8. MITIGATING IMPACTS AND RISKS THROUGH BASIN MANAGEMENT

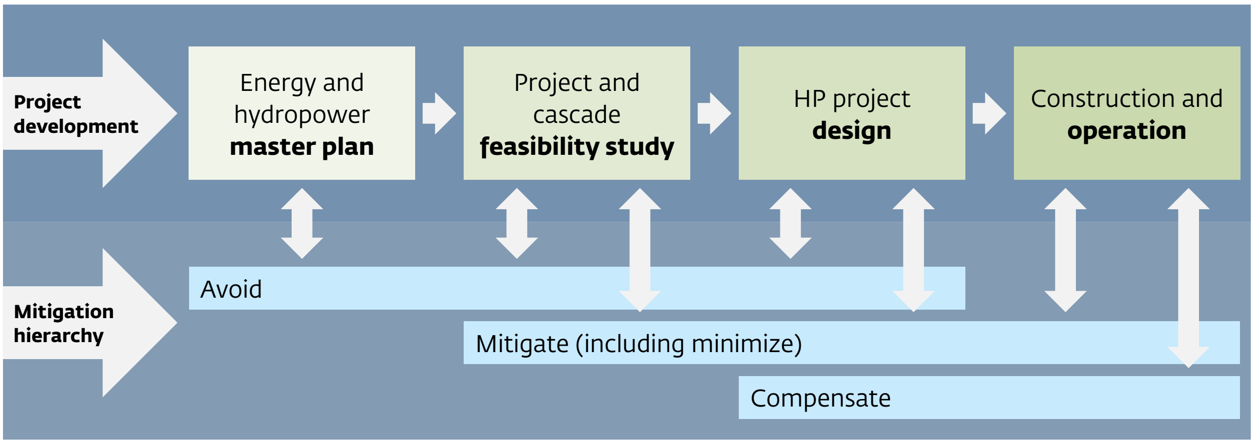
8.1 Mitigation Hierarchy Approach

Measures to mitigate impacts of hydropower development, as elaborated in Chapter 7, can include a combination of measures that may be classified into four main categories of action: avoid, minimize, restore, and offset—known as the mitigation hierarchy.

- *Avoid* through choices about project selection, location, engineering designs, and operating practices
- *Minimize* through provision of environmental flows (EFlows), fish passages, and sediment flushing facilities
- *Restore* through protection and enhancement of conservation areas and important habitats in the reservoir watershed and by restoring livelihoods and incomes of resettled communities
- *Offset* through protection of terrestrial or aquatic ecosystems with biodiversity values similar to those affected

A guiding principle of impact mitigation is that avoidance and minimization are preferred over restoration and offsetting, as opportunities to mitigate impacts and enhance benefits of hydropower are greater at earlier stages of project development (Figure 8.1). For example, impacts can be avoided during the creation of a basin, regional, or national master plan when decisions about which projects to prioritize are made. During project feasibility studies, impacts can be avoided and minimized by adjusting location, dam height, reservoir size, and other design parameters (Box 8.1). During subsequent phases (detailed design, construction, and operation), mitigation options are largely restricted to compensatory measures. Opportunities to mitigate environmental and social impacts in projects already built or under construction are limited. The main physical features of the project (dam, reservoir, powerhouse, and transmission lines) cannot be modified much. In principle, operating rules can be changed to reduce environmental and social impacts, but in practice, these rules tend to be rigidly defined in power purchase agreements. Therefore, addressing cumulative hydropower risks and impacts on the Sekong Basin requires applying the mitigation hierarchy throughout the hydropower development cycle, with a particular focus on master planning at the basin and sub-basin scale.

Figure 8.1: Risk and Impact Mitigation over the Development Cycle



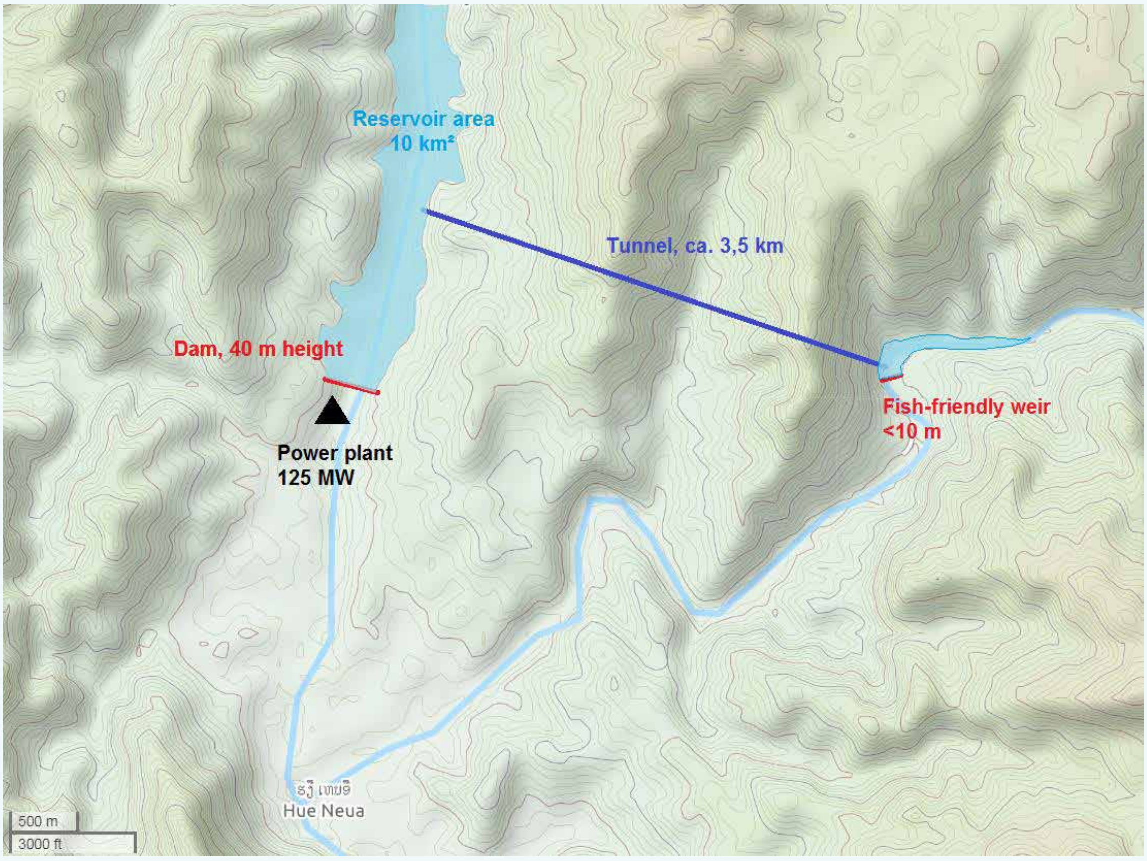
Source: MRC 2019a

BOX 1: PLANNING JOINTLY TO AVOID NEGATIVE IMPACTS

Sekong 4A will be the most expensive project in the Sekong Basin by a significant margin in terms of investment cost per megawatt installed and per annual gigawatt-hour. It will also have significant environmental and social impacts.

An alternative design for the Sekong 4A hydropower plant could reduce the cost per megawatt and the reservoir's environmental footprint. Moving the dam to a new site upstream of the confluence with the Nam Emoun (Map 8.1.1) would reduce dam height and dam volume, more than halving the area that the reservoir inundates while still having sufficient capacity to re-regulate flows released from upstream Sekong 4B when operating in peaking mode. To achieve that, an active volume of 10 million to 20 million cubic meters would be sufficient, which is 10 percent of the proposed reservoir. The power output of the revised plan would be approximately 50 megawatts less, but the investment cost and environmental footprint would also be lower. In addition, it may be technically and economically feasible to transfer water through a tunnel to the Nam Emoun River, increasing the generating capacity of the Nam Emoun hydropower plant (HPP) and offsetting some of the reduction in power that the modified Sekong 4B generates.

Map 8.1.1: Risk and Impact Mitigation over the Development Cycle



This alternative design would have several advantages in terms of environmental and social impact mitigation. First, the Nam Emoun would remain open for fish migration, assuming a small fish passage can be incorporated into the Nam Emoun dam. Second, sediment transport would be better because the flushing efficiency of the smaller Sekong 4A reservoir would be higher. Third, the area of forest lost to the reservoir would be significantly less, reducing the risk of eutrophication after impoundment and permitting continued use of the forest for non-timber forest product harvesting. Fourth, resettlement impacts would be lower. The existing design of the Sekong 4A reservoir and larger dam construction site would affect houses and some agricultural land, but the smaller reservoir in the alternative design would not.

8.2 Master Planning

Master planning enables rational decisions about which of the many possible projects in the Sekong Basin should be prioritized to meet local, national, and cross-border power generation demand while minimizing financial, environmental, and social costs (Opperman, Grill, and Hartmann 2015).

With a basin-scale perspective, it is easier to identify complementary hydropower projects that can be operationally coordinated to meet power generation needs while limiting environmental and social effects to acceptable levels. An example involving the Sekong 4A HPP and Nam Emoun HPP is presented in Box 8.1. Hydropower development in the Sekong Basin is developer driven and therefore not well coordinated to meet strategic goals. Even when three or more developers are working on the same river, there has been little observable coordination of water management and power dispatch, although there has been some cooperation in terms of access roads and transmission plans.

An integrated water resources management approach should be used during master planning to ensure that the full range of water resource uses, stakeholders, and possible trade-offs that may emerge is considered. In the Sekong Basin, this would include agriculture and forestry (using river water and ground water for irrigation), riparian communities (reliant on the river for potable water, fishing, navigation, and cultural practices), and mining and other industries (requiring river water and ground water for mineral processing and manufacturing).

A Sekong Basin master plan can establish basin- and catchment-specific requirements and targets for hydropower developments with overarching criteria such as the following:

- Environmental flow requirements (for example, minimum flows, seasonal releases, irrigation releases)
- Limits on ramping rates to minimize downstream riverbank erosion and harm to community safety
- Water quality targets such as dissolved oxygen levels and seasonal temperature ranges
- Sediment concentration limits or targets associated with coordinated sediment flushing operations
- Limits to lake-level operating ranges (for example, to support other water uses)
- Identification and protection of ecosystem, biodiversity, and wetland hotspots
- Identification of potential intact river routes for fish migration and other water uses

8.3 Power Generation Optimization

One of the benefits of master planning at a basin or sub-basin level is the possibility of optimizing power production by co-designing projects and coordinating project operations.

This is particularly relevant when multiple hydropower projects are constructed on the same river because this creates a cascade effect, with the flows released from one project affecting the generating capacity of projects downstream.

This study assessed the potential to maximize power production by optimizing operation of the seven mainstream dams planned under the full development pathway. The technical assumptions, methodology, results, and assessments are described in Appendix G.

For this assessment, three modes of operation are considered:

- *Maximization of energy output*: power plant operated mainly as run-of-river but with the reservoir used for storage in the wet season to avoid major spilling
- *Maximization of firm energy*: power plant operated at a constant output to provide as much firm power as possible
- *Dry season generation*: reservoir emptied in advance of the monsoon, and wet season inflow used to fill reservoir to generate as much power as possible in the dry season

Table 8.1 shows the dams included in the analysis and simulated power production for the Sekong mainstream dams. Differences in power generation among the three modes of operation are slight mainly because reservoirs are relatively large, and the design discharge of most HPPs is higher than the flow in the river, so there is relatively little spill, although there are some differences between the modeling results and project feasibility studies (right hand column in Table 8.1), which show higher power production for some projects. See Appendix G for more detail.

Table 8.1: Summary of Simulated Power Generation for Sekong Mainstream Dams

Hydropower project	Maximize generation	Maximize firm power	Dry season generation	Feasibility study
	(GWh per year)			
Sekong 5	1,239	1,200	1,159	1,502
Sekong 4B	736	756	757	749
Sekong 4A	734	749	752	781
Sekong 3A	368	370	371	433
Sekong 3B	307	310	310	418
Sekong Downstream B	176	180	181	206
Sekong Downstream A	423	438	439	380
Total	**3,983**	**4,003**	**3,970**	**4,469**

Note: GWh = gigawatt-hours.

There are several potential reasons for the differences in power generation between this study's model and the results of the feasibility studies. One explanation for the differences lies with the hydrological data. The power optimization model in this study uses inflows from HEC Res-Sim modeling (Section 1.2.5) that are approximately 15 percent to 20 percent lower than in the project feasibility studies. Another factor is that the production figures in the feasibility reports do not consider the upstream regulation benefits of the Sekong 5 project. This makes sense because the downstream projects cannot base their investment and financing decisions on the uncertainty that the upstream reservoir will be built and that it will operate optimally for downstream plants. Moreover, the feasibility studies do not include downstream reservoirs in their calculated tailwater level, thus overestimating the available head.

Despite these differences, overall, there is reasonable agreement between the model results in this study and the feasibility study figures for most projects, given all the uncertainties and assumptions involved in such modeling.

8.4 Coordinated Operations

Despite limited opportunity for power optimization through coordination of the Sekong mainstream cascade, there may be power optimization benefits for hydropower projects on tributaries, especially for dams in cascades on the same tributary. In particular, opportunities to coordinate cascade operations on the Xe Kaman, Nam Kong, and Xe Namnoy tributaries should be further analyzed to optimize power generation, avoid power export bottlenecks, and promote grid stability. Hydropower projects that may benefit from this analysis are the following:

- Nam Kong 1, 2, and 3 (Bolaven and Nam Kong sub-basins)
- The six dams on the Xe Namnoy tributary that divert water from Xe Pian to Xe Namnoy
- The 13 dams in the Xe Kaman sub-basin, especially the five on the Xe Kaman mainstream, but also to some degree those on its tributaries

In addition to power optimization, coordinated operations can help achieve priorities for environmental and social mitigation, management, and monitoring, including the following:

- Coordination of sediment flushing
- Synchronization of flows to trigger fish migration
- Sharing of data on biodiversity values (for example, fish species monitoring)
- Pooled financing of catchment protection and environmental offsets
- Exchange of hydrological data for power forecasting
- Coordinated flood monitoring and warnings

8.5 Institutional Arrangements

Effective planning and management of hydropower in the Sekong Basin requires appropriate institutional arrangements involving the national government, local authorities, and the private sector. Inter-ministerial coordination is particularly important because the Ministry of Environment and Natural Resources is responsible for basin planning, but the Ministry of Energy and Mines is responsible for power development planning. Integrated water resources management calls for the involvement of other ministries and agencies (for example, agriculture, forestry, industry, and tourism), communities, and other local stakeholders.

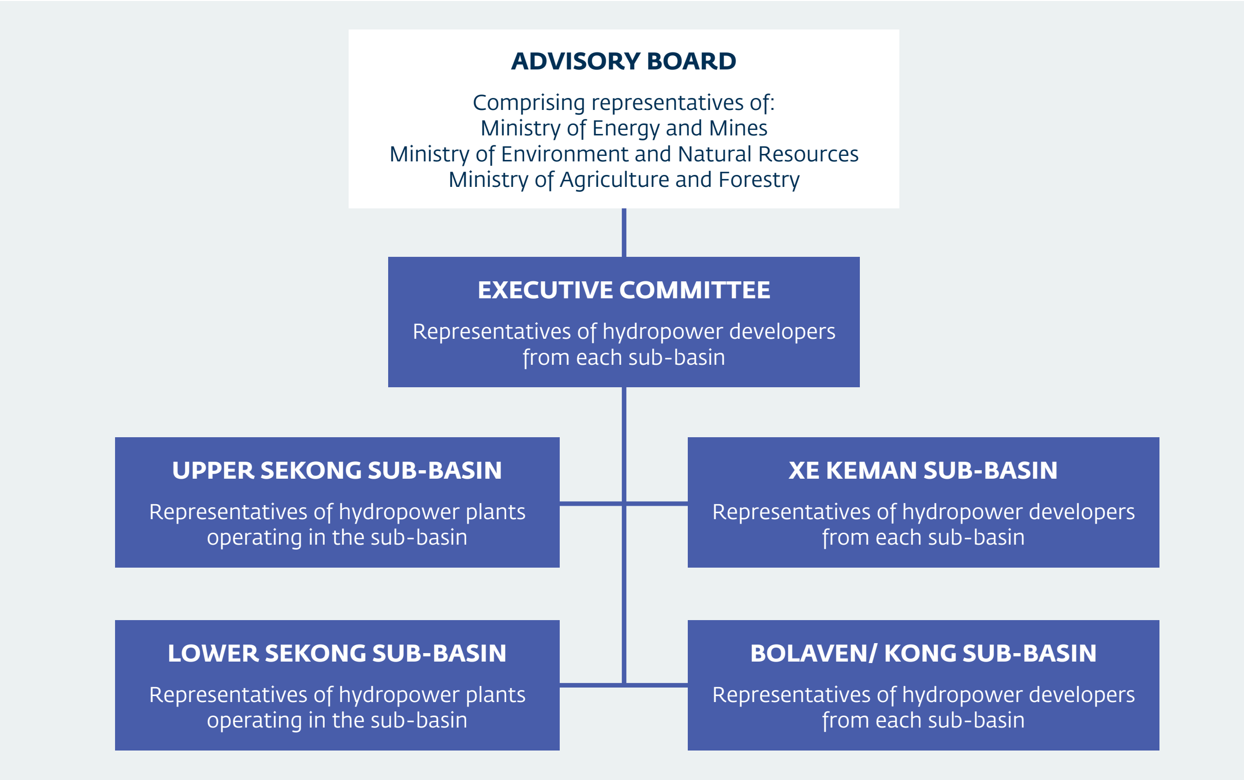
Coordination and information sharing among Sekong Basin hydropower operations could be achieved by establishing a simple co-management mechanism for the Sekong Basin organized around sub-catchments in the basin (Figure 8.2). This would be a voluntary company-led initiative coordinating closely with the Ministry of Energy and Mines that would have the following core functions:

- Communication among Sekong Basin hydropower operations, particularly within the same sub-basin
- Coordination among projects on specific matters of shared relevance (for example sediment flushing, fish passages, EFlows, and emergency procedures)
- Sharing of selected data sets (for example, hydrometeorology and water quality) to support operational decision making and power optimization
- Pooled funding arrangements for joint-management measures where appropriate (for example, watershed management and biodiversity offsets)
- Engagement with other Sekong Basin stakeholders consistent with the requirements of integrated water resource management

A co-management platform could extend to collaborative monitoring and reporting on the effectiveness of cumulative impact management mitigation. Doing so would enhance trust among participating hydropower operators and motivate closer cooperation in other areas of mutual interest.

Modest funding would be required for secretariat functions, meetings of the executive committee and sub-basin committees, and learning and information exchange events among members. To ensure long-term sustainability, the preferred funding model would be small annual contributions from hydropower operators proportionate to individual generating capacity or another simple metric, providing a surrogate indicator for a project's contribution to cumulative environmental and social impacts. As a novel entity, the co-management platform may require seed funding from development partners to support its functions for an initial period (for example, three years). During this time, operation of the platform would be fine-tuned through a process of continuous monitoring, review, and adaptive management, culminating in an external evaluation providing guidance on future operations.

Figure 8.2: Tentative Structure of Co-Management Platform



8.6 Mitigation by Design

Hydropower project design is an iterative process moving from feasibility study to final detailed design. Project design should consider environmental design requirements and mitigation targets defined in the basin master plan (Section 8.2) as well as project-specific risks identified through an environmental and social impact assessment (ESIA). Environmental and social mitigation strategies should be identified early during the feasibility phase and refined during the detailed design phase to arrive at the final design of the project. This includes detailing of mitigation infrastructure, which might include the following:

- High- and low-level outlets to help discharge of water from different levels within the impoundment and with potential to pass sediments through the dam
- Re-regulation reservoirs to dampen downstream water level fluctuations
- Aeration weirs to increase oxygen levels in the tail water
- Fish passage addressing upstream and downstream migration
- Sediment bypass channels, tunnels, or infrastructure to promote deposition of sediment at the upstream end of reservoirs where it can be periodically harvested

To improve the design of future projects, it is recommended that the above mitigation infrastructure be considered in all HPP feasibility reports. The need for such measures is often under-emphasized in feasibility reports, or project proponents reject it as too costly; summary feasibility reports reviewed for this study contained little systematic analysis of such mitigation measures. Not all will be appropriate for all projects, but failure to assess a full range of mitigation options should be considered grounds for rejecting the feasibility study.

Evidence for the efficacy of mitigation infrastructure should be carefully reviewed. For example, whereas re-regulation dams and aeration weirs are well proven, studies show that sediment flushing and sluicing are viable for only relatively small reservoirs; regarding fish passages, data are limited on designs suitable for Mekong Basin fish species.

8.6.1 Re-regulating Reservoirs

Most of the larger hydropower plants in Lao PDR with export agreements to Thailand or Vietnam have variable prices for delivery of power during peak and off-peak periods and so tend to operate at full output during peak demand hours and conserve water during off-peak hours. Some export agreements contain clauses that provide for cross-border dispatch by the power purchaser, which means that the power purchaser can call the hydropower plant operators and instruct that the turbines be started on short notice to meet urgent power needs.

This type of peaking operation has consequences for the river downstream of the power plant tailrace. Variability in flows can be high and can change from 0 to 100 percent of the hydropower plant capacity within minutes, although such extreme peaking operation is not the norm. To operate in peaking mode, a small reservoir capacity is required, but most of the power plants in the Sekong Basin seem to be designed to include this capacity. Normally, 12 hours of storage at peak outflow is sufficient for most operation modes.

If the plant operating in such peaking mode has its outlet into or near a reservoir, the effect of flow variations is only minor—slow rises and falls of a few centimeters in the level of the downstream reservoir—but when the peaking power plant discharges into a river, the flow variations can have severe effects on downstream communities and can present a danger to anyone in the river washing, bathing, or fishing. One example of the daily variation in water levels can be seen in Photo 8.1, in which regular daily variations from full output to low output can be seen on the riverbanks.

To mitigate such rapid flow variations, it is advisable for the lowest power plant along a cascade of peaking power plants to have a re-regulating reservoir volume and to operate on a more or less constant release basis. The reservoir attached to the lowest dam does not need to be large but can function well with only a few hours of storage to capture the peak hour releases from upstream. The re-regulating reservoir is then drawn down when the upstream plants are switched off, ready for the next daily cycle of peaking operation (usually at night when power demand is lowest).

Photo 8.1: Hinboun River, Lao People's Democratic Republic, at Low Flow, Showing Regular High-Flow Water Line Two Meters Higher Corresponding to Peak Outflow from Hydropower Plant Upstream

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If no regulating reservoir has been planned, it is common to impose restrictions on the rate that power output can be increased or decreased so that changes in flow rates and river levels occur slowly. This will normally remove any life-threatening situations of rapid rises in flow without prior warning.

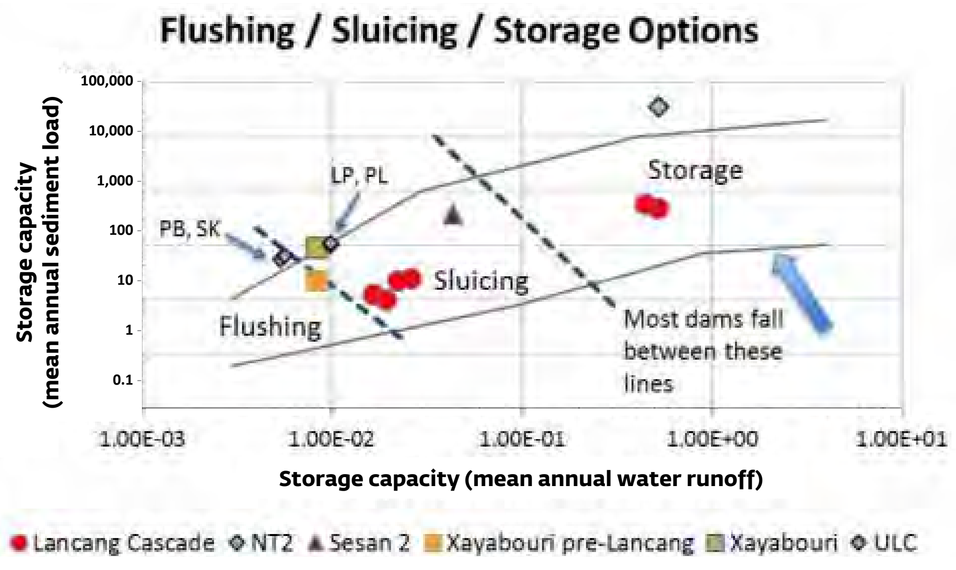
The natural laws of hydraulics will cause a dampening of such flow variations as one moves further downstream of the power plant outlet, so it is usually only the first 10 to 30 kilometers of a river exposed to peaking operation that will experience severe changes in flow and water level. One secondary effect of such flow variation is gradual erosion of riverbanks exposed to rapid river-level fluctuations. Modeling of such local downstream effects is the responsibility of each project owner and should appear in the ESIA reports for the peaking projects in question. There are no significant cumulative effects because the main effects are immediately downstream of each power plant. The study did not attempt to model such effects and did not have insight into the intended mode of operation of future hydropower plants.

8.6.2 Sediment Management Infrastructure

For very small reservoirs with a volume of less than 2 percent of mean annual inflow, sediments can be passed through the dam using low-level outlets designed for this purpose. The usual flushing procedure is to open the flushing gates fully and, if possible, draw down the reservoir level to allow erosion of sediment accumulated on the reservoir floor. Normally, only fine sand and silt can be flushed in this manner while much of the coarse sand and gravel fractions remain in the reservoir. Flushing has a cost in terms of reduced hydropower production.

Sluicing is a variation of flushing applied continually during flood inflows where incoming sediments are maintained in suspension or as rolling bed load by drawing down the reservoir as far as possible and thereby having high water velocities through the entire length of the reservoir. Because most of the incoming sediment arrives during the flood season, sluicing can be effective in maintaining sediment flows past the dam and preventing blockage of power intakes.

Figure 8.3: Mekong Cascade Dams—Suitability of Flushing and Sluicing Sediment Management



Source: MRC 2019c

Note: NT2 = Nam Theun 2; ULC = Upper Lao Cascade (Mekong mainstream); LP = Luang Prabang; PL = Pak Lay; PB = Pak Beng; SK = Sanakham.

Sluicing becomes less suitable as the size of the reservoir increases and becomes impractical or excessively costly after reservoir size exceeds approximately 20 percent of mean annual inflow (Figure 8.3). The effect of introducing systematic flushing operations is illustrated in the Mekong Hydropower Mitigation Guidelines (MRC 2019c), from which Figure 8.4 has been sourced. Here one sees the more precise modeling of the effect of optimal flushing procedure on the transport past a cascade of four mainstream Mekong dams, including Xayaburi, which is nearing completion in northern Lao PDR. More details of the modeling assumptions and results, including many sensitivity tests, can be found in the same report, but all four dams on the cascade have very small reservoirs in relation to annual inflow and sediment load. For such reservoirs, sluicing using bottom outlets can reduce trapping and pass sand and finer fractions past each dam.

A striking illustration of reservoir sediment trapping is seen in Photo 8.2, a satellite picture of the Sesan 2 reservoir in Cambodia showing incoming sediment from the Srepok River in February 2018, shortly before impoundment of the reservoir was completed. Incoming sediments were settling before reaching the dam. Sesan 2 is a relatively small reservoir, corresponding to 6 percent of mean annual inflow, but it has been assessed as technically not possible to flush (Annandale 2013).

Many existing and planned dams in the Sekong Basin have larger reservoirs (for example, Xe Kaman 1, Nam Kong 3, Houay Ho, and Xe Pian–Xe Namnoy) that will prevent sediment sluicing or flushing from having a significant mitigating effect.

This study assessed the potential of flushing the five reservoirs in the Sekong Basin with volumes up to 5 percent of annual inflow: Sekong Downstream A and B, Sekong 3A and 3B, and Nam Kong 2. Sediment transport increased by only 5 percent with flushing (Figure 8.4).

Figure 8.4: Transport of Medium-Sized Sediment in Sekong Downstream from the Lao People's Democratic Republic–Cambodian Border with and Without Sediment Flushing

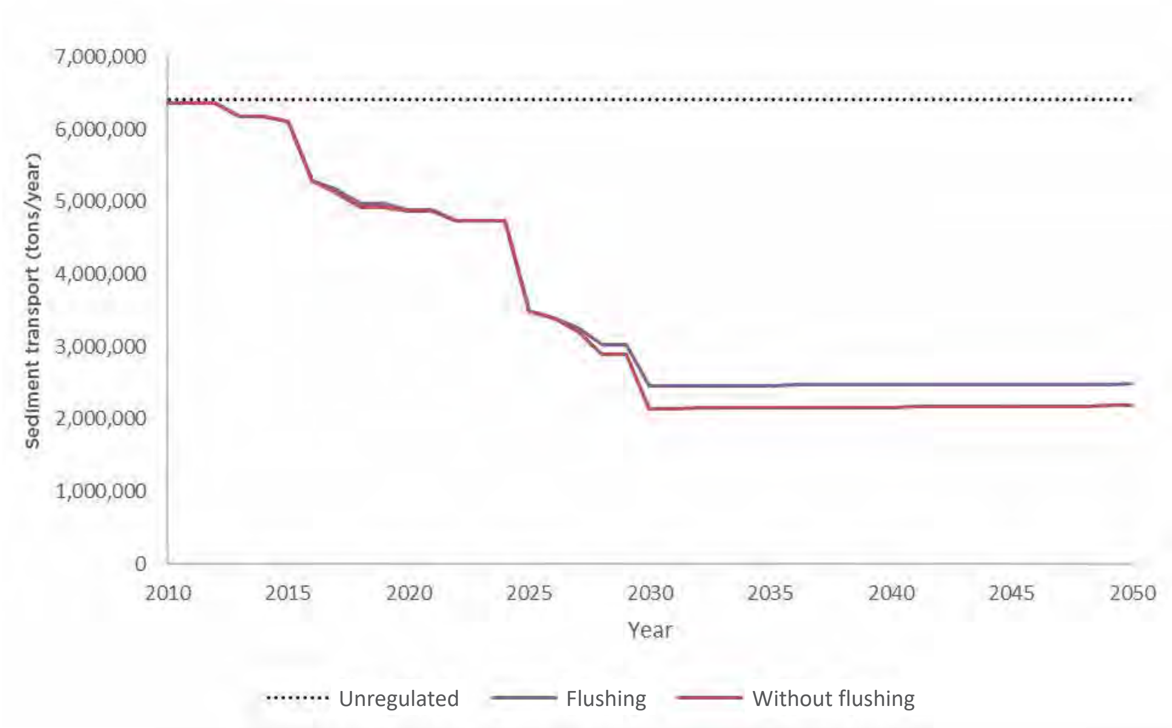


Photo 8.2: Satellite Picture of Lower Sesan 2 Reservoir, February 2018

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8.6.3 Minimizing Impacts on Aquatic Biodiversity

Fish passages should be considered for all dams but are likely to be feasible and effective only for small and medium-sized dams with a lower vertical head. Site-specific research is required to determine appropriate engineering designs that can support a diversity of fish species with realistic hydro-morphological properties (water depth and flow velocities) and accessibility from upstream and downstream. Because fish passages are always less effective than the natural situation, mitigation measures that reduce or re-allocate dams from the mainstream (as proposed in the conservative development pathway) are preferred over construction of dams with fish passages.

Environmental flow requirements need to be assessed for individual HPPs and for cascades, requiring analysis of all aspects of the flow (magnitude, frequency, timing, and quality) and how this can be optimized for aquatic and riparian ecosystems (World Bank 2018).

Community management and monitoring of reservoir fish stocks is important for long-term sustainability. If dam construction affects fish conservation zones (for example, when reservoirs flood them), new fish conservation sites should be established.

8.6.4 Social Impact Mitigation and Livelihood Restoration

The full development pathway will entail physical displacement and resettlement of approximately 12,600 additional people, who will, to a large degree, lose the land that has provided them with their livelihoods. Section 7.4 describes the extent of resettlement and displacement entailed by hydropower (and other) energy development.

One measure that could help mitigate social risks, including livelihood outcomes for resettlers and effects of in-migration on local communities, would be establishment of resettlement management units at the provincial government level. Present practice is for district government authorities to establish such units separately for each project in its jurisdiction. A permanent unit at the provincial level managing all large-scale infrastructure projects in the province and retaining a permanent staff would be better placed to mitigate cumulative social impacts that multiple projects in a basin or sub-basin would cause. Provincial resettlement committees could be mandated to monitor the livelihoods and food security status of resettled communities from all development projects within the province. Such a committee could also study availability of agricultural land for resettlement within the province to determine whether it is feasible to find good-quality resettlement land for the resettled people required to relocate under the full development pathway.

8.6.5 Environmental Offsets

If, despite appropriate mitigation measures, there are significant residual environmental effects, then offset measures should be identified and implemented. The principle is that protection of equivalent environmental values elsewhere may counterbalance unavoidable loss of environmental values. The Sekong Basin has rich forest habitats in the upper catchment that could be a focus for such an offset plan.

One approach could be to establish a joint fund for forest protection with financial contributions from all downstream hydropower projects. Contributions could be distributed based on agreed-on models (for example, per megawatt installed, per kilowatt-hour of electricity produced annually, per reservoir area lost to impoundment, or per annual inflow volume), but contributions should be mandatory and ring-fenced specifically for the protected area.

8.7 Mitigation During Construction and Operation

Construction sites in remote areas have effects that can be reduced but not avoided. Environmental mitigation measures during construction include requiring the contractor to finalize, submit, and implement the environmental monitoring and management plan drafted during the detailed design phase.

To achieve a consistent approach, the government should impose environmental monitoring and management plan standards through the concession agreement. This plan should be required to include the following:

- Erosion and sediment control plan
- Spoil disposal plan
- Quarry management plan
- Water quality monitoring plan
- Chemical waste and spillage management plan
- Emergency plan for hazardous materials
- Emissions and dust control plan
- Noise control plan
- Physical cultural resources plan
- Landscaping and revegetation plan
- Vegetation clearing plan
- Waste management plan
- Reservoir impoundment management plan
- Environmental training for construction workers plan
- On-site traffic and access management plan
- Explosive ordnance survey and disposal plan
- Construction work camp and spontaneous settlement area plan

The operational phase of a hydropower project is the longest period of the project lifecycle but is often given too little attention in feasibility reports, ESIA reports, and detailed designs. During operations, the hydropower operator needs to be actively involved in catchment management activities, including those to minimize cumulative effects. Catchment management goals should include minimization of upstream or downstream changes that might affect (joint) HPP operations. The operator needs to be aware of risks associated with new developments that might be linked to the creation of impoundment, such as water quality risks associated with increased runoff from agricultural or industrial discharges or *in situ* activities such as aquaculture. Catchment management also needs to include development and maintenance of communication systems to alert communities regarding potential for extreme flows or other unusual events (for example, sediment flushing).

Over the decades, operations will need to adapt to changing conditions associated with climate change and changes to electrical transmission systems or energy markets. Development of upstream, downstream, or tributary hydropower projects can also lead to the need for altering operations. These future unknowns highlight the need for ongoing monitoring flexibility with respect to environmental mitigation measures.