

The World Bank

Asia Sustainable and
Alternative Energy Program

EAST ASIA AND PACIFIC ENERGY STUDIES



Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades

Case Studies for Selected
River Basins in Northwest Vietnam

June 2014



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Foreword

The government of Vietnam and the World Bank have had a long collaboration in the energy sector, sharing the commitment to each of the pillars of the Sustainable Energy for All Initiative—access for all, increasing energy efficiency, and boosting the share of renewable energy resources. The World Bank is currently supporting the Vietnamese government’s development of renewable energy through the 260 megawatt Trung Son Hydropower Project and the Renewable Energy Development Project, under which up to 35 small-scale hydropower plants in a number of river cascades are planned.

The World Bank and the government of Vietnam share a commitment to all aspects—economic, environmental, and social—of the development of sustainable hydropower. Hydropower development in Vietnam comprises many challenges: one of them is to maintain quality in the face of the country’s pressure to rapidly increase power generation capacity. Vietnam greatly improved its frameworks and procedures for developing efficient and environmentally and socially sound hydropower, but room for further enhancement still remains. The World Bank is therefore pleased to support the government of Vietnam with knowledge and technical assistance to further improve the planning, operation, and maintenance of its hydropower portfolio.

Development of small-scale hydropower, the potential of which is still huge in Vietnam, has its special challenges. The complexity of small-scale hydropower is often similar to that of large hydropower, while the regulatory framework is less well defined. Small-scale hydropower is also developed by private investors, often small companies, which do not always have as much experience in developing hydropower as the large developers. And when built in cascades that include several projects in a river, small-scale hydropower may have significant cumulative impacts on values that are important to local people and the environment.

This report highlights some of the most important challenges for small-scale hydropower development in Vietnam, based on case studies of six river basins in northern Vietnam. It is the result of collaboration between the World Bank and the Ministry of Industry and Trade in Vietnam, and aims to improve the sustainability of small-scale hydropower projects. Although based on a limited number of cases, its findings are likely to be applicable countrywide, and the report provides valuable recommendations to the country’s policy makers, planners, and developers of small-scale hydropower.

The results of this study are also likely to be applicable for the development of hydropower and river basin management in many parts of the world. Globally, small-scale hydropower development is intensifying because of improved technology and knowledge and because it is a renewable energy source with large potential for providing cheap and clean electricity. Globally, development of river basins at the same time becomes more and more complex as multiple users compete for a limited water resource. The institutional arrangements and procedures must be in place to allocate water across competing needs in the most optimal manner. The World Bank is happy to share the experience and knowledge from Vietnam through this report, and I invite all those who are interested in the development of small-scale hydropower and river basin management to read and reflect on how the findings and recommendations of this study may be applicable for the challenges faced in other parts of the world.

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Acknowledgments

This report is based on a series of consultant reports conducted by the consortium of Deltares, SWECO, the Institute of Water Resources Planning, and the Institute of Geography for the World Bank and the Ministry of Industry and Trade, Vietnam.

- Screening Report: Cumulative Impact Assessment and Watershed Management for River Basin Cascades in Vietnam, November 2012
- Main Report: Cumulative Impacts and Joint Operation of Small-scale Hydropower Cascades Supported by REDP, August 2013
- Annex 1. Detailed CIA and joint operation of Nam Tha, August 2013
- Annex 2. Detailed CIA and joint operation of Ngoi Xan, August 2013
- Annex 3. Detailed CIA and joint operation of Chien, August 2013
- Annex 4. Detailed CIA and joint operation of Sap, August 2013
- Annex 5. Methods and models, August 2013

This report was prepared by the Vietnam Energy Team of the World Bank: Franz Gerner (Lead Energy Specialist), Ky Hong Tran (Energy Specialist), Thi Ba Chu (Energy Specialist), and Lien Thi Bich Nguyen (Program Assistant), in collaboration with a consultant consortium, led by Marcel Marchand, consisting of Deltares (the Netherlands), SWECO (Norway), the Institute of Water Resources Planning (Vietnam), and the Institute of Geography (Vietnam). The work was supported by Rikard Liden (Senior Hydropower Specialist) and Son Van Nguyen (Environmental Specialist) from the World Bank. The report has benefited from review by Jennifer Sara (Sector Manager), Daryl Fields (Senior Water Resources Specialist), and Wolfhart Pohl (Environmental Adviser).

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ASTAE

The Asia Sustainable and Alternative Energy Program (ASTAE) was created in 1992 as a Global Partnership Program. ASTAE's mandate is to scale up the use of sustainable energy options in Asia to reduce poverty and protect the environment through promoting renewable energy, energy efficiency, and access to energy. Currently, ASTAE is funded by the government of the Netherlands, the Swedish International Development Cooperation Agency (SIDA), and the U.K. Department for International Development (DFID).

Department of Foreign Affairs and Trade Australian Government

The department's role is to advance the interests of Australia and Australians internationally. This involves working to strengthen Australia's security; enhancing Australia's prosperity; and delivering an effective and high quality aid programme. The department provides foreign, trade, and development policy advice to the government. We work with other government agencies to ensure that Australia's pursuit of its global, regional, and bilateral interests is coordinated effectively.

Abbreviations and Definitions

BBM	Building Block Methodology	PDP	Power Development Plan
CIA	cumulative impact assessment	PECC	Power Engineering Consulting Joint Stock Company
DARD	Department of Agriculture and Rural Development	Powel Sim	Program for short-term hydropower planning (Powel AS Smart Generation family)
DOIT	Department of Industry and Trade	PPC	Provincial People's Committee
EF	environmental flow	REDP	Renewable Energy Development Program
EI	Energy Institute	SEA	strategic environmental assessment
EIA	environmental impact assessment	SHP	small-scale hydropower
EMP	environmental management plan	SIA	social impact assessment
EPC	environmental protection commitment	SHOP	Short-term Hydro Operation Planning (model)
ERAV	Electricity Regulatory Authority of Vietnam	VEC	valued ecosystem component
EVN	Electricity Vietnam		
GWh	gigawatt hour (unit of energy)		
HEC-HMS	Hydrological Modeling System		
MARD	Ministry of Agriculture and Rural Development		
MOIT	Ministry of Industry and Trade		
MONRE	Ministry of Natural Resources and Environment		
MW	megawatt (unit of power)		
PAP	project-affected people		

Cumulative Impact: Cumulative impacts are impacts that result from incremental changes caused by other past, present, or reasonably foreseeable actions together with the project. (Walker, L.J. and J. Johnston 1999. *Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions*. EC DGXI Environment, Nuclear Safety & Civil Protection. Luxembourg: Office for Official Publications of the European Communities.)

Small-scale Hydropower: Projects of less than 30 megawatts installed capacity (as per Decision of Ministry of Industry - No 3454/QD-BCN dated October 18, 2005.

Overview

Small-scale hydropower (SHP) in Vietnam is defined as those projects having less than 30 megawatts (MW) of installed power generating capacity. SHP makes a large contribution to renewable energy generation in the country. More than 370 SHP plants are operational or under construction. Several hundred more plants are planned, which would bring total power generating capacity to approximately 3.5 gigawatts (GW). Notwithstanding the advantage of carbon-dioxide-free electricity production, the proliferation of SHP plants can have detrimental impacts on the environment and on water use. To obtain more insight into the consequences of hydropower cascades and on the possibilities to improve the cascade planning process, the Vietnamese Ministry of Industry and Trade and the World Bank jointly initiated the study on *Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades Supported by the Renewable Energy Development Project in Vietnam*.

Six SHP cascades situated in six river basins in the north-west mountainous region of Vietnam were analyzed, together representing a total future maximum installed capacity of 256 MW from SHP and 200 MW from one medium-size hydropower project (table O.1). Four cascades were subjected to a more detailed analysis: Ngoi Xan, Nam Tha, Chien, and Sap.

The study found that development of SHP in Vietnam has come a long way. A well-established institutional framework in Vietnam has promulgated legal and policy procedures for hydropower development, and experience and skills are embedded in the organizations of the major ministries, institutes, and local consultants.

Nevertheless, SHP causes impacts that are sometimes overlooked. The studies for this report indicate that SHP cascades, when viewed as a system, tend to have significant impacts through aquatic habitat fragmentation because the series of diversion schemes significantly reduces river flows for long distances. Furthermore, although land take is small for each project, the required land accumulated for the cascade as a whole may be comparable to that of a large hydropower plant with corresponding installed turbine capacity. Risks of deforestation and impacts on biodiversity also follow from opening up pristine areas with access roads.

However, because SHP cascades are often built in remote mountainous areas that are unsuitable for agriculture, resettlement of people and conflicts with irrigation are normally minor. Direct social impacts are site specific and often related to minority ethnic groups. Impacts on river flows are mostly limited to within the cascade because

TABLE O.1 OVERVIEW OF STUDIED RIVERS AND SMALL-SCALE HYDROPOWER PROJECTS

River	Number of small-scale hydropower projects				Total future maximum installed capacity (MW)
	Operational	Under construction ^a	Planned	Total	
Chien	2	1	0	3	54 + 200 ^b
Nam Hoa ^c	0	2	0	2	26
Nam Tha	1	3	5	9	58.9
Ngoi Xan	3	2	1	6	53.7
Pho Day ^c	0	1	1	2	21
Sap	1	4	3	8	63.4
	7	13	10	30	256 + 200

a. As of April 2013.

b. Nam Chien 1.

c. Not included in the detailed analysis.

Source: World Bank.

of the normally small reservoir volumes for SHP. The effect of peaking, that is, power production during only a few hours of the day, may negatively affect water users just downstream of the cascade during the dry season, but the studies of the six cascades in northern Vietnam indicate that such impacts are limited.

The studies provide an important message. The cumulative impacts of SHP are not always strictly additive, and could be either underestimated or overestimated. The effects on an important ecosystem component such as aquatic fauna is synergistic (that is, the cumulative impact is more than the sum of each individual project's impact) because development of the cascade exacerbates the impacts on migration and mobility of riverine and terrestrial animals. In contrast, the project-affected people in SHP development in Vietnam are mainly affected by the changed river regime downstream of the entire cascade, and impacts are thus antagonistic (that is, the cumulative impact is less than the sum of each individual project's impact) because the addition of more dams upstream will not significantly change the downstream flow regime. Some impacts may also be indirect (such as access roads opening up pristine areas) and are often ignored, emphasizing the need to study SHP cascades as a system so as to fully understand the local conditions and interactions.

The studies of the six SHP cascades in Vietnam show that implementation of environmental flows is challenging. Several of the dams under study did not have facilities (culverts, gates) that would allow the release of an environmental flow. Furthermore, the absence of either quantitative guidelines or rules of thumb in the current regulations leads to subjective and arbitrary flow release requirements. Another essential concept for protecting valued ecosystems, intact rivers (whereby a part of the river basin, for example, a tributary adjacent to the cascade remains without any hydropower development), seems not to be considered in the planning of SHP cascades in Vietnam. Thus, room for clarification of the environmental legislation and improved enforcement of it remains.

The studies of the six river cascades further indicate that optimizing them as a system would yield significantly higher power production and higher revenues. By applying joint planning, joint operations, and joint maintenance of the plants in the cascades, costs will be lower and total benefits will be higher. Planning opportunities exist, particularly where a large reservoir can be designed at the top of the cascade, that will benefit all downstream SHP plants by yielding higher revenues through the production of more peak power. A no-regret opportunity for the

operation of both existing and future SHP cascades would be to apply power-optimization models, run at a common operations center, to optimize the storage and plant (turbine) efficiencies of the entire cascade. Such a program would require that the owners of individual SHP plants understand the benefits of cooperation and invest in it.

This study shows that SHP development still faces some challenges. SHP cascade development creates trade-offs with values important to other stakeholders, similar to the development of individual large hydropower plants. (For example, Nam Chien 1 has more installed turbine capacity per square meter of reservoir area than the other 29 SHP plants in the six cascades combined.)

The main conclusion of this study is, therefore, that the planning and development of SHP should focus on the system (or cascade) rather than on individual projects.

The main policy recommendation of this report is to break the paradigm of planning and enforcing rules for SHP on a one-project-at-a-time basis. The government of Vietnam should strengthen national- and regional-level planning for SHP, and should promote the development of robust and efficient cascades in rivers that are most suited to such development. The focus of policy change should be on future developments, but also on the implementation of no-regret measures for existing projects. The main recommended policy steps are the following:

- Strengthen the requirements and performance of participatory technical optimization and strategic environmental assessments on both the river basin and regional levels. Doing so will enable system-level optimization of the hydropower plants and of the evaluation of impacts, which will improve overall power production efficiency and will guide the mitigation and offset of negative impacts most cost effectively.
- Provide incentives for private developers to build, operate, and maintain SHP cascades in an efficient, environmentally sound, and participatory way. Possible approaches could be to promote ownership of cascades by individual or collaborative companies for joint operation and maintenance; to develop and disseminate technical assistance to build capacity for developers to cooperatively optimize construction, operation, and maintenance; and to encourage stakeholder participation.
- Set long-term tariffs at a level that would provide incentives for developers to make the necessary up-front capital investment in studies and the implementation of measures for sustainable safety, environmental, and social management.

Introduction

Background and Objectives

Increasing energy demands and concerns about global warming call for an increase in energy generation from renewable sources. Small-scale hydropower (SHP) plants can make a significant contribution to meeting this demand. However, the optimal use of this resource in a sustainable manner still remains a challenge. A cascade of small dams may have detrimental impacts on the environment and on water use in the absence of proper planning and implementation of mitigation measures. To obtain more insight into the consequences of hydropower cascades and possibilities for improving the cascade planning process to reduce such impacts, the Vietnamese Ministry of Industry and Trade and the World Bank jointly initiated the study on *Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades Supported by the Renewable Energy Development Program (REDP) in Vietnam*.

REDP provides credit lines for SHP development via participating banks. The program also has a technical assistance and capacity-building facility to assist participating banks and project developers with the preparation, appraisal, and implementation of SHP projects. Although the projects financed under REDP include requirements for environmental flow analyses, existing plants on the rivers do not necessarily follow the same policies. Furthermore, there is no documented analysis of the impacts on other water users and of the consequences of the entire cascade for the environment along different river stretches. There is thus a need for studying the complete river system and the potential additional cumulative impacts of the projects funded through REDP. Measures such as adjustment of operating rules or joint operation could optimize revenues while at the

same time reducing adverse impacts. The objective of this assignment was, therefore, to carry out a study on the cumulative impacts and opportunities for improved joint operation of cascades in six rivers where projects are funded under REDP.

Scope of the Study

The scope of the study was twofold: (1) to identify the possible unforeseen cumulative impacts of a series of SHP plants and (2) to assess the opportunity for potential optimization of their joint operation. The objective is to give operators, planners, and policy makers recommendations on how to strategically plan, implement, and operate such cascades to maximize energy production and minimize environmental and social impacts. It is not part of an official institutional planning or decision-making framework (such as the World Bank Safeguard Policies for implementing projects) and therefore not a detailed cumulative impact assessment (CIA) in the traditional meaning. Although many parts of the study use the methodology of a traditional CIA, the level of detail applied is less than in a full-fledged CIA. The study output provides indications of improvements for each cascade, but additional studies would be required to define these improvements in detail, assess their feasibility, and plan their implementation.

Because this study is not part of an official planning or decision-making procedure, it deviates from an “official” CIA in the following ways:

- Stakeholder consultation was done primarily at the level of national and provincial governmental agencies. Local stakeholders were involved to a limited extent in an informal manner (interviews).

- The analysis of environmental impacts used mostly secondary data. Primary data collection was restricted to water and sediment sampling.
- Boundaries for the analysis were set but were not observed with the same rigor as for a CIA. The flexibility afforded by the lack of formality helps in identifying significant impacts at time and space scales that may not be found when certain levels are excluded at the outset.

Setup of the Report

Chapter 2 provides a brief background of small-scale hydropower development in Vietnam, including its current planning procedures, while chapter 3 provides a description of the six studied river basins. Chapter 4 describes the approach, methods, and definitions of the study. During

the first phase of the study all six rivers were screened for potential significant cumulative impacts. The results of this screening were presented in a separate report, which is summarized in chapter 5. This screening showed that significant cumulative impacts can be expected for four of the rivers; these impacts merited further detailed analysis. These four rivers are Ngoi Xan, Nam Tha, Nam Chien, and Sap. For each of the four detailed study cases, the river basin and hydropower cascade were described, the hydrological and environmental impacts were assessed, and opportunities for joint operations were quantified. This report presents summaries of the cumulative impact analyses (chapter 6) and draws general conclusions with respect to present and future environmental conditions (chapter 7). It also summarizes the results of the optimization modeling for each cascade (chapter 8) and provides recommendations for future SHP planning and cascade operation (chapter 9)

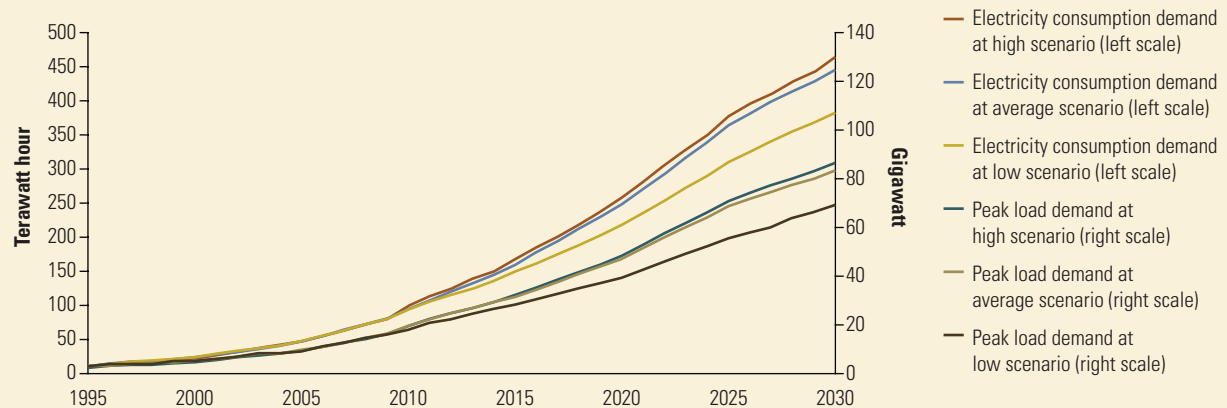
Small-Scale Hydropower Development in Vietnam

Opportunities and Challenges

According to Vietnam's 7th Power Development Plan (PDP), the country's annual electricity demand is expected to increase 11.8 percent to 15.8 percent between 2011 and 2015. Growth in demand is then expected to taper to 7.2 percent to 8.9 percent between 2026 and 2030 (figure 2.1). Hydropower is among the largest contributors to electricity production in the country and is expected to keep that position through 2020, and maybe through 2030. However, its relative share will decrease considerably to an expected 23 percent in 2020 when coal-fired plants will have a share of 48 percent, according to the 7th PDP. Although the PDP prioritizes the development of hydropower resources, no specific targets for small-scale hydropower (SHP) are mentioned.

The government of Vietnam has embarked on a major expansion of the hydropower sector, which is transforming the ecological and social systems of the country. All main river systems are or will be dammed by one or more hydropower projects—each with road access, transmission lines, and linked development shaping the terrestrial, aquatic, and social environment (Suhardiman, de Silva, and Carew-Reid 2011). SHP development has the potential to contribute significantly to this expansion (Tohoku Electric Power Company and Engineering and Consulting Firms Association 2010). Vietnam's advantages in developing SHP come from its dense system of rivers and streams. With 2,200 or more streams and rivers more than 10 kilometers in length, Vietnam has very high potential for hydropower production. In addition, average rainfall is high and the combination of widely

FIGURE 2.1 HISTORICAL AND PROJECTED ELECTRICITY DEMAND IN VIETNAM



Source: Nguyen and Duong 2009.

TABLE 2.1 OVERVIEW OF HYDROPOWER DEVELOPMENT IN VIETNAM

Type of project	Total		Operational		Under construction		Investment study		Planning	
	Projects	Capacity (megawatts)	Projects	Capacity (megawatts)	Projects	Capacity (megawatts)	Projects	Capacity (megawatts)	Projects	Capacity (megawatts)
Medium and large hydropower	110	17,680	49	11,600	36	4,630	18	1,026	7	424
SHP	1,000	7,431	190	1,466	181	2,324	276	2,583	353	1,058
SHP as percentage of total	90	30	79	11	83	33	94	72	98	71
Total	1,110	25,111	239	13,066	217	6,954	294	3,609	360	1,482

Source: Hydropower Department, Ministry of Industry and Trade 2012.

distributed streams and high relief of the terrain provides suitable conditions for SHP development.

As of 2013, 1,110 hydropower projects were operational, under construction, subject to an investment study, or planned (table 2.1). Of these, about 90 percent are SHP plants, usually considered to be projects of less than 30 megawatts (MW) installed capacity (as per Ministry of Industry Decision No. 3454/QD-BCN, dated October 18, 2005). Some 190 plants are operational, with an installed capacity of 1,466 MW, and 810 are in various stages of development. Provinces with strong potential are Son La, Kontum, and Lao Cai.

In Vietnam, SHP projects have been constructed since the 1960s. They were initially built with funding from the state budget during 1960–85 in the northern and central provinces. From 1985 to 1990, investment was also provided by ministries, industries, provinces, military units, and cooperatives. After 2003 investment by the private sector became increasingly important as the electricity market was liberalized (GIZ 2012).¹ Each year through 2017, 150–300 MW is planned to become operational.

Because it is a renewable source of energy, SHP contributes directly to a low-carbon future. Furthermore, if properly managed it can be a catalyst for the development of the economies of remote locations inhabited by poor and marginalized people (MOIT 2011). Positive impacts on the local socioeconomy include provision of employment and improved road infrastructure that provides market access for agricultural products. In some cases hydropower developers voluntarily support local communities by upgrading schools and irrigation facilities, providing agricultural extension training, and awarding scholarships.

Public opinion may tend toward thinking that SHP is green and beautiful, while large-scale hydropower projects have a reputation for causing dramatic, negative impacts to the environment. Scientists have recently raised the issue, however, that swaths of untouched nature are being fragmented by many small projects (Bakken and others 2012). Concerns have also been expressed in the media in Vietnam. In 2012, Deputy Prime Minister Hoang Trung Hai proclaimed that hydropower projects that have significant negative impacts on the environment should be rejected and existing ones that violate regulations should have their licenses revoked (*Vietnam News*, July 6, 2012). He added that provincial and city authorities should check and assess the capacity of contractors for SHP projects. And the deputy chairwoman of the People's Committee of Nam Giang District, Quang Nam Province, in which 11 hydropower plants are planned, suggested some medium and small-scale projects should be stopped. She said not only had building the plants reduced the forest areas, but the construction of roads also accidentally created favorable conditions for illegal gold exploiters to increase their activities (*Vietnam News*, October 12, 2012). Also, the strategic environmental assessment (SEA) of the 6th National Plan for Power Development quotes experts and local administrators as saying that “investors only set up hydropower projects so that they have access to logging” (MOIT 2011, 152). The SEA further mentions sedimentation and erosion problems, the drying up of lakes, disruption of fish migration, and impacts on other water users as potential problems associated with SHP.

Another pending issue is with the safety of small dams. On May 28, 2013, the Science, Technology, and Environment Committee of the National Assembly (STECNA) reported the results of the first inspection of the implementation of hydropower development law and policy. The safety

evaluation report showed that supervision of the design and construction of a number of small to medium-size hydropower projects is still not in compliance with applicable regulations. Investors have a high degree of autonomy, while the experience and skills of the workers are constrained. Small projects typically lack experienced and professional workers. Some of the projects do not comply with quality and safety regulations. STECNA has advised the National Assembly to improve the management model and create unified management regulations and an organization to be responsible for the operation of reservoirs and the safety of the dams.

To facilitate the development of SHP the government of Vietnam has received a loan from the World Bank for the Renewable Energy Development Program (REDP). REDP's objective is to increase electricity supply to the national grid from renewable energy sources on a commercially, environmentally, and socially sustainable basis. The loan provides a refinancing facility for loans made by REDP participating banks to developers of renewable energy projects. Developers of SHP projects can borrow up to 80 percent of the total financing required for construction (the remaining 20 percent is to come from shareholders). Of the 80 percent loan, 80 percent can be provided through the REDP facility, and 20 percent is a credit from the participating bank itself at commercial interest rates. The Ministry of Industry and Trade (MOIT) has been assigned to coordinate REDP implementation and gives formal approval for proposed projects. REDP also has a technical assistance and capacity-building facility to assist participating banks and project developers in the preparation, appraisal, and implementation of SHP projects (PMB 2009).

Current Small-Scale Hydropower Planning

The current planning process for SHP development involves many different agencies. Key players are the Provincial People's Committees (PPCs), three ministries—Industry and Trade (MOIT), Agriculture and Rural Development (MARD), and Natural Resources and Environment (MONRE)—their provincial counterpart departments (DOIT, DARD, and DONRE), Electricity Vietnam (EVN), and several research and consultancy institutes (Energy Institute, Power Engineering Consulting Joint Stock Company, and others). The process can be divided into 11 steps (table 2.2).

PHOTO 2.1 POWERHOUSE AT NGOI XAN 1 SMALL-SCALE HYDROPOWER PLANT



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MOIT approved a national plan for SHP in 2005. Each DOIT is responsible for SHP development at the provincial level based on the national plan. MOIT approves the provincial-level plans.

Several regulations and decisions are applicable to the environmental and social aspects of SHP development. Before implementation of Decree 29/2011/ND-CP dated April 18, 2011, on SEA, environmental impact assessment (EIA), and environmental protection commitment (EPC), the environmental impacts and social aspects were covered in each SHP project's preliminary plans. Government regulation requires either an EIA (including social aspects) or an EPC, depending on the type and scale of each hydropower project.

In accordance with Decree 29/2011/ND-CP, the national plan contains the locations with hydropower potential and also involves an SEA. For the SEA, MONRE is to establish a commission in which other ministries, such as MARD, are to be represented. Depending on the size of the hydropower project, the following are required:

- An EIA for projects with total reservoir storage volume of more than 100,000 cubic meters or power capacity greater than 1 MW. The EIA needs to be approved by MOIT, except for projects with a volume of more than 100,000,000 cubic meters, which need to be approved by MONRE.
- An EPC for projects with total reservoir storage volume of less than 100,000 cubic meters, which needs to be approved by the PPC.

TABLE 2.2 STEPS IN SMALL-SCALE HYDROPOWER PLANNING

Step	Conducted by	Activity	Approval
1. Water resource potential study	<ul style="list-style-type: none"> Water management agency and MARD Hydrometeorology and MONRE Energy Institute and EVN MOIT 	<ul style="list-style-type: none"> Build database on water resource balance by river basin Collect data on hydro regime Check available data on hydro potential of river 	MARD
2. Study of hydropower potential	<ul style="list-style-type: none"> EI of EVN 	<ul style="list-style-type: none"> Identify most likely locations of hydropower projects on rivers 	
3. Prepare hydropower components in PDP	<ul style="list-style-type: none"> EVN EI, PECCs DOIT, PPC, MOIT 	<ul style="list-style-type: none"> EVN and MOIT draft power development strategy and PDP DOIT and PPC develop provincial PDP 	Government, PPC, MOIT
4. National SHP	<ul style="list-style-type: none"> PECC1, MOIT 	<ul style="list-style-type: none"> Prepare SHP plan for Vietnam 	MOIT
5. Provincial SHP	<ul style="list-style-type: none"> EI, Institute of Water Resource Planning, and institutions 	<ul style="list-style-type: none"> Prepare SHP plan for provinces 	DOIT, PPC, MOIT
6. Prefeasibility study for individual projects	<ul style="list-style-type: none"> Funded by investor, conducted by EVN EI, PECCs, and others^a 	<ul style="list-style-type: none"> Produce prefeasibility report on project construction 	DOIT, PPC
7. Feasibility study	<ul style="list-style-type: none"> EVN EI, PECCs, and others 	<ul style="list-style-type: none"> Produce feasibility report 	DOIT, PPC
8. Technical design	<ul style="list-style-type: none"> EVN, PECCs, and others 	<ul style="list-style-type: none"> Produce technical design report 	Project owner
9. Cost estimate	<ul style="list-style-type: none"> EVN, PECCs, and others EIA team 	<ul style="list-style-type: none"> Develop investment proposal Produce EIA report 	<ul style="list-style-type: none"> MONRE approval of EIA for large projects MOIT approval of EIA for large and medium projects PPC approval of EIA for small projects
10. Construction	Construction company	<ul style="list-style-type: none"> Construction of reservoir, dam, roads, transmission lines, pipelines, canals, resettlement areas 	Project owner, supervisor
11. Operation	Hydropower plant management board	Power generation, water management, maintenance	

Source: Adapted from Suhardiman, de Silva, and Carew-Reid (2011).

Note: DOIT = Department of Industry and Trade; EI = Energy Institute; EIA = environmental impact assessment; EVN = Electricity Vietnam; MARD = Ministry of Agriculture and Rural Development; MOIT = Ministry of Industry and Trade; MONRE = Ministry of Natural Resources and Environment; PDP = Power Development Plan; PECC = Power Engineering Consulting Joint Stock Company; PPC = Provincial People's Committee.

a. Consulting studies are also provided by Water Resources University, Institute for Hydropower and Renewable Energy, Thuy Loi Transferring Technology and Consultant JSC, Investment Company Shares and Energy Development Vietnam, HECC Construction Technology and Hydroelectric Consulting Corporation, Center of Transferring Technology and Consultant Energy, Consultancy Company of University of Civil Engineering, and Consultancy Company Song Da.

Decree 112/2008/ND-CP (October 2008) is an important legislative document that stipulates the sustainable development of reservoirs with due account for all water users and functions, including environmental flows downstream of the reservoir. This requirement is reiterated in the Law on Water Resources in which the maintenance of a minimum flow is required under Articles 53 and 54. An overview of relevant decisions and decrees is given in box 2.1.

If a river basin crosses provincial boundaries, the different provincial DOITs will need to cooperate, which may lead to conflicts of interest and delays due to a more complicated planning process.

Private companies can propose a plan to construct and operate a single or a series of SHP plants. The DOIT assesses the plan from a technical standpoint and advises the PPC. The PPC provides formal approval of the plan for construction and operation. The EIA or EPC process is required to be implemented according to Decree 29/2011/ND-CP.

Several other agencies are critical at key stages of the hydropower master plan and project processes at all levels. The National Power Transmission Corporation is particularly important in small projects for ensuring connection to the national grid through input and investment in transmission line connections. The Electricity Regulatory Authority of Vietnam, established under MOIT, plays an important role in the project investment phase by setting the price that EVN pays to generators, licensing operators, and facilitating power buying and selling contracts. It also plays a role in appraising provincial power development plans (Suhardiman, de Silva, and Carew-Reid 2011).

Management and Operation

Hydropower companies manage and operate the cascade and its hydropower plants. They work according to operating rules that are approved either by MOIT or by the PPC. For instance, the operating rules for Nam Chien 2 are set forth in MOIT Decision 4385/QD-BCT

BOX 2.1 REGULATIONS AND LEGISLATION REGARDING HYDROPOWER DEVELOPMENT IN VIETNAM

- Decision 95/2001/QD-TTg (Prime Minister), June 22, 2001: Approval for electricity development planning from 2001 to 2010, taking into account needs through 2020.
- Document 923/CP-CN (Government), August 6, 2002: Prime minister entrusts Ministry of Industry with the approval process for planning on small rivers that are not included in national hydropower planning.
- Decision 3454/BCN (MOIT), October 18, 2005: Approval for small-scale hydropower planning.
- Decree 112/2008/ND-CP (Government), October 20, 2008: Prescribes the management, protection, and integrated exploitation of resources and environment of hydropower and irrigation reservoirs.
- Decree 120/ND-CP (Government), December 1, 2008: River Basin Management.
- Decree 41/2010/TT-BCT (MOIT), December 14, 2010: Method for Electricity Price Identification (for hydropower projects with capacity greater than 30 MW).
- Decision 1208/2011/QD-TTg (Prime Minister), July 21, 2011: Approval for electricity development planning from 2011 to 2020, taking into account needs through 2030.
- Circular 43/2012/TT-BCT (MOIT), December 27, 2012: Regulation for planning, investment in, and operational management of hydropower projects.
- Law No. 17/2012/QH13 on Water Resources: Management, protection, exploitation, and use of water resources, as well as the prevention of, combat against, and overcoming of harmful effects caused by water.

**PHOTO 2.2 NAM CHIEN 1 HYDROPOWER PLANT
RESERVOIR LAKE**



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of September 2009. In addition to rules for hydropower generation, the decision also covers flood mitigation, dam safety, and minimum flows. The following persons and organizations are responsible for implementing the decision:

- Chairperson of the Son La PPC
- Chief of the Ministerial Office
- General Inspector of the Ministry
- Directors of the Ministry Departments
- Chairperson of the Son La Provincial Steering Committee for Flood and Storm Prevention and Control and Rescue
- Director General of the Northwest Energy Investment and Development Joint Stock Company.

With regard to the management of the river basin and sub-basins as a whole, the PPCs are administratively responsible for daily activities, including the operation of its assets. DARD manages provincial structures such as irrigation dams and canals and drainage infrastructure. DONRE manages environmental, water, natural, land, and mineral resources. The daily operation and management of irrigation and drainage projects is often executed by irrigation and drainage management companies, overseen by DARD. Such companies operate water distribution systems down to the point at which water is delivered to a “district.”

With respect to the river sub-basins belonging to the Red River Basin it is important to mention the existence of Red River Basin Organizations. Their main objective is to improve integrated river basin planning by developing plans, monitoring implementation of those plans, and promoting coordination between sectors and administrative levels.

Note

1. GIZ wind energy project, <http://www.renewableenergy.org.vn> accessed October 2012.

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Descriptions of the Small-Scale Hydropower Cascades

The six studied rivers are situated in the northwestern mountainous part of Vietnam: Ngoi Xan and Nam Tha in Lao Cai Province; Nam Hoa, Nam Chien, and Sap in Son La Province; and Pho Day in Tuyen Quang Province (map 3.1). All rivers are part of the Red River Basin, except for Nam Hoa, which is part of the Song Ma River.

Each of the six basins contains a cascade of several small-scale hydropower plants with power capacities ranging from several to 32 megawatts (MW) (table 3.1). A medium-large hydropower plant—Nam Chien 1—is also under construction, with 200 MW capacity. The 29 small-scale hydropower (SHP) projects all together will



MAP 3.1 OVERVIEW MAP OF THE SIX STUDIED CASCADES

TABLE 3.1 OVERVIEW OF STUDIED RIVERS AND SMALL-SCALE HYDROPOWER PROJECTS

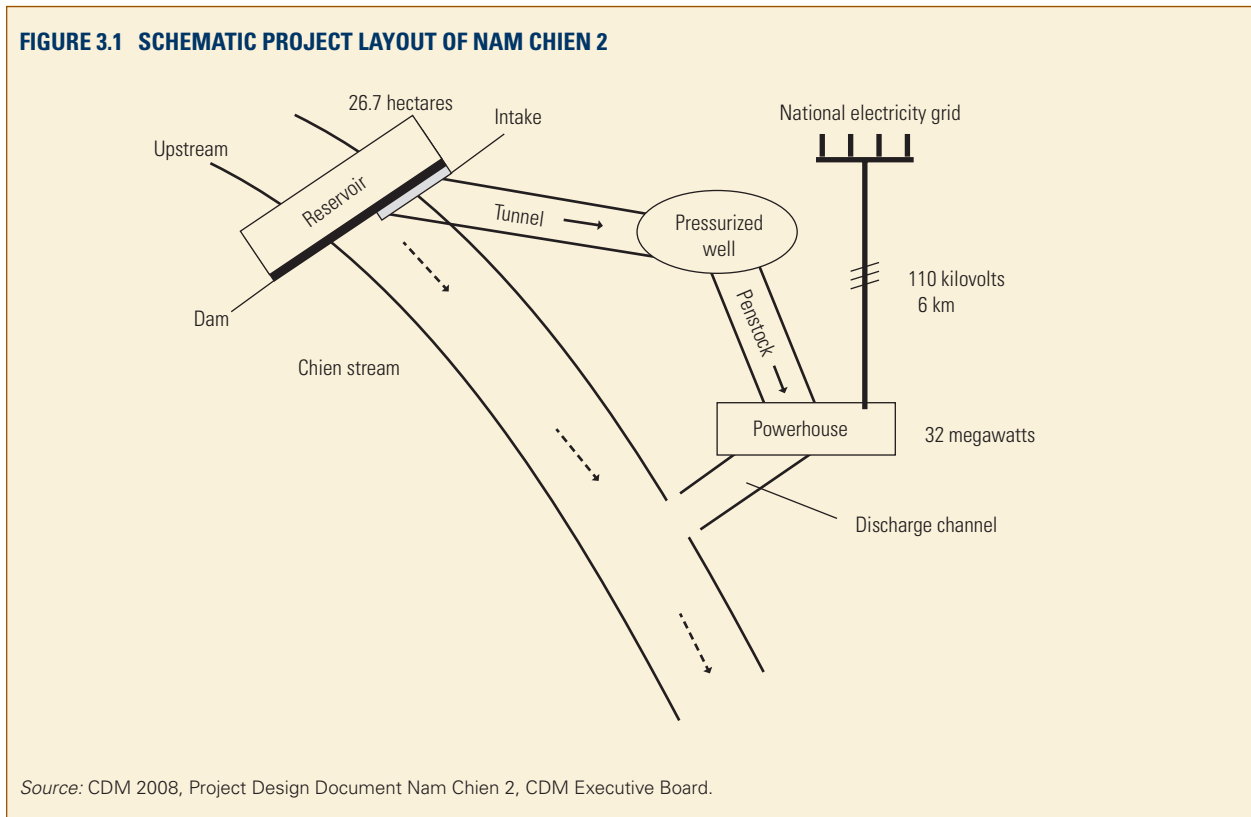
River	Number of small-scale hydropower projects				Total future maximum installed capacity (MW)
	Operational	Under construction ^a	Planned	Total	
Chien	2	1	0	3	54 + 200 ^b
Nam Hoa ^c	0	2	0	2	26
Nam Tha	1	3	5	9	58.9
Ngoi Xan	3	2	1	6	53.7
Pho Day ^c	0	1	1	2	21
Sap	1	4	3	8	63.4
	7	13	10	30	256 + 200

a. As of April 2013.
 b. Nam Chien 1.
 c. Not included in the detailed analysis.
 Source: World Bank.

have only slightly more capacity (256 MW) than Nam Chien 1. A comparison of the multiple impacts from the 29 SHP projects with the impact solely from Nam Chien 1 can provide useful insights into the cumulative impacts of SHP cascades (see chapter 5).

Seven projects fall under the Renewable Energy Development Program for financing: Sung Vui and Can Ho (Ngoi Xan River), Nam Tha 4 and 5 (Nam Tha River), Nam Hoa 2 (Nam Hoa River), Pa Chien (Chien River), and Hung Loi 1 and 2 (Pho Day River). Another four projects are currently

FIGURE 3.1 SCHEMATIC PROJECT LAYOUT OF NAM CHIEN 2



Source: CDM 2008, Project Design Document Nam Chien 2, CDM Executive Board.

under review by the Vietnamese authorities. The remainder of the 29 projects are financed through various public or private sources.

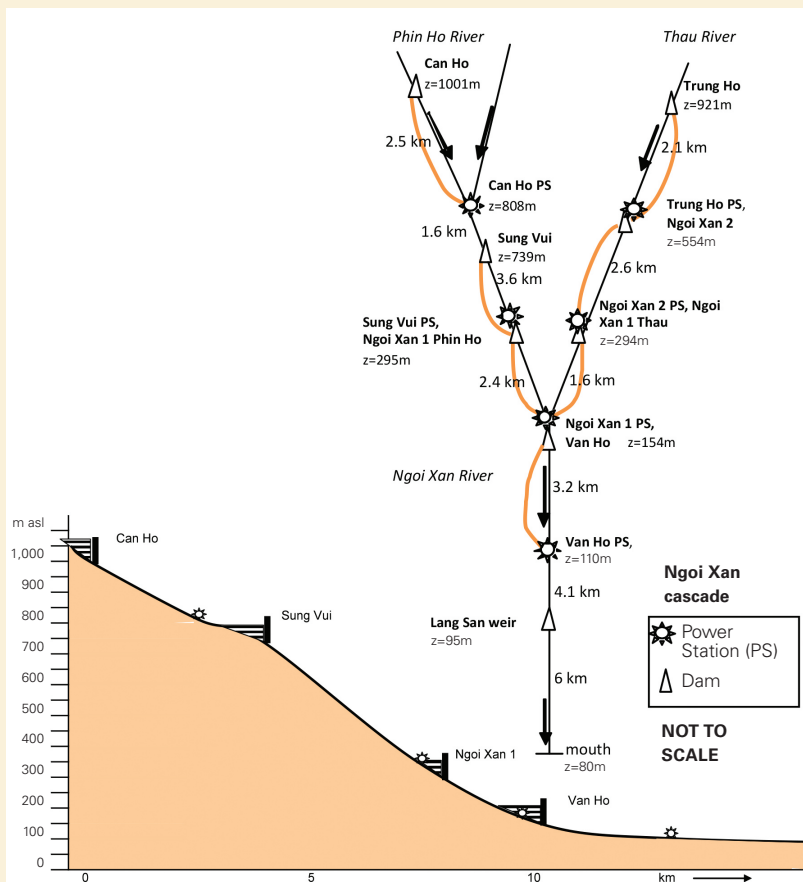
The hydropower plants all have virtually the same layout, as shown in figure 3.1. All plants divert water from the river to the powerhouse by channel, tunnel, and penstock. In most cases, the rivers are diverted over several kilometers. The generated electricity is supplied to the national grid through transmission lines. Most dams also involve a reservoir, although most reservoirs are quite small in volume compared with mean annual runoff and capable only of daily regulation (providing power for peak needs). The projects also include the construction of new roads and auxiliary resources, such as a powerhouse, a transmission station, and other facilities. Most of the cascades have dams in series, except for Ngoi Xan where some of the plants are placed in parallel on two contributing streams (figure 3.2).

PHOTO 3.1 NAM THA 6 DAM



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FIGURE 3.2 CROSS-SECTION AND PLAN VIEW OF NGOI XAN CASCADE



Source: World Bank.

Note: Dams not to scale; z = altitude in meters above mean sea level.

Approach, Methods, and Definitions

Overall Approach

The approach to the study of the small-scale hydropower (SHP) cascades consisted of data collection, field visits, desk study, and the application of a number of assessment methods and simulation models. The modeling approach was chosen based on the type of decision making and issues relevant for three different end users: (1) operators and developers of SHP, (2) planners and regulators of SHP, and (3) policy makers (table 4.1). For the hydropower operators the most important issues are

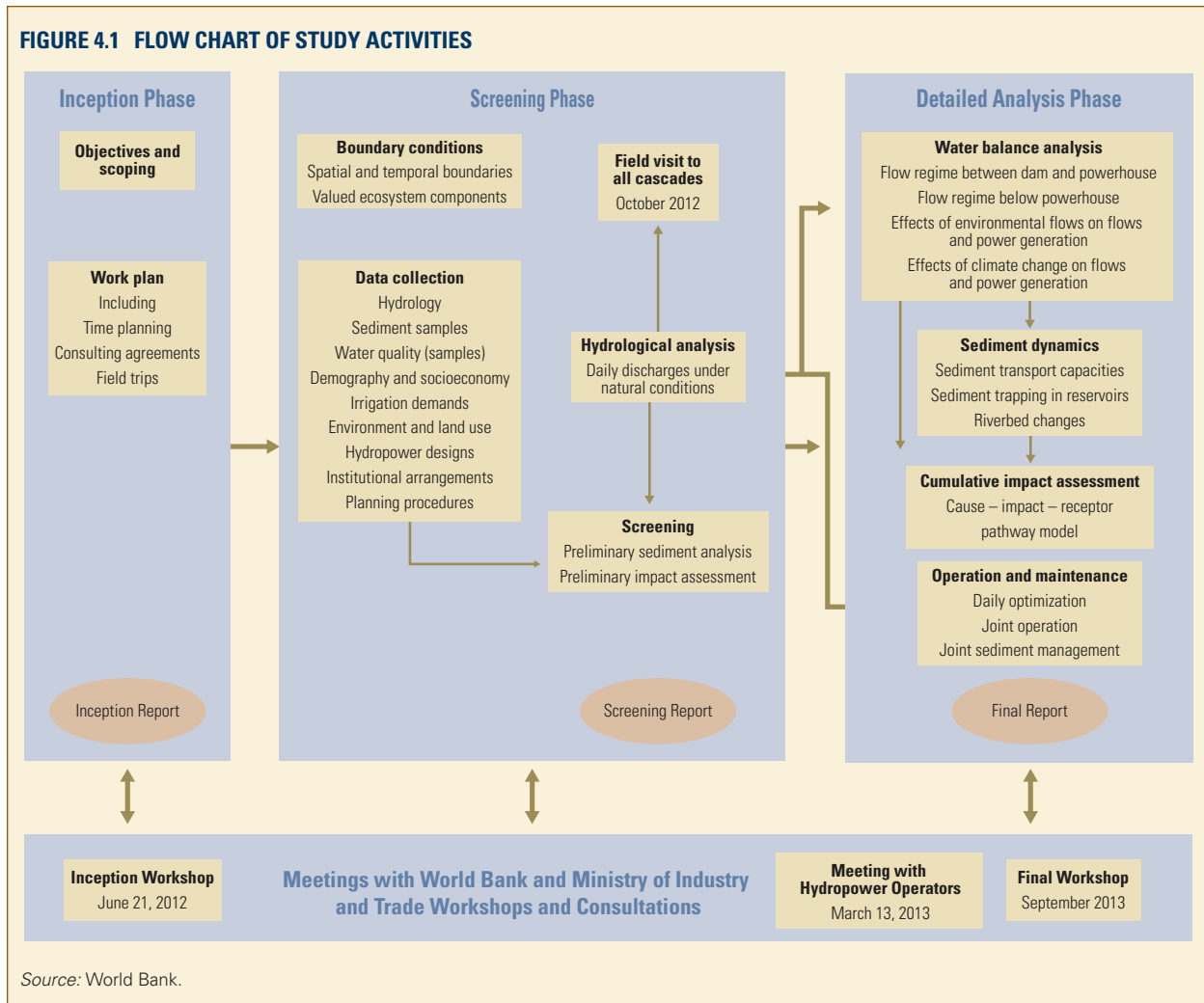
joint operation, joint sediment management, and environmental flow releases. Because practically all plants have daily peaking, the models used to study these issues have time steps of hours. At the provincial level the types of decisions include SHP cascade design, river basin management, and associated water allocation issues. Thus, a water balance model that works with daily time steps is sufficient. For the national policy-making level a daily model was used to provide insight into long-term issues such as climate change and environmental flow legislation and regulation. The general

TABLE 4.1 END USERS OF THE STUDY

Main end-user groups	Type of decision	Issues	Modeling approach	Time step
Operators and developers	<ul style="list-style-type: none"> • Design • Operating rules and maintenance 	<ul style="list-style-type: none"> • Operation optimization including joint operation • Sediment management • Environmental flow releases 	Short-Term Hydro Operation Planning model; Powel Sim (a computer program for short-term hydropower planning)	Days, hours
Planners and regulators	<ul style="list-style-type: none"> • Cascade design • River basin management 	<ul style="list-style-type: none"> • Provincial SHP planning • Mitigating and preventing cumulative impacts according to strategic environmental assessment • Water allocation • Environmental and social monitoring 	Water balance model	Days
Policy makers	<ul style="list-style-type: none"> • Long-term planning, market, and others • Legislation 	<ul style="list-style-type: none"> • Climate change • Market liberalization • Environmental flow regulation 	Water balance model	Days

Source: World Bank.

Note: A more detailed overview of responsibilities for SHP planning is given in table 2.2.



work flow of the screening and detailed analysis is depicted in figure 4.1.

Screening

During the screening phase all relevant data on the hydropower projects as well as on river basin characteristics were collected. Sediment samples and water quality samples were collected during field visits to each of the river basins. Boundary conditions for the analysis were defined with respect to geographical area, time horizons, and valued ecosystem components (VECs). The screening itself consisted of a preliminary analysis of sediment dynamics and a semi-quantitative preliminary impact assessment. After the screening phase four cascades were selected for the detailed analysis phase.

Hydrology

The main objective of the hydrological analysis was to assess the natural water availability in the various rivers on which the SHP plants are located. Time series of daily discharge were generated, either based on historical series or representing as closely as possible the hydrological conditions in the basins and sub-basins. Series were produced for both the main river and for locations between control structures such as the reservoirs and powerhouses.

For three cascades (Ngoi Xan, Sap, and Pho Day) rainfall-runoff modeling was applied, using the Hydrologic Engineering Center–Hydrologic Modeling System in combination with Watershed Modeling System software to derive the basin boundaries and drainage pattern.

Discharges for the other three cascades (Nam Tha, Nam Hoa, and Nam Chien) were derived from daily series measured inside the same basin, with a transposition factor.

Water Balance Analysis

A water balance was constructed for the four cascades studied in the detailed analysis phase, simulating the daily flows between the dam and powerhouse, and downstream of the powerhouse of each SHP plant. The results of the water balance were used to assess the effects of the hydropower generation on the river flows, as well as to analyze various levels of environmental releases on flows and annual power generation. The water balance included any other water demands in the catchment, such as for irrigation. The water balance model was also used to study the impact of a change in precipitation due to climate change on river flows and power generation.

Inflowing terms of the water balance included (1) daily discharges resulting from the hydrological analysis, (2) outflows from upstream dams and powerhouses, (3) additional runoff from the relevant catchment area, and (4) irrigation demand (negative) for the upstream catchment area. Outflowing terms of a reservoir included (1) environmental flow releases from the dams (if any), (2) discharge into the turbine for electricity production, and (3) spills if maximum levels are exceeded. The reservoir water balance was calculated with daily time steps for the time series available. Within-day variation was therefore not included, but was analyzed separately using the optimization models (see section on optimization modeling in this chapter). Evaporation, precipitation, and infiltration on or from the reservoir were omitted because these values are assumed to be quite small (most reservoir areas are smaller than five hectares).

Power generation was calculated per time step (day) by taking into account head loss due to friction and efficiency of the turbine, depending on the type of turbine. The model was validated by comparing the modeled annual energy generation with the estimated energy generation listed in the SHP design documents. A high correlation ($R^2 = 0.997$) between the model results and the specifications from the SHP developers was found.

Sediment Dynamics

The water balance results served as an essential input for assessing the effects of the dams on sediment dynamics. A modeling approach was set up using the river topography, sediment yield from the watershed, sediment transport, reservoir sedimentation, and riverbed morphology and composition. Based on an estimation of natural sediment yields from the catchment areas and using the changes in river flows, sediment-transport capacities were analyzed for all river segments in the cascade. In combination with estimated sediment trapping in reservoirs, potential sediment undersupply or overload was calculated for the river segments.

The main sources of data included those reported from SHP project documents, field observations (bed composition, elevations using global positioning system), maps, and Space Shuttle Topographic Mission data. These data are not highly accurate, but are sufficiently reliable for the intended analyses.

Network Approach for Cumulative Impacts

The cumulative impact analysis used a systematic procedure for identifying and evaluating the significance of effects from multiple activities that stem from the SHP cascade system itself and any other developments (including plans and policies) in the past, present, and future. The analysis was based on a network methodology that identifies causes, impact pathways, and consequences, that is, cause-and-effect chains from drivers and stressors to receptors (or VECs). VECs and boundaries are defined below. The network approach links activities and impacts on both the land (including the terrestrial ecosystem) and in the river (including the aquatic ecosystem). The main land-riverine interactions are outlined in box 4.1.

What Are Cumulative Impacts?

Cumulative impacts are impacts that result from incremental changes caused by other past, present, or reasonably foreseeable actions together with the project (Walker and Johnston 1999). Assessing cumulative impacts requires more than just adding up all impacts from individual projects or developments. Sometimes the total effect is larger than the sum of individual impacts because each project, as well as each impact, can interact with the others.

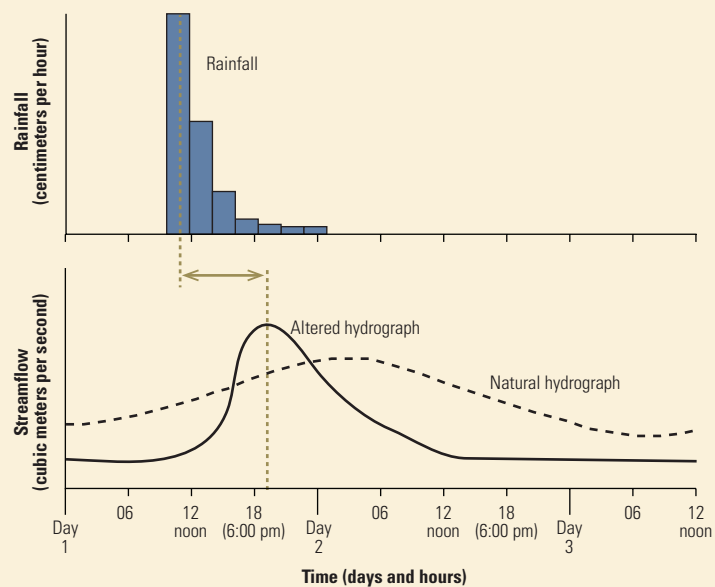
BOX 4.1 LAND AND WATER INTERACTIONS IN RIVER BASINS

Human processes shaping land and water use within a river basin affect its geophysical processes, such as water quantity and quality as well as erosion, and thus affect the riparian and aquatic ecosystems (Loucks, Bain, and Pendall 1999). Consequently, the amount of, and rate of change in, forested areas versus agricultural and urban areas affects these parameters. In three of the study basins (Ngoi Xan, Chien, and Sap) this change occurred largely before development of the SHP cascade, albeit in Ngoi Xan and Chien especially, the cascade exacerbates the impact. In Nam Tha, most of the cascade development is within pristine forest areas so the land use change stems mainly from the SHP cascade development.

As a general rule of thumb (derived from Loucks, Bain, and Pendall 1999), an acre of forest^a yields, on average, 12 percent of the precipitation falling on that land as surface runoff, and negligible soil is lost. An acre of typical agricultural land, like a corn field, yields 42 percent of the precipitation as runoff, and this surface flowing water typically carries away 73 tons of soil per year with the associated nutrients, fertilizers, chemicals, and animal waste. Urban land yields even greater runoff (Dunne and Leopold 1978). The rerouting of water overland due to different developments in river basins can, therefore, change stream flow or hydrological regime affecting the flow variability and the magnitude and frequency of floods. Furthermore, the rerouting of water by changes in land use causes very rapid movement of water and pollutants to streams. Figure B4.1.1 illustrates the change in stream flow regime, showing the effect of a rainfall event in natural and agricultural settings. In addition to greatly elevating stream flow peaks, rapid surface runoff diminishes groundwater levels that maintain the base flows of streams. This effect can greatly disturb the stream channel, stream hydraulics, water quality, the riverine habitat, and the aquatic and riparian ecosystems. The ecological integrity and complexity of flowing water systems depend on their natural dynamic character. Deviations from the natural flow regime can therefore impair water quality, ecosystem functions, and characteristics of aquatic and riparian environments (Poff and others 1997).

a. There are, of course, differences between various forest systems.

FIGURE B4.1.1 SAMPLE HYDROGRAPHS



Source: Bain and Loucks 1999.

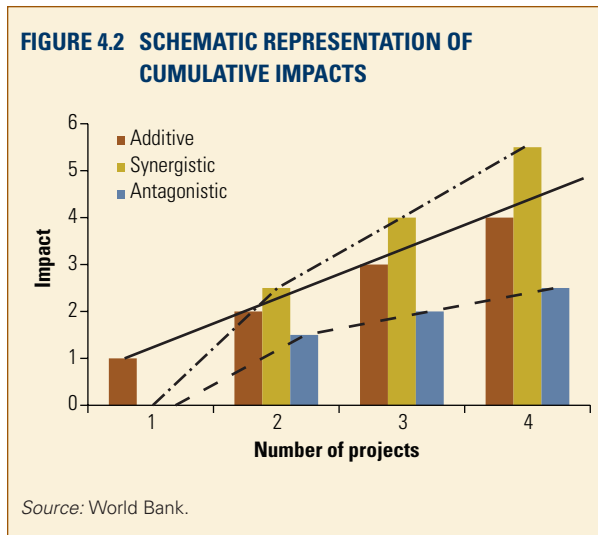
Note: Two storm event hydrographs showing a stream flow response to rainfall in settings dominated by surface runoff from land in human use (altered hydrograph) and undisturbed land (natural hydrograph).

However, one project added to another can also lead to less severe cumulative impacts than expected: for instance, the construction of a second reservoir upstream of a dam can reduce the sedimentation rate of the downstream reservoir, thereby lengthening its useable lifetime.

Cumulative impacts can occur through different interactive pathways (Bain, Irving, and Olsen 1986). Three basic interactions can be discerned:

- Strictly additive: The sum of the individual impacts from the project(s) and other actions equals the total impact.
- Synergistic: The total impact is more than the sum of the individual impacts of each project.
- Antagonistic: The total impact is less than the sum of the individual impacts of each project.

Figure 4.2 illustrates the effect of these different interactions on the overall total impact. The solid line denotes



a strictly additive effect: the impact of two projects is twice the impact of one. The dash-dot line shows the synergistic cumulative effect: the net effect is more than the sum of its constituents. The dashed line shows an antagonistic cumulative effect. Note that the cumulative impact does not become smaller as more projects are added to a cascade configuration (that is, more projects do not mean less impact). Even in an extreme antagonistic case, the total cumulative impact does not decline as more projects are added: the total impact of two projects is still more than of one project.

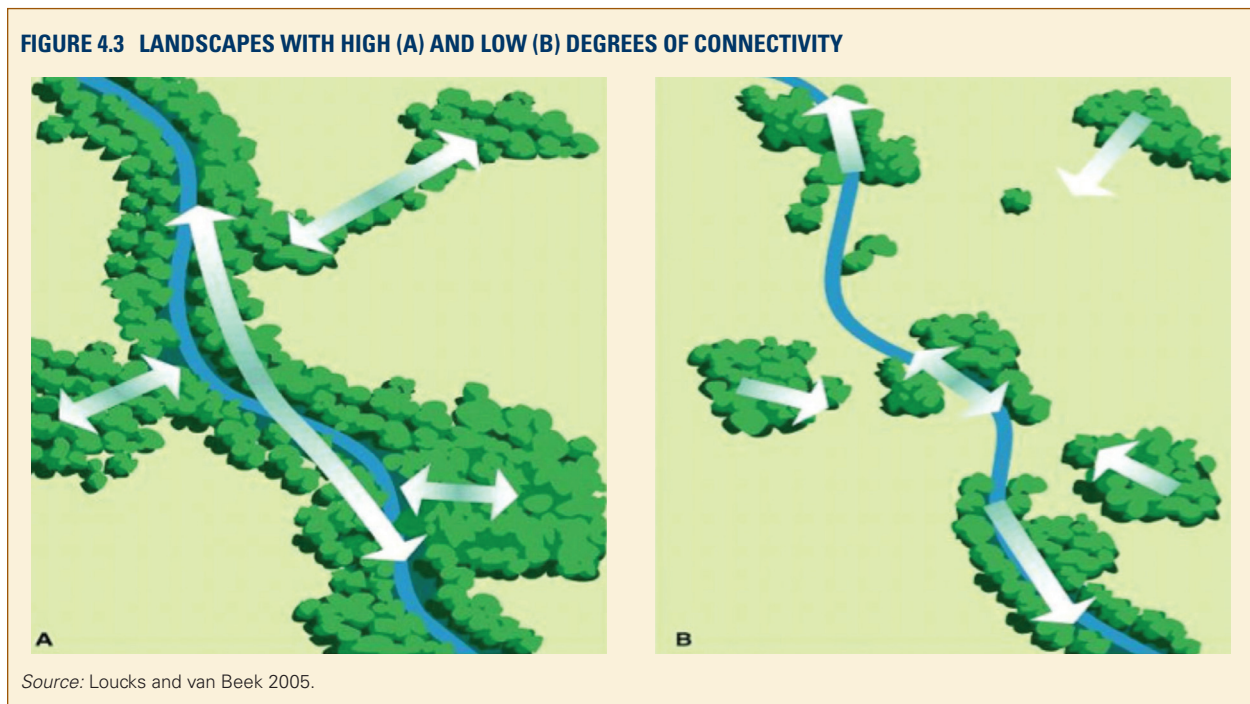
Cumulative impacts can also be related to passing certain threshold levels. For instance, some habitat loss would not have a large impact on wildlife. But when a certain threshold is passed, the entire population can be wiped out because the habitat becomes too fragmented (figure 4.3).

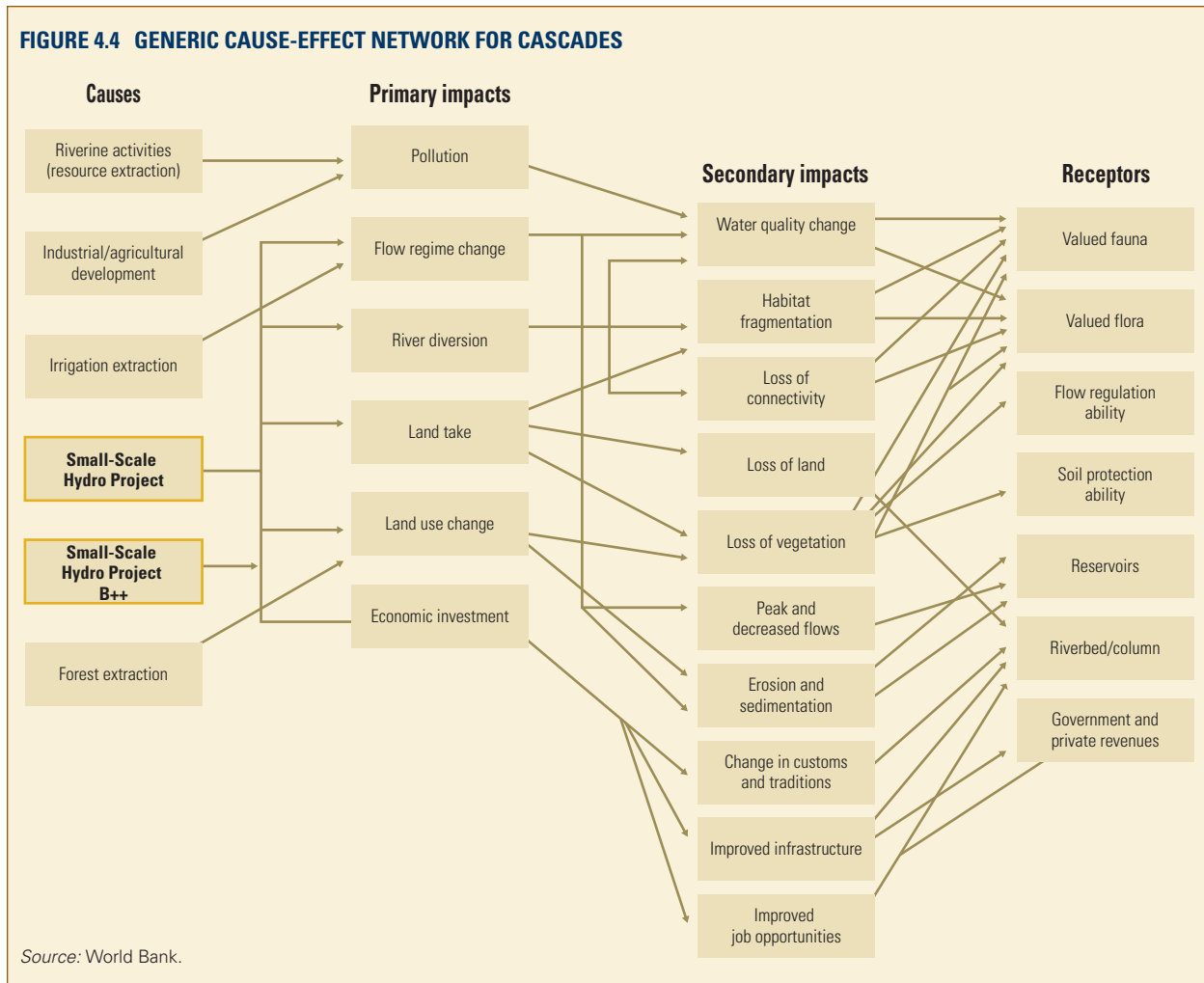
So cumulative impacts can occur in the following conditions:

- Under strictly additive, synergistic, or antagonistic interactions between projects and actions
- When the sum of the impacts exceed a threshold
- When individual impacts interact creating previously unforeseen impacts
- When impacts of multiple interventions are larger than the impact of a single intervention that meets the same objective as the multiple interventions together

An example of the latter is when the total impacts of a cascade of small-scale hydropower plants exceed those that would have occurred with a single dam with the same capacity.

This report analyzes the full range of cumulative impact pathways using a network approach,¹ together with consultation with and questions to stakeholders, to look more deeply into the relationships between the causes,





impacts, and VECs. This approach delves into more detail within and across the cumulative impact pathways. Inputs to the cumulative impact assessment were also derived from water balance modeling and from the sediment transport analysis.

How Were Cumulative Impacts Assessed?

The generic impact network used for all cascades is depicted in figure 4.4. The main components of the network are explained as follows:

- 1. Causes:** Stressors or drivers that impact the environment at large. For the studied cascades the most important and relevant stressors are (1) the occurrence of more than one SHP—the fact that it is a cascade system; (2) water demand for irrigation; (3) forest extraction; (4) riverine activities (resource extraction) and; (5) industrial and agricultural activities.
- 2. Primary Impacts:** Direct, often physical, impacts of the project. For SHP development the most important primary impacts are defined as (1) flow regime change, (2) river diversion, (3) land take, (4) land use change, and (5) economic investment. Irrigation water demand and forestry extraction, if present, impose additional effects on some of these primary impacts (portrayed in 4.4), while instream resource extraction and industrial and agricultural activities introduce an additional strong primary impact—pollution—that interacts with the rest of the impact pathway.
- 3. Secondary impacts:** Effects of the primary impact. Secondary impacts, in turn, impose effects on the receptors. For an SHP project, the most important and relevant secondary impacts are defined as (1) water quality change, (2) habitat fragmentation, (3) loss of connectivity (see box 4.2), (4) loss of land, (5) loss of vegetation, (6) reduced flows (in the river

BOX 4.2 THE IMPORTANCE OF CONNECTIVITY IN RIVERS

River basin connectivity is affected by dams and associated works, either as the result of direct dam impoundment or of ecosystem and forest clearing. Dams affect connectivity laterally, longitudinally, and vertically (Stanford and Ward 2001). Superimposed on these three space dimensions is the impact on ecological processes and functions in time (Ward 1989). Connectivity affects both ecosystem (functions and community structure) and population dynamics (migration, dispersal, fragmentation, and so on). Connectivity is illustrated in figure 4.3.

Healthy ecosystems depend on connectivity and also on the width of corridors. Thus, connectivity is a measure of how spatially continuous a corridor or a matrix is (Forman and Godron 1986); width is the distance across the stream and its zone of adjacent vegetation cover. A stream corridor with connections among its natural communities promotes transport of materials and energy and movement of flora and fauna (Loucks and van Beek 2005).

The connectivity issue relates especially to the potential population fragmentation, imposed by the dams, of the various fish species in the studied river basins. Fragmentation is related to both the downstream dispersal and the upstream migration of adult fish. Fragmentation of the adjacent terrestrial and riparian ecosystems may occur from the construction of roads, transmission lines, and other hydropower-related infrastructure.

stretch between dam and powerhouse within the cascades) and peak flows (within and downstream from cascades), (7) erosion and sedimentation, (8) change in customs and traditions, (9) improved infrastructure, and (10) improved job opportunities.

4. **Receptors:** In this study, receptors and VECs are defined in the widest sense of the term (see the next section and table 4.2 for a description). For an SHP project the most important receptors are (1) valued fauna (for example, important wildlife and aquatic species as well as species for consumption), (2) valued flora (important forest products²), (3) the ecosystem's flow regulation ability (or service), (4) the ecosystem's soil protection ability³ (or service), (5) reservoirs,⁴ (6) riverbed and water column, (7) project-affected people (PAP), and (8) government and private revenues.

Note that the economic investment pathway leads to positive impacts. Reduced erosion and sedimentation due to river diversion by an upstream reservoir will also be potentially positive for downstream reservoirs (less filling) while potentially negative for the riverbed and water column. These impact pathways are thus both positive and negative. All other pathways are negative. The economic investment pathway can potentially offset negative impacts to some degree (from land take and change in customs) on PAP as portrayed in figure 4.4.

Various impact pathways can even have a concerted or aggregated impact on a single receptor, even with only one SHP plant in place. For example, from figure 4.4 it can be deduced that aquatic fauna (various fish species)

are affected by changes in water quality, habitat fragmentation, connectivity, and peak and decreased flows. Flows even have a feedback loop on water quality (not portrayed in the pathway framework) that can further exacerbate the negative impact on the ecosystem.

Definition of VECs

The term VEC emerged, although with different wording, in Beanlands and Duinker (1983). In most literature, VECs are primarily conceived to be "environmental attributes" selected because of social, economic, aesthetic, or scientific concerns (Olangunju 2012). This biophysical emphasis has been observed by a number of researchers (Szuster and Flaherty 2002; Bérubé 2007; Noble 2010) and has primarily shaped the understanding of VECs in impact assessment, although different definitions are used depending on the context and jurisdiction of use. In contrast, some authors (for example, Shoemaker 1994; Coffen-Smout and others 2001) suggest the scope of VECs should extend beyond ecological issues to include social, economic, cultural, and natural components of the environment (Olangunju 2012).

During the screening phase, all possible impacts were listed, a selected number of which were included for detailed analysis because of their possible cumulative impacts (see table 5.1). Based on this selection and on thematic data, previous studies, and field observations, the VECs were defined using the biophysical approach to undertake a relative ranking of impact. However, in the detailed study the VECs were expanded to include social, economic, and cultural components following the

TABLE 4.2 VALUED ECOSYSTEM COMPONENTS

VEC	Description	Examples
Valued fauna	Wild animals (including fish), valued for economic reasons or high biodiversity value (threatened species).	Clouded Leopard in Ngoi Xan basin. The fish species <i>Spinibarbus hollandi</i> in the Chien basin. (Populations have declined due to over harvesting. This species is used as an indicator for ecologically healthy rivers.)
Valued flora	Forest and plant species and products valued for economic, medical, food, or high biodiversity reasons.	Rare, precious, and socially and economically important species can be found in all four basins. Rare and precious species are especially prominent in the Nam Tha basin with its pristine forest areas.
Ecosystem's flow regulation ability	The ability of the ecosystem to regulate rainfall runoff in a watershed. It is a function of forest and vegetation cover and quality, topography, as well as soil water permeability and water storage capacity.	The dense pristine forest in the upper part of the Nam Tha cascade has high value related to ecosystem flow regulation ability.
Ecosystem's soil protection ability	The ability to protect the soils in a watershed from erosion. It is a function of forest and vegetation cover and quality as well as topography.	The dense pristine forest in the upper part of the Nam Tha cascade has high value related to ecosystem soil protection ability, which is of special relevance because of the steep slopes.
Reservoirs	The physical capacity of upstream reservoirs in a cascade to store sediments and thereby reduce siltation of downstream reservoirs. This has an economic value because it increases the life span of the cascade. This is a VEC in the widest sense of the term, using the approaches of Shoemaker (1994) and Coffen-Smooth and others (2001).	Ngoi Xan, Nam Tha, and Chien cascades all have larger reservoirs upstream that trap sediment and bed load, positively affecting storage volumes of downstream reservoirs.
Riverbed and water column	This is a physical VEC at habitat and river reach level, which also affects the riverine environment and river and water use by humans. As such it also has biodiversity, social, and economic value. It is a function of flow regime, sediment transport dynamics, and topography. For instance, more erosion can lead to turbid waters, which can reduce the quality of drinking water.	The Nam Tha, Ngoi Xan, and Chien cascades all have reservoirs that significantly change sediment transport, which alters the structure and dynamics of the riverbed and water column. ^a
Project-affected people (PAP)	This is a social and economic VEC that is primarily a function of livelihood. ^b	In the Chien basin, loss of land is considered to be high. The negative impacts on the PAP are, however, largely counteracted by increased job opportunities and improved infrastructure.
Government and private revenues	Economic investment leading to energy production, improved infrastructure, and improved job opportunities.	Positive impacts on this VEC are expected in all cascades, but somewhat less in Sap than the others mainly because of lack of coordination among multiple owners.

Source: World Bank.

a. A major result is that riverbeds become more homogeneous and less dynamic. The available ecological niches in the river will be reduced, eventually affecting ecosystem composition and biodiversity (Petts 1984a, 1984b; Lillehammer and others 2009).

b. See box 4.3 for definition and assets of livelihood.

approaches of Shoemaker (1994) and Coffen-Smout and others (2001).

A questionnaire was developed for consultation with stakeholders on the importance of VECs. Although only a handful of questionnaires were completed, a general picture can be drawn. Biophysical components are seen

as the most important VECs. Forest and forest products (especially from primary forest) are most frequently seen as important, followed by soil and erosion control and river water use, and wildlife and fish fauna. Table 4.2 describes the VECs and gives examples from the studied river catchments.

Impact Ratings and Interaction Coefficients

In the detailed study impact ratings from 0 to 4 were used as follows (note that the impact can be both negative and positive as discussed earlier):

- 0 = no impact
- 1 = low impact
- 2 = moderate impact
- 3 = high impact
- 4 = very high impact

These impact values are set, throughout the impact pathway, at primary and secondary impacts as well as at receptors for each of the projects in the cascades. The impacts were scored based on a combination of expert judgment (for example, on habitat fragmentation and loss of connectivity), assessment of importance of VECs by the stakeholders (see definition of VECs), and modeling results derived from the water balance modeling

PHOTO 4.1 CONSTRUCTION OF PA CHIEN TUNNEL



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(flow regime change, peak and decreased flows, and the like). The final score for each of the receptors and VECs is the sum of the scores in the secondary impact, with its pathways leading to it, divided by the actual number of pathways affecting the VEC, so that the score remains

BOX 4.3 DEFINITION AND ASSETS OF LIVELIHOOD

Various definitions of “livelihood” have emerged that attempt to explain its complex nature. This report embraces the definition suggested by Chambers and Conway (1992):

A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living; a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term.

Livelihood assets can be categorized into the following five main groups (UNDP/IRP/ISDR 2005):

1. Human capital: Skills, knowledge, health, and ability to work
2. Social capital: Social resources, including informal networks, membership in formalized groups, and relationships of trust that facilitate cooperation and economic opportunities
3. Natural capital: Natural resources such as land, soil, water, forests, and fisheries
4. Physical capital: Basic infrastructure, such as roads, water and sanitation, schools, information and communication technologies; and producer goods, including tools, livestock, and equipment
5. Financial capital: Financial resources including savings, credit, and income from employment, trade, and remittances

SHP cascade development can have positive and negative impacts on livelihoods and thus on project-affected people (PAP). For simplicity, the focus in this study has been on two negative impacts—loss of land (natural capital) and changes in customs and traditions (human and social capital); and on two positive impacts—improved infrastructure (physical capital) and improved job opportunities (human and financial capital). Their impacts on PAP and their livelihoods are portrayed in figure 6.4.

between 0 and 4. Thus, the final score for each receptor is produced by the averaged sum of scores of the secondary impacts connected to the receptor through different pathways. Finally, the cumulative impacts on the VECs were evaluated as being synergistic, strictly additive, or antagonistic, as defined above. In those cases in which a synergistic impact is expected, an interaction coefficient is used in the calculation (see box 4.4).

Figure 4.5 shows an example of the calculation of the cumulative impact on the valued fauna in the Nam Tha River. The final score of 3.36 is the result of five secondary impacts: water quality change (score of 1), habitat fragmentation (4), loss of connectivity (4), loss of vegetation (3), and peak/decreased flow (2). The sum of these values is 14, which is divided by the number of pathways (5), giving a score of 2.8. However, because the impact on this specific VEC is considered to be synergistic at the cascade level, with an interaction coefficient set at 1.2, the final score becomes $3.36 = 1.2 \times 2.8$.

Each of the secondary impacts is calculated similarly based on the primary impacts, which, in turn, are based on the causes, according to the generic pathways (figure 4.5). One of those pathways is highlighted in figure 4.5, showing the impact of the cascade on two primary impacts leading to the secondary impact on habitat fragmentation.

The same approach was undertaken for all VECs in all cascades, including a scenario in which the SHP cascade

BOX 4.4 INTERACTION COEFFICIENTS

Two interaction coefficients can be selected to represent impact interactions between one project and any other project in the SHP cascade configuration. In the case of one pair of projects A and B, one coefficient would represent the effect of A on B and another the effect of B on A. When the interaction is synergistic the coefficient is positive and when antagonistic the coefficient is negative. Normally, a reasonable coefficient value range is between 2 (effect of A doubles the impact of B) and 0 (effect of A negates the impact of B). An interaction coefficient of 1 indicates no interaction effect, for example, a strictly additive cumulative impact (based on Bain, Irving, and Olsen 1986)

was not built. Most VECs were assumed to be subject to strictly additive cumulative impacts, so no interaction coefficient was used. Furthermore, PAP are affected by both positive and negative impacts, causing this VEC to behave somewhat antagonistically.

Based on the evaluation of the cascade projects in the selected rivers, the following types of cumulative impacts on receptors and VECs were used:

- Valued fauna: Synergistic with an interaction coefficient of 0.2.⁵
- Valued flora: Strictly additive.

FIGURE 4.5 EXAMPLE OF CUMULATIVE IMPACT CALCULATION FOR NAM THA VALUED FAUNA SHOWING PATHWAY FOR HABITAT FRAGMENTATION

Cause	Primary impacts	Impact score	Summed impact score	Number of pathways	Secondary impacts	Receptors
Instream activities	Pollution	2	3	3	Water quality change	1
Industrial activities	Flow regime change	1	8	2	Habitat fragmentation	4
Irrigation	River diversion	4	4	1	Loss of connectivity	4
Forest extraction	Land take	4	4	1	Loss of land	0
Cascade	Land use change	2	6	2	Loss of vegetation	3
	Economic investment	3	1	1	Peak/decreased flow	2
					Erosion/sedimentation	0
					Change customs	0
					Improved infrastructure	0
					Improved job opportunities	0
						+
					Sum of impact scores	14
					Number of pathways	5
					Interaction coefficient	1.2
					Final impact score	3.36

Source: World Bank.

TABLE 4.3 DEFINITION OF CASES

Case	Name	Description
0	Natural condition or reference case	Besides the natural discharge, abstractions for irrigation are included
1	Base case or cascade without environmental flow	Case 0 plus all SHP plants as planned. However, because of the uncertainty regarding environmental flows, no environmental flow requirements are included.
2	Environmental flow base case	Case 1 + environmental flow releases according to existing information from dam operators
3	Environmental flow Q_{95} case	Case 1 + Q_{95} releases for environmental purposes. The Q_{95} is determined separately for the wet (May–October) and the dry (November–May) seasons. The purpose of this analysis is to better understand the impacts on hydropower generation if releases from the dam to the river for environmental purposes are increased.
4	Climate change case	Case 1 + changed inflows due to the A2 climate change scenario (used by MONRE according to the IPCC scenarios; see table 7.2). Values for estimation of the percentage change in rainfall in 2050 are applied directly to the discharge series.

Source: World Bank.

Note: IPCC = Intergovernmental Panel on Climate Change; MONRE = Ministry of Natural Resources and Environment; Q_{95} = flow that is exceeded 95 percent of the time.

- Flow regulation ability: Strictly additive.
- Soil protection ability: Strictly additive.
- Reservoirs: Strictly additive (positive) for Sap cascade (long distance between the reservoirs) but synergistic for the others with an interaction coefficient of 0.1 (short distance between the reservoirs).
- Riverbed and water column: Strictly additive for Sap cascade (long distance between the reservoirs) but synergistic for the others with an interaction coefficient of 0.1 (short distance between the reservoirs).
- PAP: Antagonistic (both positive and negative secondary impacts influence the receptor). The positive and negative impacts are treated separately for the primary and secondary impacts but summed for the receptor.
- Government and private revenues: Strictly additive (positive).

As mentioned earlier, biophysical components were revealed in the stakeholder questionnaire to be the most important VECs. Forest and forest products (valued flora) was the category most frequently regarded as important, followed by soil and erosion control (soil protection ability), river water use (relates to both riverbed and water column, and PAP), and wildlife and fish fauna (valued fauna).

Boundaries and Scenarios Used in the Cumulative Impact Analysis

The character of this study is different from that of an official cumulative impact assessment, which would be executed ahead of time for a specific hydropower development plan for a large river and for which scenarios that include other sectors’ economic development would be highly relevant. Instead, the focus here is on providing an impact and optimization study of SHP development in cascades (see the section “Scope of the Study” in chapter 1). Because SHP plants are usually developed in small mountainous catchment areas, they are most often small diversion plants with relatively small storage. The mountainous character means that sectoral competition is generally low. Other functions are mainly related to forestry, small-scale irrigation, and industrial or agricultural development, as well as resource extraction from the river such as fishing and, to a lesser degree, mining.

Based on the above, the boundaries for the cumulative analysis were defined as follows:

- Other development sectors: Forestry extraction, irrigation, industrial and agricultural activities, and riverine resource extraction (mainly fisheries)
- Temporal: Dependent on scenarios (see below)
- Spatial: Variable, related to potential impacts on VECs (see below)

TABLE 4.4 TEMPORAL BOUNDARIES

Case	Temporal boundary	Approximate time scale
Reference case	Past	Pre-2012 (and preconstruction)
Base case	Present and near future	2012 + 10 years (construction and operation)
Environmental flow base case	Present and near future	2012 + 10 years (construction and operation)
Environmental flow Q_{95} case	Present, near, and intermediate future	2012 + 20 years (operation)
Climate change case	Distant future	2012 + 40 years (operation)

Source: World Bank.

The cumulative impacts were studied under various hydrological and water balance conditions, which allowed for a comparison between the natural situation, the impact of a cascade, the effect of environmental flows, and the potential effects of climate change (table 4.3). The effect of environmental flows was investigated under two different cases: one with flow releases according to current practice (based on information from operating rules) and one with a flow release of Q_{95} .⁶

The choice of Q_{95} was an arbitrary one and used only to illustrate the impacts on the flow regime and hydropower generation if releases from the dam to the river for environmental purposes were to be increased. The various scenarios lead to the different temporal boundaries that were set and investigated as part of the study, and are portrayed in table 4.4.

Note that the water balance model and its five selected scenarios primarily feed into the flow regime change impact pathway (figure 4.4). However, the temporal boundaries and time scales are assessed under the same conditions for the other impact pathways, for a consistent approach.

Finally, the temporal and spatial impact boundaries for the receptors and VECs were established as in table 4.5 and analyzed for each of the selected cascades (see also Cooper 2004).

As can be seen from table 4.5, the geographical boundaries vary according to the receptors and VECs. Temporal boundaries are uniform and relate to the time scales applicable to the different cases. Finally, other causes, drivers, and stressors were identified (derived from figure 4.4) that can induce additional cumulative effects through cause-and-effect chains.

Optimization Modeling

To assess whether joint operation could result in any improvement in operations or provide any other benefits, a comparison was made between each power plant maximizing its daily stand-alone revenues and maximizing the revenues of the entire cascade on an annual basis. The first situation is representative of today's operating rules; the second situation maximizes the revenues that could be obtained with complete knowledge of future river inflows over the year.

Natural flow series were used as input for the analysis using two different models.⁷

The simulation program Powel Sim was used to simulate the operation of a stand-alone project with existing operating rules, to maximize energy production within the given operational boundaries. Powel Sim is a water-course simulator that is bound to follow a production schedule hour by hour. It will follow this schedule as long as possible given the actual water inflow, remaining water stored in the reservoir, and availability of power generating units.

The optimization model SHOP (Short-term Hydro Operation Planning) was used for the ideal joint operation scenario. SHOP is a deterministic optimizer for short-term hydropower planning. It is based on successive linear programming, uses CPLEX as the solver, and uses absolutely certain information on inflows and prices for the whole year as input. SHOP also takes into account all the plants in a cascade and distributes the water and production in an optimal way within the cascade to maximize its total hydropower revenue.

TABLE 4.5 RECEPTORS AND VALUED ECOSYSTEM COMPONENTS AND THEIR GEOGRAPHICAL AND TEMPORAL IMPACT BOUNDARIES

Receptors and VECs	Geographical boundary	Temporal boundary (linked to the cases in table 4.3)	Other causes, drivers, and stressors possibly imposing cumulative effects
Valued fauna (wildlife and aquatic species)	Catchment and sub-basin area	Past, present, near-intermediate, and distant future	Mining, industrial development, irrigation, and forest extraction
Valued flora (for example, forest products)	Catchment and sub-basin area	Past, present, near-intermediate, and distant future	Mining, industrial development, irrigation, and forest extraction
Flow regulation ability	Project area for cascade and upstream catchment	Past, present, near-intermediate, and distant future	Forest extraction
Soil protection ability	Project area for cascade and upstream catchment	Past, present, near-intermediate, and distant future	Forest extraction
Reservoir (for small-scale hydropower or irrigation)	Project area for cascade and downstream irrigation weirs	Past, present, near-intermediate, and distant future	Irrigation and forest extraction
Riverbed and water column	Project area for cascade and downstream	Past, present, near-intermediate, and distant future	Irrigation and forest extraction
Project-affected people	Communes within or bordering project area	Past, present, near-intermediate, and distant future	None
Government and private economy	Commune, district, and province level	Past, present, near-intermediate, and distant future	None

Source: World Bank.

In the optimizations performed on the studied cascades, no constraints were put on SHOP except basic water-course model data such as turbine efficiency curves, reservoir curves, waterways, topology, and the like. Inflow statistics were given as input data along with prices. The reservoirs in the specific watercourses were so small that no endpoint conditions were given, except for the large reservoir in the Nam Chien watercourse. Hence, no water values (expected marginal value of saving water for later) were used for these cases.

Notes

1. There are various assessment methods and tools for cumulative impact assessment studies, including that outlined in World Bank (2012).
2. Assessed to be the most important VEC by the stakeholders in the questionnaire.
3. Soil and erosion control is highlighted as important in the stakeholder questionnaire.
4. Note that reservoirs as part of a hydro project are both a driver (cause) and a receptor.
5. The impact on valued fauna is synergistic mainly because cascade development exacerbates the impacts on migration and mobility of riverine and terrestrial animals. The impact on valued flora is additive because the impact is mainly related to the extra land area taken by more than one project.

6. Q_{95} denotes a river flow that is exceeded 95 percent of the time.
7. Because optimization programming requires substantial computing time, the models were run for a representative hydrological year. A year was considered representative if the annual runoff was close to the mean annual runoff for the whole time series and if there was no extreme runoff (neither very dry nor heavy flooding).

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Results of the Screening Phase

Activities during the Screening Phase

All six rivers were screened for potential significant cumulative impacts; in the second phase, four of the rivers were studied in more detail. The results of the screening helped identify the level of detail needed for the in-depth analysis of the selected rivers.

The screening phase started with a participatory workshop in which more than 50 representatives participated.¹ During the discussions valuable suggestions and comments were provided with respect to the objectives of and approach to the study, which in general was supported.

The provincial and district offices of various departments were visited in the screening phase to collect reports and data. During field work, all river basins were visited to obtain first-hand observations on construction sites, existing dams, and surrounding environmental conditions. Discussions were also held with operators, water quality and sediment samples were taken from the rivers, and local people were interviewed.

A desk study was performed to identify and describe all existing and reasonably foreseeable investments, plans, and activities (“stressors”) that have impacts on the river flow regime or its water quality in the six rivers. Potential receptors of negative and positive impacts from the operation of the stressors were also identified, including all valued ecosystem components that could be significantly affected. The nature of the impacts was described

and their scale qualitatively assessed. Furthermore, temporal and geographical boundaries were determined for the impact assessment²

Preliminary Impact Analysis

A preliminary analysis was conducted with respect to physical, environmental, and social impacts. During this analysis it became apparent that the small-scale hydro-power (SHP) facilities under study were built in small mountainous catchment areas where the sectoral competition for water is often low and water use is usually limited to small-scale irrigation (if present) and ecosystem services (such as fishing, flow regulation, and soil regulation). Of the 11 potential impact categories, 6 were selected for more detailed analysis in the next phase, because of their potential cumulative nature (table 5.1).

The screening also showed that larger impacts were found or expected within the cascade area as compared with downstream. The capacity of most reservoirs is small compared with mean annual flow volume. Hence, the flow regime downstream of the last powerhouse is comparable to the natural regime. However, because of peaking, the river’s daily flow fluctuations do increase. Similarly, changes in sediment dynamics are expected to occur downstream of the cascade.

The cascades exhibit significant differences with regard to the type of impact, as briefly discussed below.

TABLE 5.1 SELECTION OF POTENTIAL IMPACTS

Potential impacts	Findings during screening	Included in detailed analysis?
Temporary impacts during construction	Construction of the dam, tunnel, powerhouse, transmission lines, and the like requires access roads, material mining, tunnel blasting, excavation, and dumping leading to temporary erosion, vegetation damage, and other effects. Mitigating measures to reduce these impacts to the extent possible are stipulated in the environmental management plans for each SHP plant and the effects are assumed not to lead to permanent, cumulative impacts.	No
Impacts on grid system	Operation of the cascade may lead to instability of the power grid. This potential impact was not included because it was beyond the scope of the terms of reference for this study.	No
Impacts on greenhouse gas emissions	SHP cascades will generate renewable power with no greenhouse gas emissions; this power will displace part of the electricity otherwise supplied by fossil-fuel-fired power plants. Although this positively contributes to global environmental quality, it does not influence cumulative impacts on a local or regional scale.	No
Water quality (reservoirs and downstream)	All SHP plants have small reservoirs with very low residence times. Therefore stratification, eutrophication, or change in other water quality parameters is not expected to be significant, except for sediment transport (see sedimentation and erosion).	Yes
Sedimentation and erosion	Cumulative impacts on sediment and erosion generally result from interference with the sediment balance of the river caused by dam construction and reservoir operation.	Yes
Flow regime change	Dry season discharge will change significantly in most cascades because of peaking operations. Also, stream diversion is part of most SHP operations.	Yes
Ecosystem services	SHP facilities and secondary effects may have a cumulative impact on flow regulation of the watershed and soil protection.	Yes
Habitat fragmentation and loss of connectivity	SHP facilities and secondary effects may have a cumulative effect on habitat fragmentation and loss of connectivity for the terrestrial and aquatic environment. For the terrestrial environment this is related to land conversion while for the aquatic environment this is related to total length of the cascade as well as the number of individual projects and their diversions.	Yes
Social implications: Resettlement	Very few people need to be resettled because the reservoirs are small and mostly in uninhabited remote areas.	No
Social implications: Livelihood and local economy	Mostly ethnic minorities live in the project areas. These people typically depend on the forest or capture fisheries for large parts of their livelihood. Therefore, the cumulative impact on project-affected people needs to be considered.	Yes
Other developments and plans	Most of the cascades are being developed in remote mountainous areas with little economic activity. The other major use of water is for irrigated agriculture. In Pho Day, mining and industrial activities also exist or are planned.	Yes

Source: World Bank.

Ngoi Xan

The cascade in the Ngoi Xan River basin consists of six SHP plants on two tributaries, the Thau and Phin Ho streams, and one on the main Ngoi Xan River. Both upstream tributaries are relatively steep and are surrounded by mountainous areas with elevation ranging from 700 meters to 1,000 meters. Downstream, the power cascade slopes are gentler and agricultural activities increase. The cascade scores high on physical and environmental impacts and relatively low on social impacts. This is understandable because the cascade area is relatively sparsely populated and still has an abundance of valued ecosystem components.

Nam Tha

From a total of nine identified SHP plants, three are under construction and one has been operational since 2010. The Nam Tha stream is a tributary of the Ngoi Nhu River, which discharges into the Red River. Most of the upstream areas, where the three projects under construction are situated, are very remote, scantily populated, and densely forested. The characteristics and impacts in Nam Tha are similar to those in Ngoi Xan, but the Nam Tha cascade overall has higher physical and environmental impacts (because the development is in pristine forest areas). The Nam Tha cascade scores very high on physical and environmental impacts and relatively low on social impacts.

Pho Day

The cascade in the Pho Day River consists of two SHP plants, both yet to be constructed. The terrain of the Pho Day River is not as steep as Ngoi Xan and Nam Tha, and the surrounding valleys are more gently sloped. Most of the area within or close to the planned cascade and downstream is highly deforested as the result of human activity and is relatively densely populated. Pho Day scores low on physical and environmental impacts, but higher on social impacts.

Nam Hoa

Nam Hoa River is located upstream of the Ma River, which flows downstream through Lao P.D.R. and turns back into Vietnam where it flows as the Song Ma River and eventually into the Gulf of Tonkin. The cascade consists of two SHP plants, both of which are under construction. The river reach where the cascade is situated has a relatively mild slope, and the adjacent lands are highly deforested as the result of human activity. Distances between dam and powerhouse are very short, so the cascade will not significantly divert the river. Nam Hoa scores moderate to low on all impacts.

Nam Chien

Nam Chien is a tributary of the Da River. The cascade consists of two SHP plants (Nam Chien 2 and Pa Chien) as well as one large 200 MW hydropower dam and reservoir (Nam Chien 1). Nam Chien 1 and 2 are operational while Pa Chien is still under construction. The upper reach where Nam Chien 1 and 2 are situated is relatively steep, as are the surrounding valleys and tributaries. The lower reach, where Pa Chien is located, is much more gently sloping. Most of the area within the cascade and downstream is highly deforested as the result of human activity. Nam Chien scores high on physical and environmental impacts, but especially in the downstream section, people are affected too.

Sap

The Sap River cascade is different from the others in many respects. The cascade has eight planned SHP plants, is very long, and runs through three distinct landscapes. It starts just below a mountainous area. A major part of the cascade is located in the middle reaches consisting of a wide valley with considerable human settlement and agricultural land use. Therefore, environmental impacts are assumed to be low. The most striking feature is that the Sap River carries a large amount of fine sediment, coming from the weathering of ferrous rocks and

erosion of cultivated hill slopes. Sedimentation rates for the reservoirs are therefore expected to be high. Without regular sediment flushing, the live storage of four of the reservoirs will be severely reduced within a couple of years.

Opportunities for Joint Operation

During the screening phase opportunities for joint operation and optimization were identified. The six basins show considerable variety in SHP configuration. Most often the cascades are a combination of reservoirs with daily (and sometimes weekly) storage and river diversion. Based on the initial analysis, three cascades were considered to be promising for optimization of power generation through joint operating rules (Ngoi Xan, Nam Tha, and Chien Rivers), two moderately promising (Sap and Pho Day Rivers), and one of limited opportunity (Nam Hoa River).

Selection of Cascades for Detailed Study

The following cascades were selected for detailed studies of cumulative impacts and potential optimization of operating rules:

- **Ngoi Xan:** Among the basins with highest potential for optimizing joint operation through one owner. Water diversion in the SHP cascade creates an almost dry riverbed throughout the system.
- **Nam Tha:** High cumulative impact risk because the cascade is being developed in pristine natural areas. Water diversion in the SHP cascade creates an almost dry riverbed throughout the system.
- **Nam Chien:** A large dam (200 MW) upstream of the SHP cascade provides potential opportunities for joint operation. Water diversion in the cascade creates an almost dry riverbed throughout the system.
- **Sap:** Multiple ownership of the nine SHP plants in the system yields both challenges to and opportunities for revenue sharing through joint operation of the cascade.

The planned Pho Day cascade consists of two SHP plants: Hung Loi 1 (under construction) and Hung Loi 2. Because it is uncertain that Hung Loi 2 will be constructed and because the two SHP plants are situated very close to each other, cumulative impact risks are thought to be low. Therefore, this cascade was not studied in detail.

The Nam Hoa cascade also consists of two SHP plants, both of which are currently under construction

PHOTO 5.1 NAM HOA DAM UNDER CONSTRUCTION

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(photo 5.1). Because the powerhouses are close to the dams, the length of river diversion is very short. Cumulative impacts are not likely except for the risk to some aquatic species from loss of connectivity. Downstream impacts relate primarily to the lowermost dam and are therefore not cumulative. It is highly unlikely that changes in dry season flow patterns are discernible at the Lao P.D.R. border. Therefore, the cumulative impact score is thought to be low and does not warrant further detailed analysis.

Notes

1. Participants comprised representatives of the Ministries of Industry and Trade, Resources and Environment, and Agriculture and Rural Development; developers who were part of the Renewable Energy Development Program; the Provincial People's Committees; the provincial Departments of Industry and Trade, Natural Resources and Environment, and Agriculture and Rural Development from Lao Cai, Son La, and Tuyen Quang; Electricity Vietnam; and other relevant stakeholders.
2. The initial list of valued ecosystem components and boundaries was adjusted after the screening phase to make it more applicable for the detailed cumulative impact analysis.

Cumulative Impact Analysis of Small-Scale Hydropower Cascades

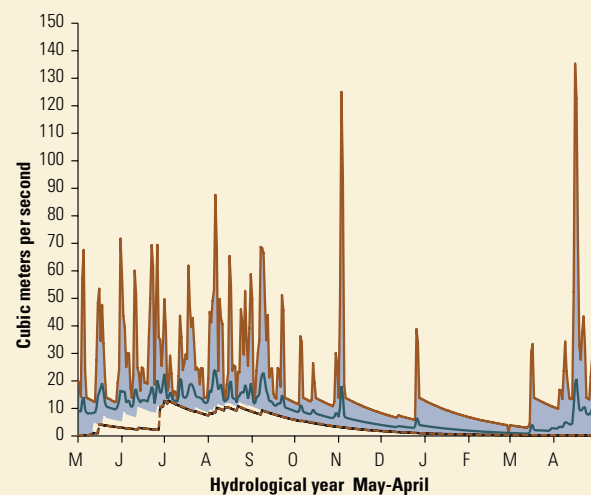
Cumulative Impacts on Flow Regime

To analyze the impact of the cascades on river flows, a model was set up to describe the discharge modified by the dams' operations. The general picture for all cascades is similar: flow regimes are altered significantly between the dam and the powerhouse because water is diverted through the tunnel and penstock to the powerhouse (see figure 6.1) This diversion leads to long periods of zero flows during the better part of the year (more than 300 days per year). Only high discharges during the rainy season are spilled below the dam, as can be seen by the flow duration curves (figure 6.2). The flow duration

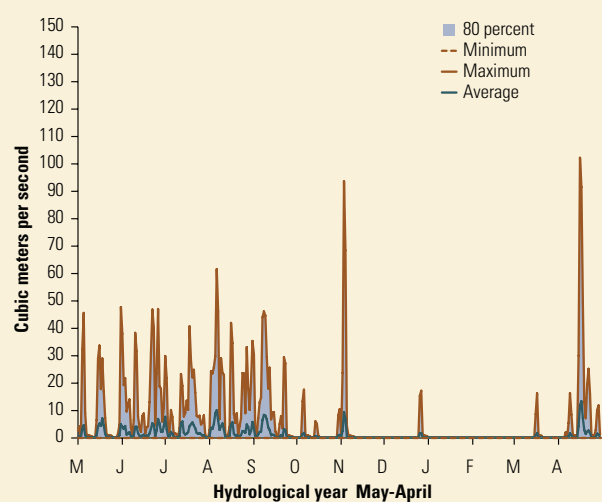
curves indicate the percentage of time during which a certain discharge is exceeded in the natural situation and when a small-scale hydropower (SHP) plant is in place. The flow duration curves show that between the dam and the powerhouse the discharge is zero most of the time (often more than 90 percent). The cumulative effect of the cascade on downstream flows is rather limited, as illustrated by how the flow duration curve tracks the "Natural" curve. The pattern is the same for all cascades: the middle-range discharges are somewhat raised below the powerhouse, but the natural pattern is not much altered for the other discharges.

FIGURE 6.1 HYDROGRAPHS OF VAN HO DAM IN NGOI XAN CASCADE

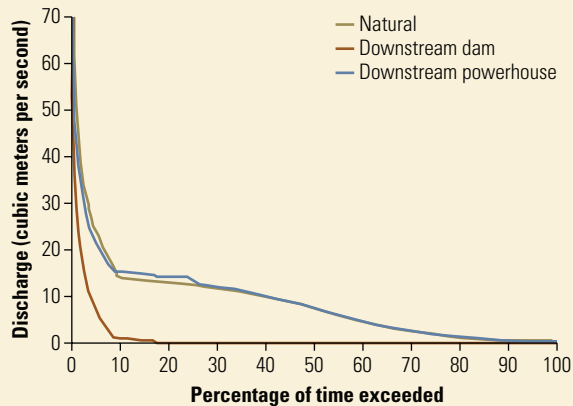
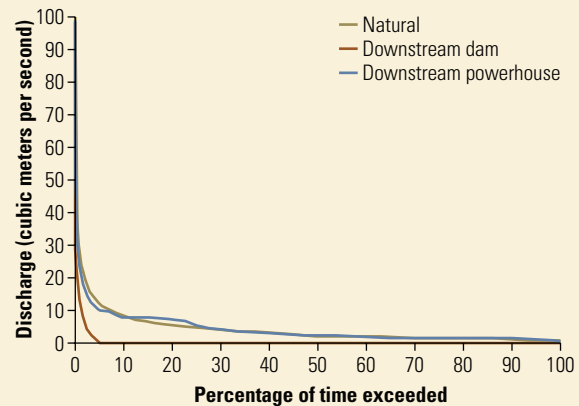
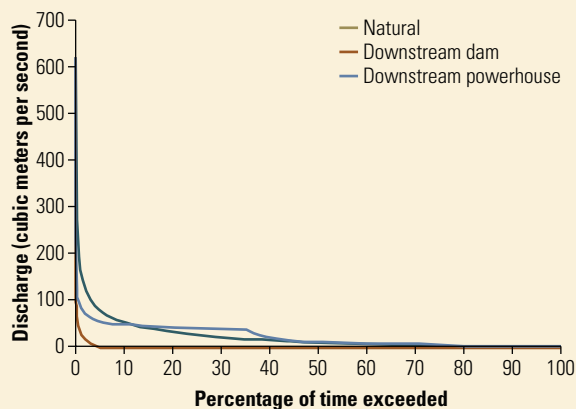
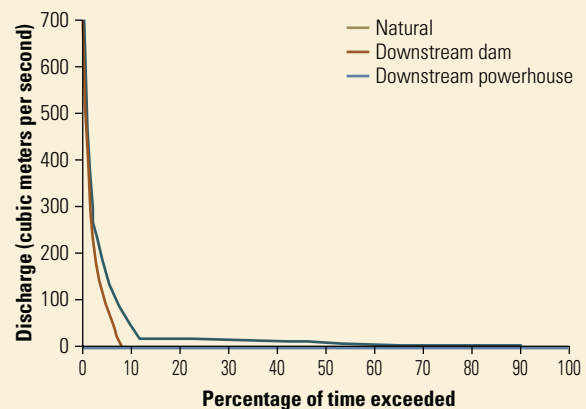
a. Hydrograph of natural flow



b. Hydrograph between dam and powerhouse



Source: World Bank.

FIGURE 6.2 FLOW DURATION CURVES FOR THE LOWERMOST SMALL-SCALE HYDROPOWER PLANTS IN THE CASCADES**a. Van Ho (Ngoi Xan cascade)****b. Nam Tha 6 (Nam Tha cascade)****c. Pa Chien (Nam Chien cascade)****d. Phieng Con (Sap cascade)**

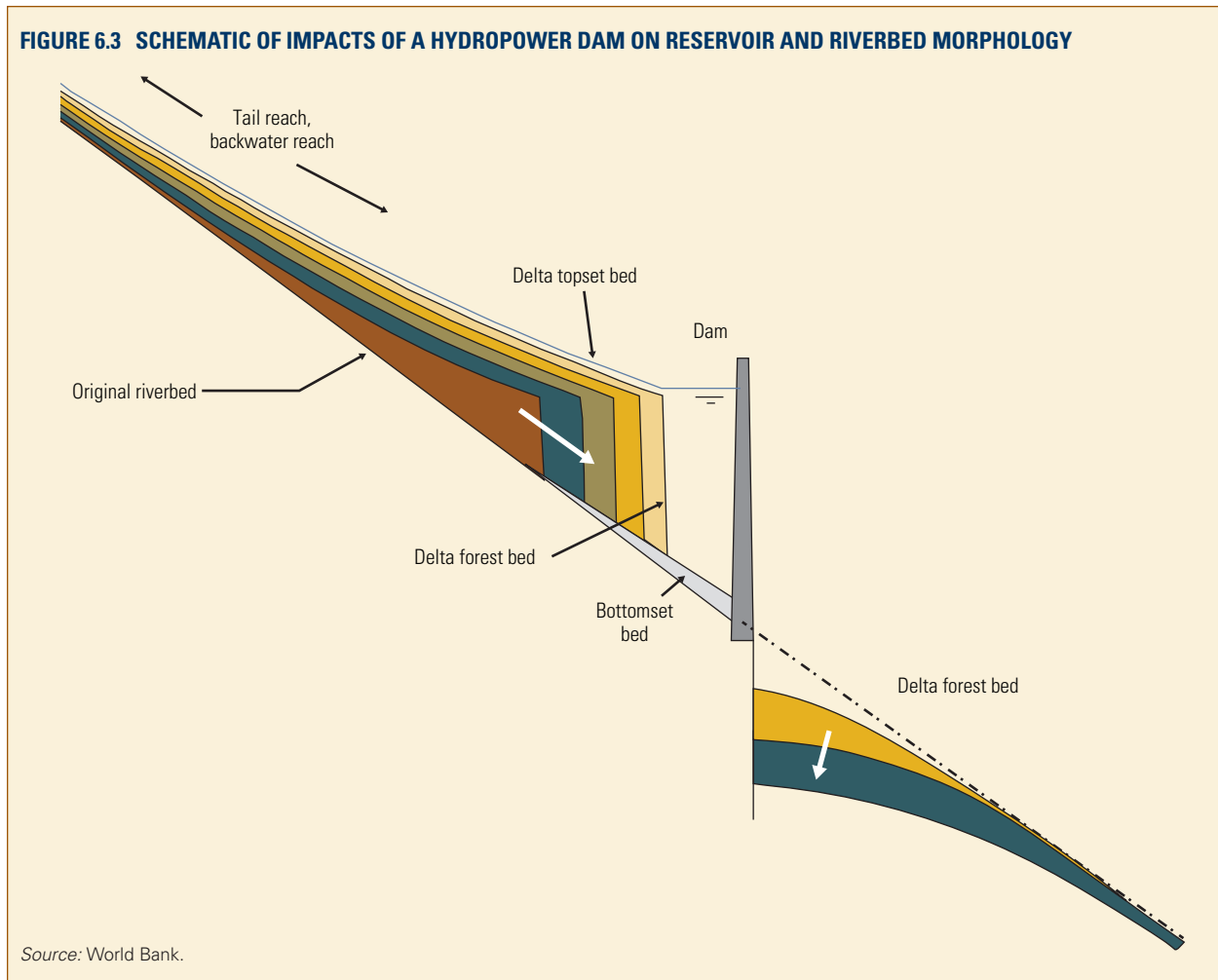
Source: World Bank.

Cumulative Impacts on Sediment Dynamics

All the rivers considered in this study are typical mountain rivers, with widely varying hydrological conditions. Upstream, these rivers are steep, narrow, and deeply incised, whereas they show expansion with broad flood plains in the foothill regions (such as the lower Nam Chien) or in intramontane depressions (such as between Tat Ngoang and Ta Niet in the Sap River). Sediments that erode from the slopes enter the main rivers through a dense network of small torrents and tributaries during rainfall events. Under natural undisturbed conditions, the main rivers carry the sediments that are eroded from the

watershed, and often a certain balance exists between the supplied sediment yield and the transport capacity of the river channel, given the prevailing flow conditions. In the river basins in the study, most sediment is supplied and transported downstream during rainfall and flood events in the wet season.

The construction of a single dam or a cascade of dams causes a significant disturbance of the sediment balance. The reservoirs intercept part of the sediment supply, and modify the hydrological conditions and associated sediment-transport capacity for the downstream reach. The major relevant impacts of this disturbance in the SHP plants under study in Vietnam follow (and are summarized schematically in figure 6.3):

FIGURE 6.3 SCHEMATIC OF IMPACTS OF A HYDROPOWER DAM ON RESERVOIR AND RIVERBED MORPHOLOGY

Source: World Bank.

- Coarse sediments (cobbles, gravel, and sand) will deposit in the head and tail reach of the reservoir (because of the decline of flow velocity). The deposits are usually deltaic, progressively filling up the pool from upstream and directly reducing the active reservoir storage capacity. When the delta front approaches the dam, an increasing amount of coarse sediments will enter the intakes. These sediments will cause severe abrasion of equipment and may block the headraces and pipes (Gyanendra Prasad Kayastha 2009). An example is shown in photo 6.1. Because of sediment deposition in front of the intake, the runner blades of the turbines at this dam have to be replaced yearly.
- Very fine sediment (clay, silt, and fine sand) will mostly pass the dams or enter the turbines, particularly for the reservoirs with small storage.
- Sedimentation in the backwater-reach of the reservoir will lead to an upstream propagating increase of bed levels as well as water levels.
- Interception of sediment by the reservoir will cause the downstream reach to be undersupplied, which will lead to degradation (Draut, Logan, and Mastin 2011). This degradation could lead to destabilization of river banks, slopes, and structures along the river.
- Because of the undersupplied sediment conditions the riverbed composition will change significantly (Draut, Logan, and Mastin 2011): during degradation (1) fine sediments are winnowed out, and coarse armor layers are formed; and (2) the lack of supply of gravel and sand will cause the bed to transit from well sorted to poorly sorted (mostly cobbles) or bimodal (cobble fraction and silt/fine-sand fraction).

PHOTO 6.1 SEDIMENTATION IN FRONT OF THE INTAKE OF VAN HO SMALL-SCALE HYDROPOWER PLANT IN THE NGOI XAN BASIN (LOOKING DOWNSTREAM)



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Note: The intakes are located in the structure in the middle of the picture. The dam crest is visible on the right.

- The modification of bed composition is often a relevant cause for disappearing habitats for fish and other freshwater fauna. The development of an armor layer may temporarily arrest the degradation.
- The reduction of erosive flood peaks will partially compensate for the lack of sediment supply: erosion processes in the downstream river will be slowed down or stopped (by armoring), especially if the new sediment-transport capacity matches that of the remaining sediment yield from tributaries in the downstream reach. However, this is true for cascades with large reservoirs, such as Nam Chien 1, but not for a cascade with only small reservoirs.
- The impacts for an SHP plant and its downstream river stretch can be divided into two groups:
 - Reservoir sedimentation impacts, expressed as sedimentation volume relative to total storage volume.
 - Riverbed impacts, that is, the rate of incision and bed-composition change measured by judging the sediment output from the dam, the reduced sediment-transport capacity, and the sediment supply from the watershed (balanced, undersupplied, or oversupplied).

Note that the impacts on bed level, as presented in figure 6.3, have both temporal and spatial scales. The influence of sedimentation and erosion gradually expands in the upstream and downstream directions. In the studied cascades, many of the dams are several kilometers apart, and often the backwater of the downstream dam reaches the toe of the upstream dam. In such a situation, a direct interaction between the impacts can exist, for example, the lack of sediment load from the upper dam can prevent sedimentation in the backwater area of the lower dam. In the Sap River the distance between some of the dams is much larger, and they are less likely to have interacting or additive impacts.

Cumulative Impacts on Valued Ecosystem Components (VECs)

For each cascade the cumulative impacts on the receptors and VECs, both without and with SHP cascade development, were assessed. A summary of the scores is given in table 6.1 and figure 6.4. The table and figure also show the difference in scores between the two cases for each receptor and VEC (the “Difference” column in the table). Before discussing the details of the assessment, this summary shows a relatively high cumulative impact for Nam Tha compared with the others. Ngoi Xan has similar cumulative impacts, but the scores are lower for most of the criteria, which is illustrated by the similar but smaller shape of the spider diagram. In contrast, the Sap basin has the lowest additional impact due to cascade development. The Chien cascade shows the highest score on revenues because it is dominated by the 200 MW hydropower plant. It also shows a relatively high impact on VECs without cascade development because the ecosystem services for flow regulation and soil protection are impaired by the loss of vegetation cover. Cascade development does not add to this impact.

Because the purpose of the assessments was to analyze the cumulative impacts on each VEC, the spider diagrams should not be interpreted as an overall score for the

whole cascade, but as a summary illustration of the individual impacts. The next sections discuss in more detail the impacts on each receptor and VEC caused by circumstances other than SHP and by cascade construction.

Reference Case: No Cascade

Forestry and forest extraction have already affected the natural ecosystem of all studied basins to a great extent, except for Nam Tha, which still harbors substantial pristine forest areas. The natural vegetation in Ngoi Xan and Chien is dominated by secondary forest and grassland shrubs. The middle part of Sap is quite deforested already, whereas the upper and lower parts still consist of more pristine forest. However, the current degree of deforestation is considered to be low compared with the other basins. Therefore, the major impact pathway in Ngoi Xan, Nam Tha, and Chien is from deforestation due to timber extraction and land clearance. This pathway affects valued flora and fauna as well as ecosystem flow regulation and soil protection.

A second impact pathway stems from **agricultural development** causing water pollution, which is apparent in Sap and Nam Tha. Agricultural development affects valued fauna and flora in the aquatic environment, including fish populations. Water pollution is also being caused by

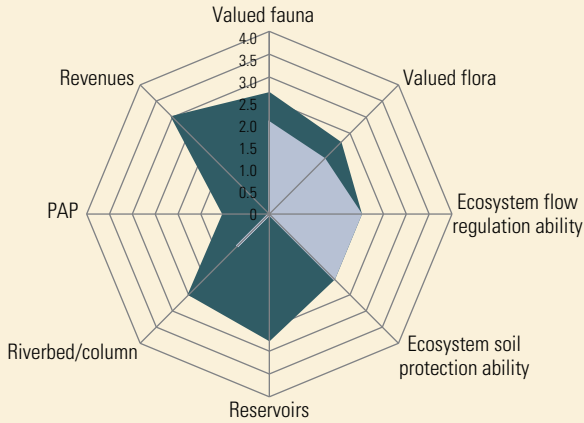
TABLE 6.1 IMPACT SCORES FOR ALL RIVER BASINS, WITHOUT (CASE 0) AND WITH (CASE 1) CASCADE DEVELOPMENT

Receptor or VEC	Ngoi Xan			Nam Tha			Chien			Sap		
	Case 0	Case 1	Difference	Case 0	Case 1	Difference	Case 0	Case 1	Difference	Case 0	Case 1	Difference
Valued fauna	2.0	2.64	0.64	2.0	3.36	1.36	2.70	3.36	0.66	1.8	2.16	0.36
Valued flora	1.7	2.20	0.50	1.7	2.80	1.10	2.25	2.80	0.55	1.5	1.80	0.30
Flow regulation ability	2.0	2.00	0	2.0	3.00	1.00	3.00	3.00	0	1.0	1.00	0
Soil protection ability	2.0	2.00	0	2.0	3.00	1.00	3.00	3.00	0	1.0	1.00	0
Reservoirs	0	2.75	2.75	0	3.30	3.30	0	2.20	2.20	0	1.00	1.00
Riverbed and water column	1.0	2.48	1.48	0	2.75	2.75	0	2.20	2.20	0	2.20	2.20
Project-affected people	0	1.00	1.00	0	1.00	1.00	0	1.00	1.00	0	1.00	1.00
Government and private revenues	0	3.00	3.00	0	3.00	3.00	0	4.00	4.00	0	2.00	2.00

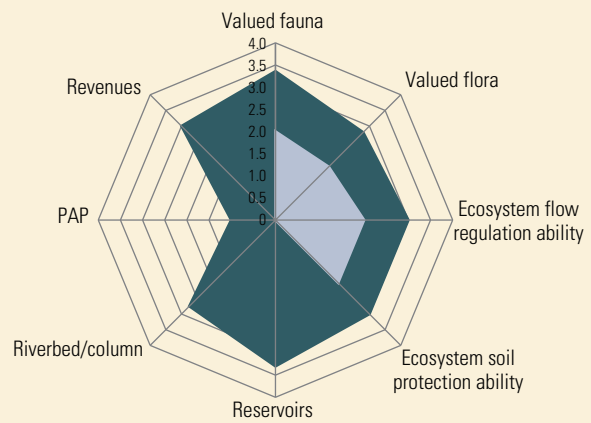
Source: World Bank.

FIGURE 6.4 SPIDER DIAGRAMS OF THE CUMULATIVE IMPACTS

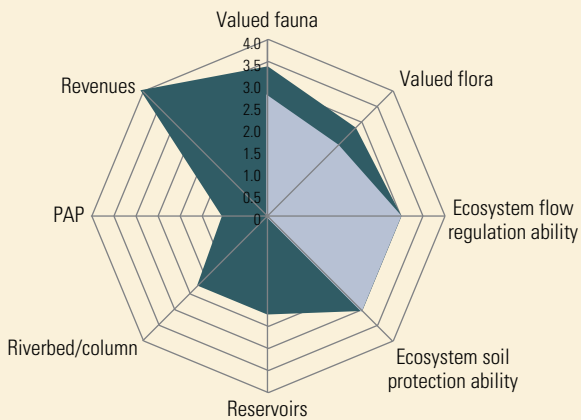
a. Ngoi Xan



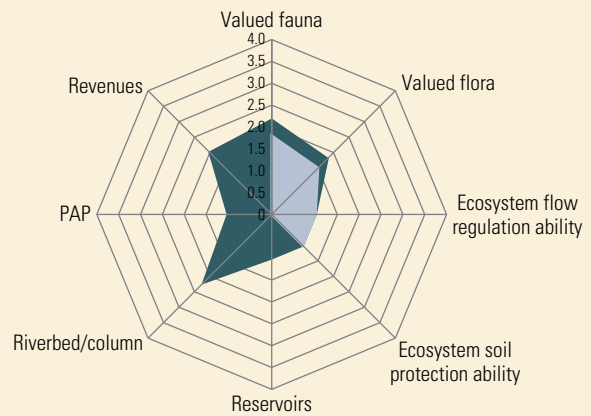
b. Nam Tha



c. Chien



d. Sap



Source: World Bank.

Note: PAP = project-affected people. Light blue represents impacts without small-scale hydropower; dark blue represents impacts with small-scale hydropower. Reservoirs and revenues are positive valued ecosystem components.

industrial development in the lower reach of Nam Tha (a paper factory downstream of the Khe Lec bridge).

Irrigation in most studied river basins is situated downstream of the cascade development. Water extraction for irrigation in the middle and upper parts of the basins is often from tributaries and mountain springs and does not significantly affect the receptors and VECs.

Fisheries activities are more prolific in the Chien basin than in the other basins, and its fish populations have been seriously degraded.

Taken together, the cumulative effects of these pathways have a moderate impact on valued flora and fauna, flow regulation ability, and soil protection ability for Ngoi Xan and Nam Tha. The impacts are somewhat higher for Chien, and somewhat lower for Sap.

Case 1: Cascade Development

The impacts of cascade development and of related present and near-future activities follow complex interaction pathways, as depicted in figure 4.4, and are dominated by development of the SHP projects. The primary and secondary impact pathways are remarkably similar for all cascades.

TABLE 6.2 PROPORTION OF RIVER DIVERTED BY THE CASCADE

	Ngoi Xan	Nam Tha	Chien	Sap
Total river length (kilometers)	21.4	16.4	26.9	66.0
Length of diversion (kilometers)	19.8	12.8	23.7	15.3
Percentage of river length diverted	93.0	78.0	88.0	23.0
Number of days per year with zero flow in diverted portion of river	304.0	331.0	346.0	324.0

Source: World Bank.

SHP development leads to river diversion, land take, and land use change, but also spurs economic investment. Economic investment leads to positive secondary impacts on infrastructure and job opportunities. Negative secondary impacts are expected on habitat fragmentation, loss of connectivity, loss of vegetation, and erosion and sedimentation. **The most important cumulative negative impact for all cascades is habitat fragmentation and reduced connectivity within the entire cascade system. This impact is synergistic in nature.** This impact stems mainly from the fact that for up to 92 percent of the river the water is diverted from its natural riverbed (table 6.2). Large stretches of river will become dry (photo 6.1) for long periods (up to 346 days for the Nam Chien cascade; see also figures 6.1 and 6.2 for illustrations). The total length of water diversion is less pronounced for Sap, but even here the loss of aquatic connectivity is substantial because over a length of 66 kilometers no fewer than nine dams will be constructed, which will be nine barriers for fish and other aquatic fauna. A comparison of the diversion from Nam Chien 1 (16 kilometers) and the other cascades together (55.6 kilometers) shows that the cumulative impact on river diversion from SHP is considerable.

Changes in receptors and VECs, however, differ between the basins, because the reference situations differ and because of interactions with other circumstances. The impacts on valued flora and fauna are slightly higher in Ngoi Xan and Chien, but for **Nam Tha the impact on valued fauna is considerably larger.** The interaction pathway, and its impacts stemming from forest extraction, is significantly intensified by SHP development in Nam Tha because of the construction of access roads and land take for infrastructure in mostly pristine forested and riverine areas. Increased deforestation in Nam Tha is also leading to greater loss in flow regulation

and soil protection ability. For Sap the cumulative impact on valued flora and fauna is considerably less, thanks to the smaller scale of new infrastructure on already heavily impaired and cultivated land in the middle valley.

For Nam Tha, Ngoi Xan, and Chien **significant impacts on the riverbed and water column are expected** because of changes in sediment dynamics: sediment is trapped in reservoirs and flow velocities change. Although the effect on sediment-transport rates is different between the cascades and even can differ between river stretches within one cascade, the net result is that riverbeds become more homogeneous and less dynamic. Available ecological niches in the river will be decreased, eventually affecting ecosystem composition and biodiversity (Petts 1984a, 1984b; Lillehammer and others 2009). The cumulative impact of sediment trapping on downstream reservoirs is positive: a relatively large reservoir upstream reduces the sedimentation of the other reservoirs in the cascade.

PHOTO 6.2 DRY RIVERBED BELOW NAM CHIEN 2 DAM

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TABLE 6.3 CUMULATIVE SOCIAL IMPACTS OF THE CASCADES

Cascade	Households resettled (number)	Households losing lands (number)	Area of permanent land loss (hectares)	Installed power (megawatts)	Power density (watts per square meter of reservoir area)
Chiena	15	240	312	54.0	17.3
Nam Tha	0	Data not available	70	45.0	63.9
Ngoi Xan	0	84	138	53.7	38.9
Sap ^b	0	269	70	23.4	33.4
Total	15	593	590	176.1	29.8
Nam Chien 1	160	160	529	200.0	37.8

a. Excluding Nam Chien 1.

b. Includes information from Muong Sang1 and Sap Viet only.

Source: World Bank.

In all studied basins, **river regime changes below the cascade are minimal**; therefore, water-use competition with downstream irrigation offtakes (such as Lang San weir in Ngoi Xan and Song Ve weir in Nam Tha) is also nonexistent. In Sap, however, two irrigation projects are situated within the cascade and concerns have been raised about impacts from the development of the cascade.

Positive impacts on **revenues (government and private) are estimated to be significant** in all cascades, except Sap. Lack of coordination between multiple owners in the SAP cascade prevents the realization of positive impacts. Negative impacts on PAP are partly offset by positive impacts from investment in infrastructure and improved job opportunities.

With regard to **social impacts**, the SHP cascades require little resettlement. However, even though the individual reservoir areas are usually quite small, the cascades all together add up to about 590 hectares, affecting about 593 households (table 6.3).¹ This is larger than the reservoir area of Nam Chien 1, which has more power generating capacity installed than the other plants put together (both existing and under construction). However, 160 households needed to be resettled for Nam Chien 1 to be constructed, whereas for the cascades only 15. Nevertheless, when comparing power density, which is the installed power per square meter of reservoir area, Nam Chien 1 scores better than the combined SHP plants (27 percent higher power density). Thus, it can be said that the cumulative impact on land take of small-scale hydropower is not negligible (table 6.3).

Conclusion

Although SHP projects affect the river regime, water use conflicts are normally limited because the areas around the cascades are typically sparsely inhabited, and agriculture depends on gravity irrigation from small tributaries rather than the main stream. Most major irrigation weirs are downstream from the cascades, as in Ngoi Xan and Nam Tha. Cumulative impacts on water use thus are normally limited to the area downstream of the entire cascade. The case studies showed that these downstream impacts are minimal because the flow regime downstream of the cascade is minimally changed (in both the wet and dry seasons).

Cumulative impacts on ecosystems are mainly due to the opening up of pristine areas for resource utilization and to the fragmentation of habitats, most notably affecting fish population and diversity. In Nam Tha, the effects are on pristine forest areas with their associated flora and fauna. In a variety of the basins important VECs were identified from studies and consultation with stakeholders, including threatened or endangered wildlife, fishes, and plants. **All four case studies show that the most profound cumulative impacts of building small-scale hydropower in cascades is related to habitat fragmentation and loss of connectivity and their subsequent impacts on the terrestrial and riverine VECs.** Release of environmental flows (see next chapter) may mitigate effects on available riverine habitat for aquatic species, although connectivity loss attributable to the cascade diversions will still occur.

BOX 6.1 SUMMARY OF CUMULATIVE IMPACT ASSESSMENT FOR STUDIED CASCADES

Although each cascade has unique characteristics, this study shows that small-scale hydropower development in the four cascades has the following effects:

- Requires minimal resettlement of people
- Requires land take comparable to that of large hydropower as measured by power density
- Is not in competition with irrigation
- Does not significantly alter flows downstream from the cascade (because of small reservoirs)
- Has little scope for multifunctional use (reservoirs are too small)
- Has a significant impact on habitat fragmentation and reduces connectivity
- Risks opening and disturbing pristine areas, leading to additional cumulative impacts from deforestation (as shown in the case of Nam Tha).

All cascades except Sap have significant cumulative impacts on erosion and sedimentation. The most profound impacts are from Nam Chien, due to the presence of the large Nam Chien 1. For Sap most sediments are carried through the system. Similarly, all cascades except Sap have upstream reservoirs that trap sediments, positively affecting the lifetime of downstream reservoirs. Box 6.1 summarizes the impacts for the four cascades under study.

Note

1. This figure is an underestimation because data on area and affected households for most of the Sap projects in the pipeline is incomplete.

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Future Small-Scale Hydropower Performance

Effect of Environmental Flows

The Importance of Environmental Flows

Stream flow regimes have a major influence on the biotic and abiotic processes that determine the structure and dynamics of stream and riparian ecosystems (Covich 1993). High river flows are important not only for sediment transport, but also for reconnecting floodplain wetlands to the channel and for recharging groundwater resources on which terrestrial ecosystems partly depend. Floodplain wetlands provide habitat for fish and waterfowl, among others. Low flows promote fauna dispersion, thus spreading populations of species to a variety of locations. The life cycles of many riverine species require an array of different habitat types whose temporal availability is determined by the flow regime. Adaptation to this dynamic environment allows riverine species to persist during periods of droughts and floods (Loucks and van Beek 2005; Poff and others 1997).

Stream flow regime is affected by stream diversion and regulation in small-scale hydropower (SHP) cascades as well as by changes in the terrestrial environment due to SHP infrastructure and other factors in the basin, such as land use change. One way to mitigate the impact of stream regulation and diversion is the implementation of environmental flows. Providing for environmental flows in the four selected cascades could be important, especially for the survival of riverine ecosystems and their associated fish species. The impacts of selected environmental flow scenarios on stream flow and power production for the four basins are described below.

Legal Requirements and Actual Implementation

According to existing government legislation, hydropower producers are required to minimize the impacts of reservoir operation on the downstream environment. Decree No. 112/2008/ND-CP of MONRE Article 9.1, for instance, states

The operation rules of the reservoir: must be developed and submitted to authorized agencies for approval before storing water; must meet all the functions of the reservoir in the prioritized order; must ensure the safety of the dam and areas downstream of the reservoir, the integrated exploitation of resources and environments of the reservoir, and the maintenance of the minimum flow in reservoir downstream; must not cause a significant change in the flow regime downstream of the reservoir; must give consideration to climate change issues; and must conform with inter-reservoir rules applying within the river basin (if any) which have been approved by the authorized agency.

As stated, a minimum flow needs to be maintained downstream of the reservoir. Article 3.1 defines the minimum flow as follows:

“Minimum flow” is the lowest flow required to maintain a river or river segment, maintain normal eco- and aquatic systems, and to ensure the lowest level for other development activity and use of water resources, according to the priorities identified in the river basin plan.

For several existing plants or plants under construction in the studied cascades, planned environmental flow releases were alluded to in documents or by the operators. It was not always clear whether these releases would be made from the dam or from the powerhouse. Ideally they would be made from the dam to benefit the stretch between the dam and the powerhouse, but not all dams have release facilities. Also, the minimum amount of water to be released varied and was not always clearly stated. Values ranged from 0.20 to 0.87 cubic meters per second (m^3/s) in the Ngoi Xan cascade (compared with an average annual natural flow of 1.0 to 6.3 m^3/s) and 0.4 m^3/s for the Nam Chien cascade (compared with an average annual natural flow of 17 to 23 m^3/s).

Whenever minimum flows were set and information was available for a particular SHP plant, the water balance model was used to assess the impact of the flows on power generation and on the environment. In addition, the impact of implementing a minimum discharge of Q_{95} on the flow regime and on hydropower production for both dry and wet seasons was studied.¹

The simulations used minimum discharges instead of the full flow regime. Although this results in less than a comprehensive environmental flow assessment, it can also be argued that some peak discharges will occur anyway because of the small storage capacity, therefore,

ensuring minimum discharges through operating rules is particularly relevant. The flow regime indicators show that peak discharges indeed still occur, but with lower peaks.

Model Results

Because a detailed assessment of the flow requirements of ecosystem components (see box 7.1) was outside the scope of the present study, any flow alteration was measured by indicators of its different components: mean annual runoff, peak discharges (highest discharge per year, averaged over all simulated years), Q_{10} (discharge exceeded 10 percent of the time over the entire simulated series), Q_{90} (discharge exceeded 90 percent of the time over the entire simulated series), dry season minimum flow (lowest discharge per year, averaged over all simulated years), and the number of days per year when there is zero flow.

Table 7.1 summarizes the model's results for the impacts of current environmental flows (when available) and of implementing a Q_{95} minimum discharge on power production and flow regime, showing the differences compared with the base case (cascade without environmental flows). The reduction in energy production is considerable with changes of 15 percent to 31 percent (in all cases except for Chien current environmental flow). For

TABLE 7.1 SUMMARY OF CASCADE IMPACTS OF ENVIRONMENTAL FLOW RELEASES COMPARED WITH THE BASE CASE OF NO ENVIRONMENTAL FLOWS

Impact	Nam Tha		Ngoi Xan	Chien		Sap
	Q_{95} vs. no environmental flow	Current environmental flow vs. no environmental flow	Q_{95} vs. no environmental flow	Current environmental flow vs. no environmental flow	Q_{95} vs. no environmental flow	Q_{95} vs. no environmental flow
Change in energy production (percent)	-31.0	-21.0	-20.0	-1.5	-15.0	-25.0
Change in energy production (gigawatt hours per year)	-57.0	-49.0	-45.0	-140.0	-149.0	-50.0
Change in zero flow days (remaining days)	-331.0 (0)	-249.0 (55)	-250.0 (54)	-346.0 (0)	-346.0 (0)	-261.0 (63)
Change in Q_{10} (normal high flows; cubic meters per second)	1.40	2.00	3.0	0.4	6.0	6.4
Change in Q_{90} (normal low flows; cubic meters per second)	1.10	0	0	0.4	4.0	0

Source: World Bank.

Note: Q_{90} = flow that is exceeded 90 percent of the time; Q_{95} = flow that is exceeded 95 percent of the time.

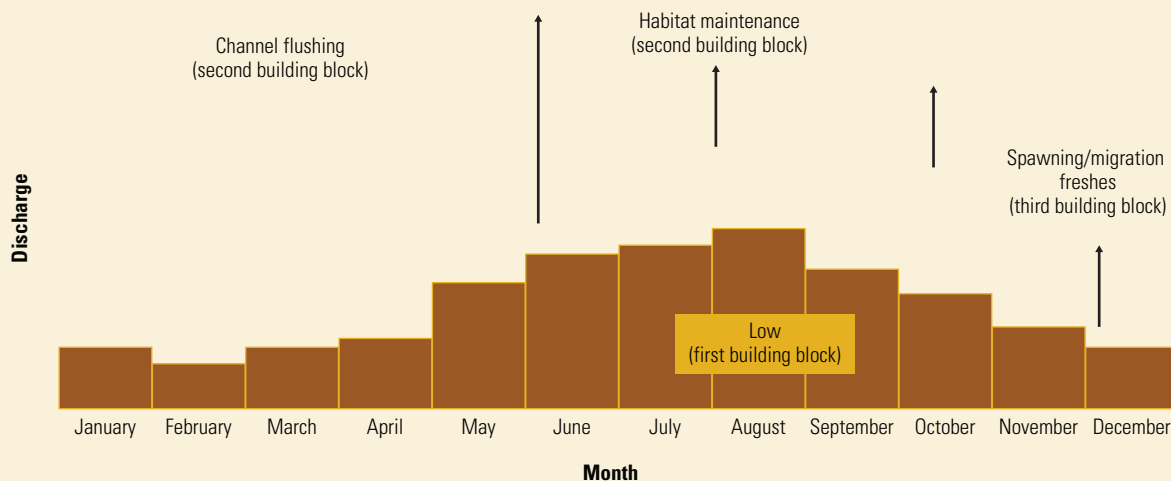
BOX 7.1 MINIMUM FLOW OR ENVIRONMENTAL FLOW?

River ecosystems are, to a large extent, the result of natural variation in the discharge regime. The magnitude, timing, duration, frequency, and rate of change of both high and low flow events are important. The required flow regime will depend on the requirements of the ecosystem components that are valued in a specific river and also implies a trade-off with other river functions, such as hydropower generation. It can be assumed that any alteration of the flow regime (topping off of high peaks, increasing low flows) leads to changes in the river ecosystem. Whether these changes can be accepted because the benefits—in this case hydropower generation—are considered more important cannot be answered with a generic rule. Instead, site-specific assessments, for which several methods are available, are required. The approaches developed in various countries around the world can be divided into four categories (Acreman and Dunbar 2004):

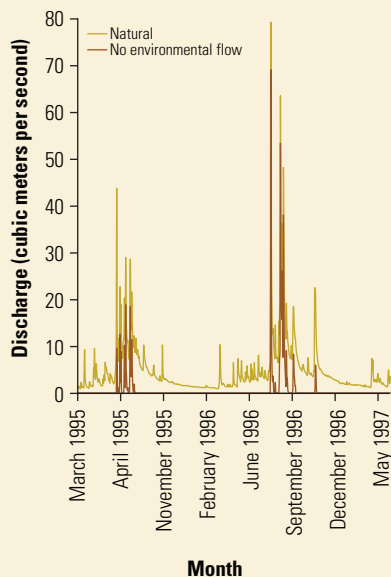
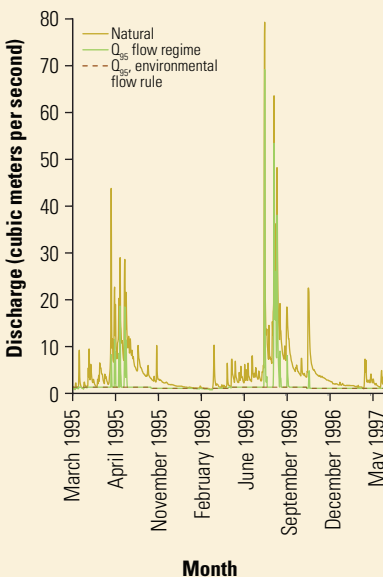
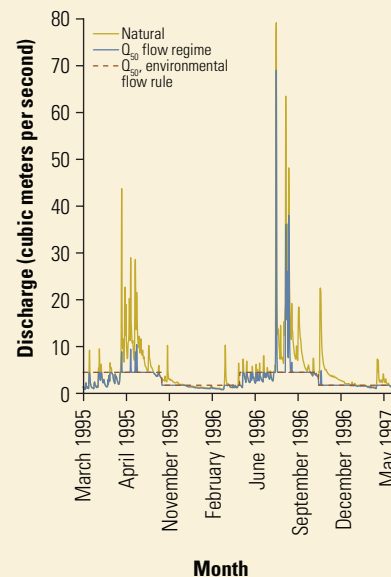
- Lookup tables
- Desk-top analysis
- Functional analysis
- Hydraulic habitat modeling

The last two groups are the most advanced and require more resources and data. Functional analysis builds on an understanding of the functional links between several aspects of the hydrology and ecology of the river system. These methods cover many aspects of the ecosystem and some of them also incorporate societal aspects, such as the Downstream Response to Imposed Flow Transformations methodology (King, Brown, and Sabet 2003). Perhaps the best known is the Building Block Method (BBM), developed in South Africa (Tharme and King 1988; King, Tharme, and de Villiers 2000). The basic premise of the BBM is that riverine species as well as other river functions are reliant on basic elements (building blocks) of the flow regime over the year, including low flows (which provide a minimum habitat for species and prevent invasive species), medium flows (which sort river sediments and stimulate fish migration and spawning), and floods (which maintain channel structure and allow movement onto floodplain habitats). An environmental flow regime can thus be constructed by combining these building blocks (see figure B7.1.1). It should be clear that a seasonal fixed minimum discharge, such as the Q_{95} or Q_{50} (see figure 7.1) eliminates most of the natural variation in discharges, and is unlikely to be able to sustain all relevant ecological processes.

FIGURE B7.1.1 EXAMPLE OF AN ENVIRONMENTAL FLOW REGIME BUILT UP USING BUILDING BLOCKS



Source: Acreman and Dunbar 2004.

FIGURE 7.1 COMPARISON OF NATURAL FLOW REGIME WITH ENVIRONMENTAL FLOW RELEASES (NAM THA 6)
a. Natural flow compared with cascade without environmental flow (base case)

b. Natural flow compared with cascade with environmental flow Q_{95}

c. Natural flow compared with cascade with environmental flow Q_{50}


Source: World Bank.

Note: Q_{50} = flow that is exceeded 50 percent of the time; Q_{95} = flow that is exceeded 95 percent of the time.

Nam Tha, Ngoi Xan, and Sap the absolute reduction is about 50 gigawatt hours per year (GWh/y), whereas for the Chien cascade the reduction amounts to 14 GWh/y under the current environmental flow regime and 150 GWh/y for a Q_{95} minimum discharge. In all cascades, the implementation of an environmental flow regime strongly reduces the number of zero flow days. In Nam Tha and Chien, zero flow days are entirely prevented, whereas in Ngoi Xan and Sap about 60 days remain, but it should be noted that these cascades also have zero flow days in the natural (no dam) situation.

Dams in the Chien cascade currently can release only very small environmental flows directly from the dam. Therefore, it may not be technically possible with the current structure to release larger amounts. Furthermore, the model results indicate that a discharge of 0.4 m³/s leads to complete prevention of “zero flow” days. However, the model does not take evaporation and infiltration into account. It is quite possible that a release of 0.4 m³/s could disappear over the 10 kilometer stretch to the Nam Chien 1 powerhouse. Additional investigations are required to better understand these processes.

Implementation of a Q_{95} minimum discharge will contribute to the prevention of zero flow days between dam and powerhouse, but little more. Because of limited storage capacity of most reservoirs, peak flows, which cannot be accommodated by the turbines, will spill over the dam. With a Q_{95} environmental flow, the flow pattern between dam and powerhouse will exhibit a fixed discharge at a very low level with an occasional peak discharge. Most discharges of intermediate size (up to 10 m³/s, for example, in Nam Tha), which used to occur at the beginning and end of the rainy season, will not be restored (figure 7.1, panel b).

If the environmental flow rule were to be as high as Q_{50} , the discharge would be closer to the natural situation, but still modified (as shown for Nam Tha 6 in panel c of figure 7.1). However, during certain periods of the dry season water volume is insufficient to meet a Q_{50} rule. This means that the river naturally has a lower discharge during these periods. Although the figure shows relatively small differences between the implementation of Q_{50} and Q_{95} , the difference in energy production is considerable, as displayed in figure 7.2. This figure shows the

relationship between increased minimum flow releases and reduction in energy production for the Nam Tha 6 SHP dam. Similar relationships can be expected to exist for the other cascades.

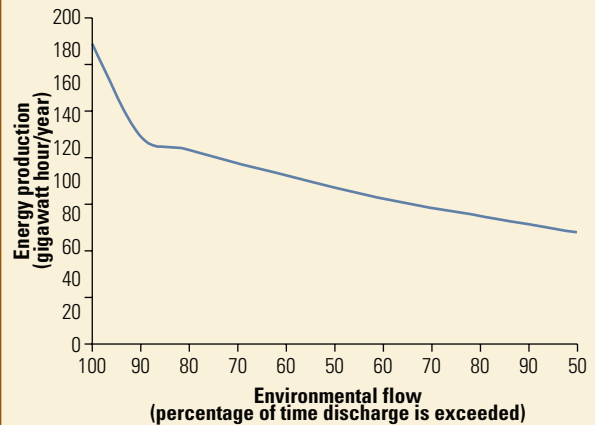
In summary, implementing a minimum river flow of, for example, Q_{95} will help restore low flow conditions by preventing the stretches between dams and powerhouses from becoming completely dry. The natural ecosystem is likely to be dependent on natural variations in discharge, and replacing those variations with a fixed minimum discharge will undoubtedly lead to a change in the ecosystem. The considerable hydropower generation losses resulting from releasing minimum amounts of water for environmental purposes mean that restoring more natural flow regimes will be financially challenging.

Effect of Climate Change

Climate Scenarios

The government of Vietnam published a report in 2009 setting forth a number of climate change scenarios for different regions in Vietnam (MONRE 2009). For the north-west region of Vietnam, three quarterly rainfall change scenarios are shown in table 7.2. Differences between

FIGURE 7.2 NAM THA 6: RELATIONSHIP BETWEEN MINIMUM FLOW RELEASES AND ENERGY PRODUCTION



Source: World Bank.

the scenarios are small. All scenarios show increases in precipitation in the period June–February, and decreases in precipitation at the end of the dry season, March–May. The analysis in this report uses the A2 scenario.

PHOTO 7.1 NAM HOA RIVER DOWNSTREAM FROM DAM



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TABLE 7.2 PROJECTED RAINFALL CHANGE FOR NORTHWEST VIETNAM
(percent, compared with 1980–99)

	December–February	March–May	June–August	September–November
A2 (high scenario)	2.9	–2.8	5.9	1.1
B1 (low scenario)	2.9	–2.8	5.9	1.1
B2 (medium scenario)	2.9	–2.9	6.2	1.1

Source: MONRE 2009.

Model Results

The expected impact of climate change on power production and flow regime in the cascades is summarized in table 7.3. In all cascades the increase in power production is between 1 and 2 percent. However, because of the variation in power generating capacity, the increase in absolute terms is highest in the Chien cascade (22 GWh/y). In all other cascades climate change is expected to lead to no more than 3 GWh/y more energy production. Because precipitation is expected to decrease during the dry season, it is possible that because of seasonal variation in pricing, the increase in total energy production may be insufficient to compensate for the loss of higher-revenue dry season energy production.

Between the dams and the powerhouses, the wetter conditions under climate change lead to a minimal reduction of days without flow (two to six days a year). The fact that no change occurs in discharges that are exceeded 10 percent (high flows, or Q_{10}) and 90 percent (low flows, or Q_{90}) of the time means that climate change does little to restore a more natural flow regime.

Relative to the base case, the assessment of the A2 climate change scenario on all four cascades shows no difference in cumulative impact. Future cumulative impacts on the valued ecosystem components and receptors in

the basins will thus be more influenced by anthropogenic impacts (irrigation, deforestation, and the like), than operation of the cascade itself, assuming mitigation via environmental flows is implemented.

Conclusion

Many of the dams lack the ability to discharge environmental flows from the reservoir. Operating rules for many hydropower plants do not stipulate an environmental flow even though it is required by law, or, if they do, the release is very small (for example, on the order of Q_{90}) and unlikely to effectively mitigate the long periods during which large stretches of the river dry out. Article 9.1 of MONRE Decree No. 112/2008/ND-CP regarding minimum flows is not entirely fulfilled in the studied cascades. Furthermore, meaningful environmental flow releases would lead to significant reductions of energy production and revenues.

Possible increases in wet season precipitation caused by climate change could result in the generation of marginal amounts of extra energy. However, this extra wet-season production may be insufficient to compensate for the loss of energy that would have been produced during the dry season, when energy is priced higher.

TABLE 7.3 SUMMARY OF IMPACTS OF CLIMATE CHANGE ON CASCADES

	Nam Tha	Ngoi Xan	Chien	Sap
Change in energy (percent)	2	1	2	1
Change in energy (gigawatt hours per year)	3	3	22	3
Change in zero flow days	–2	–6	–3	–4
Change in Q_{10}	0	0	0	0
Change in Q_{90}	0	0	0	0

Source: World Bank.

Note: Q_{10} = flow that is exceeded 10 percent of the time; Q_{95} = flow that is exceeded 95 percent of the time.

Notes

1. Q_{95} is the discharge that is exceeded 95 percent of the time, and represents a low discharge. Q_{95} was determined based on natural discharge series for the location of all SHP plants, and separately for the dry (November to April) and wet (May to October) seasons. Q_{95} is a minimum discharge, and aims to prevent zero flow days and to reduce the low flow conditions that result from the SHP plants.

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Potential for Improving the Planning and Operation of Small-Scale Hydropower Planning Plants

Planning Problems Observed

Current planning procedures do not fully acknowledge the potentially significant cumulative impacts from small-scale hydropower (SHP) cascade development. Neither environmental impact assessments required by regulation nor safeguard frameworks used for the Renewable Energy Development Program projects mention the *accumulation* of river diversion, leaving large stretches of river (up to 93 percent, see table 6.2) virtually dry during lengthy periods of the year. The consequences of such physical impacts on aquatic ecosystems were therefore not addressed. Although the assessments often recognize the change in river environment immediately downstream of an individual dam, the impact was thought to be marginal because, for example, the aquatic ecosystem of the stream section “is very poor because of sloping terrain with many big rocks” (Phuc Khnah 2010a). In the absence of an ecological inventory, it is difficult to evaluate this judgment.

Furthermore, these environmental procedures do not identify the interaction between hydropower development and deforestation that could lead to cumulative impacts. The World Bank Environmental Safeguard Framework OP/BP 4.04 Natural Habitats asks for caution in projects that would lead to the significant loss or degradation of any critical natural habitats, including those that are unprotected but of known high conservation value. This may be relevant in the case of Nam Tha: it is the only cascade being developed in a catchment area containing a remarkable diversity of flora and fauna in pristine forest cover. However, the environmental management plan (EMP) document for Nam Tha 5 states that at the project site “there are no wild animals. The terrestrial animal system is only small animals, such as mouse, dog, weasel,

cat, pangolin etc.” (Phuc Khnah 2010b). Regardless of whether the size of an animal is important for its conservation value, the pangolin is a rare animal and listed by the International Union for Conservation of Nature as either endangered or near threatened with extinction. The EMP lists the pangolin as being present (which may or may not be true) but apparently fails to recognize this as important. Providing road access into this catchment poses a very significant risk of logging and poaching. It is therefore doubtful that the terrestrial ecosystem will be “stably formed and the terrestrial fauna will tend to return and live in the area surrounding the reservoir” as is stated in the EMP.

Planning problems of another kind were observed in the Sap River basin. It proved to be especially difficult to obtain details on cascade development in Sap, probably because eight hydropower projects and six different companies are involved. In Sap, only one dam is operational; two projects were suspended in 2011 for lack of funding and remain suspended as of April 2013. Furthermore, some of the dams seem not to be attuned to each other; for example, the turbine capacity of Ta Niet (7.2 cubic meters per second [m^3/s]) in the middle of the cascade is considerably lower than that of Tat Ngoang (14.8 m^3/s) just upstream of Ta Niet. Ta Niet will therefore act as a bottleneck in the operation of the cascade. In addition, the very low reservoir volumes (and zero volume of the most upstream dam) provide a challenge to optimal joint operation.

As indicated in chapter 7, the implementation of environmental flows in the cascades is complex. The basic problem is balancing the requirement for environmental purposes against resulting reductions in power generation. Environmental flows are generally not addressed at

BOX 8.1 ARTICLE 25: MAINTAINING MINIMUM FLOW IN RIVER BASINS—GOVERNMENTAL DECREE 120/2008/ND-CP ON RIVER BASIN MANAGEMENT

1. MONRE [the Ministry of Natural Resources and Environment] shall lead and coordinate with related ministries to regulate the determination of the minimum flows to be maintained in river basins.
2. Determination of the minimum flows:
 - MONRE shall survey, investigate and determine the minimum flow requirements for the river/river section, or for each water source, in the river basins named in the Major River Basin List and the Inter-provincial River Basin List;
 - For international river basins MONRE shall, on behalf of the Government, negotiate an agreement with other countries sharing that international river basin regarding the maintenance of minimum flows in the main stream of the river basins;
 - The Provincial People's Committee shall survey, investigate and determine the minimum flow requirements for the river/river section, or for each water source, in the river basins listed in Provincial River Basin List;
 - The requirement for minimum flow levels in the river/river section must be publicized and comments sought from economic organizations involved with the exploitation and use of water, and representatives of communities living in the river basin.
3. The authority to promulgate the minimum flow in river:
 - MONRE shall promulgate the minimum flow requirements for the river/river section, or for each water source, in the river basins named in the Major River Basin List and the Inter-provincial River Basin List;
 - The Chairman of the Provincial People's Committee shall promulgate the minimum flow requirements for the river/river section, or for each water source, in the river basins named in the Provincial River Basin List.
4. Related ministries, ministerial-level agencies, government agencies, and state companies and corporations shall adjust their programs, plans, projects and regulations for water exploitation and use to ensure that the minimum river flows for the promulgated river/river section are maintained.

the planning stage, and only since 2005 has the issue gotten official attention. Some consultants calculate environmental flow requirements based on dry season mean flows using Q_{90} , which is 10 times less than flows under normal dry season conditions during which the aquatic environment is already stressed. The variable nature of environmental flows prevents the use of a fixed rule for all river basins in Vietnam. Hence, a more tailor-made approach is needed. Furthermore, governmental decrees and ministerial circulars are very general in their discussions of minimum flows (box 8.1). The efforts by the Ministry of Natural Resources and Environment to prepare guidelines for minimum flows and to establish minimum flows in priority rivers (see Instruction Note No. 490/VPCP-KTN dated July 4, 2012) are therefore welcome.

These observations concur with those made in the previous literature regarding the lack of basin-wide planning and management of water and hydropower development. Although many hydropower projects often exist on one river and in one river basin, there are no procedures

for cumulative environmental impact assessments and for promotion of coordination among projects on the same river for water and environmental management (Suhardiman, de Silva, and Carew-Reid 2011). Only a few strategic environmental assessments for hydropower development have been performed and just one for a specific river basin: Vu Gia-Thu Bon river basin (ICEM 2008).

Suggestions for Planning Improvements

Vietnam has a well-established institutional framework with thorough legal and policy procedures for hydropower development (see chapter 2). The challenges lie in the implementation and enforcement of planning rather than in a lack of planning rules. It might even be suggested that an overabundance of regulations, decrees, and decisions for hydropower development jeopardize its effective implementation. Streamlining such procedures,

for instance, by drafting specific guidelines for hydropower cascade development could be considered. These could be seen as a tailor-made strategic environment assessment for SHP development.

With regard to cumulative impacts, the scale at which those impacts are assessed is most important. This study focused on one level beyond the single SHP project. The spatial boundary then encountered is the watershed of the river. Assessment of the impacts at this level is urgently needed, as described in the previous section. However, in view of the constraints in mitigating the cumulative impacts, it is necessary to scale up one level further to ask what the consequence would be if all rivers and streams were to be occupied with SHP cascades. In Vietnam natural habitats are mostly restricted to areas defined by remoteness, high elevation, steep topography, and other factors that limit suitability for agriculture or production forestry. At the same time these areas correspond closely to those suitable for SHP development (ICEM n.d.). Hence, economic development must be balanced against preservation of biodiversity.

One recommendation is that an “intact rivers program” be adopted at the river basin planning level as suggested in ICEM (2008). In such a scheme, at least one continuous river waterway in a river basin would be kept free of barriers to migration from its headwaters to the ocean, and environmentally destructive practices would be strictly controlled within and adjacent to the intact rivers to maximize habitat quality. Such a scheme would secure complete river continuums that could maintain aquatic biodiversity and the wild fisheries of the river system, despite severe disruption to migratory pathways and loss and fragmentation of habitats in other parts of the basin. Not only would the intact river provide an area that would preserve critical fauna by providing for their life cycle requirements, it would serve as an “aquatic faunal repository” from which other parts of the system could be repopulated in the future.

Several of Vietnam’s rivers already have high proportions of their flows extracted. Based on dry season flows, four basins are in the high stress category, with the Ma River being the most stressed (almost 80 percent of dry season flows extracted) and the South East River Cluster being next (75 percent). The Red River is also approaching the high stress zone (Kellogg, Brown and Root 2009). Therefore trade-offs must be made, and perhaps this trade-off should not be between hydropower development and ecosystems within each stream, but rather between regulated and unregulated streams at a higher scale.

Optimizing Operating Rules for Hydropower

Description of Analysis

To assess possible improvements to today’s operating rules and benefits from joint operating rules, two alternative situations were modeled, assessed, and compared:

- Alternative 1: Existing operating rules or best assumption. Powel Sim was used as the simulation program with hourly resolution.
- Alternative 2: Optimized operation to maximize electricity revenues for the entire cascade. Short-term Hydro Operation Planning (SHOP) was used as the optimization program with hourly resolution.

A workshop was organized in which operating procedures were discussed with SHP operators. In addition, documents describing official operating rules for the plants were used whenever available. These operating rules were analyzed for the Ngoi Xan, Nam Tha, Chien, and Sap cascades. Subsequently, possible improvements and joint operating rules were described. To optimize the use of available water resources in a basin, joint operating rules are needed. By studying SHP plants in a cascade as a system and not as individual plants, water use for hydropower can be optimized. “Optimal utilization” can be defined as either maximization of hydropower generation or maximization of hydropower revenue. For all four cascades, boundary conditions and bottlenecks were identified. Note that neither alternative includes environmental flows and other water users in the optimization modeling. This exclusion is further discussed later in this chapter.

Market

According to Circular 18/2008 - BCT, the energy price for hydropower projects of less than 30 MW capacity is set annually. The 2013 prices used in the optimization are given in table 8.1; these data were provided by the cascade operators.

TABLE 8.1 ENERGY PRICES, 2013 (US\$/kWh)

	Peak	Off peak
Wet season (June–August)	0.029	0.027
Dry season (September–May)	0.116	0.028

Source: World Bank.

Note: Peak periods vary across cascades, but each cascade has five peak hours per day.

Model Results

Table 8.2 summarizes the plant operation optimization model results for the four cascades. For both Ngoi Xan and Nam Tha, production under alternative 1 (“operation today”) is higher than that stated in the design documents from the developers, suggesting that there is indeed considerable potential for optimization for these cascades. For the Sap cascade, however, production provided by the model appears to be much lower than suggested by the design documents. Therefore, the model results for Sap indicate that further inquiry is needed.

The simulated increase in average annual energy production for Ngoi Xan, Nam Tha, and Sap ranges between 2 percent and 9 percent and is mainly the result of reduced water spill with the SHOP model compared with the Powel Sim model. Most interesting, however, is the considerable potential increase in revenues, ranging from 20 percent to 36 percent. Table 8.2 shows that the total theoretical maximum annual gross income for Ngoi Xan (2010), Nam Tha (1986), and Sap (2004) is US\$11.5 million, US\$10.9 million, and US\$7.5 million per year, respectively. For Nam Chien, only the results of optimized joint operation using the SHOP model are shown in table 8.2,

because of lack of information on how the Nam Chien 1 reservoir is being operated. Theoretical maximum gross income for this cascade is US\$57.8 million, mainly from Nam Chien 1.

The results of the Powel Sim model indicate that the operating schedule is conservative, and in most situations the model indicates that production in off-peak hours is required. The optimization results show that the Ngoi Xan, Nam Tha, Sap, and Nam Chien cascades could increase income from scheduling with SHOP. These model results can be attributed to a combination of the following:

- Optimized use of the turbines, taking into account that their highest efficiency is reached below maximum capacity
- A reduction of spill by taking into account the entire cascade
- An assumption of perfect foresight of inflows (although not possible to fully achieve in reality, the combination of good historic flow statistics and weather forecasts normally provide fairly accurate projections)

TABLE 8.2 TOTAL MODELED ANNUAL ENERGY PRODUCTION AND REVENUES FOR THE FOUR CASCADES FROM VARIOUS TYPICAL YEARS

	Ngoi Xan	Nam Tha	Nam Chien	Sap
Alternative 1 (“operation today”) (results from Powel Sim)				
Production from Powel Sim (gigawatt hours)	236.6	200.8		152.7
<i>Production as documented</i>	216	177	1,027	255
Average load (megawatts)	27.0	22.9		17.4
Income (US\$ million/year)	9.44	9.00		5.51
Alternative 2 (optimized operation) (results from SHOP)				
Production (gigawatt hours)	257.7	210.7	1,119.0	156.3
Average load (megawatts)	29.4	24.1	128.0	17.8
Income (US\$ million/year)	11.48	10.88	57.80	7.51
Change in marginal values (2 minus 1)				
Change in production (gigawatt hours)	21.0	9.9		3.6
Percentage difference	8.9	4.9		2.3
Change in average load (megawatts)	2.41	1.2		0.4
Change in income (US\$ million/year)	2.04	1.88		2.00
Percentage difference	21.6	20.8		36.3

Source: World Bank.

Note: The “typical years” are Ngoi Xan, 2010; Nam Tha, 1986; Nam Chien, 1979; and Sap, 2004. Typical years were chosen based on proximity to mean annual runoff and lack of extremes, that is, neither very dry nor heavy flooding. SHOP = Short-term Hydro Operation Planning model; Powel Sim = Program for short-term hydropower planning (Powel AS Smart Generation family).

Power Optimization and Other Water Demands

When developing joint operating rules for a cascade, other water demands, including those for environmental flow, can be an integral part of the system. As shown in chapter 6, environmental flow releases will cause a significant reduction in power production (between 15 percent and 31 percent). If these values are strictly deducted from the values of energy production in table 8.3, reductions will be the same for “operation today” (alternative 1) and optimized operation (alternative 2). Using the model results for Ngoi Xan, Nam Tha, and Sap (table 8.2) the power reductions for both alternatives were deducted to perform sensitivity analysis (table 8.3 and figure 8.1). The results show that under optimized conditions with Q_{95} discharge releases, power production and revenues are considerably higher than if environmental flows without optimization were to be implemented. In Ngoi Xan, revenues could even be slightly higher than they would be without optimization and without environmental flows. In other words, optimization creates financial room for environmental flows.

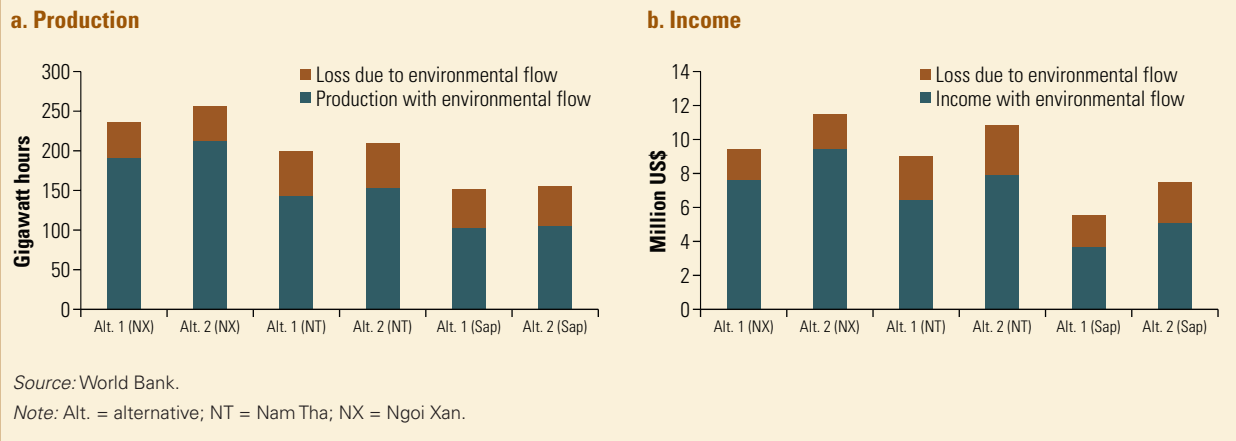
From an integrated water management perspective, optimization could partly offset the costs of environmental flow, thereby reducing the environment-power conflict. The results from the sensitivity analysis are not conclusive because environmental flows are usually released during the dry season when electricity prices are high, which lowers the average price used in the calculation in table 8.2. The conflict could possibly be further reduced by combining optimization of power revenues with flexible environmental flow demands (that is, spatially and temporally varying environmental flows as needed for environmental purposes). Additional optimization modeling that includes variable environmental flows is therefore recommended. The same approach for optimization applies to other water demands, such as irrigation.¹

For example, optimization for the Glomma and Laagen cascade in Norway is undertaken in an adaptive and dynamic manner through modeling at the basin scale that also allows for adjustments to be made seasonally and annually to meet the needs of the riverine environment

TABLE 8.3 SENSITIVITY ANALYSIS FOR THE EFFECT OF ENVIRONMENTAL FLOWS UNDER OPTIMIZATION

	Ngoi Xan	Nam Tha	Sap
Alternative 1: “Operation today” without environmental flows			
Production (gigawatt hours/year)	236.6	200.8	152.7
Income (US\$ million/year)	9.44	9.00	5.51
Average price (US\$/kilowatt hour)	0.040	0.045	0.036
Alternative 1+ Environmental Flow: “Operation today” with Q^{95} environmental flows			
Production (gigawatt hours/year)	191.6	143.8	102.7
Income (US\$ million/year)	7.64	6.45	3.71
Change in production compared with Alternative 1 (gigawatt hours)	-45	-57	-50
Percentage difference	-19.0	-28.4	-32.7
Change in income with Alternative 1 (US\$ million/year)	-1.80	-2.55	-1.80
Percentage difference	-19.0	-28.4	-32.7
Alternative 2 + Environmental Flow: Optimized operation with Q^{95} environmental flows			
Production (gigawatt hours/year)	212.7	153.7	106.3
Income (US\$ million/year)	9.48	7.94	5.11
Average price (US\$/kilowatt hour)	0.045	0.052	0.048
Change in production compared with Alternative 1 (gigawatt hours)	-23.9	-47.1	-46.4
Percentage difference	-10.1	-23.5	-30.4
Change in income compared with Alternative 1 (US\$ million/year)	0.04	-1.06	-0.40
Percentage difference	0.4	-11.8	-7.3

Source: World Bank.

FIGURE 8.1 SENSITIVITY ANALYSIS FOR THE EFFECT OF ENVIRONMENTAL FLOWS UNDER OPTIMIZATION

(environmental flows) and other water users. Such adaptive and integrated management benefits the environment and various user groups under different conditions. The flow scheme under the cascade joint operating rule aims to secure optimal implementation of environmental flows for the best environmental effect. Managing basin operation in an integrated fashion ensures sustainable use of water resources, including environmental flows and optimal water usage for all users, and thus helps the basin organization guarantee reliability of supply to the hydropower industry in the basin (Lillehammer 2011).

Opportunities for Optimization

The information on operating rules for all cascades in this study indicates that production planners have a high degree of freedom. Consequently, removing any of the practices the power plant operators have today is not recommended. More important would be to highlight possible opportunities for optimal production planning when it comes to both operating rules and joint operation in cascades.

Good joint operations would ideally be overseen by one planner, in a common operation center² for all power plants in a cascade. The planner would need good historical flow statistics and hydrological and meteorological forecasts for the coming hours and days. Joint operation is most important in the dry season, when there are large variations between peak and off-peak prices that Electricity Vietnam pays to generators.

The linchpin to success is the largest reservoir, specifically, how to operate and utilize the stored water volume, both in the short term and on a longer-term basis, to

maximize peak generation in all the SHP plants in the cascade. By using an optimization model or optimization planning tool, the best joint operation of all power plants can be achieved.

Joint operation also has to take into consideration the efficiency curves for all plants. In general, a turbine is most efficient at a point lower than maximum capacity, say, at some 80 percent of capacity. Turbines should usually not be operated at maximum load except in peak hours, when the peak price is much higher than the off-peak price, or in the wet season when water inflows are generally high.

Each of the four cascades in this study was analyzed for optimized operation. The smallest reservoir in each cascade can only be used for daily peaking. Reservoirs with larger volumes can be used for weekly and to some extent even seasonal regulation. These larger reservoirs are Trong Ho in Ngoi Xan; Nam Tha 3 in Nam Tha; Nam Chien 1 in Chien; and Chieng Pan, Sap Viet, and Phieng Cong in Sap. The most significant benefit to joint operation of the reservoirs and power plants is the ability to operate these larger reservoirs to maximize peaking generation in all downstream power plants.

In Nam Chien, the largest reservoir is very large, and will most probably be operated on a seasonal basis not directly linked to needs in the downstream SHP plants.

A special challenge in Sap is the “bottleneck” in Ta Niet and how to operate the cascade with as little spill as possible at this plant without losing peak capacity in the other plants.

Joint Maintenance

General

The main types of maintenance are the following:

- Maintaining the live storage volume of the reservoirs by sediment handling (flushing sediments and the like)
- Maintenance of the electromechanical parts to keep the plants running efficiently
- Others (civil works, refurbishment, upgrading, and so on)

Sediment Handling

In the Nam Tha and Ngoi Xan cascades, a larger reservoir is situated upstream (Nam Tha 3 and Trung Ho, respectively), making sediment removal more difficult. Therefore these reservoirs will have limited lifetimes, but it is important to have clean intakes so the plants can act as run-of-the-river when the reservoir is filled with sediment. In that case, part of the sediment could possibly

be removed so daily storage can be obtained. In contrast, all the reservoirs in Sap are very small, so flushing them frequently will be important. Nam Chien 1 is a large reservoir, so no major removal of sediments will be possible. However, the expected lifetime of its active reservoir is long. Nam Chien 2 is flushed every other year.

The effect on energy production of sediment in the reservoirs is shown in table 8.4. The reductions in annual energy are caused by increased spill due to reductions in available reservoir capacity.

Maintenance of Electromechanical Parts and Other Civil Works

So far the maintenance undertaken has been oil filling and minor works, and there are no special signs of wearing of the turbines. When needed, refurbishing turbines (repair, coating or changing of runners/runner blades) one by one can be undertaken in the dry season to reduce or avoid loss of energy production. The civil works structures are regularly inspected for cracks, corrosion, leakage, tightness, and so on.

TABLE 8.4 REDUCTION IN ANNUAL ENERGY PRODUCTION FOR VARIOUS SEDIMENT FILLING SCENARIOS

Scenario	Cascade	Reduction in annual energy production (gigawatt hours)
	Nam Chien	
1	Upper reservoir, Nam Chien: 100 percent live storage, no sediment Other reservoirs: 0 percent live storage, filled with sediment	4.0
	Nam Tha	
1	Upper reservoir, Nam Tha 3: 100 percent live storage, no sediment Other reservoirs: 0 percent live storage, filled with sediment	1.1
2	Upper reservoir, Nam Tha 3: 0 percent live storage, filled with sediment Other reservoirs: 100 percent live storage, no sediment	5.0
3	All reservoirs: 0 percent live storage, filled with sediment	6.1
	Ngoi Xan	
1	Upper reservoir, Trung Ho: 100 percent live storage, no sediment Other reservoirs: 0 percent live storage, filled with sediment	2.7
2	Upper reservoir, Trung Ho: 0 percent live storage, filled with sediment Other reservoirs: 100 percent live storage, filled with sediment	8.3
3	All reservoirs: 0 percent live storage, filled with sediment	11.1
	Sap	
1	All reservoirs: 0 percent live storage, filled with sediment	19.1

Source: World Bank.

Conclusion

Current planning procedures do not fully acknowledge the potentially significant cumulative impacts from SHP cascade development. The prescribed environmental assessments for the studied hydropower cascades mainly focus on each plant's local effects, and address impacts to the broader river basin weakly, if at all. With regard to joint operation, the simulations indicate significant potential to increase energy production, partly as a result of reduced spill. These findings lead to the formulation in the next chapter of specific policy recommendations to improve the sustainability of SHP development in Vietnam.

Notes

1. In all studied cascades except Sap, irrigation demands were found not to be in conflict with electricity production, mainly because irrigation off-takes occurred further downstream, where flows were not influenced by the cascade.

2. A common operations center is admittedly difficult to establish in cascades with many different owners. Global experience, for example, in Scandinavia, shows that joint operations do exist and can be achieved on a commercial basis, providing shared benefits for all owners.

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Conclusions and Recommendations

Development of Small-Scale Hydropower in Vietnam

Small-scale hydropower (SHP) in Vietnam has come a long way, benefiting from the knowledge gained from developing hydropower in the country over the past 50 years. The well-established institutional framework in Vietnam includes legal and policy procedures for hydropower development, and experience and skills are embedded in the organizations of the major ministries, institutes, and local consultants.

Nevertheless, challenges to SHP development remain. The studies of six SHP cascades in northwest Vietnam indicate that the cumulative impacts of building several small dams in a river may be significant. SHP cascade development creates trade-offs with values important to other stakeholders, similar to the development of individual large hydropower plants. Therefore, one main conclusion of this report is that planning and development for SHP should focus on the system (or cascade) level rather than on individual projects.

The studies for this report find that SHP cascades as a system tend to have significant impacts through aquatic habitat fragmentation because the series of diversion schemes significantly reduces river flows for long distances. Cumulative impacts on aquatic fauna are thus not strictly additive but synergistic because the SHP cascade exacerbates the impacts on migration and mobility of riverine animals. Furthermore, although land take is small for each project, the accumulated required land for the cascade as a whole may be comparable to that of a large

hydropower project with corresponding installed turbine capacity. Risks for deforestation and impacts on biodiversity also follow from the opening up of pristine areas with access roads. These are examples of indirect cumulative impacts that are often ignored.

On the other side of the coin, because SHP cascades are often built in remote mountainous areas, unsuitable for agriculture, resettlement of people and conflicts with irrigation are normally minor. Impacts on river flows are mostly limited to within the cascade because of the normally small reservoir volumes for SHP. The effect of peaking—producing energy during only a few hours of the day—may have negative impacts on water users just downstream of the cascade during the dry season, but the studies of the six cascades in northwest Vietnam indicate that such impacts are limited. The cumulative impacts on project-affected peoples related to SHP in Vietnam are, therefore, antagonistic because the addition of more plants upstream will not significantly change the downstream flow regime.

The studies of the six river cascades further indicate that optimizing the operation of the SHP plants as a system would yield significantly higher power production and higher revenues, but providing environmental flows would reduce power production and revenues. Thus, from the policy maker's perspective, balancing the trade-offs between the private benefits to SHP operators and the external benefits to the environment is important. The application of joint planning, joint operations, and joint maintenance of the SHP projects in the cascades will lower costs and increase total benefits.

Recommendations for Policy Makers

Vietnam has already taken many essential policy steps to support the sustainable development of SHP. Recent examples are the decrees requiring certain minimum environmental flow releases and minimum land take per installed megawatt for new development.

The studies underpinning this report, however, highlight the difficulties associated with the enforcement of general rules on individual new projects. Minimum flow requirements for biodiversity or ecosystem services for local people vary considerably by region, river, and even parts of the stream. And effects on deforestation and biodiversity may be much different from the physical footprint of individual SHP plants.

The main policy recommendation in this report is, therefore, to break the paradigm of planning and enforcing rules for SHP on a one-project-at-a-time basis. The government of Vietnam should strengthen planning for SHP at both the regional and national levels, and should promote the development of robust and efficient cascades in rivers that are the most suitable based on multiple criteria. Policy changes should focus on future new development, but should also address the implementation of “no-regret” measures for existing cascades, implying measures that are beneficial regardless of changes in the future.

The main recommended steps for policy makers are the following:

- **Strengthen the requirements for and performance of participatory technical optimization and strategic environmental assessments at both the river basin and regional levels.** Stronger assessments will enable both the optimization of hydropower plant operation and the evaluation of impacts at the system level. The result will be an overall improvement in power production efficiency as well as the most reasonable and cost-effective mitigation of negative impacts. Because SHP project areas are also affected by exogenous factors (especially anthropogenic factors and the growing economy), the cumulative impacts of SHP cascades will need to be periodically reassessed and updated, and actions and measures will need to be adjusted accordingly.

- **Provide incentives for private developers to build, operate, and maintain SHP cascades in an efficient, environmentally sound, and participatory way.** Ownership of cascades by individual or collaborative companies can be promoted for joint operations and maintenance, and the capacity of private developers can be built for the use of power optimization tools and for the implementation of corporate social responsibility programs.

These two recommendations illustrate the need to work on two different scales. The first recommendation focuses on the country-wide and regional planning scale, which guides where SHP projects should be built (and where not). This step should be the responsibility of the government and should clarify, at both the regional and river basin levels, how the national decrees should be implemented (for example, quantification of environmental flows). The second recommendation focuses on the cascade scale, to guide how SHP projects can be jointly optimized for maximum revenue and minimum impact. Although the responsibility of private developers, the government should provide appropriate guidance and incentives.

The main goal of the policy recommendations is to focus on what is needed for sustainable SHP—a clear regulatory framework and guidelines, and the capacity and incentives for developers to implement the framework and guidelines. Government-led planning at both the regional and river basin levels should provide clarity and detailed guidance on how the national decrees should be interpreted and implemented. Development and dissemination of skills for optimizing construction, operation, and maintenance, including active stakeholder participation, will increase the capacity of developers. The setting of long-term tariffs should provide developers with the confidence to make the necessary up-front capital investments not just for civil works, but also for sustainable environmental and social management.

Recommendations for Planners, Regulators, and Developers

Based on the observations, analysis, and conclusions from the study, a number of tangible recommendations have arisen that may improve the sustainability of SHP development in Vietnam. These recommendations target the category of end users of the study that encompasses operators and developers, planners, and regulators (see table 4.1).

Improve Cascade Efficiency

SHP cascades are intended to produce energy and earn revenues from a given river or stream. Optimization depends on both the objectives and boundary conditions. With respect to the objectives, there is a difference between producing maximum energy and gaining maximum revenues, which is especially relevant during the dry season when higher tariffs during peaking hours apply. Non-energy production objectives, such as environmental flows and flood prevention, should also play a role (although the small reservoirs associated with most SHP plants often minimize their significance). Joint operation is a promising means for optimizing water use efficiency throughout the cascade, making effective environmental and social management financially feasible.

The key to success is the largest reservoir, specifically, how to operate and utilize the stored water volume both in the short term and on a longer-term basis, to maximize peak generation in all the SHP plants in the cascade. Joint operation also has to take into consideration the efficiency curves for all plants in the cascade and utilization of the smaller reservoirs. An optimization model or optimization planning tool can help achieve the best joint operation of the power plants.

For the studied cascades and for those planned for the future, maintenance will become more important as the plants age. Reservoirs get filled with silt, and turbine efficiency declines because of wear on the units. The reservoirs should be flushed of sediment simultaneously, when the plants are shut down. This method ensures that more flushing water is available and that water with suspended material will not pass through the turbines, which could increase wear. The units should be refurbished one by one in a planned manner to minimize production and income losses. Whether units should be upgraded in the dry or wet season will depend on which is considered most important to the maximization of revenues, the value of peak capacity or the loss of more kilowatt hours in the wet season.

The main recommendations for planners, developers, and regulators are the following:

- Promote **joint operation and maintenance** and use an **optimization model or optimization planning tool** to obtain maximum energy revenues for SHP cascades while accommodating other water uses, including environmental flows.

- Promote the **design of robust cascades**, with at least one upstream dam having weekly or monthly storage capacity. Larger reservoirs, preferably upstream, should be an integral part of cascade planning when developing new SHP cascades in Vietnam.
- Raise awareness of the benefits of joint cooperation across companies and promote and design mechanisms for **convening multiple companies** along one cascade.

Reduce Negative Environmental Impacts

Environmental flows are an important and legally mandated mechanism for at least partially offsetting negative cascade impacts. However, implementation of environmental flows is challenging. Several of the existing dams do not have the technical ability to release an environmental flow. Furthermore, the absence of quantitative guidelines leads to subjective and arbitrary flow requirements, the ecological efficiency of which is doubtful.

The environmental impacts of SHP cascades may go beyond the simple summing of impacts from individual hydropower projects, and their magnitude and significance are especially dependent on other river basin developments. Because SHP development is dominated by diversion schemes with small reservoirs, the downstream cumulative effect is marginal. However, because the cascades are mainly located in upstream, remote, mountainous regions, the risks of opening and disturbing pristine areas of relatively high natural value can be considerable. Furthermore, the aquatic habitat fragmentation and loss of river connectivity associated with cascades is very hard to mitigate.

The main recommendations to reduce the environmental impacts of SHP cascades are the following:

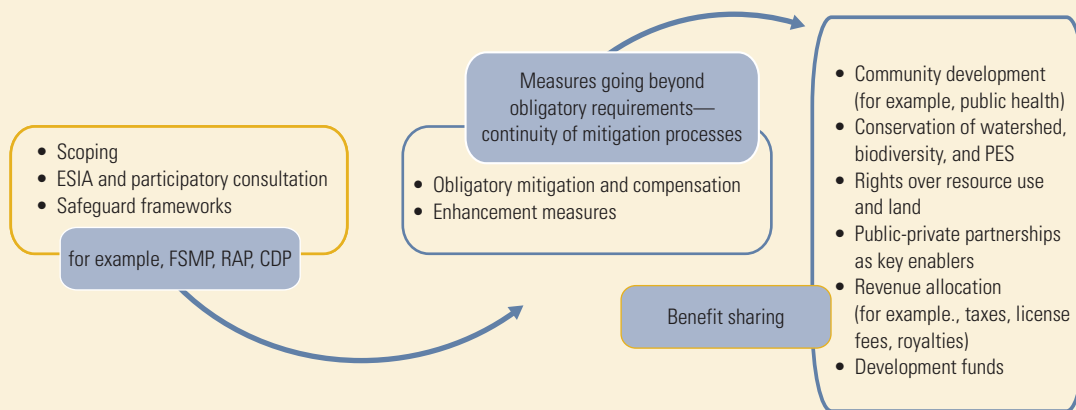
- **Prescribe a set of procedures or methods for setting environmental flows**, and ensure that appropriate environmental flow requirements are included early in the planning of hydropower cascades. Both volume and pattern of discharges should be addressed, duly considering the importance of providing high, medium, and low flow conditions during specific periods of the year. Flexibility for regional and local conditions should be allowed, after proper study and evaluation.

BOX 9.1 BENEFIT SHARING FOR HYDROPOWER DEVELOPMENT

Benefit sharing is a promising concept in sustainably implementing hydropower and water infrastructure projects, and is emerging as a supplement to the standard requirements of compensation and mitigation. Benefit sharing is being driven by a societal responsibility to ensure that local communities end up with something better than pre-project economic conditions. For benefit sharing to work, certain core mechanisms must be in place: policies and the regulatory framework (government), corporate social responsibility policies (project proponent), and community acceptance of the project. Cooperation among these three parties enables tripartite partnerships (Lillehammer, Martin, and Dhillion 2011).

Mitigation measures are normally anchored in commitments related to the environmental impact assessment and licensing processes, either in international guidelines or more specifically in national legislation and regulatory processes. Benefit sharing goes beyond these commitments and focuses on enhancing community development related to opportunities created by the projects instead of only mitigating impacts. Figure B9.1.1 illustrates the relationship and differences between traditional compensation and mitigation measures compared with benefit sharing.

FIGURE B9.1.1 FLOW CHART SHOWING MEASURES THAT GO BEYOND THEIR EXPECTED OBLIGATORY LIMITS IN QUALITY AND TIME



Source: Lillehammer, Martin, and Dhillion 2011.

Note: CDP = community development plan; ESIA = environmental and social impact assessment; ESMP = environmental and social management plan; PES = payment for ecological services; RAP = resettlement action plan.

Vietnam has been developing and piloting benefit sharing for local communities affected by hydropower projects since 2006. The A'Vuong hydropower project was selected as a pilot study for benefit sharing in Vietnam, where the government of Vietnam and the Asian Development Bank were involved. As part of the technical assistance, a draft decree on benefit sharing was prepared in 2008, for pilot testing for the A'Vuong project. The pilot was completed in 2010 and implemented by the Electricity Regulatory Authority of Vietnam in close cooperation with the Provincial People's Committee of Quang Nam Province. The pilot included a wide range of actions such as direct involvement of communities and payments for ecological services (Lillehammer, Martin, and Dhillion 2011). Such a benefit-sharing framework can be similarly utilized in small-scale hydropower development in Vietnam for future sustainability of the planning process.

- Implement regular **strategic environmental assessments** for SHP development, at least at the cascade level, but preferably at the river basin or provincial planning level. Closer interaction and cooperation between hydropower planning and river basin management, involving existing institutional structures, is recommended.
- Introduce the **concept of intact rivers**, whereby at least one continuous stream of the river basin remains free of any hydropower development, as an alternative or additional offset of the negative impacts created by habitat fragmentation and lost connectivity caused by SHP development in other areas of the river basin.
- If a strategic environmental assessment is not conducted, implement a **cumulative impact assessment (CIA)** for new SHP development, the outcome of which (for example, recommended environmental flows, sediment management, social benefit sharing, and water quality monitoring) should be mandated and reflected in the respective concession agreement. Also, the option of either SHP or medium to large hydropower should be explicitly addressed in the CIA.
- Update construction codes and standards to include **technical facilities for releasing environmental flows** and to improve construction supervision, licensing, and operational permits so as to ensure compliance with regulations regarding environmental flows.

Reduce Negative Social Impacts

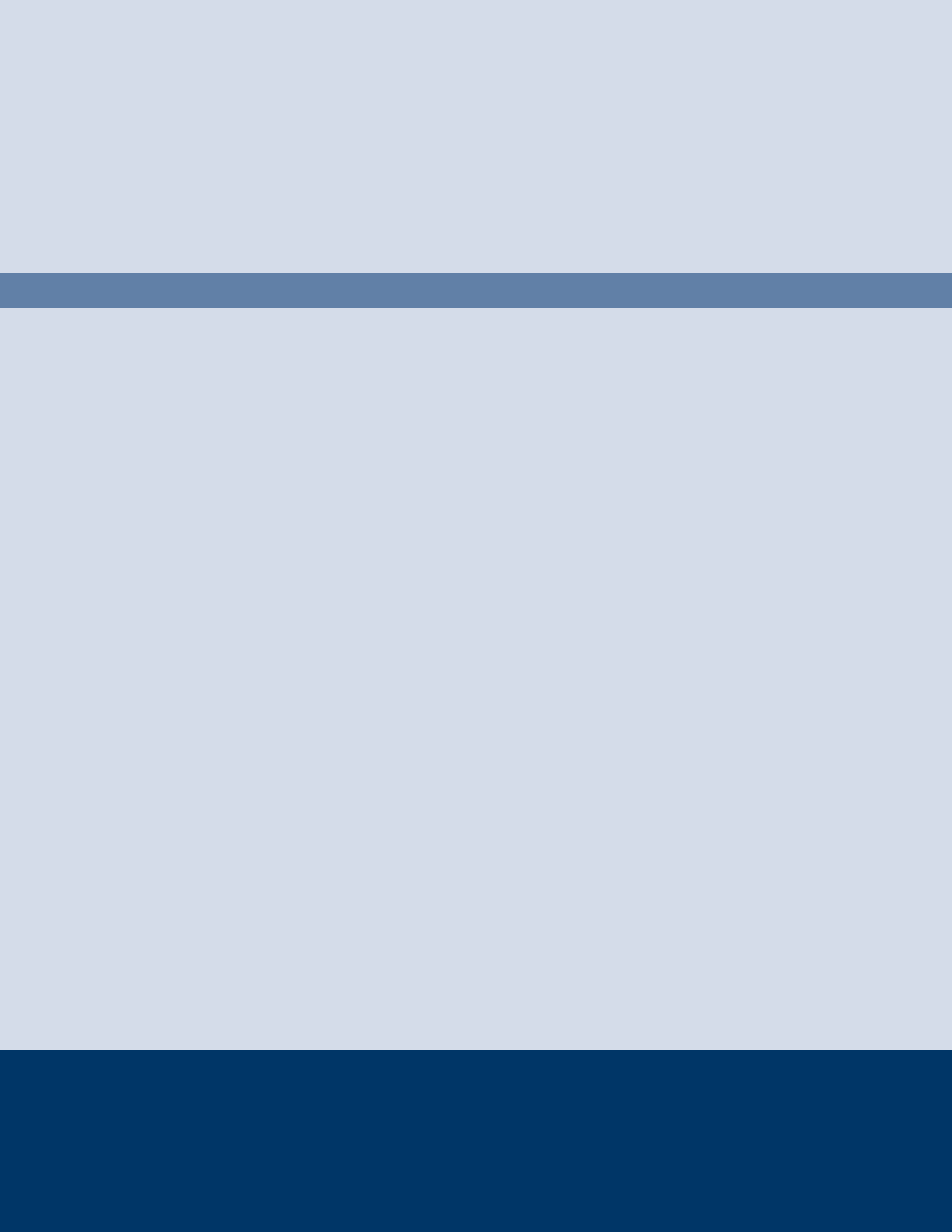
Because of their inherent characteristics (small reservoirs located in remote and thinly populated environments), SHP cascades usually affect only small numbers of people. Resettlement is often not required, but land take does affect the livelihoods of local people, for which they are compensated. In general, it seems that hydropower development has a positive effect on the local economy as well as on individual incomes. However, because cumulative effects may occur (partly due to local economic development spurred by the SHP plant) that are not always easy to mitigate, and may impinge on the traditional livelihood of ethnic minorities often found in these locations, hydropower owners could be specifically tasked with supporting local sustainable development. Benefit sharing, which goes beyond the one-time compensation for lost land, could be the vehicle.

The main recommendations for reducing negative social impacts are the following:

- Promote communication between developers and locally affected people, and develop awareness and capacity of all parties in sustainability issues. This could be accomplished by providing developers with incentives to implement corporate social responsibility programs.
- Include benefit-sharing options (see box 9.1) as a part of the planning and operation process to ensure environmental integrity, social equity, and economic efficiency in river basin development.

Reference

Lillehammer, L., O. San Martin, and S. Dhillion. 2011. "Benefit Sharing and Hydropower Development: Enhancing Development Benefits of Hydropower Investment through an Operational Framework." Final Synthesis Report. SWECO report for the World Bank.





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