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**INTERNATIONAL TECHNICAL  
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# **National Hydrology Data Assessment Lao People's Democratic Republic**

## **Final Report and Recommendations**

**August 2017**



Prepared for: The Ministry of Natural Resources and Environment and the  
Ministry of Energy and Mines  
Lao People's Democratic Republic

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## Acronym List

ADCP	Acoustic Doppler Current Profiler
DOI	United States Department of the Interior
DOI-ITAP	DOI International Technical Assistance Program
HYCOS	Hydrologic Cycle Observing System
HYMOS	Hydrologic Modeling System: an information system for storage, processing and presentation of hydrological and environmental data.
LMB	Lower Mekong River Basin
MEM	Ministry of Energy and Mines (Lao PDR)
MoNRE	Ministry of Natural Resources and Environment (Lao PDR)
MRC	Mekong River Commission, Vientiane
NUOL	National University of Laos, Vientiane
O & M	Operations and Maintenance
QA/QC	Quality assurance/quality control
SERVIR	Sistema Regional de Visualización y Monitoreo de MesoAmerica: a joint venture between NASA and USAID, which provides satellite-based Earth observation data and science applications for developing nations to improve their environmental decision making.
SIM	Smart Infrastructure for the Mekong Program, DOI-ITAP
SOP	Standard Operating Procedures
USAID	United States Agency for International Development

## Introduction

This report was prepared by the United States Department of the Interior - International Technical Assistance Program (DOI-ITAP) under the framework of the Smart Infrastructure for the Mekong (SIM) project, a U.S. Government interagency program supported by the United States Agency for International Development (USAID). The SIM overarching objective is to promote sound social and environmental safeguards relative to the development and operation of hydropower related infrastructure and other land use projects that may impact the general Mekong River environment. DOI-ITAP developed this report in response to a request from the Lao People's Democratic Republic (PDR's) Ministry of Natural Resources and Environment (MoNRE) and Ministry of Energy and Mines (MEM), to evaluate the current state of hydrologic data collection on the Mekong River and its tributaries. The Lao PDR recognizes the importance of high quality, real time hydrologic data in support of public safety (e.g., flood forecasting), environmental quality, and sustainable hydropower development. Additionally, the Lao PDR Ministries recognize the need to develop a system to better coordinate data sharing to minimize downstream impacts of changes in hydrology and water quality.

This document includes a description of the project purposes and goals, description of the study area, a project framework including a description of assessments, and a list of recommendations.

## Project Purpose

The purpose of this project is to provide technical support to the Lao PDR's MoNRE and MEM agencies. The effort includes the following goals: evaluate Lao PDR hydrologic data collection equipment and networks, and to a lesser extent, climate data collection networks; evaluate data quality control, data management, and data analyses processes; evaluate training and capacity building; and provide opportunities for the MoNRE and MEM to better accomplish their mission in the Mekong River Valley.

## Project Team (DOI-ITAP)

Participants in this effort consisted of personnel with expertise in hydrology, hydrologic data collection networks and systems, and hydrologic applications. The team consisted of four Department of Interior personnel from both active and retired ranks.

- Tim Mayer Ph.D., Hydrologist, U.S. Fish and Wildlife Service
- Molly Wood M.S., P.E., Hydrologist, U.S. Geological Survey Office of Surface Water
- Thomas Bellinger D.M., P.H., Hydrologist, U.S. Bureau of Reclamation (retired)
- Michael Roy Ph.D., DOI-ITAP Smart Infrastructure for the Mekong Program

## Project Structure

To accomplish project goals, the team traveled to Lao PDR on May 10-23, 2017. The project framework consisted of four phases and related tasks:

### 1. Literature review

- a. Conduct an assessment of the Mekong River system (including review of selected reports from previous DOI-ITAP assessments in the lower Mekong River countries)
- b. Conduct an assessment of existing hydrologic and climate data collection systems

### 2. Field evaluation

- a. Conduct interviews and field visits with MoNRE and MEM Central Office managers and staff
- b. Conduct interviews and field visits with MoNRE managers and staff in the Luang Prabang, Xayaburi (including a site visit to Xayaburi Dam), and Pakse Provincial Offices
- c. Conduct an interview with the Mekong River Commission

### 3. Assessment of Ministry capabilities and needs

- a. Conduct an assessment of the function of hydrologic and climate data networks and stations
- b. Conduct an assessment of staff skills and training
- c. Conduct an assessment of data sharing and interoffice communication
- d. Conduct and assessment of office and equipment conditions

### 4. Reporting and Deliverables

- a. Develop a trip report for DOI-ITAP
- b. Provide an assessment report summarizing findings and recommendations

- c. Conduct a return trip to Lao PDR to present assessment report, discuss findings, and provide training on selected topics

## Description of Project Study Area

The Mekong River basin is recognized as one of the great rivers of the world. Due to its importance, many publications include detailed descriptions of the area under study. Detailed overviews of the hydrology, physiography, geology, and climate for the entire river basin are provided by USDOI-ITAP (2015) and Rainboth et al. (2012). Due to the abundance of information from these sources, this section of this document will provide only an overview of the Mekong Basin with some emphasis on the reach running through Lao PDR and areas downstream that may benefit from this project.

The Mekong River is approximately 4,909 km long, making it the seventh longest river in Asia and twelfth longest river in the world (Jacobs et al., 2016). The upper 2,198 km of the river flows through China (known there as the Lancang River) while the lower river (2,711 km) passes through Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam. The lower river is typically referred to as the lower Mekong basin (LMB) (Figure 1) (USDOI-ITAP, 2015).

The drainage area of the Mekong basin is approximately 810,000 km<sup>2</sup>. The basin is ranked as being the tenth or twelfth largest river in the world based on its annual freshwater discharge (470 km<sup>3</sup>/year; note: information sources vary due to some authors assigning certain tributary rivers separate ranks). In terms of sediment discharge (160 × 10<sup>6</sup> metric tons/year) the Mekong is commonly ranked ninth among the world's largest rivers (USDOI-ITAP, 2015).

In Lao PDR, the river is divided into a northern mountainous reach (upstream of Xayaburi Dam - Figure 2) and southern lowlands (Vientiane to Pakse), where the hydrologic character of the river varies extensively due to complex physiography and the varied contribution of major and minor tributaries. Two of the most notable features of the lowermost region of the LMB are the Tonle Sap Great Lake and its connection to the Mekong River via the Tonle Sap River in the Cambodian floodplain (where flow is observed to be seasonally bi-directional), and the extensive Mekong Delta at the river's terminus in southern Vietnam (USDOI-ITAP, 2015). Though these features were not a component of this study, they are directly affected by natural events and human activity upstream. This emphasizes the need for a robust hydrologic and climate data collection system that provides quality data for evaluation of the river's dynamic hydrology for use in planning (analysis and modeling), public safety (flood early warning), and environmental concerns.

At the time of the DOI-ITAP Team's assessment, eleven dams are planned on the mainstem LMB. Two dams are currently under construction along the mainstem of the Mekong River in

Lao PDR (Figure 2). Several dams exist, are under construction, or are planned upstream, in China, as well as downstream, in Cambodia (Figure 2). These dams, when constructed, have the potential to dramatically change the hydrology, ecology, and sediment transport characteristics of the Mekong River. Anticipating and mitigating impacts will require data from a coordinated, well-run network of hydrologic monitoring stations.

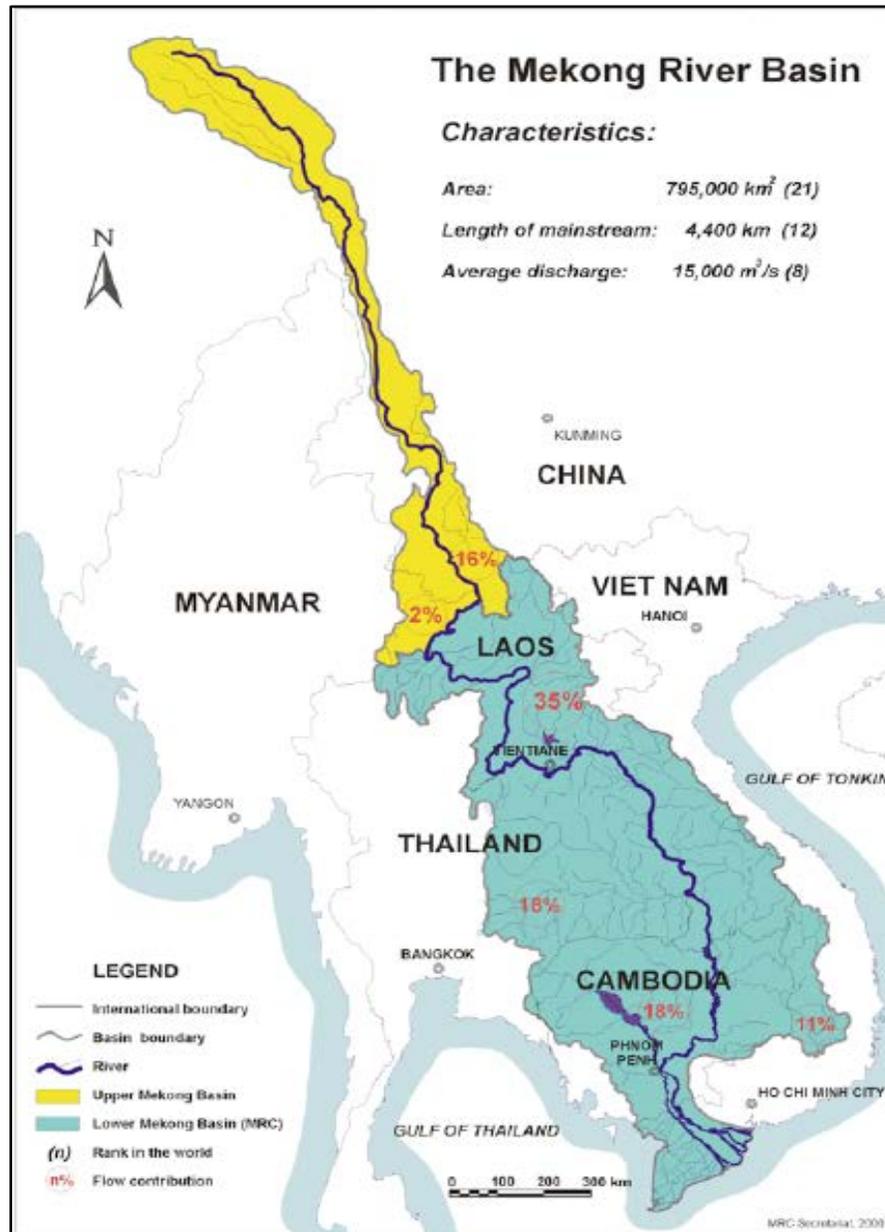


Figure 1. Mekong River and contributing drainage areas (from MRC, 2000).



Figure 2. Proposed and existing dams on the mainstem Mekong River (from Ziegler et al., 2013). Note: Dan Sahong dam in southern Lao PDR is now under construction.

## Project Framework

This effort consisted of three major project phases and components listed earlier. This section will provide a detailed description of each phase.

### Phase 1: Literature Review

The literature review phase of this effort consisted of assessing the Mekong River system and the existing hydrologic and climate data collection systems.

#### a. Assessment of the Mekong River system

The first task of this phase was to gain an understanding of the Mekong River drainage through a review of available literature. This involved an evaluation of the mainstem and tributary hydrologic characteristics including contributing drainage areas, climate characteristics, flooding concerns, sediment transport mechanisms, environmental issues, land use and development trends and plans, and the current and future state of hydropower development. Several technical reports were reviewed that provided much of the needed background information.

#### b. Assessment of the existing hydrologic and climate data collection systems

The second task of this phase consisted of gaining an understanding of the hydrological and to a lesser degree, climatic data collection systems within the Lao PDR reach of the Mekong River. This involved a literature review focusing on the history, existing status, and future plans for these systems. Specific information sought during this phase included the location of existing hydrologic and climate stations (including those in Figure 3), types of data collected, equipment used, data collection management (frequency of data collection for each parameter), data formatting and distribution processes, quality control, station management procedures, and data uses. The available literature, however, was limited, thus thorough evaluation of these systems was not possible. As a result, a field evaluation of the data collection systems was required.

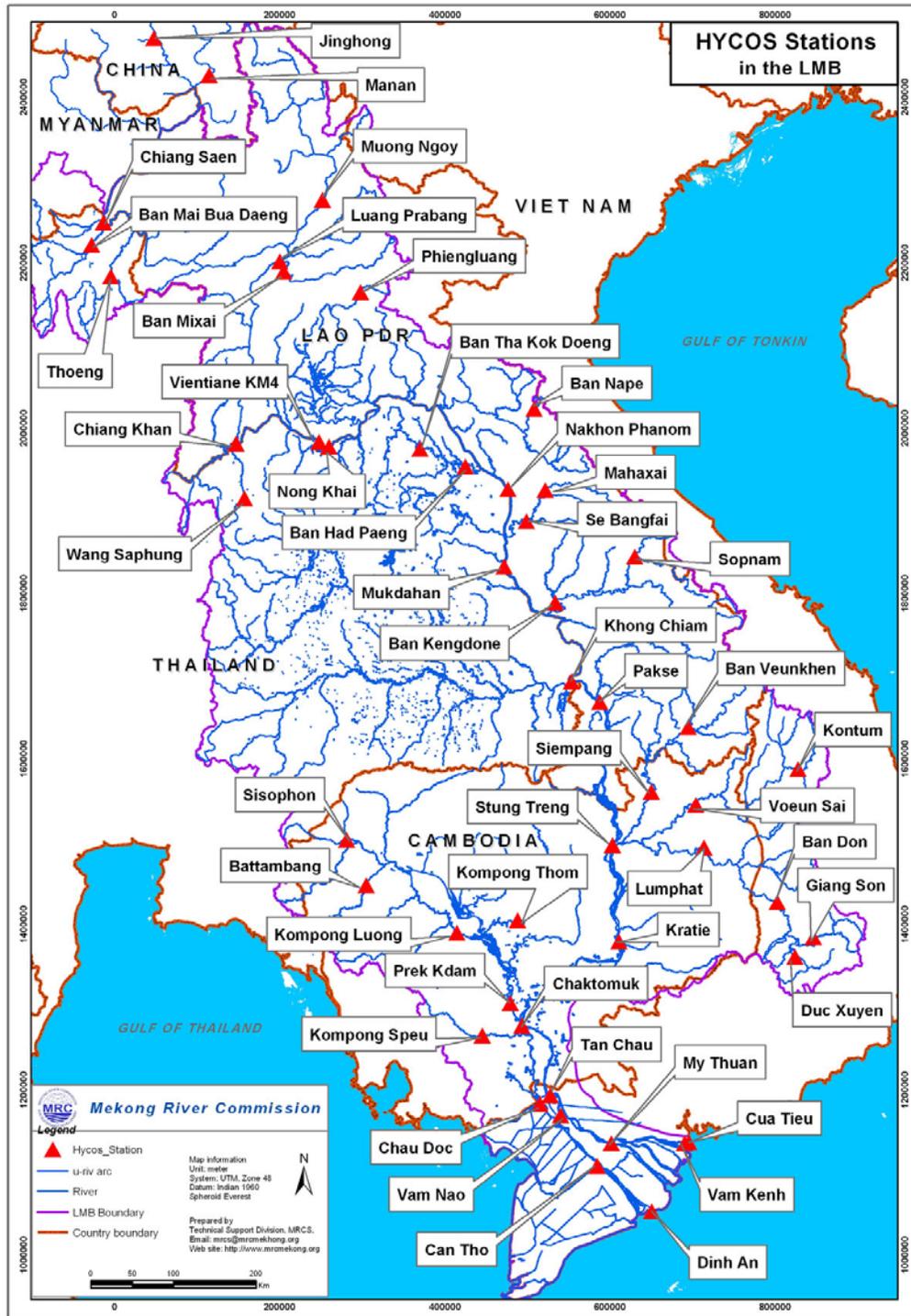


Figure 3. Map of lower Mekong River showing Hydrological Cycle Observing System (HYCOS) monitoring stations (from MRC, 2017)

## **Phase 2: Field Evaluation**

This phase required the DOI-ITAP team to travel to several MoNRE offices including the Central Office in Vientiane and the Provincial offices in Luang Prabang, Xayaburi, and Pakse. A visit was also scheduled with the Chief Hydrologist of the MRC in Vientiane to provide additional perspective. Details of these meetings are summarized in Appendices 1 and 2.

## **Phase 3: Assessment of Ministry Capabilities and Needs**

This phase focused on an assessment of the functionality of the hydrologic data collection system, staff skill levels, communication/data sharing capabilities, and field equipment functionality. The team faced a number of challenges under this phase with regard to meeting the originally defined purpose of the trip, including scheduling conflicts with agency and hydropower company representatives; language and communication barriers; and limited opportunity to observe field practices and functioning equipment. The assessment and subsequent recommendations are based on the DOI-ITAP team's best understanding of the needs and capabilities of the Ministries.

### **a. Assessment of the function of hydrologic and climate data networks**

MoNRE officials and staff expressed several common themes related to the condition and capabilities of the hydrologic and climate data networks. Overall, the staff expressed concerns regarding poor equipment condition, funding, training adequacy, and communication capabilities.

The existing hydrologic monitoring network and equipment was originally established, funded, and maintained by the MRC through the Appropriate Hydrological Network Improvement Project (AHNIP) and Hydrological Cycle Observing System (HYCOS) monitoring efforts. As outlined in several agreements, the expectation of the MRC was that after 2015, the Lao PDR, as well as the other downstream Mekong countries, would take over funding, operation, and maintenance of the monitoring network. While this transfer of responsibilities has occurred in the other countries, it has been inadequately implemented in Lao PDR. Most of the hydrologic stations have fallen into disrepair, and very few independent flow measurements are being collected at the sites. Automated recording equipment is currently non-functional at many

sites. Manual water level readings are made at these stations, once or twice per day and typically by observers, from sloping staff gages. Where discharge rating curves have been developed, they are noted to be in need of update due to the lack of independent flow measurements and/or changing channel conditions. Recent streamflow estimates at many sites are suspect because of this.

It is not entirely clear to the DOI-ITAP team why the transfer of responsibilities was not as successful in Lao PDR. MoNRE management and staff imply that the lack of continued MRC funding is mainly responsible, although it was made clear in agreements that the funding was going to end in 2015. MRC representatives view the main challenge as a lack of financial support and technical capacity within the ministries and the Lao PDR government. Either way, MoNRE seems to have been inadequately prepared for the end of the MRC funding in 2015.

MRC's current plan is to fully fund the monitoring in the Lao PDR for an additional year, and then incrementally reduce that funding over the next four years as Lao PDR takes over responsibility for the network. The MRC funding will be used to rehabilitate all existing gages and also add more mainstem gages. MoNRE and the Lao PDR government need to have a plan for autonomous financial support and technical capacity required to maintain the network after this additional funding ends.

The MRC considers the existing mainstem hydrologic network, if it were operational, adequate for purposes of mainstem operations including assessment of sediment, flow, flood conditions, and hydropower operations. However, MoNRE staff stated that there are still gaps in the network that should be addressed - especially in the eastern (near the Vietnam border) and northern mainstem reaches in Lao, and along the western reaches of the river that border Thailand. If stations are added to the existing network, there is concern as to whether MoNRE has the funding and capacity to maintain them.

Software packages used for data analysis and quality evaluation, storage and reporting include Hymet, Hydras3, and FileZila. For analyzing historical data, the primary platforms used are Excel and HYMOS. HYMOS is used for data analysis, storage and reporting, but recently Ministry's HYMOS license expired. Until the license is renewed, MoNRE cannot use HYMOS. The MRC says that licenses are considered to be inexpensive for individual countries but MoNRE representatives implied that the cost was still an impediment. The data workflow process consists of data checking and input to an Excel or HYMOS database (currently

unavailable). When discharge measurements are made, data are transmitted to Division of Meteorology and Hydrology (in MoNRE) for discharge rating development, final quality checking, and final input to the appropriate database.

MoNRE staff expressed the need for equipment rehabilitation and an improved ongoing maintenance plan for all existing automated stations. Requested equipment included current meters for discharge measurements, echo sounding equipment for bathymetric surveys, and additional sloping staff gage plates for manual water level measurements. MoNRE expressed a desire for an Acoustic Doppler Current Profiler (ADCP) system and an associated laptop for the Pakse, Savannakhet and Thakhet offices. It was noted that only one ADCP exists (at the Luang Prabang office) which was provided by MRC. Updated laptop and desktop PC computers and GPS equipment also are needed for each provincial office.

The DOI-ITAP team concluded that MoNRE staff needs to be provided with more than just equipment. They must be trained in how to use that equipment as well as receive ongoing “refresher” instruction. MRC representatives noted some problems and inconsistencies with the discharge measurements collected by MoNRE (through 2015). Measurements were not always documented adequately and standard procedures were not always followed. This points to some additional training needs for field technicians and better communication between MoNRE and MRC. MRC required discharge measurements four times per month during the wet season and two times per month during the dry season. It’s possible that if the quality of measurements could be improved, the frequency of measurements could be reduced.

MoNRE expressed a need for better communication and data sharing among its provincial and district (field) offices. Communication infrastructure such as additional mobile phones for field observers, improved Internet access, and a central communication facility are listed as a priority. A simple system such as a cell phone reporting network for MoNRE field observers would enhance the Ministry’s flood early warning and monitoring efforts.

Communication between MoNRE and MRC on flood forecasts and flood events could be improved as well. MRC expressed a desire to get more feedback on flood events in Lao PDR. Both MRC and MoNRE issue flood forecasts for Lao PDR, based data and modeling obtained from the Hydrologic Research Center in the U.S. (such as satellite-derived precipitation), but by law, only MoNRE is allowed to issue flood warnings. MRC tries to evaluate the accuracy of their forecasts by tracking flood events as they happen. However, they have limited information with

which to do this, mainly relying on newspaper articles when they appear. MRC states that information on actual floods, including locations and photographs, and subjective assessments of flood severity and flood damage, would be very useful to them. Simple maps showing the distribution of floods on an annual basis would be helpful as well. This kind of information would be fairly easy to compile and would be very useful to MRC. It would also be useful to MoNRE in evaluating the value and adequacy of their flood forecasts and hydro-meteorological network.

In addition to hydrologic monitoring, MoNRE supports a network of meteorological (climate) stations, mainly located near commercial airports. Each station consists of a suite of data collection instruments (precipitation, multi-level wind, solar input, soil temperature, cloud cover, etc.). These stations, which were funded and installed by Japan, generally serve their purpose for aircraft operations and are maintained as a priority due to international civil aviation requirements. Staff and management from the Central and Provincial offices noted that while the climate network is adequate for aviation purposes, additional precipitation stations across the Mekong Valley are desired, to enhance flood early warning capability. It was noted that several manually-read precipitation stations exist across the Mekong drainage, but the capability of this network to provide early warning for floods on tributaries may not be adequate according to MoNRE staff.

### **b. Assessment of staff skills and training**

Each provincial office noted that training was a high priority need for both professional and technical staff. Though trained hydrologists are stationed in each office, technical staff personnel have not received adequate training to optimize operation of the network. Technical staff expressed the desire to receive training on station maintenance and troubleshooting, data collection techniques, and basic analytical techniques. Lack of funding and training opportunities (including informal and formal mentoring programs) has prevented staff skill set development. In addition, there are few trained and degreed hydrologists and meteorologists to perform training.

MoNRE staff expressed a desire for more training opportunities for in-house staff capacity development. The possibility of DOI-ITAP providing training was discussed, especially in the form of a “train the trainer” program. A consideration for any training effort should have the

goal of providing MoNRE with the capability of developing their own in-house training and mentoring program that will ensure consistent and appropriate staff-skill development on a regular, recurring basis.

Training programs should be developed in the form of standardized techniques. Currently, MoNRE staff training standardization is formalized within the Ministry Standard Operating Procedures (SOPs). SOP documentation however, is likely in need of updating. For example, operation and maintenance (O&M) techniques for the Mekong HYCOS system were based on common methods originally developed from the former Soviet Union. Therefore, Ministry SOPs should be reviewed and revised with regard to the current technologies being used.

### **c. Assessment of data sharing and interoffice communication**

The DOI-ITAP team discussed the current system of data sharing and interoffice communication with MoNRE staff. Voice/data transmission, work and administrative information flow, and data sharing among MoNRE offices and other entities (MEM, hydropower companies, and neighboring nations) were discussed.

To date, there is limited support from the Lao PDR government for purchase of new or repair of existing cellular modems used for real-time data transmission at hydrologic stations. Additionally, not all field observers have cell phones or access to a reliable cell network to be able to transmit water level information to Ministry offices in real time, rendering the nation's early warning flood system as impaired.

Communication by voice is often done by telephone and email; however, a common issue among the provincial offices is the lack of a reliable Internet connection as well as the lack of laptop or desktop computers. This limits both technical and administrative communication capability.

Communication between MoNRE and MEM appears limited, though personnel from both Ministries did interact during the DOI-ITAP team's visit. MEM does not currently directly operate any hydrologic or climate monitoring stations but instead serves as a liaison between hydropower companies and MoNRE. MEM requires that hydropower companies provide them with any hydrologic data collected, as part of contractual agreements established during dam

construction. MEM states that they intend to share the data with MoNRE at a regular interval (e.g., monthly), though it is unclear to the DOI-ITAP team whether this will occur given the current state of limited communication between MEM and MoNRE.

Communication between the hydropower companies and Lao PDR Ministries (both MoNRE and MEM) also appears limited, beyond the initial interaction between MEM and the hydropower companies when signing the contractual agreements. It is clear to the DOI-ITAP team that the hydropower companies do not wish to rely on MoNRE for the collection of hydrologic data and do not see the value in sharing information with MoNRE. At Xayaburi Dam, a Thai employee of the hydropower company stated that operating their own hydrologic monitoring stations was “much better” than relying on the MoNRE monitoring network because they had direct control over their operation and reliability. However, data collection methods appear to differ between the hydropower companies and MoNRE, which could make data comparisons difficult if the datasets are shared among Ministries. For example, MRC states that sediment and water quality samples collected by the hydropower companies are often a grab sample collected near the water surface, not a depth-integrated sample as is collected by some MoNRE Provincial offices when funding is available. Grab samples collected near the water surface and analyzed for sediment and particulate-associated water quality parameters often substantially underestimate the total cross-section concentrations of these constituents and would not be directly comparable to a depth-integrated sample dataset.

Communication between the Lao PDR Ministries and neighboring nations also appears limited, though the DOI-ITAP team did not have an opportunity to explore these interactions in depth. MoNRE and MEM receive no information or data from upstream hydrologic and climate monitoring stations in China; however, they do apparently have access to Chinese satellite data because China funds many of the hydropower development projects. Hydrologic forecasting in Lao PDR may be improved through use of remotely-sensed data (rainfall, water levels) in the upper Mekong basin. MoNRE states that they have some interaction with Thailand and Cambodia when sharing hydrologic data through the MRC HydMET database, though data sharing from Lao PDR to neighboring countries is not done in “real time” because none of the automatic data transmission equipment is working as expected. Joint data collection efforts, such as discharge measurements, at some of the mainstem Mekong hydrologic stations on the borders with neighboring countries appear fraught with bureaucratic challenges. For example, if MoNRE wishes to participate in discharge measurements at the hydrologic monitoring station on the border with Thailand upstream from Pakse, they must make advance arrangements with

the militaries in both countries. Additionally, MoNRE seems reluctant to compare data collection methods with the Thai Ministry. These issues limit MoNRE's ability to measure during extreme events and to increase data quality through interaction and skill sharing with neighboring countries.

Finally, direct communication between the Ministries and MRC is prohibited by law, according to MRC representatives. MRC and the Ministries can only communicate through the Laos Coordination Team. This limitation is very inefficient and probably hurts the hydrologic monitoring effort in Laos. MRC has a lot of information and technical expertise and it would seem that direct communication between the Ministries and MRC would be very beneficial.

#### **d. Assessment of office and equipment conditions**

Several MoNRE offices are in need of upgrade and repair. The Xayaburi, Luang Prabang, and Pakse Provincial offices staff expressed a need for improved office space and field equipment storage. Issues with offices include inadequate computer equipment, Internet connectivity, and field equipment storage.

A common issue among MoNRE offices is lack of operable field equipment. Automated hydrologic stations are essentially nonfunctional and unable to transmit data. Staff gages (manual readings) installed at many stations are in disrepair, resulting in suspect data quality. Several MoNRE staff noted the need to replace vertical staff gages with sloping staff gages and to repair existing sloping staff gages in some locations.

There appear to be no operational watercraft currently owned by MoNRE. The boat owned by the Provincial Office in Pakse requires a new motor. The DOI-ITAP team is unsure whether the boat used by the Luang Prabang Provincial Office is owned or rented; however, it is not being used. MoNRE is sometimes dependent upon renting boats from local residents, an activity that has been discontinued due to lack of funding for fuel.

MoNRE appears to lack an adequate fleet of land vehicles to transport staff to data collection stations. Vehicles are in disrepair, and MoNRE lacks funding for fuel. As a result, Provincial and District offices depend on contracted field observers to collect and transmit a majority of its

data. Field observers also seem difficult to recruit. Contract pay is low, reportedly 160,000 kip per month or approximately 20 US dollars. In contrast, a Chinese hydropower development company in the Pakse area is reportedly paying observers 600,000 kip per month (just over 70 US dollars) for the same job at their hydrologic stations. Therefore, funding is needed for more effective recruitment, training, and communication capability with contracted field observers where needed. However, dependence on observers may be lessened if real time transmission equipment (cell modems) is repaired and maintained long term.

Overall, MoNRE staff state that without adequate and consistent funding and support from the government or other entities, they are limited in their ability to collect field data, maintain and transmit hydrologic and climate stations, train or directly communicate with field observers, and travel for training or meetings. The DOI-ITAP team believes there are opportunities for MoNRE and MEM to take ownership of their networks, build a consistent base of funding for supporting operation and maintenance of their stations, and support a sustainable, trained workforce. These opportunities are proposed in the following section.

## Recommendations

As a result of field interviews and questionnaire responses, the DOI-ITAP team found that the major issues that hinder MoNRE are lack of funding, a coordinated and ongoing training program, and a decisive plan to take ownership of and optimize their monitoring networks. Funding is inadequate for maintaining and correcting existing data collection equipment, primarily for the hydrologic data collection network. Funding and support also are inadequate to train technical staff and to keep professional level staff up to date with current technology. Additionally, MoNRE staff's ability to successfully operate the network suffers from a lack of ongoing training, mentoring, a standard QA/QC program, and workforce planning. Support for basic needs such as adequate office space and technology, watercraft, land vehicles, and communication support also is lacking. Based on these findings, several recommendations are provided. Recommendations are organized into five categories: Function of hydrologic and climate data networks; staff skills and training; data sharing, data management, and interoffice communication; office and equipment conditions; and research opportunities.

### Function of Hydrologic and Climate Data Networks

- MoNRE should evaluate the need for enhancement of the existing monitoring climate and hydrologic station network on the Mekong mainstem and tributaries. This need must be balanced against the added funding and support required to maintain additional hydrologic stations. While several national services have reportedly recommended expanding the monitoring network (MRC, 2012), the DOI-ITAP team believes the first and highest priority should be to ensure that existing stations in Lao PDR are properly equipped and functioning adequately.
- MoNRE should investigate new sources of funding to support operation of the hydrologic network. One possibility is to secure funding from hydropower companies to cover operation and maintenance of the existing water monitoring network. Hopefully, additional funding would improve the quality of the data, which would benefit both the Lao PDR government and the hydropower companies. MoNRE could also charge the hydropower companies more for sharing existing datasets. Reportedly, these data are sold to private companies quite cheaply now. Cost increases would be

justifiable if the data quality is improved. Additional funding could provide substantial support for equipment repairs, discharge measurements, travel and site visits to stations, and other basic operational tasks.

- MEM should consider writing into their contractual agreements with hydropower companies that a comparison measurement and QA/QC program should be established between the hydropower company and MoNRE. These programs are routinely established at hydropower facilities in the U.S. and involve biannual comparison discharge measurements made concurrently at a hydrologic station and sharing and QA/QC of datasets collected by the hydropower company. Such a program builds capacity among staff, enhances communication, ensures data quality, and promotes transparency in data collection. Implementing this program might ultimately eliminate the need to install dual, redundant hydrologic stations at the same site.
- MoNRE should seek funding to restore use of HYMOS and other appropriate software licenses and provide a mechanism to maintain license currency.
- MoNRE should consider establishing closer relationships with and allow field staff to directly communicate with equipment vendors and technical representatives (particularly with Ott Hydromet (current contact: Caleb Aw, Ott Business Development Manager in Singapore (c.aw@ott.com), CNR, and Teledyne RD Instruments) to enable more efficient equipment troubleshooting and maintenance.
- MoNRE should consider installing low cost, recording submersible pressure transducers (such as Onset HOB0<sup>®1</sup> water level logger or In-Situ Aqua Troll<sup>®1</sup> (Figure 2) or non-recording, passive (such as crest stage gages as illustrated in Figures 3-4) water level sensors in various areas to fill in data gaps. In particular, passive sensors such as crest stage gages can be extremely useful for documenting the elevation of the flood crest in multiple locations in rivers and streams. Crest stage gages are simple, low cost, reliable, and easily installed. More information is provided in Sauer and Turnipseed (2010, pgs 17-18).

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<sup>1</sup> Use of trade or product names does not imply endorsement by the U.S. Government



Figure 4. Photos of relatively low cost submersible pressure transducers used for continuous measurement of water level (Sauer and Turnipseed, 2010). On top: Onset HOB0 model U20-001-01. On bottom: In-Situ Aqua Troll 200. NOTE: These instruments do not meet USGS stage accuracy requirements ( $\pm 0.01$  ft or 0.2% of the effective stage) but can be used for many purposes not requiring this level of accuracy.

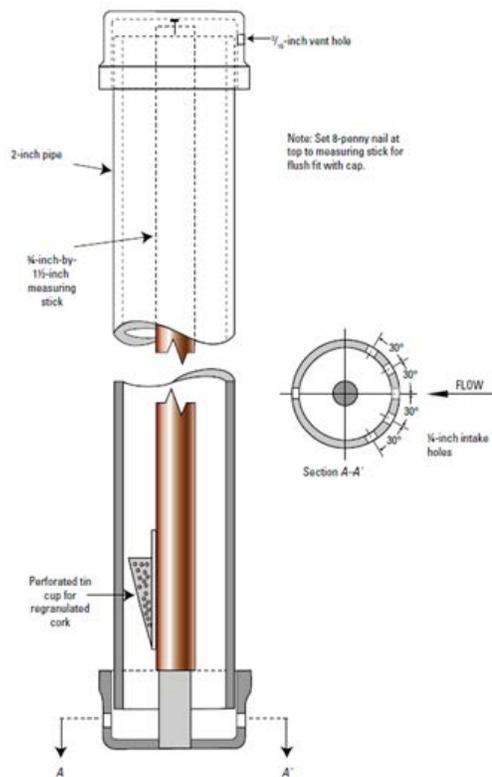


Figure 5. Details of a crest stage gage (Sauer and Turnipseed, 2010).



Figure 6. Examples of installed crest stage gages. On left: Selvage Hollow near Lebanon, Missouri, USA (photo courtesy of Paul Rydland, USGS). On right: Looking Glass River near Eagle, Michigan, USA (photo courtesy of National Weather Service).

- If equipment and future funding issues can be resolved, MoNRE and MEM should then consider evaluating and pilot testing visual data collection equipment such as remote camera systems. These cameras can be pointed at the river and/or staff gage to document conditions and automatically and remotely document staff gage readings. These cameras can take, and transmit if needed, photos or videos at defined intervals. Some cameras can be controlled (rotated, on-demand photo) remotely from the office if adequate cell or satellite service is available. Two options that have been tested in remote areas by the U.S. government are: Nupoint Systems Remote Viewer (currently Globalstar satellite based; <http://www.nupointsystems.com/remote-viewer/>) and Axis Communications cameras (cell modem based; <https://www.axis.com/us/en/products/network-cameras/>). Such cameras may assist in collecting information without needing to access the site or paying an observer to take manual readings.
- MoNRE staff mentioned some difficulty with maintaining and troubleshooting GPS equipment with ADCPs. When funding is available, MoNRE could consider purchasing a relatively low cost, portable GPS unit that can be integrated with a variety of instrumentation (including various types of ADCPs). One example is the SxBlue II Series GPS unit that works with the GLONASS satellite system (<http://www.sxbluegps.com/products/>), which has coverage in Lao PDR.

- If the quality of discharge measurements can be increased through increased training and QA/QC procedures, MRC and MoNRE staff may be able to reduce the number of discharge measurements needed during a given year (when funding is available, current strategy is 2 measurements/month in the dry season and 4 measurements/month in the rainy season). Instead, measurements could be timed so as to prioritize capturing conditions during extreme high and low discharge as well as any gaps in or portions of existing ratings with high uncertainty or scatter.
- When discharge measurements are made in support of any discharge rating development by the MRC, MoNRE should submit all raw data files (such as TRDI WinRiverII .mmt and .pd0 files) to MRC and take advantage of their QA/QC review and feedback to improve future data collection efforts.
- MoNRE, MEM, and MRC should consider scheduling coordination meetings with the NASA SERVIR-Mekong project office (<https://servir.adpc.net/>) to determine which of their satellite-based remote sensing data, decision support tools, and map products may be of use to the Lao PDR for flood forecasting and planning. In particular, SERVIR provides satellite radar-derived, near real time, rainfall and river stage estimates at select locations in the Mekong River Basin. This information could augment datasets from hydrologic stations and could support flood early warning efforts.
- MoNRE should develop a decisive, coordinated plan for taking over and independently operating the LMB hydrologic network in Lao PDR. MoNRE has been aware that many of the main elements of the LMB network established by MRC were to be taken over by the individual countries, starting in 2015. As stated previously, this transfer has not occurred successfully in Lao PDR. Though insufficient funding plays a large role in this problem, MoNRE should perform an assessment of current staff functions, an optimization of those functions, and seek out new sources of funding as mentioned above.

## Staff Skills and Training

- The DOI-ITAP team is planning to offer one or more training workshops in late 2017 and/or early 2018 to MoNRE and MEM staff. The Ministries should collaborate with the DOI-ITAP team to determine the most appropriate content of the training workshop(s). Additionally, the Ministries should consider and prioritize who among their staff would most benefit from attending the training workshop(s). Possible topics being considered for the training workshop(s) include:

- Basic troubleshooting of electronics and instrumentation
  - Basic hydrology
  - Discharge measurements using current meters and ADCPs - field procedures and data review
  - QA/QC and data management of hydrologic data
  - Development and validation of discharge ratings
  - Statistical hydrology (flood and low flow frequency statistics)
  - Flood forecasting
  - Sediment sampling
- With help from the DOI-ITAP team, MoNRE and MEM should consider developing future basic-to-intermediate technical training in basic hydrologic subjects, data collection techniques, equipment troubleshooting and basic repair, geographic information systems (GIS), databases, and statistical analyses to enable staff to independently collect, organize, analyze, and archive both climate and hydrological data. This should be an ongoing program with periodic “refresher” courses taught during annual coordination meetings (see Data Sharing and Interoffice Communication recommendations).
  - MoNRE should consider providing opportunities for staff who collect field data to develop, evaluate, and revise discharge rating curves. Building this capacity will require on-going training. First-hand knowledge of site conditions is extremely valuable for interpreting and managing hydraulic changes at gaging stations. Field staff may feel more personally invested in the monitoring if they are also helping to develop final results.
  - MoNRE should consider developing a “train the trainer” program for senior technical staff to allow for future in-house training and succession planning. This should be designed as an ongoing program for current and prospective staff. The DOI-ITAP would be happy to collaborate with MoNRE in developing such a program.
  - MoNRE and MEM should investigate opportunities to provide professional level hydrologic training and internship programs for Lao PDR students. This could involve coordination with secondary and higher educational institutions such as the National University of Laos (NUOL) or other educational entities in Lao PDR and abroad. Involving students in temporary internship or volunteer programs at MoNRE or MEM would help build student interest in environmental careers as well as build a sustainable, trained workforce.

## Data Sharing, Data Management, and Interoffice Communication

- MEM should consider developing an automated, scheduled data retrieval system to obtain hydrologic data from hydropower developers and share with MoNRE staff for early warning and network analysis. MEM states that they will begin requesting data transfers from hydropower companies on a monthly basis. MEM then plans to transfer the datasets to MoNRE, but the DOI-ITAP team is concerned that this will not work as expected. Setting up an automated reminder (even an automated email, at a minimum) or retrieval system could help ensure MoNRE's (and MRC's) access to data is more timely and predictable.
- MoNRE, MEM, and MRC should develop a data management plan for all data. Specifically the plan would discuss how data are collected, used, stored, and made available. The plan should discuss SOPs for data collection and processing and data QA/QC for data collection efforts at all locations. A data management plan assists with reproducibility and quality of data and helps ensure data and data products are consistent, well documented, accessible, and available for the long term.
- MoNRE and the other stakeholders need a discussion of software to be used going forward as a common database for consistent storage and seamless transmission of datasets among agencies. As MoNRE is aware, storing data in various Excel spreadsheets can result in inconsistent formats and transcription errors. Such a discussion should cover whether HYMOS meets agency needs, if a license can be maintained, as well as whether other commercially available database platforms would be more appropriate. Some possible options used by government agencies in other countries include Kisters WISKI (<http://www.kisters.eu/water.html>) and Aquatic Informatics AQUARIUS (<http://aquaticinformatics.com/>).
- MoNRE should consider establishing and maintaining internal and public websites that could enhance interoffice communication and data sharing and provide a higher public profile of the Ministry and its functions. The DOI-ITAP team realizes that Internet connection speeds are a significant impediment to communication and productivity, however. A number of solutions exist in web page programming (such as alternative text, page caching, HTML text browsing) to increase accessibility by users with poor connection speeds.
- MoNRE should investigate opportunities for improved coordination and communication between Lao PDR Ministries and departments, the MRC, and other

appropriate entities to identify data gaps, funding sources, data quality issues, data sharing, and other opportunities for collaboration and communication.

- MoNRE should consider offering annual coordination meetings at a central location and inviting MoNRE staff from all provinces and districts. These coordination meetings could include training and discussions on standard protocols, priorities, and common equipment issues.
- MoNRE and MEM should investigate public education opportunities on monitoring, flood warning, and environmental activities. In particular, there may be opportunities to implement “citizen science” programs to solicit cell phone photos of stream conditions taken by the public, particularly to document flood conditions in remote villages. Such photos could be used by MoNRE to better understand flooding extent and impacts but also could be shared on a MoNRE website (mentioned above) or social media account to communicate hazards to the public.
- MoNRE should seek to establish an ongoing QA/QC and skill sharing program with neighboring countries. In particular, perhaps a standing agreement could be established with the Thai government (involving approval from the Lao PDR and Thai militaries) to allow periodic joint measurements at the Mekong River hydrologic station upstream from Pakse without needing approval prior to each measurement. During these interactions, staff from the Lao PDR and Thai Ministries could compare discharge measurements, share ideas and best practices for efficient data collection, and jointly troubleshoot any equipment problems.

## Office and Equipment Conditions

- MoNRE should consider taking an inventory of all office space, and office and field equipment that includes location, condition, and feasibility of repair or replacement. It is recommended that this inventory list any additional equipment than can benefit the fulfillment of MoNRE’s mission. The list should be regularly updated.
- MoNRE should consider developing a proposed annual budget and plan (if not already available) for on-going equipment maintenance. This would provide the MoNRE Central Office with information for better sustaining hydrologic and climate monitoring missions into the future.
- When funding is available, MoNRE should consider purchasing equipment that can be shared among Provincial offices, such as ADCPs, current meters, watercraft, vehicles,

and computers. An equipment sharing program would require logistical support to track and ship equipment and close coordination with Provincial offices who need the equipment but would increase access to instrumentation for all MoNRE staff.

## Research

After the recommendations above are considered, and if and when the hydrologic and climate monitoring network is fully operational and supported, the following recommendations should be considered for advancing the use and accessibility of data generated from the network:

- MRC, MoNRE, and MEM should collaboratively consider inviting research opportunities using existing hydrologic monitoring datasets that could be used for a more robust assessment of the effects of hydropower development with regard to:
  - Habitat alteration
  - Sediment transport
  - Early warning systems
  - Flood forecasting
  - Fisheries and habitat
  - Climate change
  - Other environmental concerns
- MRC, MoNRE and, MEM should consider developing data transfer tools or websites so that research entities could readily access MoNRE hydrologic data for external research that may complement the Lao PDR Ministries' missions.

## Summary and Next Steps

This project was undertaken to provide technical support to the Lao People's Democratic Republic's (PDR's) Ministries of Energy and Mines (MEM) and the Ministry of Natural Resources and Environment (MoNRE). The effort was designed to address several goals: evaluate Lao PDR hydrologic and climate data collection equipment and networks, data quality control processes, analysis and evaluation processes, training and capacity building, and opportunities for MoNRE and MEM to better accomplish their missions in the Mekong River Valley.

Based on the findings of the DOI-ITAP team literature and field evaluations, several recommendations are proposed. Recommendations are distributed among four categories, hydrologic and climate monitoring, maintenance and operations, capacity building, and research opportunities.

The DOI-ITAP team will provide this report to MoNRE and MEM officials for review and comment. The team is also proposing at least one additional visit to Lao PDR in late 2017 or early 2018 to provide a training workshop for MoNRE and MEM staff.

In the upcoming months, the team will continue to evaluate opportunities for enhancing MoNRE and MEM interoffice coordination and data sharing, funding opportunities, on-going maintenance, and in-house training programs. As opportunities are evaluated, the team will remain in contact with MoNRE and MEM for their comments and assessment.

## References

- Jacobs, J.W., Owen, L., and White G.F. 2016. Mekong River. Encyclopaedia Britannica, Inc. Article accessed July 10, 2017, at <https://www.britannica.com/place/Mekong-River>
- MRC. 2000. Map of the Mekong River, Retrieved on August 1, 2017 from: [https://www.researchgate.net/figure/259005760\\_fig1\\_Figure-1-Mekong-River-Basin-map-and-water-distribution-in-each-country-involved-Source](https://www.researchgate.net/figure/259005760_fig1_Figure-1-Mekong-River-Basin-map-and-water-distribution-in-each-country-involved-Source)
- MRC. 2012. Final evaluation of the Hydrometeorological Mekong-HYCOS project: Final report-v4, July 2012. 55 p.
- MRC. 2017. Map of Hycos stations in the LMB, Retrieved on August 3, 2017, from: <http://monitoring.mrcmekong.org/>.
- Rainboth, W.J., Vidthayanon, C., and Yen, M.D. 2012. Fishes of the greater Mekong ecosystem with species list and photographic atlas. Museum of Zoology, University of Michigan, Miscellaneous Publications No. 201, 294 p.
- Sauer, V.B., and Turnipseed, D.P. 2010. Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A7, 45 p., <http://pubs.usgs.gov/tm/tm3-a7/>.
- USDOI-ITAP. 2015. Mekong River Fish Ecology Information Gap Assessment and Capacity Building in Laos, Final Report and Recommendations. Prepared for the Living Aquatic Resources Research Center. 42pp
- Ziegler, A.D., Petney, T.N., Grundy-Warr, C., Andrews, R.H., Baird, I.G., Wasson, R.J., and Sithithaworn, P. 2013. Dams and disease triggers on the Lower Mekong River. *PLoS Neglected Tropical Diseases* 7(6): e2166. <https://doi.org/10.1371/journal.pntd.0002166>.

# Appendices

## Appendix 1: Field Evaluation Summary

This phase required the team to travel to several MoNRE offices including the Central Office in Vientiane and the field offices in Luang Prabang, Xayaburi, and Pakse. An additional visit was scheduled with the Chief Hydrologist of the Mekong River Commission in Vientiane to provide additional perspective. Details of these meetings are summarized in this Appendix.

### **a. Meetings and field visits with Ministry officials and the MoNRE Central Office managers and staff**

On the morning of May 12, the team met with MoNRE Central Office staff to begin discussions on the national hydrologic and meteorologic monitoring network. Present at the meeting were Ms. Outhone Phetluangsy (Deputy Director General) and Mr. Prasith Deemaneevong (senior hydrologist) as well as the DOI-ITAP team.

Mr. Prasith gave an overview of the hydrologic and meteorologic network and discussed some of the major challenges faced by MoNRE. The greatest challenge posed by MoNRE appeared to be a lack of funding and signed Memorandum of Understanding (MOU) with the Mekong River Commission (MRC), who funds the operation of the hydrologic monitoring stations (also called gages or streamgages throughout this document). MoNRE staff are not able to repair inoperable gage equipment nor make discharge measurements and maintain ratings to compute continuous discharge until a new MOU is signed with MRC, which is hoped to occur during a July 2017 meeting.

### **b. Meetings and field visits with MoNRE Luang Prabang, Xayaburi, and Pakse Provincial Office managers and staff.**

**Meeting and field visit with Luang Prabang Provincial Office:** On May 13 the team travelled to Luang Prabang in northern Lao PDR to visit the MoNRE Meteorology and Hydrology Station located at the Luang Prabang airport. Accompanying the team were Mr. Prasith Deemaneevong (MoNRE) and Mr. Chantaphone Panyathong (Hydrologist; MEM). After introductions and a brief overview by the station manager and Dr. Roy, discussions focused on recent natural disasters (2016 flooding, grasshopper intrusion) and related challenges for MoNRE.

There are several challenges facing the Luang Prabang staff ranging from funding, lack of

equipment, maintenance issues, to training needs. The station lacks computer equipment and dependable Internet connectivity. Senior staffers (hydrologists) have outdated computers while support staff have no computer equipment. Since funding from the MRC ceased in 2016, measuring equipment has fallen into disrepair and basic needs for mission related functions are limited. For example, the station has only limited funding to purchase essentials such as gasoline for its vehicles. Rating curves have not been updated for discharge measurements in the past four to five years. Due to the shifting geometry of the Mekong River, this is problematic with regard to accuracy of measurements.

Training needs were listed as a high priority. Since the MRC has not recently signed an MOU and has not provided funding, the staff has had no opportunity to conduct training on equipment maintenance and operation, discharge measurements, and data analysis. On the job training from senior staff, who are knowledgeable in field and analytical techniques, is not routinely passed on to technicians.

With regard to data collection activities, the station depends on its own staff and some local contractors for data collection. There is occasional sharing of information from the hydropower developer industry, but it is limited and is only available upon request. There is a desire for better coordination with other entities with regard to collection, distribution and formatting of data. The MRC HydMET (Hydromet) database would be useful as a data coordination tool. This system is proprietary and is “key locked.” The cost for a license is out of reach regarding the local budget. Linked to this license is another needed piece of software, HYMOS, which has statistical and other tools that can draw directly from the database.

The team visited two hydrologic stations associated with the provincial MoNRE office (Mekong River at Luang Prabang (Figure 1) and Nam Khan River at Ban Mixay (Figure 2) on May 14. Equipment was found to be in disrepair and staff familiarity with station equipment (repair and troubleshooting) was limited. A seemingly identically equipped station, which was operational and transmitting data, had been installed at the Nam Khan River site by the Xayaburi Dam’s hydropower development company immediately adjacent to the MoNRE station (Figure 2).



Figure 1. Team members discussing hydrologic station operation and equipment challenges at the Mekong River at Luang Prabang. Photo by Chanthapone Panyathong, MEM.



Figure 2. Team members visited side-by-side hydrologic stations at the Nam Khan River. Photo by Molly Wood, USGS.

**Meeting and field visit with Xayaburi Provincial Office:** On the morning of May 15, the team met with staff of the MoNRE Xayaburi Provincial Office. The Station Director, a lead hydrologist, and other staff were present at the meeting.

After introductions, the Station Director and lead hydrologist provided an overview of the station staff and capabilities. The office consisted of 6 staff with one hydrologist and meteorologist. There are 11 district offices associated with this provincial office.

The needs for this province were similar to those listed in Luang Prabang Province. There is a lack of funding for equipment purchase and maintenance. Basic needs such as vehicles, boats, and gasoline are also not fully supported due to limited funding. Training funds are also an issue and there appears to be a lack of (and/or incentive for) local on-the-job training for equipment maintenance and operation, observation, rating curve development, and forecasting techniques. The Station Director also expressed a desire for better regional coordination of training and data/equipment sharing among the various offices of MoNRE. Basic needs such as reliable phone and Internet connectivity also are needed for the basic station functionality.

**Meeting with Xayaburi Dam personnel and visit the Xayaburi damsite:** On the afternoon of May 15, the team traveled to Xayaburi Dam and met briefly with CK Power Company staff, accompanied by the MoNRE Xayaburi Provincial Office hydrologist and Mr. Chanthapone Panyathong (MEM). The team viewed the dam from an overlook on the right bank (figure 3) and discussed the hydropower company's monitoring activities with their employee from Thailand, Ms. Kirana Somsook, who seemed very knowledgeable. Ms. Somsook stressed the need to operate their own hydrological stations to ensure reliability of and continuous access to the data, particularly during floods.



Figure 3. Xayaburi Dam, Xayaburi Province. Photo by Molly Wood, USGS.

**Meeting and field visit with Pakse Provincial Office, Champasak Province:** On the morning of May 18, the team met with staff of the MoNRE Champasak Provincial Office. Present at the meeting were the Deputy Director of the Office, Director of the Office’s Meteorology and Hydrology Department, the Lead Hydrologist, and two staff members. Mr. Prasith Deemaneevong (MoNRE Central Office) and Mr. Chanthapone Panyathong (MEM) also were in attendance.

The Provincial Office staff indicated that inadequate staffing, functional facilities, and equipment posed the greatest challenges for meeting their mission. In particular, they noted the need for better office space. The field staff currently uses a small building that is part of the Pakse airport for storage of equipment and general field operations. Additionally, they stressed the need for purchasing or repairing their boat and field vehicles.

Another issue raised by the Provincial Office staff was that it is difficult to retain contract

observers to make manual measurements of water level at gaging stations one to two times per day. The payment to these observers is low (about 160,000 kips per month or approximately 20 US dollars). In contrast, a hydropower development company is paying observers 600,000 kips per (just over 70 US dollars) month for the same job at their gaging stations.

As with other offices, the Provincial Office staff are reportedly not currently making discharge measurements and are not able to repair or troubleshoot non-functioning automatic water level recorders and real-time transmission equipment because of the lack of funding and a signed MOU with MRC. It is unclear to the DOI-ITAP team whether this is due to a lack of adequate training and resources or just a lack of direction from management.

In the afternoon, the team met with MoNRE Provincial Office staff at their field station near the Pakse airport. Field staff showed them various pieces of equipment used for streamgaging, including current meters (figure 4). This office does not have an ADCP meter for making discharge measurements. The DOI-ITAP team understands that discharge measurements on the Mekong near Pakse are made by the Thai government. The field station is manned by at least one MoNRE staffer 24 hours per day for weather reporting using data from the adjacent meteorological station.



Figure 4. MoNRE Central Office and Champasak Province staff demonstrate their Price AA current meter, used for making discharge measurements. Photo by Molly Wood, USGS.

On the morning of May 19, the Team met with staff of the MoNRE Champasak Provincial Office at the streamgage on the Mekong River at Pakse (figure 5). The streamgage is immediately adjacent to another streamgage operated by a Chinese hydropower development company (figure 6). MoNRE and the Chinese hydropower development company apparently do not share data from the adjacent gages, but the Chinese company may be using a discharge rating curve previously produced by MoNRE staff to compute discharge at their gage.

The MoNRE gage was equipped similarly to the other streamgages visited by the team: automatic bubbler/water level recorder, datalogger, cellular modem, and sloping staff gage. All the equipment is manufactured by OTT. The automatic water level recorder and datalogger were not operating because of a power issue, and the cellular modem was not working, likely because of a SIM card issue. MoNRE staff stated that the automatic equipment at the gage was last operational in 2016. Staff currently are making only manual water level observations using

the sloping staff gage using a paid observer in the vicinity of the gage. It appears that MoNRE would continue to pay an observer for once or twice daily manual readings of water level even if the automatic recording equipment was operational.



Figure 5. The team (with MoNRE and MEM staff) at the MoNRE hydrologic station on the Mekong River at Pakse. Photo by Simon (last name unknown), translator.



Figure 6. MoNRE hydrologic station (background, green shelter) and adjacent Chinese hydropower company hydrologic station (foreground, white cage) on the Mekong River at Pakse. Photo by Molly Wood, USGS.

### **c. Meeting with the Mekong River Commission in Vientiane.**

On the afternoon of May 22, the team met with Dr. Paradis Someth, Chief Hydrologist of the Mekong River Commission at their headquarters office in Vientiane. The meeting was arranged to gain the perspective of the MRC with regard to team findings. Questions were posed to address informational conflicts and gaps from previous interviews.

With regard to streamgage maintenance and data collection activities, Dr. Paradis stated that the operation and funding of automated data collection effort in the mainstem Mekong valley began in 2008. Some issues were noted early on with this program and additional funding was added from the French government to correct equipment malfunction. The MRC originally agreed to fund the stations for five years, from 2011 to 2015. The expectation was that MoNRE would then take over gage operation and maintenance, however, this has not been successful. Since the funding ceased in 2015, all of the stations in Lao PDR have fallen into disrepair.

Essentially, the MRC gaging stations have not been operational since 2016. MRC was concerned regarding the MoNRE upkeep of the stations and the lack of ongoing training for equipment troubleshooting and maintenance. Dr. Paradis expressed a desire for more effective training programs that focused on identifying the best people for training. It was suggested that a “train the trainer” program would be a logical first step.

The MRC was asked about a helpdesk as a tool for MoNRE staff. Dr. Paradis stated that the MRC has a helpdesk for technical assistance such as troubleshooting. The helpdesk is still a funded function of MRC and there is a desire to expand its capability. If problems cannot be solved in the field through use of the helpdesk, the MRC is willing to arrange equipment company representatives to assist with maintenance and repair. Dr. Paradis noted that individual office staff are allowed to contact company representatives on their own, though MoNRE staff currently do not appear to be doing this.

With regard to support, the MRC is planning to conduct station visits to evaluate equipment condition, staff training, advise on action to be taken. The MRC is planning to conduct these visits annually and prioritize the resolution of issues.

With regard to workflow, the MRC expressed concern over limited and “filtered” contact with field offices. The MRC cannot contact the MoNRE field staff directly as per protocol. Instead the MRC must communicate through a national coordination team resulting in inefficient information flow.

With regard to training MoNRE field staff, the greatest obstacle is budget and the distribution of funds between training, equipment procurement, and maintenance. It also was confirmed that MoNRE should consider expanding its own budget through better pricing of data that it sells to the hydropower development companies. Other budget issues noted are that MoNRE is limited with regard to its use of the MRC website - which requires a license - the DOI-ITAP team believes that this license has expired.

Other issues discussed at the meeting included the frequency of hydrologic data collection - which could be reduced to potentially limit error, border issues with Thailand when conducting measurements, and with data coordination/sharing - which could be improved with the development of a Data Coordination Center. The MRC would also like to see improved early warning and status information coordination during flood events. MRC makes flood forecasts and distributes these to the countries. But they don't receive adequate information on actual floods, which would allow them to better calibrate their forecasting tools and models. It was

suggested that this issue could be improved by expansion of the Lao PDR Flood Forecast Center. Better ground truthing of flood and flow data measurements also are desired. Finally, the team asked Dr. Paradis about their use of the NASA/USAID SERVIR program's information and decision support tools. MRC would like to support use of this information source but has not been engaged to date. SERVIR could be a useful planning tool for MRC at a high level, especially with reservoir/hydropower development in the headwaters (China).

## Appendix 2: DOI-ITAP Team Itinerary, May 2017

Date	Time	Details
5/10-12/17	Various	Team members arrive Vientiane, Lao PDR
5/12/17	0800-0900	Meeting with Interpreter
5/12/17	1000-1200	Meeting with Ministry of Natural Resources and the Environment (MONRE); Deputy Director Outhone Phetluangsy, Mr. Prasith Deemaneevong, and Mr. Bounsuek
	1400-1500	In brief meeting with USAID Lao PDR officer Glen Booth
5/13/17	0800	Meeting with Ministry of Energy and Mines (MEM) staffer Mr. Chanthapone Panyathong at airport for flight to Luang Prabang
	1400	Meeting with MONRE Luang Prabang Provincial Office, Division of Meteorology and Hydrology; Deputy Director and various hydrographers
5/14/17	All day	Site visits to streamgages on the Mekong River at Luang Prabang and Nam Khan at Ban Mixay with MONRE Luang Prabang Provincial Office staff; overnight in Xayaburi
5/15/17	0800-1000	Meeting with MONRE Xayaburi Provincial Office staff; Director of office and a Hydrologist

	1030-1230	Meeting with CK Power Company staff at Xayaburi Dam, accompanied by MONRE Xayaburi Provincial Office Hydrologist and MEM's Mr. Chanthapone Panyathong
5/16/17	1300	Team flight to Vientiane
5/17/17	0900-1300	Team meeting to discuss observations so far and to formalize questions to submit to MONRE staff for clarification
Date	Time	Details
5/18/17	0800	Team flight to Pakse
	1030-1230	Meeting with MONRE Champasak Provincial Office; Director of Department, Chief of Hydrology Group, Deputy Director of MONRE Provincial Office, and two other staff members
	1600-1700	Meeting with MONRE Champasak Provincial Office at their field office near Pakse airport
5/19/17	0930-1130	Site visit to Mekong River at Pakse streamgage
	1630	Team flight to Vientiane
5/20/17	All day	Team meeting to write trip report and discuss upcoming meeting with Mekong River Commission (MRC); Mike Roy leaves Lao PDR for Vietnam
5/22/17	1400-1600	Meeting with Dr. Paradis Someth, MRC
5/23/17	Various	Flights home for remainder of team

**Appendix 3: Lao PDR In-Country Contacts, May 2017**

<b>Ministry/Agency/Organization</b>	<b>Name</b>	<b>Position</b>
<b>Ministry of Energy and Mines</b>	Chanthaphone Panyathong	Senior Hydrologist
<b>Ministry of Natural Resources and Environment</b>	Prasith Deemaneevong	Senior Hydrologist
<b>Mekong River Commission</b>	Paradis Someth	Chief Hydrologist

## Appendix 4: Abbreviated Questionnaire, Key Questions for MoNRE and MEM

### *Lao PDR Hydrology Data Assessment*

#### Key Questions

1. Who is doing flood or water level forecasting? Are flood forecasts being produced by MRC as well as the MoNRE Central (Vientiane) and Provincial offices? If so, why are there different forecasting efforts? Why are there different forecast times (2-day, 5-day, 7-day)?
2. Does MRC communicate available products (such as flood maps) down to Central and Provincial offices? How aware are you of MRC's use of the data and resulting products?
3. If all of the hydrologic stations were working and fully operational, would there be a need for more stations? Have you prioritized existing stations (which are most important) and identified locations of future stations that would fill information gaps?
4. From your perspective, what would improve MoNRE's ability to operate, maintain, and troubleshoot equipment used at hydrologic stations?
5. What are your top three training workshop needs for 1) senior technical staff and 2) field staff?
6. Do you have written Standard Operating Procedures (SOPs) for operating hydrologic stations and reviewing the data to ensure accuracy, or is this something you want to do in the future? If you have written SOPs, can you send us a copy of the document(s)?
7. If investments are made in new technologies, such as ADCPs for discharge measurements or new cellular modems, how are decisions made on what to purchase? How is the equipment purchased? Is the majority of equipment purchased by MRC? Do the Central or Provincial offices purchase any equipment?
8. Explain the workflow for computing daily or real-time discharge.
  - a. Who develops the discharge ratings? Do MRC and the Central MoNRE office both develop ratings and for which station(s)?
  - b. When discharge measurements are made, are they immediately checked against the rating to see whether they match rated discharge?
  - c. How is the rating implemented to calculate discharge? Is Excel used to calculate rated discharge based on an entered equation or table?
  - d. After discharge is computed, how are the discharge data disseminated to those interested? Is there a standard list of receiving agencies, or are the data provided only on request? How quickly are the data disseminated?
9. Please distinguish among all of the software used for data download, management, and analysis, such as Hydras3, Hydmet, HYMOS, Excel, and Filezilla.

- a. Are there others?
  - b. What function does each software have, and why are there so many different ones used to manage the data?
10. Have you considered implementing other options for monitoring water levels and/or discharge in areas without full hydrologic stations? These options might include remote sensing, inexpensive water level measuring devices, peak water level measuring devices, and calculations using Manning's equations.
11. What are the daily duties of the field staff? Do duties vary substantially among individual field staff?
12. Do all hydrologists and hydrotechs have access to computers? What improvements are needed in IT-related equipment?
13. Do you have any questions for us? How can we provide further support?



stations? Have you prioritized existing stations (which are most important) and identified locations of future stations that would fill information gaps?

ຖ້າວ່າສະຖານນິອຸຕຸນິຍົມທັງໝົດທີ່ມີໃນປະຈຸບັນມີອຸປະກອນ ແລະ ເຄື່ອງມືຄົບຊຸດ ແລະ ເຮັດວຽກໄດ້ເຕັມກຳລັງ, ຍັງມີຄວາມຕ້ອງການສະຖານນິເພີມເຕີມບໍ່? ທ່ານໄດ້ຈັດບູລິມະສິດຂອງສະຖານນິທີ່ມີຢູ່ໃນປະຈຸບັນບໍ່ (ອັນໃດສຳຄັນທີ່ສຸດ) ແລະ ກຳນົດສະຖານນິເພີມເຕີມໃນອະນາຄົດ ທີ່ຈະຊ່ວຍແກ້ໄຂບັນຫາຊ່ອງວ່າງຂອງການສະໜອງຂໍ້ມູນບໍ່?

Answer: Yes, the distribution of The Hydromet network in Lao PDR still a gaps especially the river in Easthuen and Northuen of the country bordering with Vietnam no road access, In Westhuen (Mekong river stretch tran-sbourary with Thailand) needed added more stations in Lao side. See Attached with important

4. From your perspective, what would improve MoNRE’s ability to operate, maintain, and troubleshoot equipment used at hydrologic stations?

ອີງຕາມທັດສະນະຄະຕິຂອງທ່ານ, ກະຊວງຊັບພະຍາກອນທຳມະຊາດ ແລະ ສິ່ງແວດລ້ອມຄວນຈະປັບປຸງອັນໃດ ເພື່ອສາມາດຈັດຕັ້ງປະຕິບັດ, ສ້ອມແປງ ແລະ ແກ້ໄຂບັນຫາຂອງອຸປະກອນທີ່ໃຊ້ໃນສະຖານນິອຸຕຸ?

Answer: Yes, 1) Rehabilitation and maintenance of all existing networks; 2) Provide full of equipments and facilities such as station staffgauge plates for manual gauging, AWLR sets for prioritize selected stations, A current meter , Echo sounder set for every provincial Hydromet Divisions, ADCP with Laptop for Pakse, Savannakhet, Thakhet (in Mekong river); Communication facilitiy: MobilePhone for the station observers, Mobile GPS, PC for each center province.

5. What are your top three training workshop needs for 1) senior technical staff and 2) field staff?

ຈັດອັນດັບຂອງສາມອັນດັບຕົ້ນຂອງການຝຶກອົບຮົມທີ່ທ່ານຕ້ອງການສຳລັບ 1) ພະນັກງານວິຊາການ ແລະ 2) ພະນັກງານພາກສະໜາມ?

Answer: yes , for Both but first importance is the training for trainer and second training for observers.

6. Do you have written Standard Operating Procedures (SOPs) for operating hydrologic stations and reviewing the data to ensure accuracy, or is this something you want to do in the future? If you have written SOPs, can you send us a copy of the document(s)?

ທ່ານໄດ້ຂຽນ ມາດຕະຖານການດຳເນີນງານມາດຕະຖານ (SOPs) ສຳລັບສະຖານນິອຸຕຸ ແລະ ທົບທວນຂໍ້ມູນໃຫ້ຖືກຕ້ອງ, ຫຼື ແມ່ນສິ່ງທີ່ທ່ານຕ້ອງການຢາກຈະເຮັດໃນອະນາຄົດ? ຖ້າທ່ານໄດ້ຂຽນ (SOPs), ທ່ານຊ່ວຍສົ່ງເອກກະສານມາໃຫ້ໄດ້ບໍ່?

Answer: 1. Yes, until now we were used the SOPs for O&M was developed by Mekong HYCOS project of the MRCS; 2. Used a common methodology of Hydrological Principle we wre have luerned from the Institute former Soviet Unine CCCP (Ukraine, Odessa, Leningrat, Taskent...) and from MRCS Docs.

7. If investments are made in new technologies, such as ADCPs for discharge measurements or new cellular modems, how are decisions made on what to purchase? How is the equipment purchased? Is the majority of equipment purchased by MRC? Do the Central or Provincial offices purchase any equipment?

ຖ້າມີການລົງທຶນ ແລະ ສ້າງເຕັກໂນໂລຊີໃໝ່ ເຊັ່ນວ່າ ADCPs ສໍາລັບວັດແທກປະລິມານນໍ້າໄຫຼ ຫຼື ເຊວລູລາໂມເດັມໃໝ່, ຈະມີການຕັດສິນໃຈແນວໃດໃນການຈັດຊື້? ຈະຈັດຊື້ຊຸບປະກອນແນວໃດ? ມີຊຸບປະກອນຫຼັກໃດແດ່ທີ່ຈັດຊື້ໂດຍ MRC? ຫ້ອງການຂັ້ນສູນກາງ ຫຼື ຂັ້ນແຂວງສາມາດຈັດຊື້ຊຸບປະກອນໄດ້ບໍ່?

Answer: 1). Yes, Recently is no support from GOV for purchasing of ADCPs for discharge measurements or new cellular modems at all levels. Only one ADCP set at LuangPhabang center provided by MRCS since 2012. 2).The decisions made for purchasing of ADCP is depended on Project support (JICA support for River bank protection project, Hydropower Dam Authority or Others Research Institute for Water use and Quality (but no information). 3). Do the Central or Provincial offices purchase any equipment? Yes, They can do a purchase if supporting is available, but if you are under DMH (MoNRE), you should asked a permission from Central.

8. Explain the workflow for computing daily or real-time discharge.

ໃຫ້ອະທິບາຍຄວາມຄ່ອງຕົວສໍາລັບຄິດໄລ່ແຕ່ລະມື້ ຫຼື ການລາຍງານປະລິມານນໍ້າໄຫຼໃນຂະຂະນັ້ນ:

a. Who develops the discharge ratings? Do MRC and the Central MoNRE office both develop ratings and for which station (s)?

ຜູ້ໃດເປັນຜູ້ພັດທະນາລະດັບປະລິມານນໍ້າໄຫຼ? ທັງສອງ MRC ແລະ ສູນກາງ ກະຊວງຊັບພະຍາກອນທໍາມະຊາດ ແລະ ສິ່ງແວດລ້ອມເປັນກໍານົດລະດັບປະລິມານນໍ້າໄຫຼ ແລະ ສໍາລັບສະຖານນີໃດແດ່?

Answer: 1). For a basinwide is developed by MRCS; 2). For National use is developed by DMH, For MRC: 9 stations a long the Mekong river (including of 6 stations Joint Lao\_Thailand Discharge measurement stations) and 12 Main tributaries of Mekong. For DMH: 2 stations a long the Mekong river and 24 stations at tributaries).

b. When discharge measurements are made, are they immediately checked against the rating to see whether they match rated discharge?

ຕອນໃດທີ່ຫຼັກວັດແທກປະລິມານນໍ້າໄຫຼຖືກສ້າງຂຶ້ນ, ພວກເຂົາເຈົ້າໄດ້ມີການກວດຄືນເພື່ອໃຫ້ຖືກກັບລະດັບປະລິມານນໍ້າໄຫຼ ເພື່ອວ່າເຂົາເຈົ້າສາມາດວັດແທກປະລິມານນໍ້າໄຫຼ?

Answer: When discharge measurements are made, all data were send to DMH for Checking and input to the Database format of Discharge (Excel or HYMOS software).

**c. How is the rating implemented to calculate discharge? Is Excel used to calculate rated discharge based on an entered equation or table?**

ການຄິດໄລ່ປະລິມານນໍ້າໄຫຼ ຄິດໄລ່ແນວໃດ? ໄດ້ນໍາໃຊ້ ເອັກເຊລ (Excel) ເພື່ອໃຊ້ໃນການຄິດໄລ່ ໂດຍອີງໃສ່ສົມຜົນ ຫຼື ຕາຕະລາງ?

Answer: As above

**d. After discharge is computed, how are the discharge data disseminated to those interested? Is there a standard list of receiving agencies, or are the data provided only on request? How quickly are the data disseminated?**

ຫຼັງຈາກຄິດໄລ່ປະລິມານນໍ້າໄຫຼແລ້ວ, ຂໍ້ມູນປະລິມານນໍ້າໄຫຼໄດ້ເຜີຍແຜ່ອອກສູ່ຜູ້ທີ່ສົນໃຈແນວໃດ (ໄດ້ມີການເຜີຍແຜ່ຂໍ້ມູນແນວໃດ)? ມີລາຍຊື່ຂອງອົງການຈັດຕັ້ງທີ່ຈະໄດ້ຮັບຂໍ້ມູນ ຫຼື ຂໍ້ມູນຈະສະໜອງຕາມທີ່ຂໍມາເທົ່ານັ້ນ? ຂໍ້ມູນສະໜອງໃຫ້ໄດ້ໄວບາບໃດ (ໃຊ້ເວລາທີ່ໃດ)?

Answer: It depending on the Project and National purposed or requested.

**9. Please distinguish among all of the software used for data download, management, and analysis, such as Hydras3, Hydmet, HYMOS, Excel, and Filezilla.**

ກະລຸນາຈໍາແນກທຸກໆຊອບແວທີ່ໃຊ້ເພື່ອດາວໂລດຂໍ້ມູນ, ການຄຸ້ມຄອງ, ແລະ ການວິເຄາະ ເຊັ່ນວ່າ: Hydras3, Hydmet, HYMOS, Excel, ແລະ Filezilla.

Answer: 1) For operational data is used a Hytmet, Hydras3, FileZila softweres , 2) for historical is Excel and HYMOS ( a HYMOS is usefully for data analyzing, Storage and Reporting, but recently the HYMOS Liaience was expired, NO more used at the DMH now).

**a. Are there others?**

ມີໂຕອື່ນອີກບໍ່?

Answer: NO

**b. What function does each software have, and why are there so many different ones used to manage the data?**

ການເຮັດວຽກ ຫຼື ການນໍາໃຊ້ຂອງແຕ່ລະຊອບແວເປັນແນວໃດ, ເປັນຫຍັງຈຶ່ງມີການໃຊ້ຊອບແວຫຼາຍອັນທີ່ແຕກຕ່າງກັນເພື່ອຄຸ້ມຄອງຂໍ້ມູນອັນດຽວ?

Answer: Each software have a management level such as: Admin, Operator and User.

10. Have you considered implementing other options for monitoring water levels and/or discharge in areas without full hydrologic stations? These options might include remote sensing, inexpensive water level measuring devices, peak water level measuring devices, and calculations using Manning’s equations.

ທ່ານເຄີຍພິຈາລະນາ ການຈັດຕັ້ງປະຕິບັດອັນອື່ນໆ ສໍາລັບການຄຸ້ມຄອງລະດັບນໍ້າ ແລະ/ປະລິມານນໍ້າໄຫຼໃນພື້ນທີ່ ທີ່ບໍ່ມີສະຖານນິຕິບຸລຸດ? ທາງເລືອກເຫຼົ່ານັ້ນອາດຈະລວມເອົາ ການນໍາໃຊ້ວິໄນດເຊັນຊິງ (remote sensing), ເຄື່ອງວັດແທກນໍ້າທີ່ລາຄາບໍ່ແພງ, ເຄື່ອງວັດແທກນໍ້າທີ່ລະດັບສູງສຸດ, ແລະ ການຄິດໄລ່ນໍ້າໃຊ້ສົມຜົນຂອງ Manning?

Answer: Yes, but the cost is too high. And needed a Training and capability to do.

11. What are the daily duties of the field staff? Do duties vary substantially among individual field staff?

ໜ້າທີ່ແຕ່ລະມື້ຂອງພະນັກງານພາກສະໜາມມີຫຍັງແດ່? ພະນັກງານພາກສະໜາມແຕ່ລະຄົນເຮັດໜ້າທີ່ແຕກຕ່າງກັນບໍ່?

Answer: At recently most of staffs -stations observer are professional, is a contractor staffs (They can a farmer or a retire person)? Except Gov staff at station near down town have gotten some training.

12. Do all hydrologists and hydrotechs have access to computers? What improvements are needed in IT-related equipment?

ນັກວິຊາການອຸຕຸນິຍົມ ແລະ ນັກຕຸສາມາດເຂົ້າເຖິງ ຫຼື ນໍາໃຊ້ຄອມພິວເຕີບໍ່? ມີຄວາມຕ້ອງການອຸປະກອນໄອທິຫຍັງແນ່ເພື່ອປັບປຸງໃຫ້ດີຂຶ້ນ?

Answer: At the Central and Province, The most of staff are family with Equipment with you are working in, but the local staff (observers very rar).

13. Do you have any questions for us? How can we provide further support?

ທ່ານມີຄໍາຖາມສໍາລັບພວກເຮົາບໍ່? ພວກເຮົາສາມາດຊ່ວຍທ່ານໃນຕໍ່ໜ້າແນວໃດ ຫຼື ສິ່ງໃດທີ່ທ່ານຢາກໃຫ້ພວກເຮົາຊ່ວຍໃນຕໍ່ໜ້າ?

Answer: Yes, Training course for Data analysis and processing. Data validation and Report, Flood frequency and Low flow analysis, Hydrological statistical and Return period analysis....; Flood Forecast

equation (For Trainers)

## Appendix 6: Questionnaire for MRC

### MRC Questions:

- 1) We have read that in 2012, there were 13 HYCOS stations in Lao PDR. How well did the system function when it was first installed and developed? What is the status and value of the hydrological monitoring network in Lao PDR at the present time, from your perspective? What are the biggest challenges facing the monitoring effort now?
- 2) We heard from several MoNRE staff and offices that they have not/can not conduct any hydrological monitoring (beyond some limited collection of water level data) because MRC has cut funding to the network. Is this true? Was this funding for the HYCOS sites in Lao PDR? What is the reason for the cutoff in funding and are there plans to restore this funding? What are the future plans for the hydrological monitoring network in Lao PDR? What has been the trend in funding to MoNRE over the years? How many years with no funding at all? Does MRC have an ability to sign MOUs for longer than 1 year? Has MRC defined the highest priorities for MoNRE staff to complete with available funding?
- 3) When there was MRC funding, several provincial MoNRE offices told us that they made discharge measurements 4 times/month in wet season and 2 times/month in dry season. That seems like more measurements than necessary. Is this true and if so, why so many?
- 4) We heard a lot about flooding threats in Lao PDR (Both seasonal flooding and flash flooding from storms). What information/data is most needed to address these threats? Why is it that both MRC and MoNRE produce flood forecasts? (The Laotian forecasts may be pretty limited – 2-day forecasts of Mekong mainstem river levels). We noticed that the flood forecasts and weather reports on the MRC webpage have not been updated since late 2016 – are you still updating these? Is the limited data acquisition and collection in Lao PDR a challenge for producing flood forecasts here or are you getting sufficient information?
- 5) Does MRC have further plans to help countries address flooding? Is there a plan for an Early Warning System for flooding? What kind of hydrological and meteorological information from Lao PDR will be required to support this system?
- 6) How engaged is MRC with the SERVIR-Mekong hub and associated decision support tools like satellite-derived water level and rain, dam inundation tool, and surface water mapping tool? Are these products used by MRC to supplement any flood forecasting efforts or to provide flood warning to any of the Lao PDR MoNRE offices? Is MRC involved in conversations with SERVIR-Mekong for developing new or improved tools that would serve the Lao PDR (specifically)?

- 7) If we were to return and conduct a workshop (2-4 days) for the MoNRE hydrological staff, what kind of training would be most effective and beneficial?