yield only low quantities of groundwater. Water is present largely within the limited fracture density. At Phousan village, for example, villagers relying on these aquifers sometimes face problems of insufficient yield with pumping rates as low as 0.5 litres per second (refer to Fig 7.3, transect A-A'). Furthermore, in some places, it is possible to find salty deposits where the *Tha Ngone formation* has not been eroded, as seen on the map and cross-sections. This implies that these hard rock formations should be avoided whenever possible.

In contrast, the alluvium that forms the central part of the area can possibly hold more groundwater in the sands and gravels. Deep wells in Ekxang village have proved to support yields of about 5 litres per second and it is suspected that greater yields could be found in coarser sediments closer from Nam Ngum River. From west to east, the depth of alluvium increases toward the Nam Ngum River and then decreases again towards the edge of the plains. The exact location of salty areas below the alluvium being unknown, it is recommended that drilled wells should not exceed alluvium depth (ranging from a few meters to forty meters depending on location, as seen on map and cross sections).

Also, careful management of groundwater abstraction is needed. In the case of uncontrolled use and over-exploitation of groundwater, the pumping can possibly lead to upconing of saline water from deeper layers up to the surface and lead to contamination of shallow freshwater layers groundwater and negative impacts for water users.

Groundwater across the upper Plain is present under unconfined conditions and is accessible at shallow depths. Based on measurements at about 50 locations across the area, it is ascertained that the depth of the groundwater from below surface on the lowland areas varies generally from 0.5 to 8m in the wet season and 1.5 to 13m in the dry season. Wells situated closer to the Nam Ngum River show greater water level variations, most likely related to the river level fluctuations. This shallow groundwater can be abstracted using simple 'suction pumps' if less than 7m, 'jet pumps' at greater depths, and 'submersible pumps' for higher discharge.

Measured water levels at 29 locations in 2013-2015 where JICA (the Japanese International Cooperation Agency) had also measured water levels soon after construction in 1994, indicated that water levels have not changed significantly over the intervening two decades. This is important, in the sense that it does not indicate an immediate problem related to over-utilization across the area. These wells were selected as a part of a monitoring network for the area and have been routinely monitored by DWR since 2014.

The shallow water level across the area implies that the groundwater is at greater risk to pollution from agriculture and other landuse, and it is highly important to adopt good landuse management practices to prevent pollution and avoid contamination of the groundwater resources.

The potentiometric surface has the same morphology as the land surface topography. Thus, groundwater generally flows from the major hills in Phou Phanang and Phou Khao Khouay and the more localised Phon Mii towards the Nam Ngum. However, not all of the recharge occurs in these hills – there is recharge everywhere across the plains.

Whilst rainfall derived recharge is restricted almost entirely to the wet season, surface water is also released from the Nam Ngum 1 Dam year-round for hydropower production. In the driest months of the year, these rivers flow from the Nam Ngum into the adjacent alluvial aquifer and add to groundwater storage – this is reflected not only in water level data but in the hydrochemistry of the groundwater. Thus, the hydraulic gradients in the alluvial aquifer adjacent to the Nam Ngum may be altered between the wet season and dry season. Further details can be found in Haiblen et al., (in prep).

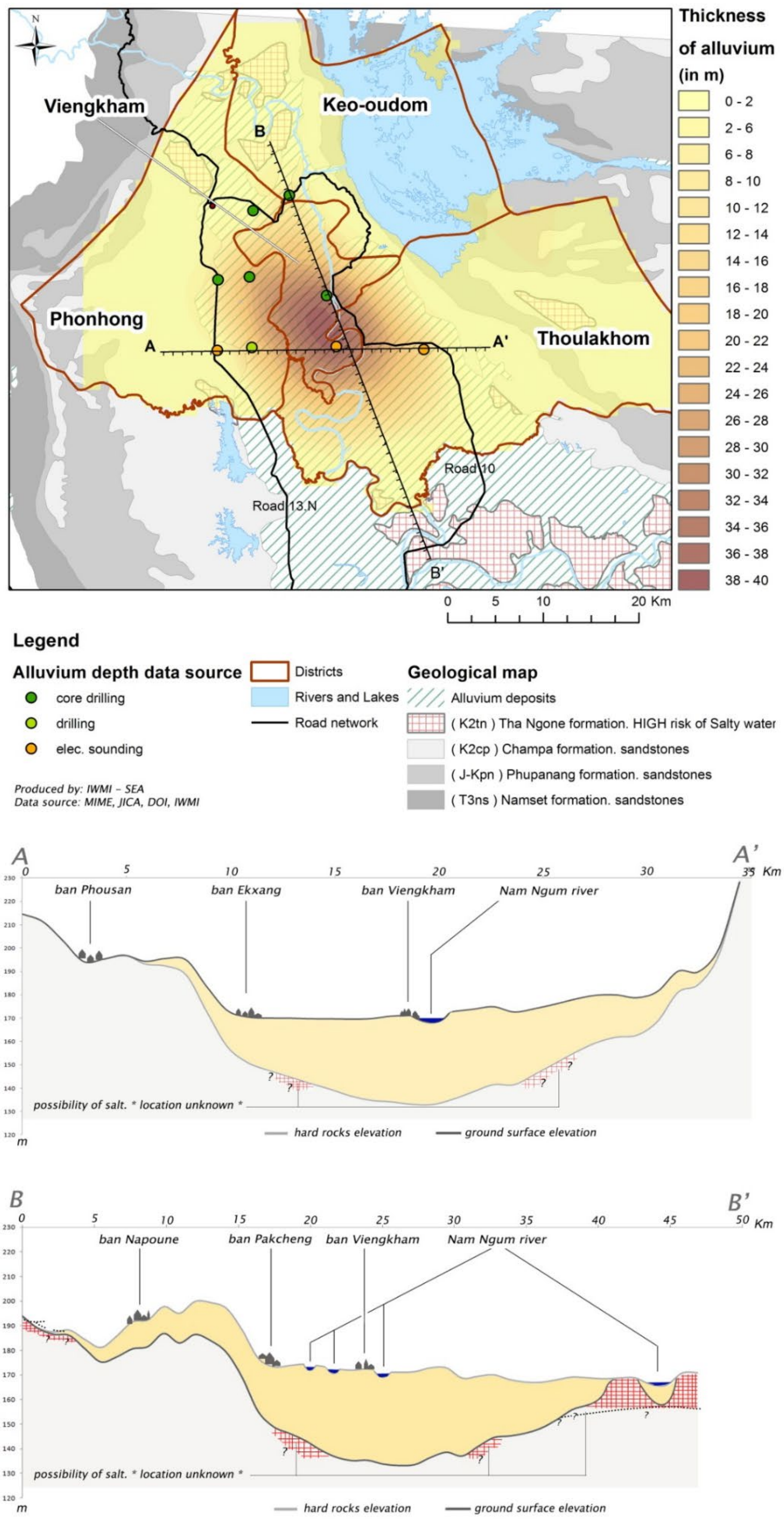

Figure 7.3 Map and cross sections across the upper Vientiane Plain indicating thickness of alluvium

7.2.2 Detailed hydrogeological assessment and water balance of the Nam Panai watershed

Owing to the detailed level of activities that have commenced in Ekxang and Phousan villages, the opportunity to scale up to watershed level and apply a watershed approach emerged in the latter part of the project in 2015. Nam Panai watershed extends over an area of 236 km² in the upper Vientiane Plain, and encompasses 29 villages (according to the 2011 National Census), including the two aforementioned focal villages.

A hydrogeological assessment and recharge/groundwater estimation have been conducted. These have been investigated through: (i) field testing of borewells and dug wells to assess properties of the aquifer units; (ii) coupled water budget and watertable fluctuation approach to estimate specific yield and annual recharge; (iii) household surveys across 4 villages to estimate groundwater use; (iv) identifying possible groundwater – surface water interactions through hydrographs analysis; (v) numerical modeling for conceptual model testing and verification, and ultimately to test alternative development scenarios.

Hydrogeological assessment showed that the transmissivity of the alluvium was around 238 m²/d with discharge rates for borewells on the alluvial plains of up to 18 m^3/h under suitable conditions. The greater majority of the population relies on groundwater for domestic purposes. Groundwater utilization in the watershed is estimated to be nearly $2x10^6$ m^3. Only 246 ha (1.1% of the watershed) is irrigated during the dry season, mainly using surface water from the Nam Ngum (river) and smaller stream and ponds when available and marginally from dug wells and residential wells. The water table depth is very shallow (1.5 m to 13 m in the dry season) and varies between dry and wet season from 1 m to 5.5 m at different locations in the watershed. The specific yield of the alluvium has been estimated using a water budget method to be 19%. This is consistent with values for sand and gravel aquifers. It is higher than estimates of Perttu et al., (2011) who derived a value of 13% using surface geophysical methods (Magnetic Resonance Sounding). The recharge in the alluvium was calculated over the watershed using the Water Table Fluctuation method. The recharge rates vary spatially. On average, recharge has been estimated to be 486 mm/y or 22% of the average rainfall in the area (2,340 mm/yr). Groundwater flow in the alluvium is predominantly from west to east, consistent with the topographic trends. Most of the discharge across the watershed is to the Nam Ngum. In fact, the Nam Ngum seems to exert a strong influence on groundwater table variation in the alluvium (Fig. 7.4). Highest variation in water table is observed in the vicinity of the river banks. A preliminary 2-layer numerical model of the watershed has been constructed for the watershed in Visual Modflow 2011.1.

Using the available data, the quantitative groundwater flow model is providing greater understanding of the most significant drivers in the groundwater system. This provides focus for where time and financial resources should be focused in further work to refine the understanding of the system. Further details on these aspects are found in Viossanges et al., (in prep) and Harris-Pascal et al., (in prep).

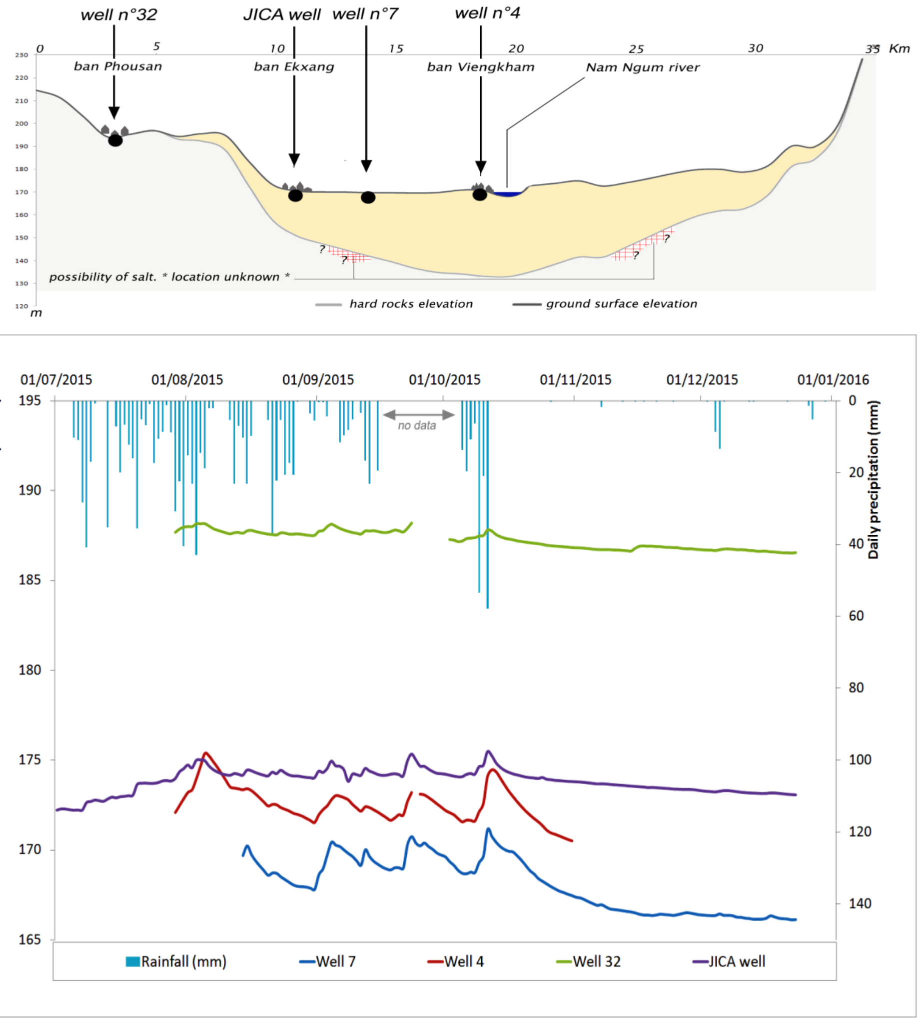

Figure 7.4 Well locations across the watershed and hydrograph responses over the second half of 2015

7.3 Soil and water quality conditions in the Vientiane Plain

7.3.1 Broadscale assessment

A broadscale survey of the soil and water quality conditions was carried out between March 4th and 25th, 2015 across twelve districts and 95 villages distributed across the entire Vientiane Plain, apart from the major forested areas (Brindha et al., in prep). Mostly open wells were sampled, and in a few cases (mostly urban areas) borewells were sampled. Soil samples were also collected close to the well locations. Soil and water were analyzed using field kits procured from Transchem Agrochemicals, India. Water parameters tested were hardness, free chlorine, chloride, arsenic, nitrate, iron, fluoride, and faecal coliforms. Soil parameters tested were pH, organic carbon, calcium, magnesium, potassium, phosphorous, sulphur, nitrate nitrogen and ammoniacal nitrogen.

For groundwater, there are concerns for some of the constituents at a number of sampling points (Figure 7.5). Faecal coliform contamination is apparent in seven sites. The major source of coliforms in groundwater is from sewage contamination, and this may reflect local pollution from leaky sewage pits in rural areas or disposal networks in urban areas. Elevated EC and chloride were apparent at two sites in the south which may be geogenic leaching from marine rocksalt present at shallow depths in some areas. Only 2 sites had nitrate levels above the World Health Organisation guideline of 45 mg/l, the highest level measurable from the test (note the national drinking guideline is 50 mg/l). Soil quality does not pose a threat to plant growth in the Vientiane Plain nor is nutrient deficiency a major issue.

7.3.2 Village level assessment

A village level assessment of groundwater quality was carried out at Ekxang vllage, Phonhong district by Ms Chindavanh Souriyapahck from DWR for her Masters Dissertation at Hiroshima University, Japan. This was supplemented by monitoring of heavy metals by IWMI. Ekxang was selected as a case as all the residents of the village are heavily dependent on groundwater resources for their domestic use and groundwater irrigation is a major activity in the village. Hence, the shallow groundwater is at risk of pollution and related health risks.

Field sampling was conducted in September 2015 (late rainy season) and in December 2015 (early dry season). On each occasion 21 wells were sampled and analyzed for eight bio-physiochemical parameters: EC, temperature, dissolved Oxygen and pH (all on-site) as well as arsenic, chloride, nitrate, and faecal coliforms (laboratory). Efforts are underway to develop a model to predict the quality of specific constituents using a portable spectroradiometer, which measures the spectral irradiance from the visible to near-infrared irradiance range.

Whilst arsenic and nitrate levels were below standard for drinking quality, the microbial water quality in the resident part of the village was problematic for most part. Faecal coliform values ranged from 0 to 35,000 MPN/100ml during the wet season and from 0 to 54 MPN/100ml in the dry season. Distinctly poorer quality was observed in the built-up areas compared to the agricultural areas, most likely owing to the high density of sanitation facilities.

Whilst the majority of the local community purchase bottled water for direct consumption from private suppliers, it is likely that some residents directly consume this water. Greater public awareness on water quality and sanitation is needed to ensure necessary precautions are taken by users. This role is intended for DWR and forms part of their stakeholder engagement program in developing the Management Plan for the Upper Vientiane Plain (refer to Section 7.6.4).

With aquifer sediments having potential to contain naturally high levels of heavy metals, and agricultural practices increasing the risk of deteriorating groundwater quality through pesticide and fertiliser residuals, it is important that such constituents are also monitored so that any occurrence of pollution can be addressed in time.

Twenty groundwater samples were collected from Ekxang in December 2014 and January 2015 and analyzed for uranium, copper, lead and zinc. Maximum uranium concentration recorded in groundwater was 0.26 µg/l; values much lower than the permissible limits of 15 µg/l prescribed by the World Health Organization. Only lead was above the maximum permissible limit (0.01 mg/l) for drinking water in eight samples in December 2014. There was no hazard due to copper and zinc. Human exposure risk through the drinking water pathway was calculated and these waters do not pose any carcinogenicity or non-carcinogenicity hazard (Brindha et al., 2016).

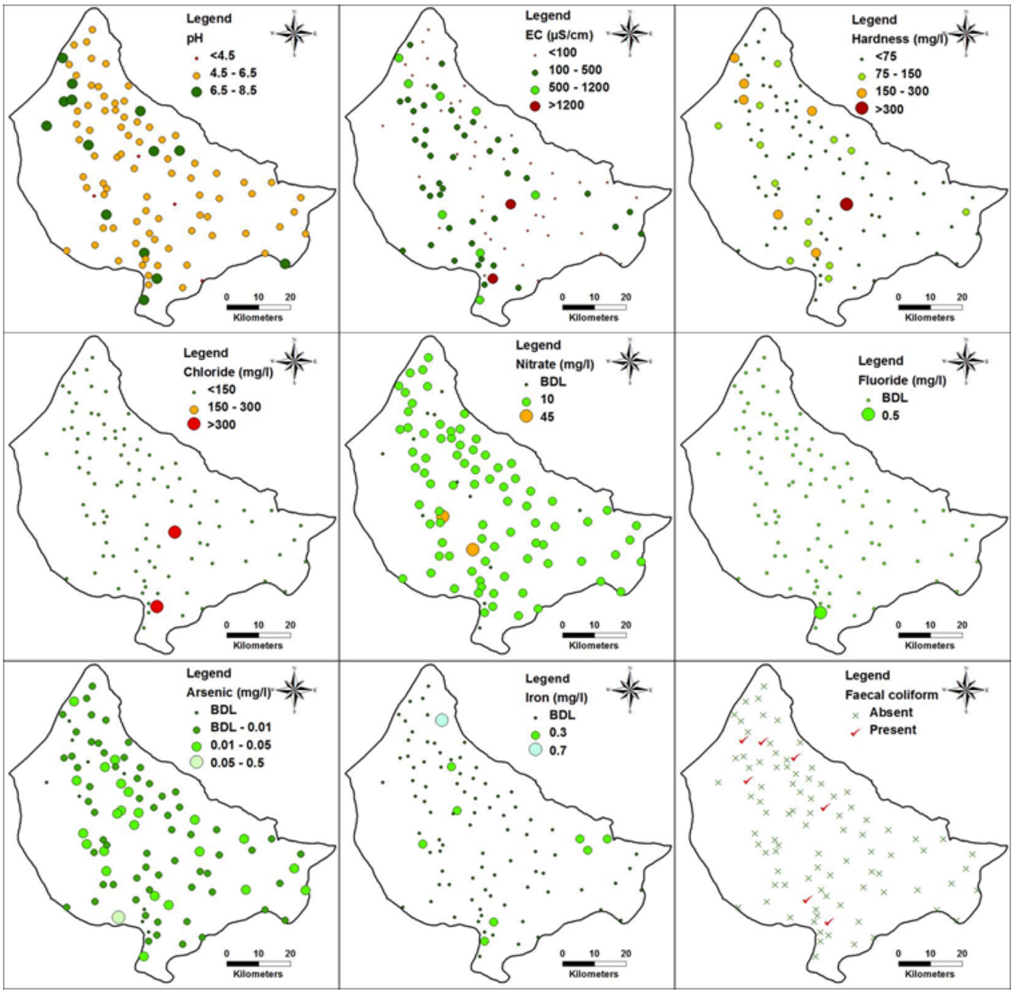

Figure 7.5 Spatial variation in water quality parameters in the Vientiane Plain (from Brindha et al. in prep).

7.4 Groundwater irrigation trials and assessments

Here we cover two trials, one addressing private, individually-managed groundwater irrigation, and another one a community-managed scheme which has been established as part of this research. Both trials have taken place at Ekxang village on the Vientiane Plain. The hydrogeological evaluations repeated in earlier sections make it clear why this village is biophysically well suited to developing interventions providing agricultural groundwater supplies. Further, the village is remote from perennial surface bodies and major surface water irrigation scheme is not an option for the village. Village meetings and field surveys confirmed that shallow dug-out wells were used in fields and deeper concrete lined rings for garden-scale irrigation. These shallow wells are susceptible to drying out at later stages in the dry season and hence the rationale for trialing deeper tube wells is that they are not prone to drying out but required higher capital and operating costs that made them better suited to being community operated and managed.

Two other trials / case studies have been conducted under this project in other areas and are described in other parts of this report, thereby taking the total number of interventions set up and tested to four.

7.4.1 Privately managed irrigation for cash crops at Ekxang village

One of the premises we began with in the project was that groundwater irrigation was non-existent in Lao PDR, apart from a restricted number of household garden-scale plots in lowland areas where groundwater could be easily accessed and electricity to power cheap pumps was available. This seemed founded as there had been no documentation of such practices before. Field visits revealed that farmers in some areas had privately owned and operated dug-out wells in their fields and were using these for supplemental irrigation during the wet season and for dry season irrigation as well. There had been no documentation of such practices before (Note: dug out wells are constructed pits with dimensions of about 5m x 5m x 5m that intersect shallow groundwater).

Two dug-out wells were selected for monitoring over one growth cycle of watermelon during the dry season. At both sites a two-wheel diesel tractor ("rot tok tok") delivers water through a small pipe to the field where it is distributed by furrows. The areas irrigated were similar for the two sites at 1.2 and 1.3 ha each. Monitoring was done in participation with two farmers who were requested to record water levels within their wells and their irrigation schedule on a daily basis. The design sought only to observe and not interfere with the farming practices. Verification was performed through periodic visits to the site and after harvest. Semi-structured interviews were carried out with both farmers separately to gain a better understanding of their agricultural practices. Those interviews also provided quantitative information on expenses and profits associated with watermelon cultivation.

At both sited the dug wells were shown to be a simple and profitable method to irrigate cash crops during the dry season. The LAK 4 million (AUD 670) investment to construct a dug well is justified from profits ranging from LAK 19-31 million (AUD) per crop for the season studied (early 2015) and from LAK 15-45 million (AUD 2,500-7,500) for the entire dry season cultivation over the period from 2011-2015 as determined from the interviews. High price volatility, differential level of inputs between winter and summer crops all affect net revenues.

Due to their limited capacity, dug wells are likely to remain a small-scale technology, and hydrogeological constraints limit their widespread applicability (Tab. 7.1). In areas where shallow groundwater of good quality is found, where land and labour is adequate and access to market is available, dug wells have a good potential to improve livelihood of smallholder farmers.

Table 7.1 Benefits and constraints of dug well irrigation in Lao PDR (after Bohsung, 2015)

Benefits	Constraints
Dug wells provide an additional/supplemental source for irrigation during dry season	Dug wells only provide a certain amount of water, therefore the area that can be irrigated is limited.
More resilient to drying out than surface water from the reservoir	Investment in dug well construction is associated with a certain risk, since its location is mostly chosen randomly (some dug wells dried up permanently)
Dug wells provide water for cash crops which generate additional income, improving livelihoods. A second crop promotes diversification	Dug wells probably remain a small-scale technology. Hard to upscale it
The limited amount of water that can be withdrawn from a dug well could be seen as safeguard against overexploitation	Dug wells are restricted to areas with shallow groundwater table (4-5 m below ground at the end of dry season)
Simple technology which requires relatively little investment cost, low maintenance and is easy to operate. Therefore it is easily transferable	Applicability is restricted to: (i) areas with shallow groundwater table, (ii) farmers with sufficient land, and (iii) locations with market access for the sale of harvested cash crop

7.4.2 Community-managed groundwater irrigation

System Description

The first community-scale groundwater irrigated scheme was implemented at Ekxang village. Two sites on opposite margins of a large paddy field were chosen by DOI and IWMI in early 2013 in consultation with the village administration and DAFO. Three large (8-inch) diameter boreholes were drilled to depths of 32 m, including two at the schools site and one at the 'nadon' site (Fig. 7.6) (DOI, 2014). Design and implementation of the irrigation scheme was undertaken by the DOI with support from IWMI, IGES, PAFO-Vientiane, DAFO-Phonhong and other research project team members.

At both sites, groundwater was extracted by using electrical submersible pumps (Tab. 7.2). Electricity was supplied at the school site via a dedicated transmission line, and at the school site relied upon a diesel generator. At the school site, water was pumped into two elevated storage tanks used for the toilet of the school and as reserve in case of a pump failure or power cut. At the nadon site, water was pumped into one storage tank. Both sites were equipped with PVC pipes (Ø 32 mm). Surface pumps were installed at both sites and delivered 0.5 l/s which restricted the irrigated area. With no restriction on the resource capacity, the irrigation system was re-designed in order to both increase the water outflow and pressure. Submersible pumps of higher discharge and bigger pipes (Ø 63 mm) replaced the previous features and system outflow reach 4 l/s at both sites. The storage tank was not adopted at the nadon site due to insufficient storage capacity and low water pressure but was kept at the school site for the school purpose. Using the pump discharge pressure allowed the use of a pressurised irrigation system (drip and sprinkler) and the pumps were then directly connected to the farmers fields, at both sites. Water was allocated to the farmers' fields via a series of secondary pipes (Ø 50 mm). Farmers could easily control water direction and flow by closing or opening gates displayed at each field. Water delivery for the school was monitored by the school staff. A water meter placed on the main gate allowed farmers to record their water use. The groundwater irrigation system designed at Ekxang village is of a high quality using Grundfos pumps and HDPE pipes. As an indicator, this irrigation system can irrigate, at both sites, 4 ha for an irrigation rate of 3 mm/day (with pump running for 8 hr/day).

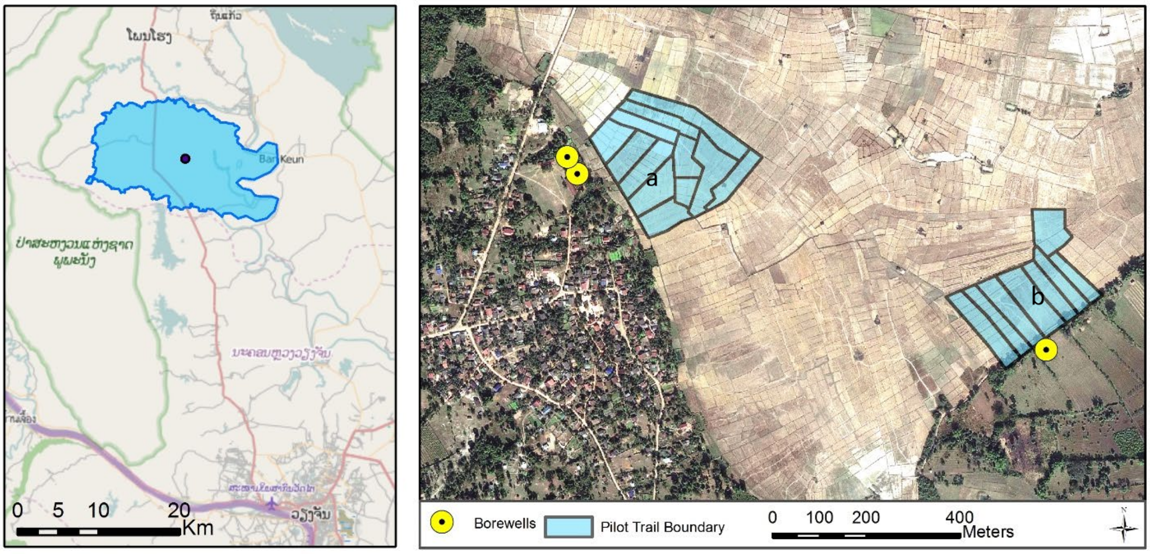

Figure 7.6 Maps of the pilot trial site. Left pane gives the Ekxang village location within Nam Panai watershed; right pane shows the pilot location (a is the school site and b is the nadon site)

Table 7.2 Irrigation facilities and characteristics at both sites

	SCHOOL	NADON
No. of tube wells	2	1
Tank Capacity (m^3)	6	3
Pump outflow (l/sec)	2 / 2	4.5
Intake depth (m)	25 / 20	25
No. of gates	11	8
Energy source	Electricity	Diesel

Local Institutional arrangements

Participatory approaches to irrigation system management are commonly used for surface water schemes in Lao PDR (Keoka, 2005; ADB 2006). A major difference between surface and groundwater irrigation was identified to be the water fee calculation and collection process. Water fee in a groundwater irrigation system must be based on the operating cost and in this case requires frequent pre- and post- payment by farmers respectively for the diesel and electricity bills.

Water user group formation began with the Department of Irrigation (DOI) policy to build the institutional structure and regulations covering mainly: (i) role and responsibilities of members, (ii) aim of the group, (iii) conflict resolution and (iv) formation of the Groundwater User Group (GWUG). The research team also produced specific Terms of Reference for the trial emphasizing the particularities of GWUG functioning (IWMI, 2015). Adjustments of the institutional rules were done during discussions and trainings with the farmers.

Farmers and land owners within the command area (see Appendix, Section 11.2) were invited to come to the GWUG training organised by DOI and others from the research team on 24/03/15. After discussion between all stakeholders and election by the farmers, the hierarchical organization of the GWUG was decided to be as follows: one head (Mr Somephane) responsible for the overall coordination and management of GWUG and assisted by two deputy heads; one per site (Mrs John for the school and Mr Odai for nadon), responsible for the operation and management of the irrigation system and in charge of the water fee collection.

The group follows the DOI rules for water user groups, which is responsible for: (i) equitable access to water, (ii) social coordination and conflict resolution; and (iii) autonomy in financial management.

Water fee management was adapted, since a regulation on groundwater fees is not yet in place. Farmers agreed to respectively record their water use and then pay to the deputy head of the group. A maintenance fee was not added to the water fee and there was no membership fee to join the group.

The measured price of pumping water at the nadon site using an electrical diesel generator at LAK 642 per m^3 was more than twice that of the school site at LAK 305 per m^3 using electricity (based on a diesel price of LAK 7,000 per litre and electricity price of 976 LAK per hour for the local urban electricity supply tariff). Farmers' lack of trust in the irrigation system and perception of the risk regarding the resource capacity was a major constraint to their engagement. As a response, the project team proposed to cover the water fee during the first dry-season if the farmers provided relevant agricultural data (crop type, water use, yield, etc.).

The research team provided training to the GWUG on sprinkler and drip irrigation, two efficient irrigation technologies which reduce farmers' irrigation costs. At both sites, sprinkler and drip demonstration plots were setup. Such practices were valued by farmers but require significant investment which limited their adoption without external support. The project supported the establishment of 700 m of drip irrigation system plus 200 m of sprinkler irrigation. Frequent informal trainings and discussions took place with the farmers, as they familiarised themselves with learning all the particularities on how to operate and maintain the irrigation system.

GWUG activities and agricultural practices

GWUG members first started to grow cash crops in December 2015. Four farmers were engaged in the pilot and fully endorsed and understood their role. Mr Tao and Mr Bounchan used drip irrigation system under 0.26 ha to grow pumpkin and watermelon. They both used sprinkler irrigation on 0.25 ha to grow morning glory, chinese cabbage, coriander, spring onion and lettuce. Mr Tom grew sweet maize, sweet potato and pumpkin under furrow irrigation on 0.25 ha. Mr Keo grew 0.75 ha of dry-season rice on behalf of the 'whole' village ("to see if there is enough water"). The water source in this paddy field comes from a surface irrigation canal supplemented by the groundwater irrigation system when the canal dried out. The total irrigated area at the school site covered 1.52 ha (details given in Appendix, Section 11.2). Farmers did not engage in farming activities at the nadon site despite major efforts from the team to make this happen. The main reason claimed was the need for two years without cropping between each cropped season of watermelon and long bean to prevent the prevalence of disease. Poor soil fertility arose as an issue as well, likely to lead to low vegetable production.

Maintenance and sustainability of the GWUG

Sustainability of the irrigation system strongly depends on farmers' understanding and ability to maintain the irrigation system. Pipes and gates require small maintenance activities that farmers are now able to conduct with some financial outlays. However, the pumps installed, even though of high quality, might constrain the sustainability of the project if maintenance is needed as there is disconnect between the farmers and pump suppliers and because of the financial outlay needed.

At this stage, the sustainability of the group is difficult to assess due to the relatively low number of farmers involved but their proper understanding of the system functioning and their engagement in recording their respective water use is a positive sign for future water fee records and collection.

Equitable water access between members is an issue that needs to be clearly considered since the irrigation system capacity is limited. At present, the irrigation system capacity meets the expectations of members but such an issue might arise in the future if there is wider adoption of groundwater irrigation in the village. This is an important factor to consider when building a groundwater irrigation system to avoid social conflict. With only about 20% of the command area at the school site irrigated, there is scope for further farmer engagement but access will need greater consideration.

Challenges and constraints

Community engagement starts by meeting local authorities such as the village head, deputy and other influential people in the community. At first the development team starts to see these people as potential members of the groundwater user group. Differentiation between the role and responsibility of the village authorities and future GWUG members was not clear. Such confusion delayed the implementation of the trial since villagers first engaged in the development of the trial were ultimately not water users.

Moreover, most villagers do not trust the groundwater resource to be sufficient and still take this first year pilot study as an "experiment" to see if "there is enough water". This general doubt across the village on the resource capacity partially explains the small engagement. Moreover, this "yes or no" perception of the resource capacity has to be carefully taken in consideration as it clearly illustrates the common misunderstanding of the groundwater resource capacity and limit. The perception lingers strong despite the repeated efforts of the team to communicate the nature of the resource and its availability.

Farmer engagement into the irrigation system and GWUG is one of the most important factors to consider while implementing such irrigation facilities. With only four farmers engaged, this engagement was restrained by: (i) the labour issue, (ii) trust and sense of ownership in the system, and (iii) non-agricultural working opportunities. These factors must be taken in consideration in future groundwater irrigated system development.

The lack of experience, from the agricultural and irrigation development sector, in developing the groundwater irrigation system brings challenges in establishing the irrigation system and the governing institution. Major challenges were related to: (i) the estimation of the resource capacity; (ii) the design of the irrigation scheme; and (iii) the water fee management and associated rules by the GWUG. The experience from the trial to date has already started to reduce the gap by teaching meaningful lessons.

The implementation of this community-scale groundwater irrigation was a great challenge in terms of coordinating stakeholders, understanding their respective expectations and designing and completing the systems. Site identification took place in early 2013, drilling finally took place in June 2014 but the irrigation scheme was fully functional only as late as December 2015. This is attributed to numerous delays, postponements and adjustments to the system (the relevant activities related to the establishment of this pilot trial are listed more completely in Section 11.2).

7.4.3 Economics of groundwater use for on-farm activities

In Ekxang village, groundwater for on-farm activities is used for both fruit and vegetable growing, and livestock farming (poultry and cattle). Regarding fruit and vegetable growing, groundwater is used by 70% of the village population at different scales. For the households involved in fruit and vegetable growing, this activity accounts on average for almost 50% of the on farm income and slightly more than 26% of the total household income. Capacity of the well, size of the cultivated area and cropping pattern are crucial factors that help identifying a range of various livelihood strategies related to agricultural groundwater use. Lined wells equipped with electric pumps (0.5-1 l/sec) are appropriate for small-scale vegetable gardens up to 1000 m^2, while unlined wells equipped with pumps operated with a rot tok tok (8-10 l/sec) are more suitable for irrigating larger areas, from 0.3 up to 1.4 ha. Although unlined wells allow the possibility of cultivating “large” scales, the water supply capacity of this technology becomes very low when the water level falls over the course of the dry season.

Economic viability of the community level pilot trial

The irrigation system set up in Ekxang village offers the opportunity to grow crops on areas up to several hectares throughout the dry season, with a constant flow of 4 l/sec for the school site and 5 l/sec for nadon site. The challenges related to this type of irrigation systems are twofold. First, such a project has to be viable for the investor and second, use of the system has to generate sufficient income for farmers to adopt the technology. Indeed, the investment cost for the school is estimated at LAK 120 million (AUD 20,000) and for nadon site at LAK 90 million (AUD 15,000).

Additional incomes as high as LAK 4 million (AU$ 670) for the dry season were achieved by farmers who made wise cropping choices and participated effectively in the scheme. For others who chose to grow rice or maintained their fields poorly, revenues were considerably less. Further details on the economic analysis are provided by Clement et al., (in prep.-a). That report uses set of economic indicators to establish the viability of the trial under the existing level of adoption as well as a scenario analysis to establish system viability under different sets of conditions.

Determinant of household income and groundwater use

To explore the impact of groundwater use on livelihood, the ordinary least squared regression was used. Regression analysis reveals that the variables related to groundwater use are statistically significant. The income generated from irrigated crops and from livestock are both significant at 1% and have a positive coefficient of the household income. These two on-farm activities have a positive impact on the household income. In particular, the factor related to irrigated crops is twice higher than the one related to livestock farming. It suggests that the use of groundwater could potentially have a significant impact on household income.

7.4.4 Groundwater irrigation research trial and demonstration, NUOL-FWR Campus, Tad Thong

A groundwater irrigation trial has been established on the Tad Thong campus of the Faculty of Water Resources, NUOL. The establishment of the trial is premised on a number of assumptions:

- adequate groundwater management in Lao PDR requires adaptive integrated groundwater resources management programs at a graduate level.
- inadequate access to water during the dry season is a major constraint to the low adoption of dry-season cropping and groundwater offers a potentially democratic means of access for smallholder farmers
- water-efficient irrigation practices are almost inexistent but could make economic sense for lift irrigation systems in reducing operating costs
- low soil fertility is a major constraint in lowland agricultural systems. Hence, agricultural system intensification with dry-season cropping must be done with conjunctive development of soil management practices.
- development of groundwater irrigation requires strong knowledge in irrigation technologies, crop water requirements, irrigation efficiency and groundwater management
- undertaking biophysical research on a campus setting is logistically much simpler than with communities but can still be useful knowledge that is transferrable to similar settings

A groundwater-irrigated experimental site was setup in late 2014 to serve as a facility for research/education and a demonstration of new soil and water management technologies. The major aim of this experimental site is to enhance knowledge and research capacity for NUOL-FWR students and lecturers on how to improve agricultural production using groundwater and on farm residues. The research studies mainly focus on: (i) irrigation efficiency; (ii) soil fertility improvement using on-farm residues and water retention management; and (iii) environmental and groundwater management.

The trial area covers a 40 m x 60 m area in the southwest part of the campus. Previously vacant land has been used adjacent to an existing 38 metre deep borehole – a former water supply well before piped water became available. Site preparation works included the following elements: land preparation, fencing, water pump and elevated water storage tank installation, sprinkler network, installation of weather station, evaporation pan and groundwater level recorder, experiment set up and monitoring. The site is divided into subplot of 8 m^2 and all treatments were applied to three subplots. Water is delivered by gravity from the header tank to the plots. Both fertilization and irrigation technologies were developed by using local materials. The irrigation technologies included conventional drip, alternative drip (i.e. pipe with holes), hand-spraying, sprinkler and furrow. Fertiliser treatments included rice husk biochar, cow manure, biochar + manure, compost, coconut mulch. The parameters measured included crop growth (roots length, crop height, leave length) every 5 days, and daily measurements of soil moisture, crop water use, labour, and sub-plot-wise crop yield, soil density, soil fertility and infiltration rate.

Meteorological and groundwater levels were measured using automatic data loggers. Bachelor students were trained in the data collection process, which was successful for directly read measurements but only moderately successful for automatic measurements, with 294 days of rainfall and 258 days of groundwater level data measured in 2015. This is mainly explained by (i) software issues, (ii) low engagement in the site maintenance (mainly due to economic reasons and low coordination) and (iii) high turn-over in the batch of students involved. This information gives the students the opportunity to understand more concretely the water cycle at the campus scale.

Examples of research outputs

Crop production and soil moisture content were improved under all fertilization treatments, with the highest yield in morning glory and highest moisture content observed for compost fertilization (Fig. 7.7a,b). These results illustrate the benefits that emerge from using on-farm residues as a cost-efficient fertilization.

Crop water use for long bean is compared under conventional drip and alternative drip, with and without the use of coconut mulch, applied at 3 kg/m^2. The drip system used 25% less water than the advanced drip system over the total growing season (Fig. 7.7c,d). Long bean production was reduced when using alternative drip irrigation. However, crop production differences must be explained by external factors affecting the production such as sunshine (in the case of alternative drip) and pest attack intensity. Coconut mulch did not clearly increase soil moisture content and crop production.

Three students are currently examining crop water use comparison between all irrigation technologies used in the experimental site (drip, furrow, sprinkler and spray) as their final year project. Cost-benefit analyses associated with each irrigation technology are being performed.

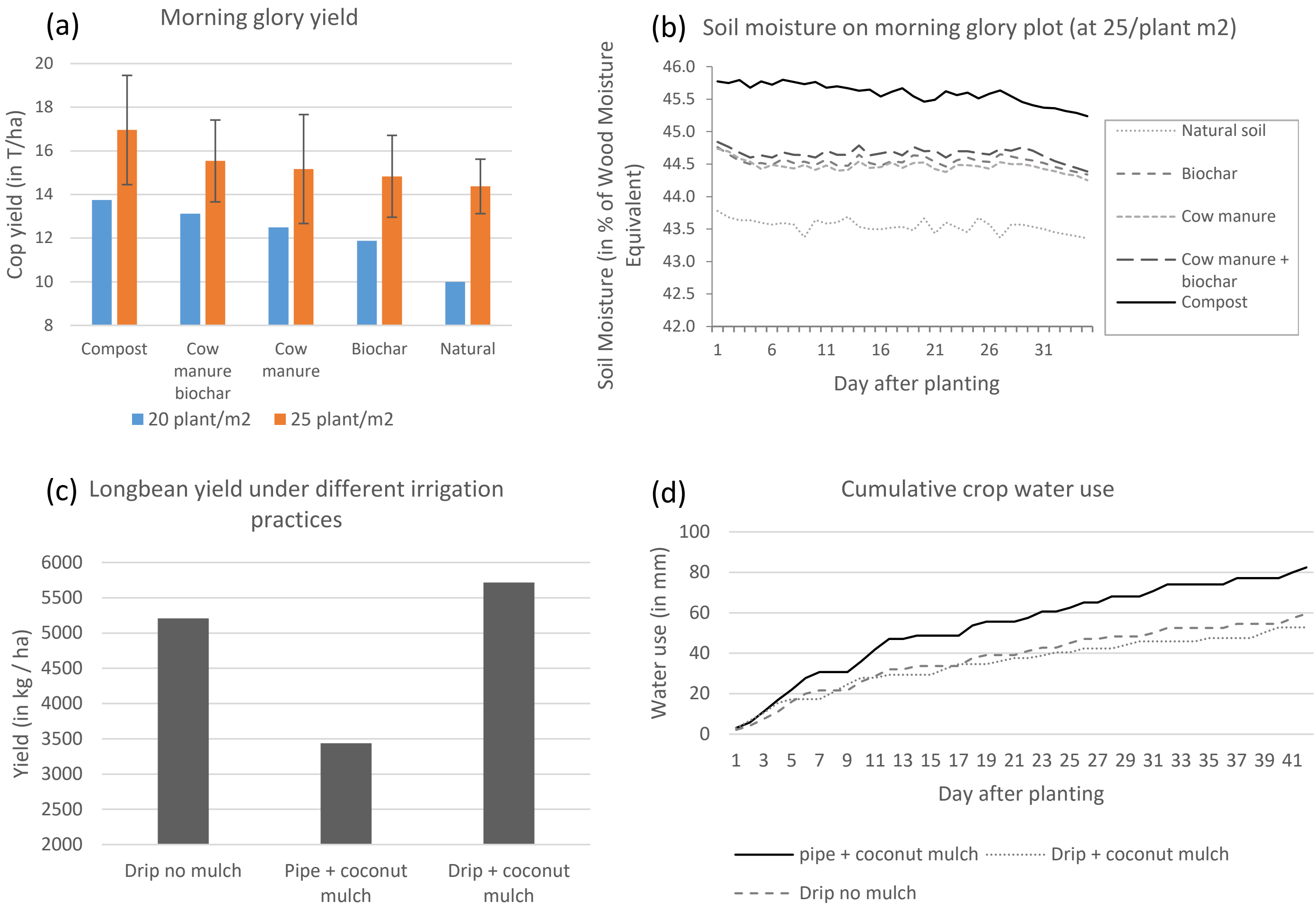

Figure 7.7 Yield data and moisture content data for morning glory with alternative soil treatments (a,b) and for long bean with drip and alternative drip (c,d)

7.4.5 Developing guidelines for community-based groundwater irrigation in Lao PDR

Guiding documents that serve to support the implementation of community surface water irrigation schemes in Lao PDR have previously been developed (Keoka, 2005). A document of a similar nature for community managed groundwater irrigation is currently under development (Clement et al., in prep.-b). The guidelines draw upon the experiences and lessons derived from the work carried out at Ekxang village, THXP and NUOL-FWR as described earlier, and supplemented by international experiences discussed in Section 7.6.

The guidelines are intended to guide and assist planners and developers in designing and managing community-based groundwater irrigation (CGWI). They may also be instructive for policy makers, international donors, development agencies and government agencies. It is designed to provide sufficient practical information about the why, how and where of implementation to encourage the development of CGWI systems that area profitable and sustainable in areas with the most potential, based on the concrete learnings from the project.

There are three specific parts to the guidelines. The first part contains reference to the information needed for a good understanding about groundwater irrigation and community management. It covers what is currently known about areas suited to CGWI and gives some indication on the scaling up potential in Lao PDR. The second part goes into more technical detail and technical guidance required to implement CGWI. This part is divided in three sequential phases covering planning, implementation and operation and maintenance, with a step-wise approach given throughout each phase. The last part contains additional information about project implementation, completion and resolving potential issues. Thus, the staging of projects are covered step by step from pre-feasibility through to system management in an integrated manner combining hydrogeological, agronomic, social and economic aspects. A draft outline for the guidelines are given in Table 7.2.

Table 7.2. Draft outline for the guideline document under development

Part 1: Defining community-based groundwater irrigation (CGWI) systems

Groundwater irrigation

- Definition
- Suitable areas
- Components of the system
- Scale of irrigation
- Type of systems

Community irrigation management

- Principles of CGWI
- Key criteria for success

Part 2: Practical steps to establish a CGWI system

Planning Phase

Step 1 - Site selection
Step 2 - Field investigation
Step 3 - Irrigation water needs
Step 4 - Defining future GWUG
Step 5 - Designing the system
Step 6 - Is the project worth funding?
Step 7 - Agreement on the implementation

Implementation Phase

Step 8 - Formalizing the GWUG
Step 9 - Well drilling and testing
Step 10 - Construction of the scheme

Operation & Maintenance Phase

Step 11 - GWUG functioning
Step 12 - Operation of the GWI system
Step 13 - Maintenance of the GWI system

Part 3: Further considerations

Sustainable groundwater use

- GW over extraction
- GW pollution
- Sustainable GW management
- International lessons

Social acceptance

- Stakeholders involvement
- Land tenure considerations

7.5 Opportunities and constraints of agricultural groundwater use in two contrasting villages in the Vientiane Plain

Two villages (Ekxang and Phousan) situated less than 10 km apart in the Vientiane Plain, but with contrasting biophysical and socio-economic conditions (Tab. 7.3) were selected for a detailed study on the drivers for groundwater adoption and the existing barriers to further development.

The study comprises of two major components: (i) farming systems and households characterization, and (ii) perception study for each defined farming systems and household typology. Fieldwork was carried out in 2013 and 2014 by IWMI with support from the Mekong Development Center (MDC).

Agricultural groundwater use has the potential to improve rural households' incomes and reduce poverty. However, the linkages between a new technology and livelihoods are not always straightforward. Access to water, land, and capital differentially shape farmers' livelihood strategies in the two villages. Farmers' perceptions of the opportunities and constraints to the technology are shaped by their farming strategies.

From Ekxang village, it is revealed that while access to water, land, capital, market, and farm labour are decisive factors that define farm households' farming practices, farmers' decisions to invest in groundwater development are rooted mainly in the central positioning of vegetable farming and high valued cash crops as a means to move from subsistence to commercial farming (through either crop diversification and/or farm specialization). From Phousan village, the key finding is that while farmers' decisions to limit their groundwater use for domestic purposes are partly shaped by their overall farming strategies to focus on rubber and cassava plantation (which rely mainly on rainfall), these strategies are also rooted in the way farmers view the aquifer's condition in relation to groundwater access and potential water scarcity. Thus, while farmers in Ekxang view groundwater development as an opportunity to intensify their crop production, farmers in Phousan view groundwater development mainly in relation to their domestic water use (e.g. bathing, cooking and washing). Moreover, while farmers in Ekxang view lack of access to land, capital, and farm labour as key constraints for groundwater development, especially with regard to the construction of unlined dug-out wells, farmers in Phousan view potential water scarcity and relatively difficult access together with the lack of access to farm land and land tenure insecurity as their main reasons to restrict groundwater use mainly for domestic purposes.

The policy implication of this work is the bringing to light of the need to better recognise how farmers view groundwater in relation to their overall farming strategies, if groundwater resources are to be successfully used as a means to reduce poverty and offer tangible support to the Government's agricultural development strategies. Great details and insights on this case study can be found in Suhardiman et al., (2016; in prep).

Table 7.3 Farming systems and household typologies in Ekxang and Phousan village

	Ekxang village	Phousan village
Livelihood Activities (N=80)		
Lowland rice	115	61
Upland rice	0	18
Vegetable farming	51	43
Rubber plantation	0	18
Cassava cultivation	0	29
Cattle raising	50	43
Poultry farm	69	60
Fishery/aquaculture	7	8
Typology of farming households (N=80)		
Small farming household (<1ha)	34	52
Medium farming household (1-2.5ha)	33	12
Large farming household (>2.5ha)	5	4
Farming household with no paddy field	5	9
Landless household (no fields)	3	3
Type of well (N=80)		
Private lined dug well	77	14
Private unlined dug well	40	0
Private deep tube well	0	33
Community well	3	33

Source: IWMI and MDC survey of 80 randomly selected households in respectively Ekxang and Phousan village, 2014

7.5.1 Hidden effects of land grabbing and dispossession on the livelihood of affected farmers

An interesting and initially unforeseen spinoff emerged by carrying out half of this set of activities in Phousan village. Phousan, with its administrative boundaries extending into upland areas as well as lowland, is situated in a zone where farmlands were incorporated into a land concession agreement between the Government and a foreign investor, resulting in the dispossession of around 800 hectares of farmland for a rubber concession. As the situation became clearer through the research activities described previously, the dynamics of so called 'land grabbing' and land dispossession are also to be examined from a case study point of view. The findings reveal how farmers coped with land grabbing differently, depending on their original land holdings, economic status and political connections. While larger farmers (owning >2.5 ha of land) could protect land holdings by investing in rubber and using their political connections, smaller farmers needed to find new on- or off-farm income sources to meet basic food requirements. The key argument offered by the research team is that understanding the multiple strategies farmers use to deal with actual land loss and the risk of losing land is crucial to understand long-term impacts and hidden effects of land grabbing and its consequences for agricultural development and the overall process of agrarian transformation. From a policy perspective, the hidden effects of land grabbing are critical to assessing the actual costs and benefits of land concessions, in Lao PDR (and elsewhere), especially in relation to current approaches to convert land into capital as a policy strategy to promote economic growth and reduce poverty. Great details on this case study can be found in Suhardiman et al., (2015).

7.6 Institutions and policy

7.6.1 Groundwater irrigation governance, review of existing agricultural policy and strategies within the broader context of water-energy nexus

Three specific activities were carried out: i) review of institutions and policies; ii) understanding cross-sectoral linkages, and iii) drawing international lessons on groundwater governance.

Groundwater irrigation is a relatively new concept in Lao PDR, though groundwater development is gaining attention due to droughts, rainfall variability and the growth in commercial farming. An important condition for institutionalising groundwater irrigation is through the establishment of strong vertical and horizontal linkages among the line agencies. Such an arrangement ensures avoiding decisions on groundwater resource development and use that incur unintended consequences, but that produce a net positive impact at all levels. Obviously, such linkages among ministries, and their policies, were nearly absent in the context of groundwater irrigation. To address such a need, this study identifies linkages between at least three ministries (and their policies, action strategies, plans and laws) as essential. Those ministries are: Ministry of Natural Resources and Environment (MONRE), Ministry of Agriculture and Forestry (MAF), and Ministry of Energy and Mines (MEM) as shown in Figure 7.8.

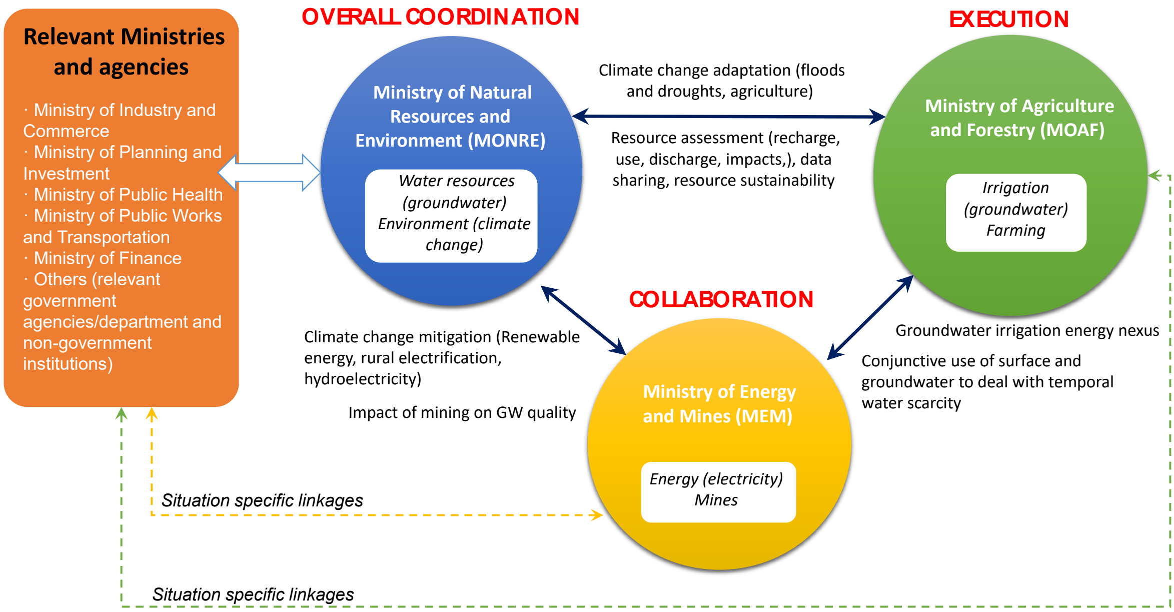

Figure 7.8 Proposed institutional linkages for institutionalizing groundwater irrigation in Lao PDR

The main rationale of better connected institutions is to enhance effective implementation of policies, plans, programs or projects while trade-offs are minimised and synergies are maximised among cross-cutting sectors — in this context they are water resources, agriculture (land) and energy. In the context of groundwater irrigation, well-coordinated institutions and policy harmonization are crucial for sustainable groundwater resource development, ensuring adequate water quantity and quality, affordable access, rational use, and active management. Such an arrangement could improve transparency and good service delivery to the ultimate beneficiaries, i.e., farmers. A guaranteed on-demand access to groundwater guards against risks posed by dry-spells or agricultural drought situations and thus increases climate resilience of the small-holder farming system.

To establish effective linkages between MONRE, MAF and MEM, roles and responsibilities of each should be well defined with minimum overlap. An entry point for such coordination should start from MAF which has specialised departments and experiences to deal with agricultural water management and implement policies and actions on agriculture development (crops, livestock, aquaculture). DOI, which is responsible for irrigation management, and has a long experience in planning policies, programs and actions, should have 'execution' role of groundwater irrigation management. DOI has both expertise and capacity to carry out technical support (construction and maintenances) and to provice training (on the operation of facilities) on agriculture water use. Concentrating its focus on execution would enhance its speciality in planning, developing and implementing country specific groundwater irrigation methods and for effective service delivery down to the farmers' level. In addition to DOI, MAF's Department of Agriculture (DOA), which is responsible for the overall development of agricultural sector in the country, can play a significant role to introduce farming systems suited for groundwater irrigation and provide training and consultation to the farmers on the profitable use of groundwater for irrigation such as growing high value crops.

As groundwater irrigation is energy intensive, MEM should have a collaborative role with DOI to prevent the potential risk of unsustainable groundwater use. A rational energy price should be identified such that groundwater abstraction is affordable to farmers and does not result in accumulated financial burden on MEM. High electricity tariff could be restrictive for farmers as it could seriously raise the cost of farm production and might increase debt on farmers. Similarly, failure to pay the fee by individual farmers could increase the accumulated financial burden on MEM which is evident in some of the lift-irrigation systems along the Mekong River. On the contrary, if the electricity price is subsidised, farmers may again resort to over pumping that could threaten resource sustainability as well as add financial burden on MEM.

In the case of MONRE, its main role should be 'overall coordination' with all line ministries and its agencies other non-government actors to the extent relevant for groundwater management. The role of the coordinating agency will require MONRE to deal with groundwater resources management issues including domestic use, drinking water and industrial uses. MONRE also inspects the activities of DOI when it comes to the development and use of water resources. MONRE is also in-charge of climate change mitigation and adaptation, its coordination with DOI and DOA are essential for implementing climate resilient irrigation system (such as groundwater irrigation) and agriculture practices (such as water efficient farming practices).

Lao PDR has been actively pursuing a policy to generate hydroelectricity for domestic consumption and export. There is an obvious connection between MONRE and MEM as the former consent is mandatory before undertaking the development of any hydroelectricity project to avoid potential negative impacts on water resources and the environment. MONRE can also collaborate with MEM to introduce decentralised renewable energy system, such as use of photovoltaic solar energy, to pump the groundwater. Again this option has to be exercised with caution so that wasteful pumping of groundwater is avoided with the surplus electricity produced.

In spite of above arrangements, situation specific needs for coordination between MEM (or DOI) and other line ministries such as while developing groundwater system for irrigation and domestic uses utilise storage from the same aquifer.

Establishment of the Groundwater Management Division of the Department of Water (GMD-DWR) Resources and the pending National Water Resources Strategy and Action Plan are significant steps within MONRE to systematise the task of groundwater management and its preservation. However, as a new institution, GMD-DWR seriously lacks adequate capacity to implement its mandates and responsibility. It will take time for GMD-DWR to boost its capacity. It could play a significant role, as similar to the Department of Groundwater Resources in Thailand, to provide services on groundwater resources management such as information generation and sharing, implementing legal and economic instruments, and doing research to advance groundwater resource management.

All three ministries have their own provincial and district offices to provide support and execute activities at the local level. Establishing a strong working level coordination within and between these ministries is an obvious challenge as groundwater irrigation is relatively a new area for the Lao Government. Table 7.4 summarises the policy options for creating a vertical and horizontal linkages within and between the three ministries, respectively.

Table 7.4 Matrix of potential options for coordinating policy and actions relevant to groundwater at different levels of key ministries in Lao PDR

	Energy and Mines	**Natural Resources and Environment**	**Agriculture and Forestry (irrigation & farming)**	**Vertical Linkage**
Central	-Policies, rules, regulations on energy (electricity) use for irrigation, most importantly, secure access to energy for irrigation, pricing; -Policies, rules and regulation on minimizing the impact of mining on groundwater environment -Horizontal: Update line ministries about plans and programs -Vertical: instruct and update new plans and programs to provincial offices	-Policies on sustainable management of groundwater resources, specifically, resource conservation, management of quantity and quality including risks of climate change. -Horizontal and vertical: same as energy and mines	-Policies on groundwater irrigation -Agricultural policies on the conjunctive use of water resources in agriculture, including, promotion of groundwater irrigation, wise use of groundwater to boost agricultural productivity -Horizontal and vertical: same as energy and mines	
Provincial	- Horizontal: coordinate with respective provincial offices on the matters related to development of groundwater resources such as supply of electricity, conjunctive use of water resources, sharing of data and information on groundwater resources, conservation of groundwater resources etc. - Vertical: implement plans and programs from the central level, provide supervision/support to district offices, and act as a bridge between central and district level agencies			
District	- Horizontal: coordinate and synchronise district level activities related to groundwater irrigation such as provisioning of electricity services for groundwater irrigation (connecting, maintenance, fee collection), collection and use of groundwater			

	resource data, an extension of agriculture services (water efficient irrigation methods, cropping options for groundwater irrigation). - Vertical: design and implement local plans and programs in line with the national and provincial level policies and actions. Provide supervision/support to village (Ban) level activities such as community activities and formalization of local institutions (such as a water user association), and act as a bridge between provincial and village level agencies	Feedback and requests Services, support, and decisions
Village (Ban) level	- Horizontal: coordinate with village level activities related to groundwater irrigation such as installation, operation and maintenance of pumps, payment of fees for electricity service, irrigation scheduling etc. Coordinate with local groups for promotion and efficient use of groundwater such as water user association, farming groups, marketing units etc. - Vertical: Request for necessary legal, technical and management support from district offices. Provide feedback on the progress and challenges of groundwater irrigation to the district level.	
Horizontal linkage	**Updates of plans, actions and outcomes for better coherence and inclusive decision making.**	

Considering the early stage of groundwater irrigation in the country, international experiences on groundwater irrigation could be a valuable lesson to design and leap-frog to a sustainable mode of groundwater resource development. Good practices could be introduced and mistakes made in other countries should be avoided. In particular, the practice of uncontrolled groundwater use practices seen since the very early stage such as in India, Bangladesh, China, Thailand (Bangkok), Japan (Osaka, Tokyo), Vietnam and other groundwater dependent countries in Asia, should not be repeated in Lao PDR. Policy awareness and necessary legal and institutional development are essential, but even more important is to improve the capacity to act and implement policies and actions by existing ministries or their affiliate departments and agencies, in particular, GMD-DWR. In this project we have identified the following modes of groundwater management, some of which should be avoided and others could be potentially adopted in parts or in whole.

Among the practices that should be avoided are:

1) Uncontrolled development of groundwater: this is a common phenomenon that was observed not only in irrigation but also in other groundwater uses categories such as urban water supply, for industries and for domestic consumption. A lack of knowledge about the limit of resource use, the absence of or weak regulatory control on groundwater use, and a lack of alternative water sources has prompted explosive growth in groundwater development and use. This phenomenon used to be widespread in Asia such as Japan, Thailand and still continue to plague prominent groundwater users such as India, Bangladesh, China and Vietnam (small-holder coffee plantations in central highlands). Introducing legal, technical or other management measures have been less effective to control the situation especially when millions of farmers are dependent on groundwater irrigation. This situation is less likely in the case of Lao PDR where surface water is in abundance and groundwater only act as insurance against rainfall deficit or dry season. However, such a scenario could not be completely denied, if relative benefits of groundwater, such as easy access, reliable supply even during the dry season and higher water use efficiency, weigh higher in future when compared with the uncertain availability of surface water sources due to climatic variability.

2) Unsustainable subsidy on energy: the state of Gujarat in India serves as a good example of energy subsidy provided to farmers. As a result of a subsidised flat rate, available energy was used in excess of what is adequate. This phenomenon had two serious implications. Firstly, over-pumping by farmers, who traditionally perceive “more water equivalent to higher productivity”, prompted rapid drawdown of aquifers. The rapid loss water-table necessitated higher energy consumption to pump the same amount of water from deeper depths. Second, implication was on the energy suppliers which incur huge financial losses due to an unprecedented rise in groundwater use. This situation appears to be highly likely in future in Lao PDR if farmers were attracted to groundwater irrigation. Firstly, farmers in Lao PDR are increasingly exposed to commercial farming besides traditional rice-based cropping system. In commercial agriculture, production decisions are often based on market signals which mean that groundwater will be in high demand due to the flexibility in its use in both wet and dry season. Secondly, Lao Government policy to harness untapped hydro-electricity potential is expected to enhance the country’s electrification rate. Farmers will benefit from the increased supply of electricity. The Government might incline to supply electricity for groundwater irrigation at discounted rate in order to make the agriculture market competitive as currently the country is importing a substantial amount of fresh vegetables, fruits and other agricultural commodities from Thailand and other countries. Finally, even if the Government does not embrace such as policy, there could be still a high chance that recovering the fee from farmers will pose a significant threat to MEM. Investigations done at surface irrigation facilities in Vientiane Capital and Vientiane Province in this project revealed an accumulation of high amount of unpaid electricity bills.
3)
4) Underdevelopment of groundwater resources: Underdevelopment of groundwater is also not desirable because it will be against the broader interest of the country’s agricultural development and poverty alleviation. Nepal is such an example where the Government has recognised and tried to promote groundwater irrigation in its fertile plains in the south by introducing various programs and projects. Use of groundwater was viewed as a gateway to land use intensification which was limited to rainfed farming due to inadequate access to the surface irrigation network. The program did make progress initially but it was far from adequate as envisioned by the national agricultural policy. Lack of energy, its high cost, and ineffective use of groundwater pumps were the key barriers to the success. This

situation is quite similar to Lao PDR, except that there is no government policy or programs in place to promote groundwater irrigation. Careful planning is important to find an entry point to promote groundwater irrigation in Lao PDR while preparing to confront potential barriers. An important lesson from Nepal is that Government has an important role in facilitating uptake of groundwater irrigation by designing effective policies and programs to ensure viabile groundwater irrigation.

5) <u>Contamination and pollution</u>: This is a serious issue not only for groundwater irrigation but also for other uses. Pollution from point and non-point sources could have serious implication for the safe use of groundwater. The problem of groundwater pollution is acuter in an urban than in a rural context. Salinity and contamination from agro-chemicals are prominent problems in the rural context. This situation is less likely in Lao PDR immediately. However, mining industry and use of fertilisers and pesticides by farmers could pose a threat to groundwater pollution.

There are also promising practices being trailed either to solve any of the above problems or to promote the profitable use of groundwater. The following are selected groundwater management practices applied in some Asian countries.

1) <u>Participatory groundwater management</u>: Unrestricted access to groundwater and a lack of clear understanding about the physical limits of resource use has been a major barrier to participatory groundwater management. A lack of clear incentive is a primary factor behind a common tendency of "not to organise and act" to manage the resource. Despite inherent barriers, various models of participatory groundwater use and management could be found scattered in different localities. These approaches could be loosely classified into following:
    a. <u>Community based groundwater (CBG) use and management</u>: Andhra Pradesh Community Groundwater Management, in the state of Andra-Pradesh State in India, is considered as one of the most successful CBG management cases. The founding principle of this CBG was to equip farmers with knowledge and tools for taking a rational decision on the use of groundwater. This approach has blended science with local wisdom to develop tools and skills through non-formal education methods that will enable the community to manage groundwater effectively. Although successful community involvement is also credited to the hardrock aquifers in the area, it provides ample of lessons for other hydrogeological environments.
    b. <u>Participation based on a shared interests of farmers</u>: participatory groundwater use can also be prompted by a shared interest of farmers in which groundwater serves as an important factor of production. Individual farmers may agree to share the cost of the groundwater facilities such as drilling, installing pumps and overhead storage tank, and distribution system. Farmers can take all farming decisions independently, except on issues such as watering schedule, monitoring the condition of facilities, and cost sharing to cover energy bills or to pay for maintenances. Such a case was observed in Khon Kaen, Thailand. Farmers will be less concerned about resource management when compared to its access security. However, such a participatory model could be transformed from a 'resource use mindset' to a good case of 'resource management mind-set' when the farmers were educated about the negative impact of water table depletion on their profitability.
    c. <u>Participation enabled through external facilitation</u>: the Government could play a decisive role to promote participatory management of groundwater resources. Government incentivise farmers by introducing a support program such soft loan, act as guarantor or in the form of direct financial or in-kind support. The case of the Nepal Shallow Groundwater program in

which up to five farmers, with each less than 1 ha of cultivable land, is necessary to get bank loan for installation of shallow tube wells without any collateral. In the preceding example of Khon Kaen also the Department of Groundwater Resources (DGR) supports farmers by installing necessary infrastructure (drilling, installing pumps, storage and main distribution line), if one or more farmers with a combined total area of 30 rai made such a request.

d. Participation prompted by factors other than groundwater: in some cases, while still sharing more than one attribute of earlier mentioned approaches, factors other than groundwater could play a vital role in the participatory use of groundwater. This is another case of Khon Kaen, which shares commonality with the approaches a) and c). The local government created a group of economically marginalised group of villagers by providing necessary tools and knowledge about farming such as land, agriculture inputs and installation of groundwater irrigation facilities to grow organic vegetables to be sold in local super markets. Groundwater initially supported vital input for growing the crop, yet a key success factor of the group was its planning vision and management approaches such as the creation of management units for cultivation, water management, harvesting, post-harvest, packaging and marketing, and administration.

In the context of Lao PDR, this project has done an assessment of the existing condition of the potential use of the above participatory approaches. The study finds that there are a lot of good examples of participatory approaches in the villages such as vegetable groups conducting good agriculture practices with the help of the local government. There are water user associations (WUA) who are in-charge of managing surface water irrigation or rural drinking water supply systems.

2) Demand management measures: There are multiple isolated cases of demand management practices being applied in different countries in Asia. These demand management measures are often dictated by the local needs and the special nature of groundwater problems at hand. Barind Multi-purpose Development Project (BMDP), Bangladesh is such an example where the integrated approach of sustainable groundwater management was promoted with a special emphasis on technical, economic, social and environmental sustainability. Command areas (50-100 acres) were demarked for each deep tube well and a target for water use efficiency was set by applying various measures such as the introduction of water use coupons, providing incentives to extension workers who succeeded in achieving efficiency above 60%, and covering pipelines to reduce evapotranspiration losses. Another demand management case could be found in the Central Highlands of Vietnam where groundwater is being used to irrigate coffee. Water efficiency was promoted by setting an optimum range of water use target per coffee plantation (reduction from existing average of 400-500 litres/per tree/application to 150 litres) through adoption of the right combination of water application method (such as drip irrigation), timing for irrigation, and improving the shades (to reduce evapotranspiration, regulate micro-climate, provide manure and improve quality of the coffee-beans).

3) Legal and regulatory measures: In many countries, a set of groundwater laws and regulations are already present. Yet, they are among the hardest to implement and succeed due to multiple constraints such as lack of information about the hydrogeology, a large number of unregistred users, and poor capacity to monitor and take actions against non-compliances. There are a few successful cases of the effective implementation of groundwater laws and regulation. Thailand is one of such cases which has responded to worsening groundwater depletion and

emergence of land subsidence by introducing laws and acts to regulate uncontrolled groundwater extraction in Bangkok. The role of the Department of Groundwater Resources has been instrumental in introducing and implementing these laws and acts successfully such as by introducing groundwater use fee equivalent to the tap water and re-locating industries outside of the Bangkok. Minqin County, Shiyang River Basin (SRB), China is another case of implementing regulatory measures. In 2007, the SRB Management Plan aimed to halve agricultural groundwater use by 2020. Among other, the plan introduced regulations (such as the closure of wells and a per capita water use restrictions) and WUAs were created to implement the regulation effectively. The main activities of the WUAs were to close wells based on common criteria such as existing well density, groundwater water quality, and salty areas, halting well usage through backfilling or by cutting the electricity connection to the well, and the use of smart cards to administer water permits.

Direct replication of these lessons in the context of Lao PDR could be impractical as most of them were introduced as a response to existing groundwater management problems under specific local circumstances. These approaches could be valuable only if appropriate lessons were introduced in Lao PDR only after a careful evaluation of the practicalities. Looking at the current situation in Lao PDR, it could be said that there is a need for more than one approaches to balance the potential threats and opportunities. However, not all approaches need to be applied at once. Important considerations among all are securing all season water for irrigation, conserving resources, and improving the resilience of farmers and climate proofing of agriculture, and minimise future trade-offs and conflicts (drinking water, industry, ecosystem flows etc.).

7.6.2 Enabling conditions to establish a community based GWUG at the Ekxang trial site

Investigation of the existing water user associations (WUAs) and vegetable groups found a close similarity with the process for forming community groups, electing its members and common objective to grow more crops and increase productivity. It is often the case that there will be a head, deputies to carry special tasks (such as accounting, water management), a unit head and members to execute routine activities. Table 7.5 summarises the purpose, benefits and major challenges of the WUAs and vegetable groups.

Table 7.5 Purpose, benefits and challenges faced by WUAs and vegetable groups

	WUA	**Vegetable Group**
Purpose	-Access to water for rice cultivation -Collect fee and pay electric bills and allowance for head, deputy, village chief -Maintain/repair canal -Planning and estimation of water demand before the planting season -Irrigation scheduling for fair distribution of water	-Grow organic vegetables for domestic consumption and for the market; -Keep record of fertiliser and pesticide use -Cooperate with district office to check the quality of products and completeness of the record keeping -Discuss and share ideas and plan for next season cropping
Benefits	-Can access water in the dry season - Two rice crops per year - Adequate production for self-consumption (food security) - Additional income from selling surplus rice	- Can acquire a certificate of Good Agriculture Practice (GAP) which is essential for gaining access to the market. Sold products, which contain stickers of GAP, fetch a higher price.

		-Increase awareness about the health benefits of organic vegetables and health risk from the use of pesticides; - Higher income from organic vegetables
Challenges	-Pumps are old and need frequent repairs -Lack funds for repair as the collected fees are inadequate to carry out major maintenances -Difficulty in collecting the user fee from tenant farmers; -Inadequate water at the tail end of the canal -The fee is not always sufficient to pay electricity bills. Unpaid bills are often paid by the Government	-Shortage of labour -Price fluctuation of vegetables -Market for organic products is still not well established -It is not always possible to grow 100% organic due to high pest infestation

A SWOT analysis was also conducted with stakeholders to identify opportunities and challenges for establishing GWUG. Table 7.6 summarises the results of SWOT analysis subject to three local institutions (WUA, vegetable groups and drinking WUA). This illustration of the features of local institutions provide a solid entry point for establishing a GWUG provided that the benefits are easily understandable and the challenges addressed.

Table 7.6 Summary of SWOT analysis of three local institutions

SWOT	**Vegetable group**	**Water User Association (Drinking)**	**WUA (irrigation)**
Strengths	-Year round production. -Low electricity bill for pumping groundwater (shallow water table and use of small pump -Easy market access (close to market)	-Good water quality and healthy local community -Reliable drinking water supply -Affordable fee (low cost for electricity and maintenance) -Can be managed by local community	- Water for rice/ vegetable production -Community in-charge of water management -Gain new experiences -Adequate food for household consumption
Weakness	-Weak technical know-how -Lack investment capital.-Weak negotiating power for the price in the market -Poor productivity -Lack experience in group management -Lack experience in marketing	-Problems of electricity fee collection -Funds inadequate for the maintenance of the pump -Lack skills and tools to repair the pump	-Irrigation infrastructure is old and its operation is not efficient -High investment cost -Higher operation cost than revenue -Insufficient experience/ knowledge of the members -The problem with collection of electricity fee
Opportunity	-Government support (focus on agriculture production for household income, Good Agriculture Practices) -Technical support from international organizations - Opportunity to learn and involve	-Access to improved and safe drinking water	-Access to credit from the banks -Access to market -Training on WUA formation and operation

Threats	-Disease -Drought -Price instability of the products in the market. -Risk of poor groundwater quality -Water logging in the wet season	-Instability of the group (change in group size, excess work load) -Lack of investment capital to install big pumps -Few technicians in the local community -Poor water quality in the source water -Inadequate water to meet the local demand	-Flood/drought -High cost of electricity -Conversion of agricultural land for another purpose -Lake shortages

7.6.3 Community groundwater management: The case of Phousan village

The village of Phousan is located 2 km west of Road No. 13 at KM 52 township on the margins of the Vientiane Plain. Phousan as it is today was created by amalgamating three villages that were formed in the late 1970's and in the mid-1980's. It has 1,861 inhabitants from three different ethnic groups (87% Hmong, 11% Khmu and 2% Lao Lum). People are dependent on groundwater for their daily water needs, since the village is located a long distance away from any watercourse and there is no connection to the distributed water supply network.

Because of the specific hydrogeological conditions where the village is located (low yielding sandstone aquifer), the groundwater potential is low and people face water scarcity during the late stages of the dry season (March – May). At this time of the year, some shallow hand-dug wells tend to dry up and the borewells yields are very low.

During the first two decades following the creation of Phousan's former villages, residents relied only on public water-wells. But since the arrival of the electricity network in 2000, well numbers have increased greatly as households have opted for private (on-their-doorstep) water wells if they are able to afford it (Fig. 7.9). Nowadays, both public and private wells are used, but only 10% of the population still rely on the public borewells equipped with hand pump that were drilled in the village as part of a development project led by OXFAM in 1998.

Groundwater management in Phousan does not rely on an official legal framework, instead it is based entirely on oral communication. There is no organization specifically in charge of this community service, nor written rules. This does not however mean that management is non-existent. In fact, the community works collectively to handle water supply matters related to resource access and seasonal scarcity. Rules exist and are largely followed by everyone.

To regulate the access to, and the use of these public water-points, villagers have defined the basic principles they all respect and can enact. Everyone can fetch water from community wells but access is on a first-come-first-serve basis, and anyone cannot fetch more than 3 to 4 buckets of water at a time. These principles aim to provide adequate access and allocation to all in need.

When groundwater scarcity increases during the hot season, everyone reduces water consumption regardless of whether they rely on public or on private water-wells. People stop growing their vegetable gardens, or continue on a reduced scale to save water and prioritise on their domestic needs. This practice is followed by the entire community. There is no specific documented rule to restrict each household's 'over' consumption, nor any particular penalty handed out. Breaking social norms would be frowned upon by the community and this carries a lot of importance.

Over the years, Phousan's residents have managed, independently, to develop a self-supply and self-regulated water system relying on the groundwater resource. Indeed, residents of Phousan still have a constrained access to the groundwater resource and would welcome support from government authorities or another organization to tackle scarcity issues in the village.

In case of Ekxang village, situated just 7 km away from Phousan, on the eastern side of Road No. 13, the alluvial aquifer there presents a higher potential for groundwater abstraction than in Phousan. The resource at Ekxang is more abundant and is heavily used for small-scale irrigation. Over-abstraction could cause the water level to fall, and shallow wells used for domestic activities would therefore be at risk of drying up. This situation would raise both environmental and social issues. It is therefore necessary that all the stakeholders are involved in developing sustainable approach to groundwater management.

The case study from Phousan village is an illustrative example that under particular circumstances – living together in harmony, limited number of users – the community groundwater management approach can be particularly appropriate to provide a management response that addresses both social and technical aspects. This does not always mean however that the bottom-up approach to groundwater management applied at Phousan can be transposed as it is to another village. It is then essential for policy-makers to bear in mind that both hydrogeologic and socio-economic conditions and context are highly important and location-specific. Therefore, top-down laws to enforce groundwater regulations or policies should recognise the diversity of contexts. Groundwater management must take into account both the aquifer system and the pattern of human use (i.e. for what purpose groundwater is used, in what quantity, with what type of well).

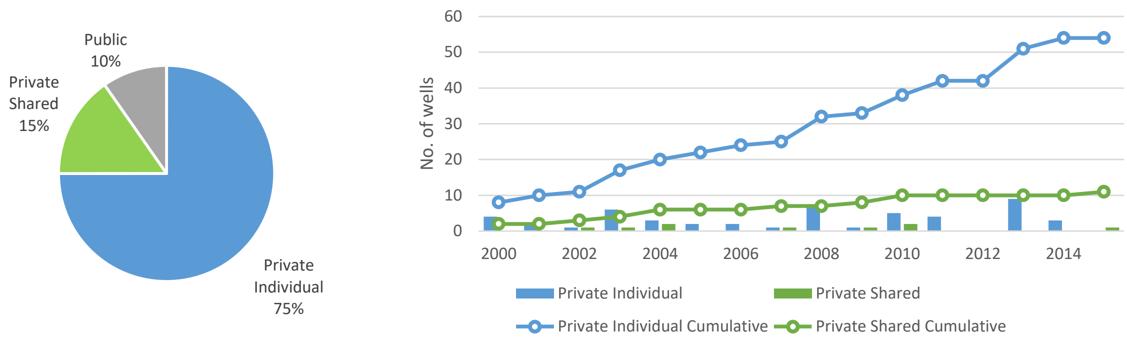

Figure 7.9 The current breakdown of public and private wells in Phousan village (left; the expansion of wells since the village became connected to the electricity grid in the year 2000 (right)

7.6.4 Emerging Groundwater Management Plan for the upper Vientiane Plain

Groundwater management is at very early stages in Lao PDR, but over the course of this project, it became clearer that there is now sufficient interest and capacity emerging to begin the process in pilot priority areas. The Groundwater Management Division of the Department of Water Resources (DWR) was tasked in 2015 to develop the first plan for the Upper Vientiane Plain (covering the districts of Keoudom, Phonthong, Toulakhoum and Viengkham districts), building upon the routine groundwater level monitoring the DWR has been undertaking since 2014 in addition to the various technical, socio-economic, institutional and capacity building activities carried out in this research project, along with other parallel initiatives. It provides a direct and tangible contribution to the National Groundwater Action Plan that has been prepared under the National Integrated Water Resources Management Support Program (NIWRMSP, 2015).

This activity will be divided into two four main tasks: (i) carry out an inventory of the existing wells in the four districts; (ii) draft a groundwater resources profile; (iii) develop groundwater regulations; and (iv) raise public awareness (Fig. 7.10) in the four districts with future plans to extend this to the other 9 districts in Vientiane Capital.

Tasks 1 and 2 are most advanced at the present time. Kick-off meetings have been held with representatives from each district and the province (DONRE and PONRE) to appraise them of the activity and to train field technicians on procedures for gathering information for the survey. Primary and secondary data from the project have been compiled and shared with DWR. Each of the project activities that have taken place within the Plain have been distilled into brief summaries in less technical language that are tailored to local natural resources managers. These are being combined and translated into Lao language before a consultation meeting is held with the local authorities and finalizing the Profile.

For task 3, groundwater management regulations in the districts are being reviewed in consultation with local authorities, and cognisant of the principles emerging from the new national Water Law, which is being finalised. Meetings were held with local communities, private sector operators and representatives from other sectors (agriculture, forestry, energy, public health etc.), to incorporate their views and needs assess their needs lets them develop their own regulation.

Finally task 4 serves to raise public awareness on groundwater management by drawing on the knowledge and information derived in previous tasks: dissemination of DWR research activities to local communities, production of periodic progress reports to media outlets, documentation of communication material (videos and posters), and developing cooperation with groundwater agencies in the region, such as the Department of Groundwater Resources in Thailand.

By the conclusion of this project it is anticipated that Tasks 1 and 2 will have been completed in full, and that the two remaining tasks will be well advanced. The activity will be carried forward beyond project cessation as this activity directly aligns with the mandate and priority of the DWR-GMD, and is recognised and supported within the highest levels of the institution.

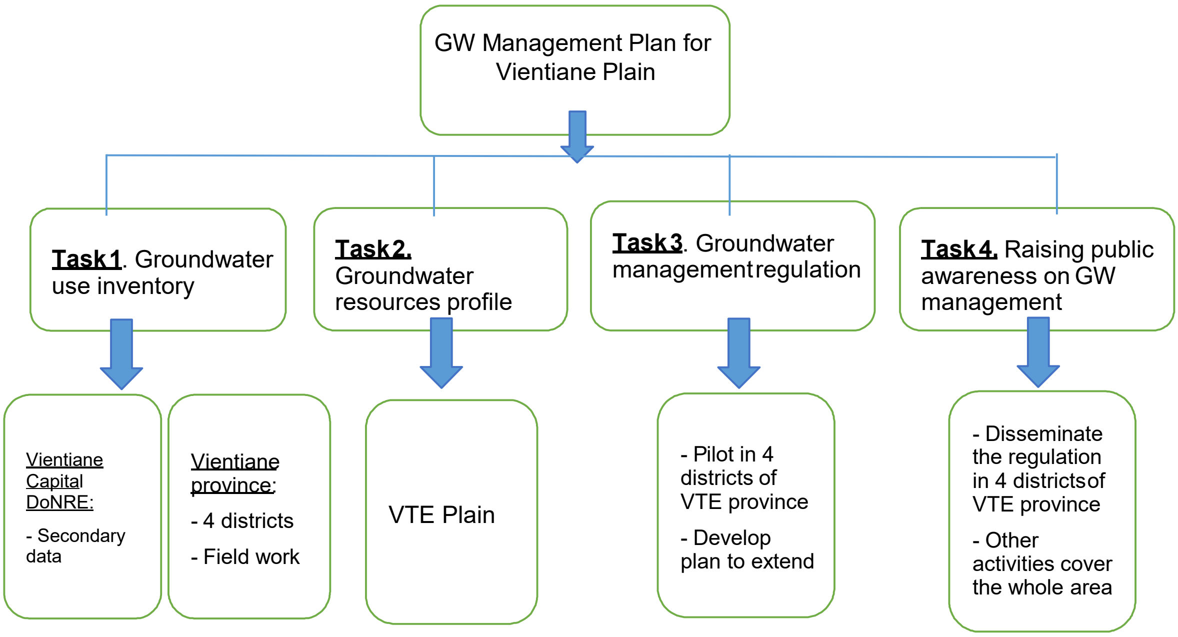

Figure 7.10 Overview of the strategy applied to groundwater management plan formulation for the Upper Vientiane Plain with scope for expansion to the entire Vientiane Plain in the future

7.7 Capacity building and training

7.7.1 Formal and informal Short Courses

The first Short Course on the fundamentals of groundwater resources was conducted in April 2013 over a 4-day period at Khon Kaen University and attended by 29 team members and invitees from within Lao PDR and Australia, as well as a number of trainers (KKU-GWRC, 2013a). As the first substantial course of its kind to be carried out specifically for Lao attendees, it sought to instil the participants with the basic principles of groundwater science and management. Formal lectures were combined with practical demonstrations of well drilling and testing and visits to groundwater technical service centre of KKU to gain exposure to a range of field equipment. Practical problems in Laos were discussed with the experienced trainers from KKU-GWRC and IWMI, and teams and plans prepared for future activities in Lao PDR.

Results from the feedback questionnaire showed that more than 89% of the participants found the format and content of the Short Course useful but more than 80% of the participants needed more time to expand their knowledge on groundwater development and management. More practical exercises and field work were requested in future Short Courses.

The second Short Course on Groundwater Modeling and Application was carried out in November 2013 over a 5-day period at Khon Kaen University (KKU-GWRC, 2013b). Being a specialist course building on the first course, only 9 attendees were specifically selected from the 5 national partner institutions: NREI (3), NUOL-FWR (3), DWR (1), DOI (1), NUOL-FES (1). The main objectives of the Short Course were to introduce to the participants the theory behind groundwater modeling using MODFLOW Flex; to provide several examples of hands-on-exercises with developing Visual MODLOW Model; and to introduce groundwater management by numerical modeling techniques with case studies. The main achievement was the passing on of basic knowledge on groundwater modeling and application to the participants, as well as encouragement to proceed further on this topic. A compilation of technical materials such as lecture notes and essential articles were provided to all participants.

An opportunity was given to each of the attendees to present their ideas to the trainers on how to apply the new knowledge in the research project and their work more generally (notice was provided well in advance). This exercise was not particularly successful. In the months that followed it became clear that the Short Course was no 'Game Changer'; and that no individual or partner institute had self-initiated or requested support to carry out a modeling study of this kind. As intense and as well received as the Course was, it was clear that any one-off effort was inadequate to build capability to a sufficient level. This was a valuable lesson learnt by the trainers. Plans to conduct a third major course on advanced groundwater management was cancelled, and instead, priority and effort given to developing a local community of practice in the field of groundwater modeling.

From September 2014 until the end of the project, six follow-up trainings/workshops with the modeling group were held (in Vientiane, Nong Khai and Khon Kaen). The main aim of these trainings was to support national researchers who are working on groundwater issues at basic and more advanced levels.

Through discussion, two case studies were identified, one extending over the entire Vientiane Plain led by NREI with DWR support and the other for the Nam Panai watershed, a subarea of the Plain (where more detailed characterization was taking place), led by IWMI and supported by DOI. Overall guidance was provided by KKU-GWRC. Efforts to develop a third modeling team focussing on modeling the Tad thong campus of NUOL-FWR has yet to eventuate, but could be an avenue for the future.

The teams presented their ideas in the earliest workshops, assembled their data and collected new data where possible, developed and debated alternative conceptual models and calibrated their models under the careful guidance of the KKU-GWRC trainers. New case studies were often presented by other members of the research project team or invitees, to introduce new perspectives and to motivate the group. In between workshops, some of the most active team members spent time at KKU-GWRC to focus exclusively on their activity.

7.7.2 Modeling outputs for the Vientiane Plain

NREI had expressed an interest and was therefore tasked to take lead in developing a groundwater model for the Vientiane Plain, extending over an area of 4,500 km^2 with upland forests, a major agricultural region, the national capital and hundreds of towns and villages and therefore presenting a major challenge under this context. Given that the expertise of the NREI team is mainly in the areas of engineering and environment, the lack of knowledge and experience in hydrogeology and groundwater resources presented a major constraint. The Short Courses and follow-up trainings served to address this.

Since the first follow-up trainings began, data has been compiled, and some data gaps addressed through new data collection. A conceptual model of the area has been prepared. A fully functioning MODFLOW model has been generated that represents the best available understanding of the aquifer characteristics, and boundary conditions and groundwater utilization to a reasonable degree. Whilst an attempt has been made to calibrate the model, given the existing gaps and uncertainties, any such calibration would be difficult to defend. What has been achieved in a technical sense is the construction of a so-called 'Operational Model' that is 'owned' and operated by NREI staff. The model provides a good foundation for addressing management issues in future. NREI are yet to reach the stage of conducting modeling independently, and still require some level of external support. To our knowledge, prior to this the only groundwater model that has been developed for Lao PDR was achieved through an earlier ACIAR project in Champone district, Savannakhet province involving Australian and Thai modelers with support from Lao counterparts (Wiszniewski et al., 2005).

7.7.3 Pre-project training in Australia

During the formulation stage of this project, IWMI was successful in raising funds from the Crawford Foundation (Australia) to send 3 Lao nationals from the partner organizations to Adelaide, Australia from 19-28 March 2012 to attend the Australian Groundwater School organised by the National Centre for Groundwater Research and Training (NCGRT) for discussions with academics at the major Adelaide universities. The participants from NREI, NUOL-FES and NUOL-FWR gained technical knowledge on groundwater which can be adopted and widely applied in the future to development challenges in Lao PDR. With increased use of groundwater expected, sustainable groundwater management should be implemented. Concept notes were prepared in advance by the participants and were discussed with potential research supervisors. The knowledge gained during the training was expected to directly contribute to work undertaken during this project and to the implementation of the Groundwater Assessment package of the National Integrated Water Resources Management Support Program (NIRWMSP) supported by DFAT and administered by ABD and GHD. The training provided a useful initiative in terms of capacity building and future cooperation between the public sectors in Lao PDR with the groundwater-related institutions in Australia. Two project team members are undertaking or soon due to start PhD studies at NCGRT universities.

7.7.4 Other trainings

Two project team members (from IWMI and NUOL-FWR) attended a regional training in late 2013 organised by IRD at the Houay Pano watershed in Luang Prabang province, to gain experience on water flow (particularly stream discharge measurement, soil moisture and bulk density estimations, soil infiltration and permeability estimations, and groundwater and stream water interactions), using simple and more advanced methods (note that both attendees have successfully applied for JAF's through ACIAR and related topics).

A one day study tour and training was led by IWMI and organised with NREI on 2 November 2015 as the final component of a two week National Groundwater Training Program, which was part of a training package organised for the NIRWMSP. In total, 45 people from various faculties/departments from NUOL and numerous government departments participated in the tour/training in the Nam Panai watershed in Vientiane Province. The participants had exposure to the hydrogeological conditions in the area; drilling and testing tube wells for irrigation; monitoring of aquifer properties, groundwater levels and water quality; exposure to community-managed tube well irrigation pilots and privately-managed dug well irrigation for cash cropping; household level groundwater use assessments; and community management of groundwater. Verbal feedback from the attendees was positive in that the training helped to better understand practical aspects in contrast to theoretical learning within the classroom. It was intended as an experience that may inspire government officers and students to pursue a career in the groundwater sector.

Trainings have been provided by IWMI staff to government officers from the Dept. of Water Resources, NREI and NUOL to monitor various environmental variables that are being used in their daily work. Undergraduate students from NUOL have been provided on-the-job-training by IWMI on soil and water quality testing. An IWMI agronomist who joined the project in February 2015, has been based at the Faculty of Water Resources of NUOL (formerly WRED) for 40% of his time to work closely with lecturers and students and help build their research capacity.

7.7.5 Exposure Visits

A study tour to Samsung district, Khon Kaen province was included in the program of the first Short Course. All course members and trainers attended. The tour/excursion yielded a number of important benefits for the project, then in its early stages:

- observing field hydrogeological conditions suited to the development of groundwater resources for irrigation purposes;
- learning about good practices in groundwater management as applied to irrigation projects;
- exchanging and gaining experience with local farmer groups in growing chemical-free vegetables;
- studying co-operative systems of water management, financial management/cost recovery and marketing of agricultural products.

Details on the visit are provided in the Excursion Guide (KKU-GWRC, 2013c). Over the course of this project, numerous other trips were made to provinces in northeast Thailand. In some cases these allowed other project team members and collaborators who could not visit in April 2013 to gain direct exposure of a similar kind. Otherwise they served to reinforce concepts presented during the modeling course and workshops.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project has worked towards:

• creating improved understanding of hydrogeological systems;

• clarity on the way groundwater is perceived and used under different contexts;

• establishing the actual costs and benefits of groundwater irrigation;

• models that assess how to achieve sustainable development and avoid negative environmental impacts; and

• strengthening technical and institutional capacity within the government, universities and other important stakeholders to execute similar studies in future.

Our scientific impacts are reflected in the way the project has addressed some of the key knowledge gaps. A non-exhaustive list of the scientific contributions is as follows:

- Greatly improved understanding of the hydrogeology, groundwater systems, water balances and water quality in several specific areas and at the national scale. This information and knowledge is currently being used by water resource managers and will be increasing relied upon for benchmarking and other purposes in the future.
- Improved knowledge of groundwater potential, recharge rates, groundwater use and groundwater quality which were poorly known in the past. These provide useful entry points for future research to refine the information and understandings further in the study areas or carry out similar works in other areas.
- Useful reports, maps and tools to guide future development and enable better management of the groundwater resources by government authorities within the water resources and related sectors. The work in the upper Vientiane Plain has found immediate uptake by GMD-DWR in the formulation of their Management Plan. All of the relevant technical information from the project has been distilled and expressed more simply in Lao language to create the 'groundwater profile' for the area and presented to local stakeholders by the project team (see Figure 7.10; task 2). This activity will be continued by GMD-DWR beyond the project. The national groundwater prospects map and associated datasets have been requested by various agencies within MONRE since this helps support their mandates in groundwater planning and implementation.
- The experimental facility at Tad Thong campus has enriched the curriculum at the NUOL Faculty of Water Resources by allowing students and lecturers to conduct practical studies directly linked to their courses on water resource management and use. This was previously not possible. With a focus on irrigation and groundwater management, this gives interesting new opportunities for practical research that serves the national interest.
- We also understand more clearly the way so-called 'bottom-up' management self-applied by local communities sustains lives, livelihoods and the resource, as well as the hydrogeological and socio-economic conditions that drive this. This information has been shared with GMD-DWR for the Management Plan and paves the way for hybrid approaches to be developed that also incorporate 'top-down' management by government in future.

- We have synthesised the current state of groundwater management in the country for the first time, identifying the range of problems faced as a means to promote more targeted efforts in this area. This has been communicated to policy makers and this knowledge is being embedded in policies and plans such as the National Groundwater Action Plan and the Groundwater Management Plan for the upper Vientiane Plain.

8.2 Capacity impacts – now and in 5 years

Capacity enhancement was built into this project from the start as a specific objective. Executing this part of the project has made much needed inroads as detailed in Section 7. We have run two formal training courses, sent local counterparts to international forums and are providing on-the-job training and facilitated scholarships for postgraduate training.

The specific accomplishments for Lao nationals include:

- 2 Lao students are carrying out PhD and MSc studies at international universities, and a third is due to start in early 2017;
- 2 Lao students have completed MScs at NUOL with regional cooperation;
- A large number of NUOL graduates have completed their research work and 4 of these are carrying out research internships at IWMI to increase their knowledge and experience.

A synopsis of the postgraduate studies underway is given in Section 11.3.

One of the most important lessons learnt over the course of the project is that blanket support of all team members and others does not work that well. A shift towards more targeted and specific support and encouragement for promising individuals demonstrating strong interest and motivation is a better approach.

The specific accomplishments for international students include:

- Imogen Goode (volunteer from Australia, Nov-Dec 2013) – Amendment of acid affected soil irrigation trial at the THXP upland site
- Anna (Snowy) Haiblen (intern from Australia, Feb 2013 - April 2014 intermittent) – Groundwater assessment of the upper Vientiane Plain
- Andy Clarke (intern from Australia, Dec 2013 - April 2014) – Geological assessments at upland and lowland sites
- Liliosa Magombedze (intern from Zimbabwe/Australia, Jan – Mar 2014) – Literature review and database development
- Marleen van Asseldonk (student from the Netherlands, June 2013) – Role of community participation in irrigation development projects
- Laure-Anne Serre (intern/MSc from France, Apr - Aug 2013) – Village level impact assessment
- Mathieu Viossanges (intern from France, Nov 2013 - May 2014) – National groundwater hotspot mapping
- Jenkins Macedo (MSc from USA, Jan – June 2014) – Biochar and fertiliser amended irrigation trial at lowland site (supported by Bourlag scholarship)
- Seinab Bohsung (intern from Germany, Oct 2014 – Mar 2015) – Dug well irrigation in the Vientiane Plain
- Jordan Vinckevleugel (intern/MSc from France, Mar – Sept 2015) – Community management of groundwater

- Christopher Harris-Pascal (intern from Australia, Mar – Sept 2015) – Groundwater modeling of Nam Panai watershed
- Cecile Coulon (intern from France, Sept 2016 – ongoing) – Case Study on groundwater governance improvements in Lao PDR for GRIPP

Almost all of these interns/students worked closely with junior members of our partner agencies, providing on-the-job training and mentorship. The international counterparts also gain benefits. The internship of Mr Christopher Harris-Pascal has a strong capacity-building focus. He took temporary leave from his employer (Geoscience Australia, GA) for the internship. He has returned with some modeling capacity which is of value to his institution.

The knowledge and new techniques taught and the reference material provided during short courses and trainings are being used in various ways. For example, academics at NUOL are using the materials prepared by the project in the curriculum they teach to undergraduate and graduate students in at least three faculties. Also, government officers from DWR have been applying some of the field techniques in other donor-supported projects, e.g. for the World Bank in Savannakhet.

The knowledge and capacity of Lao Government staff, particularly from GWD-DWR and NREI on groundwater science and groundwater modeling has been greatly enhanced. Staff of the GWD-DWR and staff at provincial and district levels are now able to do basic groundwater level monitoring and water quality testing. NREI staff are also capable of measuring groundwater levels and applying groundwater models at a sufficient level. A technical group on groundwater modeling with the government and the university has been established to help maintain the momentum gained. The relationships developed between these Lao partners and KKU-GWRC have been maintained with ongoing interactions envisaged.

Team members from DWR and NRE have been invited to forums to speak on groundwater issues on behalf of the Government, This would have not been possible four years ago and is in large part attributed to this project.

Farmers and extension officers in the Vientiane Plain have enhanced knowledge of groundwater resources and their management, and the links to climate and new development. Groundwater is being routinely monitored across the Plain since 2014 and we expect that this will continue as a mandate of the GMD-DWR into the future. The management plan for the upper Vientiane Plain is a promising development for the security of water quantity and quality over the longer term.

Farmers and extension officers at Ekxang village have been given training in rice husk biochar production methods, post-production adding to soil, irrigation installations, and soil, water and climate monitoring.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The maps generated through this study help to identify locations to drill wells more effectively and hence add value to investments and save costs through the avoidance of drilling failures. Previous drilling projects on the Vientiane Plain in the 1990s had a 60 percent failure rate from 118 wells due to high salinity and low productivity. Based on the knowledge and tools from the project, future efforts can anticipate much higher success rates at the national scale.

Farmers now have greater choices to improve their livelihoods through dry season cropping using farmer-managed groundwater technologies. Profits from these activities can be substantial for farmers if crops are chosen according to the market. There are wide opportunities across the lowlands of Lao PDR that can be utilised by those farmers. In the uplands, there are potentially prospects, however this is made more challenging by the complex physical and socioeconomic environment and potentially weaker market access. In the longer term, the likely positive economic impacts that can be attributed to this project are strongly related to way these findings are incorporated into agricultural policies, and made implementable by clear guidelines so that the full benefits are derived from the investments. Long term negative economic (and social) impacts are avoided by effective groundwater management and policies that protect the interests of all users of the resource. One of the legacies of this project is to make meaningful inroads in this area.

8.3.2 Social impacts

Farmers and extension officers at Ekxang village have been given training in rice husk biochar production methods. We have observed changes in farming practices, with 20 percent of farmers surveyed one year after the training indicating that this new knowledge came from this project. Those same farmers and extension officers, have, through the ongoing engagement with the research team during the irrigation trial, come to recognize the economic and resource value of using water saving technologies. The three different irrigation technologies were established jointly with the farmers and evaluated in terms of water use and net incomes. This was explained to the farmers through community meetings and the information made more widely available through simple information sheets that were prepared by the project.

In the communities at all the study sites, the project has made great efforts to explain, in simple terms that can be understood, the importance of protecting and sustaining their groundwater resources. Direct feedback received from those communities suggests that these messages have been registered. The impacts of these activities will only be evident in the long term. A video about the groundwater resources of Lao PDR has been produced by this project (see communication section) and disseminated through the most important social media outlets (including Facebook) as well as made accessible through the project website. This is a long term, open access resource for the community, schools, civil society and government that was never before available in Lao language.

An informal community of practice in groundwater has been established amongst the project partners and other partners that the project has interacted with. There is evidence that this community is still active being mobilised by GWD-DWR and NREI for meetings and trainings that they organise.

The profile of groundwater amongst national authorities has been elevated through the efforts of this and other projects through awareness raising activities. For example, the current (8^{th}) five year National Socioeconomic Development Plan refers to groundwater for the first time.

Our findings from Phousan village show how farmers' groundwater use is partially driven by land tenure security. This has been presented during the Land Issues Working Group policy advocacy event in November 2015, and policy recommendation to revise the current article 17 on land privatization in the Constitution have been channelled by the British Embassy representative to National Assembly along the process of Constitution amendment. The Constitution amendment process is still pending.

8.3.3 Environmental impacts

This project has provided new knowledge that will assist those tasked with addressing relevant environmental concerns. Tools developed from the project have been disseminated across all levels of MONRE and are accessible via the project website. The tools serve to better understand the potentially negative impacts of poor landuse practices on groundwater quality and the role of groundwater in supporting surface water flows and ecosystems.

Masters and PhD studies now underway by NUOL and DWR staff will provide 'local champions' who can provide new information of existing conditions and interactions between surface water and groundwater that is hoped can be used to ensure groundwater dependent ecosystem services are better valued and maintained.

8.4 Communication and dissemination activities

Communication-wise we have engaged with the local and international media, developed a wide range of communications materials (sometimes in dual languages) and presented our work at work at local, regional and international forums.

8.4.1 Media Interactions

- At project inception a Media Release was prepared and distributed to media outlets including the Vientiane Times, KPL News, Lao Phatthana Daily, Socio Economic Daily, Lao Voices, Voice of America News, Radio Free Asia, and Radio Nationale Lao.
- Radio interviews (in Lao) were given by IWMI for Radio Free Asia (http://www.rfa.org/lao/environment/iwmi-to-help-agricultural-thru-ground-water-project-04032013154321.html) and for Voice of America News (http://lao.voanews.com/content/interview-mr-boumee-maokhamphiou-information-officer-of-the-international-water-management-institute-in-vientiane-laos/1611774.html)
- The activities of the project in Ekxang village were reported in the Vientiane Times (1 October, 2014)
- An article on the project was published in the ACIAR Country newsletter in August 2014
- IWMI Today blog: IWMI partners with NUOL's Faculty of Water Resources for groundwater trials (18 November 2015)
- A two day workshop organised by CCAFS and some of the project partners on *Mobilizing Science for Climate Change, Agriculture & Food Security: Engaging the Media in Lao PDR" and "Launching of Climate-smart Village (CSV)*"was attended by around 70 participants including >50 from the Lao media across the country. Day two included a visit to Ekxang village and the irrigation trial site by all the attendees. Around six printed media stories were written soon after the workshop.

8.4.2 Communications material

- A brochure about the project was prepared in the early stages of the project (in dual languages) and distributed when engaging with new stakeholders. Both versions were subsequently revamped midway through the project.
- Project Website established: http://gw-laos.iwmi.org/ (with link to the Lao version)
- Project updates are being uploaded onto the Facebook site for CGIAR-Laos https://www.facebook.com/CGIAR.Lao

- Project polo shirts (for interviewees of socio-economic study but also researchers and other stakeholders)
- Professional photographs of Ekxang village and surrounding areas taken by Mr Jim Holmes (http://www.jimholmes.co.uk). These are available at the IWMI CommsReources multimedia site: http://commsresources.iwmi.org/pages/home.php
- Video prepared about groundwater resources and the work at Tad Thong campus, entitled: "The water under your feet in Laos" (in Lao with English subtitles). Its intended for a general audience available at:

  https://youtu.be/CGslmANO_i0
  http://gw-laos.iwmi.org/outreach.aspx

8.4.3 Forums

Communication activities of various sorts have been made at forums targeting the scientific community, policy makers, students and general public including:

- A half-day stakeholder consultation was held in Vientiane which attracted about 50 attendees (September 2012). This has been followed up by meetings with other government departments, INGOs, local NGOs and drillers.
- A one day workshop on Water User Groups in the Lao context was held in Vientiane with participants from the water, agriculture and energy sectors, including village leaders and farmers which attended to share their views and experience (September 2014)

Seminars and briefings have been made by numerous project team members at the following forums:

- World Water Day Seminar held at NUOL Tat Thong Campus (2013)
- 2nd Asia Pacific Water Summit, Chiang Mai (May 2013)
- Team members organised and contributed to a workshop on: "Groundwater in IWRM: Options and Lessons" at the 2nd Asia-Pacific Water Forum (May 2013). http://www.iges.or.jp/en/news/topic/knowledgehub_gw_20130516.html.
- Dissemination of project information at IGES Groundwater Knowledge Hub Exhibition Booth during Asia Water Week, ADB Headquarters, Manila (March, 2013)
- 3rd Mekong Forum, Hanoi
- CORRA meeting, Colombo
- 2nd Mekong-Ganga Forum, Vientiane
- Groundwater Governance and Policies Interview, Vientiane
- National Orientation on Groundwater Management, Vientiane
- World Water Day, Vientiane (2014)
- Lao National River Basin Form, Vientiane
- NAFRI 15th Anniversary Conference
- MAF/NAFRI Policy Think Tank
- 2nd NAFRI/IRAS International Conference, Vientiane (July 2015)

- Two project team contributions at the CGIAR WLE Workshop "*Managing Smallholder Groundwater-dependent Agrarian Socio-ecologies using an Ecosystem System Service and Resilience Based Approach*", Colombo (November 2014)
- Kick-off workshop on 'Development of Ground Water Management Training Program' at NUOL Tad Thong organised by the ADB NIWRMSP, (May 2015)
- Two scientific posters were exhibited by NUOL at a three day exhibition in Vientiane (Lao ITECC) organised for all Engineering Departments of the National University of Laos
- National University of Laos, Japanese Development Center (July 2015)
- ASEAN Network Workshop on satellite-based rainfall application in Bangkok, Thailand (October 2015)
- CCOP-KIGAM-UNESCO-DGR Workshop on Sustainable Groundwater Management in Mekong River Basin, Bangkok (May 2015)
- Toward Sustainable Groundwater in Agriculture - An International Conference Linking Science and Policy, San Francisco (June 2016)

8.4.4 Open Days and visits

- Project coordinator, Rural Development Fund project visited Tad Thong trial site to gather information about setting up an irrigation project and irrigation methods
- Representatives from the University of Tokyo, Japan visited Tad Thong trial site. They were in Vientiane to undertake research with NUOL on wastewater impacts at That Luang Marsh, Vientiane
- The Ekxang trial site has been visited by scientists from IRRI, CIAT and CSIRO and have shared information and feedback

9 Conclusions and recommendations

9.1 Conclusions

The biophysical activities carried out through this research have greatly improved the understanding of the hydrogeology and groundwater systems and enabled the areas of fresh groundwater and suitable productivity to be more clearly delineated. Maps and other tools have been developed to guide future development and enable better management of the groundwater resources by government authorities. The local community (farmers, drillers, water user groups etc.) and the wider community they serve would also benefit.

The alluvial deposits of the Vientiane Plain provide a significant resource for groundwater development for improving food production. However specific management practices are required due to the shallow and responsive nature of the aquifer, the influence of Nam Ngum River and the underlying salt-bearing layers. Groundwater is a vital resource for most of population. It is hoped that continued work to constrain aquifer properties and the extent of groundwater-surface water interactions may allow for a more precise calibration of the model and allow predictions of groundwater heads in the future to be made with greater confidence. The results and the model is being used for management purposes by the Department of Water Resource and the Natural Resources and Environment Institute.

A techno-economic performance of two individual farmer-managed shallow dug-out wells used for dry season cash crops has been evaluated. This has generated useful lessons on where this form of technology/approach may be best suited and highlighted the variability and factors affecting farm incomes.

The community-managed groundwater irrigation trial at Ekxang village is the first of its kind in Lao PDR and is intended to showcase this form of agricultural intervention and to stimulate further development if successful. The outcome of this trial is heavily dependent on the functioning of the groundwater user group (GWUG), a major challenge of the project and whose importance cannot be emphasised enough. If irrigation systems are designed for community management their success is dependent on the GWUG. To achieve this guidance is needed to assist future planners and developers to facilitate effective implementation of future schemes. Hence, all lessons and guidance collected through this trial, are being compiled and used in guidelines for the establishment of community-managed groundwater irrigation in the context of Lao PDR.

Considering the great potential of groundwater in Lao PDR and the fact that it is widely underutilised, it seems likely that tube wells, not dug wells, will take irrigation development forward. One question remaining is: will this technology be adopted following the community-managed model, or will its breakthrough only arrive once drilling and pumping become more affordable for individual farmers, allowing for private ownership?

Feasibility assessments in relation to the hydrogeological conditions in an upland setting, scheme design and costs, and irrigation pilots to ameliorate soil acidity were carried out at one of the villages administered by the Theun-Hinboun Power Company (THPC). Useful knowledge, insights and lessons were derived over the 15-month period of the engagement between the research project and THPC. Two major lessons were learnt in dealing with private sector partners. Firstly, more effort could have been given to cost-benefit considerations at the outset as economic considerations weighed most heavily to THPC. Some of the field activities may have been deferred until the economic viability was made clear. Secondly, the objectives of the research team did not necessarily align with the immediate priorities of the local community and THPC field staff. The latter were most interested in the adjacent, larger-scale production fields and the research team failed to maintain engagement with the local actors once the short-term project staff member had departed. When working in remote areas, having dedicated personnel with research capacity and experience is essential for successful participatory research. This requirement was not met in the second half of the experimental trial.

The socio-economic investigations at the two case study villages has revealed three major findings on how to promote agricultural groundwater use to improve farming households' livelihoods: (i) the promotion of agricultural groundwater use should be based on a firm understanding of how farmers perceive opportunities and constraints in relation with their farming systems and strategies: (ii) positioning groundwater in national agricultural development policy should be with the primary aim to provide farmers with new sources of water to sustain livelihoods and increase households' income (through for instance crop diversification) rather than for increasing agricultural production alone; and (iii) any government policy promoting groundwater use should be formulated based on how farmers could use groundwater both for farming and domestic purposes on a sustainable basis. This way, groundwater development can be designed and tailored matching resource availability and access with farmers' farming activities and strategies, without posing potential threats to existing water users.

Having carried out a detailed review of institutions and policies in consultation with relevant stakeholders, it is recommended that the Lao Government begins a process of engagement with the three key ministries (Natural Resources and Environment, Agriculture and Forestry, Energy and Mines) to coordinate the development of groundwater irrigation as a tool for addressing poverty reduction, food security, and climate change adaptation. Other sectors such as rural drinking water or industries dependent on groundwater should also be taken into consideration. The Ministry of Natural Resources and Environment is best positioned to act as a lead ministry to coordinate with all line ministries.

Ultimately, enhanced policy and institutional coordination should facilitate promotion of participatory groundwater irrigation on the ground. Potential facilitation may include: prioritised use of groundwater for boosting productivity and high value production, better marketing channels to maximise profit margin of the products produced using groundwater, groundwater to buffer risk against shortfall in rainfall and dry spells, secured supply of electricity for groundwater abstraction, and support on groundwater use and management techniques.

There has also been a strong emphasis on capacity building and training. Activities have included: (i) running short courses, internships, on-the-job training or academic study; (ii) facilitating numerous undergraduate and graduate projects; and (iii) setting up a groundwater irrigation demonstration facility on the NUOL campus to enhance the curriculum through with practical studies. The technical capacity of staff from government agencies in the water, agriculture and energy sectors and from academia have been strengthened. Over 100 Lao nationals have been trained through short courses, internships, on-the-job training and academic study. There have been around 15 undergraduate and graduate projects by Lao students completed or underway.

9.2 Recommendations

Groundwater institutions and policies are still in their infancy in Lao PDR. Increasing interest on groundwater irrigation is an impetus for taking concrete actions in this regard. The establishment of the new Groundwater Management Division of the Department of Water Resources, and importance given to groundwater in recent legal and policy documents, are significant steps to systematise the task of groundwater management and ensure its sustainable utilisation.

Here we briefly list some of the key aspects for the attention of decision makers in policy and planning to implement sustainable groundwater management for the attainment of a broad range of socio-economic benefits. These include:

i) Maintaining the efforts made through this and related projects by investing in the various groundwater management functional areas: resource assessments, monitoring, strategic planning for new supplies, O&M of existing supplies, resource protection, regulation and research. This should be carried through arrangements involving the relevant ministries and departments as outlined within Section 7.6 of this report.

ii) Finalising the Groundwater Management Plan (GWP) under development for the upper Vientiane Plain as one of the major tools to support planning and decision making in that area. This pilot GWP should serve as a basis for strengthening the institutional capacity to formulate and execute policies and laws. As active groundwater management is achieved in the pilot area, it could be scaled out to other areas where groundwater is also extensively relied upon (e.g. the lowlands of southern Laos).

iii) Maintaining capacity and continuing progress in groundwater modelling and refining the GW model developed for the Vientiane Plain to support the GWP.

iv) Supporting the local ‘champions’ in government and academia with the skills and interest to develop and manage groundwater resources effectively. They require a role in the processes outlined in the points above to have the opportunity to fully engage in groundwater to maintain their interest and capacity.

v) Promoting a sensible level of initial development in small-scale private or community-managed groundwater irrigation schemes where conditions are favourable. The guidelines under preparation will articulate the means by which this can achieved, and the institutional support that would be needed to implement this technology on a sustainable basis.

10 References

10.1 References cited in report

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10.2 List of publications produced by project

10.2.1 Journal publications (published)

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Department of Irrigation (2014) Results of Drilling Well Numbers 1/14, 2/14 and 3/14 at Ekxang Village, Phonhong District, Vientiane Province, Lao PDR. Unpublished report dated 26 September 2014, 28 pages (available only in Lao)

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10.2.3 Masters/Bachelor Theses (completed)

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Phommavong, K. (2015) Groundwater flow systems and aquifer storage for agriculture and domestic water use in Kiet Ngong Village, Pathoumphone District, Champasak Province, Lao PDR. Masters Thesis, 4th Batch Masters Programme in Environmental Engineering and Management, NUOL Faculty of Engineering, Vientiane Lao PDR.

Bouakeo, P. (2015) Estimation of Rainfall- Runoff and Ground Water Recharge in the Xebanghieng River Basin By Using Soil Conservation Service (SCS) and Base Flow Separation Methods. Masters Thesis, 4th Batch Masters Programme in Environmental Engineering and Management, NUOL Faculty of Engineering, Vientiane Lao PDR.

Kongxiong Naolee, Bachelor level student in Water Resource Management at the Department of Water Resource Management (WRED). Thesis title: *Improving crop groundwater irrigation during the dry season in rainfed agricultural systems*.

Daoxai, Bachelor level student in Water Resource Management at the Department of Water Resource Management (WRED). Thesis title: *The use of rice husk biochar and compost under irrigation management.*

Oloth Soudthiphone, Bachelor level student in Water Resource Management at the Department of Water Resource Management (WRED). Thesis: *Impact of different fertiliser types on soil moisture content.*

Vytou Heang and Poupe Keovongdy (2016) Estimating Groundwater Use from 4 Villages: Ekxang, Phousan, Luk52 and Viengkham villages in Phonhong District, Vientiane Province. Bachelor student thesis, NUOL Faculty of Environmental Science.

Phudnumxai Sengmanee and Parnthong Xaithilad (2016) Pesticide Impact Rate Assessment Of Ban Ekxang , Phonhong District, Vientiane Province. Bachelor student thesis, NUOL Faculty of Environmental Science.

10.2.4 Bachelor / Masters/PhD Studies (underway)

Mr Sinxay Vongphachan (NUOL), who was awarded a John Allwright Fellowship in late 2013, finally commenced his PhD studies at the University of Technology Sydney (UTS) in January 2015 after passing his IELTS. His topic is on surface water - groundwater interactions under the guidance of Dr Bill Milne-Holme and Assoc. Prof. James Ball.

Ms. Chindavanh Souriyaphack, a project team member from the DWR, commenced Masters Studies at Graduate School for International Development and Cooperation, Hiroshima University, Japan in September 2014. Her MSc Project is entitled: "*Groundwater quality assessment during rainy and dry seasons in the Ekxang village, Phonthong district, Vientiane province Lao PDR*".

Mr Southivone Houamboun, Masters Student in Environmental Engineering and Management from the Faculty of Engineering, NUOL. Thesis title: *Improving groundwater irrigation efficiency by modeling crop water balance.*

Sern Singthong. Bachelor student in Water Resource Management at the Faculty of Water Resource (FWR). Thesis: Long bean productivity and growth under different two drip irrigation technologies.

Siphanxay Nolasin. Bachelor student in Water Resource Management at the Faculty of Water Resource (FWR). Thesis: Irrigation efficiency of drip irrigation system and impact of coconut mulch on Long bean production.

Lengyang Keuyang. Bachelor student in Water Resource Management at the Faculty of Water Resource (FWR). Thesis: Impact of different fertilization treatments on morning glory production under two irrigation practices: sprinkler vs hand-spray.

10.2.5 Training materials

KKU-GWRC (2013a) Short Course on Hydrogeology I: Fundamental of Groundwater Resources. Proceedings of the First Short Course held at Groundwater Research Center, Faculty of Technology, Khon Kaen University, Thailand, 22-25 April, 2013, 219p (summary report also available).

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10.2.6 Publications in preparation (advanced stage)

Brindha, K., Pavelic, P., Sotoukee, T. and Douangsavanh, S. Status of water and soil quality in Vientiane Plains, Lao PDR (in preparation).

Clement, C. et al. (in prep.-a) Community-based groundwater irrigation at Ekxang village, Vientiane Plain: System implementation and initial results (intended for publication as an IWMI Working Paper).

Clement, C. et al. (in prep.-b) Handbook for implementing community managed GW irrigation in the Lao PDR (intended as a joint IWMI/IGES/DOI report).

GMD-DWR. Groundwater Profile of in Keo Oudom, Viengkham, Thoulakhom and Phonhong districts, Vientiane Plain, Lao PDR (Groundwater Management Division, Department of Water Resources publication in preparation, in Lao).

Keokhamphui, K. et al. Enhancing cash crop production through groundwater and agricultural waste applications (intended for publication in the NUOL journal).

Keokhamphui, K. et al. Improving crop water use with the use of efficient irrigation technologies and coconut mulch husk: A study on long bean production (intended for publication in the NUOL journal).

Lacombe, G. et al. Assessing groundwater recharge in the Lower Mekong Basin (intended for peer-reviewed journal).

Natural Resources and Environment Institute. Groundwater Modeling of the Vientiane Plain, Lao PDR (intended for publication as a NREI report).

Raj Shivakoti, B. et al. International experience in groundwater governance and its lesson to slowing evolving groundwater irrigation practice in Lao PDR (in preparation for peer-reviewed journal).

Raj Shivakoti, B. et al. Investigation of the enabling conditions for institutionalizing agriculture groundwater management through the establishment of groundwater user group in Lao PDR (research report in preparation).

Raj Shivakoti, B. et al. Guidelines on the formation of Community Groundwater User Groups (research report in preparation).

Suhardiman, D., Pavelic, P., Giordano, M. and Keovilignavong, O. (forthcoming) Agricultural groundwater use in the Vientiane Plain: Farmers' perceptions of opportunities and constraints. *Human Ecology J.*

Vinckevleugel et al., J. Institutional arrangements in local groundwater governance: A case study of the groundwater resource in Phousan Village (in preparation for peer-reviewed journal).

Vinckevleugel, J. et al., Perceptions of intensifying groundwater use in the Vientiane Plain in the context of livelihood strategies diversification (in preparation for peer-reviewed journal).

Viossanges M., Pavelic P., Rebelo M.L., Sotoukee T. Mapping Groundwater Resources Potential in Lao PDR (in preparation for peer-reviewed journal).

Viossanges M. et al. Estimating groundwater availability for irrigation development in the Vientiane Plain – case study of Nam Panai watershed (in preparation for peer-reviewed journal).

11 Appendixes

11.1 List of Acronyms

AUD	Australian Dollar
DAEC	Department of Agricultural Extension and Cooperatives
DAFO	District Agriculture and Forestry Office
DOI	Department of Irrigation (Lao PDR)
DWR	Department of Water Resources (Lao PDR)
FE	Faculty of Engineering (NUOL)
FES	Faculty of Environmental Sciences (NUOL)
FWR	Faculty of Water Resources (NUOL)
GDP	Gross Domestic Product
GMS	Greater Mekong Sub-region
GWUG	Groundwater User Group
IGES	Institute for Global Environmental Strategies (Japan)
IWMI	International Water Management Institute
KKU-GWRC	Khon Kaen University, Groundwater Research Center (Thailand)
LAK	Lao Kip
MAF	Ministry of Agriculture and Forestry (Lao PDR)
MDC	Mekong Development Center
MONRE	Ministry of Natural Resources and Environment (Lao PDR)
NREI	Natural Resources and Environment Institute (Lao PDR)
NUOL	National University of Laos (Lao PDR)
PAFO	Provincial Agriculture and Forestry Office
THPC	Theun-Hinboun Power Company
WUA	Water User Association

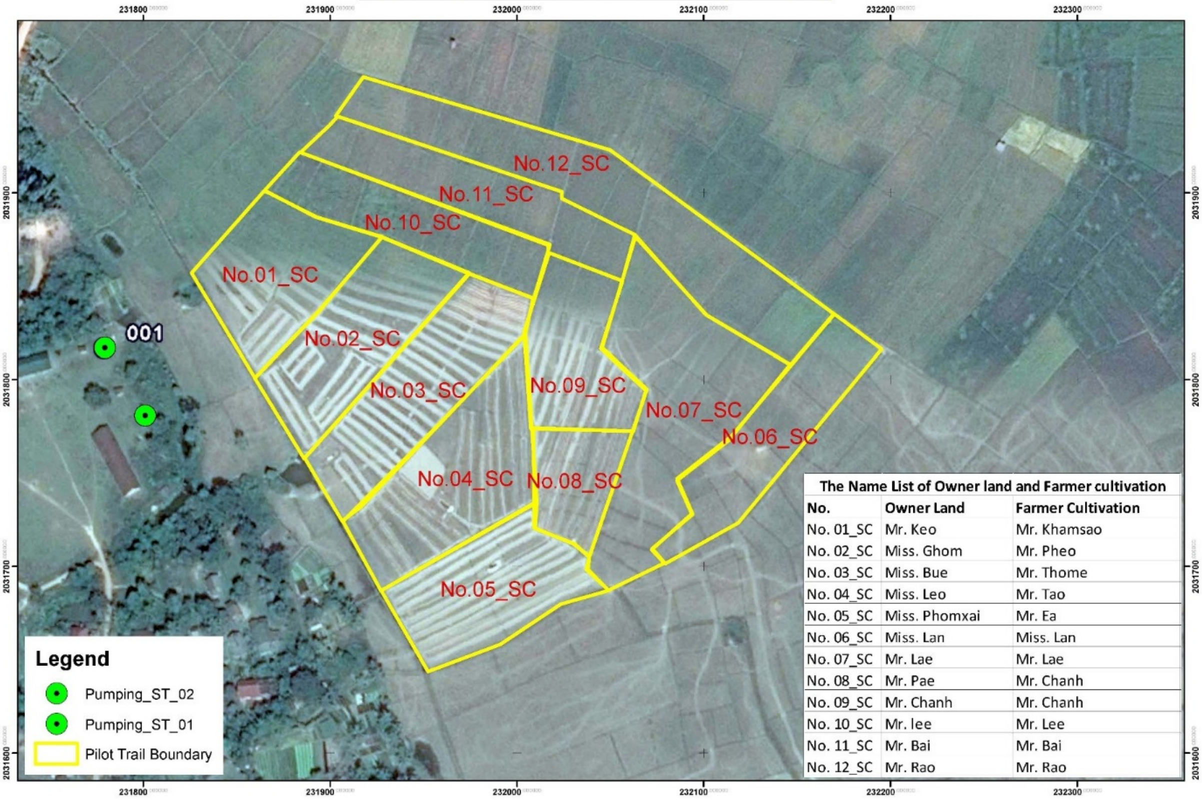
11.2 Groundwater User Group Database

Electricity rate at Ban Ekxang in 2015

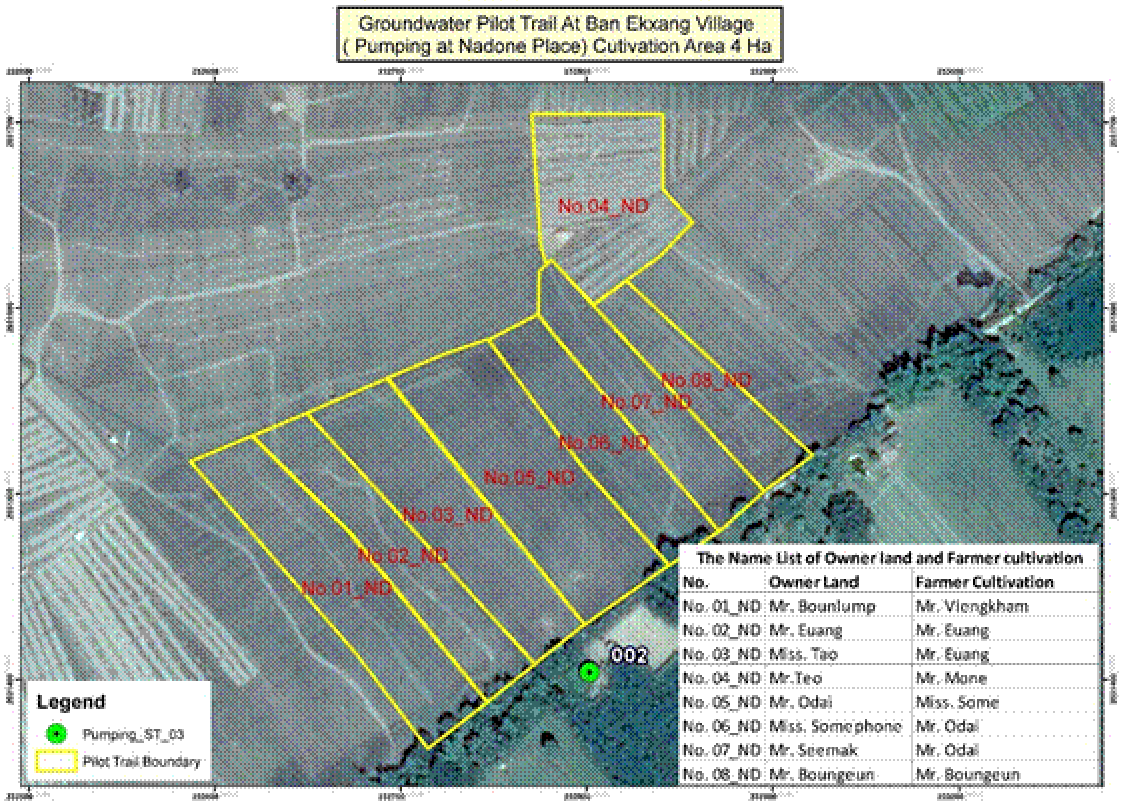
Electricity consumption (in KW)	Electricity price (kip/KW)
0 – 25	345
26 – 150	436
150 and more	979
Agricultural use	769

List of farmers and owners inside the command area at the school site

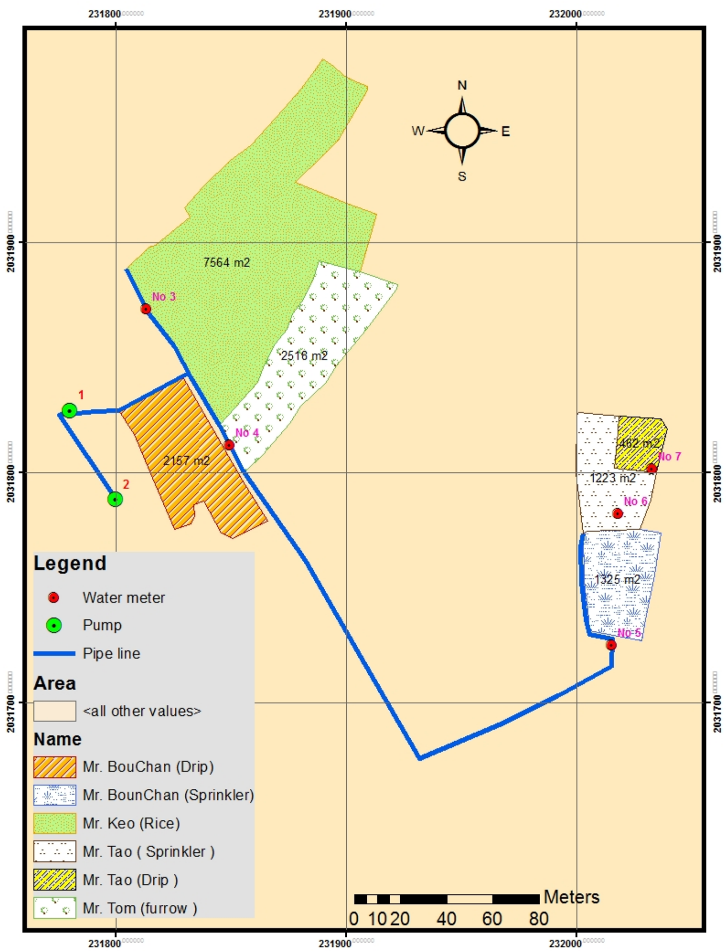
Groundwater Pilot Trail At Ban Ekxang Village
(Pumping at School Place) Cutivation Area 6 Ha



List of farmers and owners inside the command area at the nadon site



Actual growers and irrigated area at the school site (March 2016)



Establishment of the Ekxang groundwater irrigation system: time scale, constraints and accomplishment.

2014

- 6th of June to 30th of August 2014: The Department of Irrigation (DOI) drilled the Wells Numbers 1/14, 2/14 and 3/14 at Ekxang Village, Phonhong District, Vientiane Province, Lao PDR on the.

- 2nd and 3rd of October 2014: DOI and IWMI team carried out a discussion with the local community of Ban Ekxang with the aim to gather information on their perception on the groundwater irrigation trial in the dry-season. Informal discussion to explain the purpose of the trial and to gather their expectations, suggestions and concerns.

2015

- Jan 25 to 15 of February: The distribution system from the tank to the field was installed with the help of DOI staff and villagers. The pipes were laid into small furrows and covered with soil again. A fence around the tank at the school site has been constructed.

- 5th of Febuary: DOI finalised the list of participating farmers and land owners:
    - At the school site 11 farmers will participate (cultivating 12 plots)
    - At the nadon site 6 farmers will cultivate on 8 plots.
- 10th of March: Coordination meeting with members from DOI, IWMI, IGES, and NUOL. Purpose of this meeting:

    - Update on the advancement of the irrigation system construction.
    - Groundwater User Group (GWUG) training.
    - Discuss the research objectives of respective partners and actors.

- 20th of March: Two coordination meetings with DOI and IGES (skype) for the GWUG training preparation and the establishment of the Terms Of References.

- 24st of March: Groundwater User group training was held at Ban Ekxang. Agreement was not found between farmers and partners due to the lack of coordination and of understanding. This training was very important in terms of understanding the context of Lao P.D.R. agricultural development.

- 3rd and 4th April: Opening of the main gate for the first time at the school and nadon site. Under sizing of the system. Un-proper installation of pipes and seal.

- 30th of April: Presentation of the groundwater Irrigation pilot trial made by DOI to the Lao media during the launching of the Climate-Smart Village project in Ban Ekxang.

- 14th of May: Dr Binaya from IGES visited the pilot trial. IWMI and IGES conducted Farmer's interview to understand more precisely farmer's agricultural practices and expectations of the community managed groundwater irrigation trial.

- 17 of May: Coordination meeting with IGES, DOI, IWMI and NUOL. The majors aspects discussed were the completion of the irrigation scheme, the second GWUG training and the ToR of the group.

- 27th to 29th of May: Groundwater User group training organised by the Department of Irrigation and the IWMI/IGES team. Election of the head and deputy of the group. Misunderstanding on the functioning of the group and the irrigation system.

- 23th of June: Meeting with DOI, IGES, IWMI and DAEC. At this training, we all agreed on the upgrade of the pumps' discharge at both sites. Bigger pipes will be installed due to system upgrading. DAEC gave support to DOI on group functioning, irrigation technologies at the plot scale and farmers' engagements.

- 1st of July: Villagers of Ban Ekxang wrote a letter to request the Groundwater project to build a small office.

- 2nd of July: Pumping test was run at the school site during 10 hour at 2 L/s. The little drawdown reveal interesting aquifer properties and suggest that such wells can deliver a sufficient amount of water. This re-enforced the upgrade of the irrigation system.

- 8th of July: Coordination meeting with IWMI, DOI and IGES to discuss and analyses the results from the pumping test and agree on a clear plan for infrastructures upgrade.

- 16th of July: Pump break-down at the school site preventing the success of the project. Coordination meeting with IWMI, DOI and IGES for infrastructures improvement (electricity control box) and pest management.

- 13 August: Coordination meeting between IWMI, DOI and IGES for the nadon site improvement, claim for the infrastructures cost and discuss on the research plan achievement.

- 15th of August: Elaboration of the research plan for the following dry-season.

- 24th of August: Mr Vongsakda start is PhD study in Korea stop activities at the DOI and left the project.

- September: Informal meeting with farmers, DOI and IGES (skype). The generator established in the nadon sites broke down twice.

- 21th of September: Engagement of a field officer involved of the infrastructure completion and in charge of the data collection during the dry-season.

- 5th of October: Coordination meeting with IWMI, IGES and DOI. IWMI team proposed to take a lead on the infrastructures completion with support from DOI.

- 15 to 20 of October: Designing and testing of drip and sprinkler irrigation system at both sites in prevision of the next Groundwater User Group training.

- 31st of October: Replacement of the generator at the nadon. Both sites are ready to use.

- 2nd of November: Presentation of the GW irrigation pilot trial for a ADB Groundwater Management Training.

- 8th of December: Coordination meeting between IWMI and IGES to coordinate project research activities and project outputs.

- Preparation of the third GWUG training with DOI. Objective is to fully understand farmer's plan for the dry-season and make sure they fully understand the system functioning.

- 15th and 16th of December: DOI and IWMI team went to Ban Ekxang in order to target potential interested farmers. After discussion, decision was taken to cover the water fee during the first dry-season. Three farmers engage in joining the trial.

- 22nd of December: First farmer to start running the irrigation system.

2016

- 25th and 26th of January: Groundwater User Group Training organised by DOI, IWMI and IGES. Farmer's received training irrigation practices and group functioning. DAFO and PAFO provided strong support on the project and DAFO experts trained farmers on good agricultural practices (organic fertilization and pesticides).

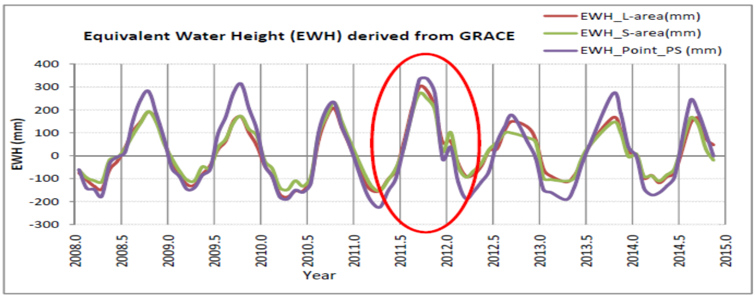
11.3 Synopsis of postgraduate studies conducted by Lao students

1. PhD Study by Mr Sinxay Vongphachanh, John Allwright Fellowship recipient, University Technology Sydney (2015 to 2018):

Seasonal Variations in Surface Water and Groundwater Interactions for Assessing Sustainable Water Use in Southern Lao PDR

Biophysical research activities presented in Section 7 relating to water quantity have largely considered only individual components of the hydrologic cycle. This study takes the analysis further to arrive at a stronger understanding of the interactions between these components. It aims to achieve broad understanding of the dynamics of surface water and groundwater interactions, both spatially and temporally, in Sukhuma district and later scaled-up throughout southern Lao PDR. Multiple techniques are to be applied including the use of stable isotopes (hydrogen and oxygen-18) and other water chemical parameters, hydrographic (baseflow) separation, hydraulic head mapping, application of GRACE data, and water balance analysis.

A preliminary analysis of data from the Gravity Recovery and Climate Experiment (GRACE) satellite reveals that the estimates of total water storage across southern Lao PDR correlate strongly with flows in the Mekong River and the Khamouan River, the major tributary in Sukhuma (Fig. A1). GRACE data appears to be well suited to estimating the total groundwater storage, surface water storage and soil moisture in southern Lao PDR, however some obstacles need to be overcome, such as quality of data and selecting appropriate techniques for data analysis.



(a)

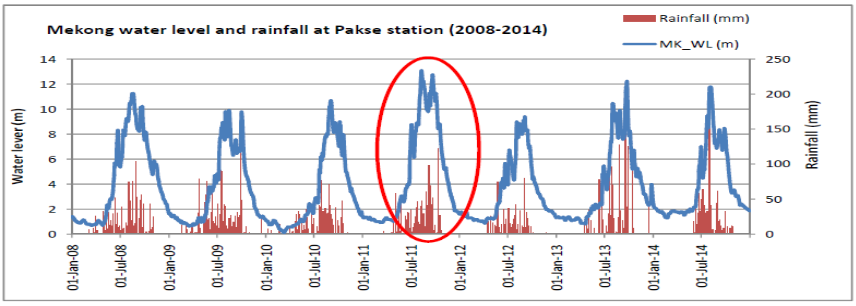


Figure A1. A comparison of the GRACE derived total water storage (expressed as EWH) and Mekong (MK) water level (WL) and rainfall at Pakse station over the period from 2008-2014 (from Vongphachanh and Milne-Home, 2015)

2. Masters Study by Mr Khamkieo Phommavong, NUOL Faculty of Engineering, (2014 to 2015) and extended through an IWMI research internship (October 2015 to September 2016):

Assessment of Groundwater Resources and Water Balance to Support Sustainable Development of Khiat Ngong Village, Pathoumphone District, Champasak Province, Lao PDR

Groundwater resources are critically vital for rural communities in southern Lao PDR as this often represents the sole source of water supply. With extremely limited knowledge on the extent, accessibility and sustainability of groundwater resources in the area, this study offers a valuable case study at a local context. Khiat Ngong village, located in Pathoumphone district, Champasak province, is a typically small (population 1,123) village situated on lowland plains, was chosen for study. The local community derive their livelihoods from farming and other small enterprises (tourism, trade etc.). As the village is remote from major rivers it relies entirely upon groundwater for domestic supplies.

Fieldwork was carried out in the village on 3 occasions between September 2014 and May 2015. For new boreholes were drilled to depths of 25 m and pump tested; groundwater levels and flow direction was determined; groundwater use estimated from household level surveys and groundwater and rainwater quality analysed.

Drilling and core sampling reveal a two layer aquifer systems comprised of Tertiary basalt lava overlaying Mesozoic sandstone throughout the area. Groundwater flow patterns are highly seasonal and a cone of depression emerges in the dry season as a result of intensive use (Fig. A2). Groundwater use for domestic supply is 19 L/capita/day, or about 7,800 m^3/yr for the village as a whole. There is minimal use of groundwater for irrigating crops at the garden scale, as most households do not have sufficient quantities of water in the latter part of the dry season. Limited sampling confirms the presence of geogenic arsenic contamination given that with 2 out of 6 sampled wells exceeding the national standard of 0.05 mg/L. Field observations reveal skin disease which is probably linked to domestic water use suggesting possible human health impacts for the local community.

Mean annual recharge is estimated by the steady-state Chloride Mass Balance method to be 753 mm/yr (~30% of mean rainfall) or 18,800x10^3 m^3/yr for the entire 25 km^2 village area. Groundwater use in the village is estimated to be around <0.1% of annual recharge. This implies that seasonal groundwater scarcity in the village in due to the restricted groundwater access (due to shallow well depths), more so than availability.

During the research internship phase of the project, the study area is being expanded to a watershed level, taking in the Beung Khiat Ngong, a Ramsar listed wetland situated adjacent to the village of high significance (IUCN, 2012). This watershed approach will more clearly identify key groundwater flow patterns and chemical trends in the area. The study ultimately seeks to promote sustainable management of the aquifer accounting for the needs of the community and the environment.

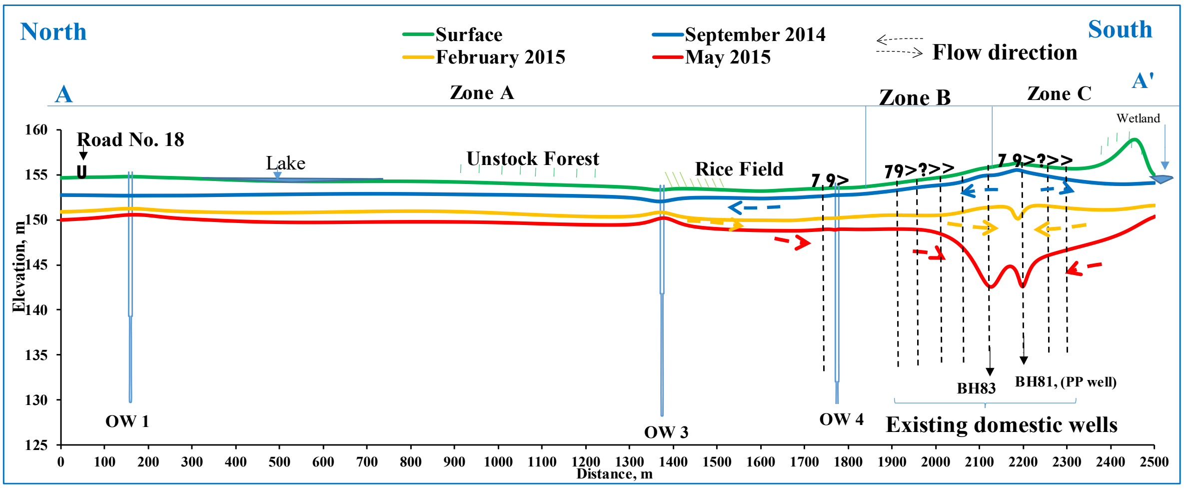


Figure A2. Seasonal groundwater flow pattern changes across Khiat Ngong village between September 2014 and May 2015 (from Phommavong, 2015)

3. Masters Study by Ms Phaylin Bouakeo, NUOL Faculty of Engineering, (2014 to 2015) and recipient of the "IWMI Capacity Strengthening Programme for National Researchers" Scholarship:

Estimation of Rainfall- Runoff and Ground Water Recharge in the Xebanghieng River Basin By Using Soil Conservation Service (SCS) and Base Flow Separation Methods

The Xe Bang Hieng (XBH) River basin is located in central of Lao PDR. The river basin has a total area of 19,400 km^2. The mean annual rainfall is 1,600 mm (at Kengdon) and the mean annual runoff is 875 mm at Kengdon (DMH, 2005). In the dry season of 1996 21,038 ha of rice field were affected by flood and 14,468 ha by droughts at Savannakhet province. In the wet season of 1996 21,038 ha of rain-fed rice fields damaged (WREA, 2009). The XBH river basin is challenge for flood and drought management every year. The objectives of this study are to: 1) estimate rainfall-runoff in gauged in the XBH river basin; 2. analyse statistics of flow data for determining flood-low flow with different return period in the XBH river basin; and 3) estimate groundwater recharge by using base flow separation in the XBH river basin.

Mekong River Commission (MRC) applied the SWAT model to analysis water resources in Lower Mekong River countries. The SWAT model uses SCS method to analysis runoff and this method is a good analysis runoff for the small scale river basin and land use change. Base flow separation is a base method for estimation groundwater recharge by use discharge data. Additionally, SCS and base flow separation are the basic methods for estimating rainfall-runoff and groundwater recharge.

The methodology included three steps such as: step 1: Collection data are literature review, review data, identified data need, collected data from DMH, CRU and Aphrodite, checking data available and field visit; step 2: Data processing data are use double mass curve to check the consistency, use runoff coefficient to analysis on rainfall-runoff and compare result from rainfall data of DMH, CRU and Aphrodit and; step 3: Data analysis are apply GIS to analysis land use and soil type, calculate rainfall direct runoff by using SCS method, analysis statistical flow data by Log-Pearson Type III or Extreme Volume method use and; apply base flow separation to estimated groundwater recharge

The result and analysis of each sub-river basins which annual rainfall 1990-2004 is 1,523 mm; an average runoff is 1,740 mm; an average annual accumulation direction runoff between land use (1997 and 2003) 4,746 mm or 1,310 m^3/s. An average maximum discharge is 14,899 mm or 4,111 m^3/s or 26,067 mm and average annual minimum discharge is 5 m^3/s or 123 mm. Analysis horological is flood frequency every 5 years and big flood every 10 years as well as low flow is every year and high low flow is every 10 years.

Moreover, an average base flow is 38 m^3/s and an average groundwater recharge is 26 m^3/s. The minimum groundwater recharge is 19 m^3/s at Plalan and the maximum groundwater recharge is 37 m^3/s.

The results of this study at the Kengdon station show the difference in the water balance study of DMH version 2007. This study is near the results of water balance study of DMH version 2005.

The recommendation of this study proposes improving processes of data collection, equipment and data management; improve land use data; Log-Pearson Type III or Extreme Volume is a good. This method is not suitable for low flow and; estimate groundwater recharge requires the use of modeling.

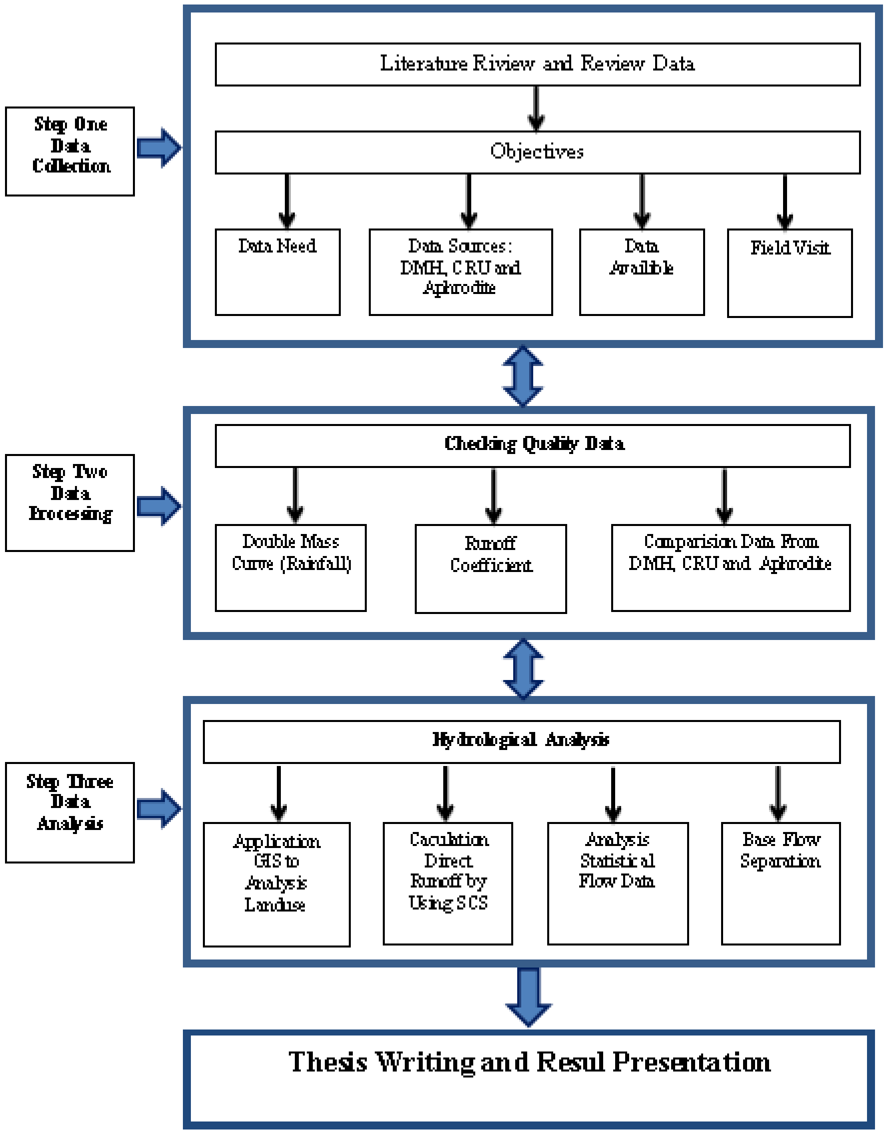


Figure A3. Framework used in the study (from Bouakeo, 2015)