NOTICE: This document contains information and results of a preliminary nature and it is subject to revision or correction and therefore does not represent final conclusions and recommendations

ORNL/TM-2015/437

SMART INFRASTRUCTURE FOR THE MEKONG (SIM) PROGRAM

Sustainable Hydropower in Lower Mekong Countries: Technical Assessment and Training Travel Report Thailand

Boualem Hadjerioua
Adam Witt

August 2015

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

Front Cover images

Top: View of tailwater and dam at the Vajiralongkorn Hydropower Plant.
Bottom: View of powerhouse and reservoir from on top of Rajjaprabha Dam.

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Environmental Sciences Division

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1. BACKGROUND AND INTRODUCTION

The US Agency for International Development (USAID), through its partnership with the US Department of the Interior (DOI), requested the support of Oak Ridge National Laboratory (ORNL) to provide specialized technical assistance as part of the Smart Infrastructure for the Mekong (SIM) Program in Thailand. Introduced in July 2013 by US Secretary of State John Kerry, SIM is a US Government Inter-Agency program. It provides Lower Mekong partner countries with targeted, demand-driven technical and scientific assistance to support environmentally sound, climate-conscious, and socially equitable infrastructure, clean energy development, and water resources optimization. The Lower Mekong sub-region is increasingly prosperous and globally competitive, with emerging regional connectivity that is improving access to water and electricity. Experience rooted in history shows that without proper foresight and preparation, attempts to balance natural resource use within the energy-food-water nexus can have detrimental social, environmental, and economic impacts. The US Government is committed to supporting sustainable economic development within the region by providing tools, best practices, technical assistance, and lessons learned for the benefit of partner countries.

In response to a request from the Electricity Generating Authority of Thailand (EGAT), a SIM project was developed with two main activities: (1) to promote hydropower sustainability and efficiency through technical assessment training at two existing hydropower assets in Thailand, and (2) to design and implement one national and two or three regional science and policy workshops, to be co-hosted with EGAT, to build common understanding of and commitment to environmental and social safeguards for Mekong Basin hydropower projects. The US Department of Energy (DOE) is leading the technical assessment (Activity 1) and has contracted with ORNL to provide expert technical assistance focused on increasing efficiency at existing projects, with the goal of increasing renewable energy generation at little to no capital cost.

ORNL is the leading national laboratory in hydropower analysis. It has a nationally recognized and highly qualified team of scientists addressing energy generation optimization analysis for small- to large-scale systems (basin, regional, and national scales) for DOE (see e.g., Hadjerioua, Wei, and Kao 2012; Kao et al. 2014). The mission of the ORNL Water Power Program is to develop technologies, decision-support tools, and methods of analysis that enable holistic management of water-dependent energy infrastructure and natural resources in support of the DOE Office of Energy Efficiency and Renewable Energy, federal hydropower agencies, the Federal Energy Regulatory Commission, the Nuclear Regulatory Commission, energy producers, and other entities.

In support of SIM, ORNL completed technical assessments of two hydropower plants owned and operated by EGAT: Vajiralongkorn (VRK) with an installed capacity of 300 MW, and Rajjaprabha (RPB) with an installed capacity of 240 MW. Technical assessment is defined as the assessment of hydropower operation and performance and the identification of potential opportunities for performance improvement through plant optimization. At each plant, the assessment included an initial analysis of hydropower operating and performance metrics, provided by dam owners. After this analysis, ORNL engaged with the plant management team in a skills exchange, in which best practices, operational methods, and technical challenges were discussed. The technical assessment process was outlined to plant management, followed by a presentation of preliminary results and analysis based on 50 days of operational data. EGAT has agreed to provide a full year of operational data so a complete and detailed assessment that captures seasonal variability can be completed. The results of these assessments and discussions will be used to develop a set of best practices, training, and procedure recommendations to improve the efficiency of the two assessed plants.

2. TRAVEL ITINERARY

This technical assessment was carried out over the course of 2 weeks, from July 20 through July 31, 2015. A summary of daily activities is outlined in Tables 1 and 2. Figures 1 and 2 show the facilities and staff of the two power plants.

Table 1. Travel summary for VRK Dam visit

Date		Activities
		WEEK 1—VRK
Mon. July 20	**Morning**	SIM kick-off meeting with Thailand Ministry of Energy, EGAT, USAID, US embassy, DOI, and ORNL
	Afternoon	Preparation of presentation materials for VRK
Tues. July 21	**Morning**	Travel by van to VRK
	Afternoon	Arrival, check-in, and preparation for VRK visit and presentation
Wed. July 22	**Morning**	Presentations from ORNL team to VRK management team: • ORNL capabilities • ORNL water power program, hydropower optimization tools, and procedures Discussion with VRK management team: data needs, skills exchange, best practices, and operational constraints
	Afternoon	Tour of the VRK powerhouse and control room
Thurs. July 23	**Morning**	ORNL preparation of technical assessment preliminary results
	Afternoon	ORNL presentation of preliminary technical assessment results to VRK management; discussion of VRK technical comments and concerns; and recommendations for plant optimization, achievement of highest plant efficiency, and monitoring protocol
Fri. July 24	**Morning**	Prepare a summary of results and a thank you letter to VRK management that outlines the mutual expectations for VRK and ORNL moving forward
	Afternoon	Return travel by van to Bangkok. Stop to visit Tha Thung Na Dam (38 MW) and Mae Klong Dam (12 MW), two existing EGAT hydropower projects

Table 2. Travel summary for RPB Dam visit

Date		Activities
		WEEK 2—RPB
Mon. July 27	**Morning**	Travel by plane and van to RPB. Initial meeting and lunch
	Afternoon	Presentations from ORNL team to RPB management team: • ORNL capabilities • ORNL water power program, hydropower optimization tools and procedures Discussion with the RPB management team: data needs, skills exchange, best practices, and operational constraints
Tues. July 28	**Morning**	ORNL preparation of technical assessment preliminary results
	Afternoon	Tour of the powerhouse and control room
Wed. July 29	**Morning**	ORNL presentation of preliminary technical assessment results to RPB management; discussion of RPB technical comments and concerns; and recommendations for plant optimization, achievement of highest plant efficiency, and monitoring protocol
	Afternoon	Travel by van and plane to Bangkok
Thurs. July 30	**Morning**	Prepare a summary of results and a thank you letter to RPB management that outlines the mutual expectations for RPB and ORNL moving forward
	Afternoon	Prepare a summary of results for USAID and the US embassy representatives. Create travel summary and begin travel report
Fri. July 31	**Morning**	Summary meeting with USAID and US embassy to relay results of technical assessment and outline next steps.
	Afternoon	Prepare thank you letter to Thailand Ministry of Energy and continue Travel Report.

Fig. 1. Vajiralongkorn Hydropower Plant site visit and technical assessment. Clockwise from top left: view of VRK dam from the powerhouse; view of VRK reservoir from on top of the dam; initial meeting and discussion with VRK management; 5 kW micro-hydro recovery turbine installed in the cooling water system; discussion with dam operator; ORNL team with VRK management team; presentation of preliminary findings; discussion of turbine operation in the control room looking down on the turbine floor.

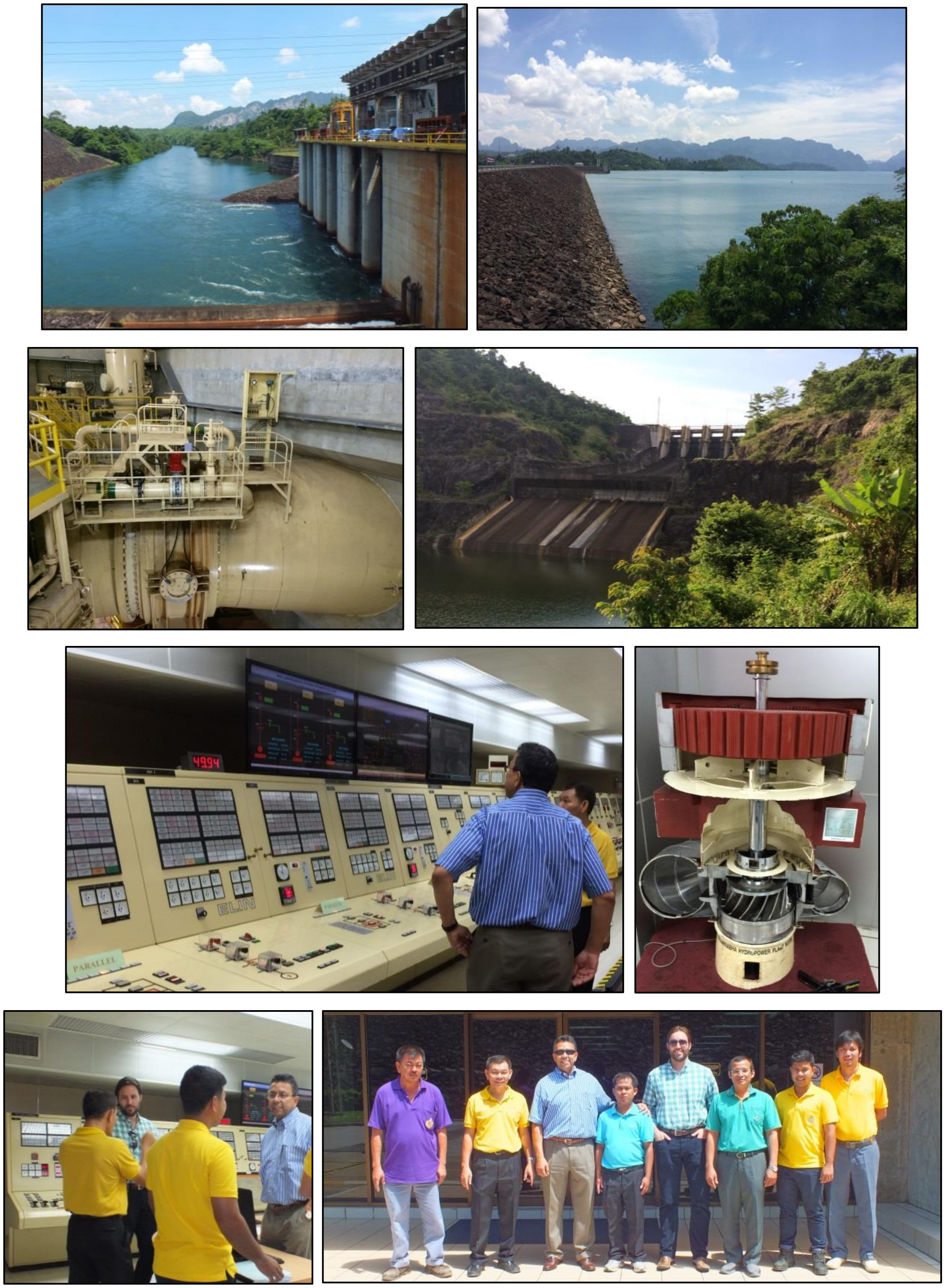

Fig. 2. Rajjaprabha Hydropower Plant site visit and technical assessment. Clockwise from top left: view of RPB tailwater and powerhouse; view of RPB reservoir from on top of the dam; RPB spillway gates; 1:10 scale model of the VRK turbine and generator; ORNL team with RPB management and staff; discussion of dam operations in control room; discussion of central dispatch in control room; 11 ft diameter intake for one turbine.

3. TECHNICAL ASSESSMENT AND TRAINING SUMMARY

The mutual understanding between the US partners and EGAT is that quantification of potential energy gains and water saved through plant optimization, while meeting all operational targets, is the primary objective of the technical assessment. To meet this objective, the ORNL team prepared summary presentations on the following topics (with supporting material from the noted references).

- Unit Level Optimization
  - Best Practices for Unit Efficiency (ORNL 2011)
  - Equipment and Civil Works Condition Assessments (ORNL 2012a)
  - Flow Measurements and Index Testing (Brice and Kirkland 1985)

- Plant Level Optimization
  - Best Practices for Plant Efficiency (ORNL 2011)
  - Environmental Impact Mitigation (Hadjerioua et, al. 1994; Witt and Gulliver 2012)
  - Hydropower Scheduling (Giles et al. 1995; Wunderlich and Giles 1987)

- Hydro System Optimization
  - Testing and Monitoring (Jones and Wolff 2007)
  - Asset Management and Planning (BOR et al. 2006; USACE 2011)
  - System Automation (Adams et al. 1999)

- Hydropower Plant Specific Technical Assessment (one each for VRK and RJB)
  - Hydro Performance Calculator (Wolff et al. 2005; Wolff and March 2014)
  - Tutorial and Interactive Assessment
  - Preliminary Optimization Results
  - Opportunities for Performance Improvement (based on assessment and analysis)

At each dam, interactive discussions took place regarding best practices, current operational practices, and similarities and differences between US and EGAT hydropower operation. The presentations, based on industry-leading research, served as introductory material that helped coax EGAT management into constructive and collaborative engagement on how to optimize hydropower.

The quantifiable goal of the technical assessment was to provide VRK and RPB with potential plant efficiency gains and water conservation opportunities that could be achieved if each plant were fully optimized. The main tool used to complete this assessment was the Hydro Performance Calculator (HPC), a software program that streamlines the calculation of hydropower plant performance analyses (March et al. 2012; Wolff and March 2014). The HPC is a well-recognized and respected industry tool whose development and utilization has resulted in an extensive library of case studies and lessons learned (see e.g., Wolff et al. 2005; March 2008; ORNL 2012b, among others).

To provide the most accurate operational analysis, the ORNL technical team requested one year of hourly operational data (unit power, headwater and tailwater elevations), as well as prototype and testing efficiency curves for each unit over a range of heads. Upon arrival on site, the ORNL team was given access to only the prior 50 days of operational data, and testing efficiencies were available for each unit at one head. Technical analyses of efficiency curves were conducted to extend the available data to a wider range of heads and generation (ASME 2002). A preliminary analysis was carried out on the limited data, and it was agreed that a full year of hourly data would be sent to the ORNL team upon their arrival back in the United States to let them complete a more robust analysis of potential efficiency improvements.

4. PRELIMINARY EFFICIENCY OPTIMIZATION RESULTS

Results were presented to VRK and RPB management teams in terms of potential efficiency gains had the hydropower plant been fully automated and optimized over the past 50 days. Plant-level efficiency gains were used to estimate a water conservation opportunity (WCO) and a lost energy opportunity (LEO). The WCO reflects the amount of water that could have been saved had the same generation occurred at the best plant efficiency point. The LEO provides an estimate of how much additional generation could have occurred over the course of 50 days had the conserved water been used to generate electricity (during the same hour it was conserved).

4.1 VAJIRALONGKORN HYDROPOWER PROJECT

Once a best plant efficiency curve was obtained for a given head, actual operational data points were plotted against it to show VRK management where efficiency gains may be possible (Fig. 3). In many instances, the best plant efficiency was nearly achieved. Room for improvement was evident at every head, noted by the points where the open circles (actual operation) fall below the blue line (optimal efficiency). Optimal plant efficiency is achieved using the smallest volume of water possible, and HPC is able to quantify the estimated volume of water used in actual generation and compare it with the volume of water required to generate the same amount of electricity at best efficiency. In this case, the open squares represent actual discharge and the red line indicates optimal discharge. Opportunities for water conservation are readily available shouldVRK consistently operate at best plant efficiency.

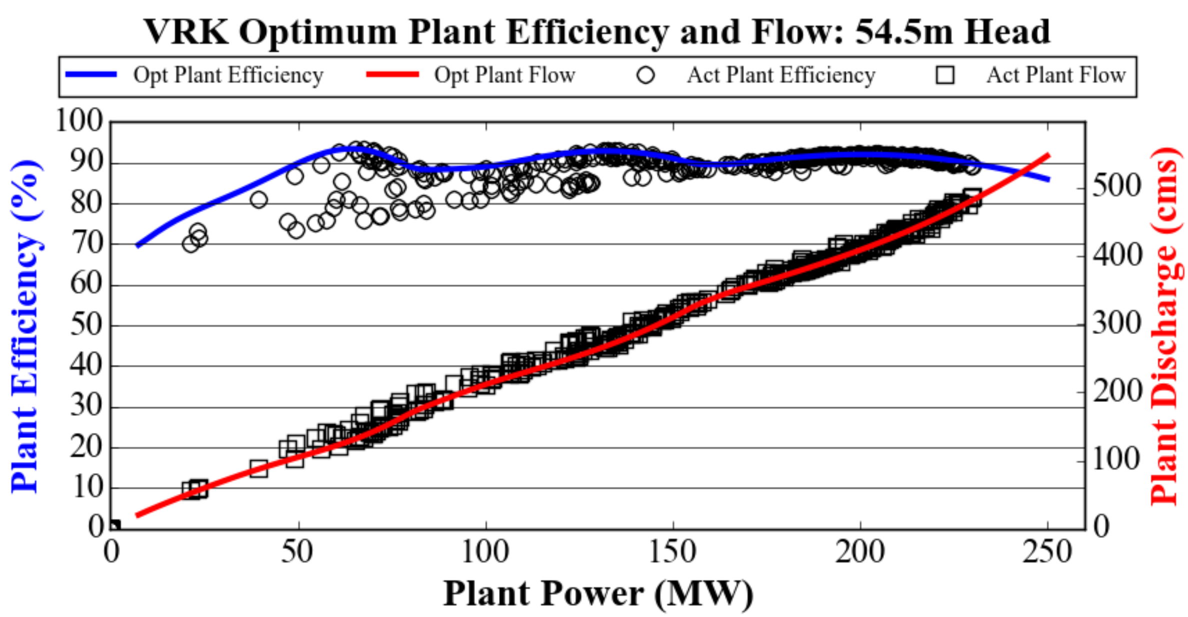

Fig. 3. Optimal versus actual efficiencies and estimated discharge for VRK at 54.5 m head.

At every head, there exists a combination of units that will provide the best plant efficiency. This efficiency is determined by index testing individual units at various heads and combining the best efficiency curves for each unit into a plant best efficiency curve. From this analysis, an optimal unit dispatch order is achieved, representing the mix of unit power that will give the best plant efficiency for a given plant power. This dispatch order was presented to VRK management for a given head. The optimal unit dispatch for a given power amount was communicated, and a discussion of dispatch within an optimization framework followed. At present, EGAT does not dispatch units based on optimal plant efficiency. Rather, a central dispatcher considers the amount of power required and equally distributes generation across whatever units did not run most recently. The ORNL team stressed the importance of unit testing to determine unit efficiency and relayed how operation at best plant efficiency can yield significant water savings and energy generation compared with current operation.

The preliminary results presented to VRK management are outlined in Table 3. These results represent what could have been achieved had the plant had been run at the best plant efficiency from June 1 through July 19, 2015. The ORNL team stressed that more data is required to run a complete analysis. The data set provided by EGAT represented only 50 days of operation in a relatively dry season. Greater efficiency improvements and water savings could occur with a full year of operational data.

Table 3. VRK preliminary performance improvement metrics

Metric	Results	Description
Water conservation opportunity (WCO)	18,800,000 m^3	Volume of water that could have been saved had the plant consistently operated at best efficiency
Lost energy opportunity (LEO)	2,270 MWh	Electricity that could have been generated using WCOs
Lost revenue opportunity	$USD 200,000 (7,000,000 THB)	Revenue that could have been gained had the LEO been generated at $90/MWh
Overall efficiency gain	1.5–2.5%	Efficiency improvement of VRK had it operated consistently at best plant efficiency

4.2 RAJJAPRABHA HYDROPOWER PROJECT

In a similar fashion, a best plant efficiency curve was obtained for various operational heads at RPB, and actual operational data points were plotted and presented to RPB management (Fig. 4). The number of operational data points was significantly smaller (60% less) than at VRK because of the low amount of generation that occurred over the prior 50 days at RPB. Despite the smaller data set, efficiency gains were still quantifiable and were communicated to RPB management. The optimal unit dispatch order was also shared with RPB, and the ORNL team emphasized the importance of operating at best efficiency rather than distributing generation equally among units.

The preliminary results presented to RPB management are outlined in Table 4. These results represent what could have been achieved had the plant had been run at the best plant efficiency from June 1 through July 20, 2015. The ORNL team stressed that more data is required to run a complete analysis. The data set provided by EGAT represented only 50 days of operation in a relatively dry season.

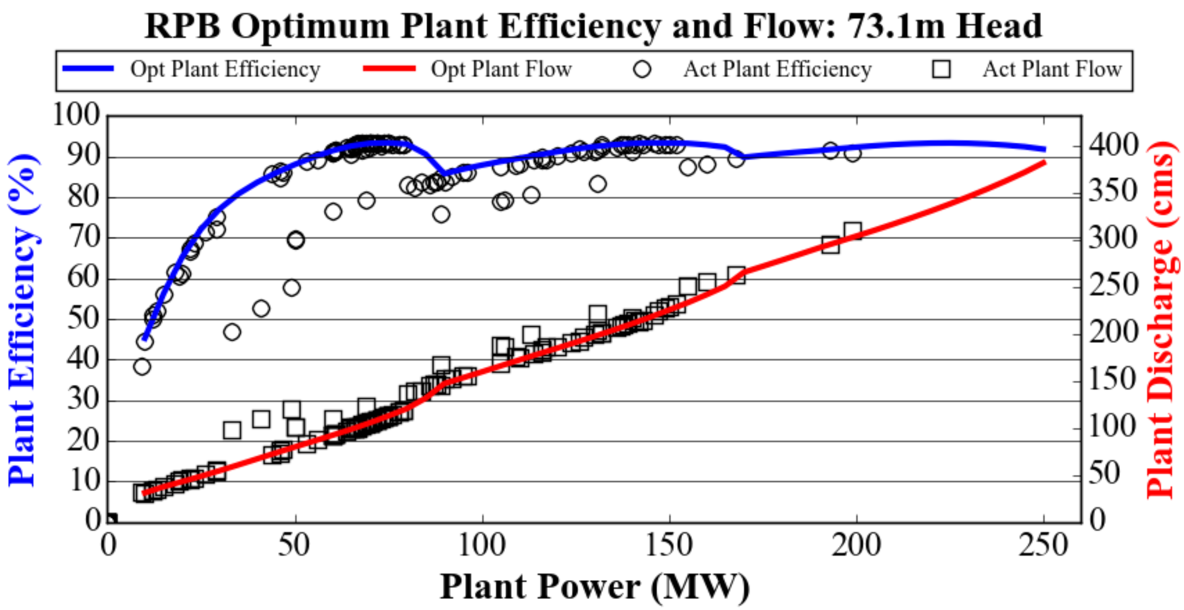

Fig. 4. Optimal versus actual efficiencies and estimated discharge for RPB at 73.1 m head.

Table 4. RPB preliminary performance improvement metrics

Metric	Results	Description
Water conservation opportunity (WCO)	2,600,000 m^3	Volume of water that could have been saved had the plant consistently operated at best efficiency
Lost energy opportunity (LEO)	450 MWh	Electricity that could have been generated using WCOs
Lost revenue opportunity	$USD 40,500 (1,400,000 THB)	Revenue that could have been gained had the LEO been generated at $90/MWh
Overall efficiency gain	1.5–2.5%	Efficiency improvement of RPB had it operated consistently at best plant efficiency

5. SIM MONITORING AND EVALUATION REQUIREMENTS MET

The technical assessment fulfilled monitoring and evaluation requirements laid out in the SIM statement of work (SOW; p. 6–7). The relevant indicators achieved are outlined below and referenced to the target indicator in the original SOW.

Number of dams assessed in Thailand (no target):

Two

Training activities: While partially accomplished they have a full planned activity that will be completed in the near future.

Number of Government of Thailand hydropower experts that receive on-site training (no target):

Approximately seven each at VRK and RPB

3.1 Number of people receiving US government–supported training in natural resources management and/or biodiversity conservation (target: 30):

Approximately seven each at VRK and RPB

3.2 Number of technical assistance interventions/services activities funded with US government assistance (target: four):

Two technical assistance activities (one each for VRK and RPB)

3.3 Number of days of US government–funded technical assistance in natural resources management and/or biodiversity provided to counterparts or stakeholders (target: 362):

7 total days (4 days at VRK and 3 days at RPB)

6. CONCLUSIONS AND RECOMMENDATIONS

The goals of the SIM technical assessment were to promote sustainable hydropower operation and improve operational efficiency at two existing hydropower dams in Thailand. This trip supported those goals by identifying opportunities for quantifiable efficiency improvements, communicating best practices, and identifying how water conservation through operation at best efficiency can be beneficial for additional multipurpose uses of the dam.

Based on the site visits, technical assessments, and discussions with dam management, the ORNL technical team is preparing a list of recommendations to improve hydropower efficiency and sustainability at VRK and RPB. The preliminary list is as follows:

1. Conduct robust index testing and measurements on a regular interval for all units.
    - Establish unit characteristics for the full operational power range (0 MW–installed capacity) for a full range of operational heads.
    - When unit testing is carried out in detail, quantify flow through each unit using tested efficiency-power-discharge diagrams rather than prototype diagrams.

2. Implement a more frequent monitoring protocol.
    - At a minimum, maintain 15 minute data tracking and archiving at all dams.
    - At a minimum, record headwater elevation, tailwater elevation, and unit power.

3. Dispatch units at each hydropower plant based on best plant efficiency.
    - Determine dispatch order for a range of operational heads.
    - Automate the full hydropower fleet to consistently achieve best efficiency.

4. Develop a condition-based equipment assessment protocol.
    - Schedule major overhauls using aneconomic-based hierarchy.
    - System-wide prioritization of equipment needs should be maintained.

5. Develop best practices for environmental impact mitigation
    - Use minimum flows to sustain aquatic health in the tailwater.

The ORNL team is in the process of preparing a full summary report of findings and recommendations for distribution to EGAT and SIM partner agencies in September. These results will serve as a framework for Thailand and EGAT to improve efficiency at all hydropower dams. The objective is to encourage

Thailand, as a regional economic leader, to share its experiences with neighboring countries and improve hydropower sustainability throughout all of Southeast Asia.

7. POTENTIAL FUTURE SIM SUPPORT

A summary meeting was held at the USAID office in Bangkok on July 31 to discuss the results of the technical assessment, the logistics for completing the following steps in the statement of work, and the remaining deliverables for the present activity of the SIM initiative (Fig. 5). The Regional Engineering Officer for USAID stated that the success of this first ORNL SIM activity demonstrated the tremendous value added that the ORNL technical team could bring to future SIM activities, particularly with regard to providing additional technical training and workshops on sustainable hydropower operation with EGAT staff, and potentially expanding this activity to other countries in the Lower Mekong.

ORNL is preparing to invite EGAT to participate in a technical workshop to exchange hydropower optimization technologies and global best practices at the ORNL campus in Oak Ridge, Tennessee. The workshop will focus on state-of-the-art energy technology solutions that aim to increase the sustainability and efficiency of existing hydropower assets, building upon the initial technical assessments. Training activities will take place over the course of 2 days and will include hands-on software simulations and interactive tutorials. Recognizing the difficulties and restrictions in place on international travel, ORNL is willing to propose two logistical alternatives in the hope including as many EGAT staff as is feasible:

1. Workshop and training to take place at ORNL in November 2015.
2. Workshop and training to take place in Bangkok in November 2015.

We hope these options provide EGAT with sufficient flexibility to consider partaking in a workshop and an exchange of hydropower engineering ideas.

Fig. 5. Summary meeting between ORNL technical team, USAID staff in Bangkok, and a representative of the US embassy in Bangkok (DOE and DOI participated via conference call).

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