# The Next Frontier of Hydropower Sustainability: Planning at the System Scale

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# The New Frontier of Hydropower Sustainability: Planning at the System Scale

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# Executive Summary

The Latin America and Caribbean (LAC) region is experiencing dynamic growth and requires large investments in electrical infrastructure. Hydropower is a major component of the region's energy supply and will provide a significant proportion of future energy growth. A 2012 high-level workshop co-organized by the Inter-American Development Bank (IDB) concluded that meeting expectations for growth of the hydropower sector will pose several challenges to governments, developers, financial institutions, civil society and other stakeholders. Many of these challenges concern the need for hydropower projects to meet evolving expectations for sustainability, defined here as energy development that is consistent with maintaining a broad spectrum of benefits and values from river systems.

Considerable progress has been made on the sustainability of individual hydropower projects, but this will not be sufficient to address the complex issues posed by multiple hydropower developments across a river basin or region. **Sustainable hydropower development also requires system-scale planning, development and management; this is the 'next frontier' in hydropower sustainability.** 'System' in this regard can refer to any level beyond individual projects that is the subject of a planning effort, be it a river basin, region, country, or interconnected grid.

**Without progress on system-scale approaches to planning and developing hydropower, the sector will likely face continued conflict**, leading to financial risk, delay or cancellation of projects, and potentially creating a sub-optimal investment context, which all can lead to missing energy targets. Further, **the lack of system-scale planning will result in missed opportunities for more optimal and balanced outcomes—those which can meet energy needs while also maintaining other key values of river systems.**

## System-scale approaches and hydropower sustainability

Sustainable hydropower is often summarized by its proponents with a simple phrase: "build the right dams and build them right."

The second part of that phrase—"build them right"—has received a great deal of attention and there has been solid progress on improving the sustainability of individual dams, including environmental impact analysis, the Hydropower Sustainability Assessment Protocol, and advances in environmental mitigation.

Although great improvements to environmental performance can be made through dam design and operation (e.g., environmental flow releases), a number of important impacts from hydropower dams cannot be mitigated effectively at the level of an individual dam. Further, project—focused approaches are often applied too late to influence dam location, which is generally the most critical factor for hydropower sustainability. Finally, a focus on individual dams also likely will miss potential synergies or opportunities that could emerge at the system scale.

Thus, although current practice has made considerable progress for building better dams, ensuring that the "right dams" are selected in the first place requires a system-scale approach.

Numerous frameworks exist that could support a comprehensive and system-scale approach, including Strategic Environmental Assessments, Cumulative Impact Assessment, and energy master plans. However, in their current application, several of these approaches have a basic limitation: they start with a proposal for specific projects and then begin to consider assessment and mitigation of socio-environmental impacts. These approaches therefore don't integrate across multiple resource values at the earliest possible stage.

Although multi-use integrated river basin planning conceptually can provide this integration, these approaches tend to focus on water-management *sectors* and not on the full spectrum of water *values*.

Though limited in number, a few examples—ranging from Maine (USA) to Norway to Vietnam—illustrate the promise of system-scale planning for hydropower that simultaneously considers a range of river values and resources. These examples illustrate an important concept for system planning: for a given level of development, there can be a number of different alternative development scenarios and these scenarios often vary widely in terms of the mix of benefits across economic, social, and environmental value sets. An optimal mix of these values across a river basin is highly unlikely to emerge through project-level planning and development; the promise of system-level planning is that it has the potential to identify more balanced development options.

For hydropower development to actually follow a path toward system-scale, balanced outcomes, there are a number of challenges rooted in both technical analysis and policy. First, those optimal or quasi-optimal outcomes must be identified, and this requires information on a range of resources and the ability to integrate that information into an analytical framework. Second, the results of that analysis must be integrated into decision-making processes. To inform these technical challenges, we present a conceptual framework below and illustrate it with an analysis in a hypothetical river basin. We conclude with a set of recommendations about how current planning processes can be reformed so that promising balanced alternatives identified through planning can be become development reality.

## Tool for system-scale planning - Iterative scenario analysis

We developed a simple framework that can build and compare development scenarios in an iterative fashion, seeking balanced outcomes across multiple values. The framework focuses on the scale of a large river basin and is illustrated with analysis of a hypothetical river basin — though hypothetical, the data were adapted from real-world geographical information for three value sets: economic (hydropower capacity and cost of energy); indigenous/social values as represented by indigenous reserves; and environmental/ecological values, represented by a biodiversity "portfolio" and connectivity of the river system. The analysis compared twelve development scenarios.

The key result from the analysis was that, for a given energy output, there was a fairly wide range in the output of other values. This example supports the hypothesis that, through system-scale planning, energy targets can be achieved

| **Scenario 4<br>Randomly developed hydropower** | | **Scenario 7<br>Intentionally designed hydropower** | |
|---|---|---|---|
|  | |  | |
| Value | Percent of total | Value | Percent of total |
| Hydropower | 62 | Hydropower | 61 |
| Indigenous intact | 59 | Indigenous intact | 77 |
| Biodiversity intact | 68 | Biodiversity intact | 73 |
| Connectivity intact | 17 | Connectivity intact | 27 |

with a more balanced output of other river values than can be achieved through individual project selection, with no significant difference in cost.

The table above shows a comparison of two of the scenarios, Scenario 4, which developed 62% of hydropower without considering other values, and Scenario 7, which focused development in the lower river. For similar energy, and comparable average cost, the latter scenario produced a much better balance of values. This result is illustrative of what may be possible; actual results will differ between basins, of course.

## Conclusions and recommendations

Critical to the pursuit of sustainable hydropower, a system-scale approach can identify potential conflicts earlier than can project-based approaches alone and allows for greater flexibility to find alternatives. For a given level of energy development, the system-scale approach has a much greater probability of producing a configuration of projects that allows maintenance of other values, including other water-management benefits as well as environmental and social values.

These general advantages translate into distinct benefits for various entities and stakeholders involved in hydropower. For developers and funders, a system-scale approach can yield greater certainty. For energy planning agencies, it increases the likelihood of efficiently meeting energy targets. Finally, for communities, environmental protection agencies, and conservation NGOs, the approach offers a greater likelihood of maintaining desired environmental or social resources.

In most countries, not just in the LAC region, current planning policies and practices are far from the system-scale approach. **But it is important to lay out a vision of an 'optimal' process that has the best likelihood of achieving sustainability**. This can promote dialogue about its pros and cons, and about how current practices and policies can be reformed to move in the direction of system-scale planning. Multilateral organizations such as the IDB can help foster this dialogue with key stakeholders.

Key components of an optimal system-scale planning approach include:

- Integrated planning directed by a lead agency, with fully engaged cooperation of other agencies and stakeholders, or a coalition of agencies and stakeholders that reflect different interests;
- Nesting hydropower planning within broader energy planning and options assessments;
- Identifying hydropower alternatives starting with a national-scale approach that identifies which basins are priorities for development, and which basins are priorities for protection;
- Within basins planned for hydropower development, using available methods to identify optimal combinations of projects to meet a range of objectives and achieve a balance of values;
- Making planning results relevant by linking them to project-level decisions regarding siting, design and operations; such decisions may include licensing, protection of 'no go' sites, and strategic mitigation requirements.

Achieving something similar to this optimal framework will require major planning reforms, and such reforms require a transition path. Depending on planning systems currently existing in various countries, generic incremental steps can be taken in the short term, including encouraging closer collaboration of agencies, building capacity within agencies and funders, and generating and improving the necessary information base – because no comprehensive plan is possible with information that is outdated, limited, lacking, or inaccessible.

Beyond these general recommendations, IDB and others could support the following activities to advance system-scale planning:

### Planning and information recommendations

- Even if agencies lack the authority to develop legally binding basin or system development plans, they can produce indicative, multi-criteria plans for hydropower development. These indicative plans can demonstrate the potential gains to be achieved through system design and provide an example of sustainable development within a basin. Further, these indicative plans can serve as an overall roadmap for planning and licensing reform by illuminating the potential benefits if actual planning moved closer toward a framework that could achieve the outcomes identified through the indicative plan.
- Establish funding sources or mechanisms that can generate the information and analyses to support good basin planning.

> ***Recommended next steps:***
>
> - Launch a set of pilot projects in a small number of target countries to demonstrate the methodology and efficacy of indicative plans.
> - Commission a study to explore the range of possible funding sources to support basin-scale planning (including, for example, a revolving fund with surcharges on licensed projects to repay the fund).

### Policy recommendations

- Integrate licensing and environmental review with basin-scale planning.
- Develop policies that can be used to legally designate protections for "avoid" or "offset" rivers.
- Incorporate a broader range of socio-environmental values into least-cost ranking and sequencing methods.

> ***Recommended next steps:***
>
> - Support demonstration projects in a few target countries to link licensing decisions with system-scale plans.

### Research and capacity building recommendations

- Refine technical tools and methodologies for building and comparing scenarios.
- Build capacity within agencies on technical approaches and also on policy solutions.
- Study benefits of the potential for system-scale planning to lower risks for funders, developers, and agencies.

> ***Recommended next steps:***
>
> - Identify funds to support ongoing work on technical tools and methodologies.
> - Conduct trainings and exchanges with agencies on technical approaches and policy solutions in conjunction with the demonstration projects mentioned above.
> - Commission a study on project risk management through basin planning.

As with any form of development, system-scale approaches will still cause impacts, even significant impacts, to environmental and social values, and there will be winners and losers. This approach will certainly not solve all conflicts and disagreements associated with hydropower development, but it has a better chance of producing outcomes that are more acceptable to a wider range of interests. **Because infrastructure has an operational life measured in decades, if not centuries, and because sustainability is much more likely to be achieved during planning and design than through retrofits or re-engineering, comprehensive, system-scale planning is a one-time opportunity to "get it right".**

# 1. Introduction: The Hydropower Planning Challenge in Latin America and the Caribbean

The Latin America and Caribbean (LAC) region is experiencing dynamic growth and requires large investments in electrical infrastructure. Governments are promoting increased energy capacity and energy security and a shift towards cleaner energy. Among continents, South America has the most abundant water resources, with annual average precipitation twice that of any other. In large part due to this hydrological abundance, hydropower in LAC has a larger share in the energy mix than in any other region, and comparative advantages in many markets. With a total installed hydropower capacity of about 140,000 MW and significant plans for new deployment, LAC is at the forefront of expansion and investment in the global hydropower sector.

For historical and political reasons, countries in the region have organized their electricity sectors in different ways. Nevertheless they share traditions and languages, as well as many river basins, and have opportunities to jointly develop their energy resources. Within the region, Brazil is assuming a role as a technology leader and investor in neighboring countries. From outside the region, European, North American, Chinese and Australian developers are interested in the Latin American market.

Hydropower is just one among several choices for energy generation and must be viewed in the broader context of LAC energy. Hydropower expansion is happening against the background of an overall energy mix which has moved in the direction of thermal generation, in particular gas, over the last two decades. This has been attributed to security of supply considerations, deregulation, and the increasing concern over environmental and social impacts of hydropower (Arango & Larsen 2010). LAC is estimated to have developed about one third of its technically and economically feasible hydropower potential. A significant amount of its remaining potential is located in areas with high biodiversity value, significant ecosystem services, indigenous communities, and potential conflicts over water resources, presenting fundamental challenges for future development planning.

A 2012 high-level workshop co-organized by the Inter-American Development Bank (IDB) concluded that meeting expectations for growth of the hydropower sector will pose several challenges to governments, developers, financial institutions, civil society and other stakeholders, including: attracting investment and incentivizing the private sector; achieving development objectives in a sustainable manner; and integrating regional considerations into hydropower planning and development.

Many of these challenges require continued regulatory reforms to ensure that only sustainable projects are approved and developed. With the long lead times of hydropower development, projects need to be selected and designed in a way that will be acceptable to regulators, banks and affected communities some years from now. Meeting these long-term sustainability expectations will require project developers with vision and willingness to innovate. These challenges are broadly similar in all LAC countries. Exchanging experiences on how different countries and companies are addressing them should help to lift the quality of all projects and to harmonize regulatory frameworks. A growing regional consensus—about sustainable energy systems in general and hydropower in particular—would also facilitate the integration between electricity grids across national borders.

Sustainable hydropower can be neatly summarized as 'select the right projects, and do them right'. This report focuses on the practical challenges involved in selecting the 'right' projects, emphasizes that this selection requires a system perspective, and proposes a systematic planning approach for Latin American and Caribbean countries. Our central premises are therefore:

- There are significant opportunities to improve the environmental performance of individual projects and these are worth exploring and implementing. However, promising gains for further improving sustainability—whether addressing current projects, future projects, or a combination thereof—lie with approaches that consider resources, impacts, and solutions at a system scale (e.g., a large river basin, a region, or an energy grid). This is supported, in some form or another, by most of the recent frameworks proposed for sustainable hydropower.

- Although hydropower developers and other stakeholders may view system-scale planning as onerous and outside their reach, we suggest that this approach actually can produce multiple benefits for developers and funders, including greater certainty, lower controversy, reduced operational constraints, streamlined review, and improved confidence in securing financing. Recent high court cases in India and Brazil, where hydropower development was blocked in entire regions because of a lack of strategic and cumulative assessments, suggest that such system-scale planning may soon become a general expectation (HydroWorld 2013; HydroWorld 2012).
- Broader adoption of system-scale planning will require an effective framework of responsibilities, incentives and practical tools, as well as some illustrative demonstrations of its utility.

# 2. Elements of a System Planning Approach for Hydropower

In recent decades there has been a global trend toward allowing markets to drive the selection of energy projects – generally based on lowest cost. During the emergence of market-driven project selection, environmental and social impacts received lower scrutiny than they do today and, to the extent impacts were considered, it was generally perceived that they could be addressed through mitigation. This resulted in a project-centered approach to decision-making for hydropower.

In a significant step forward, the IDB's 2006 Environment and Safeguards Compliance Policy mandates that for both project screening and environmental assessment, regional or cumulative environmental impacts should be taken into account. Energy authorities and developers in IDB client countries will typically consider some regional aspects when preparing new projects, and other banks and national regulatory institutions also address the regional context of projects in their safeguards and permitting policies. However, even with these broader considerations, the project-centered perspective still persists: e.g., within the context of regional cumulative impacts, what are the incremental impacts of *a particular project*? A project-centric approach has limitations where multiple projects are planned in a basin or region. As this report will argue, even the best project-centered approach cannot fully replace a system and regional perspective.

Over the past years, a number of approaches have emerged that may contribute to better basin and regional management through early avoidance and resolution of sustainability issues. While they all have a spatial optimization perspective, to date these approaches remain separate and unconsolidated. They have been developed and applied separately by different kinds of organizations in different regions, and there have been few attempts to systematically identify inter-relationships and synergies between them. Key reasons for this may be a lack of awareness of the potential contributions of other approaches, a concern that institutional responsibilities and information advantages may be diluted by cooperating with other sectors, as well as the practical challenges of introducing new planning frameworks. However, from a public policy perspective there appear to be large potential advantages in cooperative, integrated planning. And private developers are also increasingly wary of the risks of entering into situations characterized by incomplete planning and a lack of consensus or poorly framed regulatory environments.

As a major financier and knowledge provider for hydropower in LAC, and as an institution with access to governments which are ultimately responsible for planning, the IDB is interested in a review of these approaches and their implications for improved planning.

The various approaches for hydropower planning and impact assessment can be placed along a continuum of geographic scale and complexity. Depending on their specific assignment, planners may look at individual projects, cascades, or whole electricity systems. In parallel, impact assessment specialists also look at different levels of complexity and spatial extent. However, the geographic and thematic scope of typical environmental and social impact assessment is typically quite narrow. Cumulative impact assessment expands the scope to consider a project's impacts in the context of the aggregate and interacting impacts of existing and future projects in a given planning area. Increasing levels of complexity move beyond impact assessment to encompass strategic assessment of hydropower development in a basin or region. These can extend beyond hydropower to include other uses of water and to incorporate planning for the protection of environmental and social resources.

In this report, we ultimately seek to explore an additional stage – one that builds on this foundation of approaches, integrates the best practices within them, but is designed to get to an outcome one step higher. That step could be called regional optimization: finding basin- or system-scale solutions that in a larger perspective provide the highest possible sum of economic, social and environmental values.

By "optimization", here we simply mean that by planning both infrastructure development and river resource projection together, greater benefits of both types and a better balance can be realized. It is recognized that "optimization" as a term is often used in a more technical sense by scientists, economists and engineers. If a standardized parameter can be assigned to two planning objectives, a technical optimum can be calculated. With non-standardized parameters for the different objectives, the problem is more complicated. And with more than two objectives, optimization becomes more difficult yet. Money is generally the common parameter in technical optimization. However, it is often very difficult, or even impossible, to achieve a credible technical optimization by using money across the full spectrum of economic, environmental and social objectives relevant for hydropower planning in a river basin. Monetizing environmental and social values may not be acceptable to many of the key stakeholders who hold those values. And although progress has been made in valuing environmental benefits and ecosystem services, the data and the methodologies are not on par with hydropower engineering methods. Despite these challenges, we suggest that a "sweet spot" or "best fit", providing a more balanced distribution of benefits across multiple objectives, is possible and should be pursued.

Therefore, the objective of this study is to understand the state of the art, including the limitations of current planning practices, to synthesize them into a consolidated approach that leads to optimized outcomes, and to support client governments and developers with practical recommendations and tools towards more sustainable and less conflictive hydropower development.

In the remainder of this chapter, we will review the various approaches to assessment and planning, and their context in both regulated and deregulated markets. Chapter 3 will provide examples of how they are being applied - or, conversely, where they are missing - in practical planning situations, primarily focused on Latin America. Drawing lessons from the case studies, Chapter 4 will discuss the conceptual underpinning of a comprehensive planning approach which aims at regional optimization. Chapter 5 analyzes the current institutional situation in the LAC region and the steps required to improve planning frameworks.  Chapter 6 articulates a set of recommendations for integrating system-scale approaches into planning.  Appendices provide more background on the conceptual model introduced in Chapter 4, as well as an overview of the elements of a regional planning framework, in terms of tools that are available to developers, regulators and other stakeholders in hydropower development.

## 2.1 Planning in Practice: Regulated  and Deregulated Markets

Central planning approaches to hydropower remain strongly in place within countries where there has been no deregulation of energy markets. In these settings, agencies produce long-term national or regional energy development plans, with project selection based on economic least cost planning modeling, encompassing hydropower within analysis and planning for the broad generation supply mix. Hydropower projects may be included in these plans at different levels of project preparation.  Some plans include projects that have been studied for many years and are reasonably well understood both technically and in regard to their environmental and social impacts. Other plans include projects on a more speculative basis pending more detailed studies.  To the extent these plans include river basins as a planning unit, the focus has generally been on cascade modeling of energy production and the supply of peak and base load services to the region. Increasingly, agencies responsible for planning will also employ sustainability criteria (technical, economic, environmental and social) to project assessment, prompting greater attention to project impacts on downstream resources, especially if they affect other generating stations, flood management or other economically important aspects. However, where transboundary river basins are concerned the downstream flow implications are a matter for significant political intervention.

Where energy markets have been deregulated, the role of the public sector is smaller, but it may still influence development planning to varying degrees. Chile is an example of a country where the market is left to its own devices and basin social and environmental outcomes are only caught once proposals are 'on the table' (i.e. when approvals are being sought) and mitigated as necessary. In other jurisdictions, the energy market manager exercises influence over the development program through statements of forecast demand. Sometimes 'indicative' or 'reference' generation plans are also produced as guidance for developers, but individual projects are left to be proposed by the developers. In deregulated regions the role of the environmental regulator is key, but again tends to be reactive rather than proactive.

In markets with central generation expansion planning, transmission planning is integrated reasonably well with generation planning. The challenge in these regions is the role of political influence and limited involvement of market forces driving perhaps more efficient outcomes. In markets where generation has been deregulated, transmission development often remains in the public or in a more strongly regulated domain. Transmission development may then be harder to initiate, and tends to limit development as it lags the impetus from generation developers.

In both deregulated and non-deregulated circumstances external institutions such as the multilateral development agencies have historically supported generation expansion planning, maintain important analytical capabilities and are exercising some influence on future development scenarios. For example, the World Bank recently came out with reviews and recommendations on the environmental licensing of hydropower projects in Brazil (a highly structured process) and the water resource management framework in Chile (a largely market-driven framework).

The past 15 years have seen a proliferation of project-level recommendations, standards, and guidelines. A relatively broad consensus on what constitutes good practice at the project level is emerging from these diverse sources,

## 2.2 Guidelines for Siting, Design and Operations of Individual Hydropower Projects

Guidelines for individual hydropower projects range from the broadest and most generic environmental and social impact assessment, management methodologies, and bank safeguards, to work specific to dams or hydropower such as the World Commission on Dams' (WCD) report (2000), Ledec & Quintero's 'Good Dams and Bad Dams' study (2003), to the Hydropower Sustainability Assessment Protocol (or "Protocol"; IHA 2010).

A review of this body of work is beyond the scope of this study. For our purposes, what is relevant is that these various sources increasingly articulate that projects should 'fit into their context' . In what may be the best current overview article of the hydropower sector, Kumar et al (2011) emphasize the need to integrate projects into both broader energy systems and water management systems.  The WCD report emphasized the importance of high-level needs and options assessments to establish that a dam project is an appropriate response to a verified need. Additionally, these assessments should provide the context within which project-specific analysis, such as feasibility studies and environmental impact assessments (EIA), should occur. Understanding the spatial context allows the application of the full mitigation hierarchy, from avoidance through minimization, mitigation and compensation. This is particularly relevant where off-site resettlement or biodiversity offsets are planned, critical habitats have to be identified, where altered flow and sediment patterns affect the basin as a whole and may be modified by upstream and downstream projects, and where cumulative impacts play a major role.

The Protocol (IHA 2010) includes two sections relevant to this concept that projects should use within their broader context: the Early Stage assessment tool, which mostly deals with the detection and avoidance of risks in the project identification phase, and the Preparation Stage assessment tool, which considers the quality of detailed project preparation. The Protocol states as one intent of project preparation that 'siting and design are optimized as a result of an iterative and consultative process that has taken into account technical, economic, financial, environmental and social considerations'. "Basic good practice" for project planning includes to:

- Be able to demonstrate the strategic fit of a project with needs for water and energy services, and relevant policies and plans (development, energy, water, biodiversity, climate, conservation, transboundary, land use, etc);
- Engage directly affected stakeholders in the siting and design optimization process;
- Respond to many sustainability considerations in the final project siting and design; and
- Scope cumulative impacts during the assessment of project environmental and social impacts.

Current regulatory tools are most developed for, and most widely applied at, the scale of the individual project. Most countries now require EIAs which review the environmental, and often social, impacts from a project or various alternatives to a project. Project-level environmental review has significant limitations that have been well-documented (Brismar 2004). The primary weakness of project-level review is that the review generally takes place after most decisions about the project have already been made. Often significant investments in the project have already occurred or, if not, momentum and support for the project are well developed. These conditions place significant pressure on the review process to not reject the project or move its location (Fearnside 2002). Indeed, reviews of EIAs have found that they rarely result in the rejection of a project (Sadler et al. 2000). Thus, the EIA process is unlikely to instigate significant modifications or re-siting of projects, except in unusual cases, and instead it generally results in minor changes and a set of mitigation strategies.

Against this background, Ledec and Quintero (2003) emphasized that "the most effective environmental mitigation measure is good site selection" and provided an overview of potential indicators that can be used in site selection:

| Indicator | Notes |
|---|---|
| Reservoir surface area relative to energy produced (inundated ha/MW) | Global average is 60 ha/MW; lower reduces impact |
| Water retention time in the reservoir (days) | To calculate divide reservoir volume by mean river flow; generally, shorter reduces impact |
| Biomass flooded (tons/ha) | Water quality may decline with increasing biomass within reservoir; less is better |
| Length of river impounded | Shorter reduces impact |
| Length of river left dry | In case of a diversion; shorter reduces impact |
| Number of downstream tributaries | More is better, to maintain fish migration routes |
| Likelihood of reservoir stratification | Lower likelihood is better |
| Useful reservoir life | Until reservoir's storage is filled with sediment; longer is better |
| Access roads through forests | Shorter reduces impact and can assist where risks of deforestation are high |
| Persons requiring resettlement (people displaced per MW) | Fewer is better |
| Critical natural habitats affected (in terms of # of sites or ha) | Includes protected as well as unprotected areas of high environmental value; less reduces impacts |
| Fish species diversity and endemism | Sites with lower diversity and endemism are better |
| Cultural property affected (# of sites affected) | Fewer reduces impacts |

If applied prior to firm siting decisions, this approach can help planners avoid impacts, but does not yet address the interaction between several projects. In that regard, cumulative impact assessment has been one important link between projects and their regional context. The most up-to-date approach to cumulative impact assessment has been well described by the International Finance Corporation (IFC 2013). Cumulative impact assessment goes beyond enumerating project-specific impacts to 'valued environmental components' (VECs; the traditional EIA perspective), but emphasizes the need to understand the extent and distribution of VECs in a region, and how they are impacted cumulatively and incrementally by different present and future projects. Although generic, the 2013 report includes several examples of hydropower cascades. There is potential for resistance from developers against the incorporation of cumulative impacts into permitting processes. It is sometimes argued that a developer should not be held responsible for other projects' impacts, and that the scope of impact assessments will become too broad and fuzzy, causing unnecessary costs and delays. Nevertheless, many countries are starting to integrate cumulative impacts into their licensing regimes.

Globally, only a few jurisdictions have time-bound licenses, for which licensees have to periodically apply for extensions and projects are subjected to a review of their performance. The main benefit of a re-licensing scheme, such as under the United States' Federal Energy Regulatory Commission (FERC), is that shifts in societal expectations, increases in environmental and social knowledge, and changing climate conditions can be incorporated into updated license conditions (Pittock and Hartmann 2011). Such a scheme could also address the ongoing change in the basin and regional context, and ensure that projects remain a good 'fit' with their environment over time. As this adds commercial uncertainty to a project, the term of such licenses would need to be well considered.

## 2.3 Assessment Methods for Hydropower Development Programs

Methods to plan electricity development programs range from national hydropower master plans and electricity sector investment programs, to plans for hydropower cascades such as the Brazilian Basin Hydropower Inventory Studies, to utility-scale Integrated Resource Plans (IRPs). They include least-cost and multiple-criteria plans, linked with the various roles hydropower can play in regional power pools. There are also various methods to assess hydropower programs from a sustainability point of view, such as Strategic Environmental Assessments (SEA) and various regional initiatives such as the Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT) developed for the Mekong basin (ADB 2010).

Investment program planning was widespread until a few decades ago when support waned for systematic, central planning of investments. Many master plans from that period, which exclusively applied technical and least-cost criteria, still exist and are used by default. Modern master plans, which could use a broader array of criteria, rarely exist and many of the planning approaches for multiple projects described in this section are not yet being systematically applied.

However, an increasing number of examples have emerged in recent years. For example, in regions where many operating hydropower facilities already exist, basin studies have been conducted to assess key issues in the basin and to recommend how the operation of individual schemes and cascades should be adjusted to better respond to the environmental challenges in the basin (e.g., by releasing environmental flows). Australia provides two examples of these processes leading to improved environmental conditions. In southern Australia, flows were restored on the Snowy River, which had been diverted years earlier into an adjacent river basin through the Snowy Mountains Hydropower Development. When Tasmania was interconnected with the deregulated electricity market in eastern Australia in the early 2000's, the operating regime of the hydropower projects in the seven river basins in Tasmania was subject to significant review. The outcome was a constraint on the peaking operation of one of the state's largest reservoirs to avoid high pulsing flows through high conservation-value river reaches downstream.

International development agencies are increasing their interest in in system-scale planning. For example, as part of the preparation of project financings in a very complex context in India, the World Bank supported a study that highlighted potential improvements in outcomes (economic, technical, environmental and social) from a system-planning approach, compared to an uncoordinated, project-by-project approach (Haney & Plummer 2008).

Hydropower development policies, programs and plans can be informed or assessed through SEAs, which, as a category, tends to a more loosely defined set of approaches compared to project-level assessments. Hirji & Davis (2009) provide an overview for the field of water resources (although with no direct references to hydropower). Some of the few national and sub-national level SEAs specifically for hydropower programs have been completed within Vietnam (SEA International).

One example for an official hydropower planning approach that takes various non-energy aspects into account is the manual provided by Brazil's Ministry of Mines and Energy (Ministry of Mines and Energy, Brazil 2007). This is a highly formalized approach to selecting between different cascade layouts, based on minimizing their cumulative impacts, but has not gained much traction outside Brazil.

Another system approach - the Rapid Basin-Wide Hydropower Sustainability Assessment Tool (RSAT) - has been developed between the Mekong River Commission, the Asian Development Bank and WWF. The RSAT shares some similarity with the Hydropower Sustainability Assessment Protocol, but addresses multiple dimensions of sustainability where more projects exist or are planned in a basin context (MRC, ABD, WWF 2013).

## 2.4 Integrated Basin Management Concepts

In most basins, a hydropower project is only one of several water users. Hydro-economic modeling generally predicts large potential economic and social gains from coordinated planning and operations within a basin, and this potential for broader benefits underpins approaches such as integrated river basin management (IRBM; coordinating all natural resource users in a basin) and integrated water resources management (IWRM; maximizing the value of water resources in their various uses). While these concepts have both been broadly accepted in principle, they have proven difficult to institutionalize. However, some elements are now being tested, including watershed management through payments for watershed services, multiple-use reservoir management, and water re-allocation between sectors such as irrigation, hydropower and the environment. Useful reviews of these concepts include Molden (2007), International Water Management Institute (McCartney 2010), and Harou et al. (2009).

A limitation of integrated basin management approaches is that they often focus on a range of water *sectors,* but not on the full range of water *values.* Environmental water needs are rarely given the same status as traditional water uses and issues of aquatic biodiversity, fragmentation and connectivity are often disregarded in IRBM or IWRM plans. These plans also often do not address sediment transport and geomorphology, other than emphasizing soil protection in upper watersheds. Within these plans, hydropower is generally regarded as a non-consumptive user, even though water can be lost to evaporation from reservoirs, less water may be available in by-pass stretches, environmental flow patterns altered, and water quality may be impaired.

A review of modern basin planning perspectives with a stronger awareness of environmental aspects can be found in three books jointly published by UNESCO, ADB, World Wide Fund for Nature (WWF) and GIWP (China) (Pegram et al. 2012). In principle, integrated water resource planning does hold promise for better hydropower decisions, and paying attention to hydropower will pay off in better water resource and basin management decisions.

## 2.5 Conservation Planning Approaches

Originally developed for terrestrial ecosystems and for the design of protected area systems, conservation planning methods have been adapted and applied globally to freshwater systems, and promoted to support infrastructure planning decisions. Challenges include accounting for the dynamics and ecosystem services of rivers, particularly at the scales of large basins.

An overview of the state of the art from a group of freshwater scientists and NGO staff is provided in Nel et al. (2009). System and basin-wide freshwater conservation assessments and prioritizations, or conservation 'blueprints', have been produced by TNC and other organizations. Conservation planning is able to identify what would be necessary or desirable to protect, and sometimes the most efficient manner to protect it - for example – defining the minimum amount and most closely connected components of freshwater habitats and ecosystem processes required to maintain biodiversity. However, in practice it has often been quite separate from, unaware of, or not effectively linked to basin development decision processes. Only in most recent times have attempts been made to understand the linkages and translate freshwater conservation planning outcomes into reality on the ground, by influencing hydropower planning. In principle, for example, hydro-economic models could include environmental flows either as a boundary condition (absolute constraint) or as one of several values to be included in the optimization algorithm. Biodiversity offsetting requirements at the project level could lead to the protection of other river segments from development, and conservation planners could identify priority segments for offsets. Criteria in hydropower master-planning could be framed to result in a more environmentally conscious configuration of projects. It is hoped that this study will also assist conservation practitioners in identifying options to bring their expertise to bear on the planning process.

Lessons  to inform hydropower planning practice can be gleaned from various countries and rivers around the world. In this chapter, we will provide two examples from outside the LAC region, and then review seven case studies from LAC, at all levels from medium-sized river basins, to entire countries, to multi-country energy systems. Towards the end of the chapter, we will review the lessons learned and their applicability and relevance for the broader region.

The LAC region has multiple basins in different stages of hydropower development, between 'older' regions such as in southern Brazil and central Mexico and 'frontier' regions such as Chilean Patagonia, Northeastern South America, and eastern Peru.  For some of these regions, master plans were never developed, some are still relying on master plans that were developed without awareness of environmental and social concerns, and only a few have made conscious attempts at integrated planning. The roles of government agencies, state-owned utilities and private developers in planning also differ from country to country. The case studies have been selected to provide diverse perspectives on planning, with or without direct engagement by The Nature Conservancy (TNC) or by the IDB. The LAC examples are roughly ordered from more to less regulated cases.

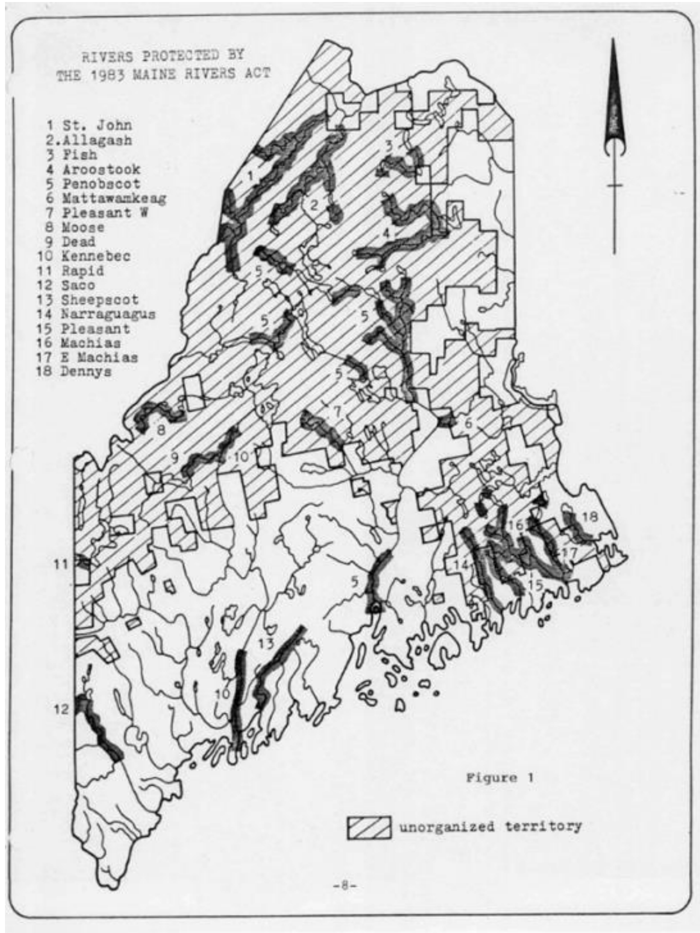
## 3.1 Examples outside the LAC Region

### *Maine (Sullivan and Giffen 1985)*

The state of Maine in the United States  confronted a growing demand for new hydropower projects in the 1970s, during a period of growing appreciation for other values of rivers and the rise of environmental legislation intended to protect those values. Maine's governor at the time, Joseph Brennan, initiated two actions to guide the anticipated increased in proposals for new hydropower projects on Maine's rivers. He issued the Maine Energy Policy, to reduce regulatory constraints on "sensible" hydropower projects, and he also directed the Maine Department of Conservation (DOC), to undertake the Maine Rivers Study to identify rivers, or reaches of rivers, with high environmental and recreational values and to propose strategies to protect those rivers.

The Rivers Study assessed 32,000 miles of river for their natural and recreational value and in 1982, Governor Brennan released an executive order designating 16 river segments, totaling 1,100 miles, for special protection—including a prohibition on new dams and a requirement that retrofits to existing dams must be consistent with protecting the values identified for that river segment in the study (Figure 1).

Later that year, Maine's Office of Energy Resources released a State of Maine Comprehensive Hydropower Plan, which identified 340 MW of additional hydropower capacity that could be developed that would be consistent with the protection of the 16 river segments. This additional capacity would represent an approximate 50% increase in hydropower capacity within Maine. The protection of river segments, along with other policies for hydropower regulation and planning, were formalized in the Maine Rivers Act in 1983.




Sullivan and Giffen (1985) suggest that the Maine Rivers Policy could serve as a model for other regions trying to plan for new hydropower development:

> The thread that unites the many diverse planning and implementation actions into the Maine Rivers Policy is balance. It does not call for sacrificing economic growth for the sake of preservation. On the contrary, by assessing Maine's long-range need for hydropower, carefully weighing the demands upon Maine's rivers, identifying the best uses for individual river segments, and providing the means to resolve conflicts, this policy recognizes that all of the beneficial uses may be integrated harmoniously on Maine's vast and diverse river resources… Without clear guidance about those Maine rivers where hydropower is not desirable, developers had wasted valuable time and money on projects that would never be built… With the direction provided by the Maine Rivers Policy, developers can now focus their efforts where hydropower is less likely to present insurmountable problems.

Governor Brennan summarized the Maine Rivers Policy as "a comprehensive plan for hydro development that would be of value to the hydropower industry as well as the public, by directing developers away from outstanding recreational scenic rivers to those which may be developed without the delays that heated controversy engenders."

Although a change in energy prices dampened demand for new projects, and very little new capacity was actually built, the state did issue permits for 100 MW of new hydropower that was consistent with the Comprehensive Hydropower Plan.

Following the “balancing approach” first formulated in the 1980s, Maine is continuing to improve its hydropower resource management. The latest large-scale initiative is occurring on the Penobscot River, the largest in Maine. It historically supported populations of migratory fish, such as Atlantic salmon, that had immense cultural and economic value. Fish populations declined dramatically following the construction of a series of hydropower dams in the early 20th century. Attempts to improve fish passage at the scale of individual dams produced little benefit. Then, in 2005, the hydropower company, the Penobscot Indian Nation, government agencies and conservation NGOs negotiated a breakthrough agreement. To improve fish passage, two dams will be removed and a third bypassed by a natural channel. Through turbine improvements at the remaining dams, energy generation will remain constant or even slightly increase. Biologists forecast that fish populations will improve dramatically, such as shad increasing from a few hundred to over 2 million. This project demonstrates that systems-scale approaches can provide a broader set of solutions for balancing energy and riverine environmental resources than can be achieved at the scale of individual projects.

The state planning exercise and the re-configuration of the Penobscot system, which was triggered by federal-level relicensing requirements, demonstrate how different approaches can lead to system-scale improvements.

### *Quang Nam province, Vietnam*

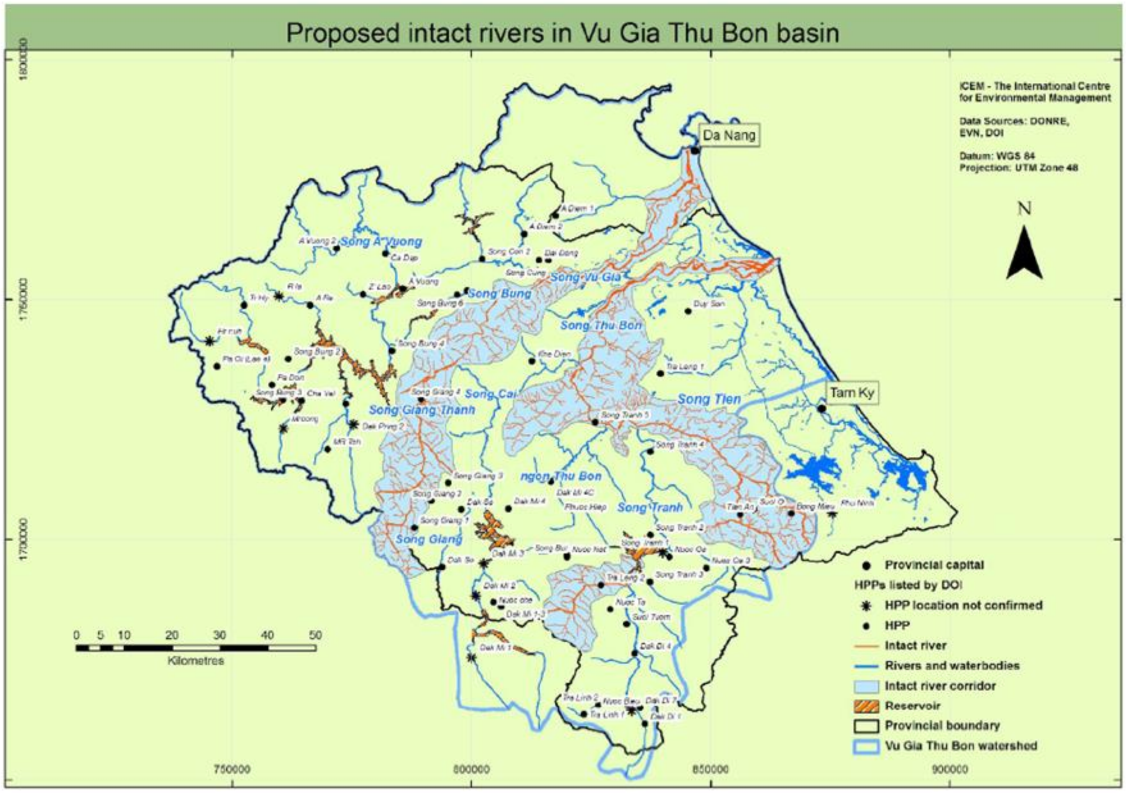
In 2008, the International Centre for Environmental Management (ICEM) produced a Strategic Environmental Assessment of existing hydropower plans for the Vu Gia – Thu Bon River basin in Vietnam (ICEM 2008). The SEA was funded by the Asia Development Bank and supervised by several Vietnamese government agencies, including the Ministry of Environment and Natural Resources (MONRE), the Ministry of Industry and Trade (MOIT) and Electricity of Vietnam (EVN).

The SEA was essentially an assessment of an existing plan for hydropower development from the MOIT and the Quang Nam provincial government. It assessed the costs and benefits associated with eight large hydropower projects (defined as >30 MW) and more than 50 small and medium hydropower projects, including the cumulative impacts of the proposed dams (Figure 2). It analyzed 15 themes for economic, social and environmental values and resources, including dry season low flows, aquatic biodiversity and fisheries, demography and migration (e.g., resettlement), ethnic minorities, and agriculture and irrigation.

The SEA concluded that the “pace and scale of proposed hydropower development is at a level which cannot be sustained.” Key recommendations included:

- Large reservoirs should be managed for multiple purposes, for example to reduce future water-supply shortages.
- A river basin fund should be created from hydropower revenues to invest in mitigation of impacts on minority groups, the environment and other affected sectors.
- The establishment of an Intact Rivers Program: “Two complete river sequences, from headwaters to sea, should be kept free from barriers in each of the Vu Gia and Thu Bon Rivers to ensure that a full sequence of habitats and migratory routes is protected in each river” (Ibid 2008).

The SEA proposed two river systems to meet the objective of an Intact Rivers Program, the Song Tien (tributary to the Thu Bon) and the Song Giang (tributary to the Vu Gia). Five small hydropower projects had been planned for the Song Giang, and the SEA noted that they would be located within a protected area and recommended that they not be developed. Similarly, several small and medium projects were proposed for the Song Tien, and the SEA noted that these “contribute only a small fraction of the total hydropower capacity for the basin (Ibid 2008)” and recommended that they not be built.




By removing a small increment of hydropower capacity from development consideration, the basin could retain two full segments of “headwaters to sea” connectivity. Individual assessment of the impacts of any of the small projects along the Song Giang and Song Tien would have undoubtedly found minimal impacts. A system-scale perspective on hydropower impacts was necessary to identify the strategic value of foregoing these small projects.

The provincial government supported the recommendations of the SEA and this decision was lauded as “a bold and visionary stance for sustainable dam development” (WWF 2008). In the WWF press release, Nguyen Duc Hai, the Chairman of Quang Nam Provincial People's Committee was quoted as saying, "Many hydropower plans and strategies are made without looking at the 'big picture', and as a result these projects can have negative impacts on the environment. The recommendations from the hydropower assessment for the Vu Gia-Thu Bon river basin will help us achieve sustainable hydropower development goals in particular, and economic development goals in general."

## 3.2 Mexico/Coatzacoalcos


The Mexican Constitution requires that only the federal government can provide electricity generation and distribution and so the Comisión Federal de Electricidad (CFE; Federal Electricity Commission), a state-owned electric utility, manages the electricity sector in Mexico. Thus, CFE is the only entity in Mexico that plans, builds and operates hydropower projects. However, recent legislation opened up the construction and operation of "small hydropower" projects (defined as < 30 MW) to the private sector.

CFE manages a system with a total capacity of 52.5 GW, with approximately three-quarters of that coming from thermal sources. Hydropower provides 22% and the only other renewable energy source with a measurable contribution is geothermal at 2% (i.e., wind and solar are negligible to date). As of 2009, Mexico had 14 large hydropower plants (10,000 MW total capacity; see Figure 3.), with 66 small projects, for a total hydropower capacity of approximately 11,400 MW. Four large projects on the Grijalba River (Chiapas state) represent nearly half the nation's hydropower capacity. Climate change legislation, passed in 2011, sets a national goal of 35% of electricity from renewable sources, with the majority of this coming from hydropower.

A CFE planning process in 1978 identified hundreds of potential dam sites based on geology and hydrology; these remain the current pool of potential dam sites used for planning purposes. Currently, CFE annually updates a plan—called the Works and Investment Program of the Electrical Sector (POISE)—which forecasts demand and plans for expansion for the next 15 years. The current POISE forecasts a need for an additional 38,000 MW of capacity to satisfy the increase in demand over the years 2011 to 2025. Of this, approximately 4,400 MW is anticipated to come from hydropower projects, with 750 MW of that hydropower total from projects that are now under construction or in the bidding process and the rest from future projects.

For hydropower planning, CFE conducts "Grand Vision" planning which focuses on national and regional plans for meeting the hydropower target for additional generation capacity. Following the Grand Vision, CFE conducts pre-feasibility and feasibility studies at the river basin scale to identify the best set of projects to build.

The Nature Conservancy and CFE signed an agreement in 2010 to work collaboratively to improve the sustainability of hydropower development and operation in Mexico. The first phase of this collaboration focuses on integrating a broader set of environmental and social resources into the early engineering stage of CFE's basin planning process for siting new hydropower projects. This comprehensive and basin-scale approach to planning is called Hydropower by Design (HbD), and is essentially the river basin form of the broader Development by Design framework (Kiesecker et al. 2010) (see Appendix 2).

Through Grand Vision planning, CFE has identified 100 potential sites for new hydropower projects across various river basins. The Coatzacoalcos River, Mexico's third largest basin located in the high rainfall south, emerged as a strategic basin for future development with over thirty new hydropower projects proposed. CFE and the Conservancy selected the Coatzalcoalcos as an appropriate basin to develop and test HbD, within the context of CFE's ongoing wider Strategic Environmental Assessment for the basin.

In the next two years, the project team will apply the framework in the Coatzacoalcos Basin. Based on this process, TNC and CFE will explore how HbD can be integrated into CFE's corporate planning and site selection processes.

## 3.3 Costa Rica/Reventazón

The electricity sector in Costa Rica is dominated by the state-owned Instituto Costarricense de Electricidad (ICE), a vertically integrated utility which is also responsible for planning the expansion of the power sector, under the guidance of the Ministry of Environment, Energy and Telecommunications. Independent generators can operate plants of up to 50 MW and up to a total of 30% of the country's capacity. In 2010, 76% of Costa Rica's electricity generation came from hydroelectricity, 12% from geothermal and 7% from thermal plants. In terms of installed capacity, 60% is hydropower, 28% thermal and 6% geothermal. Costa Rica has committed to further reducing its carbon emissions.

Costa Rica has abundant freshwater availability (27,784 $m^3$ per capita and year) and high biodiversity. A total of 135 freshwater fish species have been recorded in Costa Rica, with 19 species endemic to the country (Herrara-Vásquez et al. 2008).

Total installed hydropower capacity in Costa Rica equals 1,692 MW, or approximately ¼ of the identified hydropower potential of 6,474 MW. ICE considers that it could realistically develop only about half of the remaining potential, given that 780 MW are located in national parks and 1,700 MW would affect indigenous reserves. Much of the country's capacity is concentrated in the north and east, and consists of multiple small and medium sites, although the largest project (Diquís, 650 MW, to be commissioned in 2019) would be located in the south, on the country's largest river, the Grande de Térraba.

**Figure 4. Rivers and protect areas of Costa Rica**

The Costa Rican water sector is generally considered (including by the government) in need of institutional and legal modernization. There are no system-level authorities or plans, and the country's Water Law dates from 1942. Although there have recently been several initiatives to achieve more integrated water resources management, their status is unclear and they do not consider environmental issues such as flow regime and connectivity and how they affect ecosystem services and aquatic habitats (MINAET 2013).

However, the energy sector has recognized the need for improved watershed management and, since 2000, ICE has created a number of watershed commissions in basins of strategic importance for hydropower projects (Reventazón, Sarapiquí, Peñas Blancas, Pirrís). The national system of payments for environmental services through FONAFIFO is also being used to maintain forests in the upper watersheds.

ICE maintains a rolling generation expansion plan which uses standard least-cost criteria, and takes environmental aspects into account:

> From the perspective of the impacts of each project, the objective is to select alternatives which are environmentally viable. In principle, if all the projects in the expansion plans have been assessed environmentally, and the respective environmental costs and benefits have been included in their costs and benefits, the evaluation of options would be neutral from an environmental point of view. Therefore an effort is made to ensure that the projects under consideration have their environmental assessments, although in the intermediate or identification stage some projects do not yet have detailed environmental studies. In those cases, in the budgets of the projects reasonable percentages have to be included to cover the environmental mitigation measures. (ICE 2012)

While the strong commitment to environmental mitigation is promising, there are several practical difficulties with the described approach. Full environmental cost and benefit valuation for inclusion in all project budgets is very difficult to achieve; environmental costs and benefits are only loosely connected with mitigation expenditures. Also, the methodology would only be 'neutral' if impacts could be fully mitigated, i.e. if there was no net environmental loss or gain from the projects. It is unknown how ICE performs these project-level valuations; but presumably they are reflected in the current expansion plan. Table 2 shows projections for energy demand and peak supply requirements, as well as the projects scheduled to satisfy that demand, over the period from 2012 to 2024. Note that installed capacity is always significantly higher than required peak supply, to maintain a safety margin.

| Year | Demand | | | | Supply | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy (GWh) | % increase | Potential MW | % increase | Month | Project | Source | Potential MW | Capacity installed (MW) |
| | | | | | | Capacity installed December 2011: | | | 2590 |
| 2012 | 10087 | | 1649 | | 1 | Colima | Thermal | -14.0 | 2576 |
| | | | | | 5 | Cubujuquí | Hydro | 22.0 | 2598 |
| | | | | | 5 | Valle Central | Wind | 15.0 | 2613 |
| | | | | | 6 | Moín | Thermal | -19.5 | 2594 |
| | | | | | 12 | CATSA | Biomass | 8.0 | 2602 |
| | | | | | 12 | Cutris | Biomass | 3.0 | 2605 |
| | | | | | 12 | El Palmar | Biomass | 5.0 | 2610 |
| | | | | | 12 | Tacares | Hydro | 7.0 | 2617 |
| 2013 | 10605 | 4.90% | 1732 | 4.80% | 2 | Toro 3 | Hydro | 49.7 | 2666 |
| | | | | | 6 | Anonos | Hydro | 3.6 | 2670 |
| | | | | | 9 | Balsa Interior | Hydro | 37.5 | 2707 |
| 2014 | 11151 | 4.90% | 1820 | 4.80% | 5 | Río Macho | Hydro | -120.0 | 2587 |
| | | | | | 5 | Río Macho Ampl | Hydro | 140.0 | 2727 |
| | | | | | 6 | Chucás | Hydro | 50.0 | 2777 |
| | | | | | 6 | Cachí | Hydro | -105.0 | 2672 |
| | | | | | 9 | Cachí 2 | Hydro | 158.4 | 2831 |
| | | | | | 10 | Moín 2 | Thermal | -130.5 | 2700 |
| 2015 | 11730 | 4.90% | 1913 | 4.90% | 1 | Capulín | Hydro | 48.7 | 2749 |
| | | | | | 1 | Torito | Hydro | 50.0 | 2799 |
| | | | | | 1 | CC Moín 1 | Thermal | 93.0 | 2892 |
| | | | | | 1 | CC Moín 2 | Thermal | 93.0 | 2985 |
| | | | | | 1 | Chiripa | Wind | 50.0 | 3035 |
| 2016 | 12345 | 5.10% | 2016 | 5.10% | 1 | Reventazón Minicentral | Hydro | 13.5 | 3048 |
| | | | | | 1 | Reventazón | Hydro | 292.0 | 3340 |
| 2017 | 12998 | 5.00% | 2120 | 4.90% | 1 | | | | |
| 2018 | 13692 | 5.10% | 2233 | 5.10% | 1 | Geotérmico Proyceto 1 | Geothermal | 35.0 | 3375 |
| 2019 | 14430 | 5.10% | 2357 | 5.30% | 1 | Diquís | Hydro | 623.0 | 3998 |
| | | | | | 1 | Diquís Minicentral | Hydro | 27.0 | 4025 |
| | | | | | 1 | Geotérmico Proyceto 2 | Geothermal | 35.0 | 4060 |
| 2020 | 15212 | 5.10% | 2481 | 5% | 1 | Hidro Proyceto 1 | Hydro | 50.0 | 4110 |
| | | | | | 1 | Eólico Proyecto 2 | Wind | 50.0 | 4160 |
| | | | | | 1 | Eólico Proyecto 3 | Wind | 50.0 | 4210 |
| | | | | | 1 | Geotérmico Proyecto 3 | Geothermal | 35.0 | 4245 |
| | | | | | 1 | RC-500 | Hydro | 58.4 | 4304 |
| 2021 | 15943 | 4.60% | 2600 | 4.60% | | | | | 4304 |
| 2022 | 16646 | 4.20% | 2719 | 4.40% | | | | | 4304 |
| 2023 | 17381 | 4.20% | 2838 | 4.20% | | | | | 4304 |
| 2024 | 18148 | 4.20% | 2962 | 4.20% | | | | | 4304 |

Included in the Plan with a commissioning date of 2016 is the Reventazón project (305 MW). The Reventazón River is one of the longest and most important Costa Rican rivers and drains to the Caribbean Sea. Together with the Parismina River, with which it shares its lowest reach and mouth, the basin comprises 2,900 $km^2$ or 5.5% of the national territory, with 475,000 inhabitants (10% of the national population). The Reventazón has a series of four hydro projects on its mainstream and six on its tributaries, as well as six additional projects under preparation. The largest of these new projects, and also the largest project in Central America, is Reventazón, the last project downstream in the cascade.


| Tramo critico | Distancia (km) |
|---|---|
| Presa Cachi - C.M. Cachi | 11.0 |
| Toma La Joya - C.M. La Joya | 7.8 |
| Presa Angostura - C.M. Angostura | 9.5 |
| Toma P.H. Torito - C.M. P.H. Torito | 3.3 |
| Toma P.H. Izarco - C.M. P.H. Izarco | 8.1 |
| Presa P.H. Recentazón - C.M.P.H. Reventazón | 4.0 |
| Total | 43.8 |

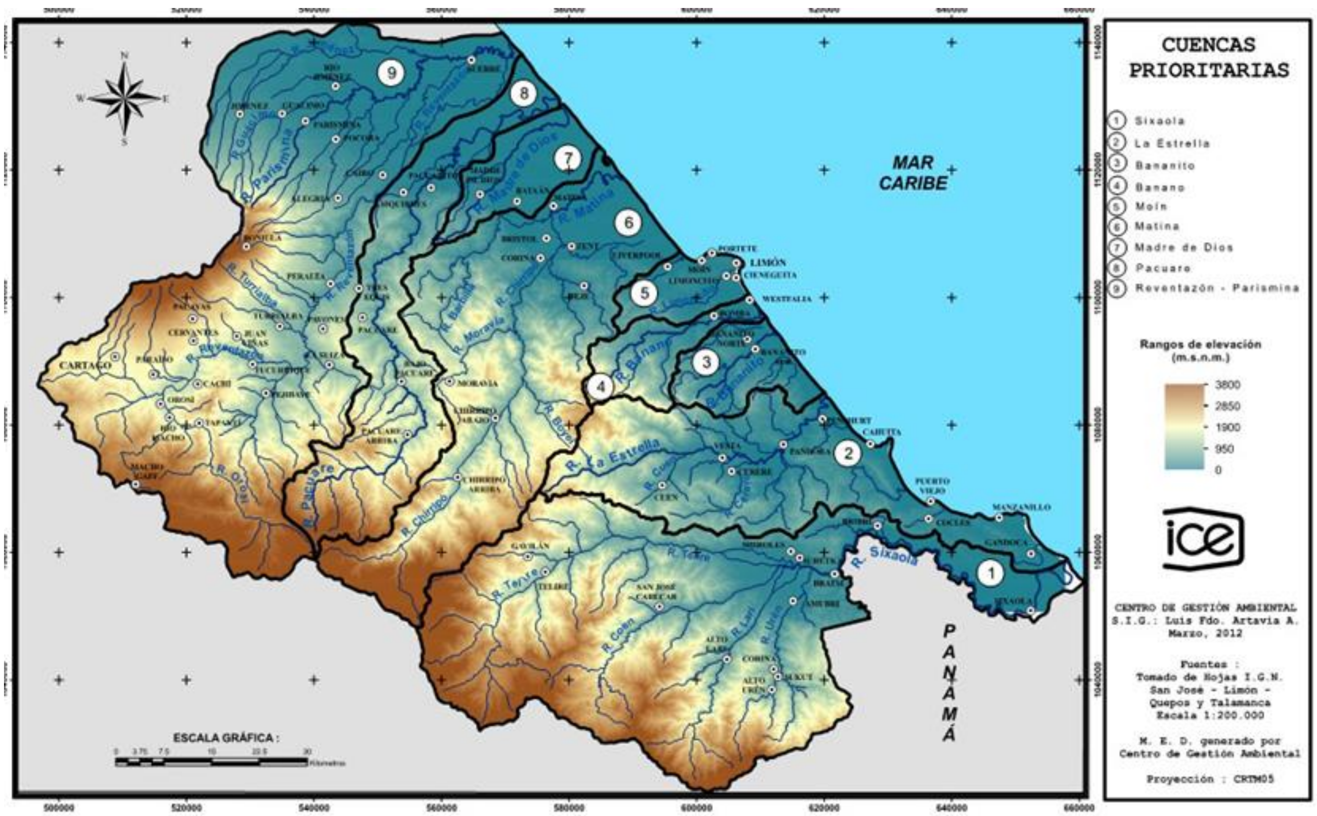
| Proyectos | Entrada | Capacidad (MW) |
|---|---|---|
| Torito | 2013 | 50 |
| Reventazón | 2016 | 305 |
| Izarco | Sin datos | 140 |

| Plantas en operación | Entrada | Capacidad (MW) | Caudal ($m^3/s$) | Embalse ($km^2$) |
|---|---|---|---|---|
| Cachí | 1978 | 108 | 54 | 3.24 |
| Angostura | 2000 | 177 | 160 | 2.56 |
| La Joya | 2005 | 50 | 54 | Sin datos |

The participation of the international development banks IDB and IFC in the financing of the Reventazón project has contributed to a series of additional environmental investigations and management measures. The following three are of particular relevance from a spatial perspective:

- A conceptual Cumulative Impact Assessment was done for the Reventazón basin. It identified the most valuable environmental resources, and recommended extensive modeling to enable ICE to quantify and manage cumulative effects on sediment, dewatered reaches, rafting and other environmental and social issues.
- To compensate for the residual impacts of the reservoir on terrestrial connectivity for jaguars and other species, migratory corridors around the reservoir will be enhanced.
- To compensate for the residual impacts of the project on the river, compounded by the cumulative impacts of upstream projects and other river uses, one of the most ambitious aquatic offset measures in LAC was conceived. All nine major rivers flowing into the Caribbean were evaluated for their characteristics, before the Parismina River – currently undammed - was chosen as the best equivalent. ICE has committed to contribute to the long-term protection of the Parismina as a healthy and free-flowing river system, including support for rapid ecological assessment, establishment of the legal basis for long term protection, and development and implementation of an Offset Management Plan. Studies are ongoing about the precise limits of the offsets site and the required interventions to restore and protect the ecological health of the Parismina.

The choice of the Parismina as an offset site came long after the Reventazón project was first entered into ICE's long-term expansion plan. Costa Rica does not currently have a planning framework which would allow a systematic assessment of trade-offs between electricity development and other ecosystem services of its river systems. The projects in

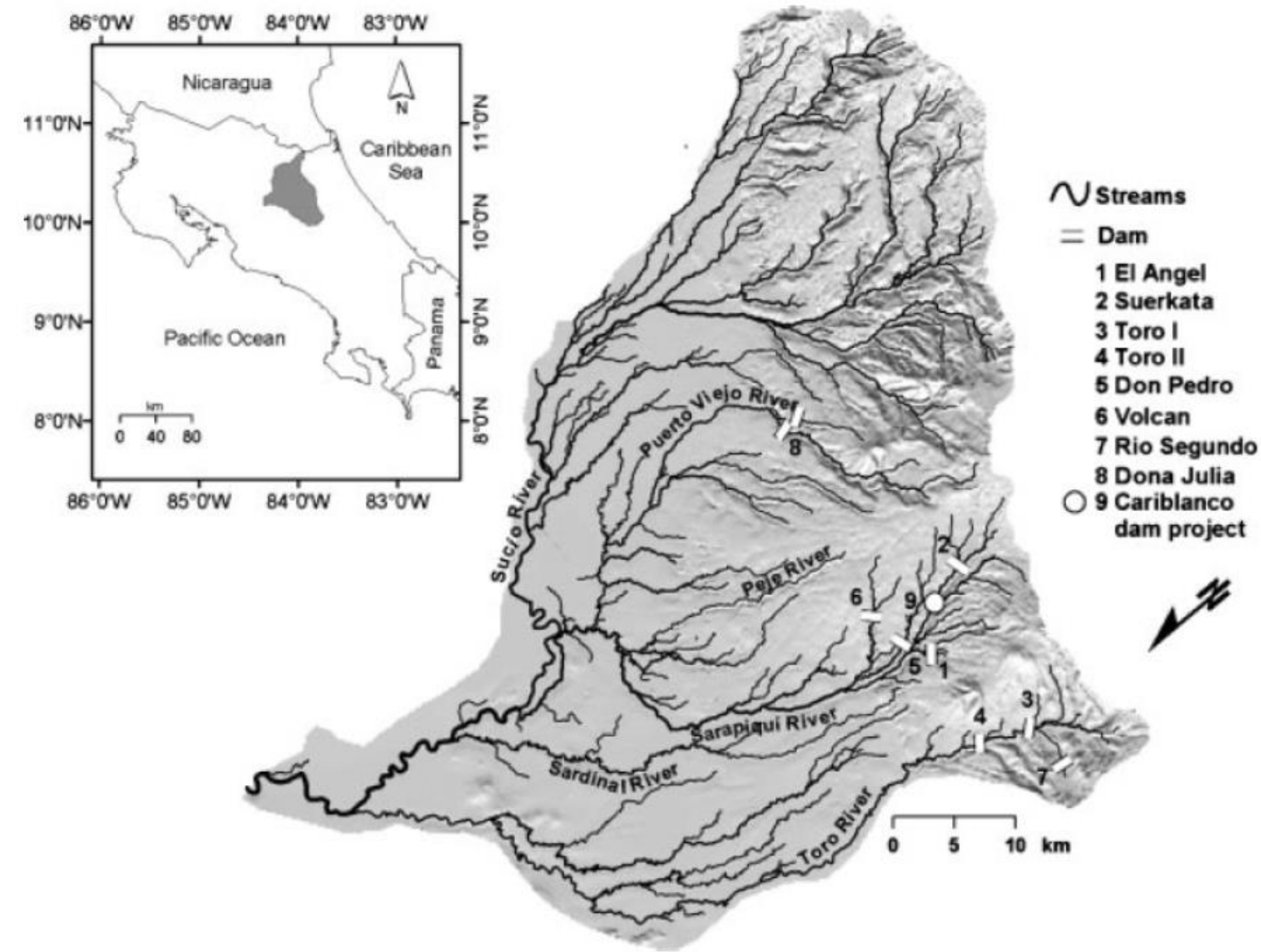



ICE's expansion plan are widely distributed across the country and current practice is to assess and mitigate projects one-by-one, rather than optimizing their location in the national territory.

Anderson et al (2006) in a review of hydropower development in Costa Rica concluded that "from an ecological standpoint the placement of hydropower plants in a river network, and relative to one another, may be more important than the size or total number of dams." They also offered a series of 'rules of thumb' for improved siting. For one of the basins which are being actively developed, the Sarapiquí in the north, Anderson et al (2007) have demonstrated how relatively simple GIS-based spatial analysis could help improve the siting of dams. Among other calculations, they compared the impact of dams in the basin on the fragmentation of the river network in different life zones, and the share of the river network upstream of dams.

The Sarapiquí analysis was undertaken by independent researchers with limited resources and yet, was able to provide useful information which could inform initial planning decisions years before results of detailed environmental assessments are available.

Costa Rica's approach has articulated a strong commitment to natural resources management, as demonstrated by its commitment to clean energy, its extensive network of terrestrial protected areas, and the effective protection of watersheds above hydropower plants. However, there is still a lack of understanding and effective conservation of aquatic biodiversity and ecosystem services. With its planning resources and access to planning-relevant data, ICE should be able to create a set of indicators which would allow high-level comparisons between alternative project options, before these enter the expansion plan and detailed environmental assessments. Gaining a complete overview of the country's rivers and their environmental and social characteristics would also allow future hydropower projects to be planned with specific offsetting measures from the beginning, thus ensuring 'like-for-like-or better' compensation.




## 3.4 Colombia/Magdalena

Colombia's largest river basin, that of the Magdalena River (273,459 km$^2$) began to be developed for hydropower in the 1960s. Hydropower is the primary source electricity in Colombia, with 9 GW of hydropower representing 65% of the total installed capacity for electricity in the country. The remainder of Colombia's electricity generation is from thermal sources, mostly gas. Total generation is approximately 60 TWh per year. The Colombian government would like to diversify the energy mix.

The Magdalena basin is the most important source for hydropower, encompassing 70% of Colombia's capacity. Most development has been concentrated in the middle portion of the basin (largely in Antioquia), on tributaries to the Magdalena and its primary tributary, the Cauca. Currently there is one dam on the upper main-stem Magdalena, at Betania (540 MW), although another dam, El Quimbo (400 MW), is under construction on the upper main-stem and Ituango (1,200 MW) will be built on the main-stem of the Cauca (see Figure 8).

Before the 1990s, electricity development in Colombia was centrally planned and managed. Then, in 1994 energy sector reforms were passed that unbundled generation, transmission and distribution and opened up the energy sector to private investment. The key ministry influencing hydropower development in Colombia is the Ministry of Mines and Energy, and specifically the Planning Unit of Mining and Energy (UPME). UPME develops forecasts of energy demand and releases multi-year reference scenarios (over thirteen tears) for new capacity.  Generating companies are of private, public or mixed ownership, and have various ways of contracting their generation and reserve capacity in the short and long term.

A plan in the 1970s identified Colombia's potential dam sites, based on hydrology, topography and geology. UPME and Cormagdalena (a National Corporation in charge of navigation, generation and distribution of energy, and environmental protection in the Magdalena River) can suggest specific new projects to be open for development. After a project is selected by a developer, it must obtain an environmental license.  For projects over 100 MW, the Colombian Environmental Licensing Authority (ANLA) issues the license while for projects below 100 MW the license is issued by the regional environmental authority. Applicants conduct an Environmental Impact Assessment as part of the licensing process.

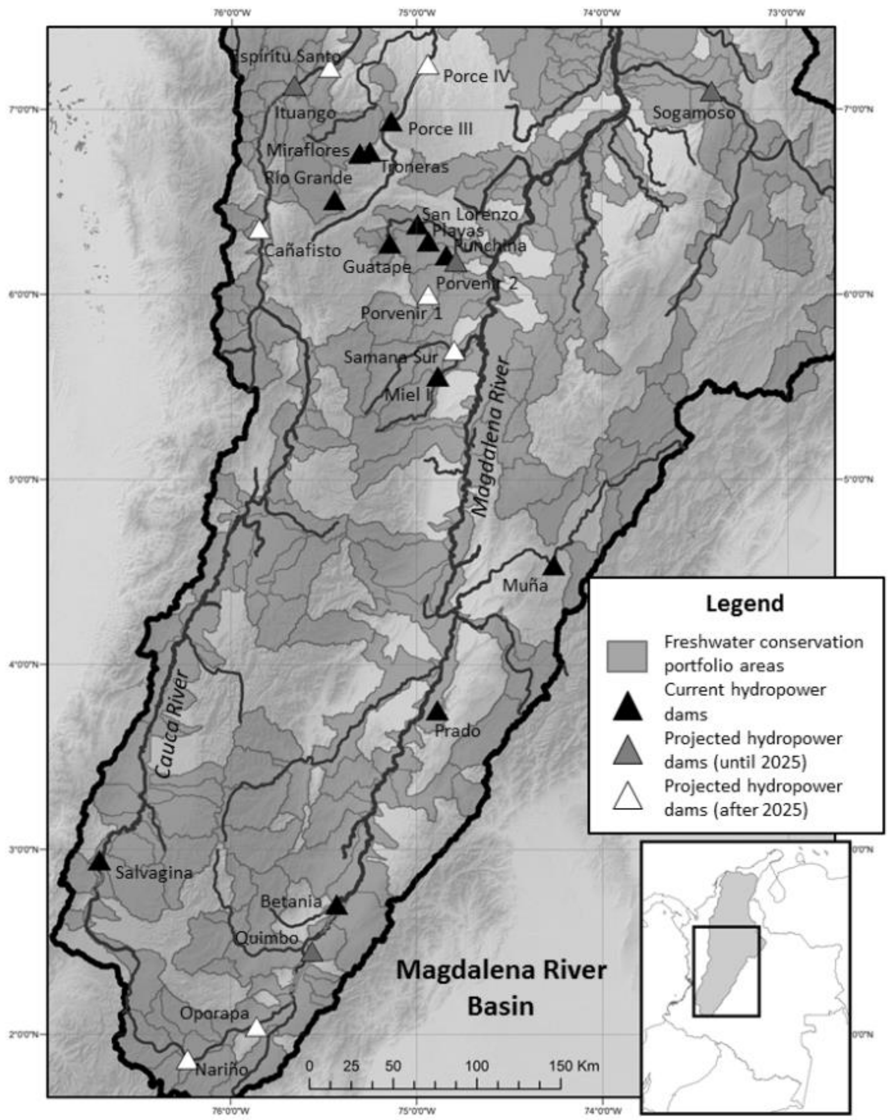
Under newly passed legislation, the environmental review and licensing of hydropower projects will encompass the "mitigation hierarchy."  The Nature Conservancy is currently working with the Ministry of Environment (MADS) and ANLA on a guidance document on how to implement the new policy. This policy includes a set of locations that should be avoided (the first step in the mitigation hierarchy) and then, for impacts that cannot be avoided or minimized, provides a method for determining freshwater offsets.

There are currently several basin-scale planning or analytical processes.

1. Cormagdalena is developing a hydraulic model of the Magdalena River and its connectivity to wetland systems.
2. In 2011, Cormagdalena signed a two-year agreement with HydroChina Corporation, a major Chinese state-owned hydro engineering company, for the preparation of a Master Plan for the Use of the Magdalena River.  This Master Plan has a 30-year planning horizon and is intended to promote the integrated use of the river's resources and services, with emphasis on navigation, energy production and ports.
3. The Ministry of Environment and Sustainable Development (MADS) is leading the development of a Strategic Plans for two macro-basins, among them the Magdalena-Cauca, which will include the identification of priority areas for conservation in the basin.

The Nature Conservancy has collaborated with Colombian ministries to develop a set of tools and strategies for influencing hydropower development in the Magdalena.  These include:

1. *Conservation blueprint*, which identifies priority areas for conservation within the basin (see Figure 8).
2. *Hydrological model and decision support tool.*  The hydrological model for the Magdalena basin can be used to predict relationships between river flow regime and freshwater ecosystem health.  The model can help identify cumulative impacts and compare alternative development and mitigation scenarios.
3. *Mitigation hierarchy for freshwater licensing.*  As described above, TNC is developing a manual to guide implementation of a new policy that incorporates the mitigation hierarchy into environmental review of water infrastructure.  Additionally, through a five-year GEF project, TNC will work with ministries to further develop the "avoidance protocol" during licensing of projects.



Espíritu Santo
Porce IV
Ituango
Sogamoso
Porce III
Miraflores
Troneras
Río Grande
San Lorenzo
Playas
Punchiná
Cañafisto
Guatapé
Porvenir 2
Porvenir 1
Samaná Sur
Miel I
Magdalena River
Muña
Cauca River
Prado
Salvagina
Betania
Quimbo
Oporapa
Nariño
Magdalena River Basin
0 12.5 25 50 100 150 Km
Legend
Freshwater conservation portfolio areas
Current hydropower dams
Projected hydropower dams (until 2025)
Projected hydropower dams (after 2025)

## 3.5 Peru

Peru has plentiful water resources, with an average total annual runoff of more than 2,000 $km^3$ and per capita availability of 68,321 $m^3$ in 2006. Almost 98% of this is on the eastern side of the Andes, in rivers draining to the Amazon. However, most of Peru's population resides within watersheds that drain to the Pacific and thus water is scarce and demand for it from various sectors is high. In these watersheds, much of the water resources potential, including small and medium-sized hydropower, has already been developed.

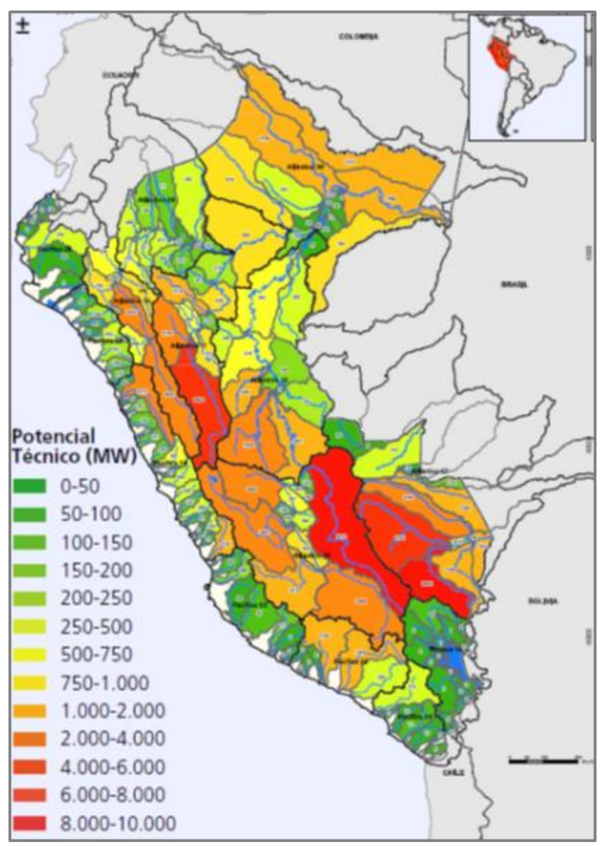
**Table 3. Consumptive and non-consumptive use of water in Peru (Autoridad Nacional del Agua 2009)**

USOS DE AGUA SECTORIAL
(2000 / 2001 - en MMC/año)

| Vertiente | USO CONSUNTIVO | | | | | | | | | NO CONSUNTIVO |
|---|---|---|---|---|---|---|---|---|---|---|
| | Población | | Agricola | | Industrial | | Minero | | Total | Energía |
| Pacífico | 2 086 | 12% | 14 051 | 80% | 1 103 | 6% | 302 | 2% | 17 542 | 4 245 |
| Atlántico | 345 | 14% | 1 946 | 80% | 49 | 2% | 97 | 4% | 2 437 | 6 881 |
| Titicaca | 27 | 30% | 61 | 66% | 3 | 3% | 2 | 3% | 93 | 13 |
| **Total** | **2 458** | **12%** | **16 058** | **80%** | **1 155** | **6%** | **401** | **2%** | **20 072** | **11 139** |

Significant potential for projects of all sizes remains in the upper Amazon basin. In the mid-1970s, the Ministry of Mines and Energy (MEM) and the national utility Electroperú identified hydroelectric resources on the rivers Marañon, Huallaga and Alto Ucayali, with support from the Soviet Union. A countrywide survey was then conducted in the late 1970s and early 1980s with support from Germany, resulting in a total exploitable potential of 58 GW across 543 projects. More recent inventory studies increased the estimated total technical potential to 98 GW, 29 GW of which would impact on protected areas and areas already under hydropower concessions, and was therefore excluded from future considerations.

**Figure 9. Peru's rivers and technical hydropower potential per basin (map 1:mapsofworld.com 2013; map 2: Ministerio de Minas y Energia 2011)**

Peru's electricity market has been liberalized, and private investors are now encouraged to develop generation projects. Although 40% of Peru's installed capacity, and 56% of its annual generation, come from hydropower, the country has developed only a small proportion of its identified hydropower potential, partly due to the discovery and large-scale development of natural gas.

Over the last few years, interest in hydropower has grown again, due to rapid growth in electricity demand and the export potential both for gas (which would then need to be replaced as a source of domestic power) and for hydroelectric power to Brazil. The 'Plan Referencial de Electricidad 2006-2015' listed nine hydropower candidate projects, but few of those have actually progressed. In 2007, the MEM selected 14 projects for consideration by Brazilian investors. The Brazilian firm Odebrecht is building one of these, Peru's second largest hydro project, Chaglla (406 MW) on the Huallaga River, with financing from IDB and BNDES. Several bilateral agreements were concluded between 2008 and 2010, according to which 6,000 MW could be developed on a 30 year BOT basis for export. A number of projects including Inambari (2,000 MW), Sumabeni (1,074 MW), Paquitzapango (2,000 MW), Urubamba (940 MW), Vizcatan (750 MW) and Chuquipampa (800 MW), and the corresponding transmission lines, are in different stages of preparation, although the concession to develop one of them (Inambari) was suspended after protests. Unlike the projects built or planned in the western basins, most of these projects are located at lower altitudes (below 1,000 meters above sea level) and hence, encompass lower heads and larger dams that may flood extensive areas. In several projects, indigenous groups are denouncing the lack of prior consultation and consent, and it has been politically difficult for the government to balance national and local interests, as well as those of different sectors.

Current problems and delays in project development have motivated a search for planning and regulatory reforms. In 2010, the World Bank published an analysis on options to facilitate hydropower development, which identified the following barriers:

- Lack of a comprehensive energy strategy and long-term planning for hydropower
- Low costs of competing natural gas development
- Lack of hydrological monitoring capacity to produce basic hydrological data
- High capital costs and limited access to long-term financing
- Licensing procedures which are excessively complex, unstable and with gaps in legislation

The study also addressed weaknesses in the consultation and EIA processes: "Given the fragility of the ecosystems in the Amazon basins and the vulnerability of social groups that can be affected, it is imperative to ensure the legitimacy and openness of consultation processes for these projects." Not all political groups are convinced, however. A group of congressmen have recently (October 2013) introduced a law which would fast-track larger hydropower projects, citing a need for 15 separate approvals.

Given the current complexities, a more strategic approach to planning might try to ensure that sector plans are compatible with each other. A review of the country's relevant strategic documents does not yield many insights, however. The 2009 national water resources strategy aims at a 'Water for All' scenario, which includes universal access, water as an engine of sustainable development, and integrated management of basins. It does not provide much guidance for hydropower development, beyond stating that water use for generation has to be made compatible with downstream consumptive water use, which may be achieved through re-regulation reservoirs. The 2001 national biodiversity strategy also contains no guidance beyond stating that impact assessment and environmental risk analysis studies for dams and hydropower projects should be undertaken. The 2009 master plan for the protected area system identifies areas which are already protected (17% of the national territory) as well as gaps (underrepresented ecosystems) in the system. While this analysis did not cover fluvial ecosystems, it is apparent that many of the priority areas for conservation are located in the basins with the highest hydropower potential. The same geographical overlap applies to the territories of indigenous people. The obvious step of overlaying the different maps to identify conflicts and compatibilities does not appear to have been done.

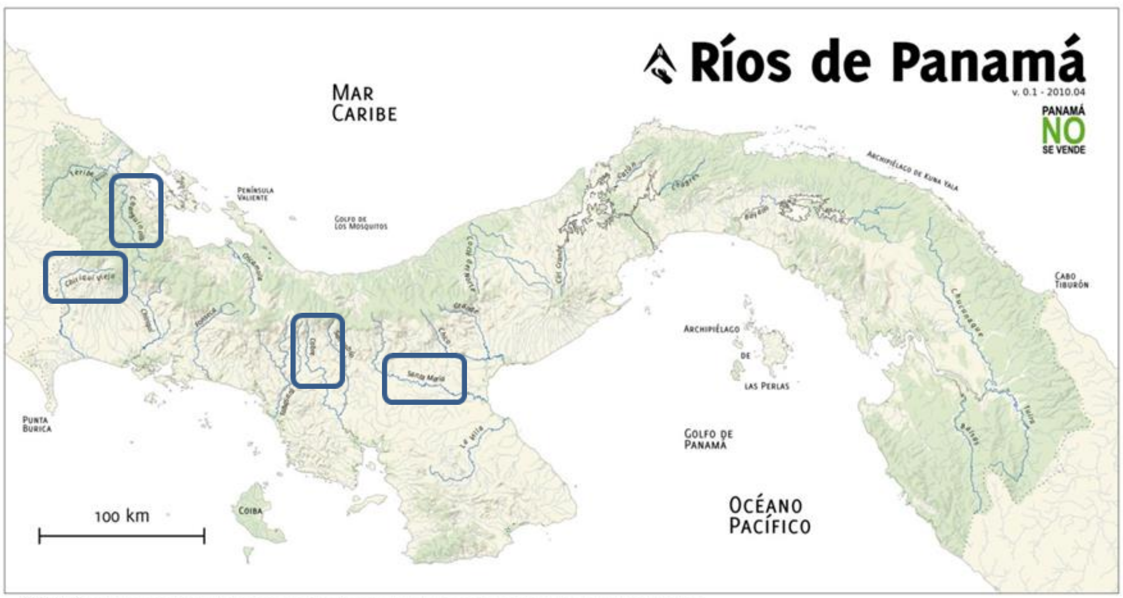
In any country, it would be difficult for project-by-project environmental impact assessments to fill these strategic gaps. This is even more difficult in Peru as impact assessments here do not typically contain scoping exercises which would identify contextual issues, and there is no central environmental agency to approve studies and licenses, which is left to sectoral agencies such as the MEM. The MEM is thus both promoter and regulator of hydropower projects. The experience with EIAs for the traditional, relatively low impact, high-head diversion projects is already mixed and does not bode well for the much larger and more complex storage projects in the Amazon basin. The World Bank (2010) recommended that "it would be useful for MEM to undertake a screening exercise with the view of eliminating, at an early stage, those projects [from the original inventory studies] that, due to the complexity and scale of their social and environmental impacts, are not acceptable according to today's standards" and that studies for projects in the same basin should be better coordinated. The MEM is also in the process of revising and updating its standard Terms of Reference for hydropower EIAs, and has received comments from the Ministry of Environment to the effect of broadening the impact areas and scope of the EIAs.

## 3.6 Panama/Chiriqui Viejo

Panama has a population of 3.3 million and a land area of 76,000 km$^2$. It has multiple, relatively short rivers both on the Atlantic and the Pacific side of the central mountain chain. Hydropower represents 60% of its electricity generation capacity. Panama's hydroelectric potential is estimated at 3,040 MW, out of which 1,170 MW have already been installed, largely in the western provinces.

The generation and distribution of electricity has been fully privatized, and there are 21 private generating companies with installed hydro capacities over 3.5 MW. The public Empresa de Transmisión Eléctrica S.A. (ETESA) runs the transmission network, acts as the system operator and also regularly updates an indicative generation expansion plan. The latest edition of the plan (2012) lists 37 hydropower projects between 1 MW and 214 MW with feasibility studies. However, some of them are not likely to be realized due to low rates of return.

**Figure 10. Major rivers of Panama (Fundacion Alamaque Azul 2010)**






The rivers with the highest hydro potential in Panama (marked in the map above) are the Río Changuinola (1,169 MW), the Río Santa María (370 MW), the Río San Pablo (244 MW) and the Río Chiriquí Viejo, to be discussed below.

The expansion plan is strictly a least cost plan. Environmental and social considerations are only taken into account as factors that could delay individual projects and thereby increase the economic costs of supply. These costs of delays can be quite substantial, at least in the short run, which emphasizes the need for thorough preparation of projects, including clear guidance on site selection. The expansion plan lists several potential reasons for delay, including community obstruction and deficiencies in the team responsible for environmental and social review. However, the risk of failure to obtain an environmental permit is not listed as a potential reason for delay. This may simply reflect the reality that permits are always granted, regardless of the specific quality of the EIA and the significance of residual impacts.

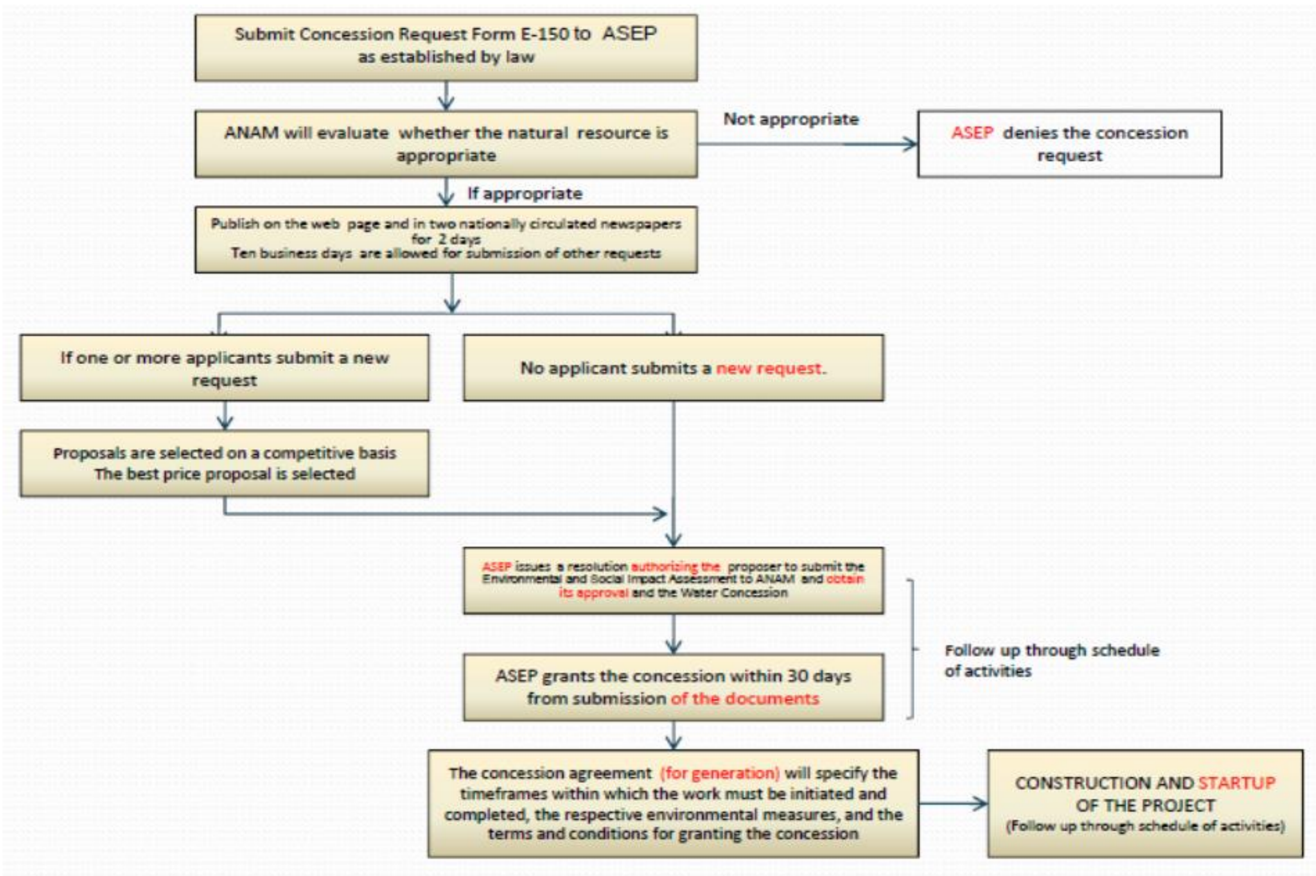
According to the National Plan for Integrated Management of the Water Resources of the Republic of Panama 2010-2030, water is relatively abundant and of good quality in most basins, but pressure is increasing. The most frequent conflicts over water occur between users of the same source without concessions; the inappropriate planning, management and distribution of concessions in the basins; the denial of access to communities to water intakes on private lands; and the construction of hydropower reservoirs which can influence the downstream availability of water. In terms of volumes, 99% of all concessions granted by the Autoridad Nacional del Ambiente (ANAM) in the period 2005-

2010 were for hydropower.

The environment is not yet included among water uses in national plans. In recognition of this gap, in 2006 ANAM introduced an interim 10% of annual average minimum flows rule. There is awareness, however, that this does not adequately reflect the conservation requirements of different fluvial ecosystems, and that ANAM's monitoring capacity is limited.

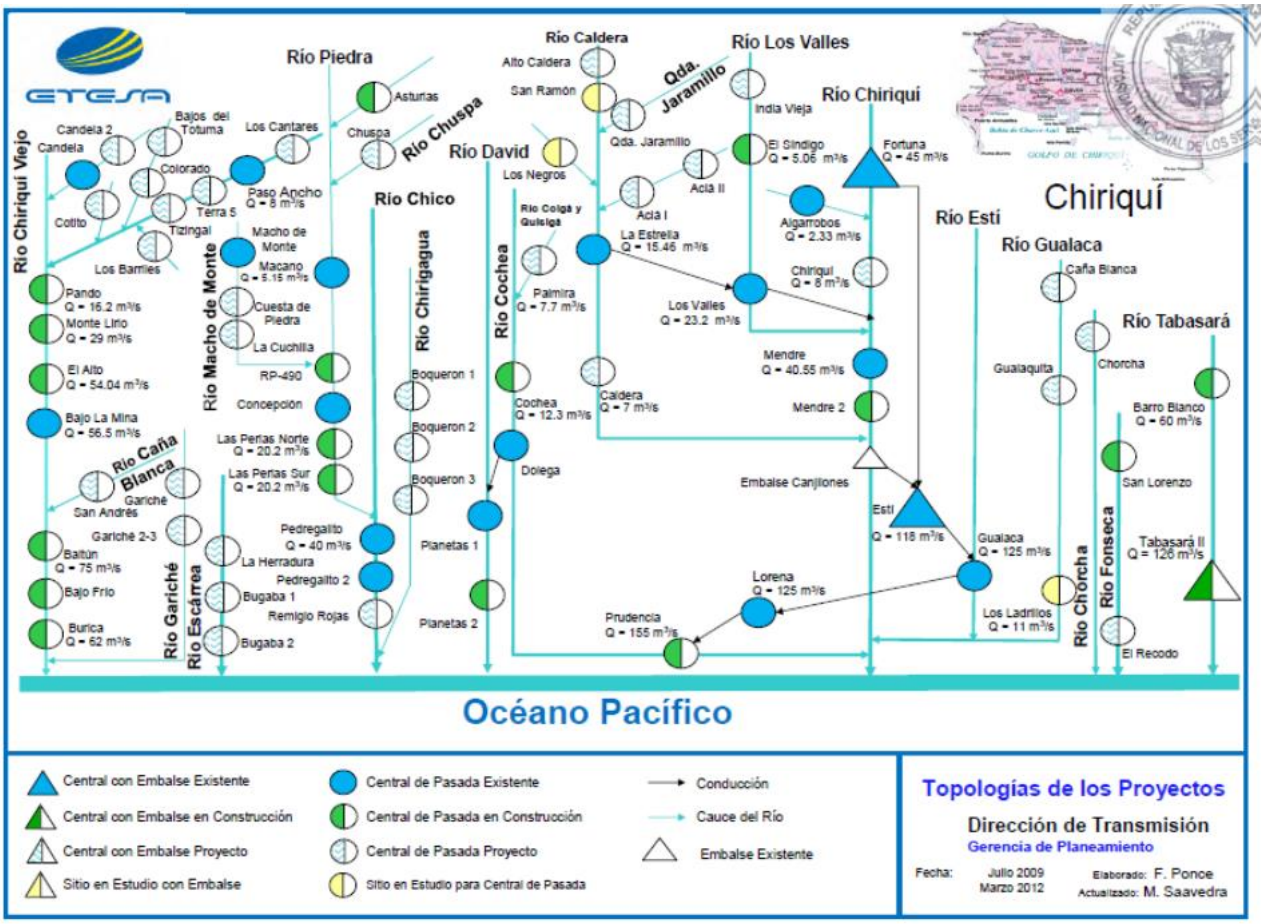
The flow chart below represents the joint permitting process between the electricity regulator (Autoridad Nacional de los Servicios Públicos de Panamá, ASEP) and the environmental regulator ANAM:

**Figure 11. Procedures for hydroelectric concession (Bim Nieto n.d.)**




Small and medium hydropower projects are currently proliferating due to favorable conditions for investors, including easily obtainable concessions. This proliferation is occurring most notably in the southwestern province of Chiriquí. One of its rivers, the Chiriquí Viejo, alone has 77% of all national water concessions of the agro-industrial sector, 33% of the hydroelectric sector, and 11% of the agricultural sector. The water resources and hydroelectric potential on the river had been studied in the 1980s by the national utilitity Instituto de Recursos Hidraulicos y de Electrificacion (IRHE), before its restructuring and privatization in 1997. Today, 13 hydropower projects have concessions and environmental approvals, while an additional 7 are being processed.

The graph below from the 2012 national generation expansion plan shows the existing and planned hydropower projects in the province, some of which also involve inter-basin transfers:




The intense activity in the Chiriquí basin has generated conflicts between developers, different economic sectors, different population groups, and environmental interests, drawing attention to this region and triggering public debate in Panama. The debate has prompted the government to recognize the urgency of modernizing and enforcing relevant legislation, particularly the 1966 water law, the 2002 basin management law, and the guidelines for environmental impact assessment, which to date lack reference to cumulative impacts.

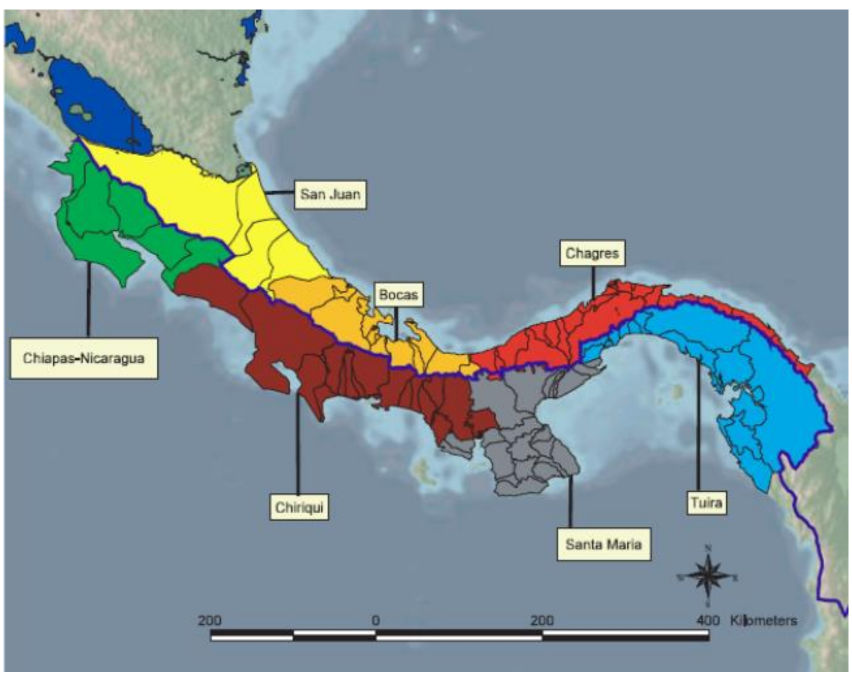
The Chiriquí River has also received international attention. For example, Panama included the river as an example of its challenges in its periodic report to the Convention on Biological Diversity in 2010. The international development banks (IDB and IFC) involved in the financing of a number of projects in the basin requested and funded additional studies on cumulative impacts and a basin management plan. The banks' review panels also got involved following an NGO complaint over two of the hydro projects (Pando and Monte Lirio). The review panels confirmed that information on cumulative impacts was limited, and that this "raises the systemic question of whether to proceed with private sector development in an environment where the information needed to fully assess the rationale behind larger strategic development decisions taken by third parties, or host governments, is not available (Compliance Advisor Ombudsman [CAO] 2012)." Potential impacts on downstream mangrove ecosystems, which cover over 400 $km^2$ in the province (ESSA 2013), provide a clear example of the type of impact that would be underestimated in the EIAs for individual projects and would require a cumulative or regional assessment to understand fully.

The initiatives supported by the IFIs are useful and may lead to some changes in the siting, design and operational regimes of future projects and to some voluntary cooperation among license-holders. However, their effectiveness may be limited in the overall basin, as many impacts are already committed to, and it will be physically and legally difficult to change those projects that are already permitted. Development of a basin management plan may not address the full range of issues relevant to hydropower because, similar to other countries, in Panama these types of plans primarily focus on water allocation between sectors and catchment protection. Unless specifically tasked, a plan for the Chiriquí basin would then not address issues specific to hydropower environmental impacts (such as upstream fish migration or sediment transport).

Concentrating on the cumulative effects in a single basin also potentially misses opportunities for finding solutions at a broader spatial scale.  A national or regional analysis could compare the relative costs and benefits of concentrating development in a few basins such as the Chiriquí Viejo, compared to dispersing projects throughout Panama. A broader vision could also identify opportunities for protected rivers and aquatic biodiversity offsets, similar to the case study of Reventazón, within Panama or even at the scale of Mesoamerica and including the future electricity trading partners of Panama.

The information foundation for these types of analyses already exists, due to the relatively high scientific interest in Central American biodiversity, but this information needs to be integrated within planning exercises and used to guide decisions. For example, Smith and Bermingham (2005) have defined seven 'biogeographical provinces' in Panama and Costa Rica with comparable fish assemblages and dispersal barriers between them. It is conceivable that a large proportion of fish biodiversity in the region could be preserved by protecting representative rivers in each of those provinces.

**Figure 13. Freshwater biogeographical provinces of Lower Mesoamerica (Smith and Bermingham 2005)**



In conclusion, there is increasing acceptance in Panama of the need to broaden and update planning approaches. According to Perdomo (2012), the Chiriquí Viejo example illustrates three weaknesses in the Panamanian planning system:

- Since the generation expansion plan is indicative or suggestive only, final investment decisions are always taken by private developers whose interests do not necessarily coincide with the public interest.
- The hydropower projects in the expansion plan have not been chosen on the basis of coordinated plans for the development of the basins, which means that they adopt designs which benefit a particular site and not an integrated or optimal use of the potential in the basin.
- Multi-purpose considerations (including irrigation, drinking water, flood control, recreation etc.) are not taken into account.

In an op-ed for a Panamanian newspaper (Antinori 2012), Panama's former IDB representative Antinori offered a similar perspective to Perdomo and reflected on the deregulation reforms in the 1990s: "We erred in leaving to the private sector the planning of these new installations, including the decision where and when to build the projects… The state has to re-take the generation planning and define the hydropower projects, favoring those with the least environmental and social impacts."

## 3.7 Northeastern South America Region (Guyanas)

The 'Northern Arc' of South America is a term for the north-eastern part of the continent, a region also known as the Guyanas, which was colonized by five different European powers and is still divided into five different political entities. These include parts of two large countries, Brazil and Venezuela, which are already reliant on hydropower for a large part of their electricity generation (78% and 65%, respectively) and three small territories, two of which are independent (Guyana since 1966 and Suriname since 1975) and one is an overseas department of France (French Guiana). Guyana is the poorest country and also the most underdeveloped in terms of its electricity sector, while Suriname and French Guiana both have one medium-sized hydropower station and their electricity consumption per capita is broadly in line with regional averages.

The Guyanas are an area of significant hydroelectric potential, with high precipitation and rivers running off the central Guiana shield. Venezuela could develop up to 20 GW of capacity on its south-eastern Caroní River alone, and is already exporting power to the northern Brazilian border state of Roraima, through the only cross-border interconnection in existence to date.

The Guiana Shield is overlain by one of the largest expanses of undisturbed tropical rain forest in the world, harboring regional biodiversity that ranks among the highest in the world. Population densities in the interior are very low and largely consist of indigenous communities. A regional conservation prioritization exercise for the Guiana shield was carried out in 2002 and, in 2011, Conservation International (CI) updated the analysis, incorporated ecosystem services, and reviewed progress toward protection (CI 2011). The CI report concluded that a large proportion (72.5%) of the surface area should be considered conservation priorities, and that significant progress has been made across the region in terms of establishing protected areas. The report also acknowledged that the region is somewhat unusual: "Identifying and prioritizing conservation areas in the Guiana Shield presents us with a challenge that conservationists are thrilled to have, but seldom deal with, namely, how to identify the most important areas for conservation in a region that remains highly intact." While its focus is terrestrial, it includes an overlay analysis which also considers freshwater availability and use. Not surprisingly, at this scale of analysis, it basically confirms that freshwater is most abundant in the mountainous interior and most valuable in the coastal plains for irrigation and domestic use. While the maps are useful, they are not sufficiently fine scaled to inform decisions about hydropower project siting, in terms of which basins are more important for biodiversity than others and should therefore be protected from development.

On March 15, 2013 a Memorandum of Understanding was signed between regional entities for the 'Northern Arc Project', which states that "pre-feasibility studies will be planned to identify and evaluate electricity demand and power supply options. In addition, the studies will assess the political, institutional, regulatory, technical, economic, environmental and social implications of a potential electrical interconnection of the Northern Arc countries." This cooperative undertaking is based on IIRSA (Iniciativa para la Integración de la Infraestructura Regional Suramericana), a loose framework for promoting transport, electricity and other interconnections between South American nations. Some initial Strategic Environmental Assessments of the IIRSA initiatives in Guyana and Suriname were undertaken as part of previous IDB technical assistance programs.

This case study will focus mostly on hydropower planning in Guyana and Suriname, but they need to be seen in a regional context, both for comparative purposes and because of the potential to link their small markets to their neighbors. The following table provides an overview of relevant data on the electricity sector in the Guyanas.

**Figure 14. Map of the Guyanas (Wikipedia)**


### *Guyana*

Among countries in the LAC region, Guyana may have the largest gap between hydropower potential and reality. Guyana Power & Light (GPL) serves only a small part of the country, experiences major operational difficulties - related to the high costs of fuel (diesel and heavy fuel oil), aged equipment and electricity theft - and is in no position to undertake major generation projects, although it will distribute the power once the first hydropower projects are commissioned.

According to IDB (IDB 2013), Guyana's government still relies for hydropower planning on a mid-1970s study (conducted by Montreal Engineering Company and funded by UNDP) which identifies Guyana's large and medium scale hydropower potential. The current list of potential sites (available at http://www.electricity.gov.gy/) is based on the original study and was last updated in 2007. The list includes comments on the progress of individual projects, providing insight into a process that must be frustrating for the government and electricity consumers, as it shows how none of the foreign project developers has managed to finalize a project, 40 years after the identification study:

| | Guyana | Suriname | French Guiana | Venezuela | Brazil |
|---|---|---|---|---|---|
| Surface area (km$^2$) | 214,970 | 163,820 | 83,534 | 912,050 | 8,514,880 |
| Population | 795,369 | 534,541 | 239,450 | 29,954,782 | 198,656,019 |
| GDP per capita (USD) | 3,584 | 8,864 | 20,904 | 12,767 | 11,340 |
| Economically feasible hydropower potential (GWh/y) | 21,900 | 7,704 | n/a | 100,000 | 763,500 |
| Electricity consumption per capita (kwh/yr) | 865 | 2,693 | 1,808 | 3,263 | 2,381 |
| Installed hydropower capacity (MW) | 1 | 120 | 116 | 14,627 | 84,000 |
| Hydropower generation (GWh) | 1 | 600 | 512 | 86,710 | 365,062 |
| Partners to the 'Northern Arc' MoU (plus IDB and AFD) | Guyana Energy Agency (GEA) | N.V. Energiebedrijven Suriname (EBS) | Électricité de France (EDF) | n/a | Eletrobras |

- Arisaru (120 MW): "In August 2003 the Government signed an MOU with the Guyana Poverty Alleviation Group, a non-governmental organization from the USA managed by persons of Guyanese origin, which granted an exclusivity period of two years to study this site. This MOU expired with the proposed developer accomplishing minimal or none of its obligations.
- Turtruba (320 MW): "Government signed a Memorandum of Understanding with a Trinidadian firm EN-MAN Services Ltd., which grants the firm a period of exclusivity until July 31, 2007 to carry out studies on the feasibility of this site. In August 2005 the developers completed their pre-feasibility study… This group is now working on strategies to access about US $10-15M required to take the project to a bankable status. A request has been made for a further extension of the MOU for two (2) years or the grant of an Interim License to facilitate the leverage of financing for the full feasibility study. Market options for the power include export of power via underwater High Voltage Direct Current cables."
- Cuyuni (62 MW): "In February 2007 the Government signed an MOU with Guyana Goldfields Inc. which grants the company an exclusivity period of two (2) years to conduct the feasibility study on the development of a hydropower plant to initially supply 35 MW electricity to its mining site at Aurora." This proposal by a Canadian miner appears to be making some progress, with support from the IFC (IFC n.d.).
- Merume (1,320 MW): "Government signed a Memorandum of Understanding with two Japanese organizations (UNIC & RITE), which granted a period of exclusivity until November 15, 2006 for studies on the site. The proposed developer had conceptualized the development of 1,750 MW of firm power at Sand Landing, Mazaruni River to supply a hydrogen based fuel plant which would have also utilized biomass. That MOU ended in November 2006. In February 2007 the Government granted RUSAL exclusive rights for an initial period of three (3) years to conduct a pre-feasibility study of this site. It is intended that the power produced would supply an aluminum smelter."
- Amaila Falls (103 MW): "A detailed feasibility study of this site was completed in 2001 and an Interim License to develop the project was granted to Synergy Holdings in July 2002 for two years and renewed until July 2007. The developer also obtained an Environmental Permit. Government, GPL and the developer, Synergy Holding signed an MOU in May 2006 for the developer to commission a 100 MW hydro plant in

December 2010 to supply power to the national grid."

Except for a few existing micro hydro plants, the only sites under advanced development appear to be Cuyuni, depending on the progress of the mine, and Amaila Falls, now with a capacity of 165 MW. However, Amaila Falls was recently suspended by the sponsor Sithe (who acquired the rights from Synergy) citing Guyana's "inability to reach consensus on a number of key legislative arrangements needed for the plant's development"(HydroWorld 2013).
The 2010 Guyana Power Sector Policy and Implementation Strategy (Klass 2010) determined that:

- "The harnessing of the country's hydropower potential, which is in excess of 7,000 MW, will be given the highest priority.
- The Potaro River Basin, with an estimated average potential of around 500 MW [including Amaila Falls on the Kuribrong tributary], will be developed to meet the needs of the national grid.
- Funds would be garnered to carry out pre-feasibility and feasibility studies to identify the best suitable location for the next hydropower development after Amaila Falls.
- Foreign Direct Investment would be encouraged for the development of the Mazaruni River Basin for large scale industrial development (e.g. aluminum smelter), and export of power to neighbouring countries [Brazil or Caribbean]. The estimated average potential of the Mazaruni River basin is around 3,500 MW."

The main reason for prioritizing these two basins (which are roughly equidistant from the coastal load centers) was the size of identified projects relative to domestic demand. The only sources for comparing the environmental and social impacts of different options appear to have been developed in conjunction with the preparation of Amaila Falls. As a potential financier, IDB insisted on an updated Environmental and Social Assessment, which came out in 2011. The assessment used high-level screening information and compared Amaila Falls favorably to several other alternatives. It also contained initial information on potential biodiversity offsets for the impact on the Kuribrong River and the falls, including:

- Expansion of an existing protected area, the Kaeiteur National Park (KNP), to include the reservoir and all or a part of the watershed above it; or expansion of KNP to include Marina Falls and/or Art Falls;
- Creation of a new protected area to protect Orinduik Falls (Wondermondo 2013); and/or
- The protection of other high-conservation value areas in the country (e.g., Tepuis and Shell Beach).

This includes options directly around the project, options with similar habitat, and options that possibly protect habitat that is rarer or of a higher value. There is no publicly available information about the current status of offsets planning.

There is an ongoing debate in Guyana on the alternatives to be pursued first. The government's position is that Amaila Falls is most advanced and needs to be implemented first for domestic needs, while pursuing ongoing talks with the Brazilian government and Brazilian developers over large-scale options in the Mazuruni basin, able to supply an interconnection with the Brazilian state of Roraima (Kaieteur News 2012).

As Guyana has committed to a low-carbon development strategy and to preserve its forests, those options that minimize forest loss from access roads, transmission lines and reservoirs should be preferred. CI et al (2009) have analyzed one of the planned regional infrastructure integration initiatives, the road to Brazil (Georgetown-Lethem Transport Corridor) (Conservation International et al 2009). The argument is made that an environmentally conscious development of that road corridor which reduces carbon emissions from deforestation, compared to other alternatives, could qualify for payments under the REDD mechanism. Similar analyses could be undertaken regarding the various hydropower options.

### *Suriname*

The only existing hydropower project in Suriname is Afokaba (189 MW), built in the 1960s by ALCOA to supply power to the bauxite and aluminium industry. Its actual generation varies according to water availability in its large (1,560 $km^2$), but shallow reservoir, Lake Brokopondo. The main utility N.V. Energie-bedrijven Suriname (EBS) purchases power from Afokaba and also operates several small thermal generation facilities.

A number of potential additional hydropower projects have long been under discussion and have seen increased attention since IIRSA. As in Guyana, their feasibility depends on demand growth, which could come from rural electrification, increased mining and industrial activity, or exports. Also similar to Guyana, these projects are pursued mostly by private initiatives, outside the scope of EBS. The two main options include:

- Tapanahoni-Jai project in south-eastern Suriname, dating back to a World Bank study of 1952 (van Dijck n.d.). This would be a complex diversion scheme to Lake Brokopondo and the Afokaba power station, to increase its capacity by 182 MW. Several smaller projects upstream on the Tapanahoni, Jai and Marowijne rivers could contribute to the scheme. Desktop studies have reportedly been undertaken by Camargo Correa from Brazil, but the project has recently been suspended by government (The Daily Herald 2013), citing concerns about social impacts.
- Kabalebo project on the Kabalebo river (envisaged since the 1970s and investigated several times by the government and mining companies as part of a 'West Suriname Plan'; its first stage would be 350 MW with a second stage that included inter-basin transfers to increase capacity to 850 MW).

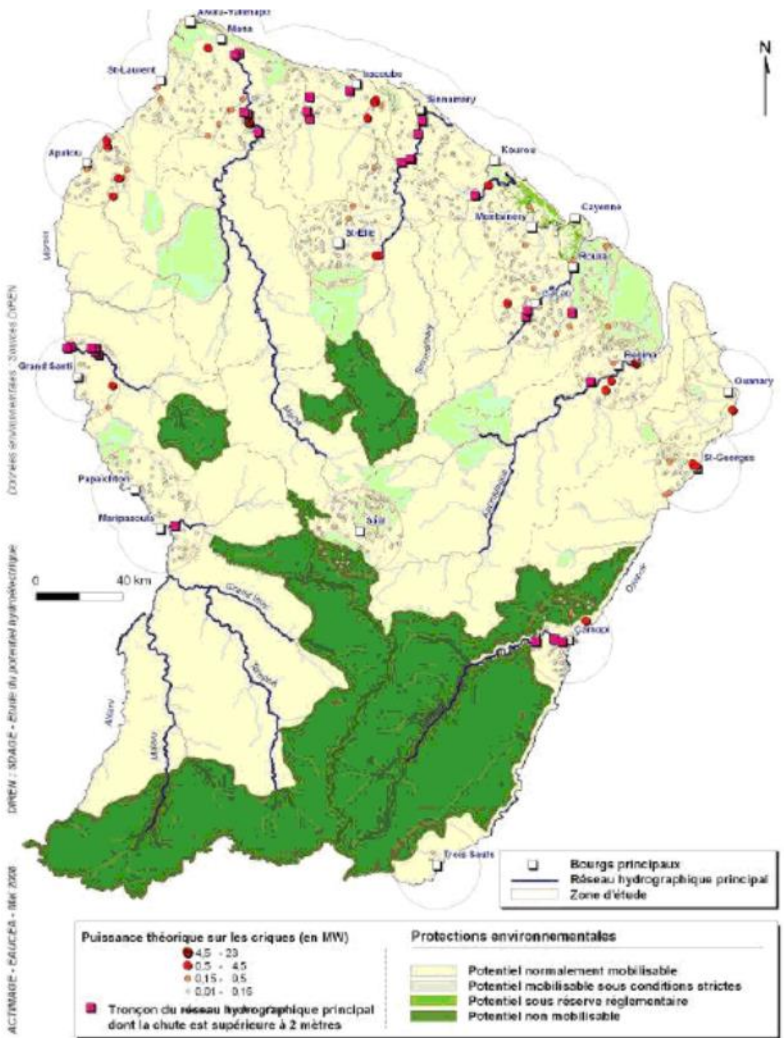

There is almost no relevant information on strategic planning in Suriname. It is known that the IDB was assisting the government with an energy sector strategy, but the outcome of this engagement is uncertain. No master plans for energy, electricity of hydropower development are publicly available, though a master plan was reportedly prepared in 2000 by TRACTEBEL "to identify the investments in new generating and transmission capacity needed to cope with growing demand in the most cost-effective way" (IDB 2012). There are also no relevant water or conservation sector documents in Suriname with a level of detail that could meaningfully inform hydropower planning. There is also a lack of hydrological data; however a planned IDB/GEF project will contribute to restoring a network of measuring stations.

***French Guiana***

The only significant hydropower station in French Guiana is Petit Saut (117 MW) on the Sinnamary River with a reservoir of 350 $km^2$, which generates much of the power required for the coastal area, including the capital Cayenne and the space center Kourou. Petit Saut was commissioned in 1994 and has been the subject of intensive research regarding its environmental impacts, notably its greenhouse gas emissions.

In terms of planning, French Guiana is a special case and provides an instructive comparison to the other countries in the region, as it is politically part of France and the European Union and thus subject to European legislation, including the Water Framework Directive.

As part of its efforts to comply with the Directive, the Comité de Bassin de Guyane recently prepared a 'Water Management Master Plan' 2010-2015 (Schéma Directeur d'Aménagement et de Gestion des Eaux - SDAGE) for the entire territory with specific actions to achieve 'good status' of waterbodies by 2015, 2021 and 2027.This was based on a broad array of background studies, including a study on the territory's hydroelectric potential. Between 1994 and 2008, a total of 69 small hydropower sites have been studied and then evaluated against a number of criteria that may constrain development, including terrestrial protected areas of different categories. The result is that numerous projects up to 23 MW still appear feasible.

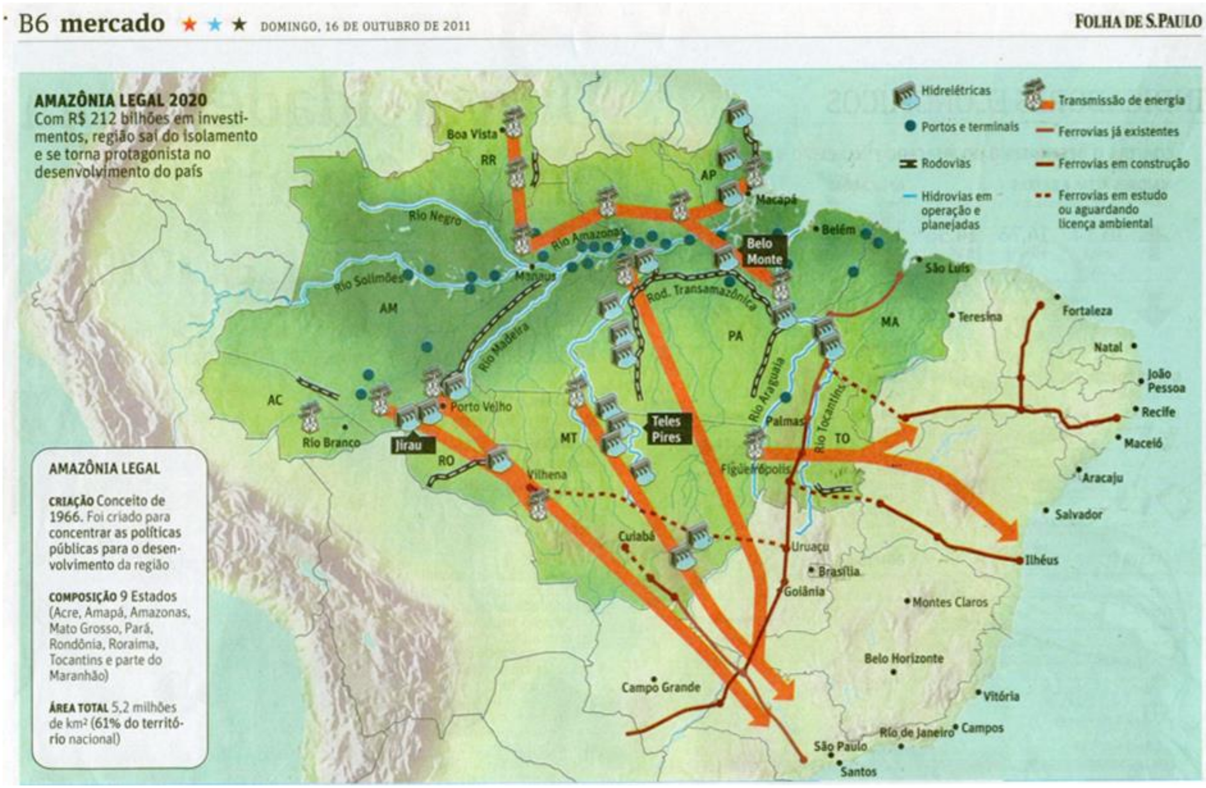



***Potential influence of interconnections on hydropower plans***

Interconnections add layers of complexity to planning. Many environmental impact assessments only consider the specific impact of a transmission line, and not the altered incentives at both ends of the line. Both regions connected by a line can increase or decrease their generation, or can trade power daily or seasonally depending on their generation profile. Similarly to opening up trade in other commodities, as long as the cost differentials in generation pay for the cost of transmission, there are economic benefits of interconnections that can be partially used to compensate or over-compensate for potential environmental costs. Further, a region which has only environmentally unfavorable options available for energy development would not need to develop any of them if it could import instead.

It is impossible, on the basis of the exceptionally poor publicly available information in the Guyanas, to predict whether interconnections will be feasible. The Brazilian interest in importing hydropower from Guyana or Suriname, with their large surplus potential, may persist, although over the last decade Brazil's own generation and transmission network in the north has made significant progress. There may also be some strategic political rationale in tying the countries in the Guyanas into a regional network dominated by Brazil.

### Figure 17. Infrastructure in the Brazilian Amazon (planned status 2020) (Folha de S. Paulo 2011)




A regional generation and transmission master plan with the objective of regional-scale optimization, taking both investment and operation costs in the electricity sector and its environmental and social externalities into account, would be methodologically complex, but a significant opportunity to improve outcomes.

## 3.8 Chile Multi-Basin Region

The development of hydropower in Chile had its origins in a centrally planned model under the direction of the sole utility energy provider ENDESA. A significant change in water resource allocation occurred from the early 1980's and, by 1989, ENDESA was privatized. Around 1,800 MW of hydropower had been developed by 1980. The planning methodology employed in the pre-deregulation period was focused strictly on meeting projected demand, with minimal environmental or social impact assessment incorporated into the planning methodology. One perspective on that era is provided by Nelson (2013) who suggests that development progressed "without noticeable conflict due to ENDESA's recognized efficiency and the absence of environmental concerns in Chilean policy until the late 1980s." However, "since that time there has been increasing pressure from international agencies and NGOs to place more emphasis on environmental dimensions in development. (Nelson 2013)"

Today there are nearly 20 owners of hydropower developments in Chile with a total installed capacity of 5,900 MW. Development has occurred in the major river basins from the IV Region to the X Region, with the south-central VII and VIII Regions having the most developed basins. Hydropower contributes around 40% of the installed capacity of Chile's Central Interconnected System. There is currently around 600 MW of hydropower under construction and it is broadly assumed that there is around 10,000 MW of further hydropower development potential in Chile.

Significant change in the management of water resources was introduced in 1981 with the implementation of a new water code whereby the allocation of water rights was fully deregulated. The reform established quite a speculative environment. Initially anybody could apply for any amount of water at no cost and without specifying the objective of acquiring the water rights. The general water administration body DGA (Dirección General de Aguas) was obliged to grant water rights provided the relevant legal procedures were followed, water rights of other users were not infringed, and there was a water flow available in the requested area. Environmental water needs were not considered. In addition to granting water rights, the DGA is also responsible for studying the availability of water in Chilean river basins.

The principle behind the creation of water rights was the search for optimal allocation and technically efficient use. The legal framework drawn up in 1981 established water as an economic asset, and therefore it was considered that the state should intervene as little as possible, allowing the market to develop the efficient use of the resource. As a result, the administration of water rights falls upon the users themselves.

Once a water right is granted to an applicant, that right can be openly traded and its use is regulated by market mechanisms. In general the government only intervenes in the process when the rights of a third party are threatened, to establish certain environmental considerations, under declared droughts, and where there are disputes between holders of water usage rights.

The water code requires that water right owners establish cooperative arrangements in the form of "Commissions' in which owners join together to equitably manage water usage. In a river basin in Chile there can be several Commissions along the length of a valley depending on the characteristics of the basin. In the upper reaches multiple hydropower developers may form into one Commission. Then subsequently irrigators typically join together in the lower reaches to form another administrative Commission. It is the role of each Commission to deal with matters relating to water usage in their section of the basin.

From a hydropower developer's perspective the water rights provide some legal certainty for investment decision-making. Since 1994, project development is also subject to regulatory oversight through an application for Development Approval including Environmental Approval.

Some of the issues that have arisen from this early reform include:

- Concentration of ownership of water rights: A significant water right holding remained with a few market players and this potentially limited the opportunity for other developers to progress potentially innovative hydropower developments.
- Lack of knowledge of ownership: There was initially no compulsory registration of water rights. It is likely that even now only 30% of the water rights in existence are on the formal register.
- Risk of sub-optimal use of the water resource: Not all owners of water rights have the capacity to develop hydropower and the rights may be held for speculative purposes only. Additionally, since land ownership and water rights are not linked, water rights can be sold without any connection to the land where the water right exists. Where the likelihood for hydropower generation exists the adjacent land has been subject to speculation and consequently impacts the opportunity for development.
- The multiple Commissions in a river basin potentially keep the various interests in a basin separated and may limit cooperation.
- Initially there were no environmental flow requirements attached to the water rights.

In 2005 there were reforms to the water code to address some of these issues:

- A holding charge is now applied to all registered water rights whereby those owning unused resources have to pay an annual license fee that doubles every 6 years while the resource is not used. This has resulted in small water right holders with limited development capacity relinquishing water rights, but large well-resourced holders have maintained their significant holdings. Also there are still many unregistered water right owners and there is no mechanism at present to seek payment from them. Consequently some speculation still persists.

- Sale and auction processes have been held to stimulate access to water rights for those able to progress development.
- It is now necessary for applicants for water rights to justify the activity that would potentially be undertaken.
- There are also now environmental flow obligations associated with newly assigned water rights.

There is a recognition within the Chilean Government that basin planning would assist in the effective management of the resource. However, there is a lack of information in many of the over 200 mostly small basins, and the process currently relies on developers to uncover environmental issues during their environmental assessment activities. This lack of information has been emphasized by Goodwin et al (2006) who promoted "the value of a central knowledge base and the importance of a system-wide monitoring program to assess pre- and post-implementation conditions and adapt operational rules" (Goodwin et al 2006). A promising innovation is a Geographic Information System being developed by the Government's land management bureau, which will identify zones of sensitivity in river basins (IDE Chile n.d).

In its 'National Energy Strategy 2012 – 2030' the Energy Ministry has noted,

> Its priority to work in partnership with the Environment Ministry to review the existing environmental processes and instruments in this area with a view to integrating new parameters, incorporating greater information about the real possibilities of electricity development, the costs involved and the impacts and to deepen the dialogue and information available to the public. This will enable environmental management in the area to be improved, improve the decisions about the location of projects, protect our environmental heritage, generate informed debate and provide a greater level of legal certainty to the approval processes.

The World Bank has recently contributed a review of the current water management institutional framework and proposes a series of measures to improve it, among which is the creation of a Secretariat of Water Resources and an increased emphasis on basins as the appropriate unit for analysis, planning and management (Banco Mundial 2011).

Community involvement in the hydropower development process is recognized as vital by progressive developers. However, development plans for the basin as a whole cannot readily be presented to community stakeholders due to the multiple ownership of water rights in the basin.

The hydropower development process in Chile remains focused at the project level with a completely deregulated market approach to water rights allocation and trading that seeks to stimulate innovative development. It will be quite a challenge to find mechanisms to assist in providing basin development guidance that aligns with this deregulated market philosophy.

## 3.9 Lessons Learned from Regional Case Studies

All case studies provide examples for the potential gains from balancing different objectives through spatial optimization. They demonstrate that such initiatives can provide value irrespective of the level of economic development and of the regulatory framework. In the two cases from outside LAC, traditional energy planning policies and processes had failed to respect environmental and social values, and balance was sought by restricting development from some portion of the river systems under consideration. While Maine was able to initiate the studies on its own, in Vietnam the Asian Development Bank provided funding from a technical assistance facility, and international expertise was brought in. The initiative to implement recommendations in both cases came from regional government leaders who understood their responsibility towards the ‘big picture’.

The examples also show that system planning is not a new approach which depends on sophisticated new insights or technologies. The principles behind it have been intuitively understood or applied through comparatively simple methods for many decades. The example of the Sarapiquí basin in northern Costa Rica showed how such metrics could be used to identify the cumulative impacts of small projects and inform decisions about dam siting

Regarding the role of regulation, the Latin American case studies illustrate the entire spectrum from tightly regulated (Mexico) to completely liberalized (Chile) electricity markets. Basin optimization considerations may be easier to introduce in more controlled environments. However, in principle countries should be able to introduce elements of basin optimization without having to roll back deregulation. Brazil, although not discussed here in detail, presents an example of a mixed system where the government is very prescriptive about which projects are going to be built, but then leaves implementation to the energy companies. Looser, more indicative frameworks may also work, such as in Guyana where two priority basins have been selected for development; although in the Guyana case it is not clear how these basins were selected and whether any other developments have increased protection from development.

In many ways, working through real examples may be the best way to present and analyze system planning issues. These cases present a variety of scenarios and institutional frameworks that are important to consider while trying to synthesize and consolidate experiences. It is unlikely that one framework can be developed that would work everywhere due to the great variety in natural, economic and institutional conditions. However, it is important to describe a standardized ideal-type approach, and to then consider its real-word applicability and adaptability. This is the purpose of the following two chapters.

# 4. Conceptual Framework and Illustration for System-scale Planning

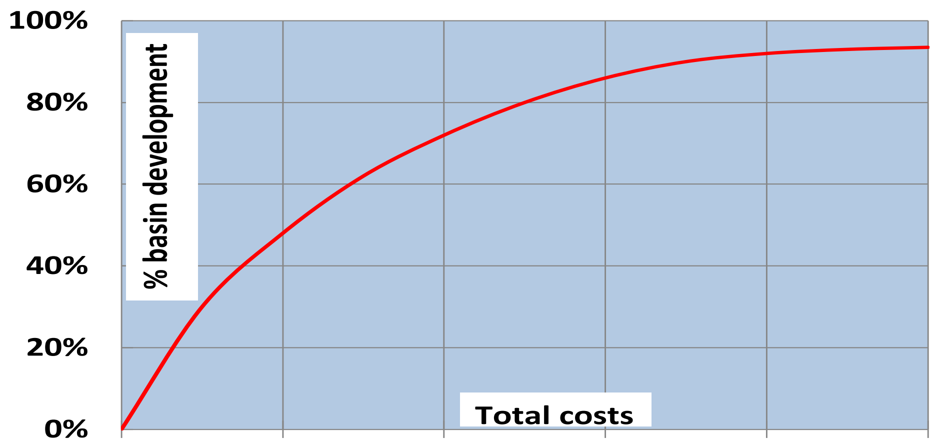
All the strands of work reviewed here -- guidelines for individual projects, methods for cumulative impact assessment, planning for the design and assessment of development programs, integrated multi-use water resource planning, and basin-scale conservation planning -- can make important contributions to more sustainable system-scale planning. Case studies in Chapter 3 have shown that there are initial examples of these methods being used in some Latin American countries. However, it appears that there may be some fundamental conceptual limitations in approaches being applied to date. Several of these—including individual project guidelines, cumulative impact assessment, and planning of sectoral development programs—generally start with a proposal for development projects and then begin to consider assessment and mitigation of socio-environmental impacts. Basin-scale conservation planning begins by identifying high priority conservation areas ("no-go" areas), which provides an information base to inform hydropower planning but, on its own, the conservation planning approach doesn't actively integrate planning in the pursuit of more optimal outcomes. Although multi-use integrated river basin planning conceptually can provide this integration, as described in Chapter 2, these approaches tend to focus on water-management *sectors* and not on the full spectrum of water *values*. Additionally , application of IRBM or IWRM has often lead to detailed plans but not changes in decisions or management. Despite these limitations, continued improvement in the range of values incorporated into these integrated planning processes will increase the utility of these approaches to meet the goals described in this report.

To illustrate that potential, this section describes a hydropower-specific planning framework which integrates different values and perspectives from the beginning and allows for regional optimization across multiple objectives. In this section we will offer a conceptual basis for system-scale planning and optimization, review some basic levels of analysis that are building blocks of an optimization process, and, finally, assemble a framework from these components and illustrate it through an analysis of alternative hydropower development scenarios for a river basin.

## 4.1 Marginal Cost Analyses: Hydropower, Environmental, Social

Not all hydropower projects are equal to one another. Some are more efficient than others in terms of total benefits generated in comparison to costs. The value of each hydropower project in a basin, considering costs and benefits, is something that can be calculated. Simple measures such as estimated capital investment and hydropower capacity or energy output are usually known with some precision early on. Other costs, such as total life-cycle costs, may be more difficult, but can be calculated.

Many river basins, if not most, have pre-existing hydropower development plans that identify the technically and economically feasible projects in the basin. Based on these types of plans, it is possible to estimate total potential feasible development of a basin, in terms of basic metrics such as capacity in MW or generation in GWh, and reasonable estimates of required capital investments for hydropower projects can be made. Based on these estimates, it is possible to plot the marginal cost of hydropower development for the whole basin; such a plot will generally show a curve of diminishing returns as full development is approached. Of course, these curves may not always be smooth or show uniformly increasing marginal costs. Some projects downstream of earlier, more expensive projects may ac-




tually show a lesser cost, as in the case of downstream units of a cascade. But the salient point is that some combination of projects will produce a majority of hydropower benefits.

Further, the *full* costs of a project—including not just direct economic costs but also environmental and social impacts—can be calculated. Some impacts can be expressed quantitatively, while other are difficult to translate into a standard parameter, such as dollars. However, conceptually we can conceive of a marginal cost analysis that plots project outputs against total economic, environmental, and social costs.

Underlying the concept of "optimization" is the notion that there should be a similar marginal cost relationship for environmental and social benefits against total costs Just as all hydropower projects are not equal, neither are all conservation opportunities or social values. This suggests that development that involves a large number of projects—and a diversity of environmental and social resources—can unfold through a number of different alternative scenarios, and that these scenarios may vary widely in terms of the mix of benefits across economic, social, and environmental value sets. It is the challenge of system-scale planning to find those alternatives that provide the most optimal mix of those values.

These analyses are theoretically possible but difficult to perform in reality. With such diverse resources in question, it can be quite difficult to realistically define the curves for all three value sets. In simple terms, we can't simply add economic apples to environmental oranges and social plums to arrive at a meaningful total. As a result, it is unrealistic to hope to assign an optimization calculation to a computer. But as a guiding concept to a three (or more) value set collaborative design, or negotiation, a key principle is clear: an effective system plan is not based on a zero sum budget. For example, perhaps 70% of a basin's total energy potential could be delivered by half of the potential dams, and this level of development may possibly maintain the basin's essential environmental and social values.

For hydropower development to actually follow a path toward system-scale balanced outcomes confronts challenges rooted in both technical analysis and policy. First, those optimal or quasi-optimal outcomes must be identified, and this requires information on a range of resources and the ability to integrate that information into an analytical framework. Second, the results of that analysis must be integrated into decision-making processes. This section describes a conceptual framework for overcoming the technical challenges, illustrated with analysis on a hypothetical river basin. Subsequent chapters offer recommendations for how planning processes can be reformed so that promising balanced outcomes identified through planning can be become development reality.

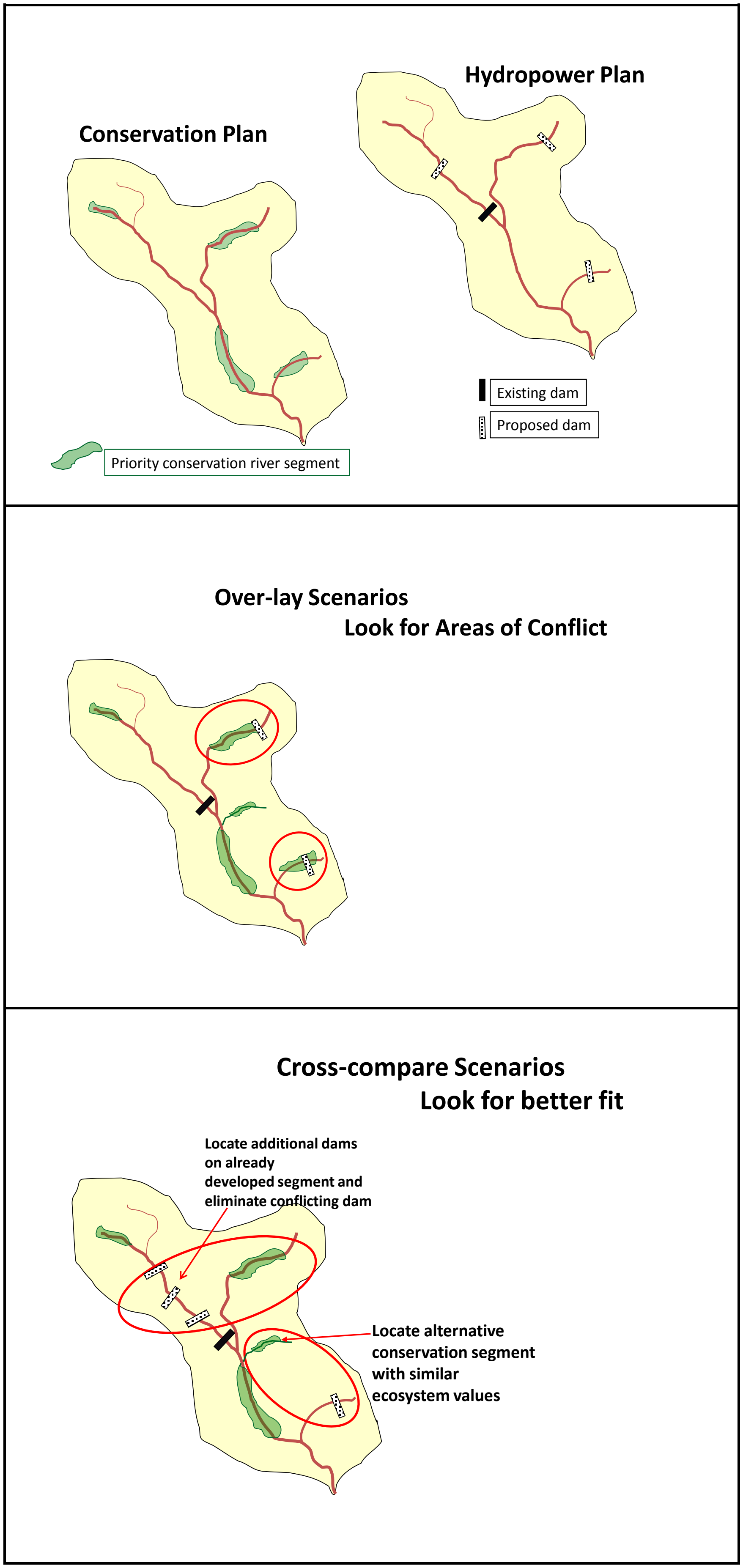
## 4.2 Scenario-Based Analyses: Base Case

Even if technical optimizations cannot be calculated by some algorithm, alternative designs can be proposed by the different users or stakeholders involved in any basin. This process is more akin to architectural design than an engineering calculation. Given the complexity inherent in designing spatially overlapping systems of hydropower and environmental and social resource protection, here we break the design process into some simplifying layers. The first, or the base case, could be a simple two-dimensional site-selection exercise, where hydropower dams are considered as points on a map, without consideration of their mode of operation (e.g., diversion, storage, multiple purposes).

The required information will be up-to-date potential project maps, environmental planning maps and equivalent social-ethnic value maps. The process ultimately selects a set of hydropower projects and a set of socio-environmental conservation commitments that give a best fit between the three value objectives. It will also involve calculation or estimation of the outputs in each value area, with the intention of looking for a design that offers a balanced mix of these values.

Below, we illustrate this two-dimensional spatial approach with cartoon-like diagrams, showing the superimposition of a dam development plan and a plan for environmental conservation, the identification of conflicts, and then the adjustment of both conservation and energy plans to reach an outcome that reduces conflicts and produces a better balance.

In Figure 19 on the following page, the top panel represents distinct plans for hydropower and environmental protection, including a "portfolio" of priority conservation sites. The second panel shows an integration of the plans, with potential conflict areas identified with red circles. In the third panel, alternative choices are selected—for both hydropower and environmental priorities—to identify a more compatible fit between the two plans. For one conflict between a hydropower project and an environmental conservation site, an alternative environmental conservation site is selected, allowing the dam to go forward. For a second conflict, an alternative dam is selected to maintain a high-value environmental conservation area.


Conservation Plan
Hydropower Plan
Priority conservation river segment
Existing dam
Proposed dam
Over-lay Scenarios
Look for Areas of Conflict
Cross-compare Scenarios
Look for better fit
Locate additional dams on already developed segment and eliminate conflicting dam
Locate alternative conservation segment with similar ecosystem values

An area representing a particular environmental value may be of high priority, but it may or may not be unique in the basin. If there is a substitute, similar area, then an alternative choice may be available for protection. It may be incrementally less efficient, but still acceptable. Similarly, a particular hydropower project may be seen as the top priority from an engineering and economic stand-point, but there may be alternative dam sites or configurations with only a little less, and acceptably less, productivity. A joint planning decision could find an optimum intersection between the hydropower and the environmental conservation values. If this could be done for a whole basin or region – done at the same time for numerous projects and areas of value for environmental conservation -- the possibility for an optimized outcome emerges.

This kind of simplified spatial analysis was actually implemented in the now well-known case of the Penobscot River, described above (section 2.1.). It involved the redesign of an existing system, as opposed to a pre-development basin plan, but the situation is analogous. Because that case involved only low-head run-of-river dams, and the problem of migratory fish passage, a relatively simple spatial reorganization allowed for a win-win solution. Three dams were decommissioned, two of which have now been removed, and fish passage was up-graded at the remaining dams. The capacity of the remaining dams was also upgraded. The net result has been widely discussed -- significantly more habitat for migratory fish, such as salmon and shad, and a modest increase in total hydropower energy.

Expanding from the initial simplified two-dimensional analysis, subsequent analyses can add more complexity, including operations of dams (storage, run of river, and peaking) and incorporating other uses of water, such as interactions between management objectives within multipurpose reservoirs (e.g., hydropower and flood control).

## 4.3 Illustration of Iterative Scenario Analysis

To illustrate the possibility of reaching an optimum design between hydropower development and social and environmental values at the scale of a river basin, we conducted a hypothetical scenario analysis. This analysis represents an advance beyond the simple "cartoon" diagram above in terms of detail and realistic application, but is still hypothetical. The Nature Conservancy is currently applying similar analyses in real basins, such as the Coatzalcoalcos basin in Mexico, in a collaboration with CFE (see Section 3.2). Because these efforts are ongoing, we cannot yet present their results.

For these scenarios we started with an actual basin. To the extent possible we used the actual data on potential dams (locations, capacity and cost) and environmental and social resources. As neccessary, we used simulated, but realistic, data., Thus, the scenarios do not represent any real place and are only for purposes of illustration – but they do represent a realistic spatial distribution of hydropower projects and environmental and social resources. Here we briefly summarize the methods and describe the key results. The full details of the analysis, including methods and more complete results, are presented in Appendix 1. The analysis was based on a river basin with a spatial distribution of three value sets: hydropower output and cost, social values, and environmental/ecological values.

The indigenous/social value set is represented by a single variable, which is the spatial distribution of indigenous reserves. We acknowledge this is a major simplfication and, in a real-world application, a broader range of values will likely need to be represented. For example, social values will often need to encompass many non-indigenous values and these may even be in conflict with indigenous values, such as widely divergent opinions on the value of a reservoir. In addition to being complex, these social/indigenous values may be fairly subjective and difficult for technical experts to quantify. In the end, the best way to capture and represent these values may depend on an inclusive process, in which affected stakeholders can express preferences for certain scenarios over others.

For environmental/ecological values we have used available information from TNC, World Wide Fund for Nature

(WWF) and others, and, where necessary, we augmented it with hypothetical, but realistic data. Environmental data included a "portfolio"—geographically designated priority areas for protection—and connectivity of the river network (with a dam representing a break in connectivity).

Value sets and their specific attributes will vary widely between actual basins. The values chosen for this illustrative scenario exercise are by no means intended as a prescription for a real-world application. For illustrative purposes, they do represent a cross-section of the types of values that will tend to be important in a real basin. The value sets and attributes to be used in each setting must be carefully chosen – presumably with full participation by all basin stakeholders.

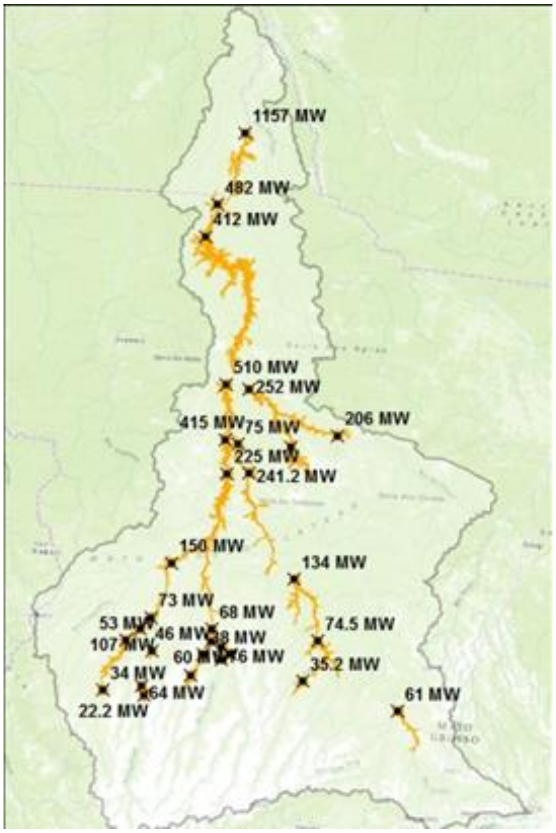
We generated a total of 12 scenarios, starting with a trio of extreme cases: (1) full hydropower devlopment; (2) hydropower development that has minimal impact on indigenous areas; and (3) hydropwer development with minimal impact on envrionment/ecological values. Next, we developed another trio of scenarios, each intended to produce approximatley 60% of the value of each of the three value sets. We then developed six further scenarios that explored different geographic objectives for development, such as concentrating dams in the lower reach of the river and leaving the majority of the upper basin undeveloped (scenarios 7 and 8) or leaving the southwest tributaries undeveloped (scenario 9). Maps depicting the spatial configuration of dams and reservoirs for all 12 scenarios are shown in Figure 20.

We have not proposed any particular calculation – any algorithm – for selecting a final recommended scenario. Here, we simply display the range of outcomes and discuss the implications of the different outcomes. If an interactive scenario analysis is used to support a multi-stakeholder process, the final "optimal" outcome may actually be a negotiated end-point as opposed to a mathematical optimum. In any event, the iteration of scenarios, continually looking for a better fit, provides a way to approach a more balanced outcome.

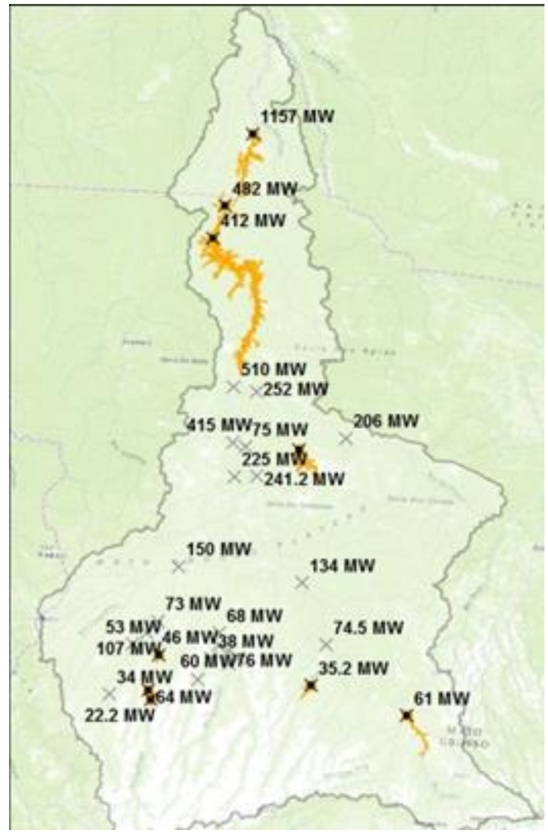
***Scenario Results***

The results of the twelve scenarios are shown in figure 20 through 22 and tables 5 and 6 on the following pages. For each value set, scenario results are expressed as a percentage of the complete or intact value set (e.g., hydropower values are a percent of full build out, biodiversity numbers are a percent of a fully intact portfolio). Complete quantitative results are contained in Appendix 1.

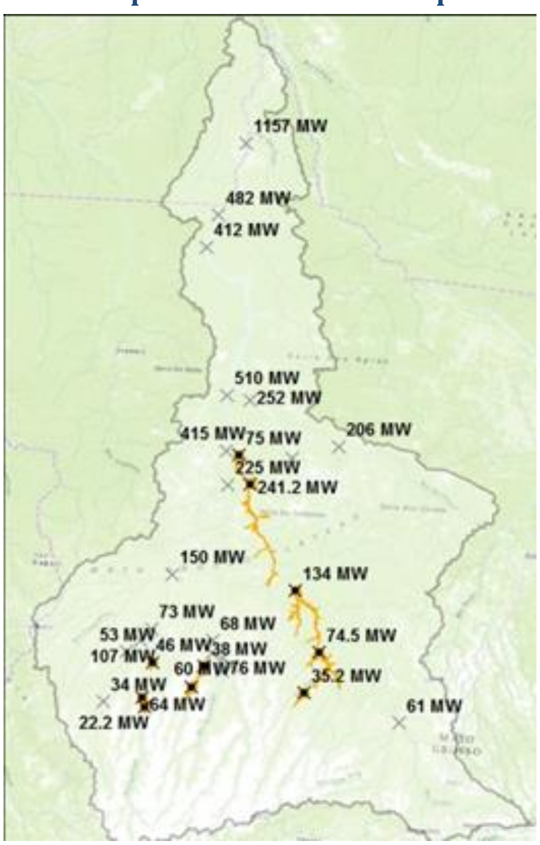
**Scenario 1:**
**Full hydropower potential**



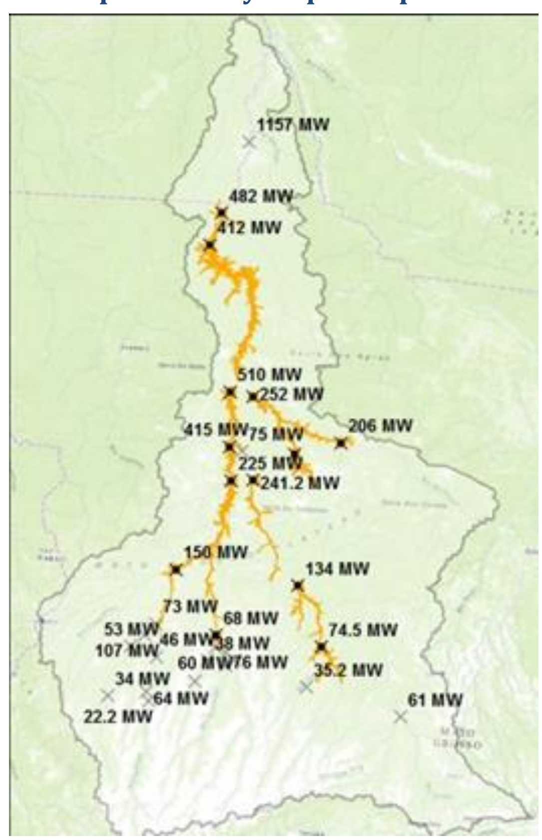

**Scenario 2:**
**Minimize impacts to indigenous lands**

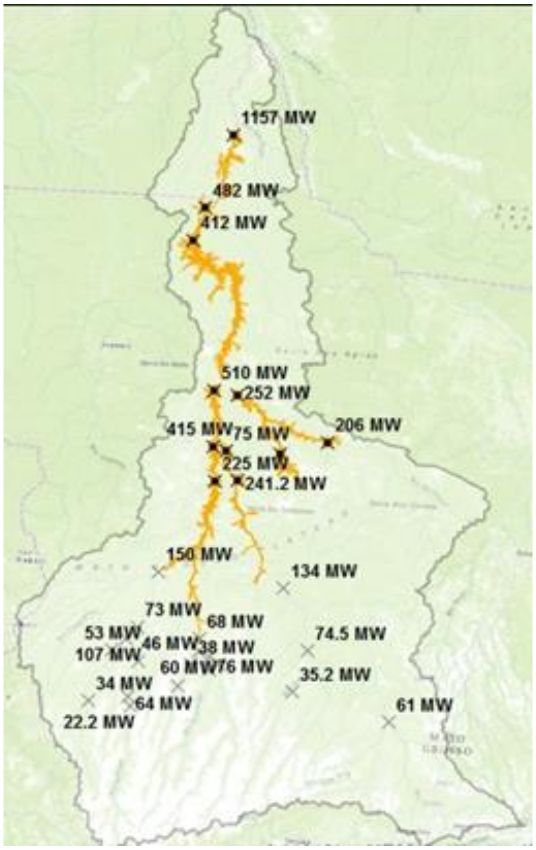


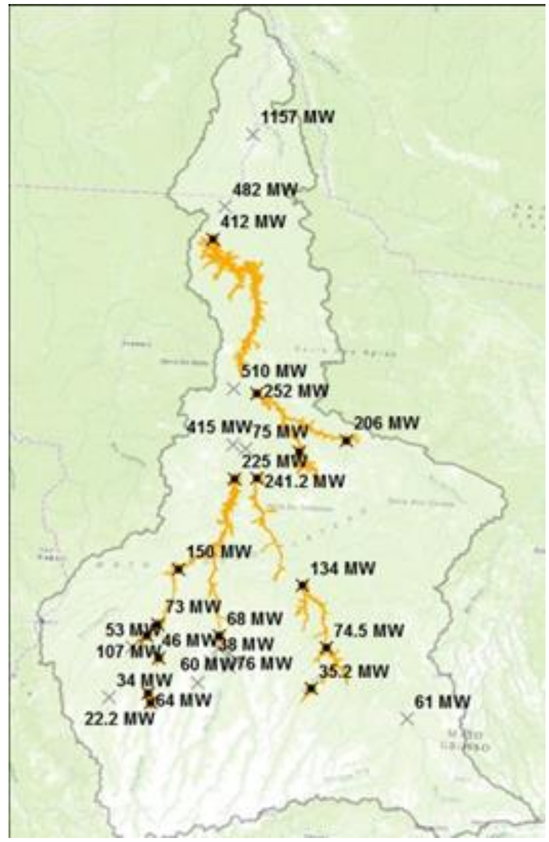

**Scenario 3:**
**Minimize impact to environmental portfolio**



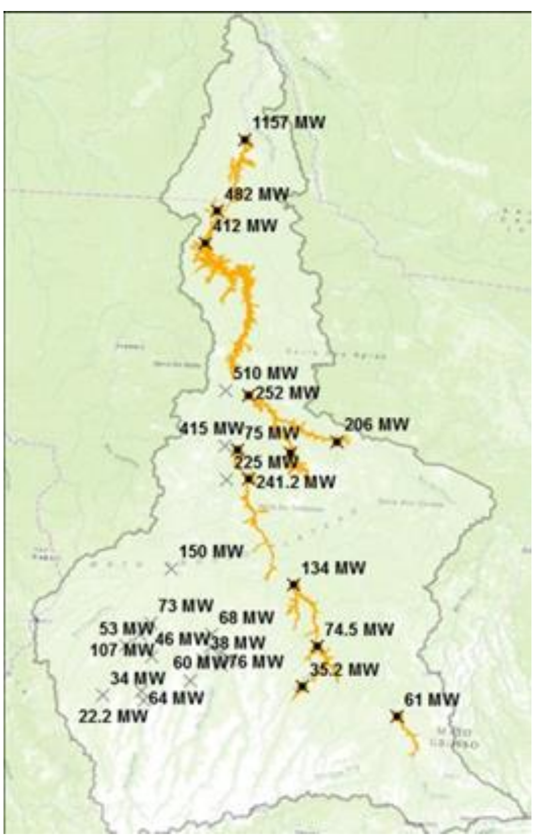

**Scenario 4:**
**Develop 60% of hydropower potential**



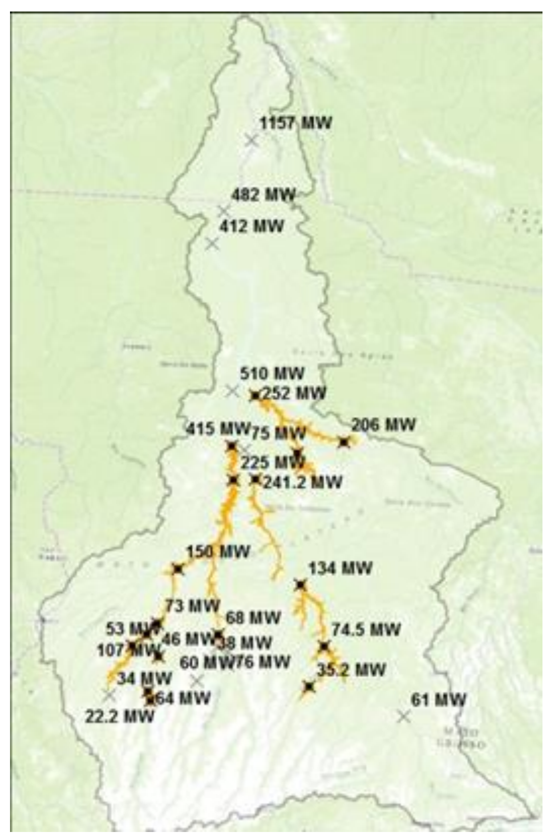


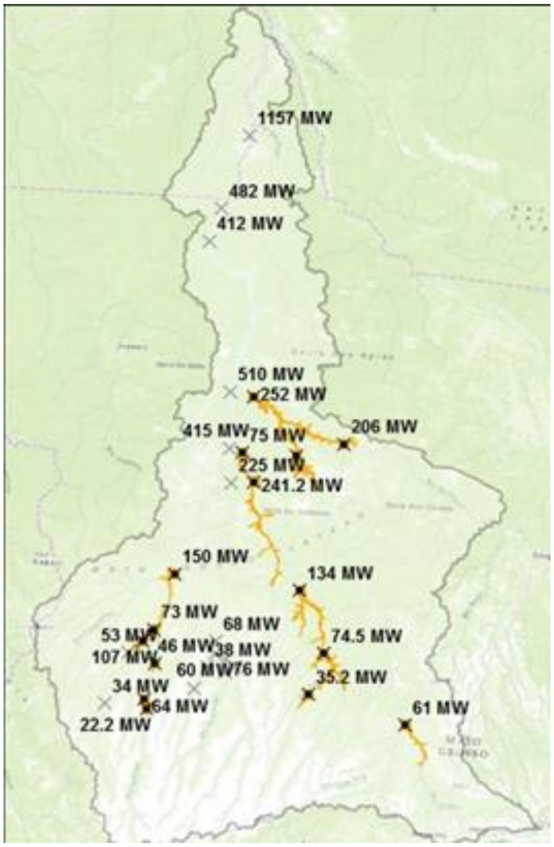




**Scenario 7:**
**Concentrate development in lower river (1)**

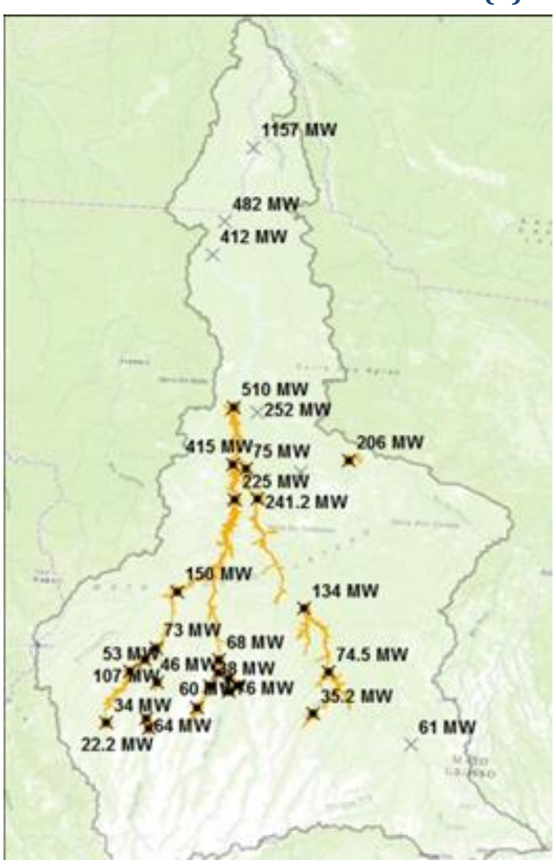


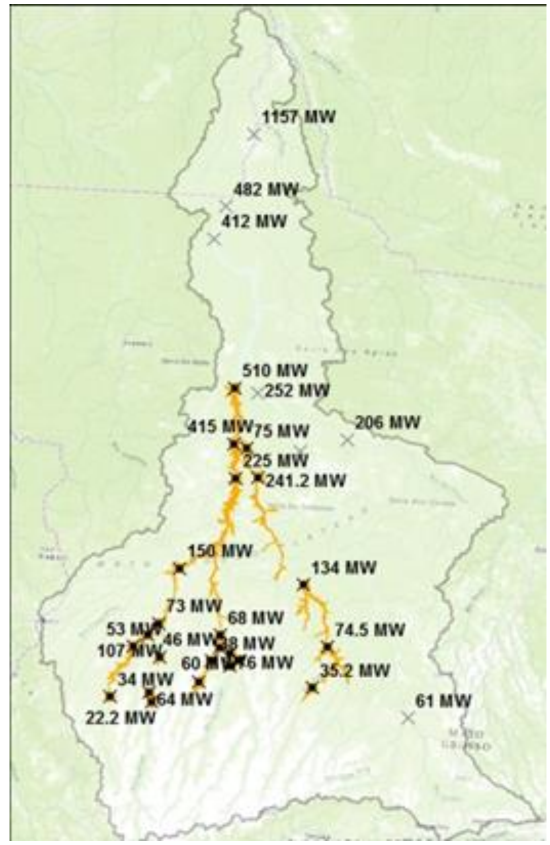

**Scenario 8:**
**Concentrate development in lower river (2)**



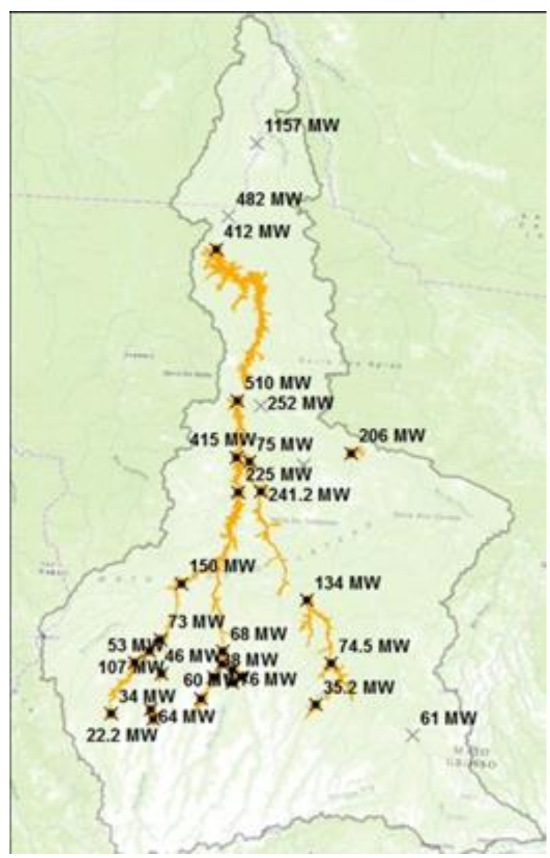



**Scenario 11:**
**Free lower and east tributaries (2)**




**Scenario 12:**
**Free east tributaries**



### Table 5 and Figure 21: Proportion of value sets produced or maintained across scenarios

For each scenario, results are expressed as a percentage of the full, or completely intact, value set (e.g., full hydropower development or completely intact biodiversity portfolio). In the table, cost is a percentage of the cost of energy from Scenario 1, full hydropower.

| Scenario | Name | Cost | Hydro | Indig. | Biodiv. | Connect. |
|---|---|---|---|---|---|---|
| 1 | Full Hydropower Potential | 100% | 100% | 55% | 51% | 14% |
| 2 | Minimize Indigenous Impact | 88% | 45% | 91% | 77% | 48% |
| 3 | Minimize Biodiversity Impact | 89% | 14% | 86% | 100% | 81% |
| 4 | Develop 60% of Hydropower | 104% | 62% | 59% | 68% | 17% |
| 5 | Protect 60% Indigenous | 103% | 76% | 73% | 66% | 17% |
| 6 | Protect 60% Biodiversity | 96% | 42% | 59% | 68% | 24% |
| 7 | Maximum development in lower river (1) | 105% | 61% | 77% | 73% | 27% |
| 8 | Maximum development in lower river (2) | 108% | 43% | 64% | 72% | 35% |
| 9 | Free upper southwest tributaries | 110% | 32% | 73% | 82% | 44% |
| 10 | Free lower and east tributaries (1) | 111% | 49% | 64% | 74% | 61% |
| 11 | Free lower and east tributaries (2) | 108% | 53% | 59% | 72% | 54% |
| 12 | Free east tributaries | 110% | 61% | 55% | 61% | 30% |

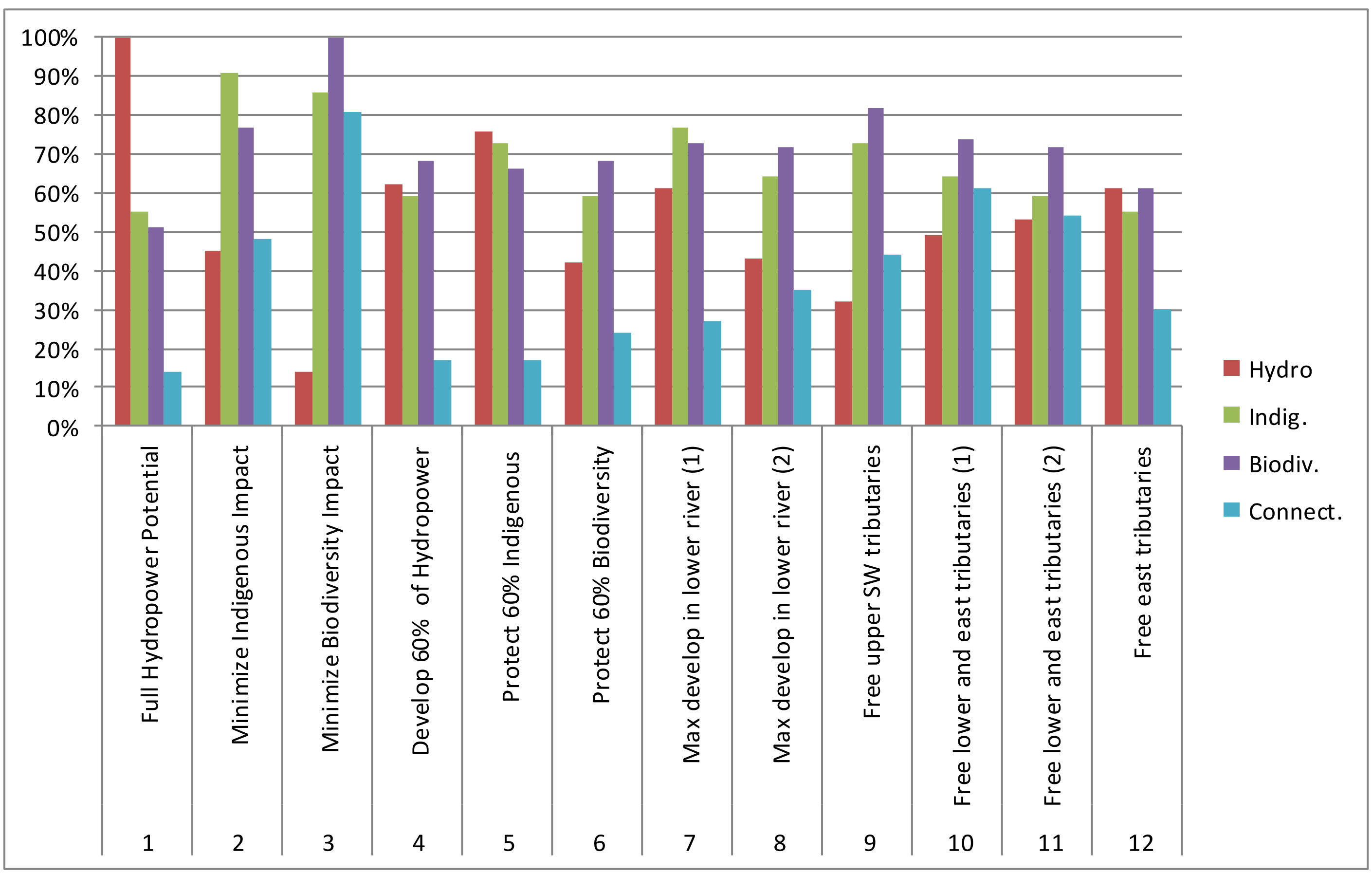
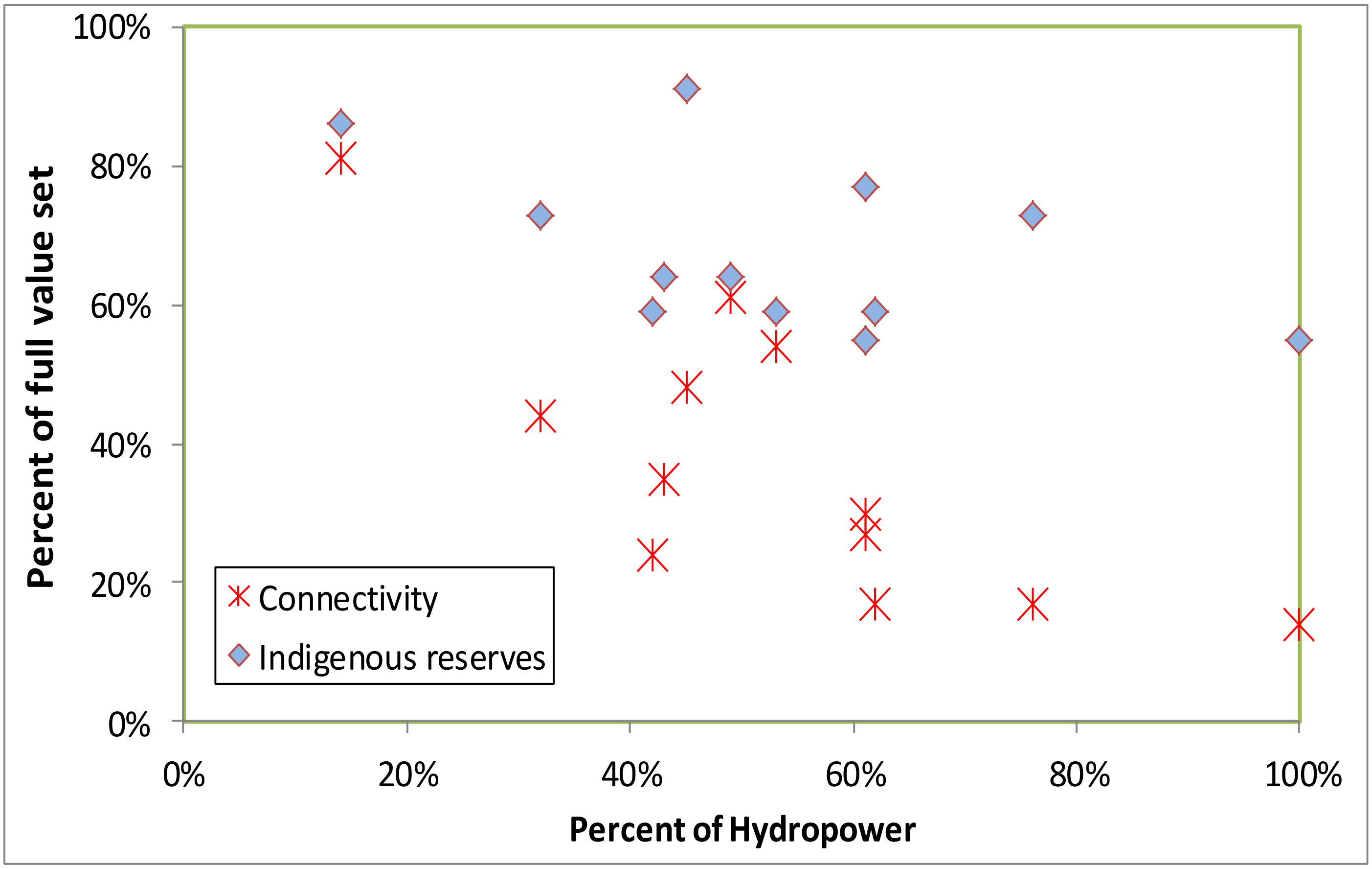


**Figure 22: Indigenous land and connectivity compared to proportion of hydropower developed in the twelve scenarios**




## 4.4 Scenario Analysis Conclusions

**Iterative Scenario Results**

The results suggest some general trends. First, as the percentage of hydropower increases, the other values generally decrease; this is the obvious expectation (figures 21 and 22).

Within that general trend, however, there are five scenarios that achieve between 53-76% of hydropower capacity while maintaining fairly high levels of other values. For example, compared to the 100% hydropower scenario, which maintained 55% of the indigenous value set and 14% of connectivity, scenario 7 maintained 77% of indigenous (with 61% of hydrpower) and scenario 11 maintained 54% of connectivity (with 53% of hydropower). While stopping short of complete hydropower development, these scenarios provide more balance across the value sets than does the full hydropower development scenario.

The results also illustrate a key concept underpinning the argument for system-level planning: for a given energy output, there can be a fairly wide range in the output of other values. To illustrate, observe the cluster of scenarios that develop between 40% and 50% of hydropower in Figure 22 and note the wide spread in connectivity values (24 – 61%) and indigenous values (59 – 91%).

By comparing multiple develpoment scenarios, it is clear that some support a broader range of benefits than others. Scenario 4 and 7 had nearly identical costs and percent of hydropower developed. However, Scenario 7 outperformed scenario 4 in all three other values (indigenous, biodversity and connectivty; Table 6).

These results support the premise that system-scale planning has a greater likelihood of acheiving a balance of benefits than can be achieved through project-scale planning and development (as shown in the Table 5, energy costs did not vary widely between scenarios).

### Table 6: Comparison of scenarios four and seven

| Value | Scenario 4 (Developed 60% of hydropower) | Scenario 7 (Maximum development of lower river) | % difference between Scenario 7 and Scenario 4 |
|---|---|---|---|
| Hydropower (% of total) | 62 | 61 | -2% |
| Indigenous intact (% of total) | 59 | 77 | + 31% |
| Biodiversity intact (% of total) | 68 | 73 | +7% |
| Connectivity intact (% of total) | 17 | 27 | +59% |

These initial, and promising, results are not necessarily representatives of all basins, of course. Each basin is distinct in terms of what values are most important and how those are distributed, and this distribution will control the range of possible outcomes from various scenarios. Further, real basins will have much greater complexity in terms of other water-management sectors and land use. Iterative scenario analysis, as described here, may be an effective way to manage this complexity, and the basic proposition likely still holds: there are scenarios that offer a better balance of outcomes, and iterative scenario analysis may reveal the "best fit" among alternatives.

Finally, a broadly acceptable system-scale hydropower design likely cannot be developed solely by a group of technical experts. Results of this type of scenario comparison are more likely to be accepted if they were developed with the involvement of decision makers and key stake holders. Such convening is a hallmark of Integrated River Basin Management, but, to produce outputs, this type of analysis and engagement must be structured such that it can lead to actual decisions and designs. Appendix 1 includes further discussion of an inclusive process for this type of iterative scenario analysis and planning.

# 5. Towards Broad Application of Regional Planning Approaches

It is broadly accepted that some form of planning is necessary to achieve the objectives of all reasonably complex social entities, whether government departments or corporations. Debates about the role of planning usually involve:

- The role of government planning (should it restrict itself to planning for the public sector or for the entire society, including the private sector);
- The planning period (should it be short-term, for periods with considerable certainty, or should attempts be made to provide forecasts and a planning framework for the medium and long term);
- The character of planning (indicative vs. obligatory or regulatory planning, and the role of adaptive management within planning frameworks);
- Planning in sectoral ‘silos vs. integrated, multi-disciplinary planning across departments;
- And the spatial scale of planning.

There is some value in recognizing that these debates are not modern discoveries, but have been going on for many decades. Awareness of the historic evolution of planning may help to design successful reforms of planning approaches.

## 5.1 A Critical Look at Historical Planning Experiences (Sanyal; Lira; and DeMattos)

In Western countries, the decades after World War II are often considered the ‘golden years of planning’. They were characterized by widespread optimism that the scientific approach to planning, which had proven so useful in war, could be applied to socio-economic development. At the same time, many newly industrializing countries introduced technocratic planning, drawing inspiration from the comprehensive planning framework that had emerged in the Soviet Union. Because socialist states had to centrally plan their economies, their planning was dominated by economists and statisticians, while in Western countries plans were more indicative and the practice was dominated by engineers. The different objectives of planning – for example, in Latin America, agrarian modernization, industrialization and rapid expansion in the provision of public services – influenced the style of planning.

Developing countries often used planning to design individual projects and estimate the amount of aid required for modernization. In some newly independent countries, planning for modernization resulted in products - often written by foreign experts - that were quite separated from the actual, pre-technocratic governance culture, and sometimes the plans were implemented, resulting in grandiose but isolated projects (for example, new capital cities or large dams such as Kariba and Akosombo in Africa).

In Latin America, planning was a key element of the economic and political thinking of the post-war period, promoted by the influential CEPAL (the United Nations’ Comisión Económica para América Latina y el Caribe). The mostly conservative governments of the time preferred to refer to planning as ‘programming’ in order not to be associated with socialist, centrally planned economies. One of the objectives agreed for the ‘Alliance for Progress’ between the US and Latin American countries at the 1961 Punta del Este conference was economic and social planning, and it became a prerequisite for receiving foreign aid. Many Latin American countries created planning ministries and planning departments within many public agencies.

However, it soon became apparent that the planners were not necessarily aligned with or aware of political realities, that the plans were often not implemented and that the planning agencies had little influence. In other words, while planning documents were being produced, they did not add up to an effective planning process. Disillusionment in the 1970s resulted in increased criticism of planning practice as technocratic, elitist, centralized, bureaucratic, and pseudo-scientific. Traditional planning institutions lost legitimacy and resources. In a paradigm shift, some planners hoped to create more bottom-up processes, open to public participation and concerned with objectives other than economic growth. Planners would become negotiators and facilitators, withholding their professional views and searching for common ground (or, in the view of those with more technocratic preferences, the lowest common denominator).

In the 1980s and 1990s, policies of deregulation and privatization further reduced the scope for planning and discredited government's ability to plan effectively. The emphasis for planning was no longer on directing the public, but rather, on attracting private investment by lowering risks and promoting public-private partnerships. Planning was sometimes portrayed as a sterile, paternalistic exercise, and "the best policy was the one that did not exist" (Lira 2006).

Contributing to this disillusionment was the attitude of many government departments and public utilities. Despite obvious shortcomings of past planning, they continued to argue that they were dealing with a narrow and technical planning problem which could be isolated from its social context. They would receive their objectives and constraints from elected politicians, their role was then to come up with a technically optimal plan, and it was then for others to implement it. This could apply equally to an energy utility, a protected areas agency, or a water resources department. Often these plans indeed applied state-of-the-art methodologies (although sometimes on the basis of rather incomplete information). Bureaucratic planners continued to be surprised, or even indignant, when outsiders did not understand or trust their methodology and did not accept their conclusions. Political decision-makers often overruled plans, for example by choosing a different hydropower project than the one that was highest ranked in the plan. Stakeholders (including other government agencies and private companies) often ignored plans, knowing that they were not binding and that the real decisions were taken elsewhere. A common complaint about technical plans was that they were impenetrable 'black boxes', and that inside those boxes many judgment calls and conflicts of interest were hidden from public view.

This criticism is not limited to energy master plans. For example, in Europe, under the Water Framework Directive, all water agencies are supposed to plan for 'good ecological status' for all water bodies under their jurisdiction. This objective did not arise through a participatory process among the stakeholders in a particular basin; instead it came from an inter-governmental process. Basin plans to achieve 'good ecological status' are developed through a tightly prescribed process, with relatively little stakeholder involvement, and not surprisingly, are not always well-known or broadly accepted. Indeed, exceptions can be made if there is an 'overriding public interest'. The same criticism can be and has been launched against conservation plans and blueprints presented by NGOs. These plans may be the result of a collaborative process between conservation experts, but are often not understandable to the general public, are unaware of other public interests and ongoing planning frameworks, and are too easily ignored by governments.

More recently, public planning has been rediscovered to some extent. Public planners are moving from regulatory to more entrepreneurial planning, copying some approaches from corporations and trying to compete with other jurisdictions for investment. As part of attempts to re-invent government, planners are trying to restore the legitimacy of planning through informed public deliberation. The planning process is seen as more important than the outcome, in the form of a document, because the process contributes technical expertise to public decisions. Good planning outcomes, i.e. planning outcomes that represent the public interest as closely as possible, are today seen to require an interaction between public experts, the market, and the democratic political process, which all contribute indispensable elements (Metcalf 2003).

## 5.2 Current Planning Frameworks in LAC Countries

As was discussed in the case studies from Latin America, hydropower-relevant planning is typically undertaken by multiple institutions, at multiple temporal and spatial scales, and divided by sectoral and territorial responsibilities. At any one time, the siting and design of new hydropower projects may be influenced by central government agency or utility plans for electricity, water, biodiversity conservation, roads or other sectors; by territorial planning for municipalities, provinces, basins, and protected areas; and by different types of plans within the electricity sector itself (for example, by public sector investment planning for the transmission network, and private sector investment planning in generation).

The planning exercises of most interest for this study are system-scale generation expansion plans, which rank and sequence future projects in a basin, region, or nation. These plans should draw on a catalogue of potential projects, reflect all current information available, and be compatible with the plans of other sectors. Most easily accessible are national-level plans, which should build on and encompass basin or regional plans.

Most countries in the LAC region now leave investment decisions with the private sector, and if they produce any expansion plans, they are seen as indicative or reference plans. In most cases, it would seem to be advisable for the private sector to follow these indications, as they are supposed to rank the lowest-cost projects first. Even with the usual caveats (that the projects still need to be assessed in detail and approved), there would also be a presumption that the government wants these projects to go ahead and that approvals can be obtained.

The role of public planning in a competitive generation environment is to provide a forecast on which the authorities can base their decisions and a tool to detect regulatory problems, which impede attainment of a system optimum (CEAC 2010). One problem which is frequently mentioned in expansion plans is the risk that some projects may not materialize in time or at all, which may cause capacity shortfalls in the system. Often social or environmental impacts are identified as the main potential cause of such delays or cancellations.

Faced with a pattern of projects failing to materialize, electricity planners could draw various conclusions and pursue different responses. They could reduce environmental oversight, making permits easier to obtain and increasing interest in investment. This response may be politically difficult, as it could be viewed as undermining other agencies' responsibilities, and further, investors and developers could still be exposed to risk from previously unrecognized or unresolved conflicts. Alternatively, planners could make planning more comprehensive and capable of directing decisions toward projects with lower environmental and social impacts, which would be easier to implement.

Some countries such as Mexico and Costa Rica have left generation in the hands of a national monopoly, presumably lessening the risk that projects are not implemented. In Brazil, while there are multiple private and public developers, government guidance is explicit and developers can only choose between those projects identified by public planners and brought to auction. Some auctions fail to attract much interest, however, and it is said that sometimes public utilities have to step in to 'save' a project. Even after a license is assigned, projects are frequently interrupted by protests and injunctions. Also in cases like Mexico and Costa Rica, plans have to be seen as indicative, with projects frequently falling out in the next iteration of the plan.

We have reviewed 16 current generation expansion plans from LAC countries to understand how much awareness they show of social and environmental concerns and how these concerns are integrated into plans and decisions.

| Country | Planning Document | Environmental and Social Considerations of Relevance to Hydropower |
|---|---|---|
| Bolivia | Plan Óptimo de Expansión del Sistema Interconectado Nacional 2012-2022 (CNDC 2012) | None ("The plan is an instrument for … rational and efficient use of natural energetic resources, development of infrastructure and logistics, and of the hydroelectric potential of the country.") |
| Brazil | Plano Decenal de Expansão de Energia – PDE 2021 (MME 2012) | Specific analysis of 34 planned hydro projects to be commissioned over next 10 years, in two regards:<br>- duration of environmental licensing process (to verify date of commissioning)<br>- high-level comparison of negative and positive environmental and social impacts<br>The general result is that projects in the north and central west have higher costs, but also higher benefits, and that none of the 34 projects are in the high cost/low benefit category.<br>The results have not been linked to project names, and the further use of the ranking is unknown. Cumulative data for all 34 projects are provided. |
| Central America | Plan Indicativo Regional de Expansión de la Generación Período 2011-2025 (CEAC 2010) | Local impacts make hydropower projects vulnerable to attacks by environmental groups. |
| Chile | Estrategía Nacional de Energía 2012-2030 (Gobierno de Chile 2012) | Does not forecast or rank individual projects (CNE does this separately, in order to plan transmission expansion, on the basis of indications by generating companies).<br>Emphasis on safeguards (health, environment).<br>"The strategy will allow the perfection of environmental management in the sector, improve siting decisions, protect our environmental heritage, generate informed debates, and bring more legal certainty to approvals processes."<br>For non-conventional renewables, a geo-referenced information platform for investors is being provided. |
| Costa Rica | Plan de Expansión de la Generación Eléctrica (ICE 2013) | Each proposed project has to carefully consider E&S impacts in its planning and design. The development of the electrical sector should minimize negative and maximize positive impacts.<br>Limitations to the proportion of the hydro potential that can be developed need to be taken into account (best sites already taken, impacts on protected and |
| Colombia | Plan de Expansión de Referencia | Protected areas reduce hydro potential from 93 GW |
| Dominican Republic | Plan Energético Nacional 2004-2015 | None |

| | | |
|---|---|---|
| Ecuador | Plan Maestro de Electrificación 2012- | Emphasis on sustainable development, commitment to |
| Guyana | Power Sector Policy and Implementa- | Two priority basins have been identified (on technical- |
| Guatemala | Plan de Expansión Indicativo del | None |
| Jamaica | Generation Expansion Plan 2010 (OUR | In the optimization modeling, renewable resources car- |
| Mexico | Programa de Obras e Inversiones del | None, other than reference to environmental norms |
| Nicaragua | Plan Indicativo de la Expansión de la | None |
| Panama | Plan de Expansión del Sistema | Risk of late entry of hydropower projects. |
| Peru | Plan Referencial de Electricidad 2006 – | None |
| Uruguay | Política Energética 2005-2030 (MIEM | Hydropower potential largely exhausted, but reference |

The following broad conclusions can be drawn from this review:

- The majority of LAC countries, and now also some interconnected regions such as Central America, undertake systematic expansion planning. Exceptions may be explained by style of government (Venezuela, Argentina), lack of institutional capacity (particularly in small countries) or a lack of motivation (as in Paraguay, with an abundance of existing capacity). A number of countries have fully institutionalized planning processes, with rolling planning and annually updated documents. Other countries that have only policy or strategy framework documents, not detailed plans, update theirs less frequently.
- Most plans use or reference least-cost planning methodologies. However, there are a number of countries which have more strategic-level planning, sometimes for the broader energy sector (not just electricity), and leave the identification of least-cost projects to the private sector.
- The environmental issue of most interest is climate change mitigation, and many plans argue for an expansion of renewables. A few even value the avoidance of negative environmental externalities in the least-cost model.
- A significant number of plans do not mention hydropower-specific environmental and social issues at all. It is of course possible that these are implicitly taken into account in the underlying catalogues of projects. However, where these draw from master plans that are decades old, this appears less likely (MEM n.d.).
- Several plans recognize the risks of hydropower projects not obtaining approvals, or investors not pursuing hydropower projects because of a perceived approval risk.
- A few plans address these risks by proposing limitations on development (for example, by avoiding protected areas in Colombia and Costa Rica). A plan in Colombia is being subjected to a strategic environmental assessment. A plan in Brazil contains a comparative ranking of all proposed projects by environmental and social impacts; however the ranking is not published and does not appear to have influenced project selection and sequencing.

The lack of integration across sectors is not restricted to energy sector planning documents. There is a comparable lack of integration in other planning documents from Latin America, at all levels. For example,

- even though Costa Rica is generally more advanced with regards to environmental management than other countries, its national Integrated Water Resource Management Strategy recognizes hydropower only as a non-consumptive user, with no further discussion of impacts on rivers and downstream water users, and the Strategy does not address aquatic biodiversity;
- In Panama, a river basin with high hydropower potential - the Río Santa María - was also one of the pilot basins for Basin Management Plans. The management plan for the Santa María noted this potential, rep-

resented by 30 identified sites, and also articulated that local communities directly benefit from new projects - for example, hydropower sector resources could be directed toward payments for environmental services in the upper watershed. However, the management plan includes no discussion about the potential impacts of hydropower development on water allocation, sediments, seasonal or daily flows, aquatic biodiversity or other issues of interest for water resources management;

- Management plans sometimes avoid discussion (which may be politically sensitive) of the impacts of 'national priority' projects, as illustrated by protected area plans for the Biosphere Reserve and National Park Gran Sumaco in Ecuador, which does not mention impacts from the the Coca-Codo Sinclair project.

Some of this lack of integration probably reflects planning in silos. However, some of it may also be a reflection of political priorities and the relative power of different government agencies and jurisdictions. Other sectors and lower-level jurisdictions may prefer to accept and adapt to hydropower plans, or even to ignore them, where they feel to have no influence, rather than challenging and insisting on providing input into plans. This may even be the case where there are formal inter-agency coordination mechanisms.

## 5.3 Introducing Optimization Planning into Current Frameworks

There are several approaches that could address this lack of integrated planning.

One approach is to broaden the information, objectives and constraints that individual agencies consider in their planning. For example, if electricity planning agencies were directed to use - and had access to - comparative assessments of the potential for conflicts or the conservation value of the various rivers with hydropower potential, they could incorporate that information in multi-criteria ranking exercises. For example, to prepare a national Master Plan for Water Resources in the 1980's, the Norwegian government evaluated 542 hydropower projects according to two criteria (cost and likelihood of conflicts), and then chose the projects that scored best to supply 10 TWh (the projected demand until 2000) out of the remaining 73 TWh potential. Countries with fewer projects to choose between could use more elaborate indicator systems or sustainability assessments to supply ranking information. In principle, least-cost planning methods could incorporate valuations for externalities and opportunity costs for all projects, but, as described in Chapter 4, it typically will be difficult to come up with universally accepted monetary values.

Incorporating broader information into these processes obviously depends on the relevant information being available. In many countries, this will not be the case, but sometimes information that was generated for other purposes can be adapted. For example, Mexico's Comisión de Áreas Naturales Protegidas (CONANP) has conducted a comprehensive gap analysis to verify that all terrestrial, marine and freshwater ecosystems are represented in the country's protected area system. The results could easily be used by CFE to establish whether any of the planned hydro projects interfere with existing or potential protected areas. Another precondition is that the planning agency has a clear perception of government and stakeholder preferences; often an agency will be reluctant to change planning processes unless an explicit objective beyond least-cost power has been mandated or a binding constraint has been imposed on it.

A second approach is to expose the planning by individual agencies to outside opinion. This may be achieved through a variety of mechanisms such as inter-agency coordination, panels of independent experts, strategic environmental assessments, boards in which stakeholders are represented, public consultation, or peer reviews.

Inter-agency commenting on sectoral plans is not uncommon. For example, in Panama the public utilities regulator and a private distribution company commented on the latest Generation Expansion Plan, and their comments and the planners' responses were included in the final version. The commenting process could certainly be expanded to include a broader range of agencies, including water and conservation agencies. However, similar to an *ex-post* strategic environmental assessment, this is less likely to provide effective, actionable integration compared to an early and iterative involvement of diverse agencies, and would work properly only in a recurring planning cycle. Stakeholder comments appear to be possible in most countries publishing their expansion plans, but absent formalized requirements to respond to these comments, it is unclear how much they will influence future plans. NGOs such as TNC can also work directly with generation planners and provide new information and planning approaches, or can publish competing visions of basin planning which will then generate a public debate.

A third approach, and one that is particularly required if agreement between different sectoral agencies and sections of society cannot be reached, is to take coordination up one level to a central planning agency, a cabinet office, or ultimately, the cabinet or president him- or herself. Cabinet-level planning departments still exist in some Latin American countries but have lost much influence. In some cases, they serve to coordinate foreign aid only, or would be unlikely to be accepted as unbiased arbitrators, as they are often closely associated with public works and infrastructure development. However, there is always the option of raising a serious political conflict to the highest level of government, and indeed many of the largest hydropower projects, whatever their status is in formal planning documents, are ultimately decided upon at that level. Unfortunately, such interventions are often guided by short-term political expediency and may undermine the rationality of planning processes.

## 5.4 Incentives to Adopt Regional Planning Frameworks

The various options to promote integrated planning for hydropower will only be adopted if decision makers in the hydropower industry, financing sector and government see an advantage in them. The private sector may be motivated to adopt some elements of integrated planning, but many elements will require government action. Therefore, it is ultimately the public sector that needs to realize that current approaches have limitations and that further improvement in hydropower sustainability will come largely through integrated planning.

This section will review the different kinds of incentives and motivations, from ones that are most familiar to industry, to more complex ones.

Starting with projects arranged in a cascade, it is fairly obvious that the location, design and operations of the different projects are interrelated and that conflicts cannot be eliminated, or an optimum reached without coordination . On the Madeira River, for example, there has been a long discussion between developers on the level of the Santo Antonio reservoir, which influences the tailrace level, and therefore the generation potential, of the upstream Jirau project. On other rivers, the challenge may be to move sediment through a cascade by way of coordinated flushing operations, or to coordinate peaking operations. It can be easily demonstrated how an upstream project that modifies flows by peaking operations, may reduce downstream generation. If the downstream project has little storage and a lower design flow, it will have to spill some of the flow arriving from upstream. It may also not be able to meet contracted energy delivery obligations any more, if these call for generation at different times than for the upstream project. Finally, in some cascade circumstances flood design arrangements for new dams will need to include special consideration of existing projects. There may be different flood design methodologies used on older dams compared with newer dams, and where a new dam is placed upstream in a cascade there is the potential to provide upgraded protection for existing downstream structures. This will save remedial costs on downstream projects, but could add to the cost of an upstream project.  Coordination will be required to achieve the optimal investment to ensure the entire cascade is afforded flood protection in line with modern international standards.

These considerations are most relevant in deregulated markets, where the projects in a cascade have different owners, are planned separately, and the regulator is not working to achieve an overall optimum, for example through licensing conditions. In such situations, it will also be particularly difficult to add physical or operational elements to the cascade which are beneficial to the whole set of projects. An example would be a storage reservoir at the top of the cascade which could provide more even outflows, flood protection, and sediment control. Costs for such a reservoir will be difficult to allocate between the different beneficiaries, as noted above, and it may have to be built by the public sector, but in a deregulated market that is unlikely. The same logic applies to the provision of environmental flows by the lowest project in a cascade. This project may incur costs because re-regulation will require a larger reservoir than otherwise necessary and because its generation schedule may be determined by downstream environmental and social considerations, and not by commercial optimization. Again, the provision of environmental flows by the downstream dam may benefit the entire cascade - or in fact licenses for the cascade may hinge on the provision of those flows - but it will be difficult to find a private sector developer willing to take up the lowest project without offsetting financial arrangements.

For cascade optimization discussions in deregulated markets, it is important to understand the legal situation. Legal systems vary in the protections provided to projects from harm from construction of a new project upstream, built by a different entity, or detrimental changes in operation at an existing upstream project. The regulator may or may not be able to change license conditions over time, to accommodate a changing configuration of the cascade. Depending on the legal framework, private developers may even decide to negotiate between themselves and compensate each other to arrive at a mutually beneficial outcome.

Beyond cascades, there are other fairly obvious advantages to coordination on a regional scale. Data for feasibility studies; ancillary infrastructure such as transmission lines, quarries, construction power and access roads; and environmental and social programs can be shared. There may be a preferred staging or sequence of construction.

The various benefits described above indicate that it should be in the developers' own collective commercial interest to overcome these interface issues – the lack of coordination that causes extra costs or reduced benefits. There are various reasons why coordination may not be occurring:

- Project owners are competitors for concessions and in the electricity market.
- There are too many project owners for bilateral negotiations to be effective.
- Individual project owners have an incentive to behave like free riders and not contribute to the provision of collective goods.

The lack of coordination is not just a problem for developers. It also reduces incentives to invest and raises the cost of electricity, and is therefore a general sectoral problem. To address these problems, governments can examine the legal and institutional framework to determine whether it can be made more effective in promoting coordination. The licensing regime or a basin management organization can contribute to better coordination. Brazil goes quite far in preparing projects in a basin, defining sites as well as many aspects of design and operations, leaving little for developers to coordinate amongst themselves. While some developers may feel constrained by this regime, the coordination provided by the government likely results in a net gain for them. Another solution is to have only one developer be responsible for one basin, region or the whole country, as in Mexico. This does not need to be a public company: as in other infrastructure sectors, regional concessions can be allocated to private companies, in effect creating 'competition for the market' instead of 'competition in the market'.

The coordination challenge discussed above is about achieving least-cost electricity in a situation with more than one project. Beyond that, there is another set of planning challenges. This is when the optimal outcome is defined in a broader way, beyond the collective commercial interest of the developers. The public interest to prevent floods, provide drinking water or other services, promote recreation or protect a tributary from development is not resolved by purely commercial considerations for the 'optimal' configuration of projects in a cascade.

The planning frameworks in countries like Brazil and Mexico go some way towards addressing this second challenge. In both examples, their public planning agencies and public utilities take some criteria beyond least-cost economics into account. A private concessionaire could also be required, through the conditions of the concession, to plan in the broader public interest. However, as has been seen throughout this report, in many cases there is still a need for energy planners – whether public or private - to adopt a broader public interest perspective, beyond least-cost electricity.

The real challenge in adopting changes is how to convince stakeholders and in particular, established and powerful public institutions that reforms are useful and ultimately in their own interest. The same arguments in favor of increasing the sustainability of individual projects can be made to persuade developers, public planners and regulators to move towards system-scale planning and optimization:

- Poorly sited and designed projects generate criticism, loss of social license to operate, delays (which may threaten energy security and have broader economic implications) and cost overruns, and a reputational risk to individual projects, their owners and a country's hydropower industry in general.
- This may also increase questions about the capacity and commitment to address environmental and social concerns, and limit opportunities for subsequent projects. Developers may find it more difficult to gain a foothold in international markets. Staff turnover and training costs may increase if a company is not perceived to be a responsible employer.
- Planning at the system scale makes it more likely that international bank standards can be met, without additional studies and changes in project concepts which are often required when banks come in. The early recognition and adoption of such standards during project development creates faster access to capital and possibly, lower cost of capital and a broader range of financial institutions who will want to lend to or invest in the company. An increasing number of Latin American commercial banks are signatories to the Equator Principles, and development banks also remain important for Latin American hydropower development. Access to carbon markets and subsidies or other incentives from renewable energy schemes may also be conditional upon demonstrating sustainability.

## 5.5 Rules for Effective Reforms

Some governments are already realizing that many sustainability risks can best be addressed at the basin or regional level, and developers, international agencies, NGOs, the academic community, the courts, and the general public are encouraging them to reform current planning frameworks.

But traditions, institutions, policies and regulatory systems are persistent. There should be no illusions that effective reforms are easy to design and implement. Even when formal changes occur, for example when a new planning agency is created, this does not necessarily change the behavior of existing institutions. In the 1960s and 1970s, development planning agencies in LAC countries often had the appearance of authority, while the real decision-making power continued to lie with treasury departments or the presidency. Over time, planning agencies were often abolished, absorbed or sidelined.

A pragmatic list of rules for undertaking effective reforms, originally proposed for water resources management, can inform those seeking to promote integrated hydropower planning (Briscoe 2003):

- *Initiate reform only when there is a powerful need, and demonstrated demand, for change.* There has to be widespread realization that current practices are causing significant problems and that system-scale hydropower planning is at least part of the solution.
- *Involve those affected, and address their concerns with effective, understandable information.* Staff in current government agencies and other organizations associated with the sector will have vested interests,

skills, relationships etc. Introducing a reform over their heads will generate resistance. They should be able to bring in their own ideas and will need to understand how the reform can benefit them and how the transition will work. Most reforms will see some potential losers (for example, the holder of a concession on a river that is likely to be declared a no-go area) that will lobby against the reform if they are not compensated. Working with a developer's association may help to neutralize individual opposition.

- *Develop a sequenced, prioritized list of reforms*. There are likely to be several steps towards fully integrated planning, some of which build on each other and some of which are more important than others. For example, a key early step which is required almost everywhere, is to generate high-level, spatially explicit information on social and environmental values in hydropower development areas, in a format which can be used for planning and decision-making purposes. In parallel, the next steps can be prepared, such as developing a mechanism for inter-agency coordination.
- *Pick the low-hanging fruit first - nothing succeeds like success*. A success in the introduction of a reformed planning system may look different to different people. Some may be convinced by a project that smoothly and rapidly goes through licensing and financial closure, as a result of the contextual information that has become available. Others may see the declaration of a river as off-limits as proof that the new system has some teeth. In any case, momentum behind the reforms will gather if they are seen to effectively influence decisions.
- *Keep your eye on the ball - don't let the best become the enemy of the good*. Ideally an integrated hydropower planning system will be based on extensive data and modeling. However, at least initially a new system will be less than perfect and involve multiple compromises. In countries with relatively low administrative capacities and low hydropower potential, simplified systems may be quite acceptable.
- *There are no silver bullets: instruments work well only as part of an overall management system*. Producing a map of priority conservation areas may generate an interest in reform, but by itself it will change little. There has to be awareness that country planning and regulatory systems are complex, with multiple objectives and stakeholders, and that individual instruments have to fit into an overall scheme. Stakeholders are going to be particularly wary of leaving decisions to 'black boxes', models that claim to provide optimal solutions but are not fully transparent.
- *Reform is dialectic, not mechanical*. The introduction of a new system cannot be fully planned in advance. There will be resistance and surprises, and there has to be a willingness to accommodate lessons learnt during implementation. Planning and regulation is a social process and cannot be replaced by a multi-criteria decision support model.
- *Reforms must provide returns for the politicians who are willing to make the changes*. Political decision-makers constantly deal with multiple reform initiatives and have to determine which ones are most likely to succeed and how their constituents will benefit from them, before they invest their time and political capital in championing a particular initiative. Benefits from planning and regulatory reforms may be relatively long-term.
- *Context matters: Fundamental principles apply, but need to be adapted to the specific context*. There are no universal approaches that can be confidently used in every country. An incremental approach, building on existing knowledge and institutions, is likely to be more effective.

## 5.6 Role of Multi-Lateral and Financing Institutions

Many of the original project identification studies in LAC were financed and designed by donors and multilateral financing agencies, which have also traditionally played an important role in promoting improved approaches to environmental and social issues at the project level. In recent years, through promoting innovative approaches such as biodiversity offsets and strategic environmental assessments, the multilaterals are again providing elements of a more integrated resource planning process. Their direct influence may be more limited than it used to be: their role as infrastructure financiers is eclipsed by other sources of finance in most LAC countries, technical assistance funds are also limited, and improved practices ultimately depend on client countries' governments' interest in accepting advice. Nevertheless, to the extent that member governments accept the multilaterals' role as 'knowledge banks', they are in a good position to advise on planning reforms. Also, it is clearly in their own institutional interest to support early, comprehensive planning from which good bankable projects will emerge, rather than trying to 'fix' questionable projects.

It appears that there are several options for financiers to promote better upstream planning, based on the above list of rules for reformers. They can for example, demonstrate the value of integrated planning in one basin where there is an obvious discrepancy between different interests and a political interest in being able to propose a more balanced solution. Some client governments or companies may be unwilling to use loan resources for such broader planning purposes. Public financiers can then either try to argue that this will save the clients' resources in the longer term, or to obtain technical assistance and other grant funding.

## 5.7 Role of Conservation NGOs

The role of NGOs with regards to improved hydropower planning is twofold. On the one hand, similar to multilateral financiers, NGOs often play an important role as international knowledge brokers and can assist both public and private sector organizations with technical contributions towards better hydropower planning. TNC's work with CFE in Mexico, with the Ministry of Environment in Colombia and with several Latin American hydropower companies falls into this category. There is increasing openness on the part of organizations in LAC to work with NGOs in this way.

On the other hand, NGOs advocate for better practices and are the drivers behind many of the changes toward more sustainable hydropower development. To advocate for more comprehensive planning, NGOs could campaign against an individual project and argue that the project's perceived faults might have been avoided with better upstream planning. Alternatively, NGOs may choose to confront the government and the general public with a conservation plan which is not compatible with the official generation expansion plan.

Science-based NGOs may have a comparative advantage in exactly those skills that are missing in most hydropower development plans, and that are not commonly available in other LAC government agencies (water, conservation etc.) either. From their background in the bio-geographical sciences and their own organizational experience in allocating scarce resources to priority conservation targets, some NGOs have long developed an understanding of spatial optimization issues. It would be advisable for them to pay more attention to public infrastructure planning, and for governments and the private sector to invite them to play a larger role.

# 6. Conclusions

This report has emphasized that sustainable hydropower, as defined as energy development that is consistent with maintaining a broad spectrum of values from river systems, can most effectively be achieved through system-scale planning, development and management. 'System' in this regard can refer to any level beyond individual projects that is the subject of a planning effort, be it a river basin, country, or interconnected grid. We recognize the gains made in recent years with project-level sustainability methodologies but consider that alone they will not be sufficient to address the complex issues presented by hydropower development.

System-scale approaches can:

- Identify potential conflicts earlier on than can project-based approaches alone, allowing greater flexibility to find alternatives;
- Produce operational efficiencies, such as for cascade operations, sediment passage, environmental flows, and safety (dam design/flood management);
- For a given level of energy development, produce a configuration of projects that allows maintenance of more of other values, including other water-management benefits and also environmental and social values. This has been demonstrated through both modeling and real-world experience.

In addition to producing outcomes that are more optimal for society overall, system-scale approaches provide specific benefits to stakeholders:

- For energy planners and agencies, the approach identifies a system capable of meeting energy demands within the context of a comprehensive plan that effectively identifies and minimizes risk to development;
- For regulatory or environmental protection agencies, the system-scale approach provides clear advantages and efficiencies compared to project-by-project approaches, and is more likely to protect and maintain the resources under their responsibility;
- Developers building projects that are consistent with a comprehensive plan will have greater certainty and lower risk of delay or cancellation, lower reputational risk and greater likelihood of achieving a 'social license' for a specific development. Environmental review may be more streamlined, and funding allocated for mitigation has a better likelihood of meeting mitigation objectives. Because of greater certainty and lower risk, developers are likely to gain improved access to funding;
- Similarly, funders supporting projects consistent with a comprehensive plan face lower risks of project delay, cancellation or reputation risk;
- Dam operators will benefit from the design and operational compatibilities built into the system;
- Conservation NGOs and communities have a greater probability of seeing meaningful protection of desired resources than through a series of dam-by-dam confrontations.

As with any form of development, system-scale approaches will still cause impacts, even significant impacts, to environmental and social values and there will be winners and losers. This approach will certainly not solve all conflicts and disagreements associated with hydropower development, but has a better chance of producing outcomes that are more acceptable to a wider range of interests. Because infrastructure has an operational life measured in decades, if not centuries, and because sustainability is much more likely to be achieved during planning and design than through retrofits or re-engineering, comprehensive planning is a one-time opportunity to "get it right". And given the dynamics of hydropower development in the LAC region at this time, this opportunity may be easily missed if planning reforms are not quickly initiated.

The risk of not transitioning toward system-scale approaches is that despite good intentions and practices at the project level, the familiar problems with hydropower development will persist:

- Continued conflict, leading to financial risk, delay or cancellation of projects, and poor investment context failing to attract funds, which all can lead to missing energy targets;
- Missed opportunities for energy development that is sustainable and that maintains other key values of river systems;
- Ongoing operational conflicts and inefficiencies.

We understand that, in most countries, current planning policies and practices are far from the approaches we are recommending. In particular, it is surprising how little experience with freshwater conservation exists in the region. Many so-called IWRM or IRBM plans do not pay attention to environmental water requirements, aquatic biodiversity, or sediment and fluvial geomorphology issues. Many protected areas agencies do not manage any freshwater protected areas and have not undertaken analyses to establish whether representative aquatic ecosystems in the country are protected. Even if there were a political opening to contribute to hydropower planning, for example by proposing an aquatic offset, many water and conservation officials might not quite know how best to use that opportunity. In order to provide a counterweight and engage in a meaningful dialogue, these agencies require substantial levels of funding, technical and political support.

But we feel it is important to lay out a vision of an 'optimal' process that has the best likelihood of achieving sustainability. This ideal can promote dialogue about its pros and cons, and about alternative approaches and components, and we suggest that multilateral organizations such as the IDB can help foster this dialogue with key stakeholders. The elements of a more comprehensive planning system that emerge from that dialogue can serve as a road map for countries, starting by working within existing regulatory and planning systems and adopting components through reforms over time.

In our view, optimal planning practice would include:

1. Integrated planning directed by a lead agency, with fully engaged cooperation of other agencies and stakeholders, or a coalition of agencies and stakeholders that reflect different interests;
2. Planning for hydropower should be nested within broader energy planning and options assessments, based on credible estimates of future demand and decisions about the most sustainable mix of options to meet that demand, including energy exports and imports, reserve requirements, energy efficiency and demand side management;
3. The identification of hydropower alternatives should start with a national-scale approach that identifies which basins are priorities for development, and which basins are priorities for conservation; such "no go" basins or protected rivers should start from existing protected areas such as national parks, and equivalent social protection areas such as indigenous territories;
4. Within basins for hydro development, various methods are available to identify optimal combinations of projects to meet a range of objectives and achieve a balance of values in the basin, through involvement of agencies and stakeholders;
5. Planning results need to be made relevant by linking them to project-level decisions regarding siting, design and operations; such decisions may include licensing, protection of 'no go' sites, strategic mitigation requirements etc.

We are aware that planning reforms have a checkered history, and that full adoption of a modern planning system requires a transition path, with close attention paid to the institutional framework and the capacity to adapt to emerging lessons. There is not one fixed framework for reform, but change can be triggered by various initiatives and take various forms. Reforms will typically be opportunistic and could be either preceded by, or result in an update to the country's hydropower master plan, an interconnection study, a strategic environmental assessment, a cumulative impacts study required by a financier, or a basin management plan.

Generally speaking, in most countries, incremental policy steps toward more comprehensive planning are legally and institutionally possible within the current framework. In some cases, legal changes might be beneficial to express explicit support for a new approach to planning, or institutional changes may clarify responsibilities. But even the absence of such changes should not be taken as an excuse to not undertake initial reforms. Depending on existing country planning systems, below are some generic recommendations for incremental steps. Multilateral agencies like IDB can work with their clients to further specify and support many of these recommendations.

1. ***Generate the necessary information*** – no comprehensive plan is possible with information that is outdated, limited, lacking, or inaccessible. For example, the identification of high conservation-value rivers needs data-intensive groundwork just as hydropower surveys do.

*2.* ***Encourage closer collaboration of agencies****.* A key step in reforms towards more balanced, system-scale hydropower planning is to bring different sectors closer together. It is imperative that planners in different government agencies, and the academics and consultants working with them, are aware of the implications of hydropower siting, design and operations for different interests. That requires early and regular interaction between disciplines and sectors. A good platform can be an assessment or planning exercise for a smaller, relatively uncontroversial basin.

3. ***Build capacity within agencies and funders****.* Agencies should recognize each other's legitimate interests and responsibilities, and devote some resources to monitor and interact with parallel planning processes in other sectors.

   a. Within energy planning and licensing agencies, build capacity for integrated planning, awareness of social and environmental values and methods to plan for multiple uses and protection of other resources
   b. Within resource protection agencies, build capacity to engage in energy planning processes, for example through gaining more familiarity with cumulative and strategic impact assessments
   c. Within funders, build capacity to promote and support system-scale planning among staff engaged in energy/hydropower lending

4. ***Incorporate a broader range of values into least-cost ranking and sequencing methods***

5. ***Develop multi-criteria indicative generation expansion plans*** Even without authority for legally binding plans, agencies can collaborate on indicative plans. These plans can demonstrate the potential gains to be achieved through system design and can offer a roadmap forward Based on the indicative plan:

   - *Energy agencies and planners* can encourage consistency with the indicative plan, to the full extent they can within their existing legal authorities
   - *Licensing and other environmental regulatory agencies* can use their existing authority to promote consistency with an indicative plan
   - *Developers* can recognize potential benefits identified with the plan and seek voluntary and cooperative agreements to pursue elements of the plan
   - *Funders* could encourage consistency with a plan, citing the lower risk associated with consistency with a comprehensive plan
   - *NGOs, community organizations and environmental protection agencies* can clearly communicate the benefits of pursuing development decisions that are consistent with the plan and encourage regulatory agencies, developers and funders to favor projects consistent with the plan

In addition to serving as a roadmap within a basin, these indicative plans can serve as an overall roadmap for planning and licensing reform – by illuminating the potential benefits that could be achieved if actual planning moved closer toward the outcomes identified through the indicative plan.

*6. While maximizing what can be done within current regulatory and planning systems, work for broader reforms of planning, licensing and decision making*

The benefits of comprehensive planning are obviously not limited to Latin America and the Caribbean. As sustainability at the project level hopefully becomes more accepted and mainstreamed—with countries, funders and developers adopting better practices—we expect attention in many countries to gradually shift to this next frontier in hydropower sustainability. In this process, the LAC region can contribute new insights and tools, as well as benefit from experiences made in other parts of the world.

A key recommendation is to be explicit about the advantages of reforms and document any benefits that have resulted from them. Changing planning practices is a rather abstract concept. It will generate more enthusiastic backing if it can be shown to resolve issues that policy-makers care about, such as avoiding project delays, reducing electricity costs, reducing conflicts in society, and contributing to energy security.

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# Appendix 1: Illustrative Scenario Analysis

The hypothetical scenario analysis (Section 4.3 of main report) was developed for illustrative purposes. For this analysis we adapted existing data from an actual basin (the Juruena tributary of the Tapajós River in Brazil). Some basic data were available from public sources as to possible dam and reservoir configuration, although we adjusted some of the dam characteristics in order to provide a more representative example. In addition, some biodiversity information was already available from work done by TNC, WWF and others, although again assumptions were made to alter or supplement this information in order to create a generally representative example. Thus the scenarios do not represent any real place and are only for the purpose of illustrating the concepts of an iterative scenario analysis. None of the scenarios should be taken as a proposal for development or for conservation of an actual river basin.

***Value sets and calculating potential impacts***

Three basic value sets were considered in this hypothetical analysis: hydropower output and cost; indigenous and social values; and environmental/ecological values.  The hypothetical basin contains a set of proposed hydropower projects. For simplicity, all are considered run-of-river projects, whether on-stream dams or diversion / power canal/ penstock projects. Note that in a real basin analysis, the mode of operation (e.g., run-of-river vs. storage), its implications for flow alteration (and downstream impacts), and alternative management scenarios (e.g., with or without environmental flow requirements) can be built into the analytical framework. In this analysis, we tracked both potential capacity, in megawatts (MW), and cost of energy in USD per megawatt hour (Mwh). In many hydropower planning contexts, the cost of energy is expressed in terms of “levelized cost of energy“ (LCOE), in $/Mwh, which integrates capital, financing, mitigation and operating costs into a single unit cost. The LCOE information used in the scenario analysis was based on some research into a number of the projects actually planned for the basin from which the hypothetical was drawn, but in several instances we filled in the cost value for certain projects with reasonable assumptions.

The potential scope of impacts of each dam was represented as a direct footprint by mapping the shape of the reservoir area (based on dam height and topography) and generating a 5-kilometer buffer around each dam location to estimate impacts from land clearing, construction, buildings and other sources. In addition to direct impacts from a dam footprint, we also tracked potential indirect impacts to the river channel downstream of each dam. By assuming all dams to be run-of-river projects, we also generalized that they will have no significant potential for storage or major alteration of seasonal flow patterns. Nevertheless, downstream of each dam, we did map areas of potential impact, such as from changes in daily flow patterns, sediment supply or temperature. We designated the downstream segment down to the confluence of the next tributary inflow as having the potential for “indirect impact”. In actual practice the potential for this type of indirect impact will vary between different projects and must be based on site-specific information. Also, quite often these types of indirect impacts can be mitigated through project-specific design and operating plans for environmental flows, sediment passage, and temperature control.

Social/Indigenous Values

In the case of the indigenous/social value set, the only readily available information we had access to concerned the location of designated indigenous areas, and we chose this to be the only variable we tracked for the social value set. Direct and indirect impacts were recorded for each occurrence where a dam, reservoir or affected downstream segment intersected or touched an indigenous area.

In a real-world application this will be a very complex subject. Many non-indigenous values will exist and in many cases will likely be at odds with the indigenous values. For example, local residents value reservoirs for recreation, tourism, or municipal revenue; traditional indigenous leaders may not. In addition to being complex, these social/indigenous values may be fairly subjective and difficult for technical experts to quantify. Analyses could also consider ecosystem goods and services that are important to communities and potential losses or changes in access to those goods and services. Ultimately, the best way to capture and represent these values may depend on some sort of inclusive process, in which affected stakeholders can express preferences for certain scenarios over others.

Biodiversity Values

Systematic freshwater conservation planning is represented in spatial products that depict conservation priorities for such things as endangered species, critical habitats, representative ecosystems, or ecosystem services to guide protection and management activities. The information and processes used to generate these products include (1) “fine-filter” approaches that identify critical habitat for endangered species (e.g. Alliance for Zero Extinction consortium) or a broader suite of species (Key Biodiversity Areas – IUCN) and (2) “coarse-filter” approaches which focus on habitat types and processes.

We developed a hypothetical, but realistic environmental/ecological assessment which, for this analysis, followed The Nature Conservancy’s approach to basin-wide freshwater conservation planning. Freshwater ecosystems were classified and mapped across the basin. These units characterize freshwater biophysical patterns and processes driven by landform, geology, stream size and gradient, among other factors. A set of these polygons was selected as a “coarse filter“ portfolio to most efficiently represent priority areas to protect and manage the environmental processes, habitats and biodiversity representative of and critical to sustain the environmental values of the basin. Each of these portfolio polygons was given a value of 1 with an additional value of 1 added for each specific ecological feature contained within the polygon: critical wetland habitat, endemic fish occurrence, turtle nesting area, critical bird habitat, migratory corridor, waterfall/rapid habitat, and unique habitat type (i.e., the polygon represented a unique occurrence of a type of classified unit). Each polygon was then given a total feature “score”, with a potential up to 8 (having all potential features represented in a single polygon. In this date set, the polygon with the highest value had a 7).

Connectivity

Because dams can fragment channel networks and migratory pathways, each scenario was evaluated with respect to the associated dams’ impact on the connectivity of the overall river network. In addition to serving as a barrier to the movement of organisms, dams and reservoirs can also alter downstream transport of sediment, organic matter and nutrients. Here we simply represent dams as a break to connectivity (i.e., a barrier to biophysical processes) but the specific impacts of a dam and reservoir on the movement of organisms, sediment or nutrients can be assessed with much greater specificity based on the design and physical setting of the dam.

To assess connectivity we used the Barrier Assessment Tool (BAT), a spatial analytical tool that quantifies the connectivity and fragmentation of channel networks. Connectivity is expressed as the longitudinal physically connected networks of a river system. Barriers to connectivity include natural source (waterfalls), and infrastructure (dams and culverts). “Hard” (e.g. no fish passage) and “Soft” (selected or partial fish passage) barriers can be defined. BAT can use spatial data for river networks and barriers from global and/or regional sources.

Summaries are generated in visual format illustrating the different continuous networks, and in tabular form providing details about the number of connected networks, length of each network, average and range of all networks, and specific information for each network such as the number of barriers and river length to the source, or mouth of a river system from a given point. The assumption for this exercise was that all dams provide hard barriers for fish movement.

The BAT was used to assess the impact of different scenarios on the networks of the main stem and major tributary rivers in order to highlight the potential fragmentation to fish passage and important biophysical processes. The connected networks of 5th order rivers and larger were assessed for each scenario. Outputs for each scenario analysis included the number of networks, the length of each network, the average of network length among all networks, and the range (shortest-longest) for each network. A baseline scenario using waterfalls that were deemed barriers to fish migration was developed. The percent of the longest network length in relation to that value for the baseline scenario is the attribute reported in the summary tables.

***Tracking Impacts of the Scenarios***

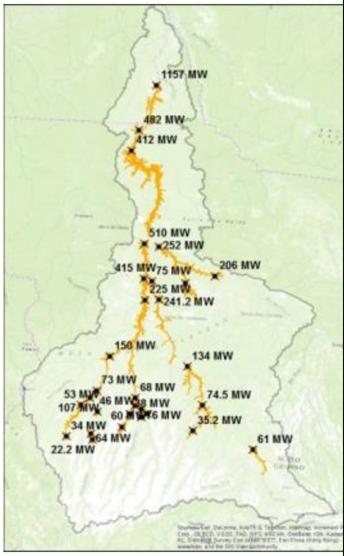
Using a Geographic Information System (GIS), the direct and indirect footprints of dams were intersected with the Biodiversity/Environmental Portfolio which contained 85 polygons representing 158 unique features, and 25 polygons representing Indigenous Lands. The intersections between the footprints and the features in each of the layers were tracked (see Scenario Results table). In the case of the environmental portfolio, the number of polygons, the area of the portfolio polygons, and the total number of features in polygons that intersected with the dam footprint were tracked and expressed as percentage of the entire portfolio. For Indigenous lands, the number and percent of polygons intersected, the total area of the indigenous polygons that were intersected, and the area that was intersected within those polygons were tracked. Connectivity was expressed as the number of contiguous mainstem and major tributary networks (this number increases with increased fragmentation), the length of the longest remaining network, and the percentage of that longest network compared to the scenario with no dams.

***Scenario Selection***

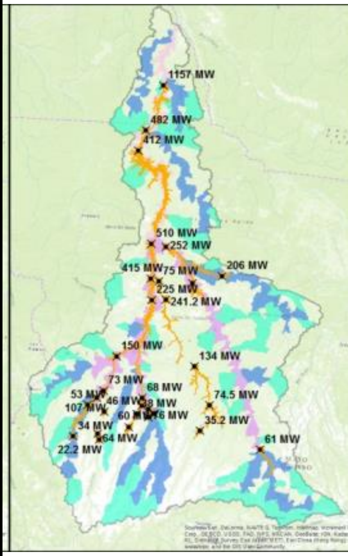
We generated a total of twelve scenarios, starting with a trio of extreme cases: (1) full hydropower development; (2) hydropower development that has minimal impact on indigenous areas; and (3) hydropower development with minimal impact on environment/ecological values. Next, we developed another trio of scenarios, each intended to produce approximately 60% of the value of each of the three value sets. We then developed six further scenarios that explored different geographic objectives for development, such as concentrating dams in the lower reach of the river and leaving the majority of the upper basin undeveloped (scenarios 7 and 8) or leaving the southwest tributaries undeveloped (scenario 9).

***Scenario Results***

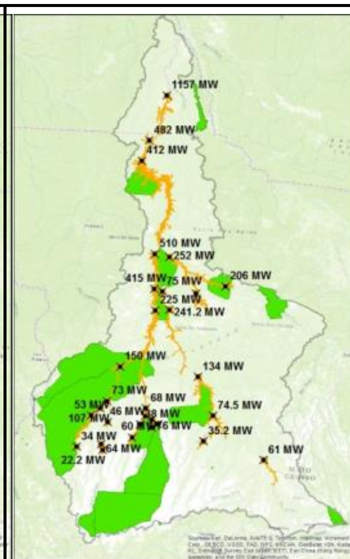
The results of the twelve scenarios are shown in the following figures and tables.



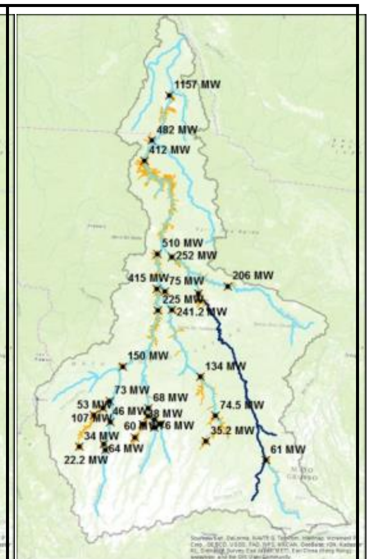

Footprint of Direct Impacts (Dams and Reservoirs)




Direct Impact Footprint on Conservation Portfolio

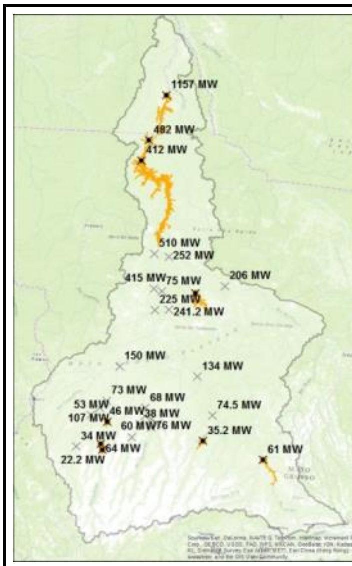



Direct Impact Footprint on Indigenous Lands




Dam Impact on river Con-nectivity

**Scenario 2—Minimize impact to indigenous lands**

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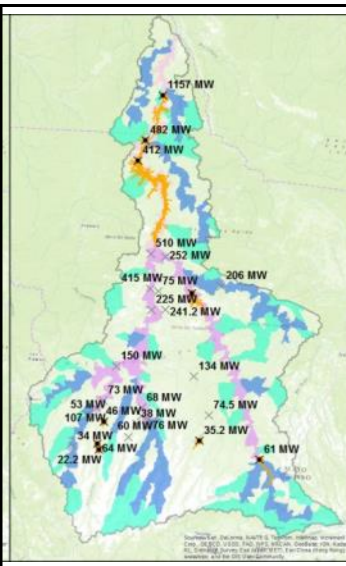
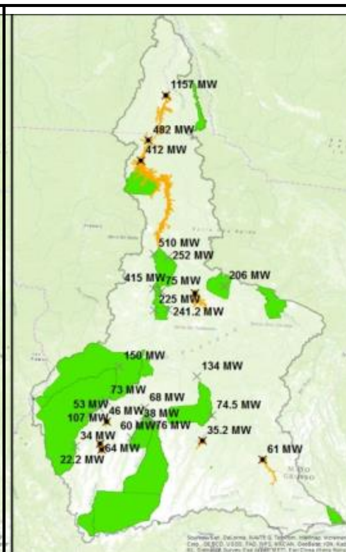
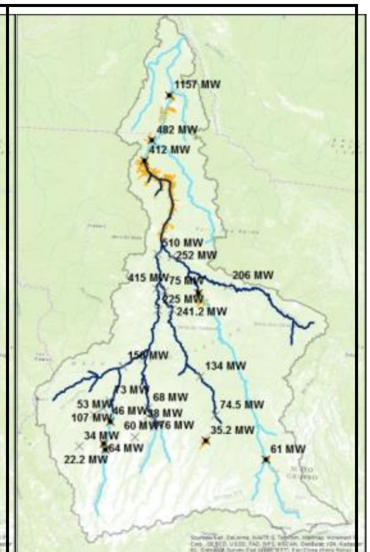


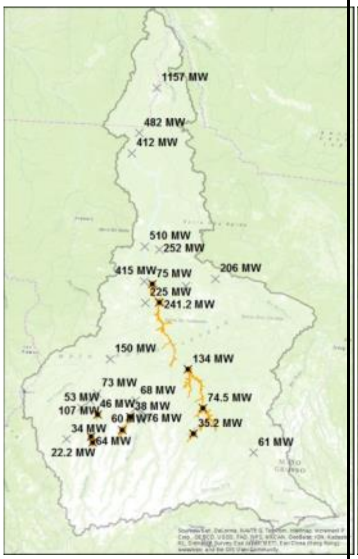

Direct Impact Footprint on Conservation Portfolio

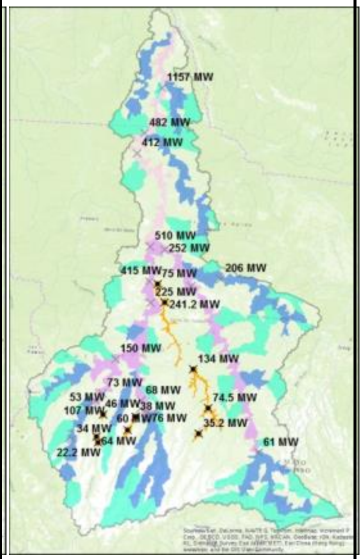


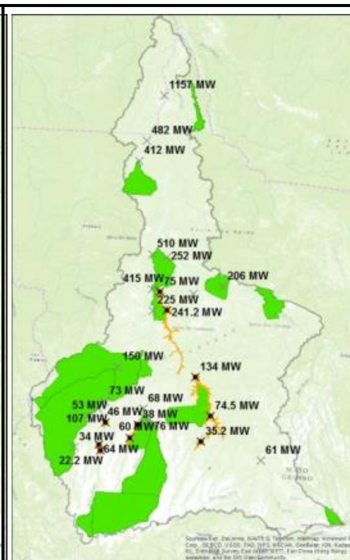

Direct Impact Footprint on Indigenous Lands

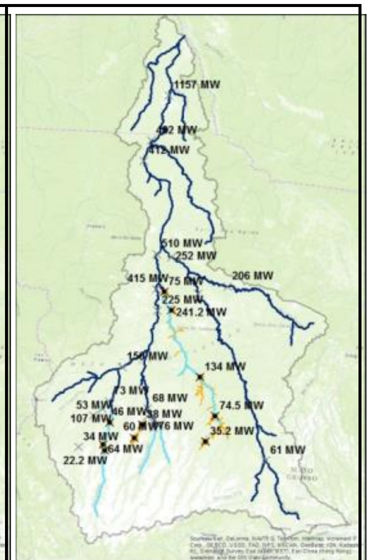



Dam Impact on river Con-nectivity



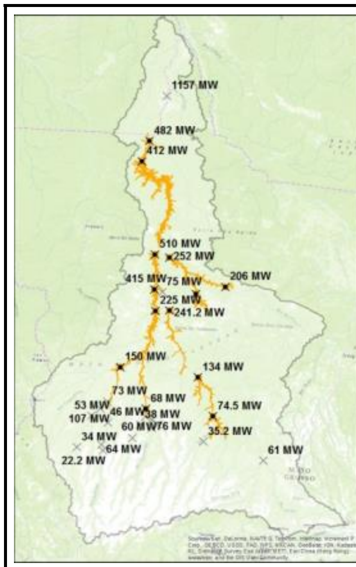



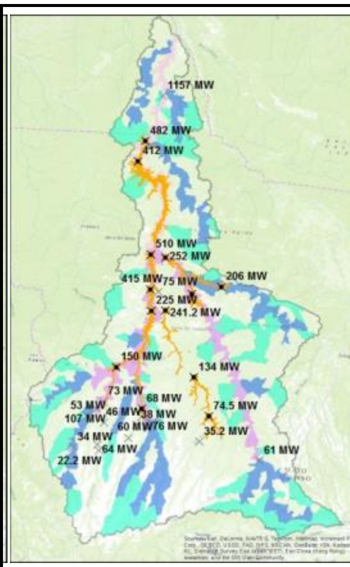



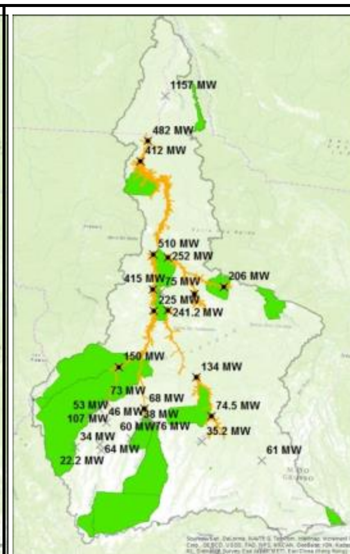



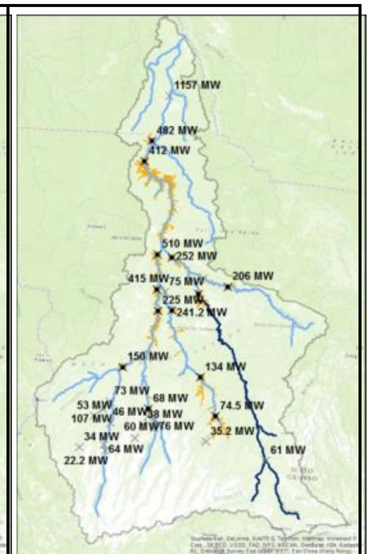

| | | | |
|---|---|---|---|
| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connec-tivity |

**Scenario 4– Develop 60% of hydropower potential**




| | | | |
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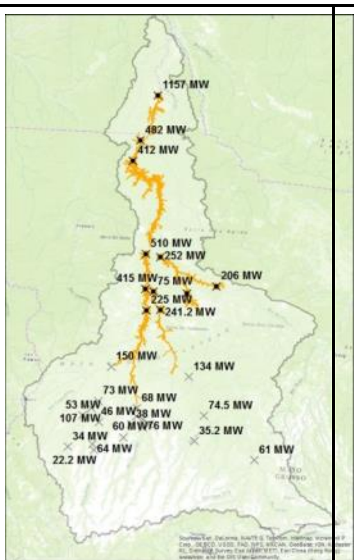
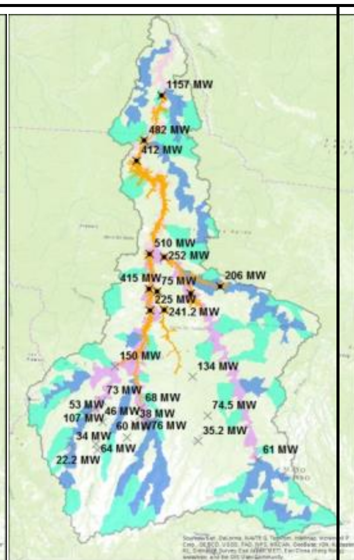
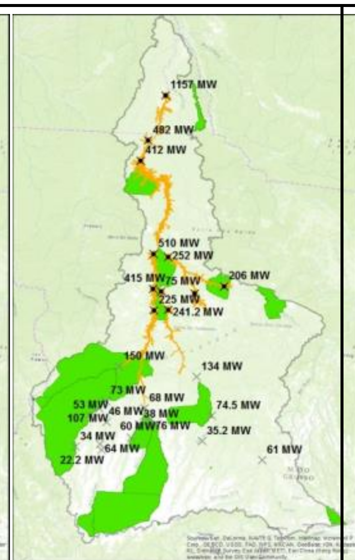
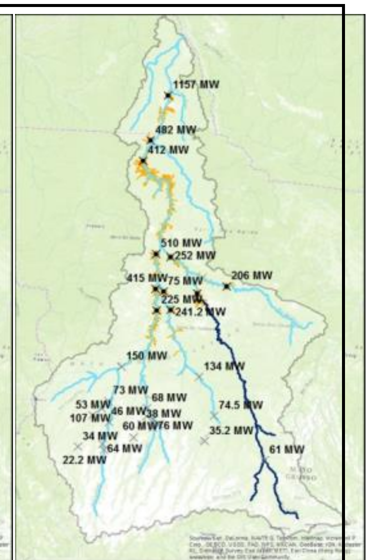
| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connec-tivity |



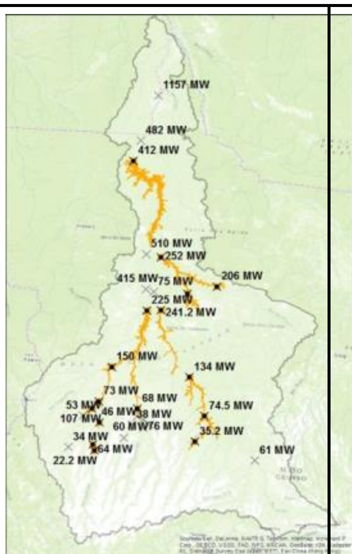



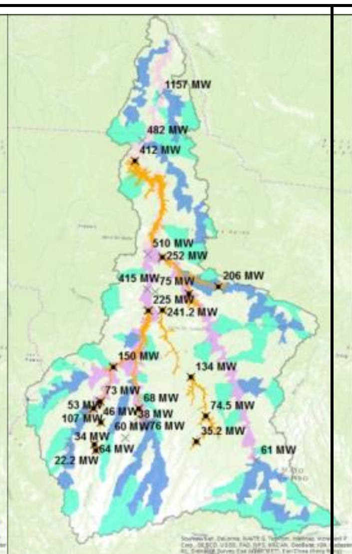



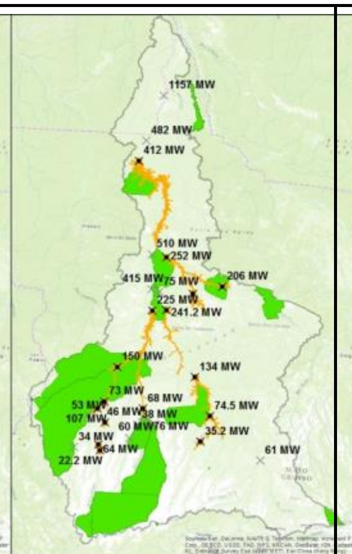



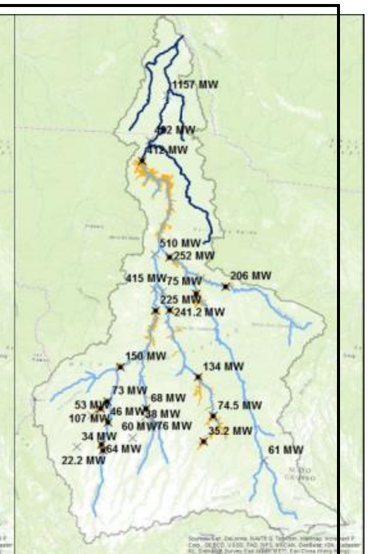

| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connectivity |
|---|---|---|---|

**Scenario 6– Protect 60% of environmental values in portfolio**

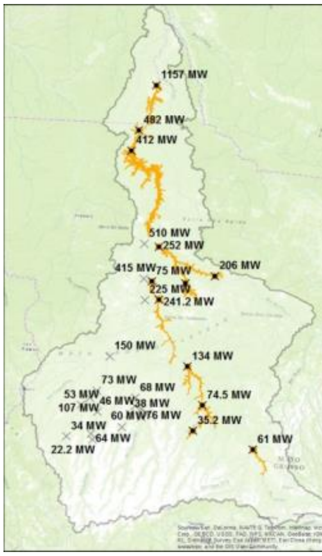


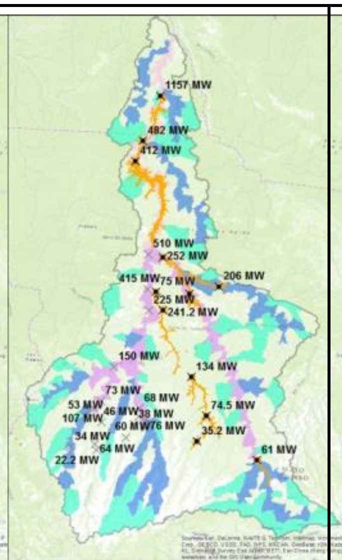



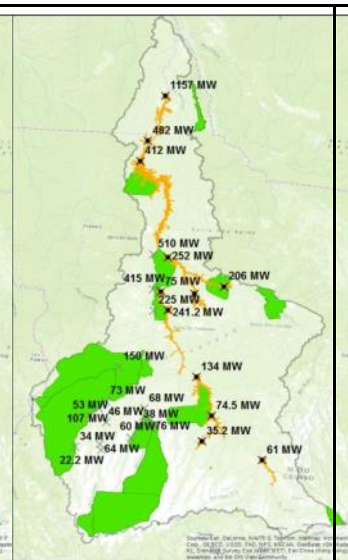

| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connectivity |
|---|---|---|---|



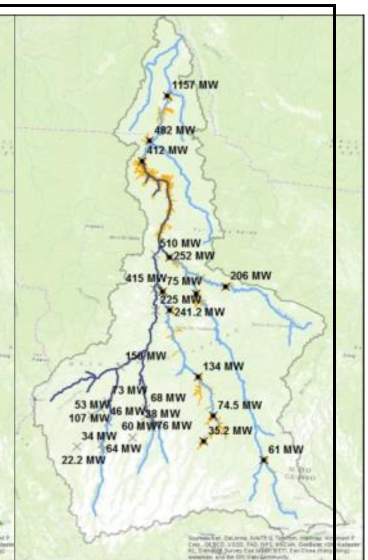

Footprint of Direct Impacts (Dams and Reservoirs)




Direct Impact Footprint on Conservation Portfolio

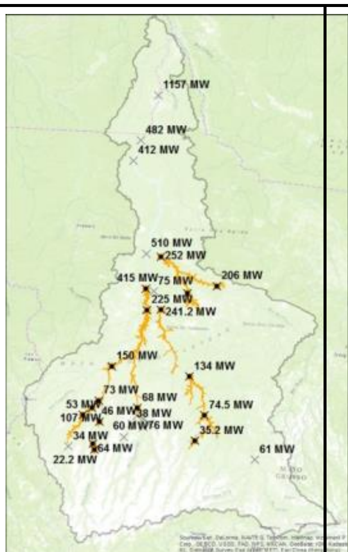



Direct Impact Footprint on Indigenous Lands

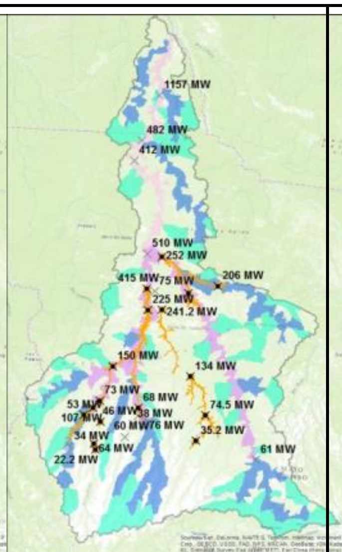



Dam Impact on river Connectivity

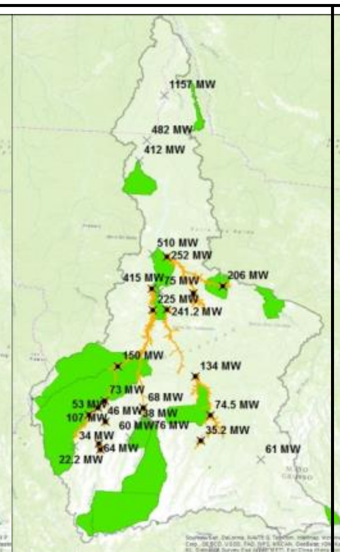
**Scenario 8—Maximum development in lower river (2)**



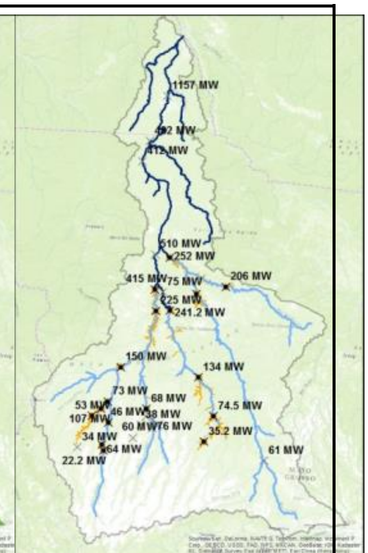

Footprint of Direct Impacts (Dams and Reservoirs)



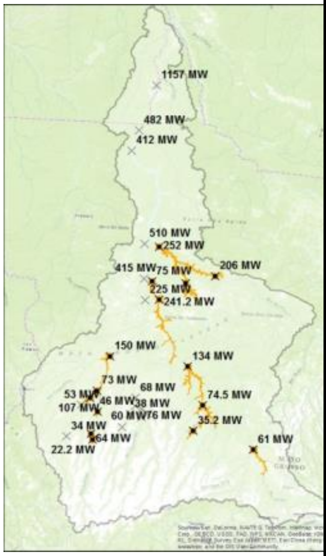

Direct Impact Footprint on Conservation Portfolio

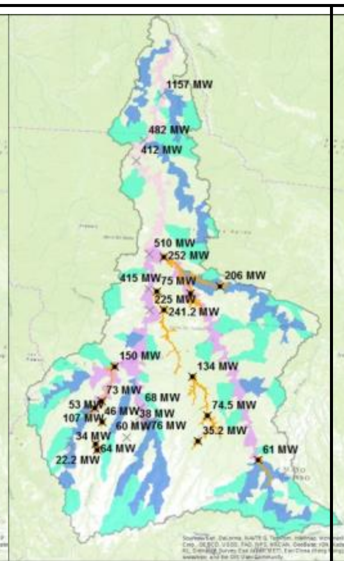


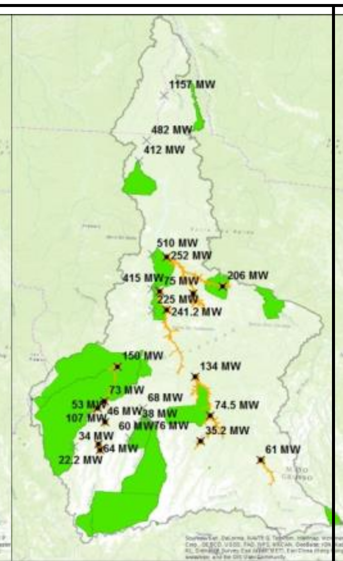

Direct Impact Footprint on Indigenous Lands

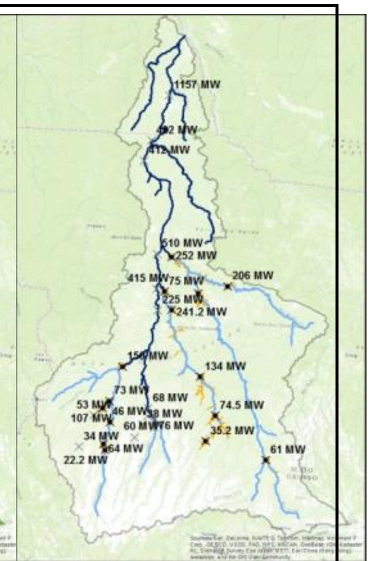



Dam Impact on river Connectivity



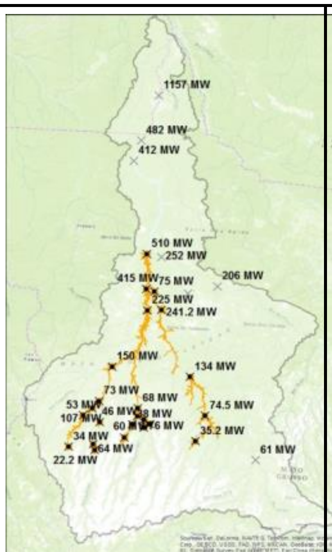



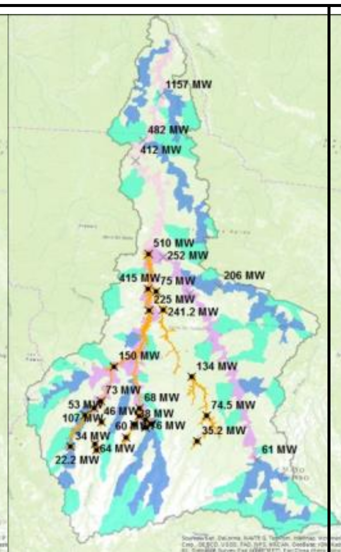



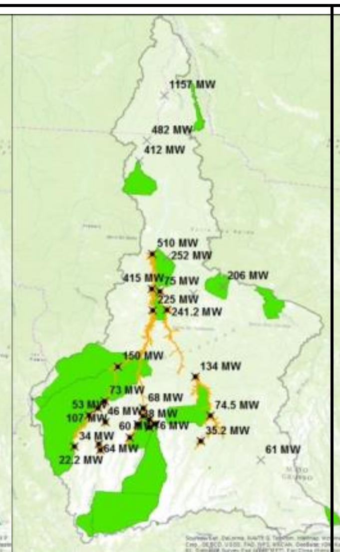



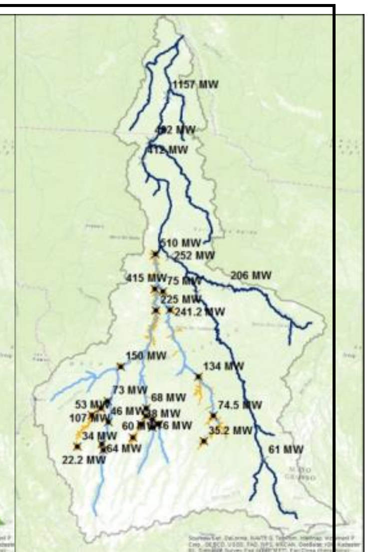

| | | | |
|---|---|---|---|
| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connectivity |

**Scenario 10—Free lower and east tributaries (1)**

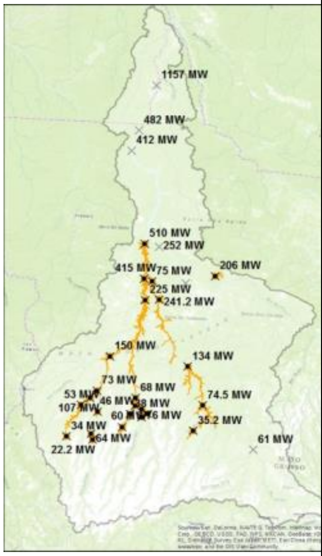


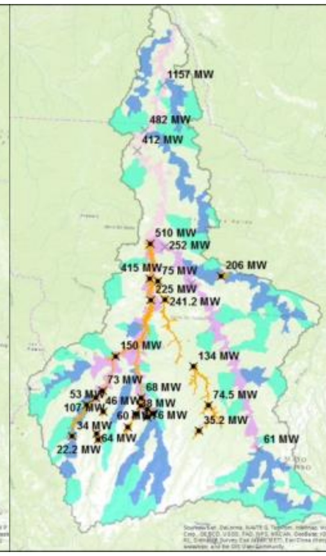



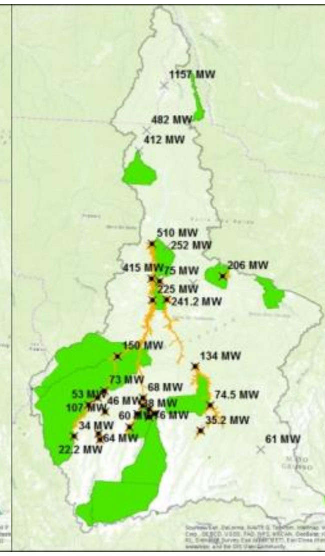

| | | | |
|---|---|---|---|
| Footprint of Direct Impacts (Dams and Reservoirs) | Direct Impact Footprint on Conservation Portfolio | Direct Impact Footprint on Indigenous Lands | Dam Impact on river Connectivity |



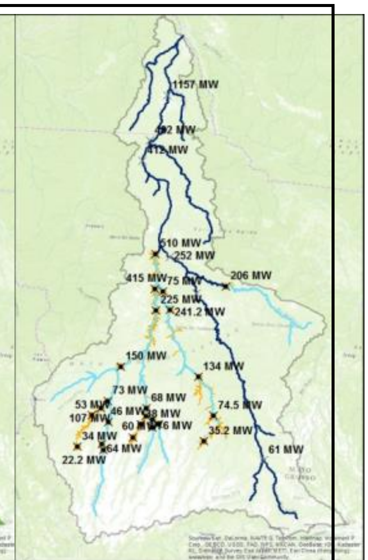

Footprint of Direct Impacts (Dams and Reservoirs)




Direct Impact Footprint on Conservation Portfolio

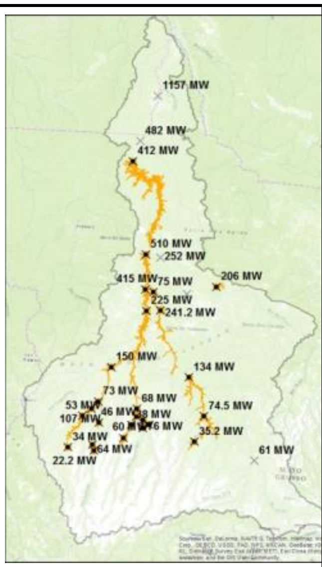



Direct Impact Footprint on Indigenous Lands

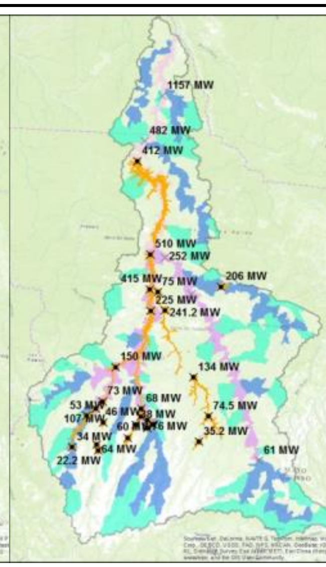



Dam Impact on river Connectivity

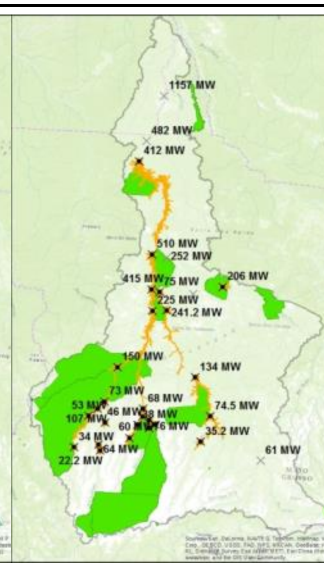
**Scenario 12– Free east tributaries**



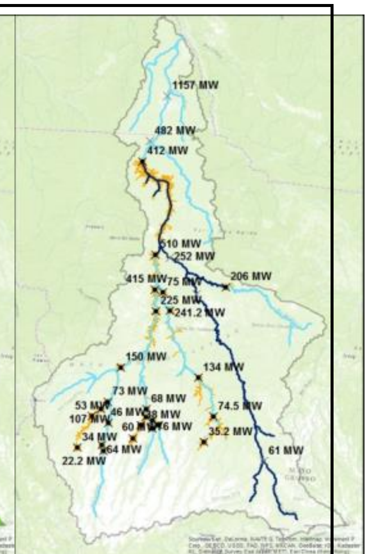

Footprint of Direct Impacts (Dams and Reservoirs)




Direct Impact Footprint on Conservation Portfolio




Direct Impact Footprint on Indigenous Lands




Dam Impact on river Connectivity

## Table 1a: Overall scenario results: Indigenous lands

| | Hydropower | | | Cost | | Indigenous Lands (IL) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total # Dams | Total MW Pot | Scenario % MW | Cost of Hydro Weighted Avg LCOE (US$/Mw-hr) | LCOE % of full potential scenario | Total # Indig Lands in Basin | Total # of Impacted Indig Lands | % of Indig Land that are Impacted | Total Area of Intersected IL Polygons (ha) | Total Area of actual Intersection (ha) | % of Intersected Polygons Impacted |
| **Scenario 1. Full Hydropower Potential** | | | | | | | | | | | |
| Direct Impact | 30 | 5,455 | 100% | 73 | 100% | 22 | 10 | 45% | 2,861,261 | 148,629 | 5% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 247,588 | 7% |
| **Scenario 2. Minimize Impact to** | | | | | | | | | | | |
| Direct Impact | 9 | 2,471 | 45% | 64 | 88% | 22 | 2 | 9% | 304,560 | 19,924 | 7% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 164,868 | 5% |
| **Scenario 3. Minimize Impact to Portfolio** | | | | | | | | | | | |
| Direct Impact | 10 | 771 | 14% | 65 | 89% | 22 | 3 | 14% | 433,615 | 28,678 | 7% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 170,729 | 5% |
| **Scenario 4. Develop 60% of Hydropower Potential** | | | | | | | | | | | |
| Direct Impact | 13 | 3,361 | 62% | 76 | 104% | 22 | 9 | 41% | 2,480,637 | 96,326 | 4% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 204,415 | 6% |
| **Scenario 5. Protect 60% of Indigenous Lands** | | | | | | | | | | | |
| Direct Impact | 11 | 4,167 | 76% | 75 | 103% | 22 | 6 | 27% | 1,189,474 | 75,048 | 6% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 193,975 | 5% |
| **Scenario 6. Protect 60% of Environmental Values** | | | | | | | | | | | |
| Direct Impact | 16 | 2,301 | 42% | 70 | 96% | 22 | 9 | 41% | 2,480,637 | 91,569 | 4% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 202,364 | 6% |
| **Scenario 7. Max develop in lower river (1)** | | | | | | | | | | | |
| Direct Impact | 12 | 3,321 | 61% | 77 | 105% | 22 | 5 | 23% | 720,311 | 57,146 | 8% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 187,403 | 5% |
| **Scenario 8. Max develop in lower river (2)** | | | | | | | | | | | |
| Direct Impact | 17 | 2,357 | 43% | 79 | 108% | 22 | 8 | 36% | 2,321,863 | 85,822 | 4% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 199,564 | 6% |
| **Scenario 9. Free upper southwest tributaries** | | | | | | | | | | | |
| Direct Impact | 15 | 1,732 | 32% | 80 | 110% | 22 | 6 | 27% | 2,158,136 | 57,705 | 3% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 184,450 | 5% |
| **Scenario 10. Free lower and east tributaries (1)** | | | | | | | | | | | |
| Direct Impact | 23 | 2,693 | 49% | 81 | 111% | 22 | 8 | 36% | 2,598,799 | 111,613 | 4% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 222,365 | 6% |
| **Scenario 11. Free lower and east tributaries (2)** | | | | | | | | | | | |
| Direct Impact | 24 | 2,901 | 53% | 79 | 108% | 22 | 9 | 41% | 2,702,487 | 120,315 | 4% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 228,578 | 6% |
| **Scenario 12. Free east tributaries** | | | | | | | | | | | |
| Direct Impact | 25 | 3,313 | 61% | 80 | 110% | 22 | 10 | 45% | 2,861,261 | 140,239 | 5% |
| Direct + Downstream | | | | | | 22 | 14 | 64% | 3,579,752 | 243,306 | 7% |

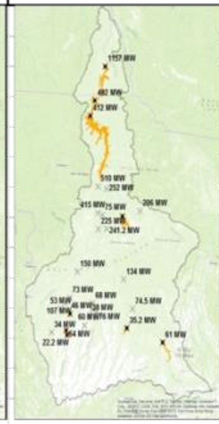
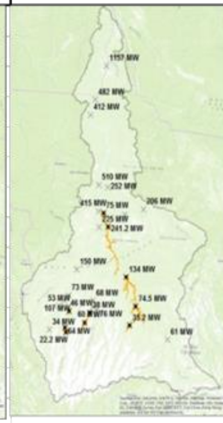
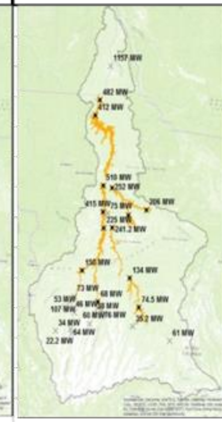
## Table 1b: Overall scenario results: Environmental portfolio

| | Hydropower | | | Cost | | Biodiversity/Environmental values in Portfolio (BD) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total # Dams | Total MW Pot | Scenario % MW | Cost of Hydro Weighted Avg LCOE (US$/Mw-hr) | LCOE % of full potential scenario | Total # of Ecological Units in Portfolio | Total # of Impacted Ecological Units in Portfolio | % Eco Units Impacted in Portfolio | Total # of BD Features in Portfolio | Total # of Impacted BD Features in Portfolio | % of Portfolio BD Features Impacted | Total area of portfolio (ha) | Area of portfolio impacted (ha) | % of Intersected Portfolio Polygons Impacted |
| **Scenario 1. Full Hydropower Potential** | | | | | | | | | | | | | | |
| Direct Impact | 30 | 5,455 | 100% | 73 | 100% | 85 | 32 | 38% | 158 | 77 | 49% | 4,043,411 | 355,798 | 9% |
| Direct + Downstream | | | | | | 85 | 65 | 76% | 158 | 129 | 82% | 6,241,388 | 755,931 | 12% |
| **Scenario 2. Minimize Impact to Indigenous Lands** | | | | | | | | | | | | | | |
| Direct Impact | 9 | 2,471 | 45% | 64 | 88% | 85 | 14 | 16% | 158 | 37 | 23% | 2,256,187 | 153,154 | 7% |
| Direct + Downstream | | | | | | 85 | 58 | 68% | 158 | 117 | 74% | 5,895,957 | 646,697 | 11% |
| **Scenario 3. Minimize Impact to Portfolio** | | | | | | | | | | | | | | |
| Direct Impact | 10 | 771 | 14% | 65 | 89% | 85 | 0 | 0% | 158 | 0 | 0% | 0 | 0 | 0% |
| Direct + Downstream | | | | | | 85 | 57 | 67% | 158 | 116 | 73% | 5,810,576 | 564,603 | 10% |
| **Scenario 4. Develop 60% of Hydropower Potential** | | | | | | | | | | | | | | |
| Direct Impact | 13 | 3,361 | 62% | 76 | 104% | 85 | 19 | 22% | 158 | 51 | 32% | 2,931,131 | 253,146 | 9% |
| Direct + Downstream | | | | | | 85 | 62 | 73% | 158 | 123 | 78% | 6,116,815 | 687,391 | 11% |
| **Scenario 5. Protect 60% of Indigenous Lands** | | | | | | | | | | | | | | |
| Direct Impact | 11 | 4,167 | 76% | 75 | 103% | 85 | 21 | 25% | 158 | 54 | 34% | 2,803,636 | 261,032 | 9% |
| Direct + Downstream | | | | | | 85 | 61 | 72% | 158 | 122 | 77% | 6,012,458 | 690,352 | 11% |
| **Scenario 6. Protect 60% of Environmental Values** | | | | | | | | | | | | | | |
| Direct Impact | 16 | 2,301 | 42% | 70 | 96% | 85 | 17 | 20% | 158 | 50 | 32% | 2,721,961 | 218,729 | 8% |
| Direct + Downstream | | | | | | 85 | 61 | 72% | 158 | 122 | 77% | 6,067,391 | 671,804 | 11% |
| **Scenario 7. Max develop in lower river (1)** | | | | | | | | | | | | | | |
| Direct Impact | 12 | 3,321 | 61% | 77 | 105% | 85 | 16 | 19% | 158 | 42 | 27% | 2,671,715 | 188,125 | 7% |
| Direct + Downstream | | | | | | 85 | 58 | 68% | 158 | 117 | 74% | 5,895,957 | 659,694 | 11% |
| **Scenario 8. Max develop in lower river (2)** | | | | | | | | | | | | | | |
| Direct Impact | 17 | 2,357 | 43% | 79 | 108% | 85 | 16 | 19% | 158 | 45 | 28% | 2,158,195 | 163,857 | 8% |
| Direct + Downstream | | | | | | 85 | 63 | 74% | 158 | 127 | 80% | 6,106,583 | 645,624 | 11% |
| **Scenario 9. Free upper south tributaries** | | | | | | | | | | | | | | |
| Direct Impact | 15 | 1,732 | 32% | 80 | 110% | 85 | 9 | 11% | 158 | 28 | 18% | 1,951,125 | 89,299 | 5% |
| Direct + Downstream | | | | | | 85 | 58 | 68% | 158 | 117 | 74% | 5,914,933 | 605,231 | 10% |
| **Scenario 10. Free lower and east tributaries (1)** | | | | | | | | | | | | | | |
| Direct Impact | 23 | 2,693 | 49% | 81 | 111% | 85 | 17 | 20% | 158 | 41 | 26% | 1,723,094 | 167,673 | 10% |
| Direct + Downstream | | | | | | 85 | 64 | 75% | 158 | 128 | 81% | 6,156,007 | 660,840 | 11% |
| **Scenario 11. Free lower and east tributaries (2)** | | | | | | | | | | | | | | |
| Direct Impact | 24 | 2,901 | 53% | 79 | 108% | 85 | 18 | 21% | 158 | 45 | 28% | 2,100,651 | 174,637 | 8% |
| Direct + Downstream | | | | | | 85 | 64 | 75% | 158 | 128 | 81% | 6,156,007 | 665,038 | 11% |
| **Scenario 12. Free east tributaries** | | | | | | | | | | | | | | |
| Direct Impact | 25 | 3,313 | 61% | 80 | 110% | 85 | 23 | 27% | 158 | 62 | 39% | 3,251,924 | 258,201 | 8% |
| Direct + Downstream | | | | | | 85 | 65 | 76% | 158 | 129 | 82% | 6,241,388 | 713,355 | 11% |

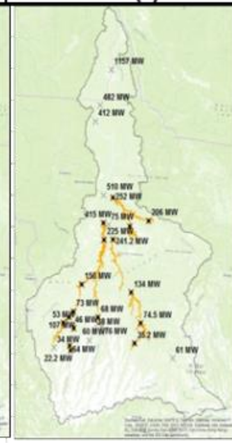
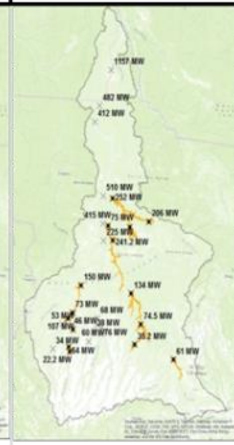
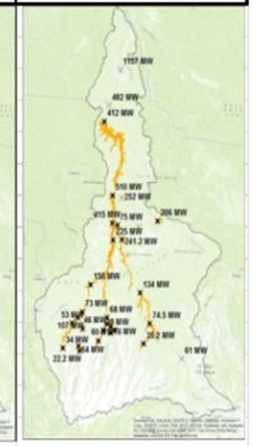
## Table 1c: Overall scenario results: Connectivity

| | Hydropower | | | Cost | | Connectivity | | |
|---|---|---|---|---|---|---|---|---|
| | Total # Dams | Total MW Pot | Scenario % MW | Cost of Hydro Weighted Avg LCOE (US$/Mw-hr) | LCOE % of full potential scenario | # of mainstem connected networks | longest connected network (km) | % of longest connected network to zero dams scenario (3715 Km) |
| **Scenario 1. Full Hydropower Potential** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 30 | 5,455 | 100% | 73 | 100% | 31 | 508 | 14% |
| **Scenario 2. Minimize Impact to** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 9 | 2,471 | 45% | 64 | 88% | 15 | 1,777 | 48% |
| **Scenario 3. Minimize Impact to Portfolio** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 10 | 771 | 14% | 65 | 89% | 14 | 2,996 | 81% |
| **Scenario 4. Develop 60% of Hydropower Potential** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 13 | 3,361 | 62% | 76 | 104% | 20 | 643 | 17% |
| **Scenario 5. Protect 60% of Indigenous Lands** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 11 | 4,167 | 76% | 75 | 103% | 18 | 643 | 17% |
| **Scenario 6. Protect 60% of Environmental Values** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 16 | 2,301 | 42% | 70 | 96% | 22 | 888 | 24% |
| **Scenario 7. Max develop in lower river (1)** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 12 | 3,321 | 61% | 77 | 105% | 18 | 1005 | 27% |
| **Scenario 8. Max develop in lower river (2)** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 17 | 2,357 | 43% | 79 | 108% | 22 | 1,290 | 35% |
| **Scenario 9. Free upper southwest tributaries** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 15 | 1,732 | 32% | 80 | 110% | 21 | 1,618 | 44% |
| **Scenario 10. Free lower and east tributaries (1)** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 23 | 2,693 | 49% | 81 | 111% | 24 | 2,256 | 61% |
| **Scenario 11. Free lower and east tributaries (2)** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 24 | 2,901 | 53% | 79 | 108% | 19 | 1,989 | 54% |
| **Scenario 12. Free east tributary** | | | | | | | | |
| Direct Impact<br>Direct + Downstream | 25 | 3,313 | 61% | 80 | 110% | 20 | 1,102 | 30% |

## Table 2a: Scenario comparison with maps—Scenarios 1—6

| | Scenario 1<br>Full Hydropower Potential | Scenario 2<br>Minimize Impact to Indigenous Lands | Scenario 3<br>Minimize Impact to Portfolio | Scenario 4<br>Develop 60% of Hydropower Potential | Scenario 5<br>Protect 60% of Indigenous Lands | Scenario 6<br>Protect 60% of Environmental Values |
|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |
| **Hydropower - % of Total Potential** | 100% | 45% | 14% | 62% | 76% | 42% |
| Capacity Mw | 5455 | 2471 | 771 | 3361 | 4167 | 2301 |
| % Cost vs Full development scenario | 100% | 88% | 89% | 104% | 103% | 96% |
| | | | | | | |
| **Indigenous Lands** | | | | | | |
| % of indigenous lands that are **NOT** affected | | | | | | |
| Direct Impact | 55% | 91% | 86% | 59% | 73% | 59% |
| Area of indigenous lands that are affected (ha) | | | | | | |
| Direct impact | 148,629 | 19,924 | 28,678 | 96,326 | 75,048 | 91,569 |
| | | | | | | |
| **Portfolio and Biodiversity Features** | | | | | | |
| % of Portfolio Biodiversity features **NOT** affected | | | | | | |
| Direct Impact | 51% | 77% | 100% | 68% | 66% | 68% |
| Area of Portfolio Polygons affected (ha) | | | | | | |
| Direct impact | 355,798 | 153,154 | 0 | 253,146 | 261,032 | 218,729 |
| | | | | | | |
| **Connectivity Features** | | | | | | |
| % Connected mainstem segments vs Natural connectivity (no dams) | 14% | 48% | 81% | 17% | 17% | 24% |
| Length of longest connected segment (KM) | 508 | 1,777 | 2,996 | 643 | 643 | 888 |

## Table 2b: Scenario comparison with maps—Scenarios 7—12

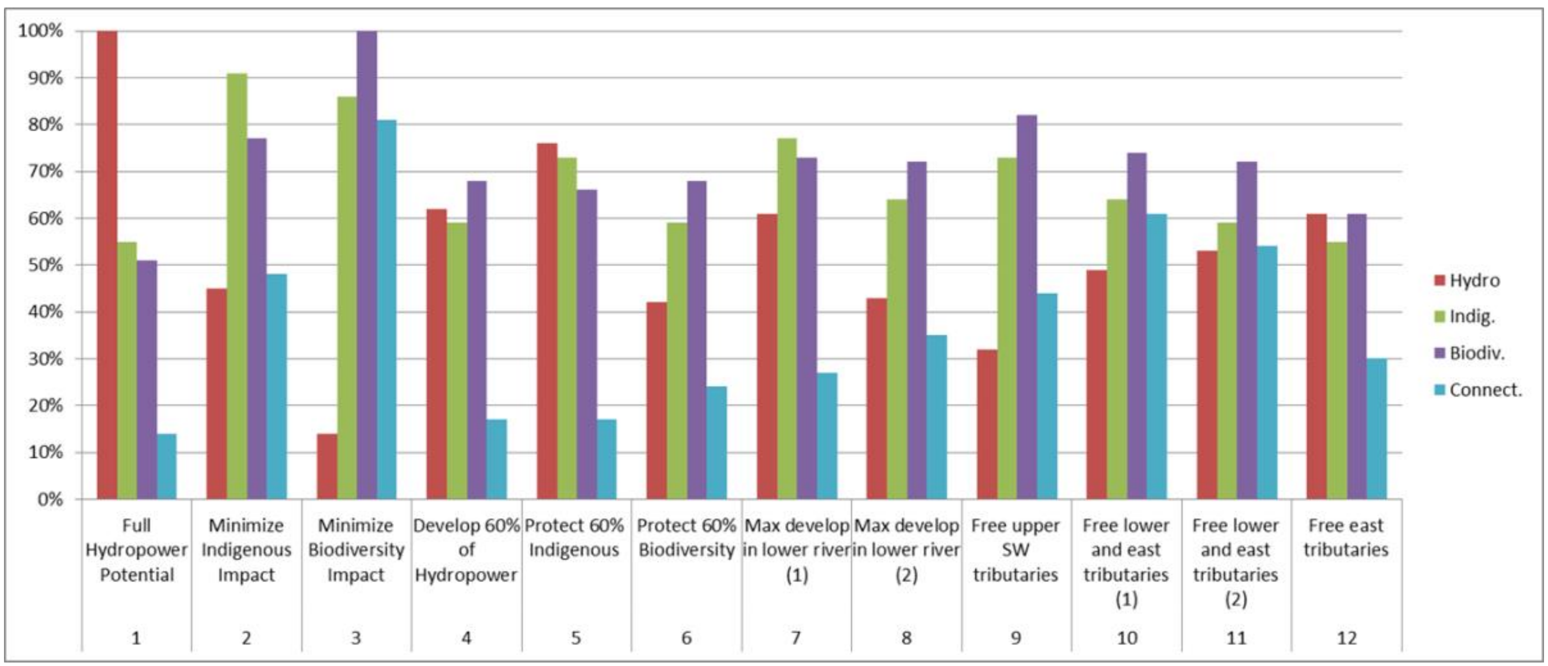
| | Scenario 7<br>Max develop in lower river (1) | Scenario 8<br>Max develop in lower river (2) | Scenario 9<br>Free upper southwest tributaries | Scenario 10<br>Free lower and east tributaries (1) | Scenario 11<br>Free lower and east tributaries (2) | Scenario 12<br>Free east tributaries |
|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |
| **Hydropower - % of Total Potential** | 61% | 43% | 32% | 49% | 53% | 61% |
| Capacity Mw | 3321 | 2357 | 1732 | 2693 | 2901 | 3131 |
| % Cost vs Full development scenario | 105% | 108% | 110% | 111% | 108% | 110% |
| | | | | | | |
| **Indigenous Lands** | | | | | | |
| % of indigenous lands that are **NOT** affected | | | | | | |
| Direct Impact | 77% | 64% | 73% | 64% | 59% | 55% |
| Area of indigenous lands that are affected (ha) | | | | | | |
| Direct impact | 57,146 | 85,822 | 57,705 | 111,613 | 120,315 | 140,239 |
| | | | | | | |
| **Portfolio and Biodiversity Features** | | | | | | |
| % of Portfolio Biodiversity features **NOT** affected | | | | | | |
| Direct Impact | 73% | 72% | 82% | 74% | 72% | 61% |
| Area of Portfolio Polygons affected (ha) | | | | | | |
| Direct impact | 188,125 | 163,857 | 89,299 | 167,673 | 174,637 | 258,201 |
| | | | | | | |
| **Connectivity Features** | | | | | | |
| % Connected mainstem segments vs Natural connectivity (no dams) | 27% | 35% | 44% | 61% | 54% | 30% |
| Length of longest connected segment (KM) | 1,005 | 1,290 | 1,618 | 2,256 | 1,989 | 1,102 |

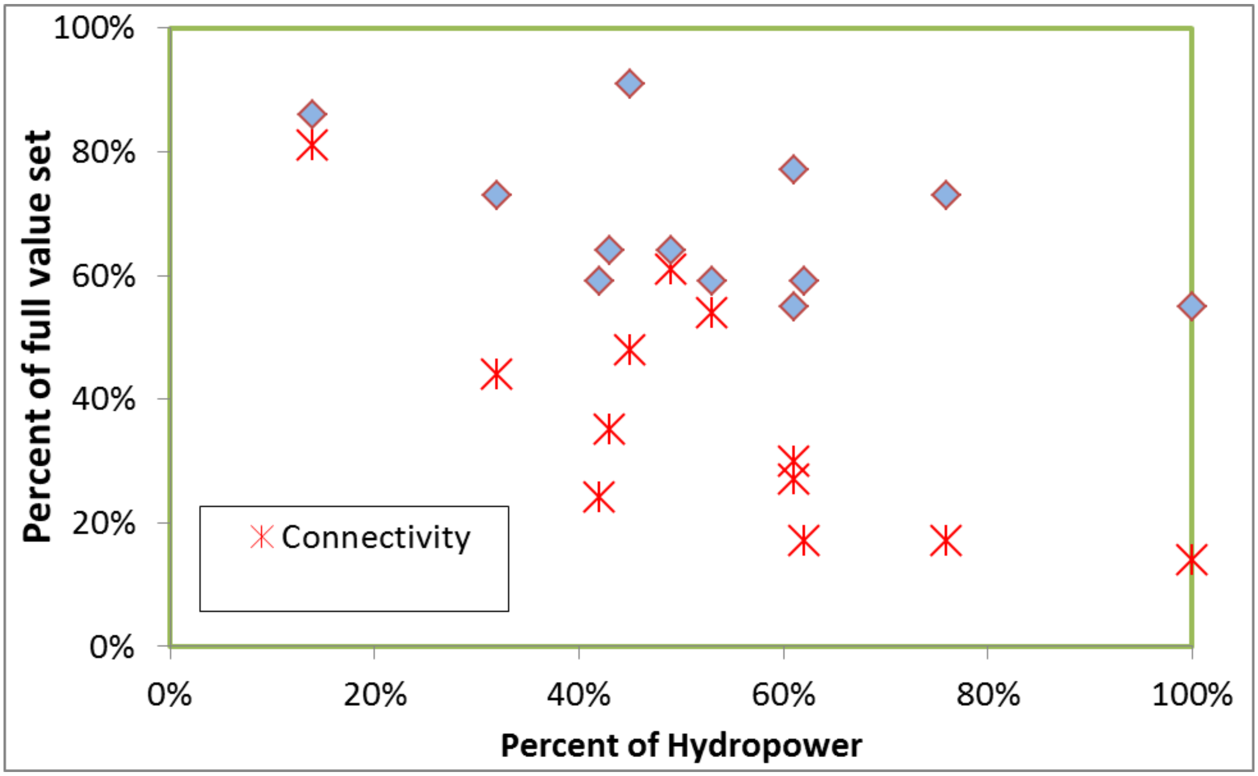
### Table 3: Summary of results for the twelve scenarios

For each scenario, results are expressed as a percentage of the full or completely intact value set. In the table, cost is a percentage of the cost of energy from Scenario 1, full hydropower potential.

| Scenario | Name | Cost | Hydro | Indig. | Biodiv. | Connect. |
|---|---|---|---|---|---|---|
| 1 | Full Hydropower Potential | 100% | 100% | 55% | 51% | 14% |
| 2 | Minimize Indigenous Impact | 88% | 45% | 91% | 77% | 48% |
| 3 | Minimize Biodiversity Impact | 89% | 14% | 86% | 100% | 81% |
| 4 | Develop 60% of Hydropower | 104% | 62% | 59% | 68% | 17% |
| 5 | Protect 60% Indigenous | 103% | 76% | 73% | 66% | 17% |
| 6 | Protect 60% Biodiversity | 96% | 42% | 59% | 68% | 24% |
| 7 | Max develop in lower river (1) | 105% | 61% | 77% | 73% | 27% |
| 8 | Max develop in lower river (2) | 108% | 43% | 64% | 72% | 35% |
| 9 | Free upper SW tributaries | 110% | 32% | 73% | 82% | 44% |
| 10 | Free lower and east tributaries (1) | 111% | 49% | 64% | 74% | 61% |
| 11 | Free lower and east tributaries (2) | 108% | 53% | 59% | 72% | 54% |
| 12 | Free east tributaries | 110% | 61% | 55% | 61% | 30% |








***Iterative Scenario Results***

The results suggest some general trends. First, as the percentage of hydropower increases, the other values generally decrease; this is the obvious expectation (Figures 2 and 3).

Within that general trend, however, there are five scenarios that achieve between 53-76% of hydropower capacity while maintaining fairly high levels of other values. For example, compared to the 100% hydropower scenario, which maintained 55% of the indigenous value set and 14% of connectivity, scenario 7 maintained 77% of indigenous (with 61% of hydrpower) and scenario 11 maintained 54% of connectivity (with 53% of hydropower). While stopping short of complete hydropower development, these scenarios provide more balance across the value sets than does the full hydropower development scenario.

The results also illustrate a key concept underpinning the argument for system-level planning: for a given energy output, there can be a fairly wide range in the output of other values. To illustrate, observe the cluster of scenarios that develop between 40% and 50% of hydropower in Figure 3 and note the wide spread in connectivity values (24 – 61%) and indigenous values (59 – 91%).

By comparing multiple develpoment scenarios, it is clear that some support a broader range of benefits than others. Scenario 4 and 7 had nearly identical costs and percent of hydropower developed. However, Scenario 7 outperformed scenario 4 in all three other values (indigenous, biodversity and connectivty; Table 4).

These results support the premise that system-scale planning has a greater likelihood of acheiving a balance of benefits than can be achieved through project-scale planning and development (as shown in the Table 3, energy costs did not vary widely between scenarios).

| Value | Scenario 4 (Developed 60% of hydropower) | Scenario 7 (Maximum development of lower river) | % difference between Scenario 7 and Scenario 4 |
|---|---|---|---|
| Hydropower (% of total) | 62 | 61 | -2% |
| Indigenous intact (% of total) | 59 | 77 | + 31% |
| Biodiversity intact (% of total) | 68 | 73 | +7% |
| Connectivity intact (% of total) | 17 | 27 | +59% |

These initial, and promising, results are not necessarily representatives of all basins, of course. Each basin is distinct in terms of what values are most important and how those are distributed, and this distribution will control the range of possible outcomes from various scenarios. Further, real basins will have much greater complexity in terms of other water-management sectors and land use. Iterative scenario analysis, as described here, may be an effective way to manage this complexity, and the basic proposition likely still holds: there are scenarios that offer a better balance of outcomes, and iterative scenario analysis may reveal the “best fit” among alternatives.

***Process for Iterative Scenario Analysis Planning***

A broadly acceptable set of development-conservation scenarios likely cannot be developed solely by a group of technical experts. It would be better if representatives of key stakeholders and decision makers were to be engaged directly in a dialogue. Such convening is a hallmark of Integrated River Basin Management, but, to produce outputs, this type of dialogue needs to be managed so that it leads to actual decisions and designs.

The process described in this Appendix is intended to generate an initial set of alternative designs for hydropower and resource protection. It should be recognized that what is proposed is just a “conceptual” and somewhat “idealized” process, presented here primarily to illustrate the sequential logic of an iterative scenario. It assumes that the necessary stakeholders have been convened and they are willing to engage in the scenario analysis. This may or may not be realistic. In fact in many basins, stakeholders may too distrustful to engage. Certainly a great deal of trust building is inherently assumed to set the foundation for any such process.

It may be necessary in the earliest stages for technical experts to carry out the scenario analysis making assumptions on behalf of the various stakeholders – putting themselves in their shoes in order to start the process and illustrate the potential outcomes.

Because of the inherent complexity of integrative planning across very different value sets, participants should be encouraged to view it as a trial-and-error, learning process. The Nature Conservancy will be exploring this process in several basins, including the Tapajos (Brazil), Coatzacoalcos (Mexico), and Magdalena (Colombia), so here we focus on the basic structure and needs of this type of stakeholder-driven scenario planning and analysis process.

First, participants will need access to information. The various stakeholders will need to be confident that their interests can be reflected, measured and mapped using the available information. Stakeholders will also need to agree to be open to the information requests of others, even if the relevance is not immediately apparent to all. To gain agreement, process facilitators can emphasize that there will be multiple rounds or iterations of the process, and that complete information in the first round is not essential. During early rounds it will be preferable to err on the side of inclusion, as there will be further opportunity for refinement. The various requested sources of information can then be integrated into a Geographic Information System (GIS).

The level of complexity of the scenarios can evolve with the process. This may help build the participant's trust in, and comfort level with, the overall process. For example, participants must be able to understand the maps, tables and data that are produced to illustrate and quantify scenarios. Overly sophisticated models may impede progress during initial stages. Again, trust in the process may grow if participants understand that the system can evolve in parallel with the discussions.

The essential decisions for this kind of planning are spatial – where to build and where to conserve. Thus maps will be a primary visual tool. But to compare scenarios, the process will need to generate quantitative outputs of important parameters (e.g., MW, fragmentation of channel network). Thus the decision support tool should be able to calculate relevant data for various scenarios. Results can be produced in both tabular form and in accessible visual diagrams (e.g. spider diagrams that can display a range of values across multiple criteria).

To assess and compare the values associated with different scenarios, the different values (e.g., hydropower, environmental and social resources) will need to have measurable attributes and a way to assess and measure the impacts of different decisions on those values. While certain values, such as hydropower, can be readily quantified, other values may be more difficult to assign values. Again, it may be necessary to start with simplified attributes, assuring stakeholders that the process will evolve toward more sophisticated measures .

The heart of the process is the generation and exploration of alternative scenarios. However, the process should not strive at the outset to generate optimal or even balanced scenarios – those can emerge with time. Rather participants can start by proposing and exploring scenarios without trying to achieve "success," in part to gain familiarity with the process. One approach to this is to start with the extreme scenarios that bracket the range of decisions: a scenario that represents full development of all conceivable hydropower projects in the basin; another that is based on no environmental impact whatsoever; another that requires no incursion into any indigenous territory. Then the impact of each of these extreme scenarios on the other attributes can be tabulated. This may help not only to bracket the range of possibilities but also to get participants familiar with the structure of the system and the jargon and special terms involved in all the different stakeholder interest value sets.

Then a more serious round of scenario proposals can move forward -- scenarios that look for intermediate positions between the extremes. By continuously tracking the impact on the attributes of each value set, the scenarios can incrementally evolve toward more balanced or optimal outcomes. The goal of the process is to identify one or more alternatives that approach an optimum point.

Following each round, participants should be given the opportunity to discuss what worked and what did not work with the prior round – focused on the scenario results, as well as the process and the information system. This will support continuous improvement in the process, and also allow for continued trust building. In the final rounds of evaluating the process, stakeholders and decision makers can begin to discuss how to advance the win-win scenarios into the actual development decision process.

An example of a similar process is the "Shared Vision Planning" process, use by the U.S. Army Corps of Engineers and other for application to a variety of multi-value water management situations (see Palmer et al.). Shared Vision Planning (SVP) is a disciplined planning approach that combines traditional water resources planning methodologies with innovations such as structured public participation and the use of collaborative modeling,. As part of its emphasis on multi-objective planning, structured public participation and collaborative modeling, it features an iterative approach to the development and analysis of alternatives.

***Complexity of Scenarios***

It may be important to mention a few more aspects of the increasing complexity that will be expected in real world basins – complexity beyond what is included in the illustrative scenarios. This analysis looks only at development impacts from hydropower. It does not consider other development pressures that are likely present in a real basin. For example, if a subject basin were concurrently undergoing agricultural land-use changes in addition to hydropower, and perhaps proposals for navigation development in tandem with the agricultural expansion, then the development value set would have to be expanded to address this range of development values. And it should be expected that those developments would cause impacts that are additive to one another and in fact perhaps even interactive, or negatively synergistic from a social-environmental value perspetive. In fact current practice for Cumulative Environmental Assessment calls for looking at the cumulation of impacts on all the social-environmental value targets ("Valued Environmental Components", "VEC's", in terms used by IDB).

This will make the scenarios extremely cumbersome. Yet this complexity is inherent in real basins. And there are not simple procedures for dealing simultaneously with all these developments and protection values. It may be that scenario-based analyses will be all the more useful in handling these multi-variant situations. The basic value proposition is still true – there is some basin-level or region-level mix of projects and protections that will give a "best fit".

***References***

1 Palmer, Richard N. et al, 2013, Disciplined Planning, Structured Participation and Collaborative Modelling – Applying Shared Vision Planning to Water Resources. Journal of the American Water Resources Association (JAWRA) 49(3): 614-628. DOI 10.1111/jawr. 12067

# Appendix 2: A Toolkit for System-Scale Planning of Hydropower

*Authors' note: This section is a work in progress.

Below is a sample of tools that can be deployed to advance system-scale planning of hydropower. This list is not exhaustive and could be expanded and tailored to meet the needs of a specific audience, such as IDB staff and clients.

**Hydropower Sustainability Assessment Protocol**

The Hydropower Sustainability Assessment Protocol (the 'Protocol') was developed by a multi-stakeholder forum (International Hydropower Association, 2011). Because it does not define what constitutes an acceptable level of sustainability, the Protocol is not a standard but, rather, an assessment tool used to measure and guide performance in the hydropower sector. The Protocol can be applied to assess projects that are in different stages of development—planning, implementation or operation—and, for each stage, scores relative performance across 20 or more sustainability topics ranging from economic and financial to environmental and social. Importantly, it also contains a section for evaluating a potential project at the earliest possible stage, considering such factors as the demonstrated need for the project and the assessment of options.

**Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT)**

The Rapid Basin-wide Hydropower Sustainability Assessment Tool was developed in 2010 by the Asia Development Bank, the Mekong River Commission and the World Wide Fund for Nature (WWF). The objective of the RSAT is to "assess hydropower sustainability within an IWRM based framework" (ADB et al., 2010). Similar to the Protocol, the RSAT is a tool for measuring sustainability, although the RSAT places greater emphasis on river-basin planning and can be used to evaluate a system of hydropower projects. While developed for the Mekong basin, the RSAT developers state that it can be adapted for use in other regions. The RSAT is composed of 10 topics and 27 sub-topics. The original RSAT has been updated in 2013.

**HydroSHEDS**

From the website http://worldwildlife.org/pages/hydrosheds:

HydroSHEDS provides hydrographic information in a consistent and comprehensive format for regional and global-scale applications. These data layers are available to support watershed analyses, hydrological modeling, and freshwater conservation planning at a quality, resolution, and extent that had previously been unachievable in many parts of the world.

It offers a suite of datasets, including stream networks, watershed boundaries, drainage directions, and other data layers such as flow accumulations, distances, and river topology information. Recently available data derived from HydroSHEDS include comprehensive layers of major basins and smaller sub-basins (~100-2,500 km2) across the globe.

A set of three extensions for use with ESRI ArcView software (version 3.x) called HydroSHEDS tools are also available.

HydroSHEDS has been developed by the WWF Conservation Science Program in partnership with the U.S. Geological Survey, the International Centre for Tropical Agriculture, The Nature Conservancy, and the Center for Environmental

Systems Research of the University of Kassel, Germany.

**Data Basin**

From the website http://databasin.org/:

Data Basin is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship.

Data Basin was built by a team of scientists, software engineers, and educators at the Conservation Biology Institute

(CBI) The core of Data Basin is free and provides open access to thousands of scientifically-grounded, biological, physical, and socio-economic datasets. This user-friendly platform enables people with varying levels of technical expertise to:

- Explore and organize data & information
- Create custom visualizations, drawings, & analyses
- Utilize collaborative tools in groups
- Publish datasets, maps, & galleries
- Develop decision-support and custom tools

Data Basin supports researchers, natural resource managers, advocates, teachers, students, and members of the engaged public. Members create and participate in working groups where they can visualize, draw, comment, and discuss relevant topics or geographies. Data Basin breaks down barriers to collaboration and negotiation for users affiliated with universities, non-profits, tribes, companies, and local, state, federal, and national governments.

**Barrier Assessment Tool**

The Barrier Assessment Tool (BAT) is a spatial analytical tool developed to assess how potential scenarios or projects will affect the connectivity of a river system, to inform studies of fish movement or other biophysical processes affected by connectivity. Barriers to connectivity include natural source (waterfalls), and infrastructure (dams and culverts). "Hard" (e.g. no fish passage) and "Soft" (selected or partial fish passage) barriers can be defined. BAT can use spatial data for river networks and barriers from global and/or regional sources.

Summaries are generated in visual format illustrating the different continuous networks, and in tabular form providing details about the number of connected networks, length of each network, average and range of all networks, and specific information for each network such as the number of barriers and river length to the source, or mouth of a river system from a given point.

The BAT was developed in support of the Northeast Aquatic Connectivity Project through a partnership among The Nature Conservancy's Eastern U.S. Freshwater Program, the Latin American Regional Science Program, and Geodata Institute of the University of Southampton. It is being used to assess how different scenarios for dam removal, development or adaptation, and road culvert upgrades would affect functional networks for fish passage. Its application to hydropower planning provides a baseline of natural barriers and networks, any existing man-made barriers, and results for different hydropower development scenarios.

**Ecological Limits of Hydrologic Alteration**

Regionalizing environmental flow management means making decisions that minimize ecological impacts of new water developments, direct water development to least-sensitive water bodies, and prioritize flow restoration efforts. These decisions hinge on a scientific understanding of how changes in the natural flow regime affect ecological conditions. The ELOHA – Ecological Limits to Hydrologic Alteration framework helps water managers meet this challenge.

Water managers, policy makers, stakeholders, and scientists with diverse expertise are using ELOHA to accelerate the integration of environmental flows into regional water resource planning and management.

For decades, environmental flow quantification has been conducted at the scale of individual river reaches, with a range of potential methodologies used to evaluate flow requirements. Holistic methodologies that account for all flow-dependent ecosystem needs are well-established, but can take years to complete for just one river reach. A more systematic approach applied at a watershed, region, or state-wide scale is required if freshwater ecosystem protection and recovery are to match the pace and extent of water resource development. Ultimately, this necessitates a scaling-up from site-by-site environmental flow provisions to the state, provincial, or national policy realm.

In numerous case studies worldwide, water managers, policy makers, stakeholders, and scientists with diverse expertise are using ELOHA to accelerate the integration of environmental flows into regional water resource planning and management.

ELOHA consists of the following steps, as illustrated in the framework flow chart:

1. Build a hydrologic foundation of streamflow data;

2. Classify natural river types;

3. Determine flow-ecology relationships associated with each river type and;

4. Implement policy to achieve river condition goals.

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**Indicators of Hydrologic Alteration (IHA)**

Indicators of Hydrologic Alteration (IHA) is a software program that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. Nearly 2,000 water resource managers, hydrologists, ecologists, researchers and policy makers from around the world have used this program to assess how rivers, lakes and groundwater basins have been affected by human activities over time – or to evaluate future water management scenarios.

This program was developed by scientists at The Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner. The software program assesses 67 ecologically-relevant statistics derived from daily hydrologic data. For instance, the IHA software can calculate the timing and maximum flow of each year's largest flood or lowest flows, then calculates the mean and variance of these values over some period of time. Comparative analysis can then help statistically describe how these patterns have changed for a particular river or lake, due to abrupt impacts such as dam construction or more gradual trends associated with land- and water-use changes.

**Sediment Simulation Screening (*SedSim*) Model**

Th *Sediment Simulation Screening Model (SedSim)* is a simulation model for the preliminary screening of sediment transport and management in River Basins. The *SedSim* model was developed at Cornell University, in partnership with the Natural Heritage Institute (NHI). The *SedSim* model is a sediment accounting tool that was originally developed for use in the Mekong River basin. This model performs a daily time-step mass-balance simulation of flow and sediment that is intended to predict in relative terms the spatial and temporal accumulation and depletion of sediment in river reaches and in reservoirs under different reservoir operating and sediment management policies. Thus, the model is expected to be used for estimating sediment transport in river basis including those that have experienced (or will experience) extensive reservoir development. The *SedSim* model runs in Microsoft Excel. The source code is written in the Visual Basic for Applications (VBA) language. The model consists of three spreadsheets, the main model interface and the input and output files.

Thomas B. Wild and Daniel P. Loucks. 2013. *SedSim* Model: A Simulation Model for the Preliminary Screening of Sediment Transport and Management in River Basins, Version 3.0: Documentation and User's Manual. Department of Civil and Environmental Engineering, Cornell University, Ithaca, NY USA. October.

**Basin and regional freshwater biodiversity and ecosystem assessments**

Systemmatic freshwater conservation planning is represented in spatial products that depict conservation priorities for such things as endangered species, critical habitats, representative ecosystems, or ecosystem services to guide protection and management activities. The information and processes used to generate these products range from a focus on areas identified as critical for endangered species (e.g. Alliance for Zero Extinction consortium), areas important for a broader suite of species Key Biodiversity Areas – IUCN) ("fine-filter approaches"), a set of areas that represent the minimum number and best remaining examples of the diversity of ecological settings and processes necessary to support known, poorly sampled, and yet unknown species and natural biological communities in a connected network (a “coarse filter approach“), to a suite of areas that are critical for ecosystem services such as soil retention, water provisions, fisheries, and other services.

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**Hydropower by design**

Dams are expanding in the later-developing world including rapid development of hydropower dams to meet growing demands for energy. Although this expansion in water-management infrastructure can meet important societal needs, a proliferation of new dams threatens to greatly diminish the ecological health of rivers in regions where rivers support high levels of biodiversity and provide livelihoods and food security to millions of rural people.

The main report (“The Next Frontier of Hydropower Sustainability”) emphasized that system-scale approaches for planning and operating water-management infrastructure offer the best opportunity for development that can provide the benefits of regulated rivers while maintaining the benefits provided by naturally functioning rivers. The expansion of hydropower and other dams is unlikely to achieve this balance if dams are planned, reviewed and licensed with a framework focused on individual sites or projects. Rather, sustainable dam development—that is, dams that are consistent with maintaining a broad range of values and resources for future generations—requires a framework focused on river basins or regions.

The Nature Conservancy is developing a framework for planning hydropower at the system scale (e.g., river basin or region) called Hydropower by Design (HbD) - essentially the river basin form of TNC's broader Development by Design framework.

"Hydropower by design" is based on the premise that energy objectives can be achieved through various alternatives and that integrated and comprehensive planning can identify those alternatives with the lowest environmental and social impacts. Most simply, hydropower by design entails the full integration of infrastructure planning with planning for the conservation of environmental and social resources. This planning occurs at the river-basin or regional scale and is underlain by the mitigation hierarchy. The steps of the mitigation hierarchy, with their hydropower application are:

1. *Avoid.* New development should avoid rivers or sections of rivers that have the most valuable resources and for which other mitigation will not be effective (e.g., a river that contains a unique biological, social or cultural resource).

2. *Minimize.* For dams that are built, impacts should be minimized to the extent possible during design, construction and operation. For example, where appropriate, dam design should include the potential for temperature control, fish passage, and the ability to release environmental flows.

3. *Restore.* Dam operations should strive to restore and maintain key river resources, such as through the release of environmental flows to maintain downstream fisheries.

4. *Offest.* Not all impacts can be mitigated through site-specific actions to minimize and restore impacts. The "residual" impact can be offset by making conservation investments elsewhere in the river basin to protect or restore similar resources.

Key components for hydropower by design include:

1. A spatial database of environmental and social resources, such as a conservation "blueprint"

2. An infrastructure plan that includes an energy objective and information on potential dam locations

3. A method for integrating these data sources through collaboration of industry, government, and NGOs and other stakeholders. This process should emphasize identification of "avoid" areas, locations that are appropriate for dam development, and a mitigation strategy that will allow individual project mitigation to contribute toward fulfillment of an overarching conservation strategy.

4. A mechanism for translating elements of the analysis, such as "avoid" locations and mitigation strategies, into decisions for project review and licensing.